An ecological evaluation of three systems of farm management using field beans

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AN ECOLOGICAL EVALUATION OF THREE SYSTEMS OF FARM MANAGEMENT USING FIELD BEANS

By

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Doctor of Philosophy
at the
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To the memory of my mother,
who first inspired me with an
interest in Botany.

This thesis is entirely the result of my own work, apart from some of the water analysis which was done in conjunction with Mr A.Y.Basahy. This work has not been accepted for any other degree, and is not being submitted for any other degree.

M. J. Parsons

CONTENTS

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Abstract

An evaluation and comparison of the flow of geochemicals through three systems of farm management is made, using *Vicia faba* L. as a crop phytometer. Organic manures form the only nutrient addition to one system (Organic), artificial fertilizers alone are applied to the second (Stockless), and the third system receives a mixture of the two nutrient sources (Mixed). The influence of the farm management upon each of the main components of the agricultural ecosystem is determined, and these are discussed separately in the five main sections of the text. Crude balance sheets are constructed to demonstrate the magnitude of the annual flow of geochemicals through each system.

The soil of the three farms is compared by chemical analysis. It is shown that where organic manures have been used, the content of available plant nutrients is significantly higher than in the soils where only inorganic fertilizers have been applied.

The flow of water through the ecosystem is determined by the use of lysimeters. A study of the chemical composition of the leachate shows that the system receiving both manures and fertilizers provides the greatest threat of eutrophication. The maximum loss of plant nutrients from the soil is shown to occur during the season of the greatest rainfall.

The rate of the fixation of energy into the system is determined by a study of the growth and yield of the crop phytometer. It is found that the long-term practice of growing separate stocks of seed on each farm, (imprinting), does not cause any physiological evolution to occur by which each plant type could become better suited to its own farm type. It is demonstrated that the magnitude of the growth of the bean plants does not show any significant effect of farm management, despite the differences in nutrient availability from the three soils. It is suggested that this lack of growth response is due to the high background level of nutrients in all the soils. The only effect of nutrient availability is shown by the size of the bean seed yield, but this effect is seen to be drastically modified by weed competition.

The flow of geochemicals into the standing crop is investigated by detailed chemical analysis of the plants throughout the season. Corresponding to the lack of growth response to the farm management, no significant effect of soil treatment can be shown to be influencing the chemical composition of the crop. There is no evidence to show any eutrophication of the crop by nitrates, but a marked death reaction is demonstrated to be causing high concentrations of lead in the bean seeds. Due to a greater biomass on the Mixed section, it was this management which incurred the greatest flow of geochemicals into the standing crop.

The phenomenon of symbiotic nitrogen fixation by the phytometer is investigated. A close relationship between the rate of fixation, the extent of nodulation and the availability of soil nitrogen is determined. The former two characteristics are shown to provide an accurate assay of the level of nitrogen in the soil. Calculation of the probable annual fixation of nitrogen shows that this is maximal on the farm where no organic manures are supplied.

From the construction of the balance sheets, and the discussion in the text, it is indicated that the management system, which is the most geochemically and economically viable, is the Mixed system. This farm produces the highest yield of bean seeds, and permits a reasonable level of nitrogen fixation by the legume, but also poses the most serious threat of eutrophication to other ecosystems. Even so, the concentration of nitrates in the leachate never exceeded the maximum safe limit suggested by the World Health Organization.

Conventions followed in the thesis

1. Measurements :

All measurements were made in SI units according to the metric scale. Where reference figures are quoted from the literature, all values are converted to the metric scale. The abbreviations used :

μg or μgm = microgramme
mg or mgm = milligramme
kg = kilogramme
mm = millimetres
cm = centimetres
m = metres
ha = hectares

2. Numbering :

- Tables and Graphs - Section number - sequential number for that section

  ie 4--9 = the ninth graph in Section 4.

- Text - paragraphs numbered according to the Universal Decimal Classification. eg Section number :1.1.2-3(1)

3. Abbreviations :

- where several elements are mentioned together in the text, and in all the tables they are listed by symbols (according to the Periodic Table)
- Farm management and imprint types :

  O = Organic
  M = Mixed
  S = Stockless
  C = Commercial

- *Vicia faba* L. varieties : Tic

  Thro, Throw = Throws

- Plot treatment : 1971 Field Trial : NF = No fertilizer

  3F = 375 Kg fertilizer/ha

  6F = 625 Kg fertilizer/ha

  : 1972 Field Trial : NFLys = Normal fertilizer lysimeter

  S+ = HFLys = High fertilizer lysimeter

  : 1973 Field Trial :

  PPKK = double normal rate of phosphorus and potassium

  NNPPKK = double normal rate nitrogen, phosphorus and potassium

  NNPK = double normal nitrogen added to normal rate phosphorus and potassium

4. <u>Description of geochemicals</u>

- In the text and tables the terms "ions", "nutrients" and "geochemicals" are used synonomously.

- Total geochemicals eg Total K = total quantity of geochemical which is extracted from the sample by concentrated acid extraction. Includes structural, exchangeable and water soluble fractions.

- Available and exchangeable : throughout the text and tables both these terms infer that the quantities described are available to the growing plants, although they have been determined by chemical methods. Strictly :

  : available = the fraction of soil geochemicals available to a growing plant, identified by analysis of plants.

  : exchangeable = the fraction of soil geochemicals which are chemically exchangeable, identified by analysis of the soil.

5. Nitrogen fixation :

- Throughout Section 5, all measurements of potential nitrogen fixation are expressed in the volumes of nitrogen fixed, but were actually one third of the volumes of ethylene produced by the reduction of acetylene, which had competitively inhibited the fixation of nitrogen.

6. Statistics :

- In all sections of the text, except in Section 3 where polynomial regressions of the growth parameters were utilized, the test used to determine the significance of the difference between sets of values was Bailey's d test (Bailey 1959). This is designed to be used where the variances are not equal. In the tables showing the results of this statistical test, a large number of abbreviations have been used :

df. or d. of f. = degrees of freedom

d = calculated values of d.

p = probability value

p values : NS = No significant difference ie $p = >0.1$

0.05 - 0.1 = No significance, but may indicate a trend.

*or <0.05 = 95% confidence level - lowest level of probability considered to show a significant difference.

**or <0.01 = 99% confidence level - difference highly significant.

R = in some tables where the difference is shown to be significant, the relationship between the treatments is indicated, ie X > Y

SD = Standard Deviation

SE = Standard Error. The bars shown on some of the graphs are values of standard errors.

INTRODUCTION

Introduction

I remember the time when the stable would yield,
Whatsoever was needed to fatten the field,
But chemistry now into tillage we lugs,
And we drenches the earth with a parcel of drugs,
All we poisons, I hopes, is the slugs.

(Punch 1846, published at the advent of the
industrial production of inorganic fertilizers).

The Biosphere

The biosphere may be defined as that part of the Earth in which life exists, and undergoes active metabolism (Hutchinson 1970); or as the region in which liquid water can exist and which receives an ample supply of energy from an external source (Penman 1970). The energetics of the biosphere depend upon the utilization of solar energy for the photosynthetic reduction of carbon dioxide by autotrophic plants, to produce organic compounds and molecular oxygen. Thus the geochemical result of photosynthesis is to produce an oxidized part of the biosphere - atmosphere and water - and a reduced part - organisms and their organic decomposition products. The maintenance of the biosphere requires a cyclical flow of the biologically important materials, which are re-used at the expense of solar energy. The movement of such materials is largely controlled by the vector of water, carrying dissolved and particulate substances through the system. As Leonardo da Vinci said : 'Water is the driver of nature'. Thus the detailed knowledge of the mechanisms of the geochemical cycling of each element in the water, in the terrestrial ecosystem, particularly concerning the processes by which the solid-liquid interface is crossed, is of enormous biological importance.

The Ecosystem

Within the biosphere there are many ecosystems, each of which has evolved to contain a diversity of species, which interact to exploit to a maximum the potential benefit from the incident energy. A natural ecosystem is controlled by a number of homeostatic mechanisms, which serve to regulate the development of the individual constituent populations of organisms. The ultimate structure of the ecosystem will depend upon the rate and magnitude of the flow of energy, and recycling of the mineral nutrients through the food chains. In terrestrial ecosystems, no matter how complex these chains may be, from green plants - herbivores - carnivores, most of the energy will be dissipated as heat, and eventually the contained organic material will be returned to the substrate. There it will undergo physical, chemical, and bacterial, decomposition to ultimately form humus. This becomes integrated with the mineral substrate particles which aggregate together to form soil, both fractions being a source of nutrients for future generations of plants. The structure of the soil will depend upon the origin and size of the mineral particles, and the proportion of decomposed organic remains, which will, in turn, influence the availability of air, water and dissolved minerals to the plants. Organic matter is one of the major factors influencing the productivity of the soil (Bruin 1965). It contributes to nutrient availability through decomposition and by acting as a chelating agent - the cation exchange capacity of a soil is largely dependent upon its organic matter content.

An ecosystem will tend to evolve towards a climax state - during the seral stages the loss of energy from the system in respiration will be less than the gross production, so that the fixed energy can be stored in an increasing biomass. The climax ecosystems represent the most efficient way of using the resources of an area to sustain life, with the minimum impact upon other ecosystems - all the energy captured in unit time is lost during the metabolism required to maintain the status quo of the biomass. This allows no net annual storage, and the nutrient gains from the substrate are balanced by the nutrient losses.

The development of Agriculture

During the first two million years of his existence, man was a destructive predator upon his environment, which consequently was able to support only a low population of individuals. About ten thousand years ago, man began to adapt the biosphere, in particular the terrestrial ecosystems, to fulfil the needs of food production, by the domestication of plant and animal species, and cultivation of the land. This initiated the spiral by which a greater food supply enabled the development of a larger population, which then required a further increase in food supply. The spiral has become steadily more acute as the advances in agricultural technology have been outstripped by the world population growth. Hence we have an accelerating impact upon the biosphere, tending towards the mass disruption of ecosystems, as an increasing fraction of the solar energy fixed by green plants, and the mineral nutrients extracted from the earth, become integrated into the biomass of *Homo sapiens*.

Within a natural terrestrial ecosystem the main factors controlling the rate of the flow of energy are the climate and the availability of the main raw materials of metabolism, which are nitrogen, phosphorus and potassium. The fertility of the soil is maintained by the weathering of bedrock and soil minerals into forms available to the plants, and the return of the organic material to the soil to maintain its structure.

Until the mid-19th century in Britain,agricultural management closely mimicked the situation found in a natural ecosystem. Species diversity was maintained so as to efficiently exploit the different fractions of the soil minerals, by the use of crop rotations. These commonly included a year of a cereal, then a root crop, a legume, another cereal, and then leys supporting livestock for several years. The fertility of the soil was preserved by the return of organic materials in the form of straw, vegetable waste and animal manure, and by a low annual removal of nutrients in the small yields gained. If one area of land became nutritionally depleted, fallowing was often employed, and new land areas were cultivated for food production. This system was very labour-intensive, but did not require the importation of nutrients and fixed energy from outside the system.

Due to the increased growth in the numbers of people to be fed, and a decreasing availability of new areas for agricultural expansion, farming has become increasingly intensive on a smaller area of land. For example, in the United States, according to Viets (1971) :

in 1944 353×10^6 acres were used for agriculture
in 1963 287×10^6 " " " " " , but this reduced area produced twice the quantity of yields as found in 1944.

Nutrient and Energy input

When the upper layer of the regolith is intensively cultivated, the mineral and organic constituents are rapidly depleted - in the last three decades, the use of crop rotations and manure has been largely discontinued in the industrialized countries because, in the short term, greater productivity can be gained from the application of inorganic salts alone, which represent large importations of energy into the system. An understanding of genetics has enabled the breeding of improved high yielding strains of crops, but these often require very high levels of available nutrients in the soil, especially the "super-cereals" of the "green revolution", which has resulted in their discontinuation by the poorer countries.

As more labour has left the land, farm management has become increasingly energy-intensive - in the form of fertilizers, pesticides, herbicides and mechanization - which has resulted in greater environmental stresses. At present, about 10% of the total world land surface is utilized for agriculture, of which 66% is devoted to cereals. Since the innovation of fertilizer manufacture in the mid-19th century (Lawes - superphosphate), the farm management practised in Britain has become successively further removed from the situation found in Nature. The species diversity has been drastically reduced, with monocultural practises becoming predominant, and the use of animal manures as a nutrient source and structuring agent has been abandoned on most of the commercial farms. Much of the plant residues are burned, or used for fodder for animals outside the producing system, and the high yields extracted annually, rapidly deplete the soil of its nutrients. Intensive mechanization with large machines encourages soil compaction, especially when cultivation of heavy soil is required in wet weather. All the modern practices tend towards a loss of the soil structure and the inherent fertility.

Due to the management techniques practised, an increasing amount of artificial inorganic fertilizers have to be applied to the land. As the soil loses its structure, and thence the nutrient-binding ability, high crop yields can only be maintained if the rate of application is enlarged; the higher the rate, the more inefficient the use of the nutrients. Net annual production can attain a level of 6-10 Kg dry organic matter/square metre/year, but most systems average only 1-3 Kg of material. This productivity is bought at the expense of stored energy in the form of fossil fuels, which are used extensively in the manufacture of agrochemicals, and in the mechanization of farm activities.

The most important plant nutrients which are applied in inorganic fertilizers are nitrogen, phosphorus and potassium. All three were origally mined; sodium nitrate from Chile, rock phosphate from N. Africa, and potash from Canada. The reserves of the latter two, although their occurrence is geographically restricted, and require costly importation and pre-treatment, should survive the world demand for several decades. However, until the early 20th century when the method of industrial fixation of nitrogen was discovered, which had been predicted to be essential by Lawes (1847) and Crookes (1896), the Chilean deposits of nitrate and the by-products of the coal gas industry were quite inadequate to supply sufficient nitrogen for world agriculture. During the first half of this century the use of fertilizers in the U.K. increased dramatically, especially for nitrate and potash production :

in thousands of tons :

Date	N	P_2O_5	K_2O
1900	16	110	7
1939	60	170	75
1956	291	386	305

This increase was partly necessary because of the increased loss of nutrients from the farmed land : in Kg/ha/year

	N	P_2O_5	K_2O	
Four year rotation	57	18	7	
Modern system	390	128	435	(Cooke 1954)

Eutrophication

Unfortunately the imported inorganic nutrients do not remain within the agricultural ecosystem, but leak out through the water systems, causing eutrophication of rivers, lakes and oceans. Eutrophication may be defined as the enrichment of an ecosystem by geochemical nutrients from outside the system. If these nutrients could be contained within the farms, such eutrophication might be an advantage to the continual production of high yielding crops. But, just as N, P and K are the most important elements for the nutrition of terrestrial plants, so they strongly influence the growth of algae and aquatic macroflora, which may choke eutrophic waterways. When these organisms die, the water frequently becomes deoxygenated, resulting in fish-kills, and a loss of the amenity value of the water. Thus eutrophication has taken the popular connotation of over-enrichment, equivalent to pollution.

Nitrogen

The supply of food is limited more by the availability of fixed nitrogen than by any other plant nutrient (Delwiche 1970). Thus, in modern agriculture, the most serious intervention into the natural biogeochemical cycles operating in terrestrial systems has been the industrial fixation of nitrogen. Since 1950, this artificial fixation has increased 5-fold, and now exceeds, by about 10%, the total amount naturally fixed by all terrestrial ecosystems before the advent of modern agriculture. In 1968, the total world production of industrially-fixed nitrogen was 30 million tons, and since then this quantity has been doubling, once every six years. This energy-intensive process has recently become very expensive, due to the rise in oil prices, for it requires 6000 K calories of energy to fix one Kilogramme of nitrogen.

Before industrial fixation, the amount of nitrogen fixed naturally by microorganisms was balanced by those denitrifying the system, but the full consequences of a much higher fixation rate, than denitrification, over a long period, is not known. One effect which is becoming evident in the regions of the world where intensive systems operate is the high concentration of nitrate in the drinking water supplies. The main source of this increased concentration is assumed to be agricultural run-off. For example, in 1968 Wadleigh estimated that in the USA, of the 7 million tons of nitrogen fertilizer added to the soil, at least 3 million tons of nitrate entered the waterways. This very soluble ion leaches rapidly from soils, and once present in the water is very difficult to remove. The only economical process which has been used to overcome this problem has been the dilution of the eutrophic water with purer supplies from non-agricultural regions. High nitrate levels in the drinking water can bring about the condition of methaemoglobinemia in young children and animals, which may result in the death of the victims.

Eutrophication of crop plants has also been demonstrated by Thorne (1957) and Ackerson (1963), who found free crystals of potassium nitrate in turnip and maize leaves respectively, where the plants were receiving high rates of nitrogen fertilizers. It is possible that if this concentrating effect occurs in the parts of crop plants used for human consumption, this source might also prove to be a dangerous result of the over-application of artificial fertilizers.

Thus the production of increased food yields necessary for the survival of man, is itself causing a pollution of the environment which may reduce the numbers of our species. The accumulation of toxic and non-degradable agrochemical wastes, and high concentrations of essential nutrients, is tending to reduce the stability and the complexity of ecosystem structure, shortening food chains, and favouring decomposition and decay. Woodwell (1970) stated that the eutrophication of the environment encourages the simplification of the biota, and increases the interaction between the mineral cycles in the terrestrial and aquatic ecosystems - the long-term trend of evolution towards stable, complex and largely autonomic systems is being reversed. In 1968, Odum suggested that such pollution of the environment should not be regarded as completely detrimental, as it may provide new opportunities for the evolution of organisms and ecosystems, but as so many of the pollutants cause widespread death and decay, it is difficult to see how this state could form the basis of an evolutionary advance (Hutchinson 1970).

Agriculture has thus become an anti-seral development, whereby the stored energy of the system becomes progressively depleted, the whole only being able to continue to operate if increasing amounts of energy and nutrients are added to it by man.

Organic manures versus Inorganic Fertilizers

Since the 1840's there has been a continuing controversy concerning the benefits and disadvantages of the farm management methods which utilize animal manures as the main source of plant nutrients. The German agricultural chemists, such as Liebig (1840), showed that plants were made up of C, H, N, and O, which they reasoned originated from the atmosphere, and P, K, Mg, and Ca, originating from the substrate. When calculating the formulae of the necessary nutrient applications for crops, they assumed that any substance discovered in the plant was serving a useful purpose. Because farmyard manure contained very low levels of the macronutrients, proportional to its bulk, they decided that it was more effective and economical to supply these in the form of simple salts from which the nutrients were speedily available to the crops. This view was controverted by Lawes and Gilbert at Rothamsted who reasoned that most of the nitrogen originated from the soil, and that when nutrients were added in organic manures, supplemented by the inorganic salts, this application was more equivalent to the nutrient recycling found in nature. The applied manures underwent gradual decomposition, making the contained nutrients available as the crop plants grew, and the humus improved/maintained the good structure of the soil. The sound nature of their beliefs can be seen from the results of the 130 year experiment on Broadbalk field at Rothamsted.

In the 1971 Ministry of Agriculture Advisory Leaflet (No. 435), the official recommendation was that the use of farmyard manure "being the solid and liquid excreta of cattle/pigs,mixed with their litter,improved the nutrient content and structure of the soil, enabling it to retain more moisture, and to provide easier cultivation." The area most likely to benefit from this treatment was suggested to be East Anglia. However, they further reiterated the German agrochemists' views that "to obtain economic returns under present-day intensive conditions it is necessary to greatly increase the amount of plant nutrients supplied to crops. As the quantity of farmyard manure is limited, this means that an extra addition of inorganic fertilisers should be made." Because livestock are now also raised intensively, fed on high protein concentrates, there may be a vast surplusage of slurry and manure in many localized areas, but no supplies of manure in others. Therefore the main problem today is that of the distribution and storage of this natural resource.

In 1970, the Strutt report stated that the use of artificial fertilisers had caused no loss of soil fertility, and that there was no evidence that organic manures from leys, and the farmyard, were a better source of nutrients. However, it did note that a low organic matter content of the soil could be serious, where there was a complete absence of livestock and a continuous monoculture of one cereal crop, especially in the areas of the country where light soils are cultivated.

The Research Project

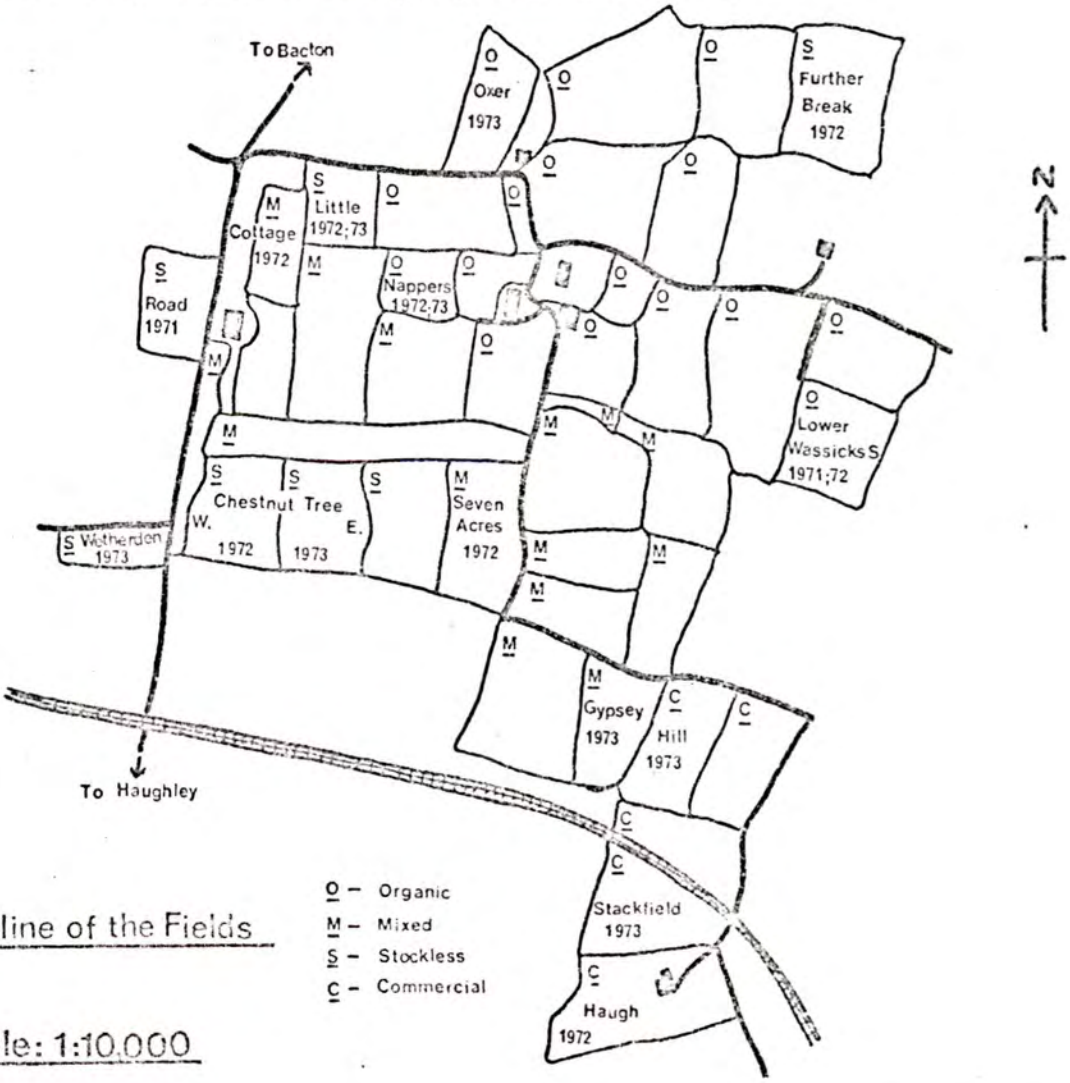
In order to elucidate, and compare, the flow of nutrients found under "natural" organic farming conditions, with those where only artificial fertilizers are used as a nutrient source, the agricultural ecosystems found at the Haughley Research Farm were investigated. The creed of the Soil Association, which was responsible for the running of the farm for most of its existence, was that the real ends of agricultural science should be to achieve high crop yields by the best utilization of the natural processes of nutrient recycling, and natural crop resistance, to produce a stable, non-polluting, self-generating and inexpensive, closed system. The initial founding of this research farm was the work of Lady Eve Balfour; through much of the farm's life additional income was provided by the selling of Organic 'Health' foods.

The Haughley Research farm is situated in E. Suffolk at a height of 200 feet above sea-level. The farm is more or less flat, and is subdivided by hedges and deep ditches into small fields of 2.5 - 3.2 hectares. In 1941 the farm was divided into three sections "for the purposes of comparing, from the health point of view, three systems of farm management, based on the different conceptions of the nature of crop nutrition." Two of the farm sections, each of 30 hectares, carried livestock, and the remaining 13 hectares were to remain without stock of any kind. The fertility of one of the stock-bearing sections (Organic) was to depend entirely upon the crop residues and animal manures produced upon that section - no manufactured agrochemicals were to be used. The second stockbearing section (Mixed) was to receive a supplementary application of chemical fertilizers, in addition to the crop residues and manures produced within that section. The Stockless section received crop residues and chemical fertilizers, with organic manures and leys excluded. Only on the Mixed and Stockless sections was the use of pesticides and herbicides permitted. The aerial view of the experimental farm is shown on Plate 1, and this also indicates the plan of the different field types.

This research project was undertaken to attempt to evaluate the agricultural ecosystems at Haughley, to determine the long-term results of the three systems of farm management upon the crop environment, to determine which system produced the most economic return in crop yield for the input of nutrients and energy, and to determine which system posed the most serious threat to the possible eutrophication of the terrestrial and aquatic ecosystems.

The complexity of even a partially man-made ecosystem is very great, and this precludes any simple, single factor analysis to provide an accurate evaluation of the system. However, because of the central role of energy in maintaining the life of organisms, an examination of the fixation of this energy (expressed as plant growth and yield), and the quantification of the flow of nutrients through the plant, soil, soil-water system, enables a more thorough comprehension of the dynamics of the ecosystem (Woodwell 1970). These ecological parameters formed the basis of the evaluation of the three farm systems at Haughley, where the phytometer chosen was *Vicia faba* L. The bean seeds produced by this plant contain 25-27% crude protein (dry weight), and have recently become a most important source of high protein flour, for human consumption. The choice of a legume also allowed an estimation to be made of the impact of these three forms of farm management, upon the natural symbiotic fixation of nitrogen.

Fig.1 Aerial view of the Haughley Research Farm.



Outline of the Fields

Scale: 1:10,000

Overall aims of the Research Project

In order to assess the long-term effects of the three systems of farm management upon the crop environment at Haughley, five methods of approach were adopted :

1. To determine the status quo of the plant nutrient supply in the three soils - the crop template.

Regular analyses of the plough-depth of top soil, and occasional sampling of the sub-soil, for the total geochemical content of a broad spectrum of elements were to be performed, throughout three years of field trials. The "plant-available" (chemically exchangeable) quantities of nitrogen, phosphorus and potassium in the top soil were also to be determined. It was planned that the nutrient content of the inorganic fertilizers and the organic manures should be defined to enable the calculation of the annual addition of nutrients to the three systems.

As no information concerning the geochemistry of this particular environment was available, a broad spectrum approach was chosen. The quantification of a wide range of nutrients was required in order to identify whether or not the farm management had altered the soil's potential for producing healthy, high-yielding crops.

2. To determine the rate, and magnitude, of the flow of geochemicals through the three farm systems in the water vector.

Monthly collections of rainfall and field drainage water were to be made for chemical analysis, and their volumes recorded, to enable the calculation of the annual addition to, and loss from, the system for the geochemicals considered.

Because the automatic monitoring of the flow of water from the existing field tile drains was anticipated to be prohibitively expensive, the installation of lysimeters was planned to be implemented for the second year's field trial. This would enable the measurement of the volume of water, and the weight of geochemicals, lost by percolation through the soil.

3. To determine the influence of the farm management systems upon the growth performance of the crop phytometer.

The farm management systems were to be evaluated, using one of the crops which had been included in the normal rotation at Haughley since the beginning of the experiment in 1941. The crop selected for the phytometer was the field bean - *Vicia faba* L. var Tic and var Throws. During the thirty-year period of the Haughley experiment, each of the three systems had been planted only with the bean seeds which had been previously produced on that section - this process is here called imprinting.

The first aim was to determine, by analysis of the growth and yield data, whether the process of imprinting had adapted any of the imprints to be able to grow better on its own management regime, rather than on another type.

The second aim was to compare the growth performance of a single seed type under the three management systems, and varying levels of fertilizer application on the Stockless section, to show how the method of nutrient input influenced the crop growth dynamics.

An initial pilot project in a greenhouse, during the winter months preceding the first field trial, was to be used to provide growth data with which to test the proposed method of polynomial regression analysis (Hughes and Freeman 1967). Following this, field trials were planned in order that the hypothesis concerning the effect of imprinting, and the effect of management, could be investigated under normal agricultural conditions.

4. To determine the uptake of nutrients by the crop phytometer.

The crop plants were to be analysed for a broad range of geochemicals, corresponding to those studied in the soil, in order to determine the pattern of the uptake of nutrients from the three regimens of farming. The plants which were to be sampled for growth measurement would be subjected to chemical analysis, so that the flow of nutrients into the standing crop could be estimated. It was hoped to compare the effect of the different farm managements upon the chemical composition of the crop at the times of the growth maxima discovered by the previous analysis of growth. The possibility of the eutrophication of the plants by free nitrate (sensu Thorne 1957), especially in the seeds, which are used for human consumption, was to be explored.

5. To determine the influence of farm management upon the symbiotic nitrogen fixation by the crop phytometer.

Using the phenomenon of symbiotic nitrogen fixation for which legumes are renowned, it was intended that an investigation should be made into the possibility of using the rate of nitrogen fixation, and the degree of root nodulation, as biological assays of the soil nitrogen status. This study would also provide an estimation of the potential natural input of nitrogen into the agricultural ecosystem.

A plan of the chronological arrangement of the research, which fulfilled these aims, is shown overleaf.

The theme running through the five methods of approach for the assessment of the farm systems was to enumerate the magnitude of the mineral input, and output, of the agricultural ecosystem. From the results it was anticipated that overall tables could be constructed to show the approximate magnitude, and rate, of the flow of nutrients through the plant - soil - soil water system. This would demonstrate the effect of the farm management upon mineral cycling, which will ultimately control the agricultural productivity.

The Chronological Arrangement of the Haughley Research Project

Research processes used, with dates	Plant material used	Treatments
1941-1970 : Imprinting	*Vicia faba* var Tic	Organic farm - Mixed farm - Stockless farm
1969-1970 : Imprinting	*Vicia faba* var Throws	" " "
1970 : Research project initiated		
1. Comparison of seed weights, to determine the effect of imprinting (Text section 3)	Tic O, Tic M, Tic S Throws O, Throws M, Throws S	
2. Comparison of seed germination, to determine the effect of imprinting and soil type (Text section 3)	Tic O, Tic M, Tic S	Petri dish - water - KNO_3 Flower pots - Organic soil - Stockless soil
1970-1971 : Greenhouse Trial		
To determine the effect of imprinting and soil type during a period of ten weeks, on :	Tic O, Tic M, Tic S	Organic soil Stockless soil
1. Crop growth - measurements of dry weight, leaf area - calculation of LAR, RGR, NAR (Text section 3)		
2. Crop geochemistry (Section 4)		
1971 : Field Trial		
To determine the effect of imprinting, soil type and fertilizer application rate upon :	Tic O, Tic M, Tic S Throws O, Throws M, Throws S	Organic soil Stockless soil - no fertilizer - 375 Kg fertilizer/ha - 625 Kg fertilizer/ha
1. Crop growth - analysis as for Greenhouse trial (Section 3)		
2. Crop geochemistry - comparisons of geochemical concentrations at the times of growth maxima, in separate plant parts (Section 4)		
3. Soil - physical analysis - chemical analysis for total and exchangeable geochemicals (Section 1)		
1972 : Field Trial		
To determine the effect of farm management upon :		
1. Crop growth (Section 3) 2. Crop geochemistry (Section 4) 3. Soil analysis (Section 1) 4. Water - analysis of rain, drainage and lysimeter leachate (Section 2) 5. Nitrogen fixation (Section 5)	Commercially obtained *Vicia faba* var Throws	Field and lysimeters - Organic - Mixed - Stockless - Stockless - high fertilizer
1973 : Field Trial		
To determine the effect of farm management upon :		
1. Crop geochemistry (Section 4) 2. Soil analysis (Section 1) 3. Nitrogen fixation (Section 5)	Commercially obtained *Vicia faba* var Throws	Fields : - Organic - Mixed - Stockless - Commercial

SECTION 1. SOIL ANALYSIS

Section 1. SOIL

1:1 Background

:1.1 The major difference between the farm management methods employed on the three farm sections at Haughley concerned the manner of the application of additional nutrients to the soil, in the form of organic manures and/or artificial fertilizers. In 1847 Lawes defined agriculture as "the production of food for man or other animals on a space of ground incapable of supporting them in the natural state". Ever since, research has been actively pursued in many countries to determine the most efficient form in which nutrients should be added to the soil to maintain its fertility whilst producing food.

:1.2 The traditional way of maintaining the productivity of arable soils in NW Europe has been through the application of farmyard manure, but since the initiation of the industrial production of chemical fertilizers, organic manures have become progressively more expensive to produce and distribute, whilst fertilizers have become much more economical. Although as the industrial production of fertilizers, especially that of nitrates, is very energy intensive, since the massive rise in oil prices, the cost differential between the use of artificial and natural nutrient sources has diminished. In many present intensive agricultural systems the practice of applying organic manures and using temporary leys in crop rotations has often been abandoned in favour of monocultural crops dependent entirely upon heavy applications of artificial fertilizers. In 1961 Williams and Cooke stated that many British soils could continue to produce good arable yields for several years without needing any application of organic materials to improve the soil structure, but in some areas soils so treated would lose their organic matter causing degradation of structure, difficult cultivation and a loss of yield.

:1.3 It has been confirmed by many agricultural scientists over the last one hundred years that the main controlling factor in the maintenance of good soil structure is the organic matter content, and the structure in turn strongly influences the growth of the plants. Whereas the application of chemical fertilizers to the soil provides immediately available plant nutrients which may be leached through the soil before they can be utilized by the crop, the use of organic manures provides nutrients slowly and improves the soil structure. As organic farmyard manure is originally derived from plants, it tends to contain most of the required plant nutrients which are held in an available form, for several years, being slowly released during the growth of the plants (McIntosh and Varney 1973). Organic matter is not essential for plant growth as normal, healthy plants can be grown in water/sand culture without a trace of humus, but under normal cropping and farm conditions it influences nutrient, air and water supply to the plants. The decomposition of organic matter promotes the formation of a stable crumb structure (aggregation) and it acts as a replenishing reserve for the release and immobilization of nutrient ions, and as a chelating agent (Schatz et al. 1964). The main part of the humus resulting from this decomposition of organic matter is in the form of a gelatinous film on the surface of small soil particles, and a direct relationship can be observed between the degree of humus accumulation, and the water holding capacity and water permeability of the soil (Inal 1973).

:1.4 Despite the often observed correlation, between the level of organic matter in the soil and the resulting fertility, the official Government Report from the Agricultural Advisory Council in 1970 stated that there was "no evidence that the disappearance of livestock from certain areas and the replacement of ley farming and farmyard manures by chemical fertilizers, has led to any loss of inherent soil fertility -- nor is there any evidence that organic matter is intrinsically a better source of nutrients." Thus the first approach to the quantification of the farming systems at Haughley was to consider the template upon which the growth of crops depends, namely the status of the soil nutrients within each management type. As has been stated, these types differ in their management through the method of nutrient addition; there follows a basic description of each management practice.

:1.5 Management of farm sections

.5.1 Organic section

The soil fertility depends upon the addition of organic manures which are supplied twice within a ten-year rotation, plus a ploughing under of the annual crop residues. Originally it was planned that all the manure used should be home-produced on this section but due to the intrinsic loss of soil nutrients, falling stocking rates and increased labour costs, production fell, so pig and poultry muck produced elsewhere have been introduced into the system. The rotations practised have been changed several times since the experiment began, but the one in operation at the time of this research study was :

oats : barley : lucerne/beans : wheat : oats : ley : ley : ley : ley
↑ Manure (after oats) ↑ Manure (after second oats)

with farmyard manure applied at the times indicated at the rate of 12,500 - 50,000 Kg/ha (5-20 tons/acre). This section has not been treated with any herbicides nor artificial fertilizers since 1941, although Calseamin has been applied at rates of 1,250 Kg/ha, but not to any of the fields used in this study. One field in the section had received sewage sludge at the rate of 62,500 Kg/ha, but this area was avoided.

.5.2 Mixed Section

The soil fertility depends upon the addition of organic manures applied as described for the organic section, plus an annual supplement of artificial NPK fertilizer applied at the rate of 375 - 1,250 Kg/ha, depending on the crop, in the form of Shell No. 3 or 5, and Nitrashell on the ley, plus a ploughing under of the annual crop residue. The rotation followed on this section was :

wheat : roots : barley : beans : oats : ley : ley : ley : ley

On some fields within the section, slurry was applied during the ley period. In addition, the herbicides Shell M25 and Gramoxone were applied to the barley and bean crops at the rate of 6.3 l/ha and 3.1 l/ha respectively. It was considered that at these rates of application any constituent elements would appear at negligible concentrations in the growing crop, soil and soil water, and therefore these compounds were not analysed. The bean seeds were not dressed prior to drilling.

.5.3 Stockless Section

The soil fertility depends upon the annual application of NPK fertilizers in the form of Fisons 52 and 53 at the rates of 188 - 1,000 Kg/ha, depending upon the crop, plus the ploughing under of the annual crop residues.

No leys were utilized in the rotation on this section, and there was no application of any form of organic manures. The rotation followed had a five-year span :

wheat : barley/sugarbeet : barley : beans : barley

As for the Mixed section, only PK fertilizers were applied to the leguminous crops. The sprays used during the rotation were Phenoxylene Plus and Carbyne, at the rate of 6.3 l/ha or Simadex at 2.5 Kg/ha.

.5.4 Commercial Section

This section was only sampled in 1973 for the comparative analysis of the crop geochemistry. Additives to this section comprised a different one of the following,applied every year,at the rate shown in brackets : Humber Fish No. 4 (310 Kg/ha) : Pig muck (41,250 Kg/ha) : Poultry manure (12,500 Kg/ha) : Farmyard manure (37,500 Kg/ha) : Sewage sludge (62,500 Kg/ha). The differences in terms of nutrient addition to the systems were defined scientifically by the detailed chemical analysis of the manures and fertilizers used during the research study. This allowed an accurate estimation of the input of the contained elements into the field ecosystem.

1:2 Analysis of Manures and Fertilizers

1:2.1 Aim To chemically analyse the manures and fertilizers used at Haughley, to enable determinations of the addition of nutrients to the farm sections to be made.

1:2.2 Methods

Table 1-1 lists the concentrations of total and available geochemicals in the manures and fertilizers used in the fields and experimental plots during the research project.

:2.2.1 Total geochemicals - The figures on Table 1-1(1) are expressed in terms of grammes of the geochemical/Kilogramme fresh manure, as this was the form in which it was applied to the fields concerned. In the actual determinations, that for total nitrogen was conducted upon fresh manure due to the loss of ammonia-nitrogen when drying this material, but the remainder of the analyses employed manure dried at 105^{o}C for 48 hours prior to wet digestion. The total Nitrogen figures are derived from the addition of Kjeldahl Organic nitrogen to the separately determined values for Nitrate-nitrogen. The methods of analyses used appear in the Appendix. The mean water content of the fresh manures was : Organic FYM - 76% water; Mixed FYM - 70% water; Poultry muck - 61.7% water.

:2.2.2 Exchangeable geochemicals (Table 1-1(2)) - Although some loss of ammonia occurred when the fresh manure was dried, even at room temperature, it was found impracticable to use the fresh material for the estimation of the NH_4-N and NO_3-N by cold distillation with magnesium oxide and titanous sulphate (see Appendix). Therefore for the analysis of available nitrogen and phosphorus (sodium bicarbonate extraction) the manures and fertilizers were dried at simulated room temperature (30^{o}C in forced air draught for 5 days). It was discovered that even this extent of drying markedly increased the quantity of available potassium, as determined by the ammonium acetate extraction method to almost the total contained potassium level, therefore fresh manure had to be used for this element.

Fertilizers were found to give levels of available nitrogen and phosphorus almost equivalent to the total geochemical content of these elements and tended to so swamp the methods chosen for soil analysis that frequently figures for the available ion would be above that derived by acid digestion. The alternative to using these concentrated dried forms was to employ massive dilution of the fertilizer, but this also introduced large errors. It has therefore been assumed that the actual available/exchangeable quantities of nitrogen and phosphorus in the fertilizers were about 90% of the totals indicated by acid digestion.

:2.3 Discussion of results

:2.3.1 Concentration of geochemicals - The main difference in terms of total ions between the three forms of manure employed was that the poultry manure contained significantly more phosphorus, calcium, magnesium, aluminium, iron, copper, zinc and lead than either of the farmyard manures. On a weight for weight basis the chief difference in chemical content between fertilizers and manures was the very much higher concentrations of phosphorus and potassium and slightly higher concentrations of nitrogen in the former compound. For this reason the weight application of manures, where used, was of necessity much greater per unit area than that of chemical fertilizers. Despite a total extractable nitrogen figure for poultry manure between that of the two farmyard manures, this had a significantly higher value for available nitrogen (mainly as ammonium), than either of the other forms. Otherwise, the pattern shown for the concentration of total geochemical ions in these three manures was maintained for the available ions, with the poultry manure having the highest level of phosphorus, but the lowest level of potassium.

Table 1-1

MANURE AND FERTILIZER ANALYSIS

Concentration of total and available geochemicals in the manures and fertilizers used on the farm systems during research study

(1) Total geochemicals (concentrations expressed as gm/Kg fresh manure and gm/Kg fertilizer)

Manure/Fertilizer	N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
Organic FYM	29.9	1.7	12.1	1.7	5.5	1.4	0.9	1.1	0.008	0.024	0.005
Mixed FYM	42.9	2.0	12.8	2.3	7.1	1.4	0.3	0.6	0.008	0.035	0.005
Poultry manure	35.3	6.1	7.0	1.0	22.5	4.3	2.1	2.8	0.042	0.211	0.013
1971 Fertilizer-Plot Trial	74.0	89.1	187.5	4.9	21.9	2.0	2.8	3.4	0.036	0.063	0.000
1972 Fertilizer-Lysimeters	69.5	94.5	181.3	4.9	1.9	1.9	4.1	3.4	0.034	0.063	0.013

(2) Available geochemicals

Manure/Fertilizer	Nitrogen			Phosphorus	Potassium
	NH_3-N	NO_3-N	Total		
Organic FYM	0.046	0.707	0.753	0.440	10.60
Mixed FYM	0.139	1.807	1.946	0.610	9.70
Poultry	2.91	2.86	5.77	0.940	8.10
1971 Fertilizer-Plot Trial	-	-	-	-	177.0
1972 Lysimeter Trial	-	-	-	-	159.3

N and P measured on manure dried at R.T.

K " " fresh manure.

Table 1-2

MANURE AND FERTILIZER ANALYSIS

Addition of geochemicals to farm system.

Fields (Geochemicals added - expressed in Kg/ha)

Year	Management type	Field	Application	Date	Rate Kg/ha	N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1972	ORGANIC	Lower Wassicks South	Poultry	Dec. '72	12,500	441	76	88	13	281	54	26	35	0.5	2.6	0.2
	MIXED	Seven Acres	0.20.20 fertilizer Dolomite	March'72 " "	250) 5,000)	-	50	50	-	1960	600	-	-	-	-	-
	STOCKLESS	Chestnut Tree West	0.20.20 fertilizer	March'72	250	-	50	50	-	-	-	-	-	-	-	-
1973	ORGANIC	Nappers	Poultry	Dec. '72	25,000	882	152	176	26	562	108	52	70	1.0	5.2	0.4
		Oxer	Poultry	" "	12,500	441	76	88	13	281	54	26	35	0.5	2.6	0.2
	MIXED	Gypsy	0.20.20 fertilizer N15.K10.Na21	March'73 " "	250 188	28	50	69	40	-	-	-	-	-	-	-
	STOCKLESS	Little	0.20.20 fertilizer	March'73	375	-	75	75	-	-	-	-	-	-	-	-
		Chestnut Tree East	0.20.20 fertilizer	" "	188	-	38	38	-	-	-	-	-	-	-	-
		Wetherden	0.20.20 fertilizer	" "	188	-	38	38	-	-	-	-	-	-	-	-
	COMMERCIAL	Hill	Poultry	Nov. '72	12,500	441	76	88	13	281	54	26	35	0.5	2.6	0.2
		Stackfield	Poultry	" "	12,500	441	76	88	13	281	54	26	35	0.5	2.6	0.2

:2.3.2 Addition of geochemicals to the farm system

.3.2.1 Table 1-2 depicts the addition of geochemicals to the fields during the nine months preceding the field trials, based on the total geochemical analyses. This table indicates one of the problems of conducting research under normally operating field conditions. Due to the pre-existence of certain rotations, which did not at any one time coincide between the three management sections, both the Organic fields studied in 1972 and 1973 received manure applications immediately prior to the experiment, whereas neither of the Mixed fields did. Thus any differences observed between the sections in the analysis of the soil, and the growth of the crop plants, may be caused either by the stage attained in the rotation, or by the management pattern itself.

In addition, separate fields within any one section tended to receive different treatments during each particular year. Thus in 1973 Nappers field received double the quantity of manure applied to Oxer field although both were within the Organic section. Similarly, on the Stockless section, PK fertilizer application in 1972 was at the rate of 250 Kg/ha, whereas in 1973 this rate ranged from 188-375 Kg/ha. These basic differences in the supply of nutrients to the soil must be remembered when evaluating any observations and measurements of the growth and yield of the crop plants.

.3.2.2 Table 1-3 lists the addition of nutrients to the individual trial plots used over the three year project. The treatments are discussed below, but complete information regarding the lysimeters will be found in Section 2 on Water chemistry, and concerning the 1973 Special fertilizer Treatment in Section 5 on Nitrogen fixation.

.3.2.2-1 <u>1971</u> In order to compare the growth of bean seeds on the Organic and Stockless soil 1.22 metre square plots were arranged in random blocks on

Lower Wassicks South and Road fields (see Section 3 on Crop Growth). The organic field had been treated two years previously with manure brought in from outside the system, apart from on a wide strip in the centre of the field. The plots used for this trial were chosen from within the untreated strip so as to measure the effect of the soil nutrient status of the original management system. Unfortunately this meant that no estimation of the addition of nutrients to these plots could be made. On the Stockless field two levels of fertilizers were applied to the plots :-

.2.2-1(1) No fertilizer application in the year of study.

.2.2-1(2) Fertilizer rate of 375 Kg/ha Shellstar No. 3 - a 10:25:25 fertilizer added as a top dressing after the bean seeds had been sown.

.2.2-1(3) Fertilizer rate of 625 Kg/ha Shellstar No. 3 applied as a top dressing. In addition, the crop residues from the previous crop of wheat had been ploughed into the soil but no estimate of the extent of this nutrient source could be made. The addition of nutrients to these plots is shown in Table 1-3(1).

.2.2-2 <u>1972</u> Sixteen lysimeters were constructed with the aim of evaluating the quantity of nutrients leached out by rainfall during the course of the year. On each of the Organic and Mixed sections four lysimeters were made, two deep (0.108 sq. metre surface area) and two shallow (1.44 sq. metres) and on the Stockless section two sets of four were dug to allow two levels of fertilizer to be applied. The Organic field (Nappers) had had no manure application since August 1970 when poultry manure had been applied at the rate of 15,000 Kg/ha, of which some would be remaining for the 1972 crop. The figures on Table 1-3(2) give the values for total nutrients which would have been applied in 1970 - the actual amount remaining cannot be estimated. The Mixed field (Cottage) was treated with 250 Kg/ha nitrochalk and 125 Kg/ha single super-phosphate

Table 1-3

MANURE AND FERTILIZER ANALYSIS

Addition of Geochemicals to Farm Systems.

Experimental Plots

(1) 1971 Stockless field - three levels of application (additions expressed in gms/1.49 sq.m. plot)

Plot	N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
3F = 375 Kg fertilizer/ha											
grammes/plot	4.1	5.0	10.5	0.27	1.23	0.11	0.16	0.19	0.002	0.004	0.000
Kg/ha	27.9	33.4	70.3	1.8	8.2	0.8	1.1	1.3	0.014	0.024	0.000
6F = 625 Kg fertilizer/ha											
grammes/plot	6.9	8.3	17.5	0.46	2.04	0.19	0.26	0.32	0.003	0.006	0.000
Kg/ha	46.6	55.5	117.3	3.1	13.7	1.3	1.8	2.1	0.023	0.039	0.000

(2) 1972 Lysimeters (additions expressed in gms/shallow or deep lysimeters)

Field & Lysimeter Details		N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
ORG - remains	-s	76.3	13.1	15.3	1.9	48.5	9.4	4.5	6.1	0.09	0.45	0.04
of 1970 Poultry	-d	5.7	1.0	1.1	0.2	3.6	0.7	0.3	0.5	0.007	0.034	0.003
Kg/ha		530	91	106	16	337	65	31	42	0.6	3.1	0.3
MIXED	-s	14.8	6.6	5.0	-	4.0	-	-	-	0.002	0.002	-
	-d	1.1	0.5	0.4	-	0.3	-	-	-	0.0002	0.0002	-
Kg/ha		103	46	35	-	28	-	-	-	0.011	0.024	-
STOCKLESS												
Normal Fert.	-s	7.2	5.0	5.0	-	-	-	-	-	-	-	-
	-d	0.5	0.4	0.4	-	-	-	-	-	-	-	-
Kg/ha		50	35	35	-	-	-	-	-	-	-	-
High Fert.	-s	16.1	17.3	28.5	0.6	0.24	0.24	0.53	0.5	0.004	0.009	0.001
	-d	1.2	1.3	2.2	0.05	0.02	0.02	0.04	0.03	0.003	0.007	0.0001
Kg/ha		112	120	198	4.4	1.7	1.7	3.7	3.1	0.03	0.06	0.01

(3) 1973 Special Fertilizer Treatments in Chestnut Tree East field.

1. PPKK - Phosphorus applied at 75 Kg/ha. Potassium applied at 75 Kg/ha.
2. NNPPKK - Nitrogen applied at 135 Kg/ha to half of the area of PPKK.
3. NNPK - Nitrogen applied at 135 Kg/ha to part of the normal field where the rate of application of phosphorus and potassium was 37.5 Kg/ha.

in September 1971 and with 250 Kg/ha Top Yield No. 5 20:14:14 fertilizer in April 1972. Both these treatments were designed for the barley crop grown in the remainder of the field and consequently provided much higher levels of nitrogen than would normally be applied to the bean crop. To all the lysimeters in the Stockless field (Little), 250 Kg/ha Top Yield No.5 fertilizer was applied, and one set of four lysimeters had an additional application of 900 Kg/ha of 10:24:24 fertilizer. The total nutrient additions to the lysimeters appear in Table 1-3(2) expressed in grammes/lysimeter and the equivalent Kg/ha. In addition, the crop residues on all sections would have been ploughed back into the soil before the lysimeters were constructed.

.2.2-3 1973 The only experimental plots were the special fertilizer treatments on Chestnut Tree East field (Stockless section). The field was sown to field beans and therefore 37.5 Kg/ha potassium and the same quantity of phosphorus had already been applied. Three weeks after sowing, the following supplementary applications were made as top dressings :

.2.2-3(1) PPKK - Normal fertilizer plus an additional 37.5 Kg/ha of potassium and phosphorus

.2.2-3(2) NNPPKK - Normal fertilizer plus 37.5 Kg/ha potassium
37.5 Kg/ha phosphorus
135 Kg/ha nitrogen in the form of ammonium nitrate

.2.2-3(3) NNPK - Normal fertilizer plus 135 Kg/ha nitrogen.

1:2.4 Conclusions

It has been demonstrated that if short term evaluations are to be performed on pre-existing farm systems, the control of the variables, especially with respect to those of nutrient additions to the system, is severely limited. The bean plants grown rarely had the precise levels of nitrogen, phosphorus and potassium which would be normally applied to this crop, as experimental plots had to be situated in the most convenient fields rather than in those designed for growing beans. It proved impossible to use fields on the different sections which were all at the same stage in the crop rotation. Thus where in the following sections the effect of the Organic management appears significantly different from that of the Mixed, this may be entirely due to the fact that the latter had not received organic manure for at least two years preceding the experiment, whereas the Organic fields selected had had manures applied immediately prior to the trials. It was considered that a meaningful comparison of the three systems could still be made, provided that these limitations were recognized prior to associating particular differences observed, to be due to management patterns alone.

The fields utilized in the research project were carefully selected from those available for geological uniformity. Therefore as far as was possible fields belonging to a single soil phase were used throughout the three years (see Appendix). At the beginning of the 1972 season, three soil pits were dug, one on each section, and the observations are incorporated into the Appendix. The chemical analysis of the soil layers is shown in the text in the appropriate section.

1:3 Soil Analysis

Aim To compare the status quo of the soils from the three farm sections and to determine whether changes have been brought about by the different management practices. This assumes that within each soil phase the soil (to plough depth) on all fields was very similar before the experiment began in 1941.

1:3.1 PHYSICAL

:3.1.1 Loss of weight on ignition

Aim To determine whether the addition of organic matter to the Organic and Mixed sections has increased the fraction which is lost on ignition of these soils, and to show any variation in the weight loss during the season.

Method Soils which had been previously dried at 105°C for 48 hours and sieved to pass a 1 mm gauge were ignited at 550°C in an electric furnace for 24 hours. The results are shown in Table 1-4 where the figures are expressed as the percentage weight loss from oven dry soil through the season of 1972.

Results The table shows that there was no significant change in the loss of weight on ignition during the season, nor were there any significant differences in this criterion between the layers 0-10 cm and 10-20 cm. The effect of soil depth is demonstrated by the decrease for 31/3/72 which is most marked on the Organic section. When the seasonal means of the three sections are statistically compared it is evident that $0 > S$ and $M > S$ although $0 \equiv M$.

Conclusions Howard (1965), using the conditions described above, explained that although this temperature did not cause decomposition of calcium carbonate, some loss of weight on ignition may have been due to the release

SOIL ANALYSIS

TABLE 1- 4 Loss of weight on ignition, using soil from the three farm systems 1972.

Expressed as percentage weight loss.

Date	Depth (cms)	Organic	Mixed	Stockless
21/3/72	0-24	5.9	6.1	4.7
	25-35	1.5	2.7	3.5
	36+	1.7	2.6	2.0
1/5/72	0-20	5.8	5.7	4.3
25/6/72	0-10	4.7	5.2	4.4
	11-20	5.7	5.2	4.2
10/7/72	0-10	5.1	6.1	4.3
	11-20	6.4	5.0	4.3
19/8/72	0-10	6.8	6.0	4.8
	11-20	6.5	5.9	4.5
20/9/72	0-10	6.5	5.3	3.7
	11-20	5.9	5.5	4.2
6/11/72	0-10	6.7	6.4	4.8
	11-20	6.8	6.1	4.9
Mean ± SE	0-10	5.9 ± 0.31	5.8 ± 0.17	4.4 ± 0.15
SD		0.81	0.45	0.39
Mean ± SE	11-20	6.1 ± 0.16	5.6 ± 0.16	4.4 ± 0.27
SD		0.42	0.43	0.10

Statistical comparison of means (using Bailey's d test)

Soil depth (cms)	O-M			O-S			M-S		
	df	d	p	df	d	p	df	d	p
0-10	9.4	0.29	NS	8.6	4.41	<0.01	11.7	6.09	<0.001
11-20	12.0	2.17	NS	6.7	10.63	<0.001	6.7	7.06	<0.001

of bound water which was not removed by prior drying at 105°C. He suggested that the actual levels of organic carbon present were about 50% of the loss on ignition figures. The figures suggest that the application of organic manures to the Organic and Mixed sections, but not to the Stockless section, results in a significantly lower content of organic matter on this latter soil. McSheehy and Rawlings (1973) analysed the top 15 cms of soil, from all three sections at Haughley, for the organic matter content, using the potassium dichromate digestion method (Tinsley) :-

Section	Mean values of organic matter as % of dry weight	Standard Error
Organic	3.38%	0.08
Mixed	3.34%	0.03
Stockless	2.81%	0.05

The pattern shown by these figures closely resembles that shown by the loss of weight on ignition with $O \equiv M$ and $O > S$ $M > S$ significant. The correlation between these results shows that the loss on ignition method is valid for use in comparisons where absolute figures are not required, and that the fifty percent figure shown by Howard does approximately relate the value to the organic carbon content.

:3.1.2 Moisture content

Aim To determine whether the pattern observed for variation in organic matter content of the soils is reflected by the moisture content of the soil, as measured through the growing season of 1973.

Method Soil cores were transported whole in plastic bags from the field to the laboratory and were weighed before and after drying at 105°C for 48 hours.

Results The results of this study are presented in Table 1-5. Although the same trends are indicated as were shown for the loss of weight on

SOIL ANALYSIS

TABLE 1 - 5 Moisture content of soils from the three farm systems 1973.

Date	Precipitation (in mm) during previous 3 days	Organic	Mixed	Stockless
27/2/73	0.50	23.34 ± 1.33 2.66	21.95 ± 0.71 1.43	20.12 ± 1.15 2.29
7/3/73	5.50	19.20 ± 0.10 0.20	21.25 ± 0.53 1.06	19.25 ± 0.17 0.34
14/4/73	0.00	22.10	20.3	16.4
21/5/73	5.00	21.10 ± 0.15 0.30	17.50 ± 0.70 1.40	16.6 ± 0.60 1.20
8/6/73	0.00	17.8	14.6	11.6
5/9/73	2.00	12.3	14.4	13.9
6/11/73	6.50	20.9	18.3	18.4
	Mean ± SE SD	19.5 ± 1.4 3.7	18.3 ± 1.2 3.0	16.6 ± 1.1 3.0

Statistical comparison of annual means (using Bailey's d test)

	O-M			O-S			M-S		
	df	d	p	df	d	p	df	d	p
27/2/73	4.7	0.92	NS	5.8	1.83	NS	6.4	2.39	NS
7/3/73	3.3	3.80	<0.05	4.8	0.25	NS	3.6	3.57	<0.05
21/5/73	3.2	5.0	<0.02	3.4	7.3	<0.01	5.9	0.98	NS
Seasonal Mean	11.5	0.67	NS	11.4	1.61	NS	12.0	1.06	NS

Samples taken from top 20 cm of soil.

Moisture content expressed as w/w % of fresh soil.

ignition, the comparison of the seasonal means show no significant differences between the management sections. Only when the soil samples from individual dates are considered, are some significant differences shown, e.g. March 1973 M > O and M > S significant to >95% level

May 1973 O > M and O > S " " >98% level

<u>Conclusions</u> The trends shown in the determination of organic matter and loss of weight on ignition are maintained in the soil moisture content. This suggests that the organic matter content of the soil does affect the supply of water to the crop plants due to an improvement of soil structure (Cooke and Garner 1954; Anderson and Peterson 1973). It is postulated that this has been brought about as a result of the management practised on the Organic and Mixed sections over the past 30 years.

However there does not appear to be any correlation between the amount of rainfall in the preceding three days with the level of moisture in the soil from any section.

1:3:2 CHEMICAL

:3.2.1 Total extractable geochemicals

.2.1.1 Aim To determine the total extractable concentrations of a broad range of geochemicals in the soil to assess how season, farm management and soil depth affect these concentrations.

.2.1.2 Method Soil is an exceedingly heterogeneous material and therefore it is difficult to obtain truly representative results when sampling large areas of land without using a prohibitively large number of samples. However, within the man-made ecosystem of a farm at least a small degree of homogenization of soil within each field will have resulted from the annual cultivation. In 1971 Webster and Beckett suggested that the variability between samples often increases with the size of the area sampled. Therefore it was decided that the most efficient method of sampling was to select at random a small site (20 m square) within the centre of each field from which soil cores could be withdrawn on the dates required. This method was suggested to give representative results by Vallis (1973).

At monthly intervals during the course of two seasons, cylindrical cores to the depth of the ploughed layer (20-25 cm) were removed from the selected sites in each field, were transported to the laboratory where they were homogenized and dried at 105°C for 48 hours, prior to sieving to pass a 1 mm gauze, and wet digestion of the sub-samples. In 1972 five soil cores from each field were bulked and later sub-sampled five times, and in 1973 fifteen soil cores were bulked and sub-sampled five times. The methods of chemical analysis used appear in detail in the Appendix.

Total Nitrogen - Kjeldahl - detected by alkaline phenol sodium nitroprusside (Allen and Whitfield 1965)

Total Phosphorus - Acid digestion - detected by vanadamolybdate method

Total cations of potassium, calcium, magnesium, sodium, aluminium, iron, manganese, lead, copper and zinc - Acid digestion - detected by atomic absorption spectrophotometer.

Results

.2.1.3 1972 Season

Table 1-6 shows the total concentrations (expressed in grammes/ Kilogramme oven dry soil) of the twelve geochemicals measured through the season of 1972, in the soil from the three farm systems, together with the seasonal means which are then used to statistically compare the sections in Table 1-7. Table 1-8 presents :-

(1) The effect of depth in the soil profile on geochemical concentrations.

(2) A visual comparison of the geochemical concentrations in the field soil with that from the shallow lysimeter previous mentioned. This was used as a check that the status of soil nutrients within the lysimeters had not significantly changed, as a result of their construction, from the situation existing in the field.

All these tables have been corrected for the interference exerted by the alkaline earths upon the atomic absorption spectrophotometer readings of the heavy metals (see Appendix). The fields used for sampling in 1972 were Lower Wassicks South (O), Seven Acres (M) and Chestnut Tree West (S). Those used for lysimetry were Nappers (O), Cottage (M) and Little (S). All these fields belonged to phase 2 soil type except Seven Acres which was in phase 1 (see Appendix).

Discussion

.2.1.3-1 Effect of season

Within Table 1-6 there are no marked seasonal trends of change in the concentration of any of the geochemicals considered during the growing season. As the major part of the total ions will be complexed into unavailable forms, or form the structural lattice, it would not be expected that cropping should significantly change these concentrations (Lawes and

Gilbert 1864). Of those elements comprising macronutrients to the plants, the proportion of available ions will be very small when compared to the total present. Nevertheless certain patterns of change were observed to occur on all sections as outlined below.

.3-1(1) Total nitrogen and phosphorus - the concentrations of both these elements decreased between March and September, but after the crop had been harvested tended to increase again. It is suggested that the decrease during cropping is due to plant uptake and leaching, especially of the nitrogen mineralized from the organic matter.

.3-1(2) Total potassium tended to show a significant net increase between the beginning and end of the growing season, but after harvesting a subsequent decrease. It is possible that more potassium is released from the organic matter and chemical fertilizer than can be utilized by the crop, and after the disturbance and uncovering of the soil at harvest these levels are then reduced by leaching.

.3-1(3) Calcium and magnesium concentrations were extremely variable, probably due to the structural nature of these two elements in the chalky boulder clay with fragments of pure chalk scattered through the profile. The levels appeared to fall on the Mixed and Stockless sections and rise or stabilize on the Organic section, but due to the high internal variability, especially of calcium, no significance can be attached to these changes.

.3-1(4) Sodium and aluminium - the concentrations of these elements are synergic and correlate inversely with the calcium changes observed. On the Organic section they decreased during crop growth, but increased after harvest, whereas on the Mixed and Stockless sections the concentrations decreased during crop growth and increased after harvest.

.3-1(5) Iron - concentrations fluctuated widely over the season, and did not appear to correlate with time nor any of the other elements.

SOIL ANALYSIS

Table 1-6. Concentration of Total Geochemicals in the Soils from the Three Farm Systems Collected during the Season of 1972.

Expressed in gm/Kg dry soil.
Cores 0-20 cm in depth.

Date	N	P	K	Ca	Mg	Na	Al	Fe	Mn	Cu	Zn	Pb
ORGANIC SOIL.												
21/3/72	2.81	0.891	3.125	18.50	1.92	0.188	26.5	17.80	0.263	0.029	0.073	0.020
1/5/72	2.43	0.768	3.625	32.50	2.42	0.213	26.5	18.50	0.250	0.032	0.095	0.048
25/6/72	-	0.757	2.940	28.10	2.13	0.138	21.5	18.65	0.244	0.016	0.085	0.023
10/7/72	-	0.838	2.880	28.90	2.18	0.132	21.4	20.80	0.325	0.055	0.119	0.057
19/8/72	-	0.959	3.145	31.20	2.01	0.213	23.5	20.10	0.207	0.024	0.091	0.023
20/9/72	2.25	0.580	3.220	25.80	2.09	0.169	21.3	18.80	0.200	0.017	0.085	0.027
6/11/72	2.28	0.715	3.095	19.50	2.84	0.181	22.0	18.80	0.250	0.019	0.085	0.022
Mean ± SE	2.44 ± 0.13	0.787 ± 0.050	3.147 ± 0.090	26.36 ± 2.07	2.23 ± 0.12	0.176 ± 0.033	23.2 ± 0.9	19.06 ± 0.39	0.246 ± 0.026	0.027 ± 0.005	0.090 ± 0.005	0.033 ± 0.010
SD	0.26	0.124	0.242	5.47	0.31	0.012	2.4	1.03	0.041	0.014	0.014	0,015
MIXED SOIL.												
21/3/72	2.50	0.842	2.375	17.30	2.75	0.080	20.6	18.0	0.213	0.035	0.076	0.026
1/5/72	2.18	0.866	1.750	18.50	1.67	0.063	16.3	19.1	0.225	0.024	0.212	0.047
25/6/72	-	0.903	2.625	16.90	2.05	0.100	23.5	19.4	0.225	0.013	0.110	0.033
10/7/72	-	0.953	2.750	17.00	1.72	0.181	26.4	21.5	0.275	0.030	0.105	(0.120)
19/8/72	-	0.916	2.562	15.80	1.79	0.138	24.0	19.5	0.213	0.012	0.085	0.019
20/9/72	2.06	0.737	2.970	9.45	1.89	0.156	23.2	19.9	0.206	0.014	0.077	0.027
6/11/72	2.33	0.916	1.750	14.00	1.34	0.080	14.3	17.3	0.213	0.007	0.079	0.020
Mean ± SE	2.27 ± 0.10	0.876 ± 0.031	2.377 ± 0.180	15.56 ± 1.15	1.89 ± 0.17	0.144 ± 0.017	21.2 ± 1.7	19.2 ± 0.5	0.224 ± 0.009	0.019 ± 0.004	0.106 ± 0.018	0.029 ± 0.004
SD	0.19	0.071	0.480	3.04	0.44	0.045	4.4	1.4	0.023	0.010	0.049	0.010
STOCKLESS SOIL.												
21/3/72	1.53	1.024	2.125	22.50	1.50	0.080	16.50	20.00	0.313	0.025	0.121	0.073
1/5/72	1.62	0.913	2.625	15.50	1.75	0.125	20.60	21.60	0.488	0.054	0.144	0.031
25/6/72	-	0.953	3.250	13.20	1.87	0.155	26.30	21.30	0.340	0.015	0.125	0.050
10/7/72	-	0.796	3.000	10.60	1.72	0.163	26.40	22.15	0.345	0.027	0.095	(0.172)
19/8/72	-	0.995	2.440	11.40	1.50	0.070	18.20	22.15	0.325	0.009	0.123	0.017
20/9/72	1.35	0.683	2.500	8.30	1.60	0.113	20.15	20.90	0.330	0.005	0.080	0.014
6/11/72	1.39	0.916	1.750	11.90	1.33	0.017	13.10	18.90	0.300	0.005	0.076	0.024
Mean ± SE	1.47 ± 0.06	0.897 ± 0.045	2.530 ± 0.190	13.34 ± 1.74	1.61 ± 0.07	0.103 ± 0.020	20.2 ± 1.9	21.0 ± 0.5	0.349 ± 0.024	0.020 ± 0.007	0.109 ± 0.010	0.035 ± 0.009
SD	0.13	0.119	0.510	4.61	0.18	0.052	4.9	1.2	0.063	0.017	0.026	0.023

Table 1 - 7

SOIL ANALYSIS

Statistical comparison of the 1972 seasonal means of concentration of total geochemicals in the soils of the three farm systems.

Element	O-M			O-S			M-S		
	df	d	p	df	d	p	df	d	p
N	5.5	1.06	NS	4.4	6.56	<0.01	5.3	6.67	<0.01
P	9.6	1.70	NS	12.0	1.67	NS	9.4	0.33	NS
K	8.7	3.70	<0.01	8.5	2.95	<0.02	12.0	0.49	NS
Ca	9.4	4.56	<0.01	11.6	4.82	<0.001	10.3	1.06	NS
Mg	10.7	1.66	NS	9.8	4.43	<0.01	8.1	1.56	NS
Na	10.0	1.81	NS	10.0	3.64	<0.01	12.0	1.43	NS
Al	9.3	1.06	NS	8.7	1.46	NS	12.0	0.40	NS
Fe	10.8	0.22	NS	11.5	3.29	<0.01	11.8	2.57	<0.05
Mn	11.6	1.36	NS	10.3	3.70	<0.01	7.4	5.42	<0.001
Cu	9.6	1.33	NS	11.8	0.88	NS	9.1	0.14	NS
Zn	7.2	0.89	NS	9.2	1.73	NS	9.1	0.14	NS
Pb	10.5	0.57	NS	10.6	0.18	NS	7.7	0.63	NS

.3-1(6) Manganese, copper, lead, zinc - the concentrations of total heavy metals tended to decrease slightly with season, or to remain at the initial levels. Most of these elements will be firmly complexed to the organic matter or structural minerals of the soil, with a very small plant uptake indeed.

The changes of concentration outlined above may have been due to factors completely separate from the effect of the growing crop such as weathering of soil minerals, leaching, volatilization, mechanical decomposition, or entirely due to insufficient sampling of a very heterogeneous medium.

.2.1.3-2 Effect of farm management

Summarizing the results of the statistical comparison of the annual means of the total geochemical concentrations on Table 1-7, the significant differences to >95% confidence level were :-

$$\left.\begin{array}{l} O > M \\ O > S \end{array}\right) \text{ for Ca, K} \qquad \left.\begin{array}{l} S > O \\ S > M \end{array}\right) \text{ for Fe, Mn} \qquad \begin{array}{ll} M > S & \text{for N} \\ O > S & \text{for N, Mg, Na} \end{array}$$

and there were no significant differences between sections :-

$O \equiv M \equiv S$ for P, Al, Pb, Cu, Zn.

.3-2(1) The calcium level in the soil in the Organic section was significantly greater than that of the Mixed section despite a heavy application of calcium in the form of dolomite in March 1972 to the latter field. From the soil pit dug on the Organic section the very high level of calcium at 20 cm can be observed (Table 1-8) and it is assumed that this was the cause of the significantly higher concentration of calcium when compared with the other two sections.

.3-2(2) The Organic field contained a higher annual mean concentration of potassium than in either the Mixed or Stockless field. Prior to the 1972 season a heavy application of poultry manure was made to this field, providing 60% more potassium per unit area than supplied in fertilizers to the other two fields. The Mixed field, (Seven Acres), had not received organic manures since the autumn of 1969 and therefore was on an equal footing with the Stockless field concerning potassium.

.3-2(3) The Organic and Mixed sections possessed significantly higher annual mean concentrations of total nitrogen than the Stockless section, showing that even on the Mixed section, where manure had not been applied for a few years, there was a significant effect of nitrogen immobilized in the organic matter within the ploughed depth.

.3-2(4) The Organic section contained significantly higher concentrations of magnesium and sodium than the Stockless soil due to the relatively high proportion of these elements supplied by the poultry manure the previous autumn.

.3-2(5) Iron and manganese were found in higher concentrations where artificial fertilizer wasapplied, although this effect was modified where remains of organic manures were present too. This occurred in spite of the fact that more total iron was supplied in the manure than in the fertilizer applications.

.3-2(6) The seasonal mean concentration of total phosphorus, aluminium, lead, copper and zinc in the soils of the three farm sections were unaffected by the farm management type.

The most interesting feature was the lack of difference between the farm sections in phosphorus concentration, despite the fact that the amount of this element applied in the poultry manure on the Organic section was 50% greater per unit area than found in the chemical fertilizer. Part of this lack of difference was due to the calculation of a seasonal mean for the comparison of the three sections which masked some of the variation between fields on individual dates. It is known from the water chemistry studies (see Section 2) that very little phosphorus was leached through the soil on any section. Upon the application of phosphate to the soil there are two stages of fixation (Olsen and Watanabe 1957) - a rapid initial reaction attributed to an exchange adsorption of phosphate ions for hydroxyl ions on surfaces of soil particles, the phosphate attaching to calcium, iron and aluminium ions. This may occur within as short a time period as ten days after initial application of fertilizer (Huffman 1962) and will be followed by a slower reaction whereby there is a gradual increase in crystal size of the precipitated phosphate. Due to the high chalk content of the clay at Haughley it is probable that most phosphorus applied to the soil, which is not immediately taken up by the crop, will be immobilized into an insoluble form such as octocalcium phosphate (Aslyng 1954). It has been shown in this research study (lysimetry and special fertilizer treatments) that where high levels of phosphate are applied to the soil in Spring, high levels tend to remain at the end of the growing season. Oknina 1973 showed that this was especially true on fertilizer treatments as opposed to manurial ones, particularly in dry years. It is postulated that each year an appreciable amount of the phosphate applied as fertilizer accumulates in insoluble forms until the levels attained on all sections are equal due to a saturation of exchange sites.

.3-3 Effect of depth of soil sample

Soil samples were removed from the three soil pits dug to examine the soil profiles on each section in March 1972. The patterns of change in concentrations of the total geochemicals with depth are shown in Table 1-8(1), and outlined below - it is probable that most of those changes were directly attributable to the soil horizons described in the Appendix, and therefore only relevant for the particular fields in which the soil pits were sited.

SOIL ANALYSIS

Table 1-8

Concentrations of total cations in the soils from the three farm systems collected during the season of 1972. (Expressed in gm/Kg dry soil).

(1) Effect of depth from which sample taken.

Soil type & depth (cms)	N	P	K	Ca	Mg	Na	Al	Fe	Mn	Cu	Zn	Pb
ORGANIC												
0-20	2.81	0.89	3.13	18.50	1.92	0.19	26.5	17.8	0.26	0.029	0.073	0.020
20-50	0.22	0.50	2.63	119.30	2.59	0.15	20.9	21.0	0.40	0.025	0.050	0.024
50+	0.19	0.46	1.25	93.30	1.33	0.13	9.6	13.0	0.29	0.022	0.056	0.041
MIXED												
0-20	2.50	0.84	2.38	17.30	2.75	0.08	20.6	18.0	0.21	0.035	0.076	0.026
20-50	0.84	0.36	2.63	8.40	2.59	0.15	32.4	18.8	0.11	0.019	0.085	0.032
50+	0.59	0.34	3.38	8.0	2.92	0.18	34.3	32.2	0.30	0.087	0.210	0.042
STOCKLESS												
0-20	1.53	1.02	2.13	22.50	1.50	0.08	16.5	20.0	0.31	0.025	0.121	0.073
20-50	0.91	0.57	2.13	49.00	1.92	0.09	19.1	20.4	0.34	0.033	0.063	0.091
50+	0.16	0.42	2.13	99.30	1.84	0.10	16.1	18.5	0.34	0.060	0.079	0.033

(2) Comparison between field soils and cropped and fallow lysimeters at end of season.

	Date and Description		N	P	K	Ca	Mg	Na	Al	Fe	Mn	Cu	Zn	Pb
ORGANIC	21/3/72	Field & Lysimeter	2.8	0.89	3.13	18.5	1.92	0.19	26.5	17.8	0.263	0.029	0.073	0.020
	20/9/72	Field	2.3	0.58	3.22	25.8	2.09	0.17	21.3	18.8	0.200	0.017	0.085	0.027
		Lysimeter												
		Cropped	2.2	0.59	3.13	31.0	2.06	0.16	20.5	18.8	0.200	0.017	0.093	0.030
		Fallow	2.3	0.57	3.31	20.6	2.13	0.18	21.8	18.8	0.200	0.017	0.078	0.026
MIXED	21/3/72	Field & Lysimeter	2.5	0.84	2.38	17.3	2.75	0.08	20.6	18.0	0.210	0.035	0.080	0.026
	20/9/72	Field	2.1	0.74	2.97	9.5	1.89	0.16	23.2	19.9	0.206	0.014	0.077	0.027
		Lysimeter												
		Cropped	1.7	0.74	2.50	15.8	1.84	0.10	21.8	15.8	0.180	0.007	0.100	0.033
		Fallow	1.5	0.84	2.00	16.0	1.67	0.13	16.8	17.0	0.200	0.007	0.130	0.014
STOCKLESS	21/3/72	Field & Lysimeter	1.5	1.02	2.13	22.5	1.50	0.08	16.5	20.0	0.313	0.025	0.120	0.073
	20/9/72	Field	1.4	0.68	2.50	8.3	1.60	0.11	20.2	20.9	0.330	0.005	0.080	0.014
		Lysimeter NF												
		Cropped	1.0	0.74	2.25	19.8	1.50	0.10	15.5	18.3	0.25	0.007	0.100	0.035
		Fallow	0.8	0.74	2.25	20.8	1.34	0.10	14.8	18.3	0.25	0.007	0.080	0.035
		Lysimeter HF												
		Cropped	1.0	0.84	1.75	20.0	1.17	0.10	13.0	16.8	0.20	0.007	0.070	0.025
		Fallow	1.3	0.75	5.50	17.0	3.34	0.13	40.5	34.5	0.45	0.015	0.140	0.020

.3-3(1) Nitrogen and phosphorus concentrations on all sections decreased with soil depth, and this was particularly marked in the nitrogen levels which closely followed the pattern found in the investigation of the loss of soil weight on ignition, demonstrating the association between total soil nitrogen and the organic matter.

.3-3(2) Potassium, aluminium and sodium - the synergic relationship suggested previously for aluminium and sodium was maintained through the soil profile. Concentrations of all three elements decreased with depth on the Organic section, increased on the Mixed section and showed little change on the Stockless section.

.3-3(3) A dramatic increase in the concentration of calcium (to over 10% dry weight of soil) at 20 cm on the Organic section explained why higher levels of this element were recorded on this section during the monthly sampling. The Stockless soil concentration of calcium also increased significantly below 50 cm, but decreased in the Mixed section to a level very significantly below that of the other two sections.

.3-3(4) On all three sections the concentrations of magnesium and manganese ions fluctuated without any consistent pattern, except on the Stockless section where manganese concentrates were unvarying through the profile.

.3-3(5) Iron and zinc concentrations tended to fluctuate together; they decreased with depth on the Organic and Stockless sections, but increased on the third field type.

.3-3(6) Lead and copper concentrations vary with depth according to the location of the field sampled.

.3-4 Comparison of field and lysimeter soils at the end of the season

The figures listed on Table 1-8(2) demonstrate the close relationship between concentrations of total geochemicals in the soil of lysimeter and field. The only elements which the excavation and back-filling of soil in the lysimeters significantly affected were :-

.3-4(1) Organic nitrogen - the fall registered in the concentration in the soil over the growing season was greater in the disturbed soil of the lysimeter than in the undisturbed field. It is suggested that the de-structuring of the soil increased aeration, enabling greater mineralization of organic matter and consequent leaching out. This correlates with the information gained in the water chemistry studies (see Section 2) where it was shown that lysimeter leachate contained significantly greater concentrations of nitrogen than in the drainage water from the field.

.3-4(2) Calcium - the decrease in concentration on the Mixed and Stockless sections during the growing season was greater in the field than in the lysimeters. On the Organic section the soil levels apparently increased more in the cropped lysimeter, but less in the fallow one than in the field. It has already been suggested that the analysis of samples of chalky boulder clay for this element is likely to give very variable results, so the observations here may either be due to soil disturbance or due to the natural background variations in the soil.

.3.4(3) Iron - concentrations in the soil of the Mixed and Stockless sections were found to increase in the field but decrease in the lysimeter, possibly due to the greater leaching in the latter situation.

It is considered that the degree of similarity of changes in the total geochemical concentration of all elements considered, except as described above, indicates that the conditions within the lysimeters were comparable with those in the open field and that despite the recognised limitations, lysimetry does fulfil a useful role in the determination of the flow of nutrients through an agricultural ecosystem.

When a comparison is made between the fallow and cropped lysimeters for the values on Table 1-8(2) there is little pattern to the changes observed to be the result of cropping the soil, in terms of total geochemical concentrations. Values for iron, manganese and copper tended to change over the season equally in fallow and cropped soil on all sections, or the latter lost more than the former. Changes in concentration of sodium were equal whether plants were present or not. The values for the concentrations of all the other elements measured,changed over the season in a manner which varied from section to section,and element to element.

Conclusions from 1972

The results indicate that despite crude sampling methods,the seasonal means of geochemical concentrations in the soil did show a positive correlation with the farm management type which had been practised over the previous thirty years. The presence of organic manures in the soil has a controlling effect upon the total nitrogen, potassium, magnesium and sodium concentrations, whilst chemical fertilizer similarly affects iron and manganese concentrations.

.2.1.4 1973 Season

As few definite seasonal trends were shown by the monthly sampling and analysis of soils for the total geochemicals in 1972, this analysis was repeated in 1973 only at the beginning and end of the growing season. Table 1-9 lists the results of these analyses and indicates where a significant change has occurred due to the season, and the direction of this change. Table 1-10 depicts a statistical comparison of the geochemical concentrations in the soils from the three sections in April and September, and the significant differences are discussed below. Table 1-11 shows the results of the chemical analysis of the soils from the special fertilizer treatments designed for the nitrogen fixation experiments. The field was analysed for the same twelve geochemicals as the other sections in order to further determine whether increasing the application of nitrogen, phosphorus and potassium altered the concentrations of the other ions. The fields sampled in 1973 were Nappers (O), Gypsey (M), Little (S) and Chestnut Tree East (S̲ - special fertilizer treatment) which all lay in the zone of soil phase 2 except the latter field which was sited in phase 1.

Discussion

.2.1.4-1 Effect of season

In general it was found that despite the use of different fields within the three sections from those sampled in 1972,the results gained from the second year's sampling confirmed those of the first, as shown in Table 1-9, and briefly mentioned below.

.4-1(1) The fall in the soil concentration of nitrogen and phosphorus found in 1972 was significant on all sections in 1973, except for nitrogen on the Stockless section.

.4-1(2) The increase in total potassium concentration during the season of 1972 was repeated although it was only statistically significant on the Stockless section.

.4-1(3) Calcium and magnesium - as found previously at Haughley great variation of total calcium concentration occurs on all sections and in 1973 there was no significant change over the season. Unlike the earlier lack of pattern of change in the magnesium concentrations, levels on all farm sections increased during the season although this was not significant on the Organic section.

Table 1-9

SOIL ANALYSIS

Concentration of total geochemicals in the soils from the three farm systems at the beginning and end of the 1973 season.

(Concentrations expressed as gm/Kg dry soil. Each mean calculated from concentration in 5 separate soil samples).

Soil type Date & Statistic	N	P	K	Ca	Mg	Na	Al	Fe	Mn	Cu	Zn	Pb
ORGANIC												
14/4/73.												
Mean ± SE	1.91 ± 0.10	0.75 ± 0.02	2.66 ± 0.15	11.0 ± 1.05	1.84 ± 0.04	0.122 ± 0.010	21.2 ± 0.7	20.9 ± 0.9	0.260 ± 0.016	0.052 ± 0.012	0.085 ± 0.007	0.028 ± 0.001
SD	0.20	0.03	0.30	2.1	0.07	0.21	1.3	1.8	0.033	0.025	0.015	0.001
5/9/73												
Mean ± SE	1.36 ± 0.09	0.56 ± 0.03	2.75 ± 0.10	12.3 ± 0.51	2.13 ± 0.23	0.148 ± 0.006	19.5 ± 0.6	17.3 ± 0.3	0.168 ± 0.006	0.020 ± 0.003	0.082 ± 0.010	0.024 ± 0.001
SD	0.20	0.08	0.23	1.13	0.51	0.01	1.4	0.6	0.014	0.006	0.021	0.003
Significant change	<0.01 D	<0.01 D	NS	NS	NS	NS	NS	<0.01 D	<0.01 D	<0.05 D	NS	<0.05 D
MIXED												
14/4/73.												
Mean ± SE	1.71 ± 0.09	0.74 ± 0.02	2.78 ± 0.11	10.8 ± 1.6	1.85 ± 0.10	0.140 ± 0.008	22.2 ± 0.7	23.9 ± 1.0	0.320 ± 0.03	0.086 ± 0.014	0.098 ± 0.012	0.035 ± 0.003
SD	0.19	0.05	0.25	3.6	0.22	0.02	1.7	2.2	0.066	0.030	0.027	0.008
5/9/73												
Mean ± SE	1.31 ± 0.06	0.64 ± 0.01	3.50 ± 0.14	10.3 ± 0.5	2.94 ± 0.35	0.147 ± 0.010	23.2 ± 0.7	23.0 ± 1.5	0.300 ± 0.019	0.033 ± 0.007	0.081 ± 0.006	0.043 ± 0.010
SD	0.13	0.02	0.31	1.08	0.78	0.02	1.5	3.3	0.043	0.016	0.013	0.022
Significant change	<0.01 D	<0.01 D	<0.01 I	NS	<0.05 I	NS	NS	NS	NS	<0.02 D	NS	NS
STOCKLESS												
14/4/73.												
Mean ± SE	1.28 ± 0.17	0.79 ± 0.02	2.46 ± 0.05	11.6 ± 0.6	1.62 ± 0.03	0.113 ± 0.008	19.9 ± 0.04	23.5 ± 0.7	0.358 ± 0.009	0.095 ± 0.023	0.121 ± 0.015	0.025 ± 0.003
SD	0.38	0.04	0.11	1.24	0.07	0.02	0.1	1.5	0.019	0.052	0.033	0.006
5/9/73.												
Mean ± SE	1.03 ± 0.03	0.61 ± 0.007	2.51 ± 0.05	11.5 ± 0.2	1.86 ± 0.06	0.168 ± 0.034	18.9 ± 0.49	19.0 ± 0.6	0.254 ± 0.018	0.025 ± 0.005	0.064 ± 0.016	0.027 ± 0.005
SD	0.06	0.02	0.11	0.53	0.14	0.08	1.1	1.4	0.041	0.012	0.036	0.011
Significant change	NS	<0.001 D	NS	NS	<0.02 I	NS	NS	<0.01 D	<0.01 D	<0.05 D	<0.05 D	NS

Significant change: Result of statistical comparison between beginning and end of season.
Where change is significant the p value is given.
Symbol: D = significant decrease.
I = " increase.
NS = change not significant to p = 0.05.

Table 1-10

Statistical comparison of the concentrations of total geochemicals in three farm systems. 1973.

Element	Date	O-M			O-S			M-S		
		df	d	p	df	d	p	df	d	p
N	14/4	8.0	1.54	NS	6.1	3.32	<0.02	6.1	2.26	NS
	5/9	6.9	0.46	NS	4.7	3.67	<0.02	5.6	4.38	<0.01
P	14/4	6.6	0.38	NS	7.6	1.82	NS	7.6	1.43	NS
	5/9	4.5	2.00	NS	4.5	1.25	NS	8.0	2.31	0.05
K	14/4	7.8	0.69	NS	4.9	1.42	NS	5.2	2.67	0.05
	5/9	7.5	4.41	<0.01	5.7	2.00	NS	5.0	6.60	<0.01
Ca	14/4	6.4	0.11	NS	6.5	0.55	NS	7.9	1.07	NS
	5/9	8.0	2.86	<0.05	5.7	1.43	NS	5.8	2.22	NS
Mg	14/4	4.5	0.10	NS	8.0	4.89	<0.01	4.5	2.30	NS
	5/9	6.9	1.93	NS	4.6	1.13	NS	4.3	3.00	<0.05
Na	14/4	4.1	0.19	NS	4.1	0.10	NS	8.0	2.08	NS
	5/9	5.9	0.10	NS	4.1	0.56	NS	4.5	0.57	NS
Al	14/4	7.5	1.04	NS	4.1	2.20	NS	4.1	3.03	<0.05
	5/9	7.9	4.02	<0.01	7.6	0.75	NS	7.3	5.18	<0.01
Fe	14/4	7.7	2.36	<0.05	7.8	2.48	<0.05	7.0	0.34	NS
	5/9	4.3	3.80	<0.02	5.4	2.50	NS	5.4	2.50	NS
Mn	14/4	5.9	1.82	NS	6.4	5.77	<0.01	4.0	1.23	NS
	5/9	5.5	6.95	<0.001	5.5	4.53	<0.01	8.0	0.16	NS
Cu	14/4	7.8	1.89	NS	5.8	1.65	NS	6.4	0.33	NS
	5/9	5.3	1.63	NS	5.5	0.83	NS	7.6	0.89	NS
Zn	14/4	6.3	0.93	NS	5.6	2.25	NS	7.6	1.21	NS
	5/9	6.9	0.10	NS	6.3	1.00	NS	5.1	1.00	NS
Pb	14/4	4.1	1.75	NS	4.3	1.00	NS	7.4	2.00	NS
	5/9	4.2	2.11	NS	4.7	0.60	NS	5.9	1.60	NS

.4-1(4) The earlier suggestion of a synergism between sodium and aluminium was not borne out by the 1973 analyses. The levels of sodium increased on the Mixed and Stockless sections as found in 1972, but neither these changes nor those of aluminium proved to be statistically significant.

.4-1(5) Iron and manganese - in 1973 the concentrations of both these elements decreased with the passing of the season but the change was only significant on the Organic and Stockless sections. Previously neither of these elements showed consistent patterns of change.

.4-1(6) Lead, copper and zinc - in 1972 none of these elements showed significant changes in concentration with the season, but in the second year all showed a decrease in lead which was significant, for lead on the Organic section, copper on all sections, and zinc on the Stockless section.

.2.1.4-2 Effect of farm management

Summarizing the results of the statistical comparison of the values at the start and end of the season, shown on Table 1-10, the significant differences valid to >95% level of confidence were :-

M > 0 for Al, K.   M > 0)   M > S)
) for Fe, Mn   ) for N, Mg
M > S for Al, K,P   S > 0)   O > S)

0 > M for Ca

and there were no significant differences between sections :-

0 ≡ M ≡ S for Na, Pb, Cu, Zn and 0 ≡ S for P

Where the results of 1973 corroborated those found in 1972 it was considered that real phenomena indicating differences caused by the particular farm management had been measured, which were not simply due to sampling methods or individual field characteristics. Where data conflicted between the two years' sampling, measurements may be defining the properties of individual fields which will vary with the geology, or may indicate sampling errors.

.4-2(1) The calcium level in the Organic field was again found to be significantly greater than that of the Mixed section. It had been considered in 1972 that this was purely the result of varying depths of geological horizons, but as the Organic fields sampled for the two years are spatially disjunct in the farm, the repetition of this result might suggest that the greater concentration of this element was genuinely caused by massive application of poultry manure which does contain a high proportion of this element.

.4-2(2) The level of potassium in the soil of the Mixed section is greater than that of either of the other two sections despite the heavy application per unit area of this element in the poultry manure on the Organic field. As these results directly oppose those of 1972 where the Organic field had the highest potassium value, the 1973 findings indicate that either sampling errors were involved, or the Gypsey field contained a higher background level of potassium in the soil. As found previously, the lowest potassium concentrations occur on the Stockless soil, which may have been the result of more rapid leaching of this ion into the subsoil (in the soil containing least organic matter), as has been shown in the Broadbalk experiment (Johnston 1968).

.4-2(3) As defined by the 1972 data, and as has been shown by the very long term Rothamsted experiments, the main effect of the application of organic manures to the soil was to increase the organic nitrogen content of the Organic and Mixed section fields, and again in 1973 the difference from the levels in the Stockless soil was highly significant. In addition, both fields receiving manures showed significantly greater concentrations of magnesium confirming the O > S pattern for this element, due to the appreciable levels in the poultry manure.

.4-2(4) Whereas no significant differences in the total phosphorus concentrations were found between any section in 1972, in the second year the Mixed section had a significantly greater soil concentration of this ion than the Stockless soil, at the end of the season. Repeating the 1972 results, there was no significant difference between the two most opposite farm management types (O ≡ S) in soil concentrations of phosphate (see possible explanation in 1972 discussion).

.4-2(5) As previously found, the total concentration of iron and manganese was significantly greater on the sections receiving artificial fertilizers.

.4-2(6) In 1973 where the variation between April and September was not masked by the comparison of sections by seasonal means, the Mixed section had significantly higher soil concentrations of aluminium than either of the other two sections. In 1972 no significant differences were found. This may have been due to the application of both fertilizers and manures to this section over several years, but as this feature did not appear in 1972, the field concerned here may have had a higher background level of aluminium, as it may have had for potassium.

.4-2(7) No significant differences were found in the soils from any section for the concentrations of lead, copper, zinc or sodium which confirms the 1972 results (except that O > S for sodium in 1972). The levels of these heavy metal ions were observed to change very little with season and as the annual input by manures, fertilizers and rainfall are negligible and removal by crops very small, it is suggested that the similarity of the soil concentrations of these ions indicate that prior to the Haughley farm management experiment, the soils of the three sections were all of the same chemical type.

Table 1 - 11

SOIL ANALYSIS

Concentration of total cations in the soils of the special fertilizer treatment experiment at the beginning and end of the 1973 season. (Concentrations expressed gm/Kg dry soil. Each mean calculated from the concentrations in 5 separate soil cores).

Date Treatment Statistic	N	P	K	Ca	Mg	Na	Al	Fe	Mn	Cu	Zn	Pb
14/4/73 PPKK												
M ± SE	0.97 ± 0.05	0.66 ± 0.04	1.94 ± 0.03	26.9 ± 0.4	1.65 ± 0.02	0.137 ± 0.001	19.2 ± 0.2	20.5 ± 0.4	0.297 ± 0.007	0.034 ± 0.002	0.073 ± 0.007	0.024 ± 0.003
SD	0.11	0.10	0.06	0.9	0.04	0.003	0.5	0.9	0.016	0.004	0.015	0.006
5/9/73 PPKK												
M ± SE	0.85 ± 0.10	0.48 ± 0.03	2.13 ± 0.07	24.9 ± 0.7	1.58 ± 0.04	0.200 ± 0.035	18.6 ± 0.7	13.8 ± 0.7	0.203 ± 0.006	0.013 ± 0.001	0.061 ± 0.002	0.021 ± 0.001
SD	0.23	0.06	0.16	1.5	0.10	0.078	1.6	1.5	0.014	0.001	0.005	0.003
5/9/73 NNPPKK												
M ± SE	0.91 ± 0.04	0.55 ± 0.02	2.21 ± 0.02	24.0 ± 0.6	1.64 ± 0.05	0.169 ± 0.010	18.8 ± 0.3	16.3 ± 0.1	0.222 ± 0.011	0.014 ± 0.001	0.062 ± 0.001	0.025 ± 0.003
SD	0.08	0.04	0.05	1.4	0.11	0.023	0.6	0.1	0.024	0.001	0.003	0.007
5/9/73 NNPK												
M ± SE	0.91 ± 0.03	0.47 ± 0.02	2.08 ± 0.05	21.6 ± 0.5	1.46 ± 0.10	0.209 ± 0.040	18.5 ± 0.6	15.9 ± 0.3	0.217 ± 0.002	0.013 ± 0.001	0.063 ± 0.001	0.022 ± 0.001
SD	0.07	0.05	0.10	1.11	0.22	0.085	1.2	0.6	0.005	0.001	0.002	0.002

Statistical comparison between total cation concentration in the soils of the three fertilizer levels at the end of the season

Element	PPKK-NNPPKK			PPKK-NNPK			NNPK-NNPPKK		
	df	d	p	df	d	p	df	d	p
N	5.0	0.55	NS	4.8	0.55	NS	7.8	0.00	NS
P	6.8	2.33	NS	7.8	0.29	NS	7.6	2.67	<0.05
K	4.8	1.00	NS	6.9	0.60	NS	5.9	2.60	<0.05
Ca	7.9	0.98	NS	7.4	3.98	<0.01	7.6	3.00	<0.02
Mg	7.9	0.86	NS	5.6	1.10	NS	5.9	1.64	NS
Na	4.8	0.86	NS	7.9	0.18	NS	4.6	1.00	NS
Al	5.1	0.26	NS	7.5	0.11	NS	5.9	0.50	NS
Fe	4.1	3.73	<0.05	5.3	2.92	<0.05	4.3	1.48	NS

Element	PPKK-NNPPKK			PPKK-NNPK			NNPK-NNPPKK		
	df	d	p	df	d	p	df	d	p
Mn	7.4	1.58	NS	5.0	2.00	NS	4.4	0.50	NS
Cu	8.0	1.67	NS	8.0	0.00	NS	8.0	1.67	NS
Zn	6.6	0.39	NS	5.3	0.83	NS	7.0	0.63	NS
Pb	5.4	1.33	NS	7.0	0.60	NS	4.6	1.00	NS

.2.1.4-3 Effect of high rates of NPK application

The results of analysing the soils from the special fertilizer treatments on Chestnut Tree East field appear on Table 1-11 and are discussed below.

Effect of season - the changes observed to occur on the OMS sections in 1972 and 1973 were repeated on all three treatments PPKK, NNPPKK and NNPK, whereby the soil concentrations of nitrogen, phosphorus, calcium, magnesium, aluminium, iron, manganese, copper, zinc and lead all showed a significant decrease (with the exception of lead) and those of potassium and sodium showed a significant increase between April and September.

Effect of rate of fertilizer application - gained by statistically comparing the concentrations of geochemical ions of the three treatments at the end of the 1973 season.

.4-3(1) Nitrogen - when significantly differing rates of nitrogen were applied in the form of chemical fertilizer to separate plots at the beginning of the growing season, due to crop uptake and leaching, there were no significant differences in total nitrogen concentration in the soil of the plots at the end of the growing season.

.4-3(2) Phosphorus and potassium - after high application rates of these elements in the form of artificial fertilizers in the spring, the concentrations in the soil remain at higher levels throughout the growing season than where application rates were low. Thus NNPPKK > NNPK significant to >95% confidence level, but although PPKK >NNPK this was not significant, probably due to low replicate numbers.

.4-3(3) Doubling the PK rate apparently significantly increased the concentration of calcium in the soil at the end of the season, but the addition of nitrogen has no modifying effect, so PPKK > NNPK)significant
NNPPKK > NNPK)

to >95% confidence limit, but that may have been a sampling anomaly.

.4-3(4) The addition of nitrogen increases the concentration of iron remaining in the soil at the end of the season so that NNPPKK > PPKK

NNPK > PPKK

are significant.

.4-3(5) The rate of application of fertilizer does not significantly affect the concentration of magnesium, sodium, aluminium, lead, copper or zinc in the soil.

The results outlined in paragraphs (1) - (5) above also apply fully to the application of high fertilizer rates in the lysimetry study.

.2.1.5 Conclusion

Despite the fact that most of the geochemicals present in the soil will be in a form unavailable to the plants, significant seasonal changes were found to occur in the concentrations of most of the elements studied. These were especially marked for nitrogen and phosphorus where the concentrations decreased during the season, and potassium, for which there was a significant net increase.

Most of the differences observed in total geochemical concentrations between farm management sections can be directly correlated with the supply of these nutrients in the manures or fertilizers.

1:3.2.2 Exchangeable nitrogen, phosphorus and potassium

2.2.1 BACKGROUND

It has long been argued as to whether or not chemical analysis (acting by exchange) is able to define the proportion of the total geochemical ions in the soil which are available to growing plants. Many extractants for each element have been proposed to elute the available fraction from the soil, but the crop response rarely fulfils the predictions from such methods due to other factors which also limit growth. The actual amount of each element available for uptake by the plant will depend upon many factors such as the plant species, growth requirement, soil type and soil moisture, and it is difficult to evaluate these variables by a chemical test. Since the days of Lawes and Gilbert (1864) it has been recognised that the quantity of any element extracted by chemical means will depend primarily upon the nature and strength of the extractant. Ideally, no major change in the chemical composition of the soil should be induced by the extraction (Hislop and Cooke 1968), as for example, Williams (1951) describes where plants were found to be able to take up more phosphate from the soil once it had been treated with dilute acetic acid to remove the "available phosphate", hence the use of anion exchange resins have become popular for the estimation of available phosphorus.

It has been demonstrated that certain tests do indicate results which correlate fairly well with the actual growth of plants upon the soils in question (Russell 1931; Black et al. 1965). Thus in addition to the analysis of soils for the total geochemical concentrations, the soils from the three farm sections were analysed for the exchangeability of the three most important macronutrients, nitrogen, phosphorus and potassium.

In the literature the terms "available" and "exchangeable" are freely interchanged, although their meanings differ. The chemical methods used to measure the exchangeability of an ion = the amount which is free to exchange with the cations of a salt solution added to the soil, but the results are used to predict the availability of an element = the amount which exists in the soil in a form which the growing plant can use. Throughout the thesis the term "exchangeable" is used to describe the quantities of nitrogen, phosphorus and potassium measured in the laboratory but inferred to be available to the *Vicia faba* crop growing in the Haughley soils.

.2.2.2 Aim To analyse the soils from the three farm sections for the concentrations of exchangeable nitrogen, phosphorus and potassium, to determine the way in which these change with the season and to evaluate the effect of the farm management upon them.

.2.2.3 Method During the course of two seasons cylindrical soil cores to the depth of the ploughed layer were removed from selected areas of the three field types, were transported to the laboratory where they were homogenized, and were dried in a forced-draught oven at 30°C for five days to simulate air drying, prior to sieving and sub-sampling. In 1972 the three distinct soil horizons in each section were analysed for available potassium and phosphorus, and enough samples from the main plough depth were collected to enable the calculation and comparison of seasonal means. In that first year only two sub-samples were analysed on each occasion for potassium and phosphorus in each soil. In 1973 the analysis for available nitrate-nitrogen and ammonium-nitrogen were included in addition to that for potassium and phosphorus, using fifteen replicates per soil type on four occasions throughout the year. In addition to the analysis of the soils from the OMS sections, the soil from the special fertilizer treatments was studied in order to discover how the addition of extra quantities of NPK affected the exchangeability of these ions in the soil. The methods of analysis employed are shown below and they are discussed in detail in the Appendix :-

Available nitrogen - extracted by neutral 2N sodium chloride (Bremner 1965)

- Nitrite-nitrogen - Griess-Ilosvay method (Barnes and Folkard 1951)

- Nitrate-nitrogen) Semi micro determination method - modifications
) of Conway procedure (Etherington and Morrey 1967
- Ammonium-nitrogen) and Bremner 1960)

Available phosphorus - extracted by sodium bicarbonate (Olsen et al. 1954)

- detected by ammonium molybdate and stannous chloride

Available potassium - extracted by ammonium acetate (Pratt 1965)

- detected by atomic absorption spectrophotometer

.2.2.4 Results The results found from the above analyses are discussed by element, for both seasons and four treatments. For each element the results are tabulated and statistically compared, and the seasonal changes are depicted graphically.

.2.4-1 NITROGEN

This element is of such major importance in crop rotation that the exchangeable fraction was described in three parts. The most important forms of exchangeable nitrogen in the soil are ammonium-nitrogen, nitrate-nitrogen and nitrite-nitrogen, all of which may be utilized by plants, but one form or another may be preferentially absorbed by different plant species depending upon the environmental conditions.

.4-1(1) Nitrite-nitrogen - the least important form of nitrogen for higher plants due to very small quantities present in most soils. The extracting solution for nitrogen was selected to enable the determination of all three forms from one extraction. The results of the analysis conducted in April 1973 appear below :-

Section	Organic	Mixed	Stockless
Mean NO_2-N	0.36	0.25	0.29
Standard Deviation	0.07	0.03	0.13
Standard Error	0.03	0.02	0.06

Values expressed in μ gm NO_2-N/gm air dry soil

Table 1-12(1)

SOIL ANALYSIS

Available Nitrate-Nitrogen in the Soil of the three farm systems 1973.

Expressed as microgrammes NO_3-N/gm air dry soil.
Each reading a mean from 15 soil cores.

Date	Organic			Mixed			Stockless		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
14/4/73	48.5	20.3	5.6	14.9	4.8	1.3	9.2	4.3	1.2
21/5/73	37.9	20.3	6.5	23.0	11.7	3.1	11.4	7.8	2.2
24/7/73	18.3	12.9	3.6	11.2	8.1	2.1	8.9	12.3	3.3
5/9/73	14.4	8.8	2.3	6.9	3.3	0.9	6.1	3.3	1.1
Mean over season	29.8	16.2	8.1	14.0	6.8	3.4	8.9	2.2	1.1

Statistical Comparison of Treatments (using Bailey's d test)

(a) Treatments

Date	O-M			O-S			M-S		
	df	d	p	df	d	p	df	d	p
14/4/73	15.6	6.22	<0.001	15.3	7.30	<0.001	27.4	3.35	<0.01
21/5/73	22.3	2.44	<0.05	18.1	4.73	<0.001	24.6	3.22	<0.01
24/7/73	23.7	1.82	NS	27.8	2.04	NS	24.1	0.61	NS
5/9/73	17.9	3.13	<0.01	17.9	3.46	<0.01	28.0	0.67	NS
Seasonal Mean	4.0	4.39	<0.02	3.1	5.11	<0.02	4.8	2.59	<0.05

(b) Change over season

Dates	Organic			Mixed			Stockless		
14/4/-21/5/73	28.0	1.43	NS	18.6	2.49	<0.05	21.6	0.96	NS
21/5/-24/7/73	23.7	3.16	<0.01	25.1	3.19	<0.01	23.8	0.66	NS
24/7/-5/9/73	24.7	0.97	NS	18.5	1.90	NS	16.0	0.85	NS

Statistical comparison

Samples compared	d.f.	d	p	R
O - M	5.4	0.3	0.1	NS
O - S	6.1	0.4	0.1	NS
M - S	4.4	0.7	0.1.	NS

The amount of exchangeable nitrogen in the form of nitrite was exceedingly small in all three soil types, and there were no significant differences in concentrations between sections. Due to these very low concentrations the determination was not repeated.

.4-1(2) Nitrate-nitrogen The most important form of exchangeable nitrogen in the soil, especially in a farm ecosystem where it is the main form of nitrogen in chemical fertilizers. The results of the analysis for nitrate-nitrogen in the soil of the three sections are shown in Table 1-12(1) and are depicted on Graph 1-1(1)

Effect of season

The graph demonstrates the marked change in the exchangeability of the nitrate-nitrogen in the soil during the season. There was a significant decrease on all three sections, but this was greatest in the Organic section soil which also had the highest concentration of nitrogen in this form. The detailed results of the statistical comparison of the change in concentration with the season are shown below.

14/4/73 - 21/5/73 : Significant increase on Mixed section
21/5/73 - 24/7/73 : Significant decrease on Organic and Mixed sections
24/7/73 - 5/9/73 : Change not significant on any section

The increase on the Mixed section indicates the movement of the nitrate fertilizer into the soil, which had been applied as top dressings in April. This increase, which is greater than that shown on the Stockless section, could also be accounted for by an increase in the rate of mineralization of some of the remaining organic matter, which has been shown to be stimulated by the addition of nitrogen fertilizer (Kundler 1970), but Gadet and Soubiées (1972) found mineralization to be depressed under these conditions. It will be noted that none of the individual decreases on the Stockless section were significant, although the graph shows there was a significant net fall over the whole season. The magnitude of loss of exchangeable nitrate-nitrogen from the soil during the season is directly proportional to the concentration of this form of nitrogen in the soil. The internal variation of replicate readings within each section also followed the pattern O > M > S as it is much easier to ensure an even distribution of nutrients over the field when they are applied in the form of dry fertilizer granules than when in the form of wet lumps of manure.

Effect of farm management

The highly significant effect of farm management upon the nitrate-nitrogen concentration in the soil is clearly demonstrated in Graph 1-1(1) which indicates the extent to which the exchangeable nitrogen content of the Organic soil was greater than in the soils of the other sections. The detailed results of the statistical comparison of the concentration appear below :-

14/4/73	O > M	O > S	M > S	significant to >99% level
21/5/73	O > M	O > S	M > S	" " >95% "
24/7/73	O > M	O > S	M > S	trend only significant to 99% level
5/9/73	O > M	O > S		significant to >99% level
Seasonal Mean	O > M	O > S	M > S	" " >95% "

Thus the soil which received an application of poultry manure in the previous autumn consistently maintained a higher level of nitrate-nitrogen in the soil throughout the season when compared with the sections which received applications of nitrate fertilizer in the spring of 1973.

Graph 1 - 1.

The Seasonal Variation in the Level of Exchangeable Nitrogen in the Soil.

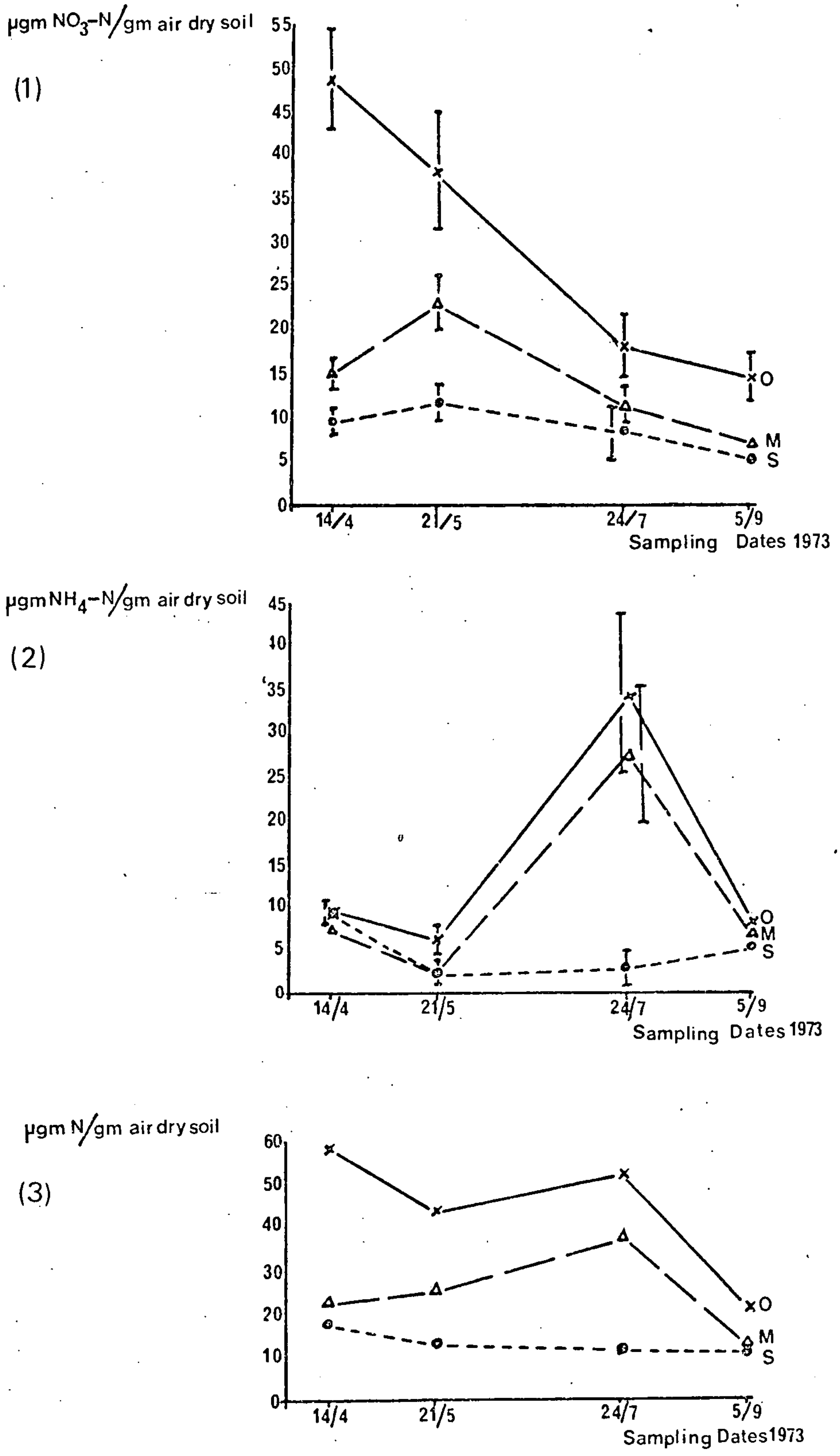


Table 1-12(2)

SOIL ANALYSIS

Available Ammonia-Nitrogen in the soil of the three farm systems in 1973.

Expressed as microgrammes NH_3-N/gm air dry soil.
Each reading a mean from 15 soil cores.

Date	Organic			Mixed			Stockless		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
14/4/73	9.0	3.3	1.0	7.6	2.1	0.5	9.0	0.9	0.3
21/5/73	5.7	4.5	1.4	2.6	3.1	0.9	2.1	1.2	0.3
24/7/73	34.4	33.1	9.2	27.0	29.3	7.6	3.0	3.7	0.9
5/9/73	7.7	4.2	1.1	6.9	3.3	0.9	5.3	2.3	0.7
Mean over season	14.2	13.5	6.8	11.0	10.9	5.4	4.9	3.1	1.5

Statistical Comparison of Treatments (using Bailey's d test)

(a) Treatments

Date	O-M			O-S			M-S		
	df	d	p	df	d	p	df	d	p
14/4/73	23.7	1.40	NS	16.1	0.0	NS	24.5	2.03	NS
21/5/73	24.9	2.20	<0.05	16.0	3.00	<0.01	18.1	0.58	NS
24/7/73	27.6	0.65	NS	14.3	3.65	<0.01	14.4	3.16	<0.01
5/9/73	26.3	0.57	NS	21.7	1.85	NS	25.0	1.54	NS
Seasonal Mean	5.7	0.70	NS	3.3	3.49	0.05	3.5	2.18	NS

(b) Change over season

Dates	Organic			Mixed			Stockless		
14/4/- 21/5/73	25.7	2.29	<0.05	24.4	5.21	<0.001	25.3	18.2	<0.001
21/5/- 24/7/73	14.5	3.34	<0.01	14.3	3.21	<0.01	17.0	0.90	NS
24/7/- 5/9/73	14.5	3.10	<0.01	14.3	2.65	<0.02	23.5	2.05	NS

The considerable differences between the Organic and Mixed sections demonstrate how quickly the exchangeable nitrate-nitrogen supplied in manures disappears from the plough depth of soil. Several years after the application of manure (Mixed section 1970) the concentrations of this form of nitrogen are closer to those in the Stockless soil than that of the Organic soil. It is suggested that the nitrate is quickly taken up by the crop plant, or being highly soluble will be leached out in the drainage water, or immobilized in the soil organic matter.

.4-1(3) Ammonium-nitrogen A form of nitrogen which is important in the soil, particularly as an intermediate form between organic nitrogen and nitrate. Despite the hundreds of papers written on the subject of nitrogen uptake by plants, it is not known in which particular form nitrogen is absorbed from the soil by each plant species. The results of the analyses of soil samples for exchangeable ammonium-nitrogen are shown in Table 1-12(2) and are depicted on Graph 1-1(2)

Effect of season

The graph demonstrates the marked variation in the exchangeability of ammonium-nitrogen during the season, particularly with reference to the Organic and Mixed sections. The results of the statistical comparison of the change with season is shown below :-

14/4/73 - 21/5/73	Significant decrease on all sections
21/5/73 - 24/7/73	Significant increase on Organic and Mixed sections
24/7/73 - 5/9/73	Significant increase on Organic and Mixed sections

The initial decrease on all sections may have been caused by the volatilization of the ammonium-nitrogen prior to the incorporation of the fertilizer into the soils. It is interesting to note that only on the Stockless section is there a net loss of NH_4-N over the growing season. Despite great fluctuations in the levels of exchangeability of this ion in the Organic and Mixed section, the state of equilibrium in the soils was maintained for the following season. This is an example of one of the possible nutritional benefits of using organic manures instead of artificial fertilizers, in that the supply of nitrogen from the manure was naturally maintained to the plants throughout the most active part of the growing season, whilst the supply from the fertilizer was much lower.

Effect of farm management

The graph shows how much closer the levels of exchangeable NH_4-N were in the soils of the Organic and Mixed sections compared with those in the Stockless soil - a clear effect of the application of organic manures to the system. The detailed results of the statistical comparison from Table 1-12(2) are shown below.

14/4/73 - no significant difference between any section
21/5/73 - O > M   O > S   Significant to >95% level
24/7/73 - O > S   M > S   Significant to >99% level
5/9/73 - no significant differences
Seasonal mean - O > S   Significant to >95% level

Thus although there were significant fluctuations of concentrations within the season, there were no significant differences between the sections at the beginning or the end of the crop growing season. Where differences did occur, the concentrations of NH_4-N were always lowest on the Stockless soil where there were few organic remains. Whereas for nitrate-nitrogen the figures for the Organic and Mixed sections were always significantly different, in this form there was a greater degree of similarity, suggesting that in both sections, nitrogen in the remaining, or newly added, organic matter was mineralized to the NH_4-N form during May, June and July. This was then lost by conversion to nitrate, leaching, volatilization, crop uptake or remineralization during the subsequent months. The consistently low values for the Stockless section indicate very low reserves of nitrogen in organic matter form for that soil type.

Graph 1-1 (3) depicts the combination of exchangeable NO_3-N and NH_4-N figures to show the total nitrogen available to the plant as measured by this extraction procedure. The significant effect of the manure which maintains a high level of available nitrogen to the plants throughout the growing season on the Organic and Mixed sections is clearly demonstrated. There was a significant net loss of nitrogen during the season on all three sections, which correlateswith the decreases observed for the total organic nitrogen concentrations previously described. However, it should be noted that these concentrations of available forms of nitrogen constitute only 2-3% of the total nitrogen concentrations measured.

.4-1(4) Nitrate-nitrogen and Ammonium nitrogen on the special fertilizer treatments

The results of the soil analysis and the comparison of nitrogen concentrations in the soil of treatments NNPPKK and PPKK appear on Table 1-13. The treatments of NNPK and PPKK are not compared, due to the complicating feature of the phosphate and potassium application rates. The top dressing of ammonium nitrate was applied to the experimental plots at the beginning of May 1973 and the effect can clearly be seen by the massive increase in both forms of nitrogen registered on 21/5/73.

Nitrate-nitrogen

The level of nitrate-nitrogen on the PPKK treatment increased in May, but not significantly so, which may have been caused by some mineralization of the natural organic matter in the field. The concentrations then decreased rapidly to a constant value. Where high nitrogen is applied to the PPKK plot, the decrease in exchangeable nitrogen is much more rapid than where applied to the single PK plot. It is postulated that where the

Table 1 - 13 SOIL ANALYSIS

Available Nitrate-Nitrogen and Ammonia-Nitrogen in Special Fertilizer Treatment on Chestnut Tree East Field in 1973.

Expressed as μgm/gm air dry soil.
Each reading a mean of four samples.

Nitrate-Nitrogen

Date	PPKK			NNPPKK			NNPK		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
14/4/73 (TOP DRESSING)	7.7	4.5	1.3	-	-	-	-	-	-
21/5/73	9.8	1.0	0.5	49.4	2.7	1.4	51.3	4.4	2.2
24/7/73	2.1	0.5	0.3	11.1	6.7	3.4	33.2	17.3	8.7
5/9/73	2.4	0.7	0.3	3.8	2.0	0.9	7.9	4.1	2.1
Ammonia-Nitrogen									
14/4/73	7.8	2.0	0.6	-	-	-	-	-	-
21/5/73	1.3	0.7	0.5	111.7	25.9	14.9	36.0	23.8	13.7
24/7/73	26.4	1.9	1.1	53.6	17.4	8.7	55.3	29.6	14.8
5/9/73	3.4	1.2	0.5	3.1	0.7	0.3	6.4	1.9	1.1

Statistical Comparison of PPKK with NNPPKK (using Bailey's d test)

	Nitrate-Nitrogen				Ammonia-Nitrogen		
Date	d.of f.	d	p	Date	d.of f.	d	p
21/5/73	3.8	27.5	<0.001	21/5/73	3.0	8.5	<0.01
24/7/73	3.0	2.68	NS	24/7/73	3.1	3.1	NS
5/9/73	3.7	1.32	NS	5/9/73	4.8	0.43	NS

levels of phosphorus and potassium are also high, these stimulated plant and microorganism growth so that the loss of nitrogen was more marked than where the phosphate and potassium application rates were lower. The comparison of NNPPKK > PPKK is only significant immediately after application, probably due to low numbers of replicates in July, and due to the drastic loss, as already described, by September.

Ammonium-nitrogen

The level of exchangeable ammonium-nitrogen on the PPKK treatment fluctuated greatly between the four occasions of sampling during the season. The only explanation put forward for the great increase in NH_4-N in late July is that possibly the samples were taken from the soil where localized release of fixed nitrogen from the decaying bean root nodules was occurring. This effect, if genuine, would not be so marked on the sections where nitrogen had been applied, due to the partial inhibition of nitrogen fixation on these treatments. It is not known why the ammonium-nitrogen figures for NNPPKK and NNPK should be so different from each other on the May sampling. This anomaly may have resulted from the uneven spread of the nitrogen fertilizer which was broadcast by hand after the bean plants had germinated. It is suggested that the apparent increase in exchangeable ammonium-nitrogen shown by the figures for NNPK in July was not truly representative of an increase, but rather a decrease from the level expected in May. As for the nitrate-nitrogen, there was a dramatic increase in the concentration of exchangeable nitrogen where this fertilizer was applied during the season. It is suggested that the NNPPKK > PPKK only in May, was due to low replicate numbers, and an increase in the concentration of N on PPKK in July, but due to genuinely low values for September, on all sections, due to the loss of nitrogen by volatilization and leaching of the highly soluble ammonium nitrate. This loss of nitrogen where it was applied, to give no significant decreases between the high and low application rates at the end of the season, correlates well with the results described for the total organic nitrogen seasonal changes.

.2.4-2 PHOSPHORUS

Method Since Daubeny (1845), many chemical methods have been assumed to measure plant-available phosphorus, but these have frequently produced conflicting results to observed growth of the plants because different species vary in their ability to take up phosphorus from the soil, depending on species, rate of growth and soil conditions (Nelson et al.1953). However, Alexander and Woodham (1958) demonstrated that the measurement of plant available phosphorus for *Vicia faba* (Tic variety) by use of a sodium bicarbonate extractant (Olsen et al. 1954), produced values which correlated well with the growth response of this species. This method is particularly applicable to Haughley soils as its efficiency is not influenced by high levels of calcium carbonate. It is probable that most phosphorus is taken up as H_2PO_4 ions in soils of pH range 4 - 9, but may also gain entry indirectly, bound to one of the cations required by the plant, depending on the form of phosphate in the particular soil.

Results

.4-2(1) 1972 Table 1-14(1) shows how the concentration of exchangeable phosphorus was found to vary according to soil depth, season and management type.

Effect of depth of soil

The decrease in exchangeable phosphorus with increasing depth of soil was particularly marked in the Organic soil profile, slightly more gradual in the Stockless soil, and only changed abruptly in the Mixed section below 50 cm. Thus almost all the plant available phosphorus in the Organic and Stockless sections was confined to the ploughed depth of soil, whereas it was spread fairly evenly to 50 cm in the Mixed section.

Table 1-14(1) SOIL ANALYSIS

Available Phosphorus in soil from the three farm systems 1972. (Expressed in micrograms P/gm air dry soil).

(1) Availability according to soil depth:

Depth (cms.)	Organic	Mixed	Stockless
0-20	20.3	33.1	47.5
20-50	0.3	23.6	4.1
50+	0.0	6.5	4.3

(2) Seasonal variation in availability (0-20 cm):

Date	Organic	Mixed	Stockless
21/3/72	20.3	33.1	47.5
1/5/72	20.0	58.0	79.5
20/9/72	20.9	49.1	39.9
Seasonal mean ± SE	20.4 ± 0.3	46.7 ± 7.3	55.6 ± 12.1
SD	0.46	12.6	21.0

Statistical comparison of seasonal mean:-

Sample	d. of f.	d	p
O-M	4.0	3.60	<0.05
O-S	4.0	2.91	<0.05
M-S	6.6	0.63	NS

This pattern correlated well with the variation with depth in calcium content shown in Table 1-8, because the higher the content, the more phosphate will be bound in an unavailable form.

Effect of season

The seasonal variation of the phosphorus concentrations showed the impact of adding phosphate fertilizer to the system on the Mixed and Stockless sections at the end of March 1972, which caused an immediate increase in the exchangeable levels. These sections showed a decrease between May and September, but the final values achieved were still significantly above those found on the Organic section. The phosphorus level in the Organic soil remained remarkably constant throughout the season due to the stabilizing effect of the organic manure. It is postulated that the presence of organic manure-remains on the Mixed section enabled the final concentration reached in September to remain above that of the Stockless section. It has been shown by many research workers that organic matter has an important controlling influence on the levels of phosphate available to plants (Huffman 1962; Johnston and Warren 1964; Williams and Cooke 1970, Lysogorov *et al.* 1973).

Effect of farm management

When the seasonal means are compared for the three farm sections : M > O and S > O are significant at the 95% level, but this was not due entirely to the addition of phosphate fertilizer in the year of study. Before the application of fertilizers S > M > O, and it is suggested that the availability of phosphorus was already significantly greater on the two sections S and M due to the retention of some of the fertilizers which were applied during the previous years.

.4-2(2) 1973 The results of the soil analysis for exchangeable phosphorus in 1973 appear in Table 1-14(2), together with the statistical comparison of the management types and season effects, which are depicted on Graph 1- 2(1). In general, the results indicated by the cursory study of 1972 were confirmed.

Effect of season

As previously found, there was a lack of variation in the concentration of exchangeable phosphorus in the Organic soil, where there were no significant differences shown at any time during the season, neither between individual data samples, nor between the beginning and end of the season, although the latter did show a slight decrease. The most variation with season occurred in the levels of exchangeable phosphorus on the Mixed section where there was a significant net increase in the values between April and September. On both sections where phosphate fertilizers were supplied, there was a significant increase at the beginning of the season due to the incorporation of the fertilizer into the soil, and an almost equal decrease at the end of the season due to a combination of plant uptake and phosphate immobilization. The significant differences found were :-

14/4/73 - 21/5/73	Significant increase on Mixed and Stockless sections
21/5/73 - 24/7/73	No significant changes on any section
24/2/73 - 5/3/73	Significant decrease on Mixed and Stockless sections

Effect of farm management

The statistical analysis of the 1973 data on Table 1-14(2) shows that for most of the season there were no significant differences in the concentrations of exchangeable phosphorus on the three farm management sections. The only significant differences were :-

14/4/73 O > M O > S significant to >99% confidence level

Seasonal mean O > M

Table 1-14(2)

SOIL ANALYSIS

Available Phosphorus in the soil from the three farm systems 1973.

Expressed as microgrammes P/gm air dry soil.
Each reading a mean of 15 separate soil cores.

Date	Organic			Mixed			Stockless		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
14/4/73	46.8	26.1	7.0	26.4	6.3	1.6	37.4	8.3	2.2
21/5/73	43.6	16.7	5.6	44.2	14.1	3.8	48.2	16.3	4.2
24/7/73	48.6	19.0	5.5	54.2	23.5	6.3	52.7	15.4	4.0
5/9/73	38.7	18.1	4.8	33.0	11.6	3.0	29.6	9.3	2.9
Mean over season	44.9	6.4	3.2	39.5	12.3	6.1	42.0	10.5	5.2

Statistical Comparison of Treatments (using Bailey's d test)

(a) Treatments

Date	O-M			O-S			M-S		
	df	d	p	df	d	p	df	d	p
14/4/73	15.7	2.96	<0.01	16.8	1.30	NS	26.2	4.07	<0.001
21/5/73	27.4	0.11	NS	28.1	0.80	NS	27.4	0.71	NS
24/7/73	26.7	0.70	NS	27.1	0.65	NS	24.2	0.21	NS
5/9/73	23.9	0.02	NS	21.0	1.72	NS	26.9	0.90	NS
Seasonal Mean	21.4	3.03	<0.01	23.0	1.81	NS	27.3	1.21	NS

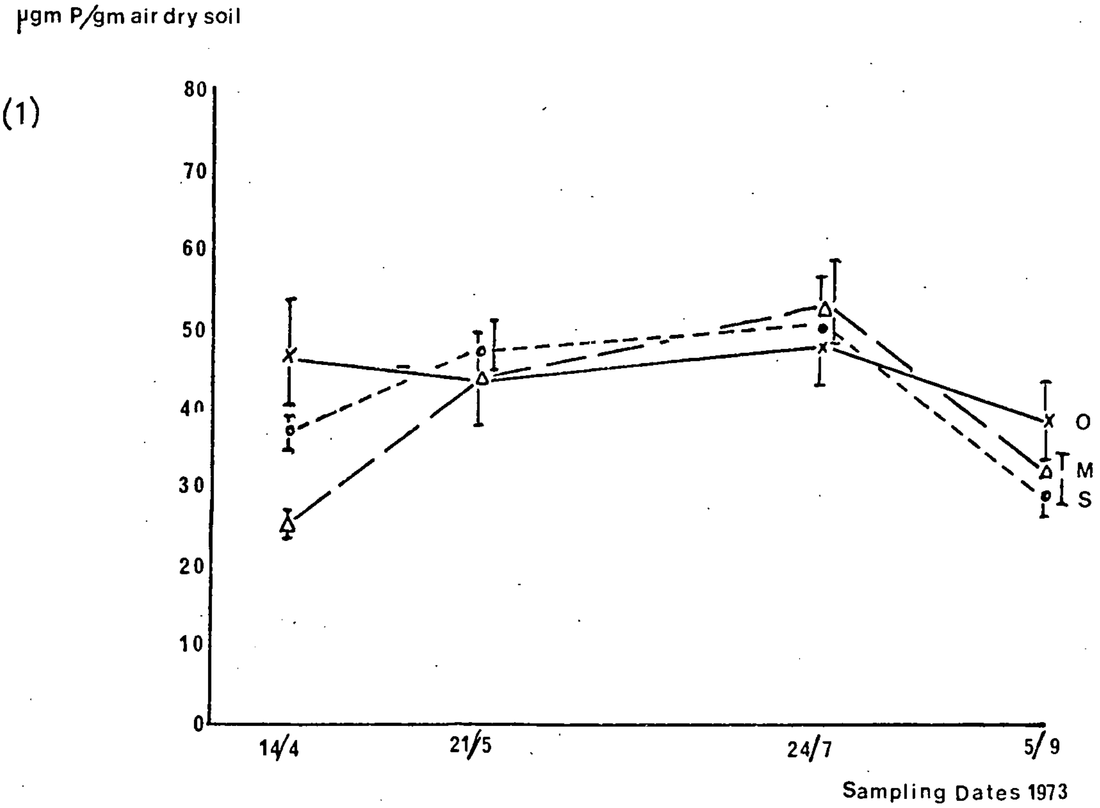
(b) Change over season

Dates	Organic			Mixed			Stockless		
14/4/- 21/5/73	23.8	0.40	NS	19.5	4.45	<0.001	20.8	2.30	<0.05
21/5/- 24/7/73	27.3	0.77	NS	23.1	1.41	NS	27.8	0.78	NS
24/7/- 5/9/73	28.2	1.46	NS	20.4	3.12	<0.01	23.6	4.92	<0.001

Graph 1-2

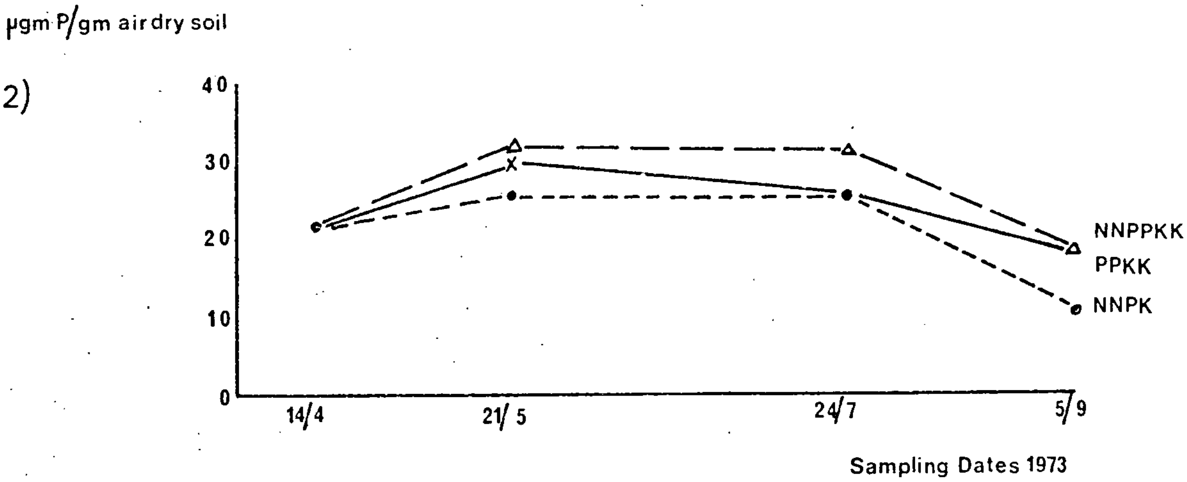
The Seasonal Variation in the Level of Exchangeable Phosphorus in the Soil.

(1)



Special Fertilizer Treatment

(2)



Thus where differences did occur, the section receiving manure alone provided more plant-available phosphorus to the crop plants, as measured by this method, than did either of those sections supplied with artificial fertilizers. These findings are in direct contradiction to those found in 1972 where the Organic section had the lowest levels of this form of phosphorus, but that may have been entirely due to the insufficient replication of sampling in the first year of soil studies. However, due to the consistent levels recorded for the organic sections within each year, it is more likely that this difference was a real phenomenon which can be explained by consideration of the amount of phosphorus supplied to the fields concerned, as shown in Table 1-2. If the figures of the mean seasonal exchangeable phosphorus for 1972 and 1973 are compared :-

Section	Organic	Mixed	Stockless
1972	20.4 ± 0.3	46.7 ± 7.3	55.6 ± 12.1
1973	44.9 ± 3.2	29.5 ± 6.1	42.0 ± 5.2

Expressed in μ gms phosphorus/gm air dry soil.

It is seen that the Mixed and Stockless sections show no significant differences of concentration of phosphorus between the two years despite the investigation of different fields, because similar quantities of artificial fertilizers had been supplied to both. However, on the Organic section the difference is significantly twice as high in 1973 than 1972. From Table 1-2 the application of poultry manure to the 1972 field at the rate of 12,500 Kg/ha was exactly half that applied to the Organic field in 1973, 25,000 Kg/ha. These differences correlate well with the exchangeable phosphorus concentrations observed in the fields during the following growing season, and explain the differences observed between the two fields within the same management type.

The overall constraint of the variation of the exchangeable phosphorus levels within narrow limits, the direct relationship between the amount of total phosphorus applied and that exchangeable, and the absence of net change between the beginning and end of the season, agree well with the data described for the total soil phosphorus concentrations, showing this element to be relatively immobile in the soil. The exchangeable fraction of the total phosphorus content of the soil has been shown to be about 8% by this study.

.4-2(3) Special Fertilizer Treatment

Table 1-14(3) shows the concentrations of exchangeable phosphorus in the soils of the special fertilizer treatment in 1973 where two rates of phosphate fertilizer were applied. The concentrations indicated for NNPK should indicate the magnitude of the exchangeability of this element in the remainder of this Stockless field. The reason that these figures are lower than those found in the main Stockless field described for 1973 was due to different application rates of fertilizer.

Effect of season

The graph 1-2(2) depicts the net fall which occurred in the exchangeability of phosphorus on all three treatments, but this was significant only for NNPK. This indicates that the doubling of the phosphate rate meant that there was a more than adequate supply of this element to the plants. The pattern of seasonal change shown in the graph was the same as that demonstrated for the Stockless field in graph 1-2(1) with little variation in exchangeability with the passage of time.

Effect of treatment

As was anticipated, the comparison of NNPPKK with PPKK showed no significant differences in the amount of exchangeable phosphorus due to the identical supply of phosphate fertilizer to those treatments. When NNPPKK

Table 1 - 14(3)

SOIL ANALYSIS

Available Phosphorus in soil from the special fertilizer treatments on Chestnut Tree East field. 1973.

Expressed as micrograms P/gm air dry soil.
Each reading a mean of 4 separate soil cores.

Date	PPKK			NNPPKK			NNPK		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
14/4/73	21.6	7.1	1.9	-	-	-	-	-	-
21/5/73	30.6	4.7	2.3	31.1	3.9	2.3	26.6	5.4	3.1
24/7/73	26.4	5.1	2.6	31.0	10.9	5.5	26.2	4.2	2.1
5/9/73	19.2	8.9	4.0	18.5	3.8	1.7	12.2	2.8	1.4

Statistical comparison of NNPPKK and NNPK. No significant differences between NNPPKK and PPKK.

Date	d. of f.	d	p
21/5/73	5.4	1.35	NS
24/7/73	3.9	0.83	NS
5/9/73	5.5	2.63	<0.05

Available Potassium in special fertilizer treatment soils on Chestnut Tree East Field in 1973.

Expressed as micrograms K/gm air dry soil.
Each reading a mean of 4 separate soil cores.

Date	PPKK			NNPPKK			NNPK		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
14/4/73	202.7	31.4	8.1	-	-	-	-	-	-
21/5/73	101.3	12.5	6.3	95.0	1.4	0.8	70.0	0.5	0.1
24/7/73	73.9	8.6	4.3	71.2	10.1	5.1	52.8	0.3	0.1
5/9/73	69.0	14.4	6.5	69.5	15.3	6.8	50.0	5.4	2.7

Statistical comparison of PPKK and NNPK. No significance differences between PPKK and NNPPKK.

Date	d. of f.	d	p
21/5/73	3.0	35.21	<0.001
24/7/73	3.0	3.61	<0.05
5/9/73	3.7	2.35	NS

was compared with NNPK the differences were found to be non-significant due to the lack of replicate samples until the end of the season when NNPPKK > NNPK.

.2.4-3 POTASSIUM

Method The most universally employed index to potassium availability in soils is the sum of the exchangeable, and water soluble, potassium as extracted by neutral I.ON ammonium acetate solution (Pratt 1965). This provides an index of the amounts of the element exchangeable at the time of analysis, but cannot indicate the rate of release of potassium from non-exchangeable forms during the cropping period.

Unfortunately in most soils the exchangeable potassium changes with drying. When the exchangeable potassium levels are high, as after application of potassium fertilizer, there is likely to be fixation (or a decrease) on drying, whereas when the soil is low in this form of the element there will be a release of potassium from non-exchangeable forms upon drying. Thus a variable error was built into the methods used in this research study when the soils were air dried, but the soils from all sections were treated equally.

Results

.4-3(1) 1972 The results of the 1972 analysis for the concentrations of exchangeable potassium in the soil from the three farm sections appear in Table 1-15.

Effect of soil depth

As found for the decrease in the level of exchangeable phosphorus, the concentration of exchangeable potassium significantly decreased with increasing depth, especially below the ploughed layer (0-20 cm). In the top soil layer the concentration of this element is much higher in the Organic and Stockless sections, but at lower horizons it is the Mixed section which maintains the highest level. It is possible that both organic manures and artificial fertilizers leave appreciable quantities of potassium in the ploughed tilth, but it is necessary to have both forms of supply present if a more even distribution of the element through the soil profile is to be obtained. As the two most contrasting management types had an equal distribution of potassium, this effect may be due more to geological horizons.

Effect of season

Although there was considerable fluctuation during the season the general trend in the change of the magnitude of the exchangeable potassium was for the concentrations in the soils receiving artificial fertilizers to decrease during the growing season, whilst those on the Organic section increased. The figures given for the soil analyses in May showed only slight increases on the Mixed and Stockless sections despite the previous application of potassium fertilizers, which may have been due to the drying error as previously explained.

Effect of farm management

The broad equality in concentrations found on the Organic and Stockless sections in March continued to be evident until June, after which time the level on the former section increased, whilst that on the latter decreased to levels equivalent to those of the Mixed section. Throughout the season the concentration of exchangeable potassium tended to remain highest on the Organic section where the application in the manure the previous autumn supplied 70% more total potassium than found in the fertilizer, when compared on a unit area basis. Thus when the seasonal means are statistically compared : O > M and O > S to >95% level of confidence.

Table 1-15 SOIL ANALYSIS.

Available Potassium in soil from the three farm systems 1972. (Expressed in micrograms K/gm air dry soil.)

(1) Availability according to soil depth (March 1972):

Depth (cms.)	Organic	Mixed	Stockless
0-20	352.8	268.8	386.4
20-50	151.2	168.0	168.0
50+	117.6	168.0	117.6

(2) Seasonal variation in availability (0-20 cm):

Date	Organic	Mixed	Stockless
21/3/72	352.8	268.8	386.4
1/5/72	420.0	285.6	386.4
25/6/72	361.2	294.0	361.2
10/7/72	386.4	243.6	201.6
19/8/72	420.0	235.2	268.8
20/9/72	470.4	218.4	268.8
Seasonal mean ± SE	401.8 ± 17.9	257.6 ± 12.2	312.2 ± 31.3
SD	43.9	29.9	76.7

Statistical comparison of seasonal mean:-

Sample	d. of f.	d	p
O-M	6.4	6.65	<0.001
O-S	8.0	2.48	<0.05
M-S	6.5	1.63	NS

Table 1-16 SOIL ANALYSIS

Change over season in availability of P and K in soil of lysimeters, and comparison with changes in availability in soil of fields. 1972.

(μgm/gm air dry soil).

1. Available P

Date	Site	Organic	Mixed		Stockless
21/3/72	Field Lysimeter	20.3	33.1		47.5
20/9/72	Field	20.9	49.1		39.9
20/9/72	Lysimeter				
	Cropped	20.9	24.4	NF.	34.4
	Fallow	25.5	27.4	"	44.5
20/9/72			Cropped	HF.	116.6
			Fallow	"	41.0

2. Available K

Date	Site	Organic	Mixed		Stockless
21/3/72	Field Lysimeter	352.8	268.8		386.4
20/9/72	Field	470.4	218.4		268.8
	Lysimeter				
	Cropped	470.4	235.2	NF.	352.8
	Fallow	487.2	268.8		386.4
20/9/72			Cropped	HF.	453.6
			Fallow		352.8

Comparison of field and lysimeter situation

Table 1-16 lists the exchangeability of phosphorus and potassium as found in field and lysimeter soils at the end of the 1972 season.

On the Organic section conditions in the field and lysimeter were closely equivalent in terms of exchangeable phosphorus and potassium concentrations. For both elements the figures were identical in the field and cropped lysimeters, but under the fallow conditions the concentrations rose more than where the soil was cropped.

On the Mixed section the exchangeable phosphorus concentrations differed markedly between the field and lysimeter readings, there being a significant decrease in the latter, but an increase in the former. For exchangeable potassium there was a close correlation within the two situations.

On the Stockless section for both elements the exchangeability levels in the field and lysimeter closely resembled each other, except that the net seasonal fall in the concentration of phosphorus was greater in the lysimeters than in the field, whilst that of potassium was less than in the field.

Under high fertilizer application rates the concentration of both elements was maintained at a high level where cropped, but where soil was fallow the concentrations fell to levels below that found where normal fertilizer rates were used.

With the exception of the concentrations of exchangeable phosphorus in the Mixed section, the nutrient status in terms of these two elements are equivalent in the open field and in the disturbed conditions found within the lysimeter. Under all three farm managements where normal nutrient levels were applied, the concentrations of these elements remained higher under fallow conditions than where cropped. For exchangeable potassium on the Mixed and Stockless sections, the final concentration in the fallow soil was identical to that of the (field and lysimeter) soil at the beginning of the season, suggesting that most loss of exchangeable potassium was due to crop uptake.

.4-3(2) 1973 The results and statistical comparison of the soil analysis for available potassium in 1973 appear in Table 1-17 and are depicted on Graph 1-3(1).

Effect of season

From the graph it can be seen that there was a decrease in the level of available potassium on all three farm sections, and this fall in concentration was significant as shown below :-

14/4 - 21/5/73 Significant decrease M and S sections to >99.9% C level
24/7 - 5/9/73 " " O, M and S " " >99.9% C level

Although the concentrations increased slightly on all three sections in July, this change was not statistically significant. The change with season was most marked on the Stockless section, and most gradual on the Organic, but all showed very sudden decreases between the end of July and the beginning of September.

Effect of farm management

The effect of the application of manure to the Organic section in the autumn of 1972 was very marked, upon the potential levels of available potassium in the soil of that section, for throughout the season the concentrations there were considerably higher than in the soil of either of the two sections which received artificial fertilizer. These differences were statistically significant as shown below :-

14/4/73	O > M	O > S	S > M	Significant	to	>95%	level	of	confidence
21/5/73	O > M	O > S	M > S	"	"	>99%	"	"	"
24/7/73	O > M	O > S		"	"	>99.9%	"	"	"
5/9/73		O > S	M > S	"	"	>99.9%	"	"	"
Seasonal means		O > S	M > S	"	"	>95%	"	"	"

Table 1-17

SOIL ANALYSIS

Available Potassium in the soil of the three farm systems 1973.

Expressed as microgrammes K/gm air dry soil.
Each reading a mean from 15 soil cores.

Date	Organic			Mixed			Stockless		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
14/4/73	378.0	93.1	24.9	269.9	32.0	8.3	310.2	46.6	12.0
21/5/73	317.5	78.6	24.9	224.0	35.2	9.1	200.5	28.0	7.2
24/7/73	348.0	73.2	19.6	240.8	41.0	10.6	229.6	65.3	16.9
5/9/73	194.9	42.0	10.9	178.1	16.6	4.3	141.1	19.7	6.2
Mean over season	309.6	80.4	40.2	228.2	38.4	19.2	220.4	70.3	35.2

Statistical Comparison of Treatments (using Bailey's d test)

(a) Treatments

Date	O-M			O-S			M-S		
	df	d	p	df	d	p	df	d	p
14/4/73	17.3	4.26	<0.001	20.5	2.52	<0.05	24.8	2.76	<0.02
21/5/73	19.2	4.22	<0.001	17.4	5.44	<0.001	26.6	2.03	<0.01
24/7/73	22.0	4.94	<0.001	27.8	4.68	<0.001	23.4	0.56	NS
5/9/73	18.1	1.44	NS	19.9	4.49	<0.001	27.5	5.55	<0.001
Seasonal Mean	4.3	3.65	<0.05	5.9	3.34	<0.02	4.7	0.39	NS

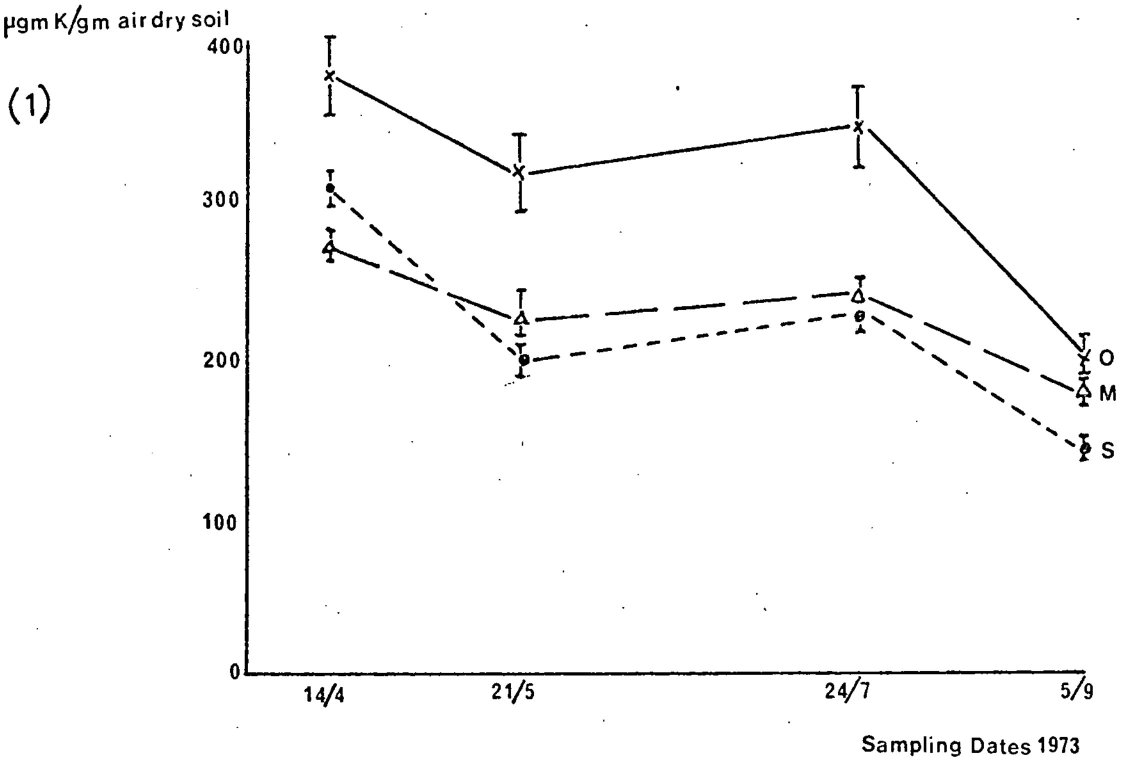
(b) Change over season

Dates	Organic			Mixed			Stockless		
14/4/-21/5/73	27.1	1.92	NS	27.6	3.73	<0.001	23.1	7.84	<0.001
21/5/-24/7/73	27.6	1.10	NS	27.6	1.20	NS	19.0	1.59	NS
24/7/-5/9/73	22.3	7.02	<0.001	18.5	5.50	<0.001	16.4	5.03	<0.001

Graph 1 - 3

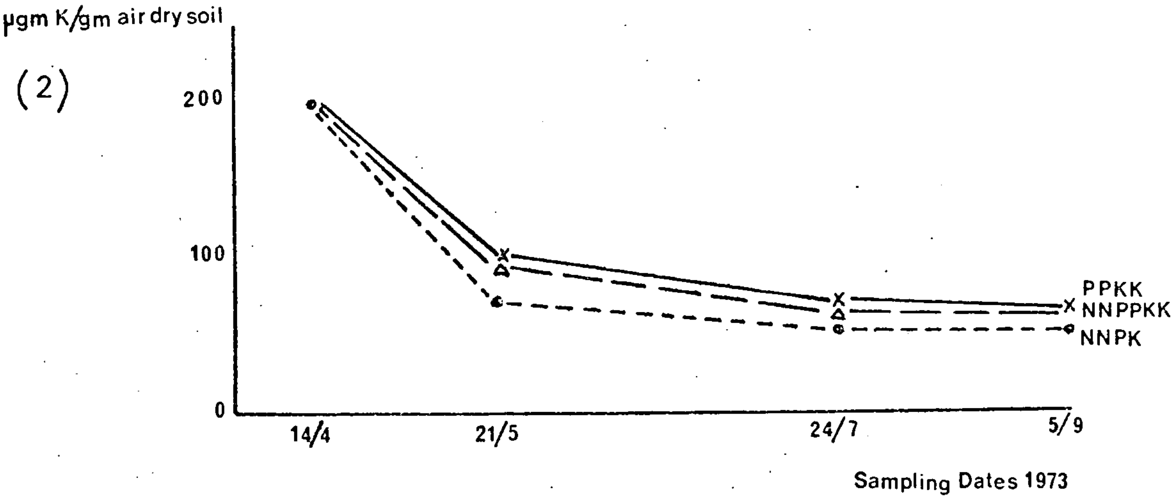
The Seasonal Variation in the Level of Exchangeable Potassium in the Soil.

(1)



Special Fertilizer Treatment

(2)



These clearly demonstrate that the levels of available potassium in the Organic section soil were at all times greater than those in the Stockless soil, and for the early part of the season greater than those in the Mixed soil too. Although initially the concentrations on S > M due to a higher application rate of fertilizer to the Stockless section, for most of the season the levels on the Mixed soil were greater than those in the Stockless soil. As in 1972, the application of total potassium to the Organic section in the form of manure was much greater (130%) than that applied in the form of artificial fertilizers to the other sections.

If the concentrations of available potassium in the soils of the different sections are compared for 1972 and 1973 it will be seen that on the Mixed and Stockless sections, when allowance has been made for the slightly differing application rates of fertilizer, the values are within the same order of magnitude despite the use of different fields for study. However, as was noted in the explanation of available phosphorus levels which differed between the two years on the Organic section due to the higher rates of manure application in 1973, for potassium this higher rate has caused lower levels of available potassium at all times, except at the beginning of the season.

.4-3(3) Special Fertilizer Treatment

Table 1-14(3) and Graph 1-3(2) show the results of soil analysis for available potassium in the special fertilizer treatments on Chestnut Tree East field in 1973. Throughout the season there was no significant difference in concentration of this form of potassium between PPKK and NNPPKK, so the presence/absence of double nitrogen did not affect the availability of this ion. On all three treatments the level of potassium decreased in the soil with the progression of the season, and throughout this time the level where the normal rate of fertilizer had been applied was lower. This difference was significant :-

21/5/73	PPKK > NNPK	Significant	to	>99.9%	confidence	level
24/7/73	PPKK > NNPK	"	"	>95%	"	"

It is probable that only the small number of replicates used here prevented the differences in September from being significant too. Thus where high rates of total potassium are applied in fertilizer or manure,so are the available potassium concentrations in the soil higher throughout the season.

.2.2.5 Conclusions The analysis of the soils showed significant effects of season and farm management upon the concentrations of exchangeable nitrogen phosphorus and potassium. The results indicated that if organic manures were supplied to a soil system every year, more nutrients would be available than from fertilizer treatments. However, where manures are only applied twice in ten year, this beneficial effect is soon lost.

SECTION 2. WATER CHEMISTRY

Section 2. WATER CHEMISTRY

2:1 Introduction

2:1.1 One of the main aspects of the growing concern about environmental pollution has been that of nutrient enrichment (eutrophication) of natural waters. Three main sources of nutrients have been identified (Kolenbrander 1972) :-

:1.1-1 Atmosphere - particles carried by wind and precipitation.
.1-2 Soil - drainage and runoff-water carrying dissolved and particulate matter from soil and applied fertilizers.
.1-3 Urban population - domestic and industrial effluent.

:1.2 It is known that the eutrophication of waters with nitrogen and phosphorus tends to enhance the growth of algae and the macroflora, and upon their death, deoxygenation of the water and fish-kills often result. A more serious factor brought about by high nitrate concentrations in drinking water is human infant, and animal, mortality from methaemoglobinemia (internal asphyxiation). Prior to 1970 most human deaths from this cause were shown to have resulted from the use of shallow sewage-contaminated wells, but in that year several cases of methaemoglobinemia in Lincolnshire occurred as a result of ingestion of the public water supply, derived from an intensively agricultural region (Tomlinson 1971). Due to this toxic effect of nitrates, the World Health Organization has defined a maximum safe limit of 22.6 mg NO_3-N/litre, with a preferred limit of 11.3 mg NO_3-N/litre. To date the only economical measure for maintaining concentrations in the public water supply in Britain below this limit, has been to employ massive dilution with purer water.

:1.3 It has been demonstrated that eutrophication of the water tends to increase proportionately with the size of population (Kolenbrander 1972) but there is considerable controversy as to whether the runoff from agricultural land, or urban sewage, is chiefly to blame. As the two most limiting nutrients for plant growth are nitrogen and phosphorus, attention has been mainly focussed upon the possible sources of these two elements. It is suggested in the literature that the main source of nitrate is runoff from the heavy applications of artificial fertilizers in intensive farming systems (Owens 1970), but that almost all the phosphate is derived from the domestic and industrial use of detergents (Bernhardt et al. 1969; Pleisch 1970).

2:2 Background to Methods

2:2.1 It was decided that it would be useful to elucidate the contribution to the eutrophication of the ground water by nutrients leached from the soil on each of the three farm management sections at Haughley. This would determine the relative threat of each type of system used, to the eutrophication of the water draining from the land, and would give a guide to the efficiency of plant uptake and soil immobilization of the macronutrients added to the system.

:2.2 In many parts of Britain, land used for agriculture overlies impervious layers of clay, where to speed drainage of water, tile-drains may be installed at a depth of about 75-100 cms. Several research workers have analyzed the effluent from such drains to determine the loss of nutrients from the land (Johnston et al. 1965; Bolton et al. 1970; Hood 1975). Although this has enabled calculation of nutrient loss under actual prevailing conditions in modern agriculture, there are several disadvantages of using such methods :-

:2.2-1 The proportion of the total water draining through the soil, which is collected by the tile system, cannot be calculated, and will vary from season to season as the subsoil drainage channels vary in capacity in dry and wet years (Williams 1970). The amount lost between the tile drains depends on the height of the water table.

:2.2-2 In most fields it is difficult to determine the precise area of land served by the tile-drain system, and frequently runoff occurs from one field onto another.

:2.2-3 It is difficult and expensive to monitor continuously the large outflow of water from a tile-drain system serving a whole field.

:2.3 To overcome these disadvantages many researchers have utilized lysimeters to study the percolation of water through the soil. The first recorded use of lysimetry was by De la Hire in ~~1688~~ (1720), followed by Dalton (1819), Way (1850), and Lawes and Gilbert (1882). Despite several major limitations whereby the conditions measured may not be directly comparable with those experienced in the open field, lysimetry has remained the most practical method for monitoring nutrient flow through terrestrial ecosystems. There are three main types of lysimeter construction :-

(1) Undisturbed monoliths - may be mechanically impracticable/ expensive.

(2) Filled tanks - natural soil structure destroyed.

(3) Tension lysimeters - total percolate volume not measurable.

:2.4 The main limitations involved in the use of lysimeters have been defined by Lipman and Conybeare (1936), Kohnke _et al_. (1940), Pratt and Chapman (1961), Low and Armitage (1970) :-

:2.4-1 Unnatural restriction of lateral water movement and root development.

.4-2 Development of shrinkage cracks, especially along walls, causing high drainage rates.

.4-3 Impedence of drainage by soil/air interface at base of container.

.4-4 Plant roots in shallow lysimeters are able to use ponded water and nutrients.

.4-5 Destruction of natural soil structure which increases the surface area of particles exposed to the solvent action of rainfall, resulting in exaggerated nutrient leaching.

.4-6 Difficult to allow and measure natural runoff water.

Despite these limitations it was considered that the use of lysimeters at Haughley would enable a comparison of the long term effects of farm management upon soil water retention, rate of leachate flow, and the leaching of macronutrients from different agricultural additives on a single soil type.

2:3 Aim To determine whether the farm management practised over thirty years had altered the ability of the soil to retain water, and to compare the loss of nutrients in the soil leachate from the three sections.

2:4 Method Over a period of twelve months from April 1972 - March 1973 the quantity of rainfall at Haughley was continuously monitored. On seven occasions the rainwater was analysed for nitrogen, potassium, phosphorus, sodium, calcium and magnesium so that estimates of the addition of these nutrients to the system, from the atmosphere, could be calculated. A series of filled, shallow and deep, lysimeters were constructed (see Appendix for details of construction) with one fallow and one cropped container of each depth on each farm section. The shallow lysimeters were 1.44 sq. metres in surface area, the deep ones 0.108 sq. metres in area. On the Stockless section two groups of lysimeters were made to allow two rates of fertilizer application to be given. The fallow lysimeters were maintained free of weeds throughout the year, whilst the cropped areas were planted at the normal cropping density with *Vicia faba* which were harvested at the same time as those plants in the field. The volume of leachate flowing out of each lysimeter was measured at monthly intervals and was analysed for the six elements previously mentioned (see Appendix for methods of analysis). Throughout the year, samples of tile-drain effluent were collected from all the fields on each section. For those fields under specific study, individual samples of drainage water were analysed. The water samples from the remainder of the fields were bulked together to provide a mean chemical analysis for each management type. Due to the expense of automatic monitoring systems it was not possible to measure the volume of tile-drainage effluent, but the results of the chemical analysis of this water were used to show how comparable the conditions within the lysimeters were with those of the open field.

WATER ANALYSIS

Table 2-1 Concentration of geochemicals in rainwater
(Concentrations in mg/litre)

Date of collection	Org N	NO_3-N	Total N	K	Na	Ca	Mg
11/4-1/5	1.50	0.84	2.34	3.00	4.20	7.00	2.50
2/5-22/5	0.70	0.22	0.92	1.80	2.00	1.80	0.40
23/5-22/6	1.50	0.14	1.64	3.50	7.20	3.80	0.75
23/6-25/7	1.50	0.22	1.72	0.50	0.90	3.00	0.31
26/7-19/8	1.50	0.20	1.70	0.30	0.90	1.10	0.25
20/8-19/9	0.50	0.90	1.40	1.10	0.60	8.30	7.30
20/9-10/12	5.10	0.84	5.94	4.00	6.00	7.00	9.00
Mean	1.76	0.48	2.24	2.03	3.11	4.57	2.93
S.E.	0.58	0.13	0.64	0.56	1.02	1.08	1.39

Other metals:	Al	Fe	Cu	Zn	Pb
Means	0.070	0.230	0.012	0.050	0.020

Discussion of Results

2:5 Addition to the system

(The input of nutrients in fertilizers and manures, and from symbiotic nitrogen fixation, is discussed in Sections 1 and 5 respectively).

:5.1 Table 2-1 demonstrates how variable the concentrations of the macronutrients in the rain water were during the ~~twleve~~ twelve months considered. On each occasion the water was analysed for phosphate, but concentrations were always below the level of accurate determination (0.05 mg/1). The mean concentrations of Organic nitrogen,(assumed to be mainly NH_4-N) and NO_3-N, fell within the range found elsewhere in the literature, but no concentration figures were found for the other elements which were determined :-

		NO_3-N mg/1			NH_4-N mg/1
e.g.	Haughley	0.48		Haughley	1.76
	Berkshire	0.40	(Hood 1975)	Berkshire	0.70
	Rothamsted	1.50	(Cooke and Williams 1970)		
	New York	0.10	(Collison and Mensching 1932)	New York	1.01
	Israel	0.03-2.00	(Feth 1966)	Israel	0.4-2.2

The highest concentration of nitrogen occurred in the period of greatest rainfall, which coincides with the findings of Hood (1975). It has been suggested that nitrate-, and ammonium-, nitrogen in rainfall is derived almost entirely from the dissolution of gaseous oxides of nitrogen and ammonia (Gambell and Fisher 1964), but that lightning may be partly responsible too (Viemeister 1960). Junge and Manson (1961) state that there is a constant fallout of nitrogen compounds from the stratosphere, which will be dissolved in precipitation, whilst Hutchinson (1954) suggests

WATER ANALYSIS

Table 2-2(1) Addition of geochemicals to lysimeters in rainfall. Mg/lysimeter.

(a) Shallow

Date	Rainfall (cms)	Volume (litres)	Org N	NO_3-N	Total N	K	Na	Ca	Mg
6/3/72-10/4	3.75	54.0	95.0	25.9	120.9	109.6	167.9	246.8	158.2
11/4 -1/5	1.43	20.6	30.9	17.3	48.2	61.8	86.5	144.2	51.5
2/5 -22/5	2.50	36.0	25.2	7.9	33.1	64.8	72.0	64.8	14.4
23/5 -22/6	4.62	66.5	99.8	9.3	109.1	232.8	478.8	252.7	49.9
23/6 -25/7	5.55	79.9	119.9	17.6	137.4	40.0	71.9	239.7	24.8
26/7 -19/8	2.00	28.8	43.2	5.8	49.0	8.6	25.9	31.7	7.2
20/8 -19/9	4.03	58.0	29.0	52.2	81.2	63.8	34.8	481.4	423.4
20/9 -10/12	9.15	131.8	672.2	110.7	782.9	527.2	790.8	922.6	1186.2
11/12 -6/1/73	1.20	17.3	30.4	8.3	38.8	35.1	53.8	79.1	50.7
7/1 -26/2	1.83	26.4	46.5	12.7	59.1	53.6	82.1	120.7	77.4
27/2 -6/3	0.63	9.1	16.0	4.4	20.4	18.5	28.3	41.6	26.7
TOTAL Annual add.	36.70	528.4	1208.1	272.1	1480.2	1215.8	1892.8	2625.3	2070.4

(b) Deep

Date	Rainfall (cms)	Volume (litres)	Org N	NO_3-N	Total N	K	Na	Ca	Mg
6/3/72-10/4	3.75	4.05	7.1	1.9	9.0	8.2	12.6	18.5	11.9
11/4 -1/5	1.43	1.54	2.3	1.3	3.6	4.6	6.5	10.8	3.9
2/5 -22/5	2.50	2.70	1.9	0.6	2.5	4.9	5.4	4.9	1.1
23/5 -22/6	4.62	4.99	7.5	0.7	8.2	17.5	35.9	19.0	3.7
23/6 -25/7	5.55	5.99	9.0	1.3	10.3	3.0	5.4	18.0	1.9
26/7 -19/8	2.00	2.16	3.2	0.4	3.7	0.7	1.9	2.4	0.5
20/8 -19/9	4.03	4.35	2.2	3.9	6.1	4.8	2.6	36.1	31.8
20/9 -10/12	9.15	9.88	50.4	8.3	58.7	39.5	59.3	69.2	88.9
11/12 -6/1/73	1.20	1.30	2.3	0.6	2.9	2.6	4.0	5.9	3.8
7/1 -26/2	1.83	1.98	3.5	1.0	4.4	4.0	6.2	9.1	5.8
27/2 -6/3	0.63	0.68	1.2	0.3	1.5	1.4	2.1	3.1	2.0
TOTAL Ann. Add.	36.70	39.6	90.6	20.3	110.9	91.2	141.9	197.0	155.8

TOTAL ANNUAL ADDITION of other metals.

	Al	Fe	Ca	Zn	Pb
Shallow lysimeters	37.0	121.5	6.3	26.4	10.6
Deep lysimeters	2.8	9.1	0.5	2.0	0.8

WATER ANALYSIS

Table 2-2(2) Total annual addition of geochemicals to farm systems in rainfall using mean 1972 analysis. Kg/ha.

Year	Total Rain-fall (cms)	Total volume (l/ha)	N	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1971	44.5	44.5×10^5	9.97	9.03	13.84	20.34	13.04	0.31	1.02	0.05	0.22	0.09
1972	42.0	42.0×10^5	9.41	8.53	13.06	19.19	12.31	0.29	0.97	0.05	0.21	0.08
1973	46.5	46.5×10^5	10.42	9.43	14.46	21.25	13.62	0.33	1.07	0.06	0.23	0.09

that the nitrate in rainfall is derived from atmospheric ammonia by photochemical oxidation. However, none of these explanations account for an increase in the concentration of nitrogen with increased rainfall. It is probable that most of the elements detected in the rainfall in this agricultural region originated chiefly from wind eroded soil particles which had been carried up into the atmosphere. The fact that most of the higher concentrations for all elements considered occurred at, or immediately after, the times of maximum mechanical soil disturbance (seed drilling - March, crop harvest - September) tends to confirm this probability. This, and the figures found for Haughley, would also explain why Junge (1958) found that rainfall over increasingly alkaline soils contained greater concentrations of NH_4-N, although it is not known how local this effect is likely to be in Suffolk.

:5.2 Table 2-2(1) shows the actual rainfall recorded each month, together with the calculated addition of macroelements to each lysimeter, and the total addition in mg/year (April 72 - March 73). The second table 2-2(2) presents the total annual addition of these elements to the field in Kilogrammes/hectare, using the mean rainfall analysis figures obtained for 1972-3. Again for nitrogen, the figures for total annual addition to the farm system fall within the range suggested in the literature, although the quantity will depend upon the total annual rainfall :-

Haughley (1972)	9.4 - 10.4	Kg	N/ha/year
Allen _et_ _al_. (1968)	8.7 - 19.0	"	"
Van Schreven (1970)	8.5	"	"
Von Krzysch (1958)	10.0	"	"
Low and Armitage (1970)	12.5	"	"

The total addition of the other elements measured, also agrees with figures found in the literature, although the information is very scarce; e.g. Low and Armitage (1970) K : 9.6 Kg/ha/year, Ca : 19.0 Kg/ha/year. It must be noted that the total annual rainfall during the three years of research in Suffolk of 42 - 46 cms (17 - 19") was well below the average expected for East Anglia.

2:6 Loss from system

2:6.1 Loss of water

One of the aims of the lysimeter study was to discover whether or not the farm management type influenced the retention of water by the soil. Tables :6.1-1, 1-2 and 1-3 present the results of this study, showing volume of lysimeter leachate, volume of water taken up by the growing bean crop, and volume of water lost by evaporation respectively, on the three farm sections.

:6.1-1 Volume of lysimeter leachate (litres)(Full details on Table 2-3 overleaf)

Treatment	April-September,1972 Growing Season				April 1972-March 1973			
Lysimeter type	Shallow		Deep		Shallow		Deep	
	Cropped	Fallow	Cropped	Fallow	Cropped	Fallow	Cropped	Fallow
O	11.5	21.3	3.5	5.0	26.3	39.9	10.8	12.7
M	12.2	25.5	0.6	5.0	30.2	44.1	9.8	(5.0)
S-NF	12.1	23.8	1.6	6.7	29.1	28.7	9.6	15.6
S-HF	(8.0)	19.6	1.7	7.8	23.0	38.7	11.5	16.5
Total rainfall	343.8		25.8		528.4		39.6	

Key : (5.0) = Some water-logging, impeded drainage
S-NF = Normal fertilizer treatment
S-HF = High " "

There appeared to be no consistent correlation for any lysimeter type or farm management section, between the volumes of leachate and

Table 2-3

Volumes of leachate lost from the Lysimeter April 1972 - March 1973

Shallow Lysimeters (leachate in litres)

Period of Collection	Organic C	Organic F	Mixed C	Mixed F	Stockless C	Stockless F	Stockless + C	Stockless + F
11/4 - 1/5/72	0.4	3.0	5.0	5.0	4.9	4.5	1.0	2.7
2/5 - 22/5	0.6	2.3	0.2	2.7	0.4	2.0	0.4	1.1
23/5 - 22/6	2.4	4.8	0.9	5.0	1.0	5.0	2.2	4.9
23/6 - 25/7	3.9	1.8	0.0	4.1	0.0	3.4	0.0	4.9
26/7 - 19/8	1.4	4.7	1.6	4.9	3.0	4.9	1.6	4.9
20/8 - 19/9	2.8	4.6	4.5	3.9	2.8	4.0	2.8	1.1
20/9 - 10/12	3.9	4.6	4.6	4.1	4.5	4.9	4.9	4.5
11/12- 6/1/73	3.7	4.6	4.6	4.1	4.4	0.0	2.9	4.9
7/1 - 26/2	3.9	4.7	4.5	4.8	4.1	0.0	4.7	4.9
27/2 - 6/3	3.3	4.8	4.2	5.1	4.0	0.0	2.4	4.8
TOTAL	26.3	39.9	30.2	44.1	29.1	28.7	23.0	38.7

Deep Lysimeters (leachate in litres)

11/4 - 1/5/72	0.6	0.2	0.3	0.3	0.4	0.4	0.4	0.6
2/5 - 22/5	0.8	0.6	0.0	0.5	0.6	0.5	0.3	0.6
23/5 - 22/6	1.6	0.8	0.0	1.0	0.6	1.3	0.0	1.4
23/6 - 25/7	0.2	0.8	0.0	1.4	0.0	1.2	0.0	2.6
26/7 - 19/8	0.0	1.0	0.0	0.9	0.0	1.5	0.0	0.9
20/8 - 19/9	0.4	1.6	0.3	0.9	0.0	1.8	1.0	1.7
20/9 - 10/12	3.1	4.7	3.7	0.0	3.5	4.0	3.7	4.0
11/12- 6/1/73	1.1	0.0	1.0	0.0	1.1	1.3	2.5	1.3
7/1 - 16/2	2.4	0.5	3.6	0.0	2.6	2.8	2.9	2.7
27/2 - 6/3	0.8	0.5	0.9	0.0	0.8	0.8	0.7	0.7
TOTAL	10.8	12.7	9.8	5.0	9.6	15.6	11.5	16.5

precipitation, especially on the fallow soils. This agreed with the findings of Dreibelbis (1946).

The individual monthly leachate volumes are presented on Table 2-3. It is noted that although the deep lysimeters included soil from the semi-pervious chalky clay horizon, the volume of leachate in proportion to the total rainfall volume available was much greater from the deep lysimeters, especially in the fallow conditions. It is probable that the soil moisture content in the deep lysimeters was initially much higher than found in the plough depth alone, (shallow lysimeters) and evaporation less, due to greater depth. Therefore the amount of rainfall required to produce an outflow of leachate would be much less for the deep lysimeters compared to the shallow, even when the difference in their surface area is taken into account. The figures for the deep lysimeters were in close agreement with Low and Armitage's (1970) results, showing that 20-30% of the precipitation drains through cropped arable soil. Unfortunately it was not feasible to build replicate lysimeters in each field, and therefore a certain amount of internal variability within a single management type,must be expected to reduce the significance of differences between management types.

Thus the differences observed between the leachate volumes from S-NF and S-HF, which were adjacent within the same field, were sometimes greater than those between field types. The bracketed figures in these tables indicate that, when the lysimeters were dismantled at the end of the experiment, blocked outflow pipes were found to have impeded the drainage of water from the containers, which explained the low leachate volumes collected.

:6.1-2 Differences between cropped and fallow lysimeter leachate volumes during the growing season (litres) - uptake by plants

Treatment	Shallow lysimeters			Deep lysimeters		
	Volume difference	Plant number	Volume /plant	Volume difference	Plant number	Volume /plant
O	9.8	35	0.28	1.5	3	0.50
M	13.3	55	0.24	4.4	7	0.63
S-NF	11.7	40	0.29	5.1	9	0.57
S-HF	11.6	40	0.29	6.1	9	0.68

For the cropped lysimeters, water loss will be mainly due to transpiration, but will include some evaporation from the soil surface until the crop gives complete shade. The loss of water from fallow lysimeters, after subtraction of leachate, was assumed to be entirely by evaporation from the soil surface. Ideally the same number of plants should have been grown on each lysimeter type : 35-40 on shallow and 3-5 on deep (for normal field density), but due to exaggerated edge effects in the smaller surface area of the latter type, more plants were sown. The problem was further complicated by plant mortality.

Table :6.1-2 shows the result of dividing the difference in leachate volume between cropped and fallow lysimeters, by the number of plants grown, which is then the value of the minimum transpiration loss per plant during the season. It is likely that this quantity was greatly supplemented by the amount of water apparently lost by evaporation, as shown in Table :6.1-3, but the actual water loss due to evaporation alone was not measured. It is suggested that the figures derived from the deep lysimeters were largely due to an initially greater storage of soil water in the lower soil horizons. Thus when these considerations are taken into account, so as to remove the varying plant density effect, there was very little difference between the farm management types.

It is suggested that most of the observed water loss was the result of evaporation from the soil surface. It was found that the mean soil water content during the growing season was 18% w/w. Thus in the total soil volume of 360 litres in the shallow lysimeters, and 36.1 litres in the deep lysimeters, only 64.8 litres and 6.5 litres of water would be required respectively, to maintain the observed water content. The remainder of the water would have been lost by evaporation, or would have been potentially available for transpiration in the cropped lysimeters.

:6.1-3 Volume of water evaporated from the soil surface or potentially available to plants (litres)

Treatment	April 1972 - September 1972		April 1972 - April 1973	
	Shallow	Deep	Shallow	Deep
O	257.7	14.3	423.7	20.4
M	253.5	14.3	419.5	(28.1)
S-NF	255.2	12.6	(434.9)	17.5
S-HF	259.4	11.5	424.9	16.6

Conclusions concerning Water Loss.

As would be expected, the evaporation from three fields within the same local region was found to be very similar on the three farm sections. Thus despite small significant differences observed in soil moisture between the sections during the growing season (see Soil section Page 30), the overall conclusion must be that the farm management type practised had not substantially changed the ability of the soil to retain water in a form available for plant growth, when figures are considered for an entire growing season. It is probable that any differences in soil structure, brought about by the higher organic matter content shown to exist on the Organic and Mixed sections, would be negated by the soil disturbance necessary to construct the lysimeters, and consequently the expected differences in water holding capacity lost.

2:6.2 Loss of Geochemicals

Presentation of Results

:6.2.1 Concentrations of geochemicals in lysimeter leachate and field drainage water

Tables A1(1) and (2)	Full details of the monthly concentrations of the major geochemicals in the lysimeter leachate, expressed in milligrammes/litre , plus the calculated annual mean values.
Table A1(3)	Concentrations of five micronutrients in the lysimeter leachate at the beginning and end of the growing season.
Tables A2(1) and (2)	Results of chemical analysis of field drainage water collected at intervals throughout the year, individually from the fields under special study, and bulked samples from all the other fields in each section.
Table 2-4	A summary of Tables A1 - A2.
Table 2-5	A statistical comparison of the concentrations of geochemicals in the lysimeter leachate with that of field drainage water.
Table 2-6	A statistical comparison of the concentrations of geochemicals in the lysimeter leachate from the three farm management sections.

:6.2.2 Loss of geochemicals from the lysimeters

Tables A3(1) - (3)	The monthly loss of geochemicals from the lysimeters, expressed in milligrammes/lysimeter, and the calculated total annual loss from each of the four treatments.
Tables A4(1) - (3)	Monthly losses expressed in Kg/hectare
Histogram 2-1 to 2-3	Histograms of the monthly loss of six geochemicals from the shallow lysimeters.
Histogram 2-4	The total annual loss of geochemicals from lysimeters expressed as grammes/lysimeter, shown as a histogram.

Histogram 2 – 5 The total annual loss of geochemicals from lysimeters expressed as kilogrammes/hectare equivalent, shown as a histogram.

:6.2.1 Concentrations of geochemicals in lysimeter leachate and field drainage water

Discussion of results

Lysimeter leachate

.2.1.1 From the full result tables of the concentrations of geochemicals in the lysimeter leachate Tables A1(1) – (3) certain conclusions can be drawn :-

.2.1.1-1 The highest concentration occurring at any one time, and the largest range of concentrations during the season, occurred on the Organic field for most of the elements measured :-

Organic –	highest	concentrations of	N, NO_3, K, Na, Al, Zn
Mixed –	"	"	Mg, Ca, Cu
Stockless – (High Fertilizer)	"	"	Fe and Pb

These findings correlate well with the chemical analysis of the soils (see Section 1).

.2.1.1-2 The lowest concentration ranges tended to occur on the Mixed section for most elements (no manure supplied to these Mixed fields for two years):-

Mixed –	lowest	concentrations of	N, NO_3, K, Na, Al, Zn, Pb
Stockless	"	"	Fe
Stockless (High Fertilizer)	"	"	Ca, Mg, Cu

.2.1.1-3 The month at which the maximum concentrations of each element occurred are shown below :-

Element	Lysimeter type			
	Shallow Cropped	Shallow Fallow	Deep Cropped	Deep Fallow
Organic N	May	May	Apr-May	May
NO_3-N	O,M Sep-Dec	O,M July-Aug	Sep-Dec	O,M July-Aug
	S,S^+ Apr-June	S,S^+ Apr-May		S May
				S^+ Sep-Dec
K	O Apr-May	June-Sep	O,M Aug-Sep	O,M Apr-May
	M,S,S^+ Aug-Sep		S,S^+ Apr-May	S,S^+ Aug-Sep
Na	Apr-May	O Aug-Sep	O,S^+ Apr-May	Apr-July
		M,S,S^+ Apr-May	M,S Sep-Dec	
Ca	O,M Feb-Mar	June-Sep	O Jan-Feb	O Apr-May
	S Aug-Sep		M Aug-Sep	M June-July
	S^+ May-June		S,S^+ Sep-Dec	S,S^+ Aug-Sep
Mg	O,S^+ May-June	O,M,S^+ June-July	O June-July	July-Sep
	M,S Aug-Sep	S Sep-Dec	M,S,S^+ Sep-Dec	

Many of the high concentrations occurred within the first four months after the application of fertilizer (April - July) during the main period of crop growth. This was the period for high leachate concentrations on the Organic section, even though manures had not been applied since the previous autumn. It is suggested therefore, that nutrient loss was enhanced by the disturbance of soil structure which occurred during the construction of the lysimeters, which allowed greater leaching than was possible in the undisturbed soil. Even so, the mobile ion of nitrate did not leach out to give maximum concentrations until September - December on cropped Organic and Mixed shallow lysimeters, nor on any of the four types of deep cropped lysimeters. During the period April - July rainfall was low, and except for the shallow fallow lysimeters, total leachate volume tended to be low too. Thus any leaching of the soil during that time of maximum availability of nutrients from the fertilizer application would result in high loads of geochemicals, per unit of water outflow. This explains the high concentrations of most elements observed early in the season. Despite a greater depth of soil through which the water had to flow before being collected, the maximum concentrations of most elements in the leachate from the deep lysimeters also occurred at the same time of year as for the shallow containers.

.2.1.1-4 The lysimeter leachate was analysed for phosphate on several occasions, but the levels were at all times below those measurable, using the methods chosen (see Appendix). The negligible amount of phosphate in the lysimeter leachate agrees with the findings of Maschhaupt (1941), Stauffer (1942), Allison (1955), Pfaff (1963), Cooke and Williams (1970), all of whom found that the removal of phosphate by dissolution in the soil percolate was often too low to be measurable. Because of the rapidity by which added phosphorus is precipitated as insoluble forms, particularly in alkaline soil, the movement of phosphorus through the soil profile is very slow. For example, Cooke and Williams found that phosphorus moved down through 1 cm per 5-8 years, in the soil below the ploughed layer. Any phosphorus which is lost from the soil system is usually associated with suspended soil particles, and is therefore more frequently lost by erosion runoff from the soil surface.

.2.1.2 Field drainage

From the full result tables of the concentrations of geochemicals in the field drainage water Tables A2(1)(2) certain conclusions can be drawn :-

.2.1.2-1 The highest concentration of almost all the elements measured was found on the Mixed section. The only exception was that the Organic fields produced the highest concentrations of organic nitrogen, copper and lead.

.2.1.2-2 The maximum range of concentrations of geochemicals in the drainage water also occurred on the Mixed section, whilst the minimum range of concentrations was found on the Stockless section fields,which agrees with the soil chemical analysis :-

Organic fields	- maximum range of N, Cu minimum range NO_3, Ca, Mg, Zn
Mixed fields	- maximum range P, K, Ca, Mg, Al, Fe minimum range N, Pb
Stockless fields	- maximum range of NO_3, Zn, Pb minimum range P, K, Na, Al, Fe, Cu

These two conclusions do not contradict the findings from the lysimeter experiment,where the Mixed section tended to produce the lowest concentrations of geochemicals in the leachate, if the rotation stages are considered. On the Mixed fields studied by lysimetry, due to the particular stage reached in the pre-existing rotation, no organic manure had been supplied for two years. In effect, therefore, most of the immediately leachable geochemicals were derived from the artificial fertilizer application alone. But of the fields considered for the drainage-water chemistry, several had had manures added immediately prior to the season studied, and were therefore supplying leached geochemicals from both manure and fertilizers (see Introduction - Soil Section).

.2.1.2-3 The timing of the maximum concentrations of geochemicals in the field drainage water depended upon the farm management type practised. Thus on the Organic and Mixed sections, where manure had been applied in November, maxima occurred either immediately or during early Spring; on the Mixed and Stockless sections, where fertilizer had been applied in March, most leaching occurred in early summer.

Thus, by element : N, NO_3, Cu, Zn - maxima occurred in November or April

: P, K, Na, Ca, Mg, Pb, Fe - maxima occurred February - May

.2.1.2-4 If the annual mean concentrations of geochemicals in the field drainage water from the three farm sections are statistically compared, there are no significant differences for any of the elements measured. Thus apparently the differences in farm management showed no effect upon the drainage effluent from the tile drains. However it is suggested that these results were probably gained for several reasons :-

.2-4(1) Within each management section, each field was given a different treatment of manure and/or fertilizer, depending on the stage attained in the existing rotation. Thus the internal variability of the composition of effluent between fields within each section, when the drainage water was bulked together, would provide a wide range of ~~geochmeical~~ geochemical concentrations and reduce the differences between sections.

.2-4(2) The concentrations of geochemicals in the drainage water fluctuated with season, so that although figures for individual months of the year may have shown significant differences between sections, the calculation of annual means reduced the overall variability of concentrations. Due to the infrequency of running drains during the dry year of study, and to the time required for chemical analysis of the water, samples were bulked, which prevented the calculation of standard errors for each month, and hence no statistical comparisons through the year could be made.

.2-4(3) In many of the fields sampled, drainage water from the outlets in one field would have originated from several fields, not necessarily all of the same management type.

.2.1.3 Comparison of lysimeter leachate with field drainage water

Table 2-4 summarizes the full details of the concentration of geochemicals in the lysimeter leachate and the field drainage water. Table 2-5 depicts the results of a statistical comparison of their annual means.

.2.1.3-1 The results of the comparison show that although for organic nitrogen, the lysimeter method gave an accurate guide to the amount lost by leaching of the soil into the field drains, the concentrations of all the other elements measured differed to a varying extent between the two methods of water collection. The two elements showing a most consistent difference were :-

.3-1(1) Nitrate-nitrogen - the disturbance of the soil structure incurred in the construction of the lysimeters, exposed more soil-particle surface area to the solvent action of rainfall (Kohnke and Dreibelbis 1940) so that the loss of this very soluble ion was significantly greater from all lysimeter types than from the field drains. This effect was particularly marked on the Organic and Mixed sections, the soil of which had possessed more structure before its disturbance.

.3-1(2) Sodium - on all types of lysimeters the leaching of this element was significantly less than from any of the tile drains on all three farm sections.

.2.1.3-2 In addition, for some lysimeters on some sections, the concentrations of potassium, calcium, and magnesium, were less in the leachate from the lysimeters than from the normal field drainage. This effect was found mainly in the shallow lysimeters and only on the Mixed and Stockless sections. The discrepancies between field and lysimeter drainage geochemical concentrations, of all four alkaline earth elements, can be simply explained by considering the soil profiles described in the Soil Section 1. In the Mixed and Stockless fields, the soil horizon with the highest concentrations of these elements was below 50 cms, which was therefore below the level leachable in both the shallow and deep lysimeters, but above the tile drains (75 cms). Thus the water percolating through the Mixed and Stockless lysimeters passed through less of the alkaline-earth-rich horizons than the water entering the lower tile drains - this effect would have been particularly marked in the shallow lysimeters which were only 25 cms deep. This effect was not shown to produce discrepancies on the Organic section (except with reference to sodium), because the main strata rich in all these elements was well above 50 cms, within the constructed lysimeters.

.2.1.3-3 Despite these differences between lysimeter leachate and field drainage, it was considered valid to use a comparison of the lysimeter leachate results, to evaluate the effect of soil use (fallow or cropped), and farm management, upon the eutrophication of the ground water. The chemical analysis of the contained soils at the beginning and end of the 1972 growing season (see Soil Section 1) showed that for most elements the situation within the lysimeters was broadly equivalent to the conditions of soil in the open field. The main serious error which would result from predicting the loss of geochemicals from the field drains, by extrapolation of the lysimeter leachate results, would be an overestimate for nitrate loss, and an underestimate for sodium.

Table 2-4

WATER ANALYSIS

Mean concentration of geochemicals in lysimeter leachate and field drainage water.

Water sample details		ORGANIC N			NITRATE-N			K			Na			Ca			Mg			Al	Fe	Cu	Zn	Pb
		Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	Mean	Mean	Mean	Mean
ORGANIC - Cropped	-S	41.3	28.6	8.6	7.3	4.1	1.2	5.5	4.2	1.3	11.9	3.4	1.0	80.6	26.0	7.9	5.6	2.1	0.7	0.36	0.56	0.05	1.30	0.05
	-D	39.8	19.9	6.3	6.8	3.2	1.1	3.9	3.3	1.1	10.5	2.5	0.8	77.3	20.8	6.9	4.0	2.2	0.7	0.50	1.65	0.21	0.04	0.05
Fallow	-S	39.9	24.4	7.4	9.4	10.8	3.2	6.5	2.5	0.8	11.4	2.5	0.8	89.9	22.8	6.9	4.8	1.5	0.4	0.01	0.25	0.03	0.08	0.05
	-D	38.8	21.3	6.8	9.3	10.1	3.2	1.2	0.6	0.2	13.7	4.5	1.4	105.5	36.1	11.4	3.1	0.8	0.2	0.37	1.70	0.05	0.10	0.05
Drainage.		37.1	6.9	2.0	2.7	1.7	0.5	4.3	4.3	1.1	18.9	5.1	1.3	89.7	24.9	6.4	5.6	1.6	0.4	0.22	0.41	0.02	0.21	0.06
MIXED - Cropped	-S	35.8	11.5	3.6	8.0	4.7	1.5	1.4	1.1	0.3	5.8	2.2	0.7	79.7	20.3	6.4	3.9	1.0	0.3	0.17	0.66	0.05	0.12	0.03
	-D	32.4	8.1	3.1	5.1	2.1	0.8	1.6	1.6	0.6	7.4	3.2	1.2	98.5	67.9	25.7	4.9	3.5	1.3	0.15	1.60	0.29	0.05	0.03
Fallow	-S	35.0	16.8	5.3	6.5	2.9	0.9	1.4	1.2	0.4	6.4	2.3	0.7	87.1	25.7	8.1	3.9	1.1	0.7	0.05	0.33	0.02	0.04	0.05
	-D	34.4	12.6	5.1	7.5	0.8	0.4	1.1	1.0	0.5	6.5	1.1	0.5	99.1	20.9	10.4	3.4	0.9	0.5	-	-	-	-	-
Drainage.		36.3	4.3	1.2	2.5	1.9	0.5	5.8	6.6	1.7	20.7	9.5	2.4	87.5	24.7	6.4	5.2	2.6	0.7	-	0.54	0.02	0.21	0.07
STOCKLESS - MF - Cropped	-S	37.7	10.0	3.2	2.0	2.0	0.6	3.0	1.8	0.6	4.8	2.2	0.7	71.9	24.7	7.8	2.4	1.1	0.4	0.20	0.55	0.03	0.03	0.03
	-D	44.0	19.3	6.8	5.8	4.7	1.7	1.2	0.8	0.3	7.2	3.8	1.3	91.9	43.3	15.3	3.4	1.3	0.5	0.10	0.75	0.06	0.37	0.04
Fallow	-S	33.5	15.3	5.4	3.1	3.4	1.2	6.2	2.8	1.0	7.0	1.6	0.6	77.1	16.5	5.8	3.8	0.6	0.2	0.40	1.67	0.03	0.04	0.03
	-D	37.2	19.0	5.7	4.1	2.3	0.7	1.9	1.7	0.5	7.7	3.5	1.1	115.7	60.1	19.0	4.4	1.9	0.6	0.22	1.31	0.16	0.59	0.06
Drainage.		33.4	6.5	2.2	1.6	1.8	0.6	4.9	3.1	0.8	20.7	5.5	1.5	96.3	29.7	7.9	5.3	1.8	0.5	0.27	0.46	0.01	0.21	0.09
STOCKLESS - HF - Cropped	-S	42.9	21.0	6.6	4.4	3.8	1.2	4.0	1.8	0.6	5.5	1.3	0.4	64.2	23.0	7.3	2.5	1.1	0.3	0.23	0.75	0.03	0.02	0.05
	-D	37.3	13.2	4.7	9.0	4.4	1.6	1.1	0.5	0.2	7.0	2.7	1.0	93.7	25.6	9.1	3.0	0.9	0.3	0.25	1.80	0.06	0.22	0.07
Fallow	-S	39.3	17.9	5.4	3.5	3.0	0.9	2.8	1.7	0.6	6.3	2.1	0.7	77.9	23.2	7.3	3.1	0.9	0.3	0.23	0.80	0.04	0.15	0.12
	-D	36.3	15.8	4.8	5.8	5.4	1.6	0.8	0.7	0.2	5.8	1.7	0.5	62.1	28.6	8.6	2.3	0.6	0.2	0.13	0.66	0.07	0.18	0.04

Table 2-5

WATER ANALYSIS

Statistical comparison of geochemical concentration in lysimeter leachate with that in field drainage water.

Field	Lysimeter (cropped)	ORGANIC N				NITRATE N				POTASSIUM				SODIUM				CALCIUM				MAGNESIUM			
		df	d	p	R	df	d	p	R	df	d	p	R	df	d	p	R	df	d	p	R	df	d	p	R
ORGANIC	Shallow	11.1	0.47	NS	-	13.1	3.46	<0.01	L>D	20.9	0.68	NS	-	23.8	4.19	<0.001	D>L	21.0	0.90	NS	-	18.1	0.00	NS	-
	Deep	10.8	0.41	NS	-	13.1	3.66	<0.01	L>D	20.1	0.25	NS	-	21.4	5.49	<0.001	D>L	21.8	1.35	NS	-	15.2	2.00	NS	-
MIXED	Shallow	11.0	0.13	NS	-	11.4	3.44	<0.01	L>D	11.7	2.27	<0.05	D>L	16.2	5.84	<0.001	D>L	22.0	0.86	NS	-	19.5	1.76	NS	-
	Deep	8.0	1.18	NS	-	11.7	2.71	<0.02	L>D	13.1	2.10	NS	-	18.3	4.93	<0.001	D>L	6.8	0.42	NS	-	9.3	0.20	NS	-
STOCKLESS	Shallow	15.6	0.86	NS	-	17.1	0.46	NS	L≡D	12.5	1.58	NS	-	18.2	9.75	<0.001	D>L	21.5	2.20	<0.05	D>L	21.6	4.92	<0.001	D>L
	Deep	8.4	1.47	NS	-	8.8	2.33	<0.05	L>D	9.2	3.46	<0.01	D>L	19.3	6.78	<0.001	D>L	10.8	0.26	NS	-	18.6	1.25	NS	-

.2.1.3-4 Most of the references to the concentration of geochemicals lost in lysimeter leachate and field drainage water, in the literature, refer to the levels expected for nitrogen. The reported concentrations are very variable, depending upon the volume of rainfall, soil type and crop, amount of fertilizer or manure used, and method of collection and analysis of the percolate.

The range found is 1.8 - 91.5 mg N/litre of water, but the mean expected concentrations are :-

2.7 mg NO_3-N/litre - Sylvester (1961)
5-10 " " " - Cooke and Williams (1970)
8-12 " " " - Tomlinson (1970)
5-14 " " " - Bolton _et al_. (1970)
10-30 " " " - Hood (1975)
2-63 " total N/litre - Johnston _et al_. (1965)
46-53 " " " - Fischbach _et al_. (1973)

Thus the range of mean annual concentrations found at Haughley, of 32-44 mg N/litre and 1.6 - 9.3 mg NO_3-N/litre, do fall within the range of figures collected from the literature. It is not known why both the leachate and field drainage water from all management sections showed greater concentrations of organic nitrogen, and less of nitrate-nitrogen, whereas most authors have found that most nitrogen is lost in the nitrate form.

Although no phosphorus could be detected in the lysimeter leachate, the field drainage water showed annual mean concentrations of 0.29 - 0.63 mg/litre, which were within the same order of magnitude as concentrations reported in the literature e.g. 0.05 - 0.27 by Johnston _et al_. (1970). Very few references to the concentrations of potassium, sodium, calcium and magnesium expected in drainage water were found, but those available agreed with the Haughley results, viz :-

	Haughley	Literature	
Potassium :	0.8 - 6.5 mg K/l	Bolton *et al.*	0.9 - 1.7 mg/l
		Cooke and Williams	0.4 - 5.2 mg/l
Sodium :	5.5 - 20.7 mg Na/l	Cooke and Williams*	7.4 -44.8 mg/l Mean of 19.0 mg/l
Calcium :	62 - 116 mg Ca/l	Cooke and Williams	62 - 246 mg/l
Magnesium :	2.3 - 5.6 mg Mg/l	Cooke and Williams	0.8 -28.8 mg/l

* Note - This further demonstrated that the levels of sodium in the lysimeter leachate were very low.

.2.1.4 Effect of lysimeter type on leachate geochemical concentration

Within a single management section the variation in the mean annual leachate concentration of geochemicals between the fallow and cropped condition, the shallow and deep form, did not follow any consistent pattern. There were no significant differences between lysimeter types at the 95% level of confidence. The only trends found were :-

.2.1.4-1 Concentration of potassium was higher from the shallow lysimeters on all management sections.

.2.1.4-2 Concentrations of potassium, sodium and magnesium on the Stockless soil, were greater from the fallow lysimeters than from the cropped containers.

.2.1.5 Effect of farm management upon the concentration of geochemicals in lysimeter leachate

The results of the chemical analysis of lysimeter leachate from each farm management section were statistically compared and the results are shown on Table 2-6. Out of 144 pairs used for comparison to demonstrate effect of farm management, only 38 pairs showed any significant difference.

Table 2-6

WATER ANALYSIS

Statistical comparison of geochemical concentrations in the leachate from different lysimeters (Using annual means for comparison)

Nutrient	Fields compared	Cropped Shallow				Cropped Deep				Fallow Shallow				Fallow Deep			
		df	d	p	R	df	d	p	R	df	d	p	R	df	d	p	R
Org N	O-M	13.4	0.59	NS	-	12.7	1.06	NS	-	17.9	0.54	NS	-	13.9	0.52	NS	-
	O-S	12.7	0.39	NS	-	15.3	0.45	NS	-	18.4	0.70	NS	-	18.2	0.18	NS	-
	$O-S^+$	18.2	0.15	NS	-	15.7	0.32	NS	-	18.3	0.07	NS	-	16.6	0.30	NS	-
	M-S	17.6	0.40	NS	-	9.7	1.55	NS	-	18.0	0.20	NS	-	14.1	0.36	NS	-
	$M-S^+$	14.0	1.04	NS	-	11.8	0.88	NS	-	20.0	0.57	NS	-	12.6	0.27	NS	-
	$S-S^+$	12.9	0.70	NS	-	12.4	0.81	NS	-	20.1	0.76	NS	-	19.3	0.12	NS	-
Nitrate N	O-M	18.1	0.37	NS	-	12.4	1.30	NS	-	11.5	0.85	NS	-	9.2	0.56	NS	-
	O-S	14.8	3.79	<0.01	O>S	11.9	0.53	NS	-	12.6	1.80	NS	-	9.8	1.58	NS	-
	$O-S^+$	19.2	1.71	NS	-	12.1	1.20	NS	-	10.7	1.74	NS	-	13.4	0.97	NS	-
	M-S	12.2	3.75	<0.01	M>S	10.0	0.37	NS	-	13.9	2.25	<0.05	M>S	13.8	4.42	<0.001	M>S
	$M-S^+$	17.1	1.90	NS	-	10.3	2.24	0.05	$S^+>M$	18.1	2.31	<0.05	$M>S^+$	10.8	1.00	NS	-
	$S-S^+$	13.6	1.71	NS	-	14.0	1.39	NS	-	14.0	0.27	NS	-	19.8	1.72	NS	-
K	O-M	11.5	3.15	<0.01	O>M	13.7	1.92	NS	-	14.6	6.07	<0.001	O>M	7.2	0.22	NS	-
	O-S	13.9	1.79	NS	-	10.3	2.50	<0.05	O>S	14.2	0.25	NS	-	12.9	1.27	NS	-
	$O-S^+$	13.9	1.07	NS	-	9.5	2.64	<0.05	$O>S^+$	17.5	4.11	<0.001	$O>S^+$	19.1	1.33	NS	-
	M-S	15.0	2.42	<0.05	S>M	8.4	0.57	NS	-	7.9	4.53	<0.01	S>M	14.9	1.23	NS	-
	$M-S^+$	15.0	3.94	<0.01	$S^+>M$	7.0	0.79	NS	-	18.1	2.19	<0.05	$S^+>M$	2.6	0.60	NS	-
	$S-S^+$	18.0	1.25	NS	-	11.6	0.33	NS	-	10.7	3.06	<0.02	$S>S^+$	13.7	1.96	NS	-
Na	O-M	17.2	4.84	<0.001	O>M	10.9	2.10	NS	-	19.0	4.55	<0.001	O>M	10.7	4.80	<0.001	O>M
	O-S	17.6	5.92	<0.001	O>S	11.5	2.06	NS	-	16.8	4.68	<0.001	O>S	17.0	3.33	<0.01	O>S
	$O-S^+$	13.1	5.82	<0.001	$O>S^+$	14.6	2.82	<0.02	$O>S^+$	19.5	5.15	<0.001	$O>S^+$	11.3	5.27	<0.001	$O>S^+$
	M-S	18.1	1.02	NS	-	13.1	0.22	NS	-	13.3	0.65	NS	-	13.2	1.09	NS	-
	$M-S^+$	14.7	0.37	NS	-	11.9	0.26	NS	-	16.8	0.10	NS	-	14.7	0.99	NS	-
	$S-S^+$	14.6	0.86	NS	-	12.7	0.12	NS	-	16.8	0.80	NS	-	14.5	1.58	NS	-
Ca	O-M	18.6	0.09	NS	-	6.8	0.80	NS	-	18.2	0.26	NS	-	14.7	0.46	NS	-
	O-S	18.9	0.78	NS	-	9.6	0.87	NS	-	10.9	1.83	NS	-	16.5	0.48	NS	-
	$O-S^+$	19.1	1.53	NS	-	13.4	1.46	NS	-	19.9	1.22	NS	-	17.2	3.03	<0.01	$O>S^+$
	M-S	17.2	0.77	NS	-	10.0	0.22	NS	-	16.3	1.00	NS	-	13.2	0.84	NS	-
	$M-S^+$	17.8	1.60	NS	-	7.5	0.18	NS	-	18.1	0.86	NS	-	14.1	3.16	<0.01	$M>S^+$
	$S-S^+$	18.1	0.72	NS	-	17.8	0.11	NS	-	17.0	0.09	NS	-	14.3	2.67	<0.02	$S>S^+$
Mg	O-M	14.9	2.36	<0.05	O>M	8.9	0.60	NS	-	18.7	1.58	NS	-	8.1	0.71	NS	-
	O-S	15.4	4.57	<0.001	O>S	14.9	0.72	NS	-	13.8	2.00	NS	-	13.6	2.06	NS	-
	$O-S^+$	15.4	4.43	<0.001	$O>S^+$	12.5	1.32	NS	-	16.3	3.21	<0.01	$O>S^+$	17.0	2.58	<0.02	$O>S^+$
	M-S	17.7	3.19	<0.01	M>S	7.5	1.07	NS	-	14.4	0.25	NS	-	14.9	1.50	NS	-
	$M-S^+$	17.7	2.98	<0.01	$M>S^+$	6.7	1.36	NS	-	17.5	1.82	NS	-	7.2	2.68	<0.05	$M>S^+$
	$S-S^+$	18.0	0.20	NS	-	13.8	0.67	NS	-	17.1	2.00	NS	-	11.8	3.50	<0.01	$S>S^+$

Where $p => 0.05$ registered as NS.

R = Result where signif.

Summarizing the results by element (the figures in brackets indicate the number of times the differences were shown) :-

.2.1.5-1 Organic nitrogen - the only geochemical which showed no significant difference between any management section or lysimeter type, correlating well with the evidence from the field drainage analyses.

.5-2 Nitrate-nitrogen - some differences occurred in all four lysimeter types. There were :- O > S(1) M > S (3) M > S^+(1) showing the influence of adding organic manures to the O and M sections, either directly by nutrient content, or indirectly improving drainage rates through the soil.

.5-3 Potassium - the main differences occurred in the shallow lysimeters, but the overall significant differences were :-

O > M (2)	O > S (1)	O > S^+ (2)
S > M (2)		S > S^+ (1)
S^+> M (2)		

Thus although the recent application of organic manure caused the greatest concentration of potassium to be leached from the Organic section, high and normal fertilizer rates applied to the Stockless section leached out potassium more rapidly than from Mixed soil, where fertilizers were applied each Spring. It is possible that the application of organic manure to the Mixed section two years earlier had lost most of its own potassium before this experiment, but that the organic remains left prevented rapid leaching of the fertilizer K.

.5-4 Sodium - there were no differences between the Mixed and Stockless sections, but in many comparisons the concentration of sodium leached from the Organic section was significantly greater,because the upper soil layer in that field was much richer in this element than in the other sections, (see Soil Section 1.). Thus $O > M$ (3) $O > S$ (3) $O > S^+$ (4)

.2.1.5-5 Calcium - the only significant differences occurred on the deep fallow lysimeters, and all involved the lack of calcium flowing from the high fertilizer treatment. It is not known why this should have occurred.

.2.1.5-6 Magnesium - both fields which had received organic manures leached greater concentrations of magnesium than from the Stockless field.

Thus $O > M$ (1) $O > S$ (1) $O > S^+$ (3)
$M > S$ (1) $M > S^+$ (2)
$S > S^+$ (1)

Again there was a lack of magnesium in the leachate on the high fertilizer treatment, especially in the deep lysimeter type.

.2.1.6 Conclusions concerning concentration of geochemicals in farm soil percolate

.2.1.6-1 Lysimeters

.1.6-1(1) Due to the recent application of organic manure prior to the experiment, the Organic field tested by lysimetry, leached out geochemicals in greater concentrations than from the other management types.

(2) The highest concentrations of geochemicals occurred during the growing season, when the flow of percolate volumes through the soil was low.

(3) The lowest concentration of geochemicals leached from the soil was found on the Mixed section, where manure had not been applied for two years. The phosphate being leached out of lysimeters on all farm sections was found to be negligible.

(4) Although the situation was complicated by the disturbance of soil incurred in lysimeter construction, and by the different depths of soil layers in the profile of each field, some differences in concentration

of geochemicals in lysimeter leachate could be attributed to farm management. The concentrations of geochemicals determined in the leachate, fall within the range quoted from the literature, even though the leaching of sodium at Haughley was lower than expected.

.2.1.6-2 Drains

.1.6 2(1) Due to a wide variety of treatments between fields within each section, to the use of bulked water samples, and to fluctuating seasonal geochemical concentrations, no significant effect of the farm management was demonstrable. However the trend found, was for the highest concentrations of almost all elements measured to occur on the Mixed section, due to the application of both organic manures and artificial fertilizers in the year of study.

(2) Only for organic nitrogen was there a consistently close correlation between the field drainage and lysimeter leachate results. However whilst automatic weirs for the continuous monitoring of the outflow from field drains remain so expensive, and subject to practical problems, lysimetry will continue to be used to estimate the loss of nutrients from the ecosystem.

(3) The annual mean concentration for nitrate-nitrogen in the drainage water was well below the WHO limit referred to at the beginning of this section. Even in the water from the lysimeters, where soil disturbance had significantly increased the leaching of this ion, the danger limit of 11.3 mg NO_3-N/1 was not exceeded on any farm section.

2:6.2.2 Loss of geochemicals from lysimeters

Tables A3(1) - (3) in the Appendix record the actual monthly loss of geochemicals from each lysimeter during the 1972-3 period. The losses of six of the macronutrients from the shallow lysimeters are presented in histogram form in the text to demonstrate visually the differences in the magnitude of loss (Histogram 2-1 to 2-3). Two further histograms illustrate the total annual loss of geochemicals expressed in grammes/lysimeter and Kilogrammes/hectare equivalents (Histograms 2-4, 2-5).

Discussion of Results

The following conclusions can be drawn from the results :-

.2.2.1 The largest single monthly loss of geochemicals occurred on different farm sections, depending on the lysimeter type :-

Treatment	Cropped shallow	Cropped deep	Fallow shallow	Fallow deep
O	N, Na, Mg, K	N, K	NO_3, K, Na, Mg	N, Na, Ca
M	NO_3, Ca	Na	Ca	
S		Ca, Mg		K, Mg
S^+		NO_3	N	NO_3

The maximum loss of nitrogen and nitrate occurred on S^+ because of the more immediately available nature of the nitrogen, in the high rate of application of fertilizer supplied to this lysimeter type. Even so, where cropped in the shallow depth, losses were greater from the sections which had previously received organic manures, because of the higher quantities of these geochemicals supplied.

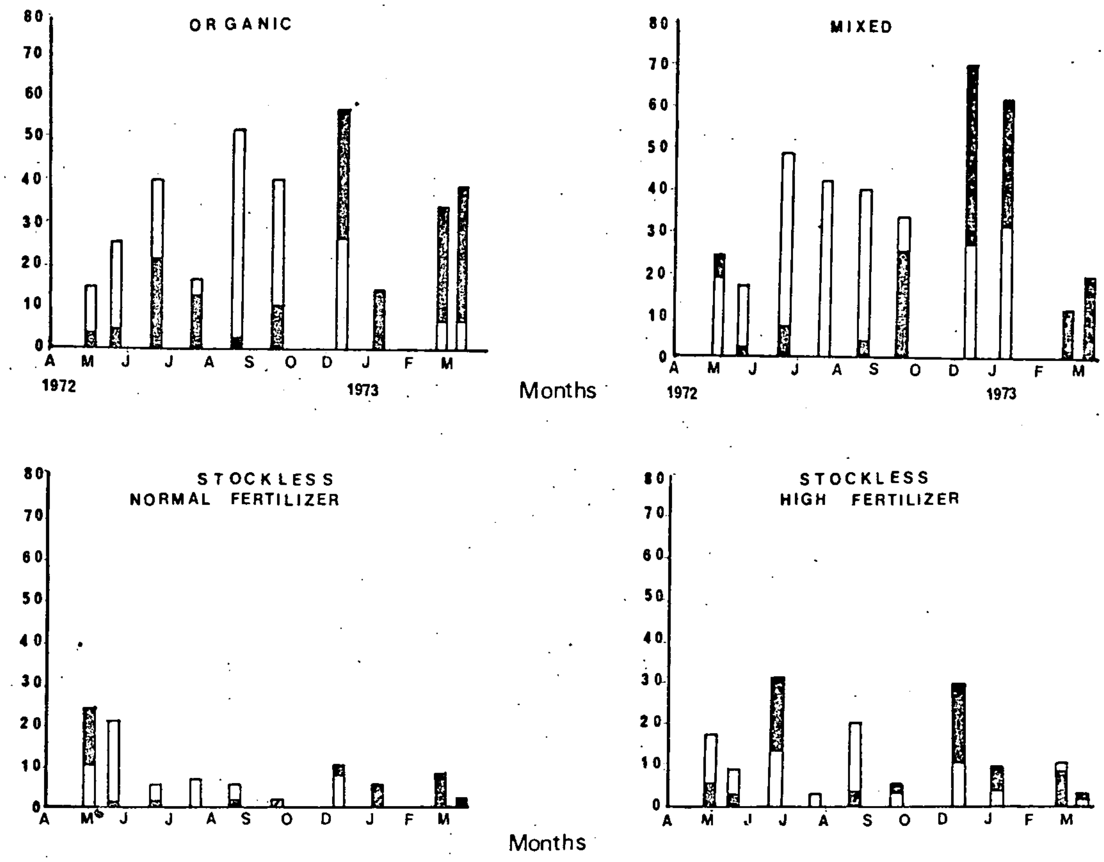
.2.2.2 The histograms of monthly losses show that the most striking difference between the farm management types was for nitrate-nitrogen, where the effect of organic manures in the soil was clearly demonstrable in providing this ion for leaching, by mineralization throughout the year. Tomlinson (1971) suggests that at least 30-60 kg N/ha/yr is mineralized from organic matter in British soils, and that the amount is significantly greater where organic manures are supplied.

Graph 2-1

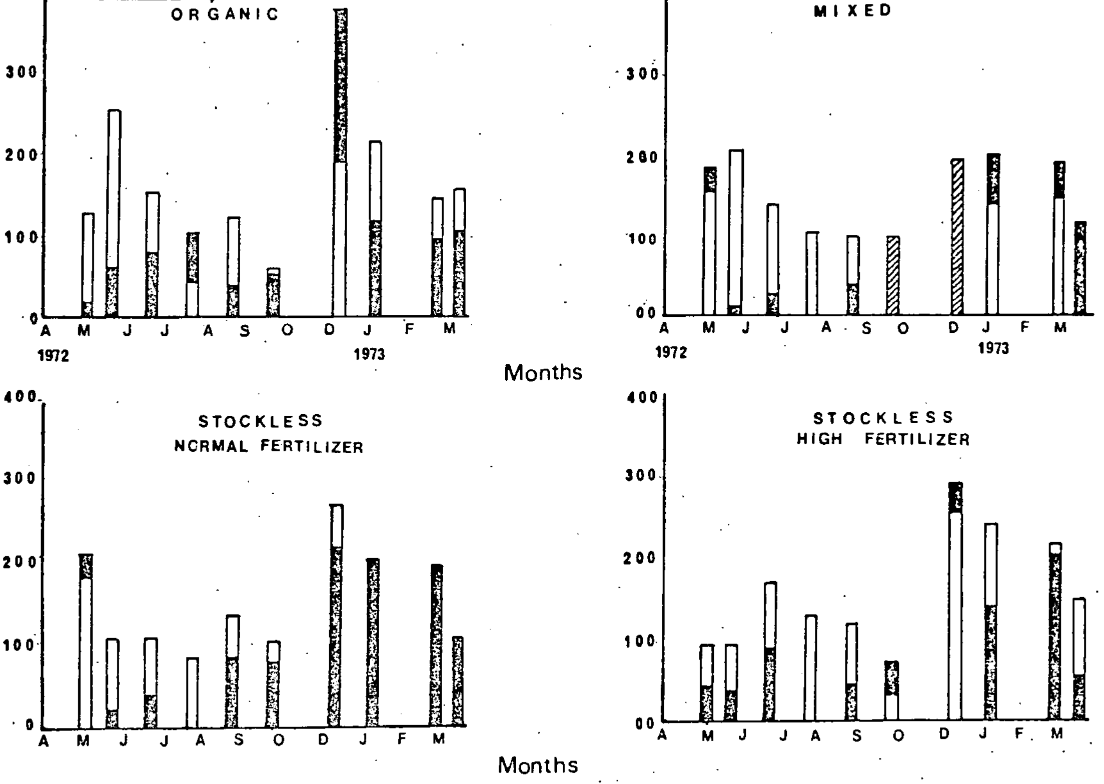
The Monthly Loss of Geochemicals in the Lysimeter Leachate Mgm/Shallow Lysimeter

Key: Cropped ▮ Fallow ▯ Equal ▨

NITRATE NITROGEN



ORGANIC NITROGEN

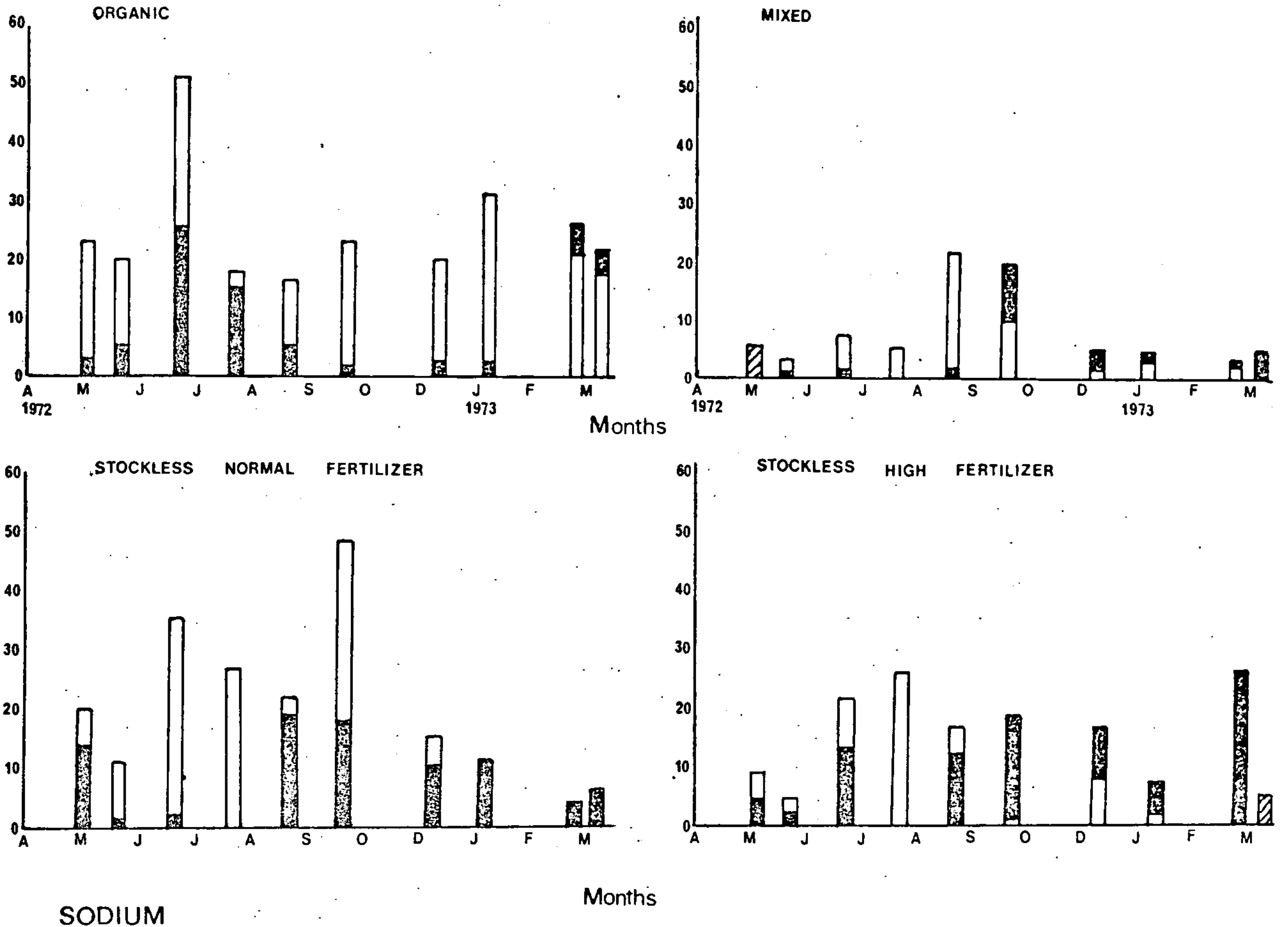


Graph 2 - 2

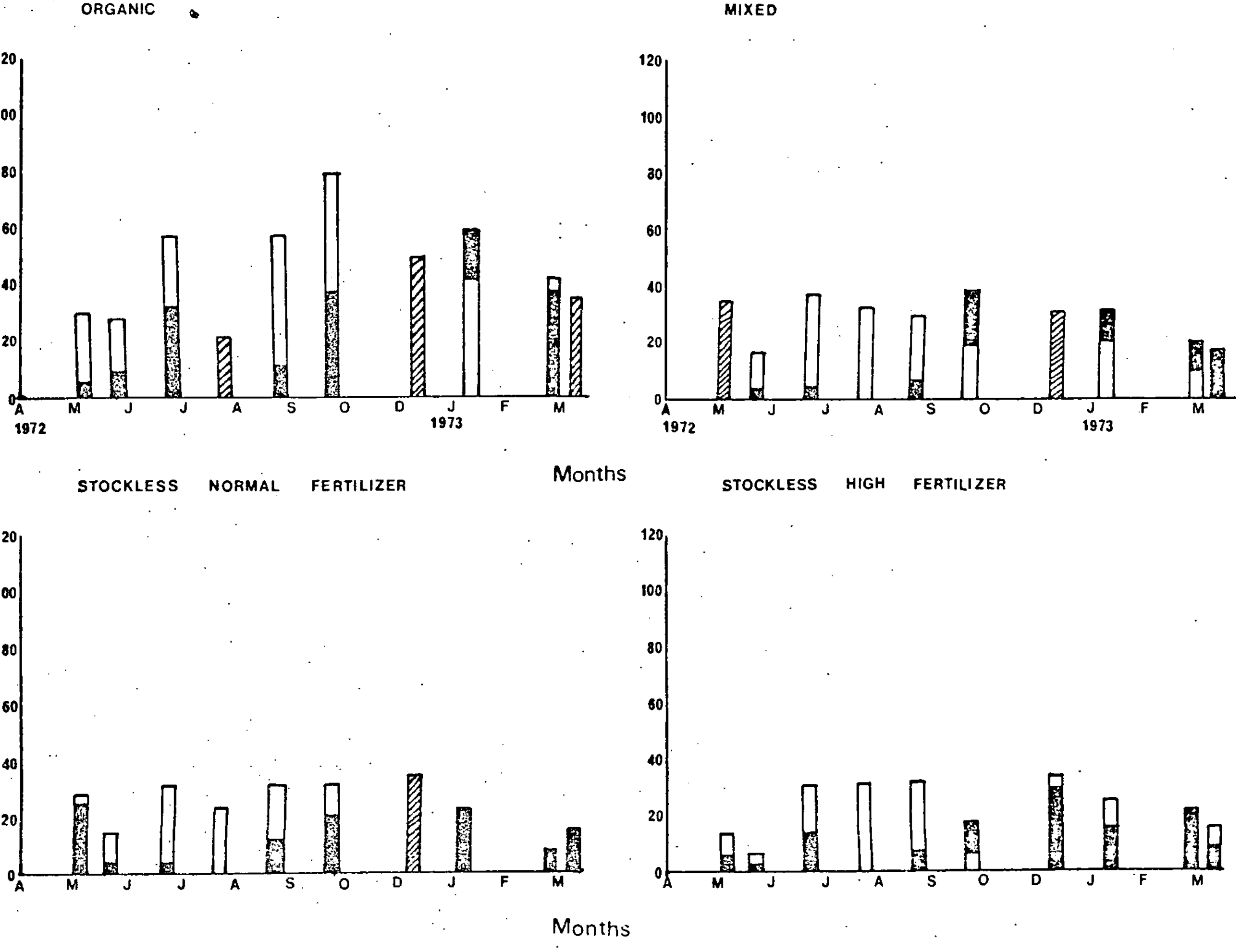
The Monthly Loss of Geochemicals in the Lysimeter Leachate Mgm/Shallow Lysimeter

Key: Cropped ▓ Fallow ☐ Equal ▨

POTASSIUM



SODIUM

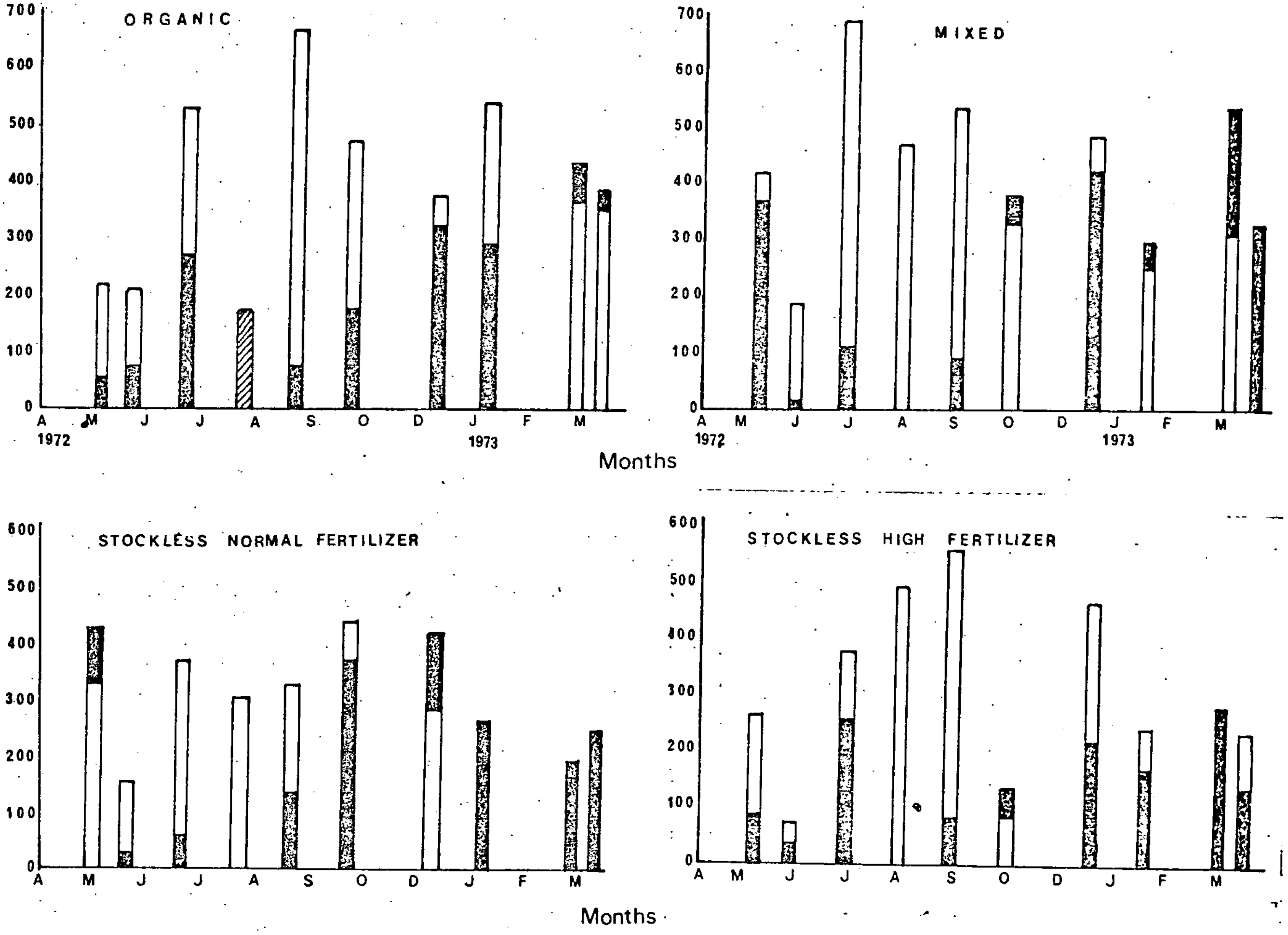


Graph 2-3

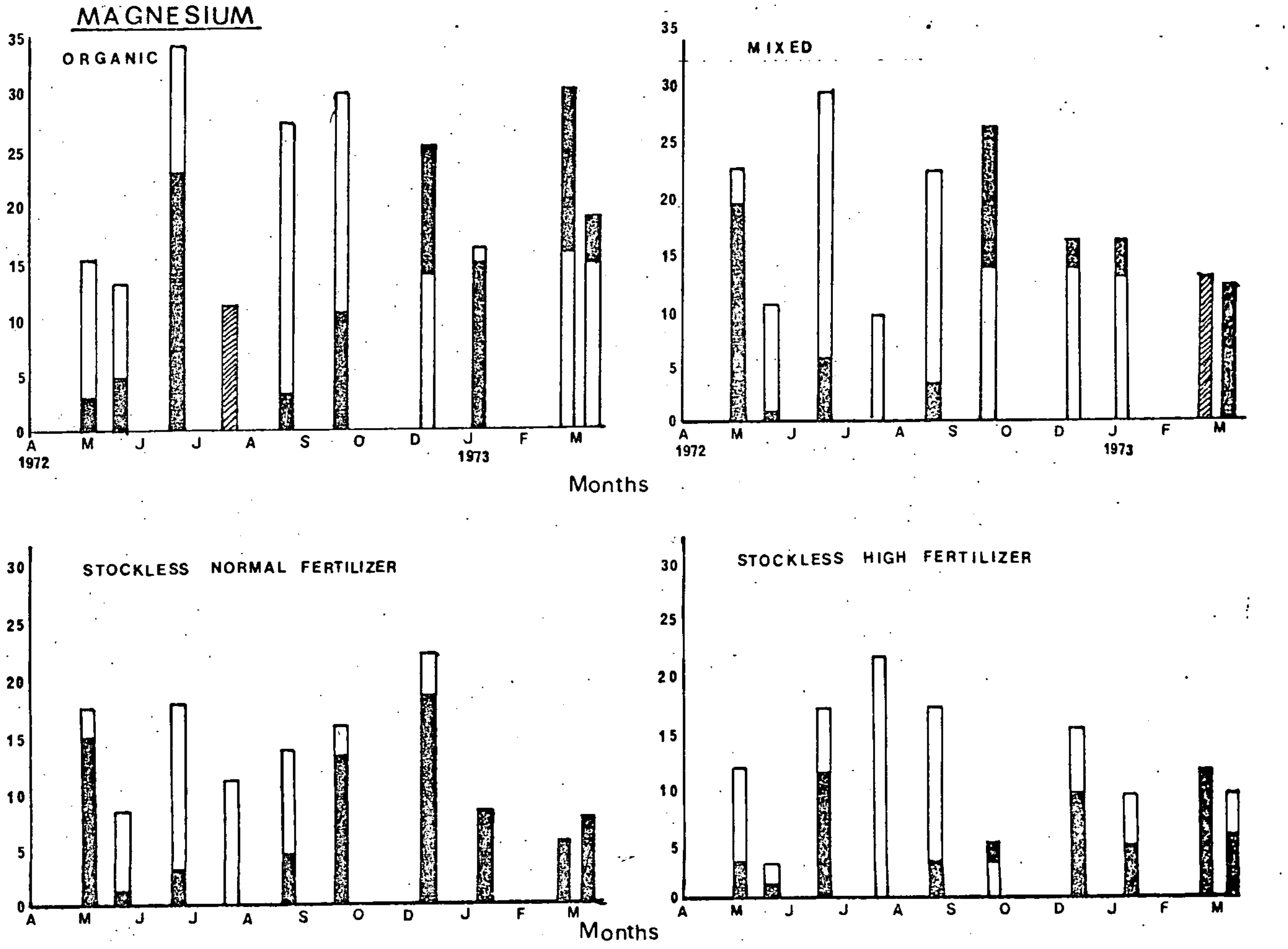
The Monthly Loss of Geochemicals in the Lysimeter Leachate Mgm/Shallow Lysimeter

Key: Cropped ▒ Fallow ▯ Equal ▨

CALCIUM



MAGNESIUM



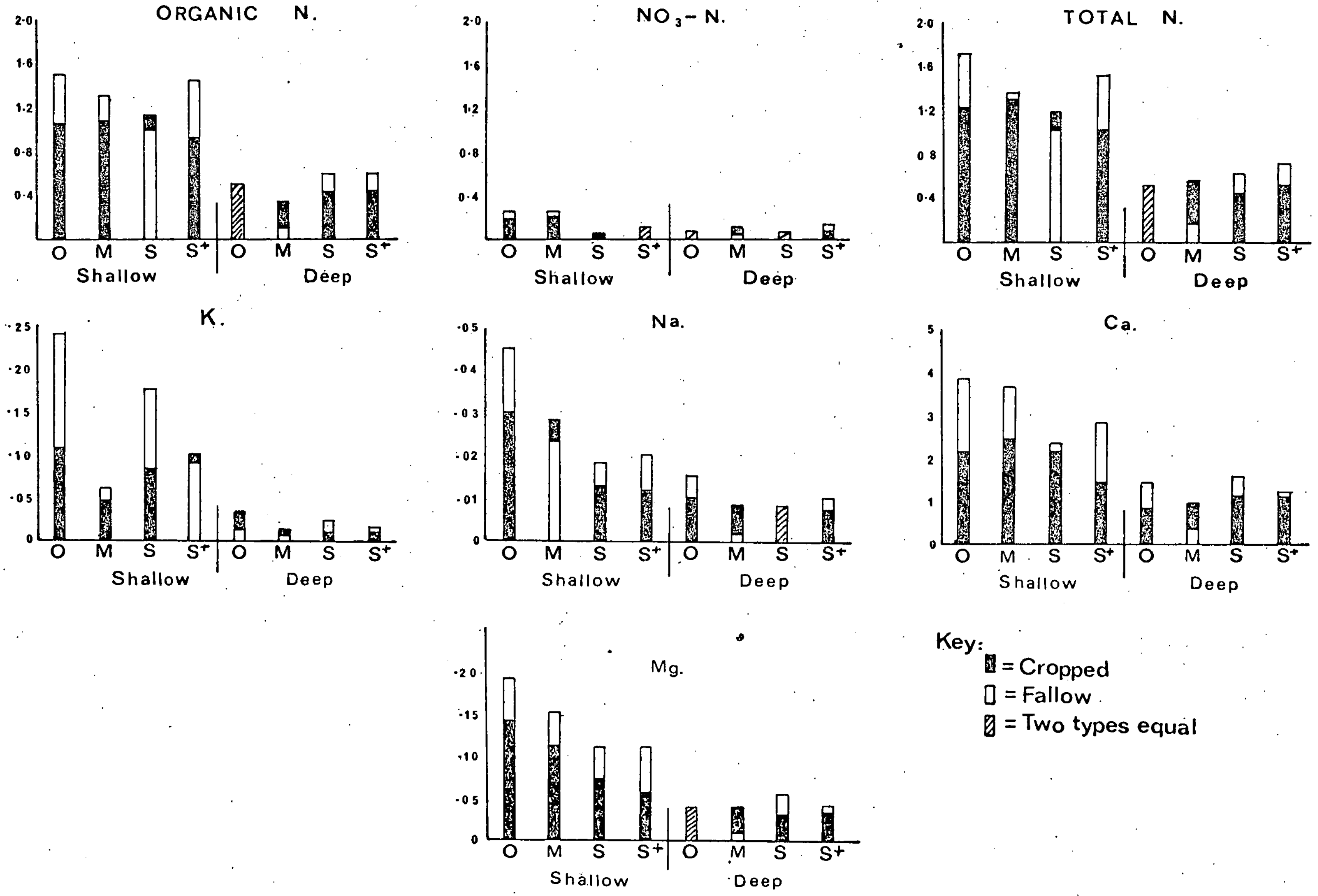
.2.2.3 The annual loss of geochemicals was significantly greater from the deep lysimeters on all treatments. This is evident from the Histogram 2-5 only, because the surface area of the deep lysimeters was but 1/13 that of the shallow containers. Despite the smaller surface area, and a total volume only 1/10 that of the shallow lysimeters, the loss of leachate volume proportional to the total rainfall available, was greater from the deep lysimeters than from the shallow. This was probably due to less evaporation per unit volume of soil, due to greater depths. It is suggested that the greater loss of ions observed was due to the inclusion of the lower soil horizons in the deep lysimeters, which were rich in several geochemicals due to geological layering, and where many geochemicals leached from the surface layers, previous to this experiment, may have been redeposited. The possession of these deeper layers would have thus enabled greater leaching losses to be recorded for the deep lysimeters, despite their smaller volume.

.2.2.4 The greatest leaching of the geochemicals was found from the fallow lysimeters where there had been no competition from plant uptake and no protection of the soil surface from the rainfall. The only exceptions to this rule were found where partial blockage of the outflow pipe caused waterlogging of the lysimeter, and restricted leachate volumes (M - deep, all geochemicals; S - shallow, organic nitrogen; S^+ - shallow, nitrate).

.2.2.5 The total annual loss of geochemicals, as shown in Histogram 2-4, 2-5 , demonstrates the following pattern, showing the effect of farm management to be complex :-

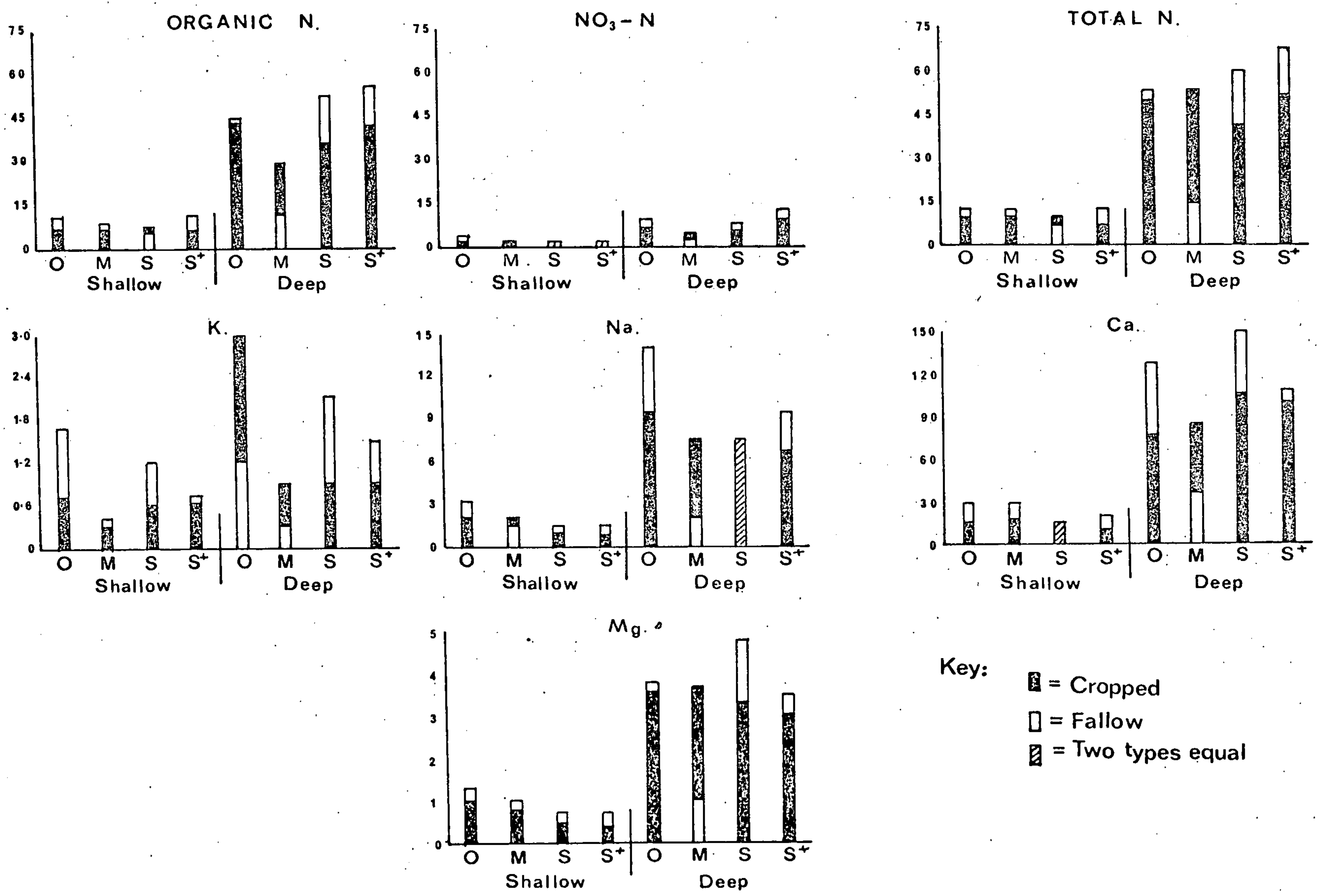
Graph 2–4

The Total Annual Loss of Geochemicals in the Lysimeter Leachate Gm/Lysimeter/year



Graph 2-5

The Total Annual Loss of Geochemicals in the Lysimeter Leachate. Kg/hectare/year



Summary Table	Lysimeter type			
Element	Shallow cropped	Shallow fallow	Deep cropped	Deep fallow
N	$S > M > 0 > S^+$	$0 > S^+ > M > S$	$0 > S^+ > S > M$	$S \equiv S^+ > 0 > M$
NO_3-N	$0 \equiv M > S^+ > S$	$M > 0 > S^+ > S$	$S^+ > S \equiv 0 > M$	$S^+ > 0 > S > M$
K	$0 > M > S^+ > M$	$0 > S > S^+ > M$	$0 > M \equiv S^+ \equiv S$	$S > S^+ > 0 > M$
Na	$0 > M > S > S^+$	$0 > M > S^+ > S$	$0 > S \equiv M > S^+$	$0 > S^+ > S > M$
Ca	$M > S > 0 > S^+$	$0 > M > S^+ > S$	$S > S^+ > M > 0$	$S > 0 > S^+ > M$
Mg	$0 > M > S > S^+$	$0 > M > S \equiv S^+$	$0 \equiv M \equiv S^+ > S$	$S > S^+ \equiv 0 > M$

From this summary table, several conclusions can be drawn :-

.2.2.5-1 In the shallow lysimeters where the ground was fallow, the greatest total annual loss of all the geochemicals, apart from nitrate, occurred on the Organic section, least being lost from the normal fertilizer treatment on the Stockless section. The loss of most elements from the Organic section even exceeded that from the high fertilizer treatment S^+. The total volume of leachate collected from this type of lysimeter showed that the relationship between the treatments was : $M > 0 > S^+ > S$ which exactly explained the relationship between treatments for the loss of nitrate-nitrogen. The differences in total leachate volumes also elucidated the relative losses from the Organic and Stockless treatments, which were $0 > S^+ > S$ for all geochemicals measured in the shallow fallow lysimeter leachate.

.2.2.5-2 In the deep fallow lysimeters least loss of geochemicals occurred on the Mixed section, whilst most was lost from the Stockless soil. This relationship can again be explained by considering the total leachate volume lost during the year which followed the pattern $S^+ > S > 0 > M$ (see Table 2-3).

.2.2.5-3 Where the lysimeters were cropped, the relationship between the losses from the different treatments is less easy to explain. From both the shallow and deep containers, the most potassium, sodium and magnesium was leached out of the Organic section, partly due to the geological layering previously mentioned, and partly due to the addition of geochemicals to the three sections in the manures and fertilizers, at the beginning of the season. If the relationship between the four treatments, for the initial addition of nutrients, is extracted from Table 1-3 in the Soils Section 1, the magnitude of loss from several lysimeter types can be explained. Thus, in the Spring of 1972, the addition of nutrients in manure and fertilizers to the lysimeters followed the pattern :-

N	$0 > S^{+} > S > M$	Ca	$0 > M > S \equiv S^{+}$
K	$S^{+} > 0 > M \equiv S$.	Mg	$0 > M \equiv S \equiv S^{+}$
Na	$0 > M \equiv S > S^{+}$		

These patterns correlated with the total annual loss of geochemicals from the lysimeters as follows :-

: N - Complete correlation deep cropped, partial correlation deep fallow S, S^{+} M
partial correlation shallow fallow 0 S^{+}, S

: Na, Mg - " " " shallow cropped, shallow fallow

: Ca - " shallow fallow lysimeter

There was no correlation shown between the rate of addition, and rate of loss of potassium, for any lysimeter type.

.2.2.5-4 The loss of most geochemicals through leaching was low from the shallow cropped lysimeter on the high fertilizer treatment, because of the small application of sodium, calcium and magnesium, coupled with a low total annual leachate volume $M \equiv S > 0 > S^{+}$.

.2.2.6 If the total quantity of each geochemical added to the lysimeters in the rainfall (Table 2-2(1)), during the period April 1972 to March 1973, is compared with the total quantity leached out during that time,(Table 2-6 and Histogram 2-4) it can be seen that for several geochemicals, on most management sections, there was a net gain over the year. If the supply of nutrients from the fertilizers and manures, and the loss of nutrients into the crop plants are ignored :-

: K and Mg - large net gain on all management sections and lysimeter types
: Na - " " " " " " " except on Organic in the deep fallow
: N and Ca - slight net gain on shallow cropped O, S, S^+, but no change on M
- " " " " " fallow M
- large net losses on shallow fallow O, S, S^+ and deep lysimeters on all sections.

The mean quantities lost and gained over the 12 month period are shown below (Kg/ha) :-

Element	Addition in rainfall	Loss, shallow lysimeters	Loss, deep lysimeters
N	10.3	10.0	48.0
K	8.5	0.8	1.5
Na	13.1	2.0	7.8
Ca	18.5	19.0	99.0
Mg	14.7	0.8	3.4

It is probable that the loss from the deep lysimeters was closer to the actual loss of geochemicals from the field drains over the year, than was that from the shallow containers, due to the inclusion of the lower soil layers which influence the composition of the percolate. It must be remembered that the concentrations of geochemicals lost in the deep lysimeter leachate and field drainage water mainly differed in the levels of nitrate (L > D) and sodium (D > L). In addition, D > L for potassium on the Stockless field. Thus the annual losses of geochemicals shown to occur from the deep lysimeters will probably be a slight underestimate for potassium and sodium, but may be equivalent to the field loss for nitrogen, (nitrate-nitrogen a very small proportion of the total) calcium and magnesium. In the absence of the field drainage volume data, it is suggested therefore that the annual loss of nitrogen and calcium from the fields would be greater than the addition in the rainfall, but that the loss of potassium and magnesium would have been less. The results for potassium, calcium and nitrogen agree with the research results of Low and Armitage (1970) who found that the rainfall supplied more potassium, but less calcium and nitrogen, than was lost by leaching. However, they also found that more magnesium was leached than was supplied in the rainfall, which disagreed with the results from Haughley. A full balance sheet, including all sources and sinks of these geochemicals in the farm ecosystem, is shown in the final Discussion at the end of the thesis.

.2.2.7 The losses of geochemicals estimated in terms of Kilogrammes lost/hectare of land, which are reported in the literature, vary over a very broad range, as do their concentrations (previously described). Again, most information concerns the loss of nitrogen, for which the range of loss reported is 11 - 186 Kg N/ha/year.

.2.2.7-1 The losses tend to be greater from fertilized fallow land than from areas cropped, except where the crop concerned is a legume which supplies nitrogen to the soil through symbiotic nitrogen fixation. (*Vicia faba* at Haughley fixed 120-520 Kg N/ha/year depending on the farm management section used. See main Discussion for inclusion of this nitrogen source into an overall balance sheet at Haughley.) A considerable amount of nitrogen is lost by leaching, even from unfertilized land, due to the mineralization of nitrogen held in the organic matter. Thus :-

Land use		KgN lost /ha/year	Source
Unfertilized fallow arable soil		17 - 20	Lawes *et al.* (1882)
		25	Kolenbrander (1972)
		34	Allison *et al.* (1955)
		38	Hall and Russell (1919)
Normal fertilizer application Fallow :		68 - 78	Lawes *et al.* (1882)
		89	Low and Armitage (1970)
Normal fertilizer application Cropped :		33	Kolenbrander (1972)
		13 - 111	Johnston *et al.* (1965)
	legume :	30 - 130	Tomlinson (1971)
	legume :	43 - 186	Sylvester (1961)

Thus the mean loss of 49 KgN/ha/yr observed from the deep lysimeters, which is suggested to be the probable mean loss of nitrogen from the three farm sections at Haughley, was well within the range reported in the literature.

.2.2.7-2 The loss of phosphorus at Haughley was not calculable due to the absence of the element in the lysimeter leachate, and the absence of volumetric data on the loss of drainage water from the drains.

.2.2.7-3 The mean loss of potassium at Haughley which was suggested to be slightly underestimated by the loss from the deep lysimeters, of 1.5 Kg/ha, falls very near to the range of losses expected by Low and Armitage (1970) of 2.0 - 8.0 Kg/ha, which is still below the level of the potassium supplied in the rainfall.

.2.2.7-4 The only reference to the loss of calcium from a farm system was again found to be in the paper by Low and Armitage (1970), who found 58 - 112 Kg/ha/yr to be leached out from fallow ground, but only 15/Kg/ha/yr from beneath clover. Thus the quantity leached from the deep lysimeters at Haughley of 99 Kg/ha/yr was by no means excessive.

.2.2.8 The magnitude of the relative losses of the geochemicals from the field systems at Haughley followed the pattern Ca > N > Na > Mg > K > P which corresponds fairly closely to the relative addition of geochemicals in the rainfall Ca > Na > Mg > N > K > P. All the investigators who have reported upon the relative losses of these geochemicals from the farm soils have shown this pattern to exist :-

e.g.	Lawes _et_ _al_. (1882)	Ca > Na > N > Mg > K > P
	Kohnke and Dreibelbis (1940)	Ca > Mg > K > Na
	Dreibelbis (1946)	Ca > Mg > K > P
	Kilmer _et_ _al_. (1944)	Ca > Mg > K > P
	Bolton _et_ _al_. (1970)	Ca > Mg > N > K > P

Despite slight variations of the pattern, the greatest loss is always that of calcium, and least leaching loss of potassium and phosphorus. This tends to confirm the suggestion made at the beginning of the Water Chemistry section, that very little phosphate in the rivers is likely to have originated from agricultural land.

.2.2.9 The months when the maximum loss of geochemicals occurred were drawn up into a table to be compared with that for the months of maximum geochemical concentrations in the lysimeter leachate. In the table, all managements are grouped together where possible, thus it shows the degree of similarity/difference of the effect of the management type upon the leaching loss :-

(The asterisks * indicate the points at which the maximum loss, correlated with the maximum leachate concentration, for each geochemical considered.)

Element	Lysimeter type			
	Shallow cropped	Shallow fallow	Deep cropped	Deep fallow
Org N	Sep-Jan	O,M *May	Sep-Dec	Sep-Dec
		S,S$^+$ Sep-Dec		
NO_3-N	O,M *Sep-Dec	*May-Aug	*Sep-Dec	Sep-Dec
	S,S$^+$*May-June			
K	O,S$^+$*Jan-Feb	O,S$^+$*June-July	O,S$^+$ Sep-Dec	O,S$^+$ Sep-Dec
	M,S *Aug-Sep	M,S *Aug-Sep	M,S Sep-Feb	M,S Jan-Feb
Na	O,S,S$^+$ Sep-Jan	O,S,S$^+$ Sep-Dec	Sep-Dec	O,S,S$^+$ Aug-Dec
	M Aug-Sep	M June		M (July)
Ca	O,M,S$^+$ Jan-Feb	*June-Sep	*O,M,S$^+$ Jan-Feb	Sep-Dec
	S May		S *Sep-Dec	
Mg	O,S$^+$ Jan-Feb	O,M *June	O *June	O Sep-Dec
	M,S Sep-Dec	S *Sep-Dec	M,S *Sep-Dec	M,S$^+$ *June-July
		S$^+$ Aug-Sep	S$^+$ Jan-Feb	S *Aug-Sep

.2.2.9-1 Although the farm management and lysimeter type did modify the date of maximum loss by leaching of some geochemicals, most leaching occurred during September-December. During that time the deep lysimeters showed maximum volume of leachate on all management sections (except for M which had become permanently blocked), but generally low concentrations of geochemicals in the water. Although the leachate volumes from the shallow lysimeters were also high at that time, they were not at their maximum. This timing of maximum loss correlates to a much better degree with the total rainfall,which was at the highest in the Autumn months concerned. In the cropped lysimeters the soil was disturbed in September during the harvesting of the *Vicia faba* plants, and the flow of nutrients in these soils would then be reversed downwards by the Autumn rains.

.2.2.9-2 Where the soil was fallow, and the lysimeters shallow, the loss of several geochemicals was at a maximum during the Summer months May-August, during the second highest rainfall period of the year. This period was also the time of high outflow of leachate volume, and high concentrations of geochemicals in the water (see asterisks). However the flow from the deep fallow lysimeters was low during that time, due to the longer period of time required to percolate through the less pervious deeper soil layers, and the maximum loss of geochemicals was delayed until September-December.

.9-3 Where the soil was cropped, the maximum leaching of most geochemicals occurred after harvest, except for the rapid removal of nitrate-nitrogen from the fertilized plots on the Stockless field in May. However in the deep lysimeters S and S^+ this maximum loss was again delayed until the period of heaviest rainfall, and high volume of leachate (Sep-Dec).

.9-4 Where fertilizer had been applied, potassium leached out from the M and S sections during August-September despite low rainfall, correlating with high concentrations of this element in the water, but this did not occur on the treatments of O and S^+. This can be explained by the much lower leachate volumes from the latter two treatments.

.9-5 The number of geochemicals for which the individual management letters (O M S S^+) are listed on the table indicates that for most lysimeter types there was a dependence upon the farm management type, for the timing of the maximum leaching loss.

.9-6 The lack of asterisks (except on the shallow fallow lysimeter column) shows that for most geochemicals and lysimeter types, the maximum loss occurred at the time of maximum rainfall and leachate volume outflow, not when the concentration in the leachate was at a maximum.

2:7 Overall Conclusions

:7.1 The total annual loss of nutrients from the farm systems at Haughley was shown to depend upon soil use and depth considered, rainfall volume, volume of drainage water, the form and quantity of nutrients applied to the soil at the beginning of the season, and the concentration of geochemicals in the water outflow.

:7.2 The outflow of most nutrients tended to be greater from the land supplied with organic manures than where artificial fertilizers alone were supplied, as shown by the higher concentrations in the drainage from Organic lysimeters and Mixed fields. As was found by this research, Lawes et al. (1882) demonstrated that the application of farmyard manures caused high losses of nitrate throughout the year in the drainage water, and Williams (1970), that farmyard manure supplied more nitrate to the ground water system than did inorganic fertilizers. However Kolenbrander (1972) showed that because more than twice as much nitrogen must be supplied to a farm system in organic manures,as given in inorganic fertilizer form, to give the same crop yield, for a given rate of nitrogen in Kg/ha, farmyard manures actually leached out less nitrogen than from the fertilizers, corroborating the evidence of Raney (1960). If the relative additions and losses of nitrogen at Haughley are compared, it is seen that the total amount of nitrogen supplied to the Organic section lysimeters was 10 times that applied in the normal fertilizer rate on the Stockless section, and 5 times that applied to the high fertilizer treatment. Despite this, the total annual loss of nitrogen was actually slightly greater from both fallow and cropped lysimeters on both the Stockless treatments, because of the dependence of annual loss upon drainage flow rate rather than upon the concentrations of nitrogen in drainage water alone. Thus, considered on a "per unit of nitrogen supplied basis", organic manures pose less of a threat to the nitrogen eutrophication of ground waters than artificial fertilizers, but when manures are applied in quantities of up to 25,000 Kg manure/ hectare it is likely that this relationship will be reversed.

:7.3 No evidence was found from any of the farm management sections at Haughley of levels of nitrate nitrogen which even approached the WHO limit of 11.3 mg NO_3-N/1. McCarthy *et al.* (1967) stated that in their view the greater use of fertilizer was contributing greatly to the changes of nitrogen and phosphorus levels in surface water supplies, yet Tomlinson (1970), in his survey of eighteen river systems in Britain, showed that during the period of 1953-1967 there had been no increase in the concentration of nitrates, despite a four-fold increase in the use of nitrogen fertilizer during that time. From the results of this study it is concluded that the agricultural contribution to the eutrophication of rivers by phosphorus is negligible, and that despite the use of high levels of artificial fertilizers, which leach more nitrogen per unit nitrogen applied than do organic manures, the quantities of nitrogen lost do not alone account for the high levels of nitrates in some rivers in the south of England.

:7.4 Despite the limitations of lysimetry, Kolenbrander (1972) demonstrated a close correlation between the losses from lysimeters on clay arable land in the Netherlands,with the discharge of nitrogen into the river system (33 Kg N/ha/yr). The results described for the total annual loss of nutrients at Haughley correspond well with the findings of other research workers, using both lysimetry and tile drainage systems, as quoted in the literature, especially from the deep containers where the soil depth was roughly equivalent to that served by the field drains. The results showed that more potassium, magnesium and sodium were added to the soil in the rainfall than was lost from the fields in the leachate, even where large quantities of potassium fertilizer had been applied in the Spring. Thus the atmosphere contributes more of these three elements to the river systems in the rainfall, than is likely to be lost from the most intensive arable agricultural system. This conclusion was reached despite the findings of White _et al_. (1971) which suggested that 50-75% of the ions entering the soil from the atmosphere did so as a dry deposit, and therefore the addition of nutrients to the soil system in the rainfall was only a small fraction of the total.

SECTION 3. ANALYSIS OF CROP GROWTH

Section 3. ANALYSIS OF CROP GROWTH

3:1 Introduction

:1.1 During the first twenty years of this century many people researching into the growth of plants were attempting to define the observed progression of development in mathematical terms, in order that the growth and yield under different treatments could be accurately compared. Many of the formulae so produced included ambiguous variables associated with the influence of the immediate environment, or with the different stages in the life of the plant (Gressler 1907; Robertson 1908; Balls and Holton 1915; Reed and Holland 1919; Mitscherlich 1919). In all these papers, measurements of dry weight, shoot length, leaf area, leaf weight, and seed yield weight were used as standard parameters, but the relationships between them were expressed in different ways. In 1919 Blackman likened the growth of an annual plant to the mechanisms of compound interest, whereby the increase in dry weight during any interval of time was added to the "capital" for further increase by growth in later life. He suggested that the production of dry matter by a plant will be totally dependent upon the initial weight of the seed and the length of the growing period, and that comparative investigations should be made on this basis.

:1.2 The most important advances in the standardization of the quantitative analysis of plant growth were made by Briggs, Kidd and West (1920). They stated that the comparison of plant growth on different treatments should be made, using the relative growth rate (RGR), which they defined as the increase in dry weight, per unit dry weight, per unit of time. This was an expression of the efficiency of the plant to produce dry matter and they recognised that this would be affected by light intensity, temperature, and the mineral and water supply to the plant. As 80-90% of the dry weight increase was determined to be due to the accumulation of carbon compounds, through photosynthesis, they further suggested that the rate of assimilation per unit dry weight would be a function of the amount of leaf area per unit dry weight.

:1.3 The relative growth rate is the result of a complex integration of metabolic reactions and therefore in itself it has no direct physiological significance, but it can be resolved into two components :-

(1) Unit Leaf Rate - increase in dry weight of the plant per unit of leaf area. This was defined as the Net Assimilation Rate by Gregory (1917) and this name is adopted here.

NAR = Net Assimilation Rate = $1/A \,.\, dW/dt$ where A = leaf area t = time

W = dry weight of plant

(2) Leaf Area Ratio - the fraction of the plant responsible for producing new material.

LAR = Leaf Area Ratio = A/W

These two expressions together form the index of relative growth rate :

LAR x NAR = RGR or $A/W \times 1/A \,.\, dW/dt = 1/W \,.\, dW/dt$

Thus a concept for comparing the growth of plants under different treatments by the use of an expression which was relevant to the whole growth period had been determined. By the use of the easily measured parameters - leaf area and dry weight - recorded upon a number of occasions during a set growth period, accurate statistical analysis could be utilized, to determine where significant differences in the growth of plants had occurred.

:1.4 Subsequently many results of work performed before 1920, which it had not been possible to analyse accurately, were subjected to comparison, using the calculated relative growth rate (Ballard and Petrie 1936).

Extensive research has since been completed, which was based from the start upon the Briggs et al. (1920) concept, particularly for elucidating the response of crop plants to various agricultural conditions - Williams (1936), who studied the variation in growth indices as affected by the supply of phosphorus - Watson (1947) who investigated the effect of temperature upon Net Assimilation Rate - Blackman and Wilson (1951) who studied the relationship between NAR and light intensity, to demonstrate the effect of shading in the growth of arable crops.

:1.5 Most studies which have used the three standard growth indices have required the use of large batch samples of plants in order to allow statistical treatment of the data collected on each sampling occasion. In 1967 Hughes and Freeman published the results of a growth study in which the emphasis was placed upon the entire growing season. A computer was employed to derive the standard growth indices by a regression of results, using frequent harvests of very small numbers of replicate plants within each sample. This enabled the consideration of a large number of treatments simultaneously, by avoiding very time-consuming measurement of large batch samples, and it served to reduce the amount of information at risk upon any one harvest occasion. Because of the limited time and labour available for the study of the growth of *Vicia faba* plants at Haughley, the Hughes and Freeman approach was adopted in this study, both in the greenhouse experiment and in the field trials. The method involved is described in greater detail below.

3:2 Method of Growth Analysis

:2.1 The primary data required for this method are those described earlier : leaf area, total plant dry weight and times of harvesting. As plants increase in size, so does their absolute variability, but transformation of the primary data to logarithmic form renders the variability more nearly homogeneous with time. The polynomial regression of sufficient fit to the logarithms of total dry weight and leaf area on time is determined by the Least Squares method - this makes the sum of the squares of the discrepancies between the observed and fitted values as small as possible. A cubic is considered to be adequate for both weight and leaf area, so that two equations are derived :-

$$\mathrm{Log}_e\ W = a + bt + ct^2 + dt^3$$

$$\mathrm{Log}_e\ A = e + ft + gt^2 + ht^3$$

where W = dry weight

A = leaf area

t = time

:2.2 The progress curves of the relative growth rate, leaf area ratio and net assimilation rate are obtained by differentiation of the regression equations above, according to the classical formulae shown in 3:1, thus :-

$$\mathrm{RGR} = \frac{d(\mathrm{Log}_e\ W)}{dt}$$

$$\mathrm{LAR} = \mathrm{antilog}_e\ (\mathrm{Log}_e\ A - \mathrm{Log}_e\ W)$$

$$\mathrm{NAR} = \frac{d(\mathrm{Log}_e\ W)/dt}{\mathrm{antilog}_e\ (\mathrm{Log}_e\ A - \mathrm{Log}_e\ W)}$$

Thus the derived data obtained are in the form of smooth curves fitted over the whole of the growth period, instead of mean values for periods between pairs of sampling occasions, as produced by earlier methods. Interpretation of the results is aided by comparing the fitted values with the observed values, and by using an estimate of error for all the fitted values. The standard errors of the items in the regression equation, and of the calculated values derived from them, are estimated from the residual sum of the squares after removal of the sum of squares due to the linear, quadratic and cubic terms.

:2.3 The computer programme supplied by Hughes and Freeman had been written in Algol 14 for use on an Elliot computer, but the Fortran form supplied by Dr Thornley of the National Vegetable Research Station was used after slight modification, in the IBM360 computer in Durham. In the original paper it was stated that this method had been designed for experiments in controlled environments, but that the system was also applicable to glasshouse and outdoor investigations. Dr Hughes kindly agreed to run a check on the results from the data of this project, through the computer at Reading, but unfortunately he died before this could be completed.

:2.4 The computer converts the dry weights and leaf areas of the individual plants harvested to natural logarithms and arranges the harvesting times in ascending order. The final computer printout reads :

:2.4.1 Equations for Log$_e$W and Log$_e$ A, standard errors of constant terms and of linear, quadratic and cubic coefficients; partition of variance and covariance into linear, quadratic, cubic, between-sample residual and within-sample components.

.4.2 Log$_e$ W observed, mean fitted Log$_e$ W and S.E. of fitted value

.4.3 Log$_e$ A " " " Log$_e$ A " " " " "

.4.4 For each harvesting time, the mean fitted value of RGR and its S.E.

.4.5 " " " " " " " " " " LAR " " "

.4.6 " " " " " " " " " " NAR " " "

:2.5 The form of computation allows the number of plants taken per sample, or the interval between harvests to be altered within any individual treatment, without alteration of the programme being necessary. It is suggested that three plants per sample are adequate for the described method, although this means that the standard error for the sample at any one time will then be much larger than would be expected by the older batch-harvesting methods. Hughes and Freeman suggest that this loss of accuracy at each point during the growing season is more than compensated for by the increase in the number of treatments, and harvesting times, which can be encompassed by this method.

3:3 An assessment of the effect of farm management upon the growth of *Vicia faba*

3:3.1 Background

At the beginning of the Haughley Experiment a single seed type for each crop was sown upon all three farm management sections. Throughout the following thirty year period, prior to this research study, the seed for each crop, grown within each farm section, was derived entirely from the seed produced on the same section the previous year. Thus three sets of seed, of type O, M and S were available for each crop grown on the Haughley Farm. The process of growing crops, from seed produced previously on the same farm management section is here called imprinting, and hence the three seed groups produced (O, M, S) are called imprint types. The variety of *Vicia faba* which had been subjected to imprinting for thirty years was Tic. In 1970, due to the increasing susceptibility of this variety to Chocolate Spot (*Botrytis* spp), a modern commercial variety (Throws) was introduced, which is less susceptible to fungal attack and has less tendency to lodge. Thus at the beginning of this study, two varieties of *Vicia faba* were available as phytometers, to assess the effect of farm management; Tic, which had been imprinted every year for thirty years, and Throws, which had been imprinted for a single year.

:3.2 Aim

.2.1 To determine whether the imprinting of the *Vicia faba* (Tic and Throws varieties) had caused any physiological differences to be evolved in the seeds, causing in turn the development of a dependence of each type upon the farm management section from which it originated.

.2.2 To determine whether more differences had evolved in the Tic (compared to the Throws) variety, due to a longer imprinting period.

.2.3 To determine the effect of the farm management upon the growth and yield of *Vicia faba*.

:3.3 Experiments

The experiments conducted to fulfil the aims of the research study are described and discussed separately below. The overall plan of experiments can be seen on the flow diagram.

:3.4 An investigation of the *Vicia faba* seeds produced at Haughley

:3.4.1 Seed weight 300 Tic bean seeds and 150 Throws seeds of each imprint type were selected at random from the Haughley store. One third of the total number of each type was used to determine each of - the dry weight (after drying at 105°C for 24 hours) - the fresh weight (as stored) and the imbibed weight(after soaking in distilled water for 48 hours and blotting off).

Results

The results showing the mean weight of each imprint type, with standard deviation and standard error, are presented on Table 3-1, together with the results of the statistical comparisons between the imprint types.

Where differences between imprint types occurred, the most significant trends for both varieties were according to the pattern S > M > O. Thus in all three categories of moisture content measured, the seeds produced on the Stockless section (despite longer storage) were the heaviest. Although the Throws seeds had only experienced one season of imprinting, this variety showed more consistent differences between the imprint types than did the Tic variety.

The colour of the Throws seeds from the three sections was identical, but for the Tic variety the O seeds were yellow, the M seeds brown, and the S seeds dark red. This difference was later shown to be entirely due to different storage times - the colour darkens with age.

Table 3-1

Characteristics of the dry, fresh and imbibed weights of the *Vicia faba* seed produced at Haughley (Weights expressed in grammes)

SD = Standard deviation SE = Standard error

Seed Type	Dry weight			Fresh weight			Imbibed weight		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
Tic O	0.615	0.135	0.014	0.692	0.159	0.016	1.265	0.266	0.027
M	0.560	0.121	0.012	0.717	0.140	0.014	1.314	0.228	0.023
S	0.659	0.146	0.014	0.754	0.127	0.013	1.285	0.240	0.024
Throws O	0.238	0.035	0.005	0.275	0.028	0.004	0.560	0.054	0.017
M	0.260	0.028	0.004	0.313	0.042	0.006	0.608	0.027	0.009
S	0.277	0.064	0.009	0.341	0.035	0.005	0.663	0.086	0.027

Moisture content of bean seeds as stored

(percentage of fresh weight)

Tic O	11.1%	Throws O	13.5%
M	21.9%	M	16.9%
S	12.6%	S	18.8%

Statistical comparison of seed imprint weights

Seed Type

Tic	Df	d	p	R	Df	d	p	R	Df	d	p	R
O - M	197.0	3.06	<0.01	O > M	197.6	1.19	>0.1	NS	192.6	1.40	>0.1	NS
O - 2	195.5	2.22	<0.05	S > O	193.0	2.82	<0.01	S > O	198.2	0.56	>0.1	NS
M - S	192.1	5.21	<0.001	S > M	194.5	1.95	>0.05	NS	198.1	0.88	>0.1	NS
Throws												
O - M	94.4	3.67	<0.001	M > O	73.8	5.43	<0.001	M > O	64.5	5.33	<0.001	M > O
O - S	75.8	3.90	<0.001	S > O	98.2	11.00	<0.001	S > O	81.4	7.36	<0.001	S > O
M - S	67.5	1.72	>0.05	NS	87.5	3.50	<0.001	S > M	57.0	4.23	<0.001	S > M

:3.4.2 Seed germination and ecesis

Method

A comparison of the rate of germination of the O, M and S Tic seeds was made, using (1) moist filter papers in Petri dishes in the laboratory, and (2) soil from the top 15 cms of the fields of the Organic and Stockless section farms, in flower pots in the greenhouse. The seedling performance (ecesis) during the first week in the pots was investigated. In addition, the effect of three concentrations of potassium nitrate upon germination in the Petri dishes was determined.

A number of seeds of each type were randomly selected from the store and were imbibed in distilled water for 48 hours. Ten bean seeds were placed on a moist filter paper in a Petri dish, which was kept in the dark, at room temperature for a week. Ten replicate dishes of each imprint type were made, and 5 mls of distilled water were added to the dishes once every two days. A further ten replicates of each imprint type were made for each of the three concentrations of potassium nitrate solution. The imbibed seeds were placed at the rate of three seeds per 10 cm diameter flower pot, on the surface of soil from the Organic and Stockless sections, with nine replicates per seed type on each soil. The pots were covered with black polythene sheeting in a greenhouse and were watered with distilled water every second day. All these treatments were examined daily, when the percentage germination, and the lengths of the radicle and plumule, were recorded.

Results

The results are presented in Table 3-2 and are drawn on Graphs 3-1, 3-2 and 3-3.

Table 3-2(1)

The germination of *Vicia faba* seeds

(1) Germination in Water - % germination (%G). Mean plumule (P) and radicle (R) lengths in millimetres, with standard errors

Seed Type	Tic O			Tic M			Tic S		
Time (days)	%G	R	P	%G	R	P	%G	R	P
1	77.0	2.0±0.1	-	68.0	5.0±0.2	-	6.0	-	-
2	98.5	6.0±0.2	-	95.5	6.0±0.2	-	42.0	4.0±0.3	-
3	99.5	11.0±0.5	-	98.5	9.0±0.6	-	74.5	5.0±0.3	-
4	99.5	17.0±0.8	7.0±0.7	98.5	12.0±0.6	6.0±0.5	78.0	6.0±0.3	-
5	99.5	21.0±0.9	12.0±0.6	98.5	16.0±1.3	9.0±0.7	81.0	7.0±0.6	-
6	99.5	23.0±1.0	15.0±2.0	98.5	18.0±1.1	11.0±1.2	81.0	8.0±0.4	2.0±0.4
7	99.5	28.0±1.0	19.0±1.0	98.5	20.0±1.7	13.0±1.4	81.0	9.0±0.4	3.0±0.4

(2) Germination in Potassium nitrate

Seed Type	Tic O			Tic M			Tic S		
Time and Treatment	%G	R	P	%G	R	P	%G	R	P
2 days									
Water	98.5	6.0±0.2	-	95.5	6.0±0.2	-	42.0	4.0±0.2	-
0.1% KNO_3	93.0	4.0±0.1	-	98.0	4.0±0.1	-	13.0	2.0±0.1	-
1.0% "	90.0	3.0±0.2	-	95.0	3.0±0.1	-	15.0	2.0±0.1	-
10.0% "	3.0	0.0	-	10.0	1.0±0.1	-	3.0	0.0	-
4 days									
Water	99.5	17.0±0.8	8.0±1.3	98.5	14.0±2.2	6.0±1.1	78.0	6.0±0.7	-
0.1% KNO_3	100.0	12.0±1.6	6.0±1.9	100.0	11.0±1.3	3.0±0.7	60.0	5.0±0.8	-
1.0% "	100.0	13.0±1.4	6.0±1.9	95.0	11.0±0.8	3.0±0.9	68.0	7.0±0.9	-
10.0% "	5.0	0.0	-	13.0	4.0±0.6	-	3.0	0.0	-

Table 3-2(2)

The germination of *Vicia faba* seeds

(3) Germination in soil

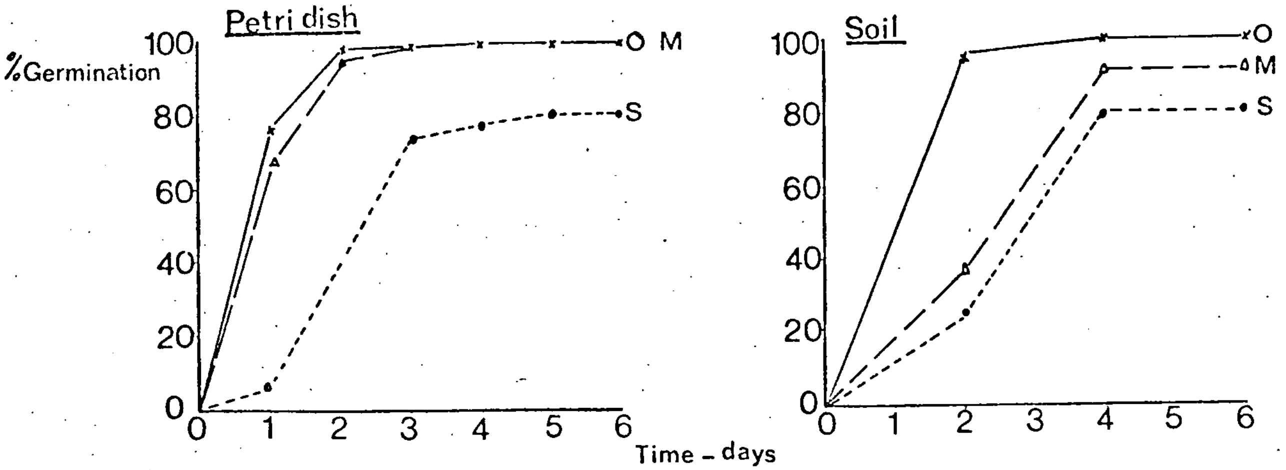
Seed type	Tic O			Tic M			Tic S		
Time (days) and Soil type	%G	R	P	%G	R	P	%G	R	P
O Soil									
2	96.0	4.8±0.5	-	96.0	5.0±0.6	-	37.0	1.6±0.3	-
4	100.0	48.0±5.0	13.0±2.0	100.0	32.0±5.0	10.0±3.0	92.0	17.0±4.0	-
6	100.0	96.0±6.0	42.0±4.0	100.0	78.0±7.0	37.0±4.0	92.0	19.0±4.0	20.0±3.0
S Soil									
2	96.0	7.0±0.6	-	96.0	5.1±0.5	-	26.0	1.9±0.5	-
4	100.0	50.0±5.0	11.0±3.0	100.0	40.0±6.0	9.0±2.0	81.0	20.0±3.0	-
6	100.0	102.0±8.0	37.0±4.5	100.0	88.0±8.0	30.0±3.0	81.0	21.0±3.0	14.0±3.0

(4) Dry weight of 7 day seedlings (weight in grammes)

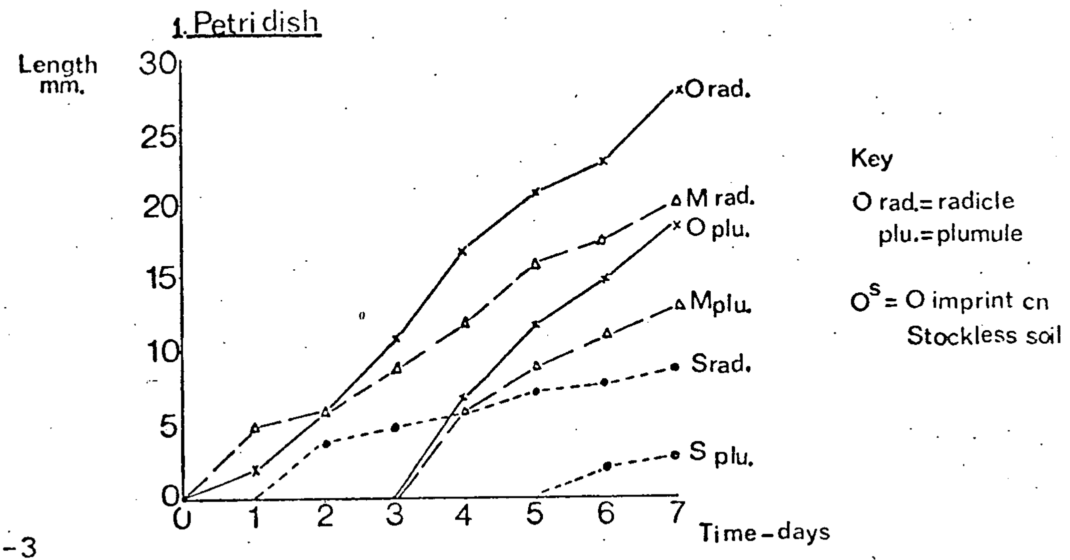
Seed type	Tic O		Tic M		Tic S	
Substrate	Dry wt. seedling	Wt. change in 7 days	Dry wt. seedling	Wt. change in 7 days	Dry wt. seedling	Wt. change in 7 days
Water	0.696	+0.081	0.652	+0.092	0.613	-0.046
O soil	0.543	-0.072	0.549	-0.011	0.680	+0.021
S soil	0.491	-0.124	0.524	-0.036	0.612	-0.047

Seed Germination and Early Growth

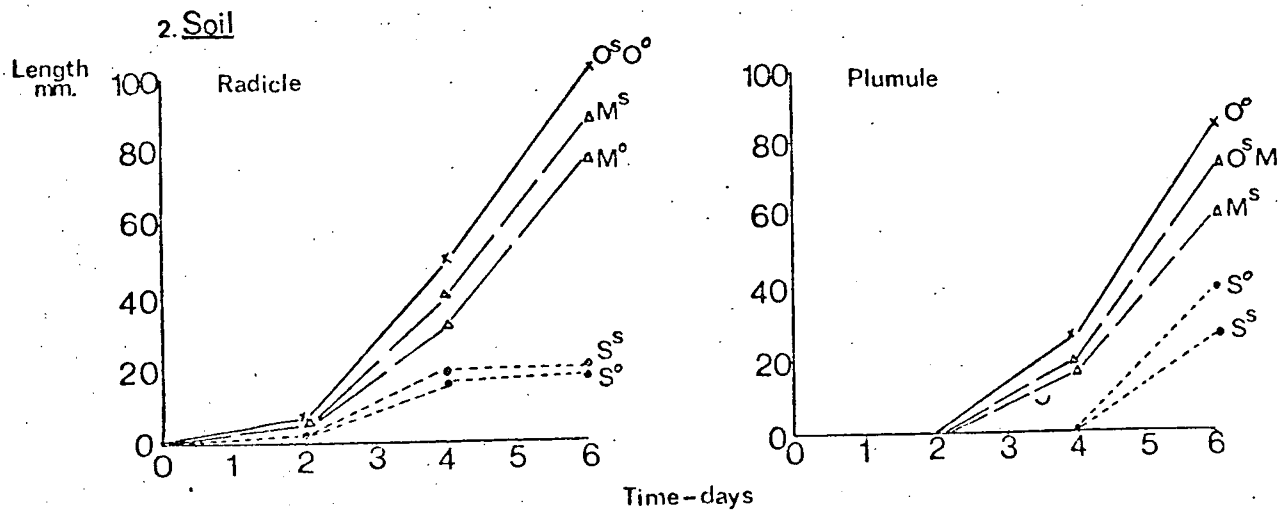
Graph 3-1 Rate of Germination



Graph 3-2 Growth of Seedlings during the first Week



Graph 3-3



Discussion

Text tables (1) and (3), and graph 3-1 demonstrate that the rate and percentage of germination of O and M seeds was much greater than that of S seeds, both in water and on O and S soil. The influence of soil type showed no effect upon the success of germination of O and M seeds, but for S seeds a small difference was exhibited, so that the percentage germination was better on O soil than S soil. Table (1) and Graph 3-2 show that the rate of growth of the radicle and plumule of seeds grown in water, followed the pattern O > M > S, as shown for the percentage germination against time. The radicle and plumule of germinating O and M imprint types were measurable at the same time (day 0 and day 3 respectively), but those of S seeds appeared 1 - 2 days later. On both water and soil substrates, the S seeds frequently became smothered with fungal hyphae and the tips of the radicles tended to wither before the initiation of the plumule. Thus on Table (4), O and M seeds both showed an increase in weight in water, but a decrease on soil, whereas S seeds lost weight in water and gained weight on the Organic soil due to the action of the fungus. The greater loss of weight by all imprint types on the Stockless soil correlated with the greater growth of the radicles on that soil, as shown on Table (3). However all seeds showed the greatest rate of plumule growth on the Organic soil. This apparent influence of soil type upon germination is summarized in Graph 3-3, but none of the differences within any imprint type were significant at the 95% level.

The germination of seeds in potassium nitrate solution was investigated because it has been suggested (McEwen 1970) that the addition of nitrates to a bean field may enhance plant yields, but that the presence of nitrogen when sowing may reduce germination. Upon the initial application of such fertilizer, high local concentrations of this very soluble ion would exist around the seeds. This test showed that only the highest concentration (10% KNO_3) significantly reduced the percentage of successful germination by all seed imprint types, but that all concentrations tended to reduce the rate of growth of the radicle and plumule. Subsequent to this research, it was found by Welch _et al_. (1973) that high nitrogen levels in the soil restricted the germination of _Glycine_.

Conclusions

The only differences observed were that the Tic S seeds were darker in colour, and exhibited poorer germination and growth in the first week, than the Tic O and M imprinted seeds. These differences may have been caused by a genuine physiological variation between the seed imprint types, but it was more probable that this was purely the result of a longer storage time for S seeds. Garner and Sanders (1935) referred to the common practice of using old field bean seeds for sowing. They, too, found a reduction in the rate of germination with increasing age, but they suggested that the climatic conditions prevailing at the time of harvesting controls the subsequent germination, more than seed age. The S seeds of both Tic and Throws varieties were heavier than those imprinted on the O and M sections. Although this could have been due to the length of storage time for Tic seeds, all Throws seeds were of the same storage age. Thus the difference in Tic weights may indicate a change brought about by imprinting. The only effect of the soil type on the performance of the seedlings was the differential rate of extension of the plumule and radicle, but this was not statistically significant.

:3.5 Greenhouse Pot Experiment

:3.5.1 Aim

During the winter of 1970-71 a ten week pot trial was conducted in a Dutch light greenhouse in Durham in order :-

(1) To determine whether the imprint type, or soil used, influenced the growth of the *Vicia faba* plants over a longer period than was used for the germination studies;

(2) To provide plant material for testing the proposed chemical analysis methods;

(3) To provide growth data to test the Hughes Freeman computer programme.

:3.5.2 Method

The Tic seeds of each imprint type were sown at the rate of three seeds per 10 cm diameter pot, separately in soil from the Organic and Stockless farms at Haughley. Fifty-four replicates of each treatment were arranged within nine 6 x 6 Latin squares (as described in the Appendix) in the greenhouse, where conditions of light and temperature were maintained as constantly as possible. Small samples of three plants per treatment were harvested at random, at frequent intervals, during the ten week period. Measurements of shoot length, leaf area and total dry weight were made on each plant prior to chemical analysis (see Section 4).

:3.5.3 Results

The raw data shown on Table A5 demonstrate that when there was only a small population of trial plants, from which small samples were drawn, destructive sampling, as was practised in this project, encouraged any overall trends to be masked by the great variability within the population. It was not possible to trace the development of one particular plant throughout the experiment, and consequently the gradual increase in shoot length, leaf area and dry weight values incorporated many fluctuations within each imprint type. Thus comparison between plant or soil types using only the raw growth data would prove very difficult.

To overcome this problem the Hughes-Freeman computer growth analysis programme was used, which fitted curves to the changing Log Weight and Log Area for the plants in each treatment, and hence calculated the Leaf Area Ratio (LAR), Net Assimilation Rate (NAR) and the Relative Growth Rate (RGR). The fitted data are presented in Tables A6(1) and (2). The standard errors shown in the tables, and the graphs 3-4, 3-5, 3-6 are those calculated between the actual growth curves and the fitted curves. The results of the growth analysis thus enabled the comparison of :-

(1) three plant types on one soil - effect of plant type on growth
(2) each plant type on two soils - effect of soil type on growth

The graphs demonstrate that the volume of soil and conditions of light were not sufficient to allow normal growth of the plants beyond day 65, except for S plants in O soil. After that time, the plants became progressively etiolated and the leaves shrivelled, and the experiment was thus terminated at ten weeks. There were several shortcomings of the greenhouse experiment which it was thought would limit the validity of the results with regard to predicting performance under field conditions. The main limitations were :-

(1) The length of the trial was very short compared with a normal field season, thus the influence of imprinting upon plant development to maturity,could not be estimated.

(2) The competition for water and nutrients was greater than in the field due to a very small permitted rooting volume.

(3) The soils were homogenized prior to the experiment which would have destroyed much of the natural soil structure. The soils were

removed from the fields in November when a full year's crop had already been grown on these sections subsequent to the application of manure and fertilizers.

(4) The day length and temperature could not be constantly maintained due to several power cuts.

:3.5.4 Discussion

.4-1 From the actual raw data as measured : (where capital letters indicate plant type, lower case soil type)

(1) Short length Oo > Os; Mo ≡ Ms; So < Ss

(2) Leaf area - effect of plant type - on organic soil S > M > O
was not consistent
- on Stockless soil M > S > O
- effect of soil type Oo > Os; Mo < Ms; So ≡ Ss

(3) Dry weight - effect of plant type - on organic soil O ≡ S > M
was not consistent
- on Stockless soil S > M > O
- effect of soil type Oo > Os; Mo < Ms; So ≡ Ss

Although overall trends are difficult to compare or determine from the raw growth data, within a single soil type, S or M seeds appeared to grow better than O seeds. The effect of the soil type was that O plants grew best on their own soil, but M and S plants grew equally well on both soils, or slightly better on Stockless soil. The soil type affected both leaf area and plant dry weight according to the same pattern.

.4-2 Using the fitted growth data from the computer programme

Once the raw data have been processed by the computer programme, the fitted curves of the seed and soil types can be statistically compared. This can be done for the whole experiment using analysis of variance on the printed out regression equations. Additionally Hughes and Freeman (1967) stated that a direct comparison can be made between the fitted values at any given time, using the calculated standard errors to test for the significance of any difference between treatments. The degrees of freedom are taken from the regression equations, and the figure found by dividing the difference between any two fitted values, by the difference of their standard errors, can be treated as a normal deviate, i.e.

$$\frac{\text{Fitted value}_A - \text{Fitted Value}_B}{SE_A^2 + SE_B^2}$$

The fitted curves for the five parameters have been drawn on Graphs 3-4, 3-5, 3-6. These demonstrate well the recession of growth which set in at the 58th day of the experiment (except in Stockless plants on the Organic soil), probably induced by the overcrowding of the plants in small flower pots. The only differences which were found to be statistically significant by the above described method of direct comparison of the curves, appear in Table 3-3.

Due to the degree of similarity between the fitted growth curves for most of the duration of this experiment, shown visually by the graphs and statistically by the direct comparison method, the very computer-time-consuming process of the analysis of variance of the printed out regression equations was omitted.

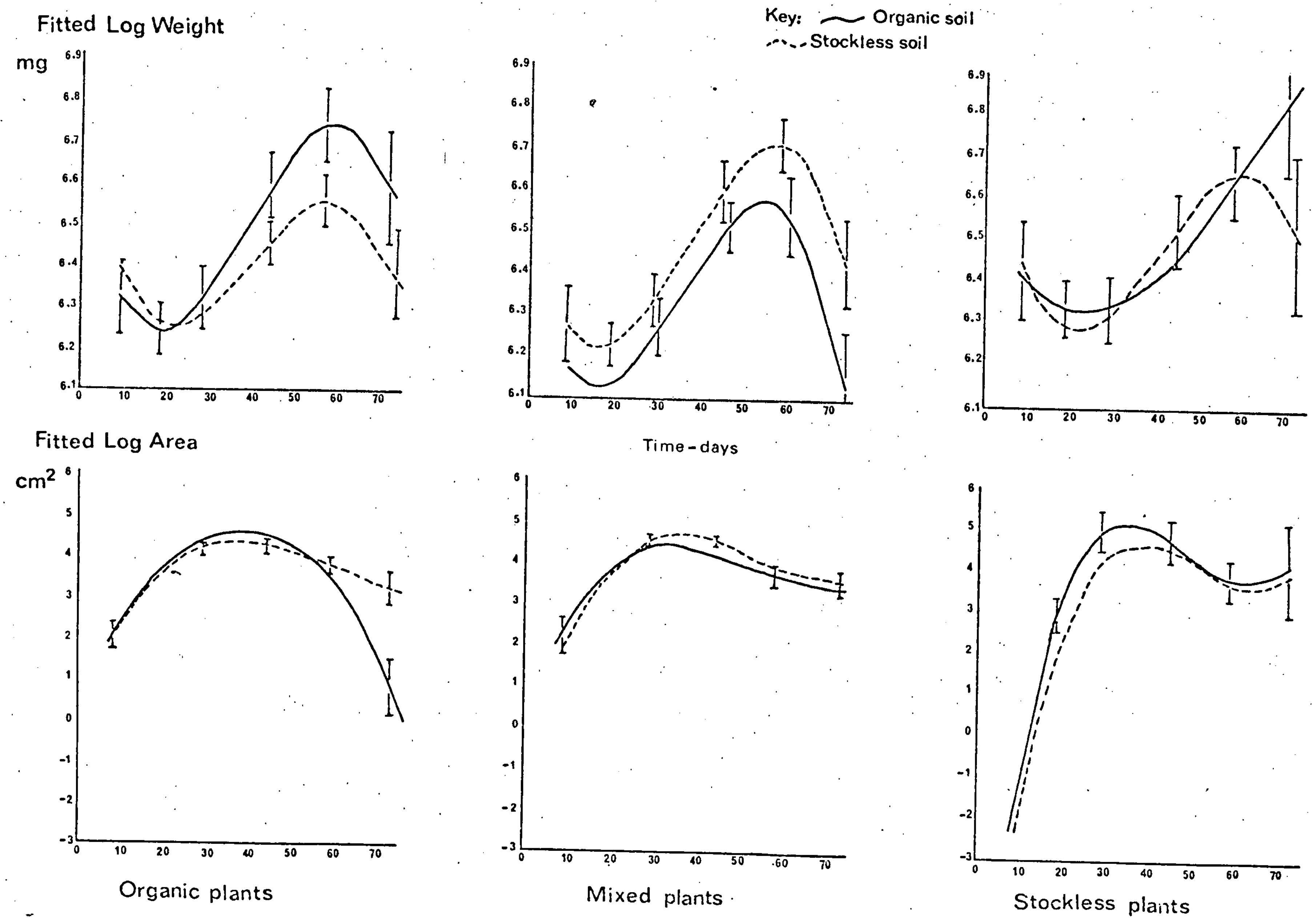
In the discussion of the results of the statistical comparison shown on the previous table, the value of $p = <0.1$ is considered to indicate a trend towards a significant difference between treatments.

4-2(1) Effect of plant imprint type on growth

O v M - except at the end of the ten week period when the fitted log dry weight values were O > M, on both soils wherever there was a significant difference in fitted growth parameters M > O. These differences tended to occur towards the beginning of the experiment on S soil,

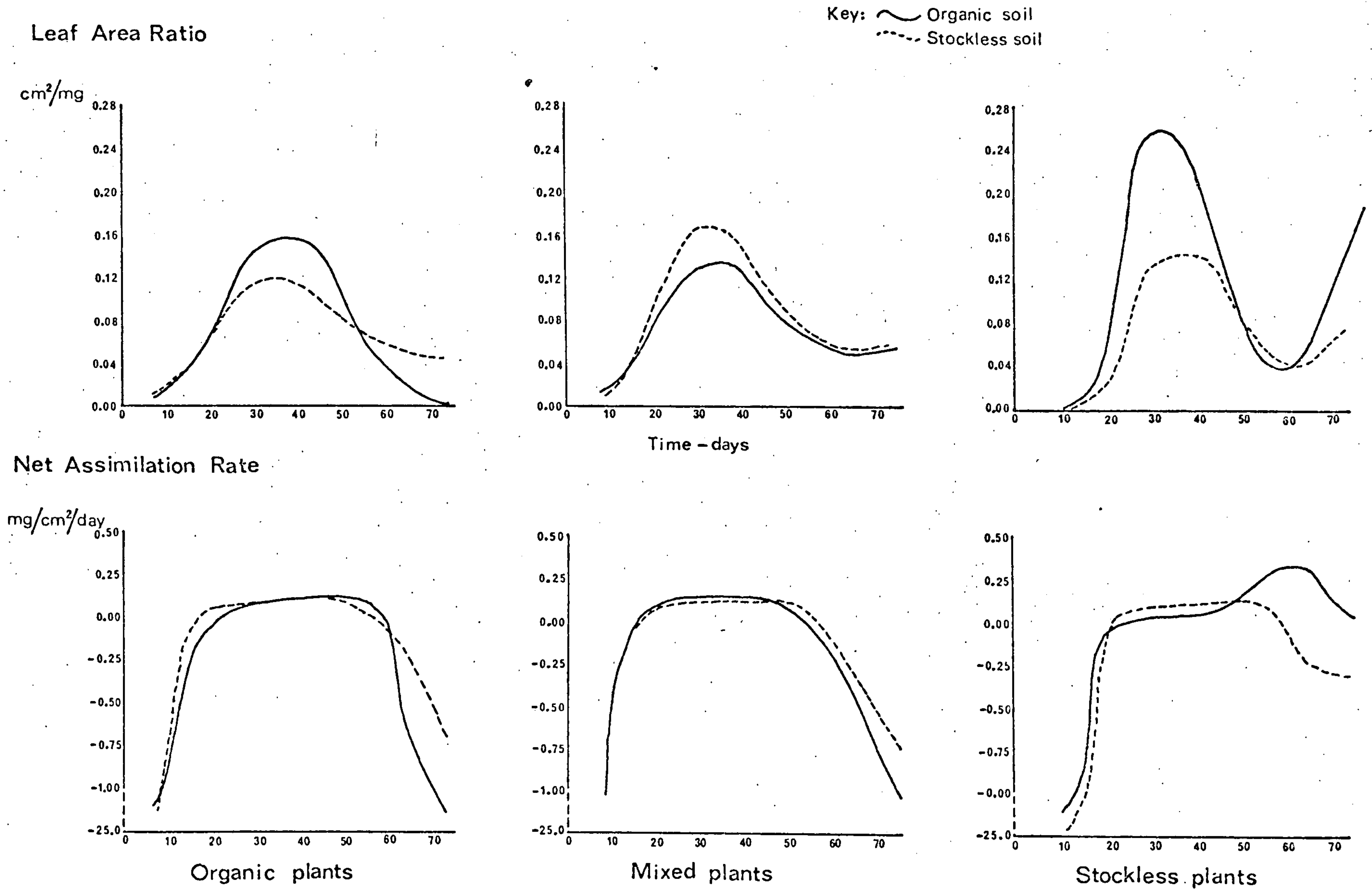
Graph 3-4

Crop Growth - Greenhouse Trial 1971



Graph 3-5

Crop Growth - Greenhouse Trial 1971



Leaf Area Ratio

Net Assimilation Rate

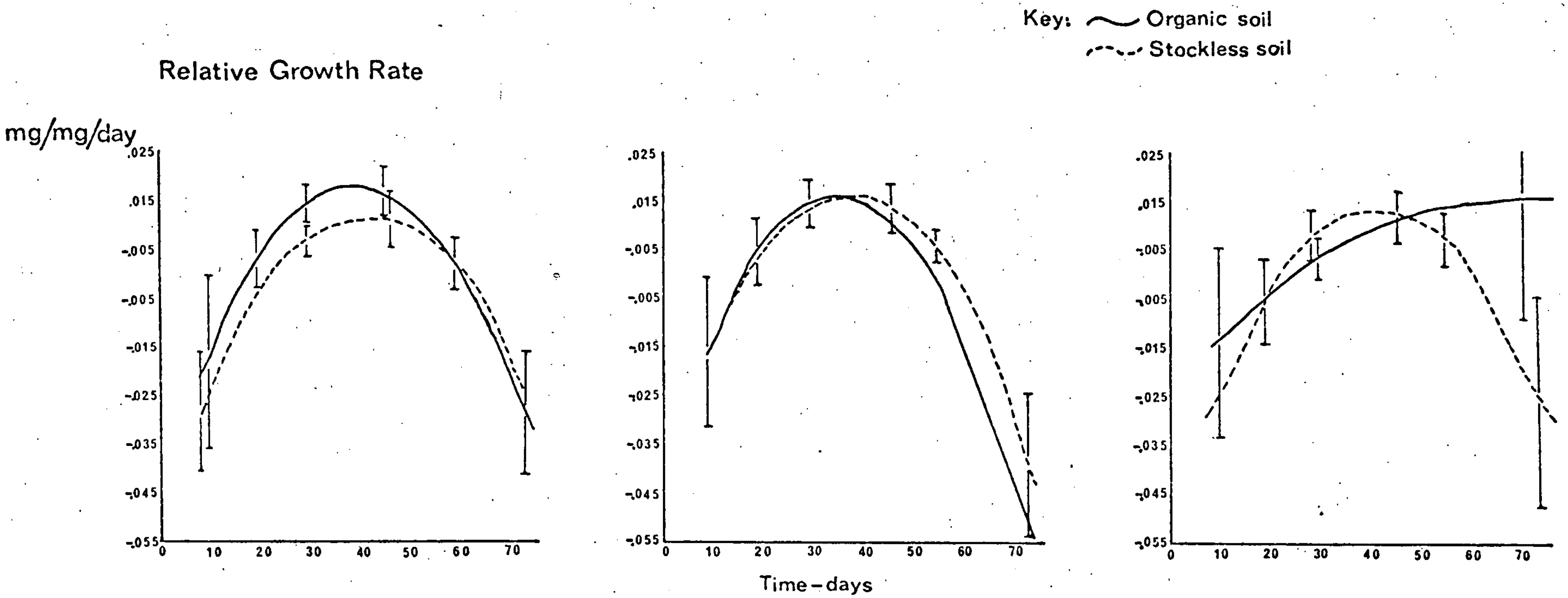
Organic plants

Mixed plants

Stockless plants

Graph 3-6

Crop Growth - 1971 Greenhouse Trial



Organic plants Mixed plants Stockless plants

Table 3-3

Age of plants at which the differences between the growth of the imprint types were significant (Greenhouse Trial)

(-) = no significant difference

Result considered to be significant when p = <0.1

Plant types Compared	O v M			O v S			M v S		
Growth parameter and Soil type	Age (days)	p Value	Signif. result	Age (days)	p Value	Signif. result	Age (days)	p value	Signif. result
F Log Wt									
O soil	65-73	<0.05	O > M	-	-	-	12-19	<0.1	S > M
							65-73	<0.05	S > M
S soil	51-54	<0.1	M > O	-	-	-	-	-	-
F Log Area									
O soil	65	<0.1	M > O	9-16	<0.01	O > S	9-16	<0.001	M > S
	73	<0.01	M > O	73	<0.05	S > O	19	<0.1	M > S
S soil	26-29	<0.1	M > O	9-16	<0.001	O > S	9-12	<0.001	M > S
				19	<0.05	O > S	16-19	<0.05	M > S
LAR									
O soil	65-73	<0.01	M > O	12-16	<0.05	O > S	9-19	<0.01	M > S
S soil	19-45	<0.1	M > O	9-19	<0.01	O > S	9-19	<0.001	M > S
							23	<0.02	M > S
NAR									
O soil	-	-	-	-	-	-	26-29	<0.05	M > S
							65-73	<0.05	S > M
S soil	-	-	-	-	-	-	-	-	-
RGR									
O soil	-	-	-	-	-	-	23-26	<0.05	M > S
							58-73	<0.05	S > M
S soil	26-29	<0.1	M > O	-	-	-	-	-	-

but towards the end of the period on the Organic soil. Differences were rarely significant at less than p = 0.1 and therefore may have been entirely due to the variability within a single population.

O v S - the only significant differences shown, concerned the leaf area parameters where O > S significant to p = <0.05, was the main trend.

M v S - apart from differences of leaf area, the only significant differences between these plant types occurred on the Organic soil, but the trend for all growth parameters was M > S except at the end of the experiment when S > M.

.4-2(2) Effect of soil type on growth

The growth of the three plant imprint types was more variable upon the Organic soil, but the only differences which were statistically significant are shown below :-

O plants on O and S soil - differences only occurred at age of 58-73 days when growth on S soil > O soil for F. Log Area and LAR, but growth on O soil > S soil for F. Log Weight (p = <0.01).

M plants on O and S soil - only significant difference was shown for F. Log Weight where growth on S soil > O soil at day 65, but only to p = <0.1.

S plants on O and S soil - despite the continued growth of S plants on O soil after day 58, the fitted curves show no statistically significant effect of soil type, for any of the growth parameters calculated.

:3.5.5 Conclusions from the Greenhouse Trial

The use of the computer growth programme enabled the statistical comparison of the effect of various treatments upon the growth of *Vicia faba* plants, even when very small samples were harvested. The results of the computer analysis agreed with the observations made upon the raw data, but by removing the irregularities in the measured values, revealed the true differences where these occurred.

From the results obtained, it appeared that where significant differences were caused by plant imprint or soil type, these were only evident for a short part of the ten week period. Where differences occurred between plant imprint types, they followed the pattern M > O > S, except towards the end of the experiment when O > S > M, due to the greater sensitivity of the M plants to the poor growth conditions. The results may indicate that some changes in the growth response had been brought about by the imprinting of seeds during the thirty year period. If imprinting was responsible for the observed differences, this would support the statements made by Thompson (1937) who showed that the availability of soil nutrients to the parent plant *(Lactuca sativa)* at the time of seed maturation, affected seed yield and subsequently affected the physiological behaviour and growth of the seeds. For several growth parameters there were indications that the organically imprinted seeds grew best on the Organic soil, whilst the Mixed and Stockless imprinted seeds grew better on the Stockless soil, but this experiment involved too many limitations to allow firm conclusions to be made. The experiment needed repeating on a field scale for the duration of a whole season, to determine whether or not these results would be found when the crop was growing under the normal agricultural conditions - indicating that actual physiological evolution had taken place.

Where the soil type showed any significant effect, growth of all plant types on the Organic soil tended to be more variable than on the Stockless soil, which may have been due to the more uneven distribution of nutrients in the former soil (see Section 1). The soil type only exerted influence over plant growth towards the end of the ten week period, especially upon the organically imprinted type.

3:3.6 1971 Field Trial

:3.6.1 Aims

(1) To determine whether the differences in growth between seed imprint types indicated by the greenhouse trial were exhibited under field conditions,over an entire growing season at Haughley. This to determine whether imprinting had caused any physiological evolution within *Vicia faba*, fitting each imprint type to optimum growth upon its own farm management section.

(2) To determine the response, as measured by the yield and the growth parameters previously described, of each imprint type to increased rates of artificial fertilizer. (The account concerning yield response can be found in Section 3:3.9.)

:3.6.2 Method

Latin squares of small subplots 1.2 metres square were laid in the Organic and Stockless fields (Lower Wassicks South and Road field, respectively) as shown in the Appendix, to give a random separation of the plant types used. In the Stockless field three blocks were used, one for each level of fertilizer applied :-

NF : no fertilizer applied to soil
3F : 375 Kg/ha Shellstar No. 3, a 10:25:25 NPK fertilizer designed for field beans
6F : 625 Kg/ha Shellstar No. 3

The additional fertilizers were applied to the plots at the time of sowing of the seeds. The seeds used in this experiment were *Vicia faba* var. Tic and var. Throws,of imprint types O, M, S. In both fields there were three or four replicate plots of each Tic imprint, but only one plot for each Throws imprint. The plots were sown with seed at the normal density for *Vicia faba*, which was 27 plants per square metre.

Section 3 : Plate 1

The early growth of the *Vicia faba* plants.

(1) The appearance of the plants 7 weeks after sowing

(2) The state of growth found after 12 weeks

The growth of the plants was determined by random sampling of the plots at fortnightly intervals throughout the growing season, harvesting three plants for each treatment and imprint type. The plants were washed, measured and dried as described for the greenhouse trial, prior to chemical analysis (see Section 4). The data were subjected to the Hughes-Freeman computer growth analysis so that the fitted curves of the six plant imprint and variety types,growing on the four nutrient levels, could be directly compared.

:3.6.3 Results

The comparison of the growth of the plants growing on the Organic and Stockless section was made more difficult because the first sowing of the bean seeds on the former section was completely devoured by rooks. By the time this field has been resown, five weeks had elapsed since the sowing of the Stockless field. Due to the later planting, growth on the Organic section tended to be faster than normal, so that the plants of both sections were finally harvested,bearing ripe seeds,on the same calendar date, at the ages of 24 weeks (S) and 19 weeks (O). In addition to any differences of growth being possibly caused by natural population variability, imprint type, or farm management, this shortened growth cycle also had a profound effect upon the plants' performance. A preliminary discussion considering the raw growth data as measured,is followed by a description of the results derived from the computer growth programme. The raw data are presented on Table 3-4 in the text, the fitted data on Tables A7(1-3) and on Graphs 3-7 to 3-11 in the text.

:3.6.4 Discussion

.4-1 Raw growth data

The treatments and plant types were compared with respect to the age at which the maximum growth was attained, and the magnitude of the maxima.

Table 3-4

The Raw Growth Data collected from the 1971 Field Trial.

1. Length of shoot - soil to apical bud (cms).

Treatment	STOCKLESS - NO FERTILIZER						STOCKLESS - 375 Kg FERTILIZER/ha						STOCKLESS - 625 Kg FERTILIZER/ha							ORGANIC					
Age of plant (weeks)	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Age of plant (weeks)	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S
3	3.1	2.9	2.8	3.0	2.6	2.5	2.5	1.7	2.6	2.4	2.2	2.9	2.9	2.7	3.0	2.7	1.6	2.5	3	7.0	6.5	6.5	8.0	8.0	8.0
5	3.5	4.0	3.5	5.3	4.2	4.3	3.3	3.7	3.3	4.8	4.0	4.0	3.7	3.3	4.0	5.0	4.8	4.5	5	13.0	18.5	13.0	11.5	14.5	14.0
7	16.0	16.5	14.5	11.5	13.0	13.5	20.0	17.5	18.5	15.0	13.0	15.0	21.5	21.5	18.5	20.0	12.5	13.0	7	31.5	34.5	29.5	20.0	22.0	23.0
10	43.0	48.0	47.5	44.0	42.0	42.0	49.5	51.0	42.0	40.0	42.0	43.0	45.0	52.0	40.0	42.0	45.0	38.0	9	-	-	-	-	-	-
12	80.0	82.0	62.0	69.0	70.0	80.0	75.0	79.0	73.0	67.0	66.0	78.0	78.5	83.0	78.5	82.0	90.0	82.0	13	106.0	105.0	99.0	82.0	97.0	63.0
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	108.0	111.0	112.0	90.5	104.0	91.7
18	145.0	121.0	122.0	124.0	132.0	148.0	129.0	139.0	133.0	141.0	126.0	127.0	123.0	131.0	133.0	138.0	142.0	142.0	19	110.0	114.0	113.0	64.0	92.0	95.0
21	136.0	136.0	129.0	133.0	136.0	133.0	137.0	137.0	115.0	143.0	131.0	135.0	133.0	123.0	137.0	129.0	141.0	138.0							
24	109.0	132.0	109.0	118.0	115.0	119.0	104.0	100.0	104.5	118.3	114.0	114.0	115.0	107.0	128.0	123.0	125.0	123.0							

2. Total Leaf Area (square centimetres)

3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3	29.1	38.3	29.2	31.9	28.3	34.9
5	27.1	34.2	24.6	20.7	27.3	20.9	33.9	33.7	28.9	24.4	30.9	28.9	35.1	39.1	17.1	20.0	20.1	24.7	5	92.7	105.8	87.4	83.3	62.8	104.6
7	135.8	224.6	178.8	102.2	161.2	164.7	184.9	139.6	149.5	142.1	168.5	170.6	114.9	148.1	162.1	180.1	144.0	159.6	7	246.2	284.5	594.7	109.9	148.2	124.6
10	448.4	410.8	365.5	455.4	510.6	527.0	427.6	514.3	331.0	392.0	564.5	381.9	381.8	417.7	455.5	385.4	480.0	470.5	9	521.1	649.3	1215.1	339.7	296.4	241.7
12	868.2	1127.9	859.7	787.1	1026.3	1046.9	752.3	676.3	521.4	752.3	676.3	521.4	897.1	722.6	896.3	1170.9	1012.7	1289.4	13	1068.0	1095.6	1061.2	737.4	634.0	745.3
14	1100.2	1215.6	1351.2	1110.5	1313.5	1572.9	1300.0	1250.6	946.1	840.3	787.3	1146.3	1259.0	1307.0	1219.0	1342.1	1300.0	1305.3	16	519.8	728.9	0.0	673.1	1012.0	[illegible]
18	1871.7	1316.9	1963.7	1842.1	1707.5	2228.6	2423.9	954.3	1684.7	1162.6	914.5	2160.1	1982.3	1120.0	941.8	1746.9	1930.1	1285.6	19	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	137.1	0.0	198.8	0.0	177.4	0.0	71.6	0.0	0.0	140.8	0.0	0.0	175.1	139.6	50.0	35.8	201.1							
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

3. Total Dry Weight (grams)

3	0.58	0.58	0.58	0.24	0.23	0.29	0.53	0.57	0.59	0.24	0.20	0.25	0.57	0.53	0.56	0.22	0.25	0.26	3	0.49	0.58	0.61	0.22	0.23	0.26
5	0.62	0.68	0.63	0.24	0.34	0.29	0.58	0.65	0.51	0.22	0.31	0.32	0.60	0.65	0.54	0.26	0.23	0.32	5	1.03	1.29	0.87	0.71	0.76	0.75
7	1.57	1.95	1.75	0.93	1.23	1.63	1.85	1.11	1.62	1.32	1.11	1.62	1.06	1.65	1.86	1.79	1.33	1.33	7	2.05	2.61	1.85	0.99	1.78	1.31
10	5.65	4.92	6.69	5.79	4.68	5.83	5.21	5.68	3.29	3.59	5.03	4.72	4.89	5.50	5.75	4.21	4.71	4.77	9	3.74	4.23	3.38	3.25	3.87	2.25
12	14.40	16.83	10.67	9.96	14.22	12.38	12.00	9.76	8.10	8.99	10.36	13.61	11.18	9.37	12.44	14.06	14.66	13.65	13	17.01	22.29	20.64	11.42	11.14	12.64
14	27.62	27.95	22.69	18.40	12.74	13.40	24.68	26.20	10.39	23.10	24.02	19.44	25.43	29.91	25.25	19.02	23.62	18.69	16	24.07	27.16	38.10	19.74	25.96	22.07
18	54.87	45.82	62.95	40.14	53.42	68.81	61.72	43.10	58.92	44.07	38.84	56.26	63.56	43.48	54.02	63.37	47.56	41.87	19	28.65	13.03	16.87	20.79	14.21	16.76
21	45.44	53.98	44.18	63.88	56.01	54.25	48.78	45.55	49.57	40.98	62.19	55.24	37.43	41.31	43.70	46.09	54.39	59.69							
24	28.65	22.91	32.98	19.42	32.33	36.44	25.17	25.58	23.78	22.13	35.21	19.71	31.74	19.98	25.78	35.30	39.69	30.31							

Each reading is a mean of three samples.

(1) The maxima of shoot length, leaf area and dry weight on Table 3-4 are underlined, and from this it can be seen that neither the treatment nor plant type had much influence upon the age at which these maxima occurred. The most important age of the plants with reference to these criteria was week 18. The rapid senescence after that age was evident by the reduction of leaf area, the foreshortening of the stem due to apical death, and the decrease in dry weight of the whole plant, despite the increasing weight of the developing seeds.

(2) Within the Stockless section, the maximum shoot length and dry weight occurred at the age of 18-21 weeks for all plant imprint types, for both varieties, and at all rates of fertilizer application. Maximum leaf area tended to occur slightly earlier. The only apparent effect of the different fertilizer treatments upon the timing of the maxima was found for four plant types (Tic M, Throw O, M, S), whereby increasing the fertilizer rate from NF to 6F enabled the attainment of maximum shoot length three weeks earlier. Similarly for maximum leaf area, increasing the fertilizer application rate from NF to 6F enabled Tic M, Tic S and Throws S plants to achieve the maximum four weeks earlier.

(3) Within the Organic section there was much more variation in the timing of the maxima, but there appeared to be no clear relationship between the age of attainment and the imprint type. Due to a reduced growing season, the maximum shoot length and dry weight were not attained until the final or penultimate harvest.

(4) Despite the time lag between the two farm management sections, the maximum leaf area occurred at the same calendar time on both, although the maxima of dry weight and shoot length occurred at different calendar times (the same plant age).

(5) All plant types on all treatments achieved the stage of maximum flowering at the same calendar time (18th June 1971). This agreed with the results of McEwen (1970) who found that flowering dates of *Vicia faba* were unaffected by varying the rates of fertilizer application. By an accelerated growth in higher temperatures and longer photoperiods, all the plant types on the Organic section caught up in development with the plants which had been sown earlier on the Stockless section.

(6) Probably due to the shorter growing season, all the imprints on the Organic section reached significantly lower maximum shoot lengths, leaf areas and total dry weights, than the same imprint types on the Stockless treatments. The magnitude of the maxima of all three measurements for both plant varieties was broadly equivalent on the Stockless section, but on the Organic section the Throws variety showed much less growth than the Tic variety - the former variety being more affected by the shorter growing season.

(7) There was no consistent nor significant effect of imprint type upon the growth performance, as measured by short length, leaf area or dry weight, shown under any of the treatments used.

(8) There was no consistent nor significant effect of treatment upon the growth performance of any of the plant imprint types grown, which could not be explained by a difference in planting dates.

Conclusions from the raw growth data

Without the use of statistical analysis the trends identified by considering the raw growth data were :-

(1) The farm management origin of each plant imprint type had not affected the growth potential of *Vicia faba* plants for any treatment given.

(2) No consistent effect of increased nutrient availability was exhibited by the growth of any plant imprint type.

(3) The timing of the maximum leaf area and maximum flowering were controlled by day length and temperature, whereas attainment of maximum shoot length and dry weight may have been determined more by the age of the plant.

.4-2 Fitted growth data

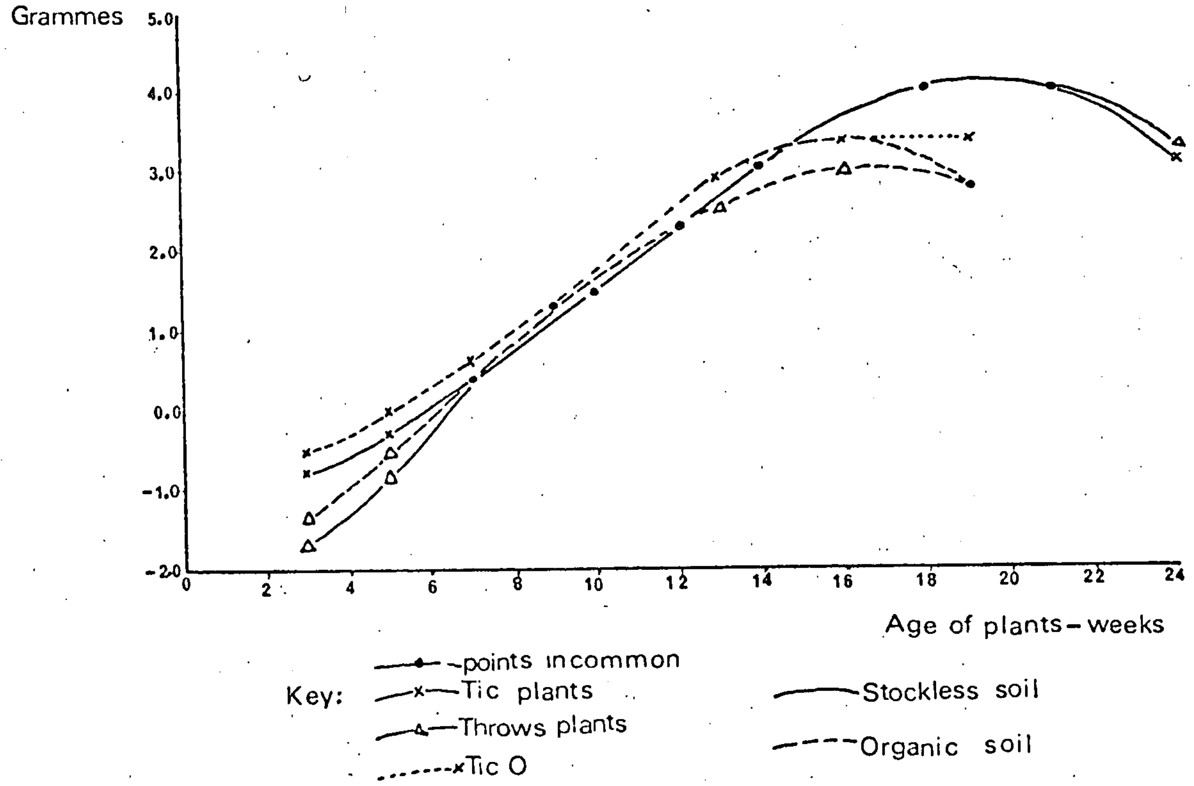
Graphs have been drawn for the growth indices in order that a visual comparison of the growth of plant types on the various treatments can be made. Each point on the fitted curves was then compared statistically between treatments and plant types, as previously described, in order to determine the net effect of these on plant growth. Because of the later sowing on the Organic field, the fitted growth curves of the plants on the two sections were compared, using the age of the plants (in weeks) as the x axis on the graphs, rather than calendar time. The effect of the twenty four combinations of plant type and nutrient treatment are discussed in turn, for each of the fitted growth indices.

.4-2.1 Fitted Log Dry Weight - (Log grammes) - Graph 3-7

(1) Due to the very close similarity of the fitted curves produced by the computer analysis, for the progress of the Log Dry Weight of the plants during the season, these can only be drawn if they are resolved into a total of four lines. Thus one curve accurately represents the Log Dry Weight of all six imprint types, growing under all three levels of fertilizer application, on the Stockless field. The only divergence occurred at the age of 3-5 weeks (significant to $p = <0.05$) and 21-26 weeks (not significant) when the Tic and Throws lines differed, due to a significantly lighter seed weight in the latter variety. The level of fertilizer

Graph 3-7 Crop Growth - 1971 Field Trial

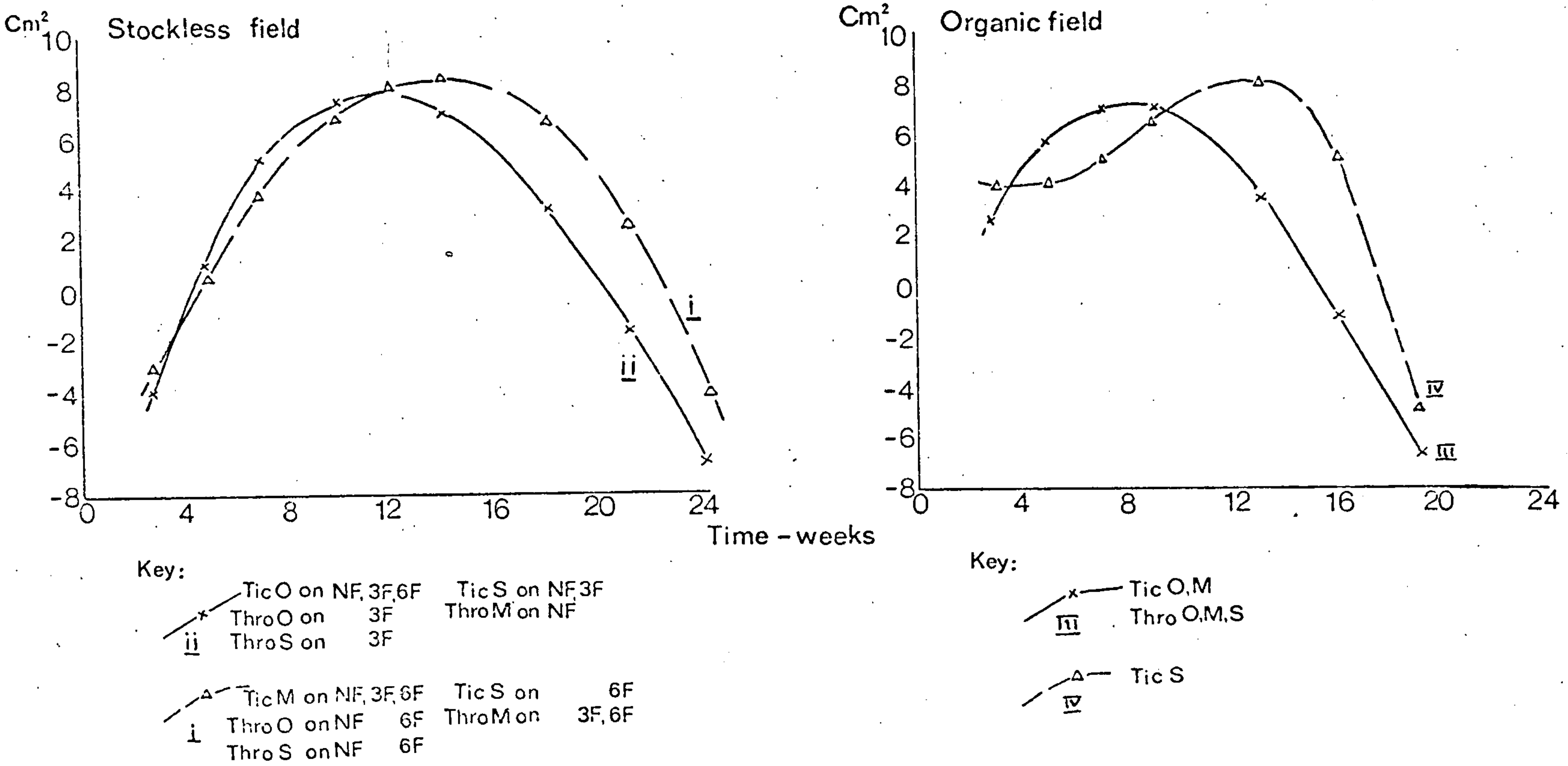
Fitted Log Dry Weight



Graph 3-8

Crop Growth - Field Trial 1971

Fitted Log Leaf Area



applied had no significant effect upon the gain in dry weight of any imprint type during the entire season. Similarly on the Organic field, two curves suffice on the graph, one for each *Vicia faba* variety, and again these were only significantly different at weeks 3-5 ($p = <0.02$).

(2) On neither farm sections used did the imprint types show any influence upon the gain in dry weight of the plants, with the exception of Tic O on the Organic field at 19 weeks, where the dry weight did not fall, but this example was not significantly different (at the 95% confidence level) from M and S plants.

(3) The only significant difference between the plants on the Organic and Stockless fields was that those on the former section attained a lower maximum dry weight, (to $p = <0.01$), than those on the latter, due to the shorter time available for growth. Even so, the dry weights at the final harvest did not differ significantly between the management types.

(4) All plant types on both fields tended to attain maximum fitted dry weight at the same calendar time.

.4-2.2 Fitted Log Leaf Area - (Log square centimetres) - Graph 3-8

In order to clarify the differences between the development of leaf area of plants on the Organic and Stockless fields, the fitted curves for these sections were drawn separately.

(1) Stockless field

Two fitted curves accurately represent the course of leaf area development over the season for the 18 combinations of plant type and fertilizer treatment. The graph demonstrates a slight difference in response by the plant imprint types to the three levels of fertilizer, but these did not segregate out according to variety. Curve i depicts the development of the leaf area of the plants growing mainly on the higher levels of fertilizer, although the response to NF and 6F appeared to be identical for Tic M, Throws M and Throws S. The maximum leaf area was slightly higher, and was attained three weeks later than on the lower fertilizer levels. The difference was maintained throughout the latter half of the growing season.

Curve ii shows the pattern of development followed, mainly by the plants growing on lower levels of fertilizer, although Tic O followed this course for all levels of fertilizer, and Tic M was not represented at all by this line.

Thus on the Stockless field there was some indication of differing responses by the three plant imprint types, particularly between Tic O and Tic M, and Throws O and Throws M, but none of these differences were significant at the 95% confidence level.

(2) Organic field

The development of the leaf area of five imprints was identical, and can therefore be accurately represented by the single curve III. Only Tic S diverged from this pattern (shown by curve IV), whereby the development to attain the maximum leaf area was much more rapid, so that a slightly lower maximum was achieved five weeks earlier than shown by the other plants, on the Organic field. The curves III and IV only differed significantly ($p = <0.05$) at week 16, because Tic S demonstrated an earlier senescence.

(3) Apart from Tic S, all imprint types achieved the same maximum leaf area, at the same age, on both management sections. The only significant difference between the development of leaf area on the Organic and Stockless treatments was that areas were greater ($p = <0.05$) on the former section, for the first seven weeks of the experiment - due to faster growth by later sown seeds.

.4-2.3 Leaf Area Ratio = increase in leaf area according to dry weight of plant (square centimetres/gramme dry weight). (Graph 3-9)

The pattern of development of the LAR with age, differed markedly on the two farm sections, therefore the graphs were again drawn and discussed separately.

(1) Stockless field

A single curve IV can be drawn to accurately represent the progress of change of the LAR for all three Throws imprints, growing on all fertilizer levels. For these plants, neither increasing the availability of nutrients, nor the previous one year of imprinting, influenced the leaf area developed per gramme total dry weight of the plant. For most of the season a second curve I adequately represents the pattern of LAR for all imprint types of the Tic variety, but the maximum LAR achieved differed in magnitude and timing for each type. Thus the maxima for Tic O (I) and Tic S (II) were very similar and occurred at week 8, whilst that for Tic M (III) coincided with that of the Throws plants and occurred at week 7. The level of fertilizer applied had no influence over the LAR response by any plant type. None of the maxima were significantly different.

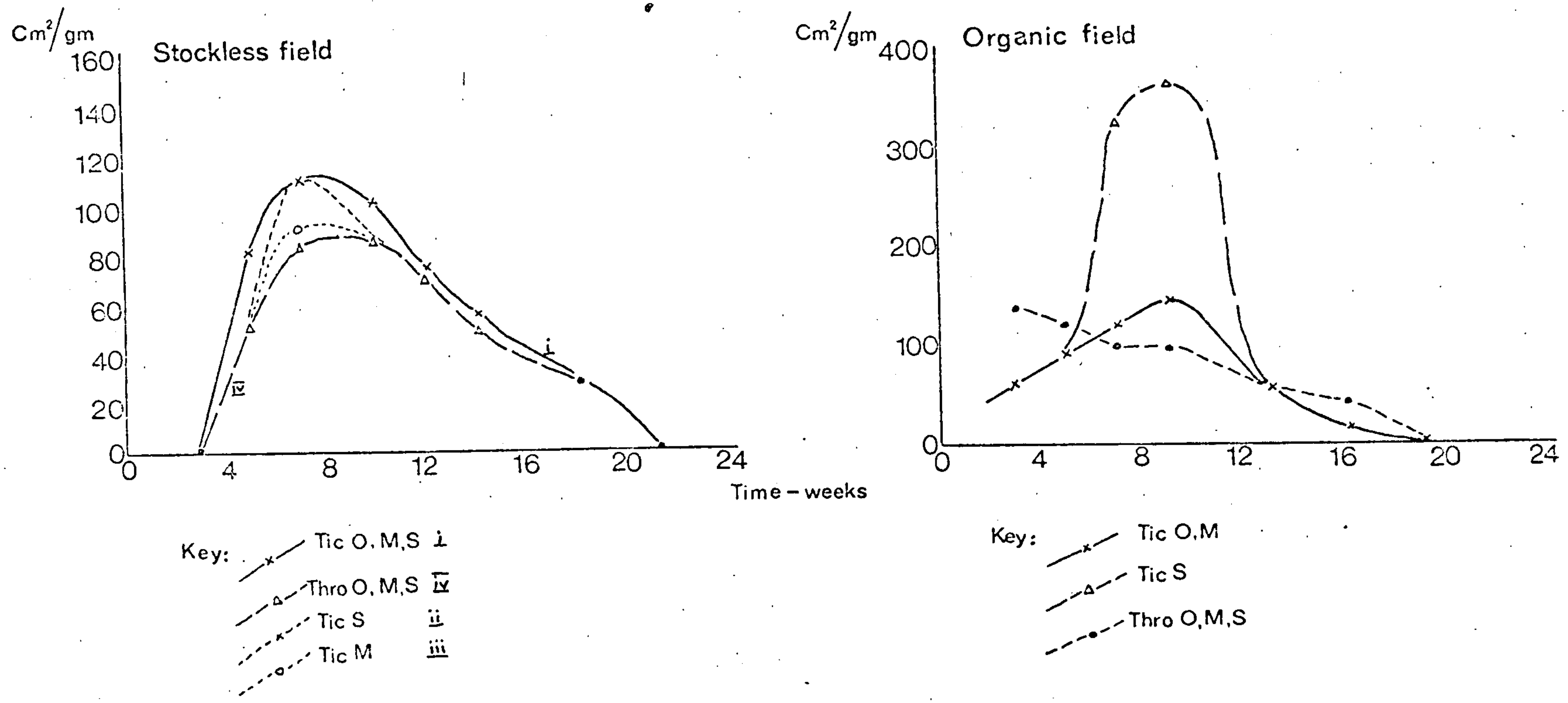
(2) Organic field

Corresponding to the difference exhibited by Tic S in terms of fitted Log Leaf Area, the progress of LAR of this imprint type showed a marked variation from the course exhibited by the other five types, particularly with regard to the maximum achieved. The LAR variation with time, for Tic O and Tic M, was identical, but much lower than for Tic S except for weeks 3-5, 13-19, when all three followed the same course. As on the Stockless section, the effect of imprinting on Throws O, M, S, showed no influence at all on the LAR produced on the Organic section.

Graph 3 - 9

Crop Growth - Field Trial 1971

Leaf Area Ratio



(3) Comparing the graphs of LAR from the Organic and Stockless section

The magnitude of LAR for Throws plants after week 6 showed no differences between the sections, although before that age there was great variation between the management types. The Tic variety plants had much higher LARs throughout the growing season on the Organic section, which may have been due to the later planting. As the Throws variety showed little difference between management sections, it is possible that the difference observed in the Tic plants was due to the effect of the Organic soil. As a result of later planting, or a farm management effect, Tic plants on the Organic section achieved maximum LAR at the same age as the Stockless grown plants, whereas Throws plants achieved their maximum five weeks earlier, corresponding to the same calendar time as the Stockless plants. All plant types on both sections achieved one-half pre-maximum LAR at 4-5 weeks of age, and one-half post-maximum LAR at 12-14 weeks of age.

.4-2.4 Net Assimilation Rate - increase in weight in grammes/square centimetre leaf area/week (Graph 3-10)

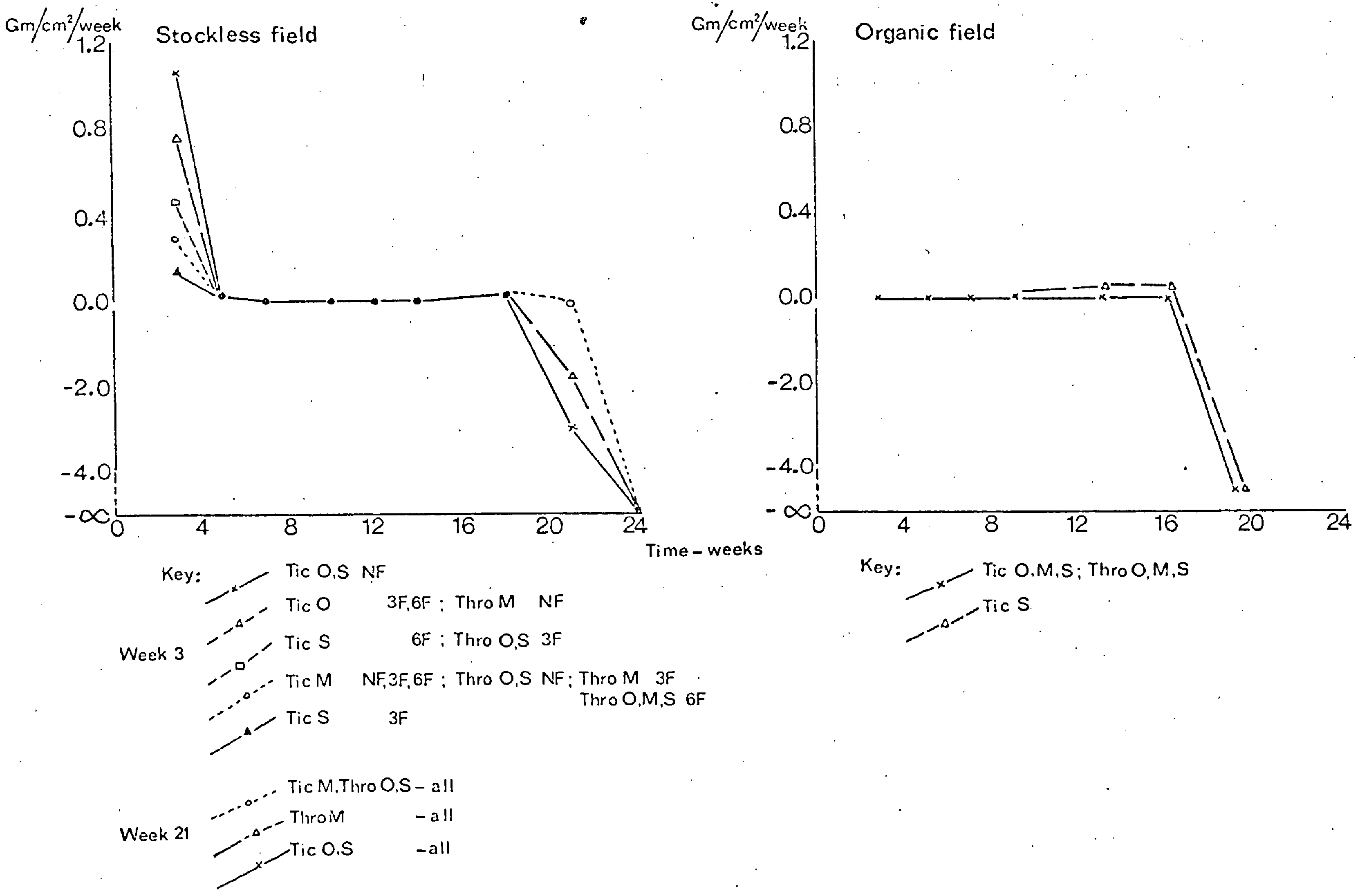
(1) At the beginning of the season, leaf area increased more rapidly than dry weight, causing a fall in the curves on the Stockless graph, but development was so much more rapid on the Organic section that this stage had been passed, by the first sampling date (3 weeks of age). During the mid-section of the growing season the dry weight and leaf area of the plants increased together, so that there was no net change in the value of NAR. After week 18, senescence rapidly caused a reduction of leaf area to zero, and total dry weight decreased slightly too.

The graphs of the change in NAR with season, for the Organic and Stockless plants, were drawn separately to show the faster initial development and earlier senescence on the former section, due to later sowing of the seed.

Graph 3-10

Crop Growth - Field Trial 1971

Net Assimilation Rate



(2) On the Stockless graph, the several curves demonstrate that the progress of NAR through the season varied slightly between weeks 3-5 and 18-24, depending on imprint type and fertilizer treatment, but these did not segregate out into any clear pattern. The differences exhibited between treatments during maximum growth at the beginning of the season, were not the same as those existing during senescence. In an examination of the groupings of imprint types on the NAR graphs, it was interesting to find that the Throws variety plants nearly always separated out in the opposite way to the Tic variety. Thus :-

		Tic	Throws
Week 3-5	NF	0 ≡ S > M	0 ≡ S < M
	3F	0 > M > S	0 ≡ S > M
	6F	0 > S > M	0 ≡ M ≡ S
Week 18-24	NF	M > 0 ≡ S	M < 0 ≡ S
	3F	M > 0 ≡ S	M < 0 ≡ S
	6F	M > 0 ≡ S	M < 0 ≡ S

But the imprint types 0 and S, from the two most opposite farm management treatments, tended to respond in the same way together, especially during senescence.

(3) As previously found for other growth indices, the Tic S plants were the only imprint type to diverge in the course of the NAR development during the season on the Organic section, but the extent of this divergence was not significant. All five other imprint types coincided in their NAR values exactly.

.4-2.5 Relative Growth Rate = LAR x NAR - increase in weight grammes/gramme/week (Graph 3-11)

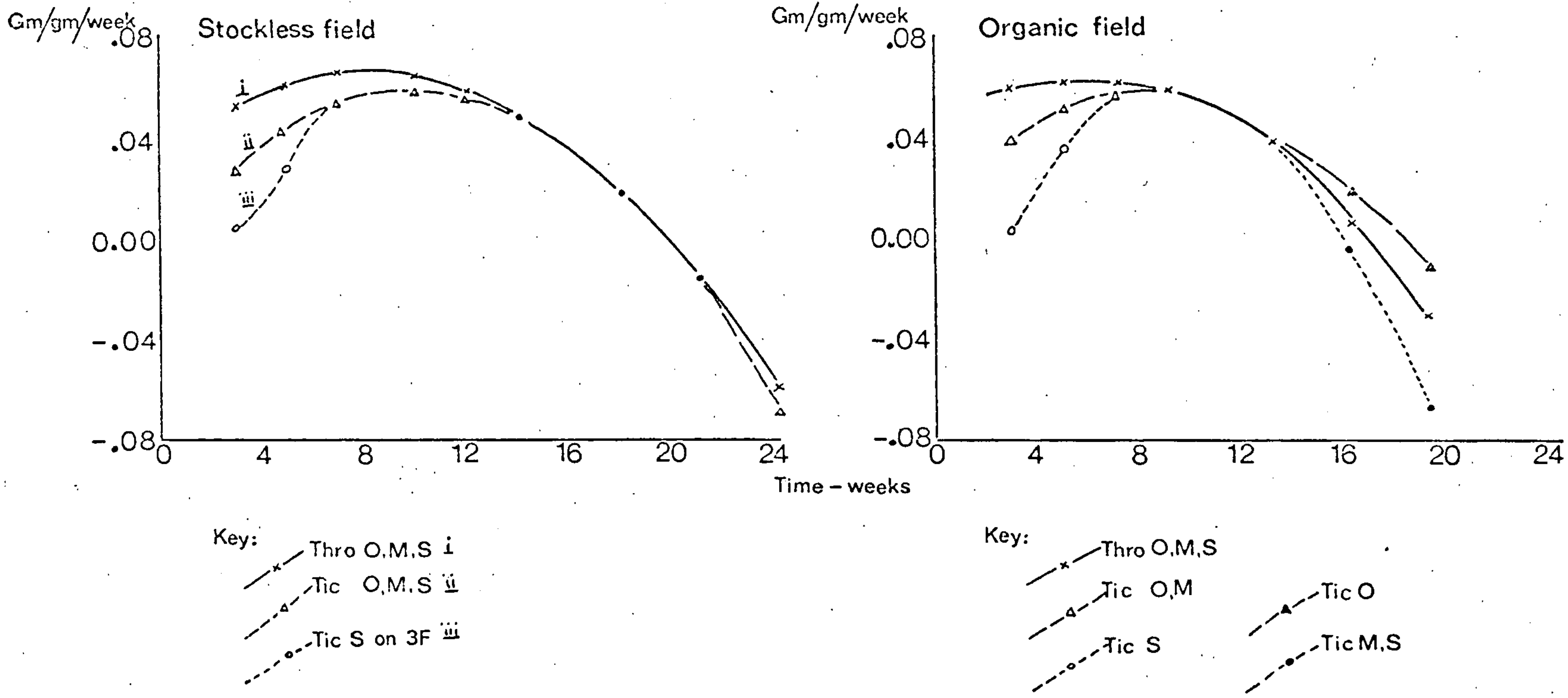
(1) Stockless field

A single curve I can be drawn, to accurately represent the calculated relative growth rate of all three Throws imprints, on all

Graph 3-11

Crop Growth - Field Trial 1971

Relative Growth Rate



fertilizer levels, because although Table A7(3) indicates some slight differences between OMS on the three treatments, these were not significant at the 95% level of confidence. Curve II represents the growth rate of all Tic imprint types, except Tic S on 3F during early growth, when this showed a slower growth rate (curve III). Maximum growth rate was achieved by Throws plants at eight weeks of age, and by Tic plants at 10 weeks of age. The differences between varieties were not significant.

(2) Organic field

The overall growth rate of plants upon this section depended greatly upon the imprint type and variety, hence the complex Graph 3-11(2). Again the progress of NAR for all Throws plants can be accurately represented by a single curve, which shows that initially the growth rate of these plants was greater than that of the Tic variety. During the first eight weeks of growth, Tic O and M grew equally well, but Tic S differed significantly (to $p = <0.05$) because the plant growth accelerated more rapidly than for O and M imprints. At week 16, the rate of senescence of Tic M and S plants was significantly greater (steeper incline of line) to $p = <0.01$ than that of Tic O. This difference was maintained through to week 19 ($p = <0.05$).

(3) For all Throws and Tic imprint types the progress of RGR through the first half of the season was very similar on the Organic and Stockless soils, all tending to reduce their growth rate at the same age. The only differences in the growth of the plants between the sections occurred after week 12, when, due to effect of calendar time, the senescence of O grown plants became more rapid than that of S grown plants.

:3.6.5 Conclusions from the Growth Analysis

(1) The imprinting of *Vicia faba* upon the three farm management sections was shown to have a small effect upon the growth responses of the

resulting plants where the process had been practised for many years (Tic variety), but for most parameters these differences were not statistically significant. Where imprinting had only been used for one year, (Throws variety), no differences between the seed types were observed for any of the growth parameters measured.

(2) The growth differences expressed by the three imprint types of Tic beans, were especially evident upon the Organic farm section, where for most parameters Tic O and M segregated out together, separately from Tic S. However, for the calculated relative growth rate which assessed the whole response of the plants (RGR = NAR x LAR), Tic O plants showed slow initial growth and slow senescence, Tic M showed slow initial growth, but rapid senescence, and Tic S plants both grew and senesced quickly. These differences may indicate that, to a small degree, imprinting had caused some dependence of the imprint type upon its own farm management type.

(3) The main differences brought about by imprinting *Vicia faba*, tended to be exhibited in terms of the age of achieving certain growth maxima, or the onset of senescence, rather than by the magnitude of the parameter measured.

(4) Changing the rate of application of the artificial fertilizers did not profoundly affect the magnitude of growth of any of the plants, except for Leaf Area and Net Assimilation Rate values. The fertilizer level interacted with the imprint types, to change the timing of the achievement of the maxima, and the onset of senescence. It has been found by several people, working on many different crops, that even where no change in the magnitude of growth or yield is brought about by application of fertilizer, the timing of flowering, maximum dry weight, and senescence, may be altered by the availability of nutrients from the soil (Borodin (1931) - barley; Boatwright and Haas (1961) - wheat; Tewari (1965) - soybean; McEwen (1970) - field bean).

It must be assumed from the lack of growth response by the plants to the fertilizer rates, that the level of available nutrients in the soil, where no fertilizer had been applied, were adequate for the growth of the bean plants, due to the retention of nutrients from the previous crop of wheat. Steenbjerg and Jakobs (1963) stressed that an experiment designed to show the effect of fertilizer on growth should be performed on a nutrient deficient soil, so that there would be no interference from integral nutrients. However, it was evident that there were no deficient soils at Haughley, thus the absence of any effect of increasing the fertilizer rates on growth could be expressed in terms of diminishing returns (Liebig 1855). Even where deficient soils have been used for nutrient experiments, problems may occur due to the soil properties. Thus Singh et al. (1973) found that the maximum crop response to added phosphorus did not occur on very deficient soils, because as soon as fertilizer was added, the phosphate was fixed into an unavailable form by the soil.

If the excess nitrogen applied to the Stockless field reduced nitrogen fixation by the root nodules (see Section 5), the level of nitrogen in the fertilizer, must have been sufficient to compensate for this suppression, so that there was no net effect upon the rate of growth.

(5) The timing of the maxima of the growth parameters was determined by a combination of treatment effect, plant variety and imprint type. Thus for :-

(5)-1 Dry weight - for all plant imprint types, of both varieties and on both farm management sections, the timing of the maximum depended upon calendar time.

(5)-2 Leaf area - the timing of the maximum depended upon plant age except for Tic S where it was controlled by calendar time.

(5)-3 LAR - for Tic variety the occurrence of maximum depended upon plant age.

- for Throws variety the occurrence of maximum depended upon calendar time.

(5)-4 NAR and RGR - achievement of maxima depended upon plant age.

(6) For most of the growth parameters considered, the differences occurring between the Organic and Stockless sections could be fully explained by the later planting date on the former section. Although the maximum dry weights achieved on the Stockless section were greater than on the Organic section, due to a longer period of time available for growth, the magnitude of maximum leaf areas showed no differences. For the calculated growth rates and ratios, the variations of the fitted curves were due to a faster early development, and an earlier onset to senescence, by the plants with the shorter growing season.

3:3.7 1972 Field Trial

:3.7.1 Aim

To compare the growth of a single seed type (*Vicia faba* var. Throws, bought commercially) on the three farm sections at Haughley, to check the conclusions reached concerning the effect of farm management upon growth in 1971.

This trial served to monitor the progress of growth on the different farm sections with reference to the chemical analysis tests made (Section 4), and the nitrogen fixation study (Section 5). It was also used to demonstrate the differences in yield between the plants grown in the field and those in the experimental lysimeters.

:3.7.2 Method

All the fields and lysimeters were successfully sown with Throws seeds within the same week in March. In order to follow the farm rotation the fields used for sampling were Lower Wassicks South (O) (as used in 1971), Seven Acres (M) and Chestnut Tree West (S). Upon six occasions during the growing season, five plants were removed at random from a small area in the centre of each field. They were measured for shoot length, leaf area and dry weight, as previously described, prior to chemical analysis.

:3.7.3 Results

The raw data as measured, and the fitted data from the computer programme, are listed on Table A-8. Some of the fitted curves are drawn on Graph 3-12.

:3.7.4 Discussion

.4.1 Raw data

(1) Shoot length - there was no significant effect of farm

management upon the magnitude of the shoot length at any time during the season, and the maxima attained occurred on the same date on all treatments.

(2) Leaf Area - the plants on the Organic and Stockless farm sections achieved their maximum leaf area at the same time, but those on the Mixed section reached this stage five weeks later. In magnitude the maxima followed the pattern O > M > S.

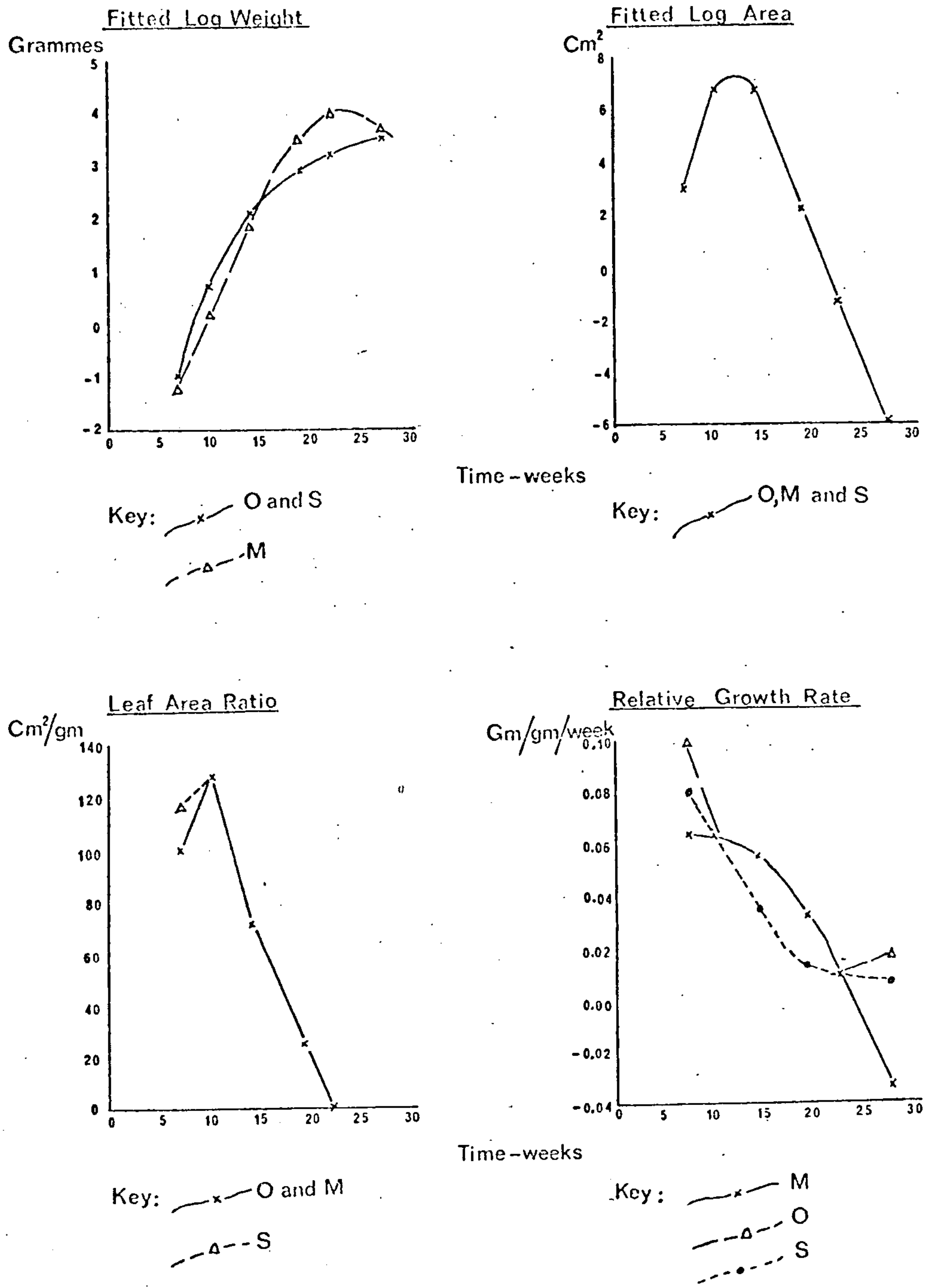
(3) Dry Weight - the plants on the Organic and Stockless sections achieved equal maximum dry weights at the same time, whilst those on the Mixed section attained a greater maximum value five weeks earlier. Thus in magnitude, the maximum dry weights followed the pattern $M > O \equiv S$ due to the greater weight of bean seeds, and pods per plant, on the Mixed section.

By comparison, the dry weights achieved at final harvest time, by the plants grown in the four lysimeter types, were very significantly lower than those found under natural field conditions. Whereas in the field-grown plants, the yield of bean seeds was responsible for most of the dry weight in the harvested plant, yields in the lysimeters were very low, with the dead stems contributing most weight to the plants. In the lysimeters, the relationship between management sections for overall plant dry weight was $S > S^{+} > M > O$ and for bean seed yield $S^{+} > S > M > O$. Thus the bean yield from plants grown under lysimeter conditions did not provide a true representation of the field situation.

.4-2 Fitted data

(1) Fitted Log Weight - throughout the growing season the dry weights of plants on the Mixed section differed from those on the Organic and Stockless fields, where the fitted dry weights were at all times equal. The dry weight of M was significantly ($p = <0.01$) lower during the early part of the seaon, but significantly higher ($p = <0.01$) than O and S after week 17 until harvest time.

Graph 3 -12 Crop Growth - Field Trial 1972



Note: O,M and S are types of Farm Management

(2) Fitted Log Leaf Area and Net Assimilation Rate - the fitted values of these parameters showed no effect of farm management type at any time during the growing season.

(3) Leaf Area Ratio - the progress of this parameter was very similar on all three management types, except during the initial four weeks when the leaves of the S plants developed more quickly than those on the other two sections. This difference was significant to $p = <0.01$ for $S > O$ and $S > M$. After week 10 there were no significant differences between sections.

(4) Relative Growth Rate - Graph 3-12 shows that although the growth rate of the plants on the Organic and Stockless sections differed slightly from each other at the beginning and end of the season, these differences were not significant and, for most of the season, development and senescence rates on these two sections were equal. However the growth rate of plants on the Mixed section differed significantly, for most of the season, from those on the other two sections. By the time of the first sampling, the maximum rate of increase of dry weight had already been achieved (i.e. prior to week 7), which corresponds well with the timing of this maximum in the 1971 Field Trial (week 7). At week 7 the maximum on M had only just been achieved, but for the O and S plants the rate of increase in dry weight was already falling sharply. By week 19, when the rate of increase on M had begun to fall steeply, the rate of increase on the other two sections had begun to level out. Thus at weeks 7, 14, 19, 27, the growth on M was significantly different to $p = <0.01$ from that of plants on O and S treatments.

:3.7.5 Conclusions

The results of the 1972 Field Trial bore out the findings of the 1971 trial - very few significant differences in growth were found between plants growing on the Organic and Stockless sections, despite the differences in the form of nutrient supply. Thus the differences between the Organic and Stockless sections observed in the 1971 Field Trial were probably entirely due to the later planting on the former section, and not due at all to an effect of farm management. For most parameters measured, the growth of plants on the Mixed section (where there was a maximum availability of nutrients from both organic and artificial sources), differed significantly from that shown on the other two farm management types. There was a significantly higher yield of bean seeds from the Mixed section plants. The lysimeter plants were not representative of the situation in the field.

3:3.8 1973 Field Trial

:3.8.1 Aim

To conduct a very brief survey of the growth of *Vicia faba* var. Throws on the three farm sections at Haughley, and on the Special Fertilizer Treatments used for the study of nitrogen fixation, to show the effect of additional inorganic nitrogen.

:3.8.2 Method

Ten plants were removed at random from each treatment, upon three occasions during the 1973 season. Each plant was measured for its shoot length, number of live leaflet pairs and number of inflorescences.

:3.8.3 Results

The results which appear below are referred to in Section 5 (effect of additional inorganic nitrogen upon nitrogen fixation) and in this section (effect of farm management upon yield of *Vicia faba*). The table shows the mean values with standard errors.

Table 3-5

Raw growth data from the 1973 Field Trial

			Treatment					
Growth Parameter	Date	Age (weeks)	O	M	S	PPKK	NNPPKK	NNPK
Mean shoot height (cms)	23/5	10	23.0±1.0	17.3±1.4	17.7±0.9	16.3±0.6	18.5±0.6	-
	7/6	12	69.8±1.9	55.2±0.9	55.1±1.4	52.3±1.0	48.2±0.9	48.8±1.3
	20/6	15	107.0±1.6	90.0±1.8	86.0±1.7	79.3±2.0	71.9±1.4	81.1±0.9
Number of live leaflet pairs	23/5	10	5.0±0.2	5.1±0.1	5.2±0.2	4.9±0.3	5.0±0.1	4.7±0.3
	7/6	12	6.5±0.5	10.3±0.3	10.3±0.5	11.1±0.3	11.5±0.3	9.8±0.5
	20/6	15	16.0±1.0	26.0±1.0	29.0±1.0	25.0±2.0	26.0±2.0	24.1±1.0
Inflorescences	20/6	15	2.5±0.3	6.5±0.4	6.4±0.3	6.0±0.2	6.5±0.3	6.2±0.2

:3.8.4 Conclusions

(1) Despite a longer stem, the average plant on the Organic system had significantly fewer live leaflet pairs than the plants on the Mixed and Stockless sections. Much of the increased lengthening of the internodes (Organic section) was seen to be due to light competition caused by a heavy infestation of the field by *Sinapsis arvensis*,(see photograph), which resulted in very few inflorescences per plant and consequently a low seed yield.

Growth on the Mixed and Stockless sections differed slightly with longer stems on M but fewer leaflet pairs. Stockless plants were potentially the most efficient,with shorter stems and a greater leaf area.

(2) On the Special Fertilizer Treatment,the addition of nitrogen to the double PK reduced the mean shoot length, but increased the number of leaflet pairs and inflorescence. When nitrogen was added to the normal PK rate the effect on growth was to slightly, but not significantly, lengthen the total shoot height, but to reduce the number of leaflets, and slightly, but not significantly, increase the number of inflorescences per plant.

3:3.9 Yield of seed by *Vicia faba*

:3.9.1 Background

Several aspects of the dynamics of the *Vicia faba* phytometer have already been discussed to demonstrate the outward expression of farm management in terms of the growth of the crop, but from the farmers' position the most important parameter by which to assess the effect of a system will be crop yield. The ultimate decision concerning the selection of one farm management approach in preference to any other will be determined by the best economic return which can be gained from the crop yield, in relation to the investment required for the input of seed, fertilizers, manures and labour.

:3.9.2 Aim

To assess the farm management at Haughley by a consideration of the characteristics of bean seed yield by the *Vicia faba* plants, over a three year period.

:3.9.3 Method

At the final harvest of the *Vicia faba* crop, ten plants were removed at random from each field studied and a number of measurements were made. These included the number of pods per plant; the number of seeds per pod and hence per plant; the dry weight per seed, and hence of seed yield per plant; and from these were calculated the predicted yield of seed (Kg/ha). In 1971 the development of the bean seeds over the final six week period was investigated for each of the three plant imprint types of the two varieties Tic and Throws. In 1973, in addition to the study of the three main farm sections, measurements of plants grown on the Special Fertilizer Treatment area, (used for nitrogen fixation study), and the Commercial section were included.

(1) Achievement of maximum flowering :

Stockless with herbicides

Organic without herbicides

(2) State of bean field at harvest time

:3.9.4 Results

The results from the 1971 study are shown in full detail on Table 3-6, and the summarized results for all three years are presented on Table 3-7.

:3.9.5 Discussion

.5.1 1971

(1) The results shown on Tables 3-6 are discussed by considering plants on the Organic and Stockless sections measured on the same calendar date. Thus, according to the stage in development, plants of age 13, 16 and 19 weeks on the Organic section were considered equivalent to plants of 18, 21 and 24 weeks on the Stockless section. The final calculated mean yield was derived from the estimate of the plant density in all fields of 27 plants/square metre, and the mean bean seed yield per plant.

(2) From the table it is evident that the measurements of potential yield made six weeks prior to final harvest proved to be a poor guide to the actual final yield found. During the six week period many pods and seeds failed to develop beyond the initial stage. Of those which did fully develop, many pods dried out and dehisced, scattering their seeds on the ground before the final harvest date. In some instances whole pods were lost due to the abscission of the peduncles from the dying stems. Thus, particularly between weeks 21 and 24, the numbers of seed borne on each plant were substantially reduced.

(3) The two main characters influencing the final yield of seed harvested were the number of pods per plant, and the dry weight per seed. Although the yield of seed from all imprint types on the Organic section was lower than that produced on the Stockless section plants, this was chiefly due to lower numbers of pods per plant - the numbers of seeds per

Table 3-6

The Yield of Pods and Seeds from the 1971 Field Trial.

Dry weights are expressed in grammes.
Each reading is the mean from ten plants.

Treatment	STOCKLESS - NO FERTILIZER						STOCKLESS - 375 Kg FERTILIZER/ha						STOCKLESS - 625 Kg FERTILIZER/ha							ORGANIC					
Age & measurement	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Age	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S
Week 13																			Week 13						
No. pods/plant	12	15	15	9	17	32	13	12	9	22	25	23	14	9	18	21	28	24		9	5	9	6	6	6
Total pod wt./plant	16.2	13.3	23.1	6.7	18.7	24.0	13.3	11.0	11.4	17.2	16.9	21.5	28.4	15.9	18.1	25.5	16.6	15.0		1.15	0.33	1.43	0.79	1.05	1.25
Dry wt./pod	1.35	0.89	1.54	0.36	1.10	0.75	1.02	0.92	1.27	0.78	0.68	0.94	2.03	1.14	1.00	1.21	0.59	0.63		0.13	0.07	0.16	0.13	0.18	0.21
No. seed/pod	3	3	3	4	4	3	4	3	3	3	3	4	3	3	4	4	4	4		-	-	3	-	4	-
No. seeds/plant	36	45	45	36	68	96	52	36	27	66	75	92	42	42	72	84	112	96		-	-	27	-	24	-
Week 21																			Week 16						
No. pods/plant	12	11	9	20	16	19	13	10	12	17	21	22	11	16	9	17	23	23		7	7	8	9	14	10
Total pod wt./plant	24.8	29.2	26.8	35.4	33.2	32.4	31.4	25.0	31.8	27.7	36.2	31.3	24.6	19.9	24.3	28.4	30.7	34.7		10.4	10.7	17.7	8.5	6.8	10.0
Dry wt./pod	2.06	2.65	2.98	1.77	2.07	1.71	2.42	2.50	2.65	1.63	1.72	1.42	2.24	1.24	2.70	1.67	1.34	1.51		1.49	1.52	2.21	0.94	0.49	[illegible]
No. seed/pod	3	4	3	4	4	4	3	3	4	4	3	4	3	3	3	4	4	3		3	3	3	4	3	3
No. seeds/plant	36	44	27	80	64	76	39	30	48	68	63	88	33	48	27	68	92	89		21	21	24	36	42	30
Week 24																			Week 19						
No. pods/plant	8	7	6	11	11	17	7	6	11	9	18	10	9	7	6	16	17	17		7	3	4	7	6	6
Total pod wt./plant	15.4	11.9	19.2	8.8	16.4	20.4	16.2	17.5	17.6	9.9	10.0	10.0	22.4	12.6	13.9	19.2	23.8	18.7		15.2	5.7	8.9	10.3	8.9	5.9
Dry wt./pod	1.90	1.70	3.20	0.80	1.50	1.20	2.30	2.90	1.60	1.10	1.00	1.00	2.50	1.80	2.30	1.20	1.40	1.10		2.17	1.90	2.22	1.47	1.48	[illegible]
No. seed/pod	3	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3	4	3		3	3	3	3	3	3
No. seeds/plant	24	21	18	33	44	68	21	18	33	27	54	30	27	21	18	48	68	51		21	9	12	21	18	18
Mean dry wt./seed	0.592	0.600	0.634	0.368	0.329	0.361	0.554	0.552	0.587	0.335	0.334	0.337	0.629	0.667	0.581	0.377	0.318	0.363		0.479	0.481	0.495	0.274	0.300	[illegible]
Mean dry wt. seed/plant	14.21	12.60	11.41	12.14	14.48	24.55	11.63	9.94	19.37	9.05	18.04	10.11	16.98	14.01	10.46	18.10	21.62	18.51		10.10	4.33	5.90	5.80	5.40	[illegible]
Mean yield seed in Kg/ sq. metre	0.384	0.340	0.308	0.328	0.391	0.663	0.314	0.268	0.523	0.244	0.487	0.273	0.459	0.378	0.282	0.489	0.584	0.500		0.273	0.117	0.159	0.157	0.146	[illegible]

pod remained constant under both management types.

(4) Under all four treatments, all imprint types of the Throws variety of *Vicia faba* produced significantly smaller and lighter seeds than the Tic variety plants, but this was more than compensated for by a significantly larger number of pods per plant on the former variety.

(5) From the table there do not appear to be any clear consistent trends of difference concerning the yield of seeds, between the three imprint types, in either variety. In the previous discussion on growth, certain small differences were shown to exist between the Tic imprint types (few of these were statistically significant), but very few were shown between Throws imprint types due, presumably, to the shorter imprinting period. When the yields of bean seeds were considered, the great variability between imprint types of both varieties indicated no influence of this process upon seed production.

(6) In order to clarify the effect of the fertilizer treatment upon seed production, a summary table overleaf shows the mean Tic and Throws yields calculated from the three imprint types.

Mean Yield of Pods and Seeds by Tic and Throws Plants

Variety		Tic				Throws			
Treatment		Organic	S-NF	S-3F	S-6F	Organic	S-NF	S-3F	S-6F
Parameter and Time (weeks)									
Number of pods/plant	H-6	8	14	11	14	6	19	23	24
	H-3	7	11	12	12	11	18	20	31
	H	5	7	8	7	6	13	12	17
Number of seeds/plant	H-6	24	42	36	46	24	70	76	96
	H-3	21	36	40	36	36	72	73	114
	H	14	21	24	22	19	48	37	56
Dry weight /seed(gms)	H	0.49	0.61	0.56	0.63	0.29	0.35	0.34	0.35
Dry weight seed/plant (gms)	H	6.8	12.8	13.4	13.9	5.5	17.0	12.6	19.6
Yield seed (Kg/ha)	H	1830	3440	3680	3730	1490	4610	3350	5240

(Where : H = Harvest time)

The earlier discussion of the growth parameters concluded that no differences of growth were caused by altering the rate of application of NPK fertilizer on the Stockless section. From this table, however, a clear influence over yield was seen to occur, so that the yields of Tic plants followed the pattern 6F > 3F > NF > Organic - increasing the rate of NPK application increased bean seed yield, agreeing with the findings of

Mc Ewen (1970) and Hardy et al. (1971). For the Throws variety, due to an unexpected reduction in the number of seeds borne per plant, between H-3 and H on the mid-fertilizer level, the pattern of yield was 6F > NF > 3F > Organic.

(7) Both varieties suffered poor yields on the Organic section, which may have been due entirely to the shorter growing season on that section, or due to treatment, or due to a combination of the two effects. The reduction in yield, compared with that on the three fertilizer treatments, was greater for the Throws variety, where there was a severe reduction in the number of pods per plant, and a lessening of the dry weight per seed, whereas Tic plants suffered only the latter reduction.

.5-2 1971-1973

(1) Table 3-7 includes the figures for yields from the Throws plants on the Organic (LWS) and Stockless fertilizer (Road) plots in 1971, for comparison with the seed production measured under normal field conditions in 1972 and 1973. The figures for the Organic section confirm the postulation that the low yields in 1971 were due to a shorter growing period, rather than being truly representative of the field situation on that management type. However, the yield from the 'no fertilizer' treatment in 1971 proved to be roughly equivalent to that from the Stockless fields in 1972-3, in terms of pod and seed number, although the dry weight per seed was greater in 1971. The Road field used for the Stockless plots in 1971 must have had a high background level of nutrients remaining from the previous wheat crop and applied fertilizer, so that no nutrients were limiting to growth.

(2) In Table 3-6 the total predicted yield of seed was calculated, using the figure of 27 plants/square metre density, which was found to be the mean density throughout the season on all farm sections. Thus to predict the total yield per hectare :-

Table 3-7

DYNAMICS OF CROP GROWTH

Summary Table of Crop Yield of Throws Variety under Three Systems 1971/73.

Each mean calculated from 10 samples.

Field Type and Date	Field Name	No. pods /plant	No. seeds /plant	Dry wt/seeds (gms) ± SE	Dry wt/seeds /plant (gms) ± SE	Predicted yield Kg/ha	Actual yield	% Actual :predicted
ORGANIC								
1971	L.W.S. plot	6	19	0.290 ± 0.013	5.50 ± 0.5	1490	1490	-
1972	L.W.S.	14	44	0.436 ± 0.022	19.18 ± 1.3	5184	3510	68
1973	Oxer	13	47	0. 40 ± 0.013	11.28 ± 1.5	4240	2640	62
	Nappers	10	30	0.320 ± 0.019	9.60 ± 1.2	3480	1320	38
Mean field		12	40	0.332 ± 0.019	13.28 ± 0.9	4301	2490	56
MIXED								
1972	7 acres	19	63	0.359 ± 0.009	22.62 ± 1.8	6102	3050	50
1973	Gypsey	19	63	0.273 ± 0.009	17.20 ± 1.1	6290	3490	56
Mean field		19	63	0.316 ± 0.009	19.91 ± 1.5	6196	3270	53
STOCKLESS								
1971	Road plot	13	48	0.350 ± 0.009	17.10 ± 1.0	4610	4610	-
1972	ChTW	15	55	0.333 ± 0.009	18.32 ± 0.8	4941	3550	72
	F. Break	-	-	-	-	-	3390	-
1973	Little	11	42	0.295 ± 0.009	12.40 ± 1.2	4430	3010	68
	Wetherden	10	28	0.325 ± 0.016	9.09 ± 0.9	3270	2850	87
	ChTE	13	44	0.251 ± 0.009	11.04 ± 1.7	4080	3010	74
Special Plots								
1973	PPKK	12	40	0.288 ± 0.009	11.51 ± 1.6	4130	4130	-
	NNPPKK	13	40	0.273 ± 0.013	10.92 ± 1.9	4080	4080	-
	NNPK	11	33	0.266 ± 0.013	8.77 ± 1.3	3160	3160	-
Mean field		12	43	0.301 ± 0.006	12.94 ± 0.6	4180	3162	75
COMMERCIAL								
1971	Tips	-	-	-	-	-	2920	-
1972	Church	-	-	-	-	-	3640	-
1973	Hill	19	67	0.273 ± 0.013	18.29 ± 1.8	6370	2820	44
	Stackyard	22	67	0.266 ± 0.006	17.80 ± 1.4	6480	2850	44
Mean field		21	67	0.270 ± 0.009	18.05 ± 1.6	6425	3058	44

Abbreviations:
L.W.S. = Lower Wassicks South
7 acres = Seven Acres
ChTW = Chestnut Tree West
ChTE = Chestnut Tree East.

Yield = Mean dry weight bean seeds per plant x 270,000 x F

where F was the factor required to convert the dry weight to the fresh weight, as collected. The moisture content of the bean seeds at harvest for all sections fell in the range 24-27%, with a mean of 26.2% water. Thus on Table 3-7, the column marked 'predicted yield' was calculated in this way. The following column labelled 'actual yield' was the bagged weight recorded by the farm after the field had been combined, the figures showing great discrepancy from the predicted yields due to several factors listed below :-

(2).1 The density of bean plants in the randomly thrown one metre quadrat was not truly representative of the conditions over the whole field, due to lower densities in headlands, in weed infested areas, in tree shade, and where local death of the crop had occurred. Thus the figure of 27 plants/square metre was the maximum density of plants in the field.

(2).2 It is possible that the plants chosen at harvest time, from which the figure of the mean seed weight/plant was calculated, were not truly representative of the plants over the whole field. Although plants were collected at random, those which had lodged were not included, due to minimal bean formation.

(2).3 Whilst the stems of the bean plants were drying and the pod cases becoming blackened, many pods dehisced and lost their contained seeds. For many plants whole pods may fall to the ground. This was particularly marked during combining when many thousands of bean seeds were lost in this way. Between the field and the weighing station further losses occurred.

Thus the predicted yield is the maximum which would be expected if there were no losses prior to, and during, harvesting, and if there were no barren plants or open areas in the field. The experimental plots harvested by hand in 1971 were of uniform density and did not suffer such harvesting losses. For 1972, from the relationship between the actual and projected yield, it was possible to determine the number of plants/ha in each section which would have been standing in the field if all plants had borne the mean dry weight of seed found :-

	O	M	S
Projected yield Kg/ha	5;180	6,102	4,940
Actual yield Kg/ha	3,510	3,050	3,550
No. plants in field/ha bearing mean crop weight	182,930	135,000	193,970

However, it is unlikely that there would have been as few plants as these numbers in the field, because, as previously stated, very few plants will have produced the mean seed weight/plant. Therefore in the Crop Geochemistry (Section 4) section, the figure used to estimate the mean removal of nutrients from the field in the whole plants at harvest time was 270,000 plants, as this was the best approximation to the number of plants which could have been harvested. But when considering losses of nutrients in the bean seeds alone, where figures are available, the actual yield of seeds was used.

(3) Table 3-7 demonstrates the great variability of the yield of bean seeds within each section,from different fields, and separate years. Even where the number of pods per plant, and the number of seeds per plant, remained constant within a section (M), there was a large variation in the dry weight per seed, and hence the total yield. Within the Organic section, the considerable difference in yields in 1973 between Oxer and Nappers fields was due to the very intense competition for light and moisture from the heavy infestation of charlock in the latter field (see photograph). It was predictable that a low yield would occur on Nappers from the poor inflorescence formation (see 3:3.8). All the Organic fields tended to suffer

from this weed as no herbicide could be applied, but the invasion into Nappers field was particularly marked. Hewson et al. (1973) showed that in dry years (such as 1973), when soil moisture was at a premium, the reduction in yield due to competition for water, nutrients and light could be up to 80% for *Vicia faba*. The competition reduced both the number of pods/plant and the dry weight/seed. Within the Stockless section, where most bean fields were sited during this research project, the variation in yields between fields was very marked. Although the number of seeds/pod remained fairly constant, the number of pods/plant and dry weight of individual seeds was very variable.

(4) The yield of bean seed from the Organic, Mixed, Stockless and Commercial fields was statistically compared (Bailey 1959) to determine which differences between the mean yield/section were significant. The results appear below :-

Parameter	Dry weight of seed				Dry weight of seed/plant			
Statistic	df	d	p	R	df	d	p	R
Field types compared :-								
O v M	45	1.23	>0.1	N S	30	5.66	<0.001	M > O
O v S	34	2.82	<0.01	O > S	45	0.54	>0.1	N S
M v S	27	2.03	<0.05	M > S	22	6.53	<0.001	M > S
O v C	45	4.77	<0.001	O > C	28	3.77	<0.001	C > O
M v C	39	4.84	<0.001	M > C	38	1.20	>0.1	N S
S v C	28	4.19	<0.001	S > C	21	4.33	<0.001	C > S

Individual seed weight - despite the great range of values found on all sections except the Commercial fields, individual seed weight on plants grown on the sections receiving organic manures was greater than that of plants grown on artificial fertilisers alone. This does not agree with the conclusions reached from the initial survey of Throws bean seeds produced in 1970, at the beginning of the growth survey, but those seeds had been in store for several months prior to investigation, and had been produced in a different year. For many results concerning research into the growth of crop plants, the influence of season is more marked than any other factor (Alexander and Woodham 1958). The individual seed weight on the Commercial section was significantly the lowest of any management in 1973. The relationship between the sections was O $\equiv$ M > S > C.

Seed weight per plant, and hence yield/hectare - due to the similarity in numbers of seeds per plant between the Commercial and Mixed sections, there was no significant difference in the overall yield of these managements, but they were both significantly more productive than either the Organic or Stockless sections. Although the conditions of management concerning the form of nutrients added to the system were very similar for M and C, the latter received organic manures every year (see Soils section 1), thus the input of nutrients was more expensive for the yield return. Thus the Mixed section was the most economically productive system. Although the Organic seeds were significantly heavier individually, than those produced on the Stockless section, the latter plants contained more seeds per pod, and hence no significant differences in yields were observed. Thus the relationship between the sections for seed weight per plant was found to be : C $\equiv$ M > O $\equiv$ S.

(5) Table 3-7 also records the effect of the Special Fertilizer Treatments in 1973 on the yielding capacity of the plants. The effect of adding double nitrogen to the PPKK treatment was to lower the number of seeds per pod, to reduce the dry weight of individual seeds and the dry weight of seeds per plant, but none of these reductions were statistically significant. When the double nitrogen application was added to the normal

level of phosphorus and potassium, the reduction effect upon all three of these parameters was increased. Thus the depressing effect of double nitrogen was partly compensated for by the higher levels of PK. This follows the trend found concerning the effect of the nitrogen treatments upon the nitrogen fixation by the *V. faba* root nodules,where (although not significant) PPKK > NNPPKK > NNPK (see Section 5). These results do not conflict with the findings of 1971, where increasing fertilizer levels altered the yield of Throws plants, because different rates of application,of different fertilizers,were used in the two seasons.

:3.10 Overall conclusions from Growth Section

(1) The effect of imprinting *Vicia faba* seeds caused small changes in the growth of the consequent plants, but these changes were mainly statistically non-significant, and did not fit any imprint type to grow better on its own management type - no physiological evolution was proved to have occurred. Elhomidi, Moursi and Ahmed (1968) stated that seed physiology and performance were not easily changed by nutritional, or environmental,factors.

(2) The field trials demonstrated that increasing the rates of fertilizer application affected the date of attainment of the maxima of the growth parameters measured, but did not change significantly the magnitude of growth, except with regard to yield. In 1971, increasing the rate of NPK fertilizer significantly increased the yield of bean seeds, but in 1973 this reduced the yields, although not significantly. In agreement with McEwen (1970) and Welch et al. (1973), the return in yield, produced by the addition of nitrogen fertilizer to beans, would be uneconomical farm management.

(3) The greenhouse and field trials demonstrated that although the main influence upon the growth of the bean plants was the type of farm management upon which they were growing at the time of study, there were no significant differences in growth or yield between the Organic and Stockless systems. A significant increase in growth and yields was found in plants on the Mixed and Commercial systems, with the greatest economic return occurring on the Mixed section.

SECTION 4. CROP GEOCHEMISTRY

Section 4 CROP GEOCHEMISTRY

4:1 Background

4:1.1 Under natural conditions, growing plants are subject to an accretion of nutrient ions from, and loss to, their environment; the chemical composition of the plant is thus a net result of this bidirectional movement. The main source of the nutrients for the plant is the rooting medium from which minimum quantities of certain geochemicals are required, to maintain the growth of the plant. The uptake of nutrients through the root system is controlled by a complex of interacting factors which are difficult to investigate accurately. The plant has only a limited ability to discriminate between various ions and other soluble substances in the soil, so that some geochemicals which are unnecessary, or even toxic, to the plant may enter the root system (Turner 1969). The principal factors controlling geochemical uptake are :

:1.1.1 The form in which the geochemical occurs in the soil, and its concentration in the soil solution, at the active root surface (Nielsen 1972).

:1.1.2 The rate at which the reserve of each element can move from the labile pool in the soil to the root surface e.g. nitrate very mobile, phosphate immobile.

:1.1.3 Conversion rate of non-exchangeable to exchangeable forms by weathering, microflora, mineralization and leaching.

:1.1.4 The efficiency of the roots to transfer the external geochemicals to the vacuoles of the cortical and endodermal cells.

:1.1.5 The soil moisture - the dilution of the soil solution displaces the cation exchange equilibrium so that adsorption of divalent ions increases, and that of monovalent ions decreases (Arnold 1967).

:1.1.6 The rate of growth of the roots through the soil, and the rate of increase of the absorbing surface area.

:1.1.7 The rate of utilization of each geochemical, which will depend upon the stage attained in the growth cycle (Boatwright and Haas 1961), influencing the concentration gradients within the root, and between the root and soil.

:1.1.8 The presence of any low concentration, toxic substances acting as specific inhibitors, or high concentrations of a normal soil component acting as a non-specific inhibitor (Bollard and Butler 1966).

:1.1.9 The ionic balance within the plant.

4:1.2 During the process of ion uptake, the electrochemical neutrality within the plant must be maintained (Kirkby 1969). As plants absorb inorganic ions at different rates, the ionic equilibrium may be controlled by

(1) the excretion of H^+ or HCO_3^- ions into the rooting medium,

(2) within the plant, by accumulation of organic acids (e.g. malate),

(3) by the recombination of the metal cations to form salts, with anions absorbed, or produced by the plants' metabolism (Dijkshoorn 1969).

In this latter way the shortage of one cation, for example potassium, may be partly replaced by the excess of another, e.g. sodium, without any apparent anomalies of total ion accumulation. Thus the growth of a plant will be strongly influenced by the balance of cations and anions, both in the rooting medium and within the plant. The metallic ions tend to exert their ionic charge when within the plant, and these must be compensated for by negatively charged nitrate, sulphate and phosphate ions. After these have been used for charge neutralization, any excess of cations over anions will be balanced by carboxylate ions, produced from absorbed bicarbonates, or released during the metabolic assimilation of nitrate (Böning et al. 1932). Therefore a given nutrient supply will only support the maximum growth rate of a plant when there is an adequate amount of each ion absorbed, to allow utilization of the ions and the maintenance of the normal concentrations of carboxylates (de Wit et al. 1963).

4:1.3 Many research workers have demonstrated the complex interaction, and antagonism, between geochemicals in the soil-plant system, which so strongly influences the resulting chemical composition of the plant tissues. Kirkby and Mengel (1967) showed that the form in which nitrogen was supplied to the tomato plant had a profound effect upon the uptake of several other cations. Thus when nitrogen was available in the ammonium form there was a reduction in the uptake of Ca^+, Mg^+ and K^+ due to a confliction of charge, whereas nitrogen in the form of nitrate enhanced cation uptake. In agriculture, the predominate source of nitrogen to crop plants is in the form of nitrate. Where ammonium ions were applied, these were quickly converted to the negatively charged ion, but where nitrification was inhibited, either naturally or artificially (to reduce leaching losses of nitrate), a large uptake of ammonium ions was found to result in a reduction of the inorganic cation uptake. Thus where NH_4^+ and K^+ are applied, especially to light acid soils, Mg^+ deficiency may result. Richards (1956) showed that potassium deficiency was increased when nitrogen was applied as ammonium, instead of nitrate.

4:1.4 Few experiments have been conducted with whole plants in a controlled environment, using nutrient culture, where the concentrations of geochemicals were as low as is found in the soil solution (Nye 1969), but where this has been done (Russell et al. 1954, Loneragan and Asher 1967), the plant uptake was directly proportional to the supply concentration of each geochemical. In soil, the limiting factor for the uptake of nutrient ions is the number of ions at the root surface, which will be proportional to the concentration of that geochemical in the soil solution (Gunary and Sutton 1968). Because of the dependence of nutrient uptake by the plant on the concentration of ions in the soil, it has been recognised by many people that the chemical composition of a plant can be satisfactorily used as a guide to the availability of nutrients in the rooting medium (Greenham and White 1959, Boynton and Oberly 1966, Wilson 1973). Hence the use of leaf analysis has become an established method to determine deficiencies of nutrient geochemicals in agricultural crops. Bould and Parfitt (1973) showed that the level of phosphorus in leaves of apple trees could be used to predict the flowering performance and yield, and that a critical concentration value was recognisable, below which phosphate was limiting to maximum growth.

4:1.5 Many experiments have been conducted in an attempt to elucidate the complex relationships which control the uptake of geochemicals into the plants, and to investigate the extent to which uptake is proportional to the availability in the soil. In 1969, Hodgson stated that organic complexing played a vital role in the uptake of micronutrient cations, especially with reference to the heavy metals. Although interactions between cations do occur, Anderson et al. (1973) showed that the uptake of Cr, Ni and Co in oats was proportional to the supply in the soil, and Dolar and Keeney (1971) demonstrated this to be true for Cu. Broyer et al. 1972), working on *Phaseolus* and barley, and Jones et al. (1973), on ryegrass, described the direct relationship between lead concentrations in the roots, and the available level in the soil, but showed how this was modified by the sulphur content of the soil. The degree to which the analysis of plant material can predict the availability of geochemicals in the soil, as determined by chemical analysis of the soil, will depend upon the methods and species used.

4:1.6 In 1953 Sen and Sundara Rao, and in 1973 Khare et al., demonstrated that increasing phosphate levels in the soil increased the phosphate and calcium concentrations of the legumes grown upon it. Boatwright and Haas (1961) showed that the timing of the maximum uptake in wheat was influenced by the particular geochemical considered, by the plant part, and by the stage attained in the plant's growth cycle. Nitrogen concentrations in the plants were increased by the addition of nitrogen to the soil, but the addition of nitrogen and phosphorus decreased the nitrogen concentrations, due to the dilution effect of increased growth. Because many plants can absorb nitrates to an excess, over and above the amount required for metabolism, which may accumulate in the unchanged ionic form, van Burg (1966) analysed plant tissue for nitrate to determine whether they had an adequate supply of this geochemical in the soil. Bassioni (1973) suggested that the uptake of nitrate in barley was strongly influenced by the uptake of the associated cation. The higher the valency of the cation, the greater the stimulatory effect i.e. Th > Al > La > Mc > Ca > K - the cations acting as catalysts, or affecting the formation/dissociation constant of the nitrate carrier complex. Tewari and Mandel (1972) confirmed the work of Loew and May (1901) and Hunter (1949), showing that magnesium aids the absorption and distribution of phosphorus in soybean plants, so that phosphate uptake was enhanced by increasing soil levels of magnesium, but decreased by adding calcium. Bould and Parfitt (1973) demonstrated the intricate interdependence of five major plant nutrients :-

Concentration of N in leaf increased by increasing available N or P

Concentration of K in leaf increased by increasing available K, but decreased
by increasing P or Mg

Concentration of Ca, Mg in leaf increased by increasing available P, but
decreased by increasing K

Concentration of P in leaf decreased by increasing available N, high P
interferes with Zn and Fe translocation

4:1.7 The plant tissue composition may also depend upon the water stress in the plant (Nezgovorova 1957 - oats and maize) and the age of the plant parts analysed (Jacoby and Dagan 1969) , because once inside the plant, the geochemicals will be translocated from one part to another, depending on demand. Thus when growth is mainly apical, geochemicals will continue to move through the xylem to the lower leaves until these achieve maximum size, when assimilates and some ions (potassium) will be exported to other plant parts in the phloem. However, calcium has been shown to be retained in the leaves, so that by continuing the intake, the concentration of this ion will accumulate in the older leaves, particularly in legumes. During senescence the efficiency of the phloem decreases, and the reduced ability to export assimilates will mean that many compounds may accumulate in the dying leaves (Thrower 1967 - soybean). Thus the composition of the leaf material will depend upon its position on the plant and its age (Ward 1964; Kirkby and DeKock 1965). In addition, during senescence of the plant, a minimum level of each ion required may be maintained in the actively-forming seeds by transfer of endogenous nutrients from another part of the plant, after the external source has been depleted, or lost due to the death of the roots (Dijkshoorn 1969).

4:2 Investigation of the geochemistry of the bean plants

4:2.1 Aim

(1) To determine whether the farm management at Haughley influenced the chemical composition of the *V. faba* plants - the discussion in section 4:1 indicates that the chemical composition of a plant frequently reflects the nutritional status of the soil upon which it is growing.

(2) To compare the plant imprint types at the physiological level, on the basis of their chemical composition.

4:2.2 Method

The plants used for the measurement of growth from the greenhouse and field trials (Section 3) were subjected to chemical analysis, as described in the Appendix. The effect of the soil treatment and the imprint type upon the plant chemical composition was measured at frequent intervals during each experiment, by determining the concentration of the geochemicals in the tissues, expressed in parts per million.

4:2.3 Results

The results of the chemical analysis determinations are discussed separately for each experiment, in terms of the concentration of each geochemical (μgm/gm plant). The effect of the treatments and plant type upon the biochemical composition of the crop was evaluated in each trial, at the times of the various growth maxima determined in Section 3. Because of the number of treatments used, the sampling of each imprint type was not often replicated - therefore, in the comparison of the composition of different plant imprints, statistical analysis of any differences could not always be used. However, where the imprint type was shown to have no apparent effect upon the composition, within each treatment, the three imprints of the two varieties have been considered to be replicates of a single population, in order to calculate the mean composition for the treatment - this has enabled the statistical comparison of the treatment effects.

4:3 1970-1971 Greenhouse Trial

4:3.1 Aim

To provide plant material upon which to perfect the techniques of chemical analysis, to enable an initial determination of the effect of the plant imprint and soil type upon the chemical composition of the crop.

4:3.2 Method

The *Vicia faba* plants were grown and sampled as described in Section 3. The methods of chemical analysis used are shown in the Appendix. The plant and soil types used for this trial are shown below :-

Measurements	Plant material			Treatment
Crop geochemistry - plants analysed for : NO_3-N, N, P, K, Ca, Mg, Na and Zn	Tic O	Tic M	Tic S	Soil - from Organic farm - from Stockless "

4:3.3 Results

The full analytical data are shown on Tables A9 and A10 Some of the results are presented in the following graphs to demonstrate the effect of the plant imprint type, and that of the soil type, upon the chemical composition of the plants, expressed as the concentration of each geochemical per gm dry weight of the whole plant. In this pilot project no replication of the chemical analyses was made, which prevented the use of statistical analysis in the evaluation of the data produced.

4:3.4 Discussion

The salient features of the graphs are described with reference to :

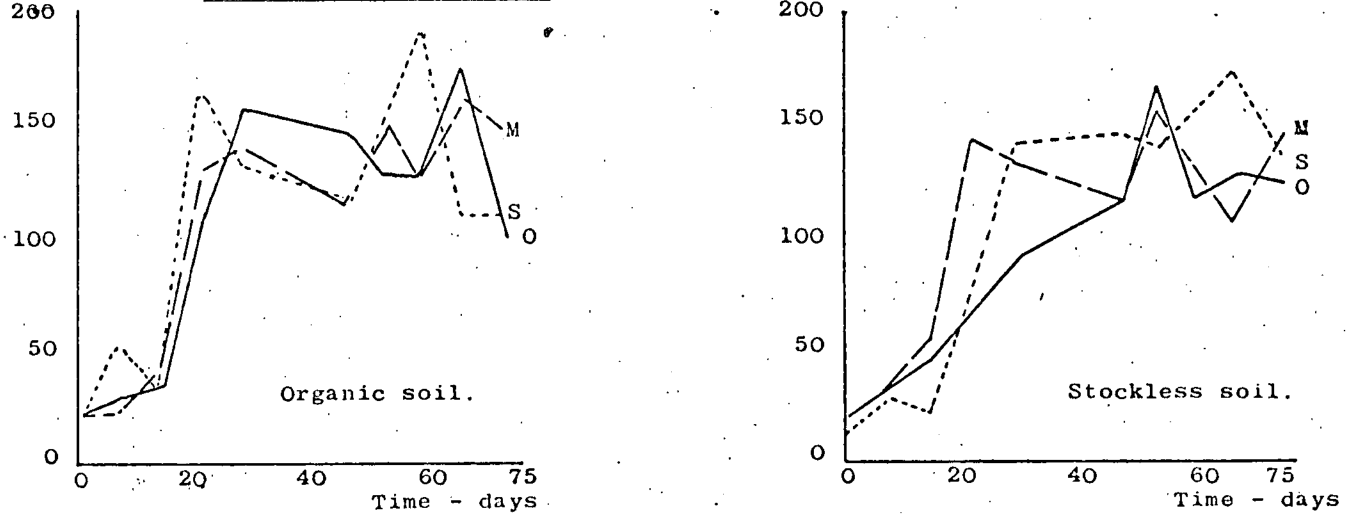
(1) The influence of imprint type upon the chemical composition

(2) " " " " soil " " " " "

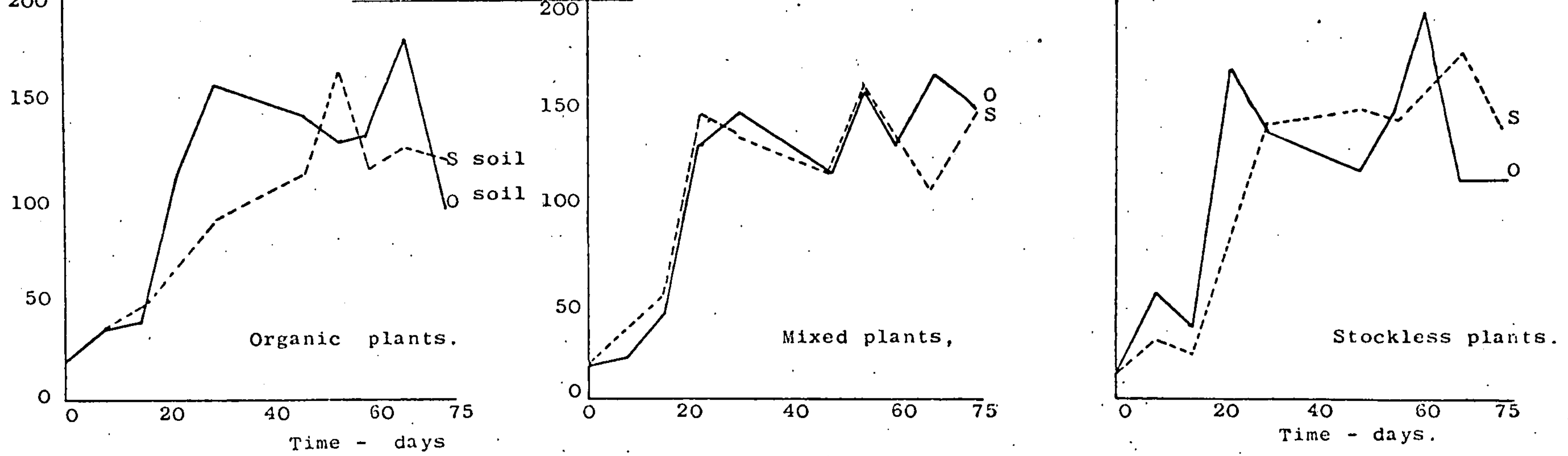
GRAPH 4 - 1. : NITRATE NITROGEN.

The Chemical Composition of the Crop as influenced by the Imprint and Soil Type. (μgm NO_3-N /gm whole plant)

1.Effect of Imprint Type.



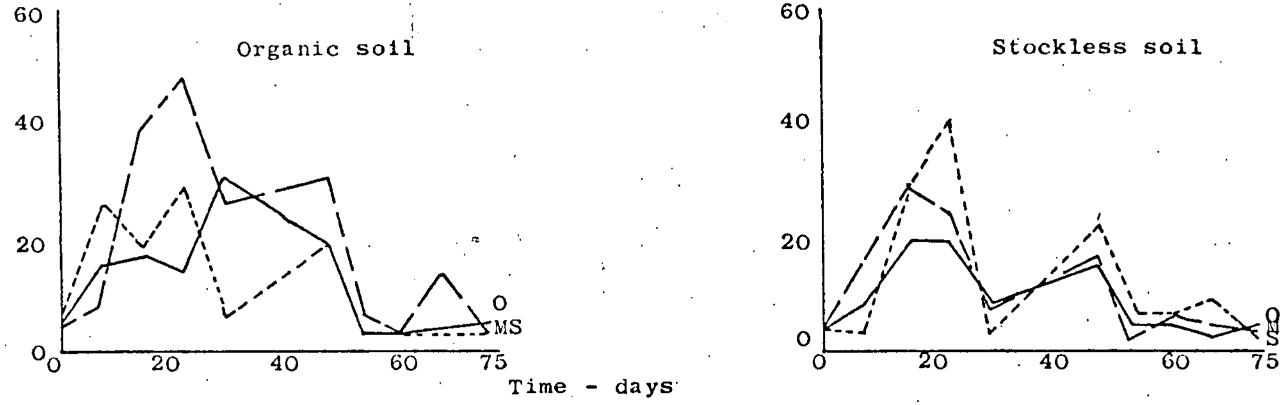
2.Effect of Soil Type.



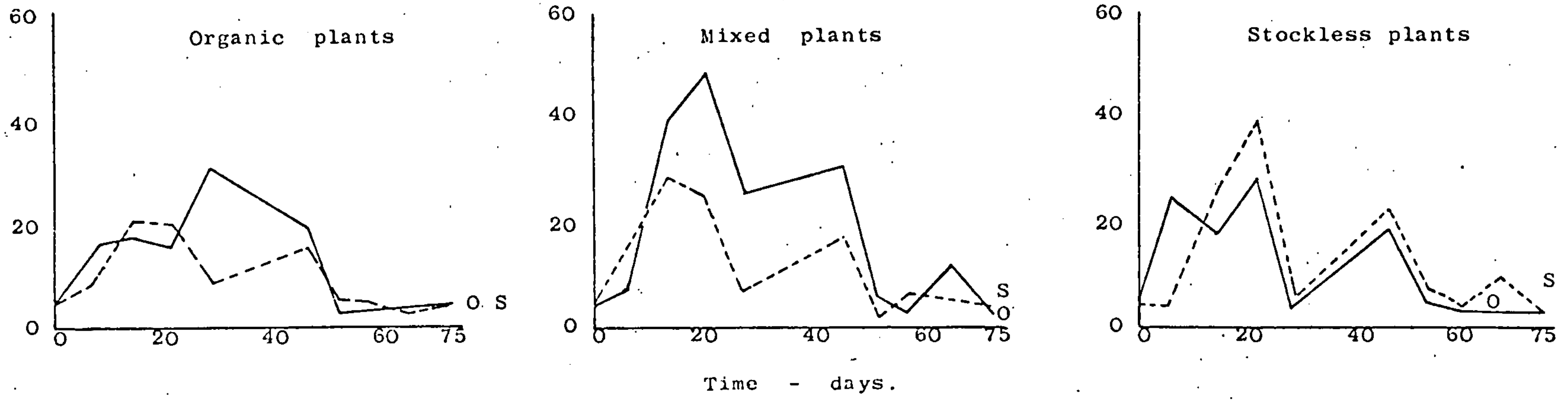
GRAPH 4-2: ORGANIC NITROGEN.

The Chemical Composition of the Crop as influenced by the Imprint and Soil Type.(mgm N/gm whole plant)

1. Effect of Imprint Type.



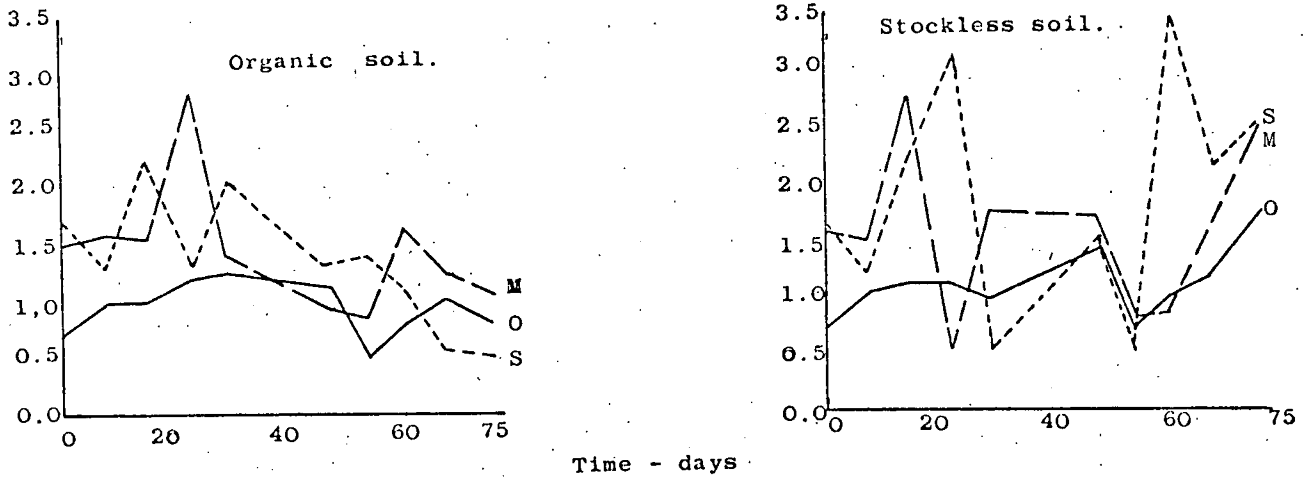
2. Effect of Soil Type.



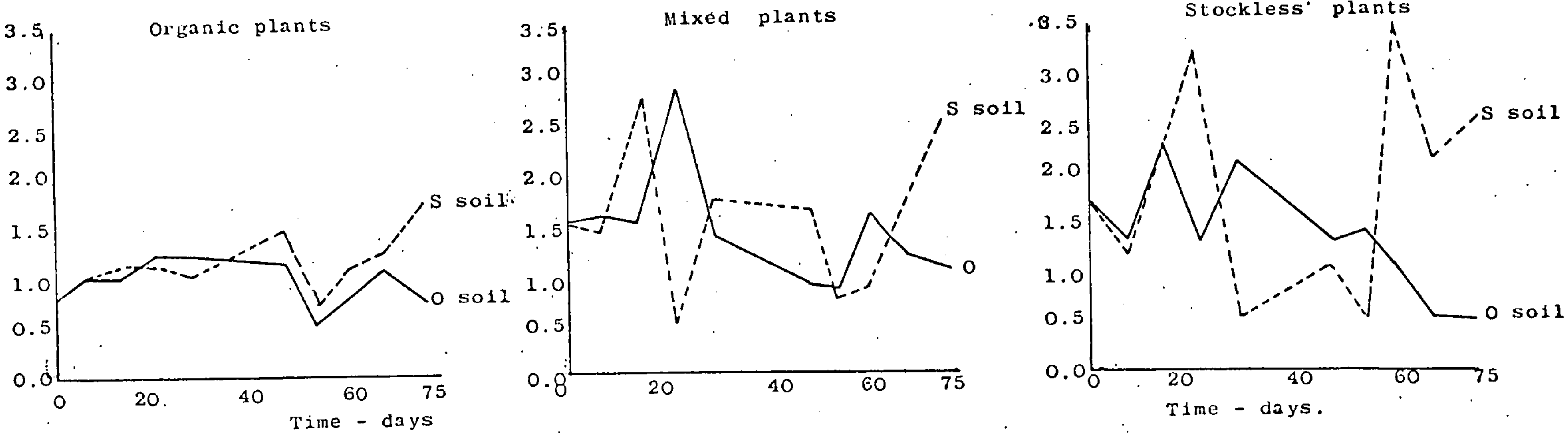
GRAPH 4 - 3: PHOSPHORUS.

The Chemical Composition of the Crop as influenced by the Imprint and Soil Type.(mgm P/gm whole plant)

1.Effect of Imprint Type.



2. Effect of Soil Type.



4:3.4.1 Nitrate-nitrogen (Graph 4-1)

(1) No consistent effect of the imprint type was evident, except that the Tic S plants contained the highest maximum concentrations on both soils.

(2) The soil type had little apparent effect, except that the maximum concentrations on the Organic soil were higher than on the Stockless soil, for each imprint type.

:3.4.2 Organic nitrogen (Graph 4-2)

(1) The effect of the imprint type upon the nitrogen concentration, itself depended upon the soil type. Thus on the Organic soil, M > O ≡ S, but on the Stockless soil S > M > O,which indicated a possible affinity between the imprint and the soil type. The reduction in the nitrogen concentrations after day 45,was also shown by the values for the total nitrogen/plant, indicating that this was a real effect of the senescence brought about by the poor growing conditions, rather than due to a dilution caused by the growth of the plants.

(2) The plants from the farms receiving organic manures absorbed most nitrogen from the Organic soil, whilst the plants from the Stockless farm absorbed most nitrogen from the Stockless soil - this may have been an indication of an adaptation of the imprints to their own farm management type. Plants on the Organic soil showed the greatest range of nitrogen concentrations, correlating with the greater heterogeneity of nitrogen distribution in that soil (Section 1).

:3.4.3 Phosphorus (Graph 4-3)

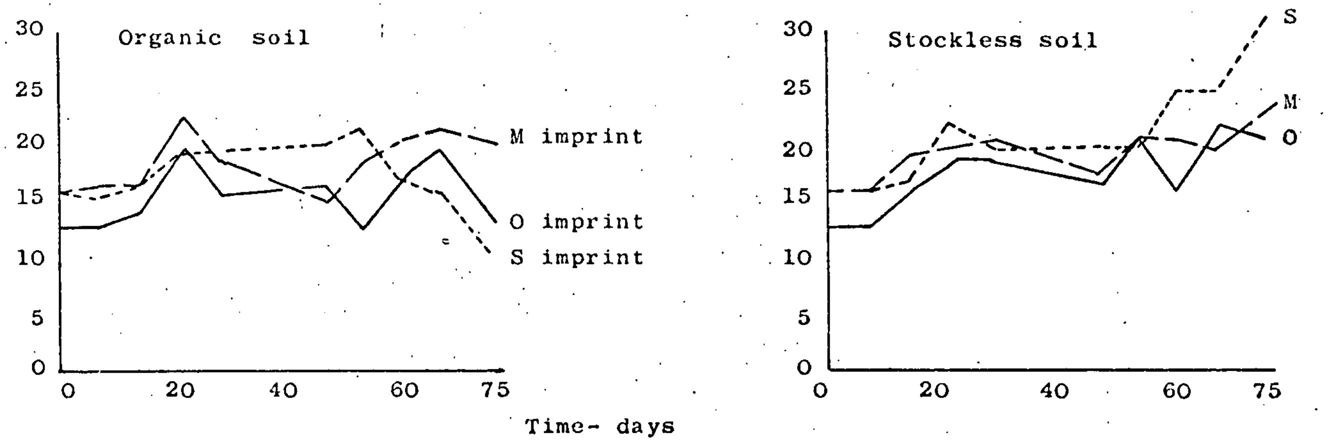
(1) On both soils the M and S imprints tended to have higher and more variable concentrations of phosphorus than the O imprint plants.

(2) For all imprints there were greater concentrations of phosphorus on the Stockless soil, which correlated with the greater exchangeability of this geochemical in that soil (Section 1).

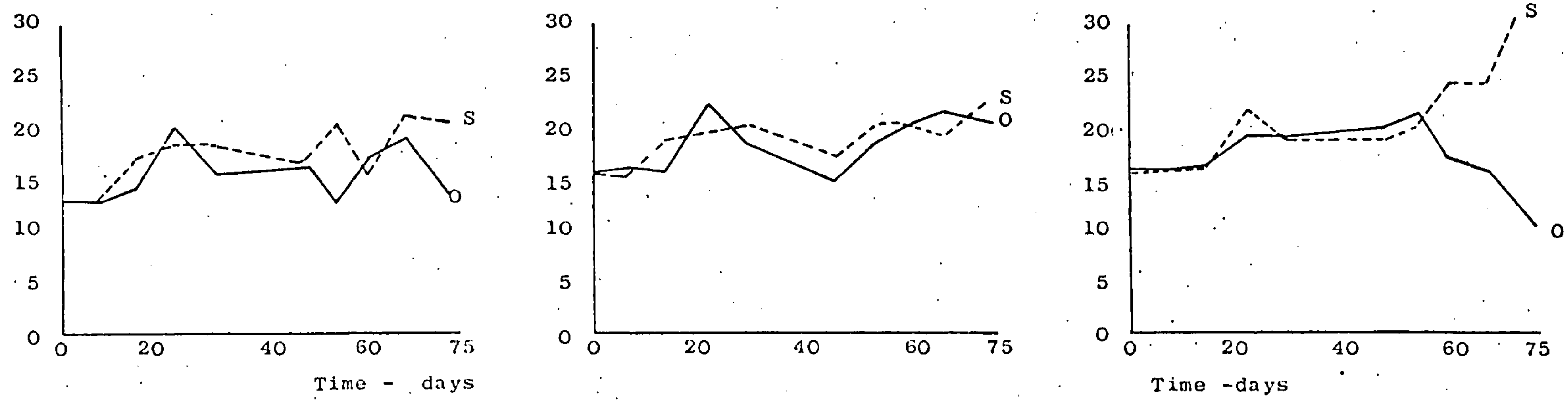
GRAPH 4-4 : POTASSIUM.

The Chemical Composition of the Crop as Influenced by the Imprint type and Soil Type.(mgm K / gm whole plant.)

1. Effect of Imprint type.



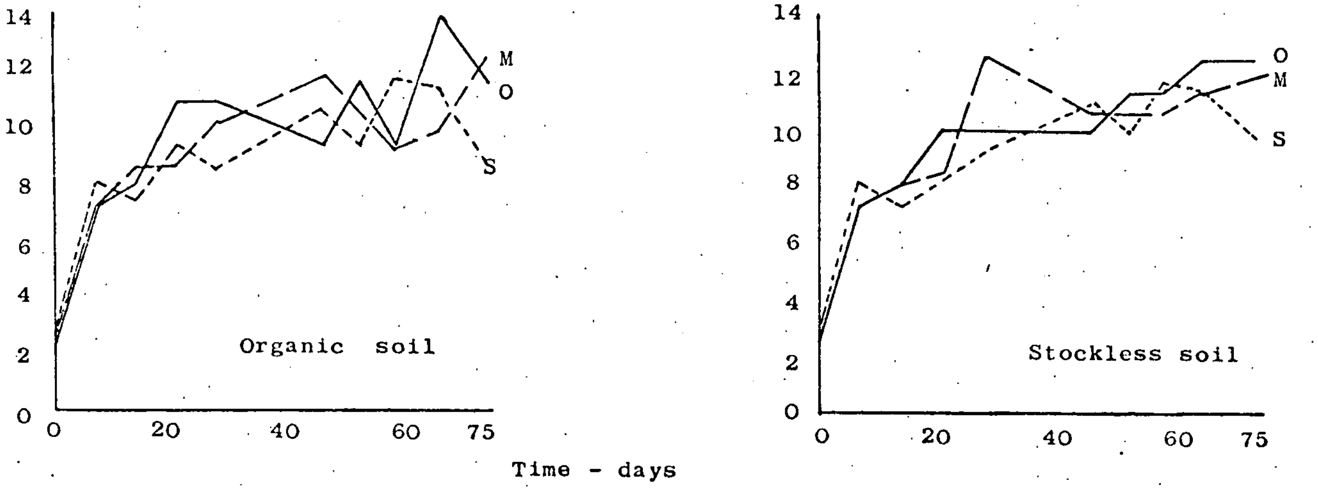
2. Effect of Soil Type.



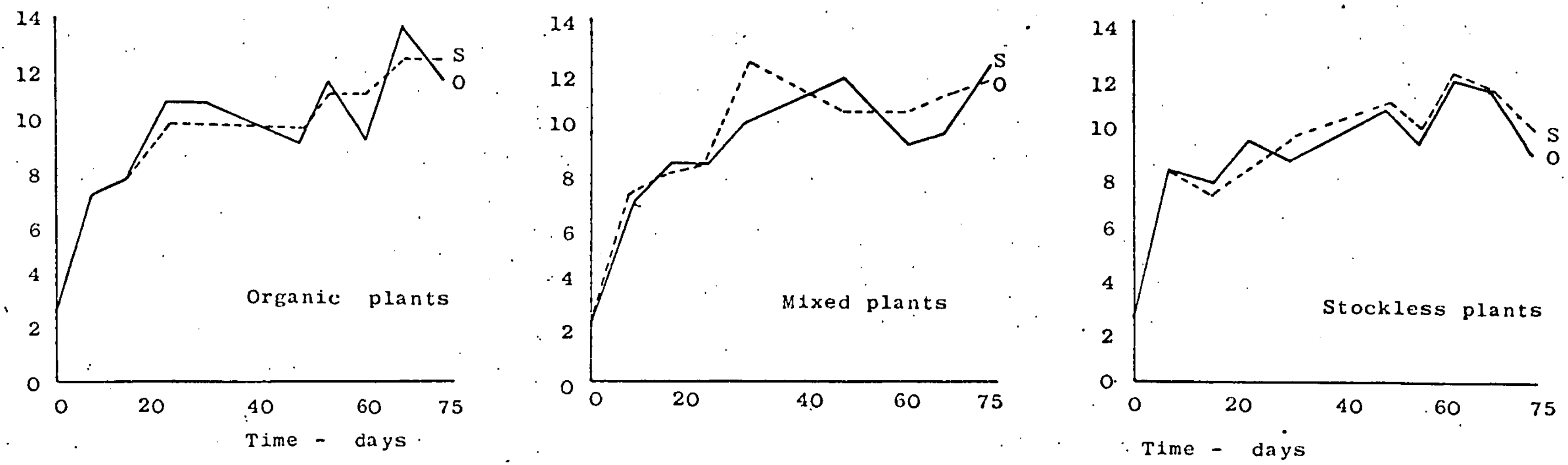
GRAPH 4-5 : CALCIUM.

The Chemical Composition of the Crop as influenced by the Imprint and Soil Type.(mgm Ca/gm whole plant)

1. Effect of Imprint Type.



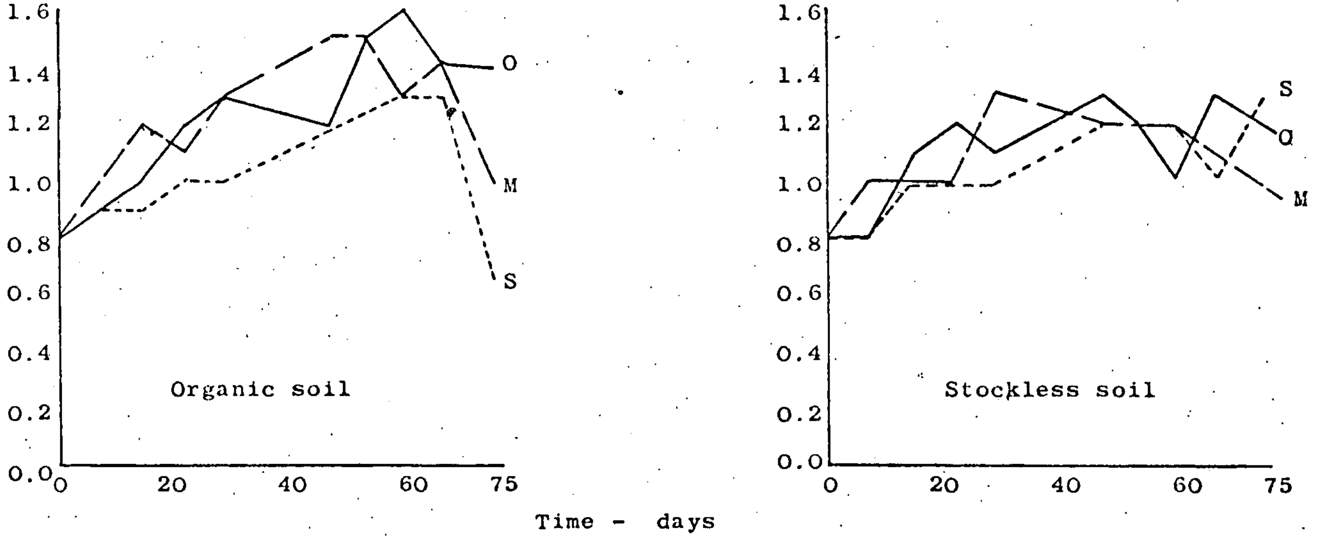
2. Effect of Soil Type.



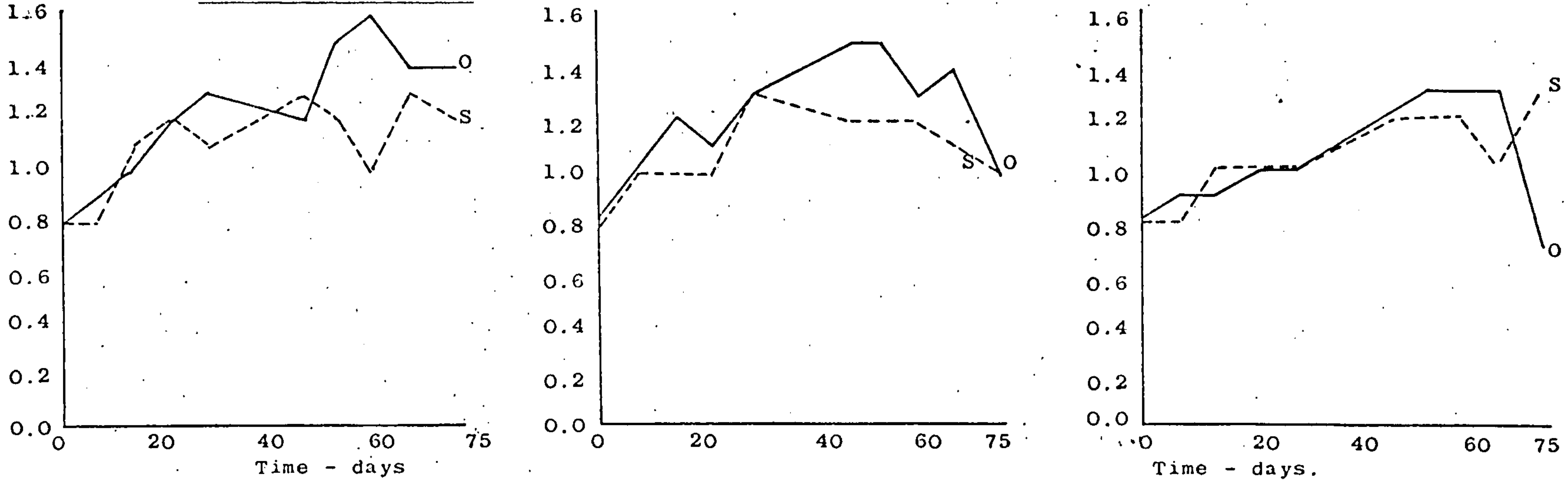
GRAPH 4-6: MAGNESIUM.

The Chemical Composition of the Crop as influenced by the Imprint and Soil Type.(mgm Mg/gm whole plant)

1. Effect of Imprint Type.



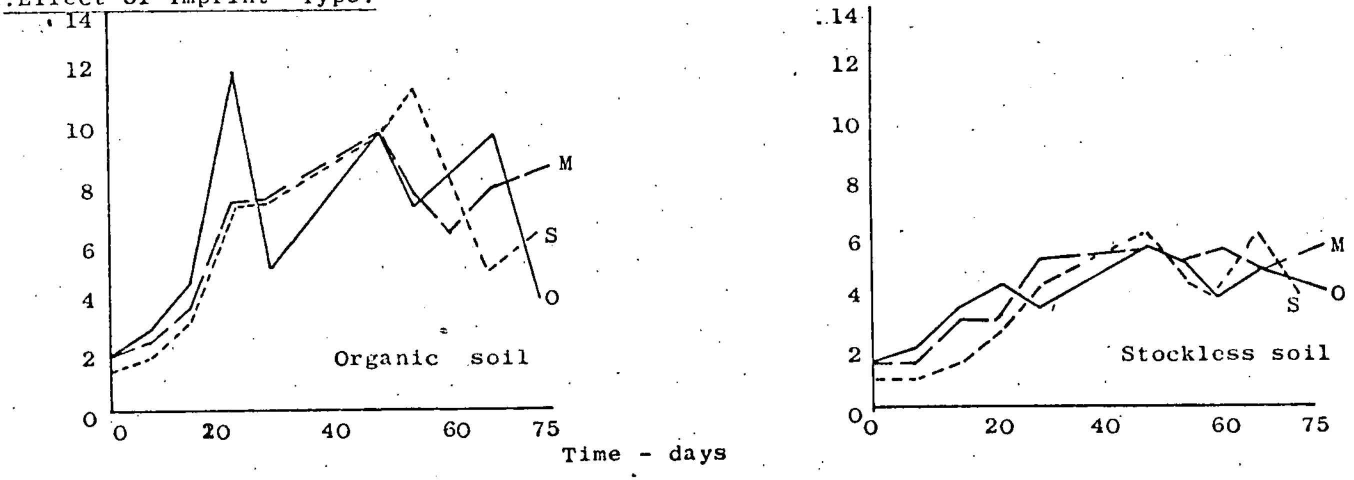
2. Effect of Soil Type.



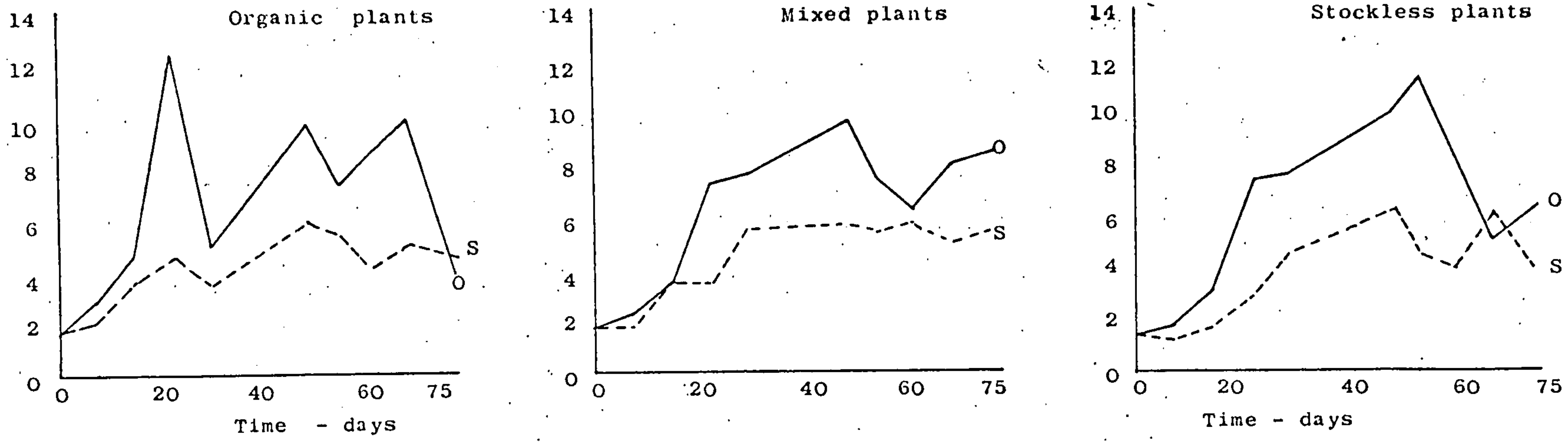
GRAPH 4-7 : SODIUM.

The Chemical Composition of the Crop as influenced by the Imprint and Soil Type.(mgm Na/gm whole plant.)

1.Effect of Imprint Type.

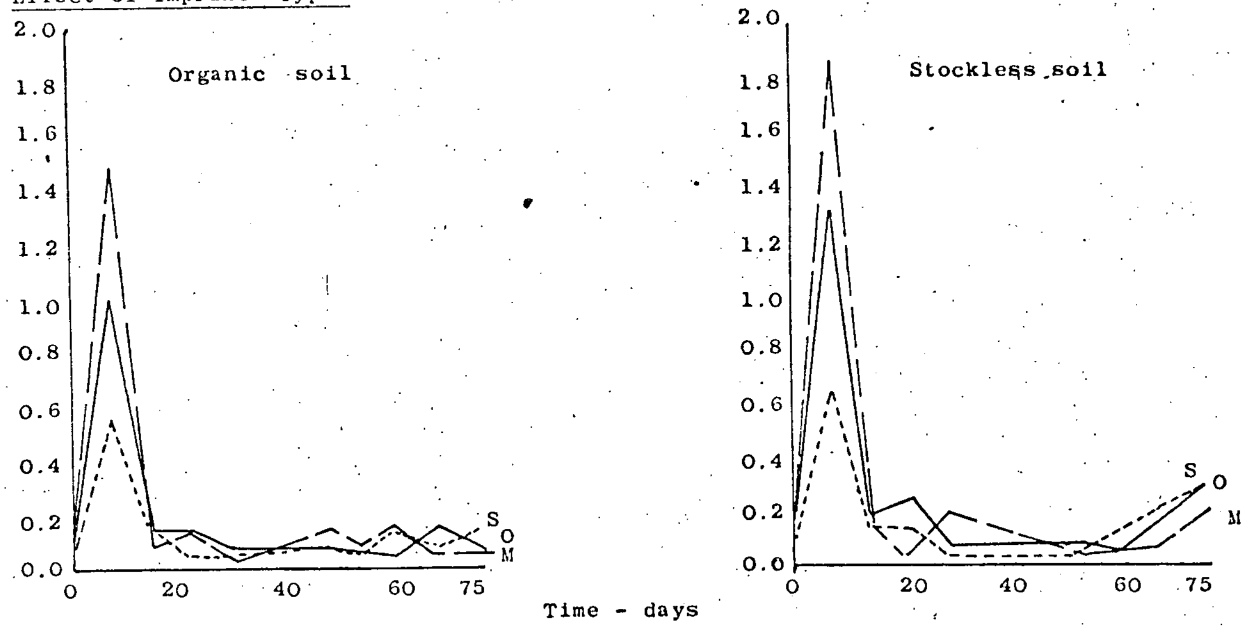


2. Effect of Soil Type.

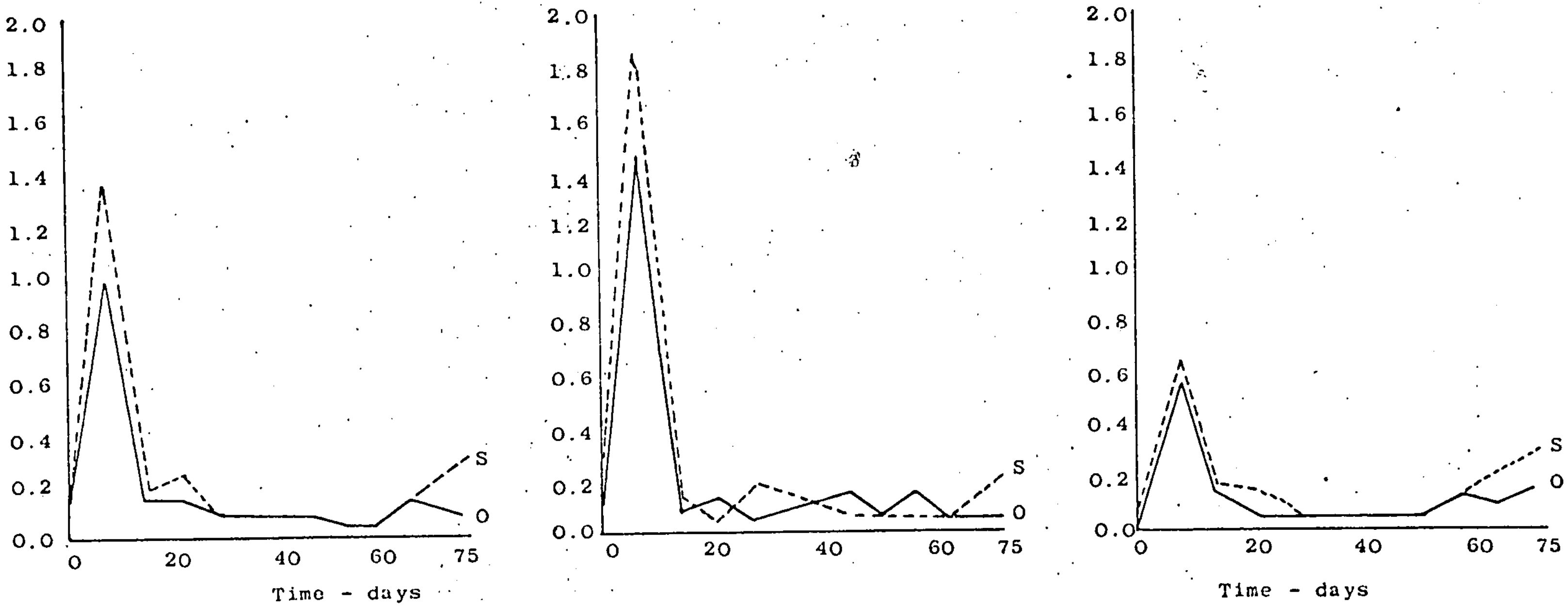


The Chemical Composition of the Crop as influenced by the Imprint and Soil Type.(mgm Zn/gm whole plant)

1. Effect of Imprint Type.



2. Effect of Soil Type.



:3.4.4 Potassium (Graph 4-4) and Calcium (Graph 4-5)

(1) For potassium, the imprint type only influenced the plants' chemical composition during the final few days of the experiment, but for calcium there was no imprint influence at all.

(2) The soil type showed no influence over the concentration of potassium and calcium in any of the plants grown.

:3.4.5 Magnesium (Graph 4-6) and Sodium (Graph 4-7)

(1) There was no effect of imprint type upon the concentrations of either of these geochemicals in the plants.

(2) For both geochemicals the range was wider and concentrations higher on the Organic soil, which correlated with the higher total levels of these in that soil (Section 1).

:3.4.6 Zinc (Graph 4-8)

(1) The only consistent difference attributed to the imprint type was M > O > S, but this only occurred on the first sampling occasion.

(2) Again the only difference between soil types occurred on the first sampling occasion when S > O for all imprints.

4:3.5 Conclusions

4:3.5-1 The chemical composition of the plants was found to vary between the imprint types for several geochemicals, but only for organic nitrogen did the difference suggest that a physiological adaptation to the farm management type may have taken place during the imprinting process. It must be concluded that, for most geochemicals, the particular ancestry of the bean seeds used had no influence over the chemical composition of the plants produced.

.5-2 The soil upon which the plants were growing during the trial exerted a positive influence over the plant chemical composition as follows :-

(1) The greatest range and the maximum concentration values of nitrate-nitrogen, organic nitrogen, magnesium and sodium tended to be found in the plants growing on the Organic soil. This correlates well with the soil chemistry data from the 1971 Field Trial (Section 1), which showed that the concentration of all these geochemicals was significantly higher in the soil from the Organic system.

(2) The greatest range and the maximum concentration values for phosphorus and zinc were found in the plants growing on the Stockless soil - analysis of the soil showed that this system contained the highest concentration of these geochemicals (Section 1).

(3) The soil type showed no definite influence upon the concentration of calcium and potassium in the plants, despite a significantly greater concentration of these in the Organic soil. The uptake from this soil type may have been reduced by the Kirkby-Mengel effect mentioned in 4:1, where the absorption of positively charged ions from the soil can be reduced by the presence of NH_4^+ ions. Chemical analysis in Section 1 showed that the levels of the ammonium ions was significantly greater in the Organic soil.

4:4 1971 Field Trial

4:4.1 Aims

To repeat the greenhouse trial under normal agricultural conditions in the field, using *Vicia faba* var. Tic and var. Throws, to determine the possible influence upon the chemical composition of the plants by :

- the plant imprint type
- the farm management type
- the fertilizer application rate.

4:4.2 Method

The plants were grown and sampled as described in Section 3, and were subjected to the chemical analysis methods shown in the Appendix. The plant types and soil treatments used for the trial are shown below :-

Measurements	Plant material	Soil treatments
Crop geochemistry - plants	Tic O, Tic M, Tic S	Organic soil.
analysed for : NO_3-N,	Throws O	Stockless soil:
N, P, K, Na, Ca, Mg, Al,	Throws M	-no fertilizer
Cu, Zn, Pb	Throws S	-375 Kg fertilizer/ha
		-625 " " "

4:4.3 Results

The chemical analysis data collected for the 24 combinations of plant type and treatment, at frequent intervals throughout the growing season, enabled the determination of the effect of the imprint type and farm management as measured upon the following :

1. The composition of the bean seeds, and hence the addition of geochemicals to the system in the bean seeds sown.

2. The seasonal variation in the geochemical composition of the plants, and hence the mean seasonal concentrations.

3. The distribution of the geochemicals in the separate plant parts, determined at the age of five weeks, and twenty-four weeks.

4. The maximum ion concentration attained during the season.

5. The chemical composition of the plants at the growth maxima (Dry Weight and Leaf Area Index).

6. The maximum flow of geochemicals into the crop biomass, and the loss from the system in the final harvest.

The results are discussed under these headings on the following pages. The geochemical composition of the plants is expressed in terms of the weight of geochemical/gramme dry weight of plant material.

4:4.4 Discussion

:4.4.1 Addition of geochemicals in the seeds sown

Table 4-1 shows the results of the chemical analyses of the bean seeds sown on the farm in March 1971. Several differences in the composition of the seeds of the two varieties were found, especially for the concentrations of calcium, phosphorus, aluminium and zinc. The influence of the plant imprint type was only shown by the S type, of both varieties. For example :

- Concentrations in Tic S plants much lower than in Tic O and Tic M for Ca and Na.
- Concentrations in Throws S plants much lower than in Throws O and Throws M for Na, K and Zn.

Apart from these trends there was no consistent pattern to indicate any effect of imprinting upon the chemical composition of the seeds sown.

The second part of the table shows the calculated addition of the geochemicals to the ecosystem in the seeds, when they were sown at the normal rate of 250 Kg/ha. These figures are used under the "Gain" heading in the main Discussion.

TABLE 4-1. CROP GEOCHEMISTRY

CONCENTRATIONS OF GEOCHEMICALS IN SEEDS USED 1971.

(1) Concentration of ions in seeds. Expressed as mgm ion/gm dry weight seed

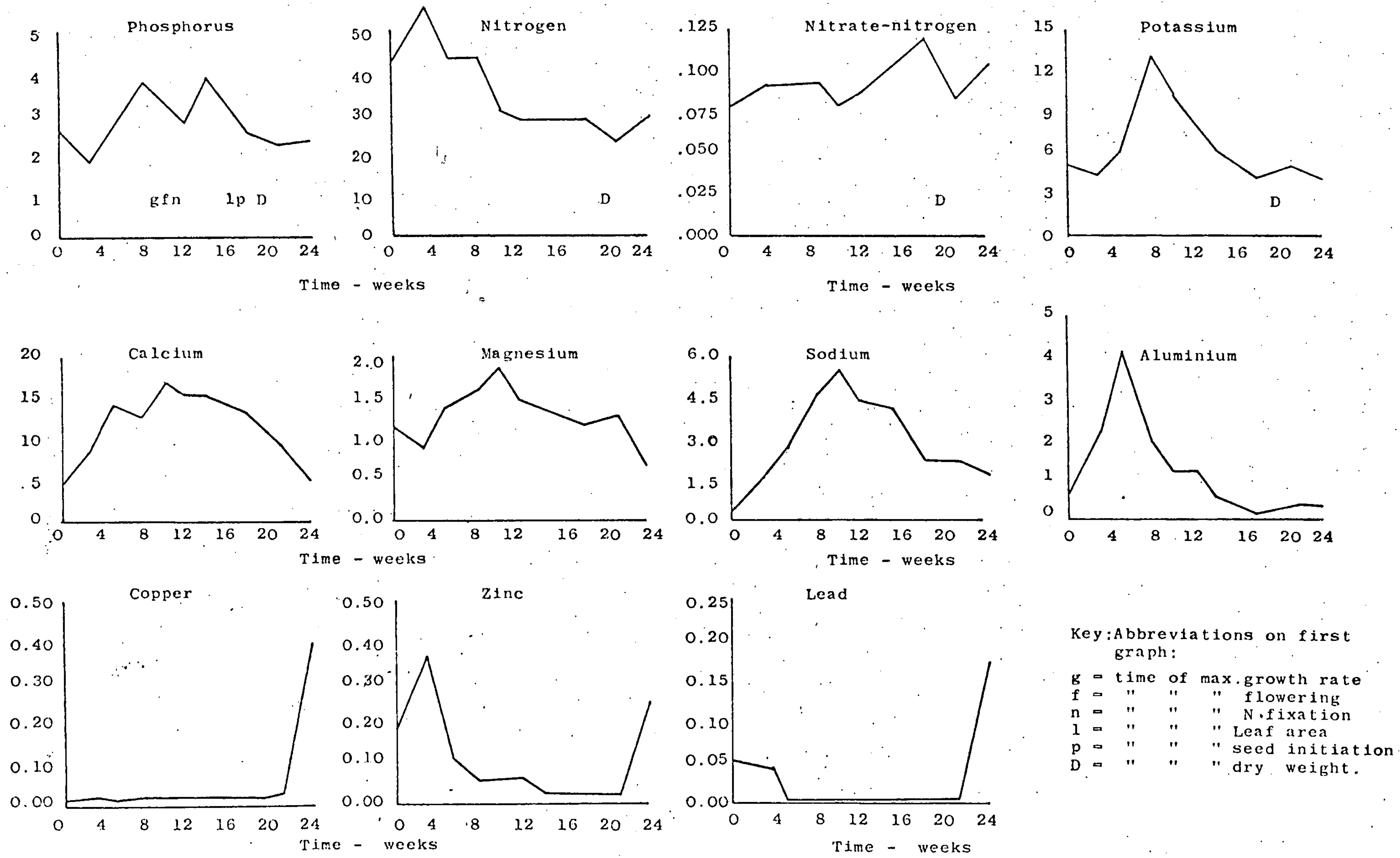
Seed type	P	N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zu	Pb
Tic O	3.5	37	0.08	1.4	1.12	0.59	5.2	0.4	0.014	0.006	0.040
Tic M	4.7	28	0.07	1.9	1.52	0.25	7.0	0.1	0.016	0.016	0.040
Tic S	3.7	47	0.05	0.4	1.47	0.03	9.7	0.2	0.009	0.009	0.040
Mean	4.0	37.3	0.07	1.2	1.37	0.29	7.3	0.23	0.013	0.010	0.040
SD	0.6	9.5	0.02	0.8	0.22	0.28	2.3	0.15	0.004	0.005	0.000
Thro O	1.3	51	0.10	4.6	0.8	0.50	4.2	0.8	0.013	0.415	0.030
Thro M	1.6	50	0.07	5.5	0.9	0.80	4.2	0.7	0.020	0.420	0.070
Thro S	1.5	45	0.10	5.7	1.1	0.05	0.7	0.7	0.012	0.140	0.070
Mean	1.5	48.7	0.09	5.3	0.9	0.45	3.0	0.73	0.015	0.325	0.057
SD	0.2	3.2	0.02	0.6	0.2	0.38	2.0	0.06	0.004	0.160	0.023

(2) Addition of nutrients to field in seeds used (freshweight). Expressed as Kg ion/ha

Tic O	0.78	8.3	0.017	0.31	0.25	0.13	1.15	0.08	0.003	0.001	0.009
Tic M	0.94	5.5	0.014	0.38	0.30	0.05	1.39	0.02	0.003	0.008	0.008
Tic S	0.84	11.7	0.012	0.09	0.34	0.01	2.21	0.05	0.002	0.002	0.009
Mean	0.85	8.5	0.014	0.26	0.30	0.06	1.58	0.05	0.003	0.004	0.009
SD	0.08	3.1	0.003	0.15	0.05	0.06	0.56	0.03	0.001	0.004	0.001
Thro O	0.28	11.0	0.021	0.99	0.17	0.11	0.90	0.16	0.003	0.089	0.006
Thro M	0.33	10.3	0.015	1.13	0.19	0.16	0.86	0.13	0.004	0.086	0.014
Thro S	0.31	9.3	0.020	1.18	0.23	0.01	0.15	0.15	0.003	0.029	0.015
Mean	0.31	10.2	0.018	1.10	0.20	0.09	0.64	0.15	0.003	0.068	0.012
SD	0.03	0.9	0.003	0.10	0.03	0.08	0.42	0.02	0.001	0.034	0.005

GRAPH 4-9

The pattern of change in the tissue concentration of geochemicals in whole plants during the season.1971.(mgm/gm dry plant material)



:4.4.2 Seasonal variation in the geochemical concentrations

The progress curves of the concentrations of the geochemicals in the plants during the season were plotted for each treatment. For each geochemical there was a specific shape to the curve so produced, which was not altered by any treatment. The only effect of the various treatments was to alter the magnitude of the concentrations, not the way in which they varied with the growth of the plant. A specimen of the characteristic progress curves for each geochemical is shown in Graph 4-9.

The concentrations of phosphorus, calcium, magnesium and sodium followed the pattern of plant growth, with low values when the plants were young, rising to a peak at the maximum growth rate, and then falling as the plants started their senescence. Organic nitrogen, zinc, aluminium and potassium tended to follow the same pattern as each other, although the timing of their maxima varied slightly. The concentrations of the heavy metals, copper and lead, were below the detectable level for most of the season, but increased dramatically during the last three weeks of senescence prior to the final harvest. The concentration of the nitrate-nitrogen increased gradually during the trial, to a maximum at the time of the main extension of the bean pods.

:4.4.3 Seasonal mean of the geochemical concentrations

(1) Using the chemical analysis data collected during the whole season, the seasonal means were calculated for each of the twenty-four treatment combinations (Table 4-2). Although some differences of composition had been indicated in the seeds sown, there was very little apparent effect of imprinting upon these seasonal means. Statistical analysis revealed there to be no significant differences between any pairs of imprints, within any of the four treatments, for any geochemical. Because the heavy metals were only detectable at the beginning and end of the season, they were omitted from this

Table 4-2 The Seasonal Means of the Geochemical Concentrations in the Plants grown in the 1971 Field Trial.

Concentrations are expressed in mgm/gm dry weight (NO_3-N values in µgm/gm dry weight).

Treatment & Plant Type	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Treatment & Plant Type	P	Org N	NO_3-N	Ca	Mg	Na	K	Al
NO FERTILIZER									625 kg FERTILIZER/ha								
Tic O									Tic O								
Mean	2.86	35.7	87.6	12.1	1.3	2.9	6.8	1.2	Mean	2.96	36.9	104.6	10.97	1.3	2.9	7.8	1.3
SD	1.27	11.4	23.7	4.8	0.45	1.4	3.6	1.8	SD	0.75	8.1	19.1	4.4	0.2	1.5	3.6	1.4
Tic M									Tic M								
Mean	2.8	37.6	102.3	15.8	1.3	3.1	7.2	1.3	Mean	3.1	35.6	98.2	11.4	1.3	2.9	7.3	1.3
SD	0.9	14.8	21.3	10.0	0.3	1.5	3.8	1.3	SD	0.6	11.0	15.8	5.8	0.6	1.7	3.3	1.5
Tic S									Tic S								
Mean	3.3	37.9	95.7	12.6	1.5	3.3	6.8	1.1	Mean	3.0	35.1	100.4	10.4	1.3	3.3	8.1	1.2
SD	0.8	10.7	20.5	5.0	0.4	1.5	3.4	1.3	SD	0.8	11.8	24.8	5.4	0.4	1.5	5.1	1.1
Throw O									Throw O								
Mean	3.2	37.0	97.2	13.5	1.3	2.9	7.9	1.1	Mean	2.9	35.4	98.3	10.9	1.3	2.9	6.9	1.3
SD	1.2	12.6	23.9	5.9	0.5	1.6	3.0	1.3	SD	0.7	14.4	16.4	6.5	0.8	1.7	2.9	1.3
Throw M									Throw M								
Mean	2.9	34.8	104.9	12.4	1.2	2.8	7.2	1.5	Mean	2.9	37.7	96.3	11.4	1.5	2.8	9.0	1.3
SD	0.7	13.8	13.8	5.5	0.5	1.4	4.4	2.0	SD	1.0	9.8	18.9	6.7	1.1	1.5	5.7	1.5
Throw S									Throw S								
Mean	2.8	36.2	99.4	12.9	1.1	3.5	7.7	1.3	Mean	2.7	38.4	88.4	10.8	1.2	2.7	7.5	1.3
SD	0.8	10.7	16.9	5.3	0.2	2.6	3.3	1.6	SD	0.8	14.1	15.6	6.6	0.4	1.4	4.2	1.3
375 Kg FERTILIZER/ha									ORGANIC								
Tic O									Tic O								
Mean	2.96	35.2	98.6	12.3	1.3	3.0	7.5	1.5	Mean	2.34	33.1	86.6	12.6	1.4	4.0	6.8	1.5
SD	0.85	9.8	35.8	4.9	0.51	1.7	3.7	2.1	SD	0.66	8.2	18.4	4.0	0.4	1.3	4.0	1.0
Tic M									Tic M								
Mean	2.9	34.3	101.8	12.1	1.2	3.2	7.1	1.3	Mean	2.3	32.3	87.6	14.3	1.5	4.9	6.3	1.4
SD	0.8	11.8	30.1	4.5	0.4	1.5	4.1	1.5	SD	0.5	9.4	24.5	5.0	0.4	2.1	3.8	0.9
Tic S									Tic S								
Mean	2.7	37.4	93.7	10.7	1.2	3.7	7.3	1.5	Mean	2.6	37.1	85.0	13.2	1.6	3.9	7.6	1.6
SD	1.3	11.7	17.6	4.7	0.4	2.7	3.4	1.6	SD	1.0	5.7	12.6	4.1	0.4	2.6	3.5	1.2
Throw O									Throw O								
Mean	2.9	35.2	91.3	11.2	1.1	2.8	7.1	1.2	Mean	2.4	37.3	89.9	15.4	1.6	4.0	6.8	1.6
SD	0.7	12.6	25.5	4.9	0.3	1.8	3.6	1.2	SD	0.8	8.9	12.5	3.9	0.4	1.8	2.6	1.1
Throw M									Throw M								
Mean	2.6	28.7	94.3	12.3	1.3	2.9	7.8	1.5	Mean	2.2	38.4	87.0	15.1	1.7	4.1	6.0	1.6
SD	1.0	8.7	23.0	5.7	0.3	1.6	4.6	1.8	SD	0.8	15.8	18.5	4.0	0.4	2.1	2.1	1.0
Throw S									Throw S								
Mean	2.9	38.3	94.7	11.4	1.1	2.8	7.0	1.1	Mean	2.2	34.0	77.0	15.9	1.6	4.2	5.9	1.5
SD	1.6	16.6	20.5	4.1	0.4	1.6	4.1	0.9	SD	0.8	8.3	25.1	4.0	0.5	1.9	3.2	0.9

Number of observations per mean calculated - Stockless fertilizer = 9 samples.
Organic field = 7 samples.

table. It is most probable that the lack of significant differences between the seasonal means for each imprint type was due to the marked seasonal fluctuations referred to in 4:4.4.2.

(2) In the same way, statistical comparison of the four treatment means for each geochemical showed no significant differences between any of them.

Thus any true differences between treatments may have been masked by the use of the seasonal means. Alternatively, the apparent lack of any differences between the treatments may indicate that the flow of the geochemicals from the soil into the crop was very similar on all the experimental plots. This possibility was supported by the lack of difference in the crop growth (Section 3) between any of the four plot types. This further implies that the level of nutrients in the Stockless soil, where no fertilizer was applied in the year of the trial, was adequate for crop growth, and that the additional fertilizer applied only provided an excess of nutrients which would be leached through, or bound into, the soil.

:4.4.4 Location of geochemicals in the shoots, roots and nodules at the age of five weeks from sowing

Because of the possible masking effect of using the seasonal means for the treatment and imprint comparisons, the chemical composition of the plants was compared at a number of times during the season.

.4-1 The first comparison to be discussed was made at the age of five weeks, upon the separately analysed shoots, roots and nodules. At this age it was still possible to remove the whole root system from the soil. When the results of the analyses were examined, it was found that there was no consistent pattern to indicate that imprinting had had any effect upon the chemical composition of the bean plants.

Table 4-3

The mean geochemical concentrations in the stems and roots of 5 week plants

(Means calculated from six readings) SD = Standard Deviation
* = Significant to p = <0.05
** = Significant to p = <0.01
NS = No significant difference

Shoots

Treatment	Dry Wt	P	OrgN	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn
	(gms)	mg	mg	μg	mg	mg	mg	mg	mg	μg	μg
Organic-mean	0.65	2.5	40.3	87.5	20.0	1.9	4.7	8.0	1.5	19.2	36.7
SD	0.14	0.4	4.6	11.3	2.1	0.2	2.1	1.0	0.5	6.3	40.0
S-No fertilizer	0.21	3.4	56.0	107.0	13.6	1.0	1.3	9.5	2.0	18.2	125.0
SD	0.03	1.2	3.8	10.3	2.8	0.1	0.1	1.4	0.2	8.0	82.0
S-375 fertilizer	0.20	2.1	53.5	95.8	14.0	1.0	1.4	7.6	3.2	14.0	95.0
SD	0.03	0.5	6.3	19.1	2.6	0.2	0.4	1.1	0.3	1.1	21.0
S-625 fertilizer	0.20	2.5	54.0	83.3	13.2	1.0	1.5	8.0	3.3	26.3	175.0
SD	0.08	0.7	2.0	13.0	2.2	0.1	0.4	1.1	1.1	4.7	64.0
Significant Differences	0 >S **	N>3 *	S>O **	N>O N>6**	O>S *	O>S **	O>S **	N>3 *	N,3,6>O** 3,6>N**	6>3 **	3,6>O* 6>3*

Roots

Treatment	Dry Wt	P	OrgN	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn
Organic-mean	0.25	2.4	26.7	87.5	12.6	2.2	4.3	6.2	5.4	18.8	92.7
SD	0.09	0.8	7.6	11.3	1.4	0.3	1.1	3.3	1.8	6.0	100.0
S-No fertilizer	0.23	2.9	40.0	107.0	12.7	1.6	2.4	3.5	7.3	23.7	139.0
SD	0.03	0.8	6.7	10.3	2.0	0.2	0.4	1.0	1.7	7.0	150.0
S-375 fertilizer	0.22	2.5	35.8	95.8	12.0	1.4	2.4	3.8	6.6	17.2	104.0
SD	0.10	0.9	10.2	19.1	3.5	0.5	1.1	2.1	2.5	5.2	26.0
S-625 fertilizer	0.23	2.1	39.0	83.3	13.3	1.3	2.4	3.8	5.9	26.0	138.0
SD	0.10	0.6	4.9	13.0	2.1	0.4	0.7	0.7	1.5	4.5	53.0
Significant differences	NS	NS	N,6>O *	N>O* N>6*	NS	O>S **	O>S *	NS	NS	6>3* 6>O*	NS
Analysis of nodules - No fertilizer			44.0	135.0	6.2	1.3	2.5	9.7	2.8	17.0	17.0
375 "			55.0	160.0	4.9	1.3	3.3	14.2	2.3	15.0	42.0
625 "			50.0	125.0	10.0	1.8	2.4	10.2	4.9	17.0	37.0

.4-2 Because of this apparent lack of effect of imprinting, the values for the six imprints within each treatment were used as replicates, to enable the statistical comparison of the concentrations of geochemicals in the plants from the different treatments. The means used, and the results of the statistical comparison, are shown on Table 4-3. From this table :

(1) There was an inverse relationship between the supply and the uptake for P, NO_3-N and K.

(2) There was a direct relationship between the fertilizer application rate and the uptake of aluminium, copper and zinc - increasing the application increased the concentrations of these cations, but did not affect the uptake of any of the other geochemicals.

(3) The chemical composition of the shoots was more affected by the treatment than that of the roots; comparing the plants on the Organic and Stockless sections :

$O > S$ for Ca, Mg, Na $S > O$ for NO_3-N, N, Al, Cu, Zn

$O \equiv S$ for P and K

(4) The treatments did not alter the location of the main concentrations of each geochemical :

Stem > Root	P, N, K, Pb
Root > Stem	Mg, Al
Stem ≡ Root	NO_3-N, Ca, Cu, Zn

(5) There was no apparent effect of treatment or imprint type upon the chemical composition of the root nodules.

Section 4:4.4.9 describes the distribution of the geochemicals in the plants at the end of the growing season.

:4.4.5 Maximum geochemical Concentration

The second comparison of plant and treatment types was made at the time of achieving the maximum concentration of each geochemical in the plant tissues.

TABLE 4-4. CROP GEOCHEMISTRY

MAXIMUM CONCENTRATION OF GEOCHEMICALS IN WHOLE PLANTS 1971.

Plant Type	Concentrations expressed as mg ion/gm dry plant material										
	P	N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
NO FERTILIZER											
Tic O	5.0	56	0.13	17.2	2.0	5.3	12.9	5.8	0.47	0.28	0.76
Tic M	4.6	64	0.12	18.9	1.8	5.8	15.4	4.2	0.80	0.49	0.17
Tic S	4.7	55	0.12	18.2	2.0	5.9	12.9	4.1	0.32	0.33	0.11
Thro O	5.1	61	0.12	18.0	2.0	5.3	16.4	3.7	0.87	0.54	0.13
Thro M	4.1	64	0.12	19.8	2.0	4.9	14.9	6.3	0.31	0.30	0.25
Thro S	4.0	54	0.12	19.9	1.6	9.5	16.4	4.7	0.50	0.32	0.09
Mean	4.6	59.0	0.12	18.7	1.9	6.1	14.8	4.8	0.54	0.37	0.25
SD	0.5	4.6	0.006	1.1	0.2	1.7	1.6	1.0	0.24	0.110	0.26
375 Kg.FERTILIZER / HECTARE.											
Tic O	4.2	53	0.17	17.9	2.0	5.5	15.4	6.8	0.44	0.38	0.13
Tic M	4.2	53	0.14	20.0	1.9	5.4	16.9	4.9	0.77	0.53	0.17
Tic S	4.3	61	0.11	15.4	1.8	9.5	13.4	5.3	0.69	0.41	0.10
Thro O	4.1	59	0.14	18.2	1.6	5.6	14.9	3.6	0.93	0.57	0.12
Thro M	4.1	55	0.12	19.4	1.7	5.3	14.4	6.1	0.93	0.57	0.09
Thro S	4.5	70	0.13	15.8	1.5	5.7	14.4	2.7	0.76	0.57	0.05
Mean	4.2	58.5	0.14	17.8	1.8	6.2	14.9	4.9	0.75	0.50	0.11
SD	0.2	6.5	0.02	1.9	0.19	1.6	1.2	1.5	0.18	0.09	0.04
625 Kg.FERTILIZER / HECTARE.											
Tic O	4.1	51	0.14	16.5	1.6	5.1	13.4	4.5	0.05	0.46	0.14
Tic M	4.1	55	0.12	23.2	2.7	5.5	14.9	4.8	0.19	0.50	0.07
Tic S	4.5	53	0.15	16.7	1.9	5.6	17.4	3.5	0.20	0.24	0.23
Thro O	4.1	70	0.14	20.4	3.1	5.7	13.4	3.7	0.33	0.23	0.07
Thro M	4.5	53	0.12	20.7	4.3	5.6	21.9	5.0	0.24	0.23	0.66
Thro S	4.0	61	0.11	19.4	1.9	4.7	16.9	4.1	0.13	0.29	0.10
Mean	4.2	57.2	0.13	19.5	2.6	5.4	16.3	4.3	0.19	0.32	0.21
SD	0.2	7.2	0.01	2.6	1.0	0.4	3.2	0.6	0.10	0.12	0.23
ORGANIC											
Tic O	3.1	45	0.12	18.6	1.9	5.4	13.2	2.9	0.17	0.31	0.10
Tic M	3.1	50	0.13	22.2	2.0	7.7	13.5	2.7	0.06	0.34	0.22
Tic S	3.8	47	0.11	18.2	2.0	9.5	12.4	3.4	0.16	0.36	0.09
Thro O	3.8	53	0.11	19.7	2.0	8.0	10.2	2.8	0.04	0.50	0.03
Thro M	3.4	72	0.11	20.6	2.3	8.1	9.7	2.8	0.11	0.38	0.15
Thro S	3.4	49	0.13	19.7	1.8	8.2	11.4	2.2	0.04	0.28	0.04
Mean	3.4	52.7	0.12	19.8	2.0	7.8	11.7	2.8	0.09	0.36	0.11
SD	0.3	9.9	0.01	1.4	0.17	1.3	1.6	0.4	0.06	0.08	0.07

TABLE4-5. CROP GEOCHEMISTRY

CONCENTRATIONS OF GEOCHEMICALS AT MAXIMUM DRY WEIGHT 1971

Expressed in mgm ion/gm dry wt. plant material.

Plant Type & Treatment	Age (wks)	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn
NO FERTILIZER.											
Tic O	18	2.9	25	0.13	15.8	1.3	2.0	2.5	0.02	0.02	0.06
Tic M	21	1.9	25	0.08	8.8	1.1	2.3	4.7	0.10	0.02	0.01
Tic S	18	3.0	37	0.11	14.0	1.8	2.7	4.4	0.04	0.02	0.02
Thro O	21	1.6	19	0.08	8.6	1.0	2.4	4.6	0.10	0.03	0.01
Thro M	21	2.1	18	0.09	9.3	1.2	2.2	4.5	0.16	0.02	0.01
Thro S	18	3.0	30	0.12	13.5	0.8	2.1	4.5	0.08	0.03	0.02
Mean		2.4	25.7	0.10	11.7	1.2	2.3	4.2	0.08	0.02	0.02
SD		0.6	7.1	0.02	3.1	0.3	0.2	0.8	0.05	0.004	0.02
375 Kg.FERTILIZER / HECTARE.											
Tic O	18	3.2	34	0.17	15.5	1.0	1.5	5.2	0.05	0.01	0.03
Tic M	21	1.6	20	0.09	8.4	1.1	2.3	7.2	0.25	0.02	0.02
Tic S	18	2.6	27	0.11	11.2	0.6	2.4	4.3	0.05	0.02	0.01
Thro O	18	2.3	26	0.14	9.9	1.1	2.1	4.3	0.10	0.02	0.02
Thro M	21	1.6	25	0.06	9.4	1.2	2.0	5.6	0.33	0.02	0.02
Thro S	18	2.5	24	0.12	14.0	1.2	1.6	5.0	0.20	0.02	0.02
Mean		2.3	26.0	0.11	11.4	1.0	2.0	5.3	0.16	0.02	0.02
SD		0.6	4.6	0.04	2.8	0.2	0.4	1.1	0.12	0.004	0.007
625 Kg.FERTILIZER / HECTARE.											
Tic O	18	2.8	35	0.10	12.4	1.1	3.5	5.2	0.10	0.02	0.02
Tic M	18	2.2	27	0.12	10.3	1.0	2.7	3.4	0.10	0.01	0.01
Tic S	18	2.5	28	0.10	14.7	1.9	2.6	6.0	0.10	0.02	0.02
Thro O	18	2.7	27	0.10	14.1	1.0	2.4	4.0	0.10	0.02	0.08
Thro M	21	1.7	28	0.09	9.5	1.0	2.4	4.9	0.20	0.01	0.02
Thro S	21	2.8	15	0.09	8.0	1.0	1.5	4.9	0.42	0.01	0.02
Mean		2.5	26.7	0.10	11.5	1.2	2.5	4.7	0.17	0.02	0.03
SD		0.4	6.5	0.01	2.7	0.4	0.6	0.9	0.13	0.004	0.03
ORGANIC											
Tic O	19	2.5	27	0.07	7.0	0.9	2.9	4.2	0.50	0.01	0.08
Tic M	16	2.7	23	0.09	12.7	1.6	3.1	3.7	0.70	0.02	0.03
Tic S	16	3.2	30	0.08	13.6	2.0	2.9	7.2	0.40	0.02	0.02
Thro O	19	2.3	29	0.08	8.2	1.1	3.1	3.2	0.70	0.01	0.02
Thro M	16	2.7	26	0.10	10.7	1.7	2.8	5.9	0.45	0.02	0.01
Thro S	16	2.6	24	0.08	13.4	1.8	2.5	2.9	0.60	0.01	0.04
Mean		2.7	27	0.08	10.9	1.5	2.9	4.5	0.55	0.02	0.03
SD		0.3	2.7	0.01	2.8	0.4	0.2	1.7	0.13	0.004	0.03

.5-1 Table 4-4 shows the maximum concentration achieved during the season for each geochemical. This occurred at a different age of the plant for each geochemical considered (Graph 4-9), but, as previous stated, the timing was unaffected by either the imprint or soil type. However, due to the shorter growing season on the Organic system, the plants growing there achieved earlier growth and geochemical concentration maxima.

.5-2 The low standard deviations shown on Table 4-4 indicate how small an effect the imprint type had upon the magnitude of the maximum concentration of each geochemical. Even in the case of the heavy-metal concentrations, where there was more variation between the imprints, no clear pattern emerged.

.5-3 Within the Stockless section, when the imprint types were used as replicates to calculate the treatment means, the magnitude of the maximum concentrations of P, Org N, NO_3-N, Ca, Mg, Na, K, Al and Pb were unaffected by the rate of fertilizer application. The concentrations of Cu and Zn were affected in inverse proportion to the rate of fertilizer applied.

.5-4 When the Organic and Stockless sections were compared, the relationship between the treatments was :

$O > S$ for Na - only statistically significant $O > 6F$ treatment

$S > O$ for P, K, Al, Cu and Zn

$O \equiv S$ for N, NO_3-N, Ca, Mg, Pb

:4.4.6 Concentration of geochemicals at the Maximum Dry Weight

The third comparison of the chemical composition of the crops was made at the time at which the crops achieved Maximum Dry Weight.

.6-1 Table 4-5 presents the concentrations of the geochemicals recorded at the maximum dry weight of the plants. There was a trend indicated, by which the S and O imprints of both bean varieties contained higher concentrations of some geochemicals, but this pattern was not consistent throughout all treatments, nor for all geochemicals. This was the only effect of the imprint type upon chemical composition which was evident at the maximum dry weight.

.6-2 Using the imprint types as replicates, the treatment means were statistically compared (Bailey 1959, d test).. The results of this comparison were :

(1) The rate of fertilizer application had no significant effect upon the concentrations of P, Org N, NO_3-N, Ca, Mg, Na, K, Al, Zn.

(2) The rate of fertilizer application significantly affected Cu by inverse proportion ($p = <0.05$).

(3) $0 > S$ for Mg, Na, Al concentrations ($p = <0.01$).
$S > 0$ for Cu and NO_3-N concentrations ($p = <0.05$).
$0 \equiv S$ for P, N, Ca, K and Zn.

.6-3 Table 4-6 shows the total weight of geochemicals per plant at the time of the achievement of the Maximum crop dry weight - these values were considered in order to determine whether a growth dilution factor was operating, whereby a constant quantity of one geochemical/plant would give a low concentration reading/gm in a large plant, but a higher reading in a small plant.

(1) The previously observed trend for S and 0 imprints to have larger concentrations than M was repeated, but for fewer geochemicals than before.

(2) As for .6-2, the only geochemical to be significantly affected by the fertilizer application rate was Cu, in an inverse manner.

(3) Due to the greater dry weight of the Stockless plants (Section 3), the total crop content of all the geochemicals measured was greater upon the Stockless section, except for Zn, where $0 \equiv S$ due to the high variability, and Al, where $0 > S$ despite the lower plant weight on the Organic section. Hence the only two geochemicals affected

TABLE4-6. CROP GEOCHEMISTRY

CONCENTRATIONS OF GEOCHEMICALS AT MAXIMUM DRY WEIGHT 1971.

Expressed mgm and gm ion/plant

Plant type & Treatment	Age (wks)	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn
NO FERTILIZER.											
Tic O	18	158.4	1.36	7.1	865	71.0	107.8	137.7	1.1	1.33	3.43
Tic M	21	101.6	1.43	4.4	831	58.9	118.9	268.8	5.4	0.83	0.42
Tic S	18	188.8	2.31	7.0	879	110.3	172.3	278.4	2.5	1.47	1.86
Thro O	21	106.2	1.21	4.9	496	66.4	142.4	318.5	5.9	1.55	0.50
Thro M	21	121.5	1.05	4.9	491	74.0	98.7	285.0	10.5	1.21	0.54
Thro S	18	205.0	2.04	8.0	927	58.0	143.0	311.0	5.7	1.83	1.15
Mean		146.9	1.6	6.1	748	73.1	130.5	267	5.2	1.37	1.32
SD		43.9	0.5	1.5	200	19.3	27.2	66	3.3	0.3	1.2
375 Kg.FERTILIZER / HECTARE.											
Tic O	18	197.5	2.11	10.7	954	58.6	91.6	318.5	3.0	0.87	2.0
Tic M	21	74.7	0.91	4.0	361	53.3	100.2	338.6	11.0	0.8	0.8
Tic S	18	152.1	1.60	6.4	663	37.3	139.2	254.1	3.0	1.39	0.8
Thro O	18	101.5	1.15	6.0	438	47.2	91.4	189.1	5.7	1.14	1.08
Thro M	21	106.1	1.69	3.7	523	73.0	106.6	390.0	17.9	1.05	1.35
Thro S	18	140.0	1.35	6.6	788	67.0	90.0	284.0	10.9	1.25	0.82
Mean		128.7	1.46	6.2	621	56.1	103.2	296	8.6	1.08	1.14
SD		43.8	0.4	2.5	224	13.0	18.8	70	5.8	0.2	0.5
625 Kg.FERTILIZER / HECTARE.											
Tic O	18	178.2	2.23	6.1	790	67.4	220.9	332.7	7.8	1.3	1.3
Tic M	18	97.7	1.16	5.4	448	45.0	118.0	148.5	5.2	0.6	0.4
Tic S	18	133.4	1.53	5.3	795	99.3	138.6	324.2	6.3	0.95	0.81
Thro O	18	173.2	1.72	6.2	910	64.1	156.9	259.0	8.3	1.27	4.98
Thro M	21	95.0	1.65	4.6	473	58.0	115.6	292.0	10.5	0.52	0.92
Thro S	18	81.0	1.03	4.5	493	41.0	87.0	176.0	12.4	0.83	0.28
Mean		126.4	1.55	5.4	652	62.4	139.5	255	8.4	0.91	1.45
SD		41.9	0.4	0.7	202	20.8	46.3	77	2.7	0.3	1.8
ORGANIC											
Tic O	19	71.1	0.78	2.1	202	27.0	84.0	119.6	13.7	0.34	2.37
Tic M	16	66.5	0.60	2.3	399	44.0	86.0	87.9	19.7	0.49	0.85
Tic S	16	119.7	1.14	3.0	531	74.7	115.0	265.0	15.8	0.73	0.67
Thro O	19	50.0	0.60	1.7	172	23.8	65.1	67.1	15.2	0.21	0.50
Thro M	16	58.3	0.57	2.7	342	41.8	94.9	104.4	16.0	0.35	0.13
Thro S	16	55.9	0.50	1.7	315	39.6	55.7	60.1	14.1	0.43	0.72
Mean		70.3	0.70	2.3	327	41.8	83.5	117.4	15.8	0.43	0.87
SD		25.4	0.2	0.5	132	18.1	21.2	75.7	2.1	0.18	0.8

TABLE4-7. CROP GEOCHEMISTRY

CONCENTRATIONS OF GEOCHEMICALS AT MAXIMUM LEAF AREA INDEX 1971.

Expressed as mgm ion/gm dry wt. plant material

Plant type & Treatment	Age (wks)	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn
NO FERTILIZER.											
Tic O	18	2.9	25	0.13	15.8	1.3	2.0	2.5	0.02	0.02	0.06
Tic M	18	2.1	25	0.12	11.0	1.5	3.1	2.1	0.02	0.02	0.03
Tic S	18	3.0	37	0.11	14.0	1.8	2.7	4.4	0.04	0.02	0.03
Thro O	18	2.2	32	0.11	18.0	1.2	3.2	4.1	0.02	0.03	0.02
Thro M	18	2.3	30	0.12	12.6	1.0	2.1	4.6	0.02	0.02	0.02
Thro S	18	3.0	30	0.12	13.5	0.8	2.1	4.5	0.08	0.03	0.02
Mean		2.6	29.8	0.12	14.2	1.3	2.5	3.7	0.03	0.02	0.03
SD		0.4	4.5	0.01	2.5	0.4	0.5	1.1	0.02	0.004	0.02
375 Kg.FERTILIZER / HECTARE.											
Tic O	18	3.2	34	0.17	15.5	1.0	1.5	5.2	0.05	0.01	0.03
Tic M	14	4.2	30	0.14	14.0	1.2	3.8	4.9	1.0	0.03	0.03
Tic S	18	2.6	27	0.11	11.2	0.6	2.4	4.3	0.05	0.02	0.01
Thro O	18	2.3	26	0.14	9.9	1.1	2.1	4.3	0.1	0.03	0.02
Thro M	18	2.7	27	0.12	13.1	1.1	1.8	3.2	0.2	0.02	0.02
Thro S	18	2.5	24	0.12	14.0	1.2	1.6	5.0	0.2	0.02	0.02
Mean		2.9	28.0	0.13	13.0	1.0	2.2	4.5	0.3	0.02	0.02
SD		0.7	3.5	0.02	2.1	0.2	0.9	0.7	0.4	0.004	0.008
625 Kg.FERTILIZER / HECTARE.											
Tic O	18	2.8	35	0.10	12.4	1.1	3.5	5.2	0.1	0.02	0.02
Tic M	14	4.1	22	0.09	13.0	1.2	5.5	7.5	0.3	0.04	0.06
Tic S	14	4.5	30	0.10	16.0	1.5	4.6	4.3	1.0	0.03	0.03
Thro O	18	2.7	27	0.10	14.1	1.0	2.4	4.0	0.1	0.02	0.08
Thro M	18	2.7	28	0.11	13.2	1.1	1.5	6.0	0.05	0.02	0.04
Thro S	14	4.0	34	0.09	14.9	1.3	3.6	7.7	0.05	0.03	0.04
Mean		3.5	29.3	0.10	13.9	1.2	3.5	5.8	0.3	0.03	0.04
SD		0.8	4.8	0.01	1.3	0.17	1.4	1.6	0.4	0.006	0.02
ORGANIC											
Tic O	13	2.0	28	0.06	14.3	1.6	4.5	4.4	0.6	0.02	0.03
Tic M	13	2.0	27	0.08	11.1	1.2	4.7	4.0	0.7	0.01	0.08
Tic S	9	3.8	38	0.08	15.4	1.8	9.5	10.9	2.2	0.03	0.03
Thro O	13	2.7	32	0.09	17.5	1.7	3.5	9.4	0.6	0.01	0.04
Thro M	16	2.3	22	0.10	13.2	1.6	3.7	4.0	0.6	0.01	0.01
Thro S	16	2.5	23	0.08	14.3	1.8	2.5	2.7	0.6	0.02	0.03
Mean		2.6	28.3	0.08	14.3	1.6	4.7	5.9	0.9	0.02	0.04
SD		0.7	6.0	0.01	2.1	0.2	2.5	3.4	0.6	0.007	0.02

by the proposed dilution factors were magnesium and sodium, i.e. although the concentrations of these two were greatest in the organically grown plants, there was less total weight of them in the total standing crop, than in the Stockless field.

:4.4.7 Concentrations of geochemicals at the Maximum Leaf Area Index

The fourth comparison of the geochemical concentrations was made at the time at which the crop attained Maximum LAI. The Maximum Leaf Area Index provides a growth parameter for the comparison of geochemical concentrations, which is independent of the direct measurement of dry weight. The Leaf Area Index is an expression of the ratio of the leaf area of the plant to the area of the ground shaded. The maximum LAI occurred at about 18 weeks of age on the Stockless field, but the greater the quantity of fertilizer supplied, the earlier this maximum was attained. On the Organic section this stage was reached at 13 weeks of age (corresponding calendar time to that on the Stockless section). Table 4-7 shows the concentrations of geochemicals in the plants at the stage of maximum LAI.

(1) There was no clear effect of imprint type upon the concentration of any geochemical.

(2) The only geochemical concentrations which were significantly affected by the changing fertilizer application rates were :

P, K and Zn - directly proportional)
) (p = < 0.05)
NO_3-N - inversely proportional)

(3) 0 > S for Mg, Na and Al (p = <0.05)
S > 0 for NO_3-N and Cu (p = <0.05) but not for 6F
0 ≡ S for P, N, Ca, K, Zn.

This pattern coincides exactly with that found at the maximum dry weight, although these two growth maxima did not occur at the same age of the plants.

:4.4.8 Maximum flow of geochemicals into the standing crop - short-term storage

From the full analytical results of the 1971 Field Trial the maximum value for the "geochemical concentration x total plant dry weight" was determined. Due to the seasonal fluctuation in concentrations this did not always coincide with the timing of the maximum plant dry weight. Using the estimate of 270,000 plants per hectare, the maximum flow of geochemicals into the standing crop was calculated - this was used for the fifth comparison of the plants' chemical composition - the values are presented in Table 4-8. These figures do not refer to the quantity of geochemicals lost from the ecosystem, only that which is mobile within it, for leaf fall and senescence of the root will return some of these total quantities to the soil.

.8-1 For the geochemicals where maximum flow did coincide with the maximum plant dry weight, the earlier observed pattern of O and S imprints having higher geochemical concentrations than M imprints occurred as a non-significant trend. All imprint types showed some differences in the flow of geochemicals into the standing crop, but not according to any consistent pattern. Maximum flow did not coincide with the timing of the maximum plant dry weight for Na, K, Al, Cu, Zn.

.8-2 As previously, the means calculated from the six plant types within each treatment were used to statistically evaluate the treatment effect. The conclusions drawn from this analysis were :

(1) The rate of fertilizer application had no significant effect upon the short-term storage of P, N, NO_3-N, Ca, Mg, Al or Pb in the standing crop.

(2) The short-term storage of K was affected by the fertilizer application rate so that 3F > NF ($p = <0.05$). For Na, Cu and Zn, increasing the rate of fertilizer application decreased the magnitude of maximum flow into the plants.

TABLE 4-8. CROP GEOCHEMISTRY

MAXIMUM FLOW OF GEOCHEMICALS FROM SOIL INTO PLANTS - SHORT TERM STORAGE

Expressed in Kg/ha (using an estimate of 270,000 plants/hectare

Plant Type	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
NO FERTILIZER.											
Tic O	42.8	360.5	1.91	233.6	19.2	39.4	68.3	4.1	3.6	2.2	2.0
Tic M	34.7	385.3	1.54	224.4	18.6	38.3	72.6	7.2	5.1	3.1	0.53
Tic S	51.0	622.4	1.89	237.3	29.7	46.4	75.1	5.7	2.9	1.9	0.87
Thro O	28.7	350.7	1.32	194.9	17.8	38.3	86.1	2.3	5.3	3.3	0.64
Thro M	32.8	428.2	1.76	181.4	20.0	30.8	77.0	5.8	2.7	1.9	0.91
Thro S	55.4	551.3	2.16	250.3	15.7	38.6	84.0	3.2	4.6	2.3	0.61
Mean	40.9	449.7	1.76	220.3	20.2	38.6	77.2	4.7	4.0	2.45	0.93
SD	10.7	112	0.3	26.6	4.9	4.9	6.8	1.8	1.1	0.6	0.5
375 Kg.FERTILIZER / HECTARE.											
Tic O	53.3	570.5	2.90	257.6	15.8	24.7	93.9	5.0	3.6	2.1	0.63
Tic M	29.7	322.4	1.67	134.7	14.4	29.4	91.5	7.1	5.9	3.6	1.18
Tic S	41.1	430.9	1.73	179.0	15.7	37.5	115.3	4.8	5.0	3.0	0.36
Thro O	27.4	328.3	1.62	118.3	12.7	24.7	77.5	4.7	5.6	3.4	0.39
Thro M	28.7	458.2	1.27	141.2	19.7	28.9	105.3	6.9	9.1	5.6	0.84
Thro S	47.5	366.1	1.78	212.8	22.1	31.6	76.7	4.6	5.2	2.7	0.33
Mean	38.0	412.7	1.83	173.9	16.7	29.5	93.4	5.5	5.7	3.4	0.62
SD	11.0	94.6	0.6	53.4	3.5	4.8	15.2	1.2	1.8	1.2	0.3
625 Kg.FERTILIZER / HECTARE.											
Tic O	48.1	600.8	1.70	213.3	18.2	59.6	89.8	5.1	0.41	0.35	0.82
Tic M	33.1	313.5	1.46	132.3	29.9	44.0	91.3	5.7	1.03	1.30	0.28
Tic S	36.1	413.9	1.43	214.7	26.8	37.5	87.5	6.8	1.43	1.0	0.85
Thro O	46.8	464.4	1.67	245.7	17.3	42.4	77.0	10.2	3.2	1.8	0.47
Thro M	37.0	444.7	1.46	170.1	15.7	35.4	78.8	5.6	2.6	1.35	1.86
Thro S	50.2	278.9	1.32	133.1	16.7	23.5	82.1	6.7	1.1	0.65	0.31
Mean	41.9	419.4	1.51	184.9	20.8	40.4	84.4	6.7	1.6	1.08	0.77
SD	7.3	115	0.15	47.0	6.0	11.9	6.0	1.8	1.1	0.5	0.6
ORGANIC											
Tic O	19.9	210.4	0.58	65.6	7.8	25.4	32.3	3.7	1.30	0.65	1.04
Tic M	18.0	162.8	0.62	107.7	11.9	28.1	24.0	5.3	0.19	0.46	0.52
Tic S	32.3	308.9	0.81	143.4	20.2	31.1	71.6	4.3	0.73	0.43	0.43
Thro O	13.5	160.9	0.51	70.2	8.6	18.3	28.9	4.1	0.11	0.14	0.14
Thro M	15.7	153.9	0.73	92.3	11.3	25.6	28.1	4.3	0.41	0.16	0.46
Thro S	15.1	134.2	0.46	85.1	10.7	15.0	21.9	3.8	0.11	0.19	0.16
Mean	19.1	188.5	0.62	94.1	11.8	23.9	34.5	4.3	0.50	0.34	0.46
SD	6.9	64.1	0.13	28.6	4.4	6.1	18.6	0.6	0.47	0.20	0.33

(3) Because of the lower plant weight on the Organic section, the flow of P, N, NO_3-N, Ca, K and Zn was greater $S > 0$ ($p = <0.01$).

(4) Despite the lower total crop biomass on the Organic section, there were no significant differences in the magnitude of the short-term storage of some geochemicals, between the Organic and Stockless treatments, at some fertilizer rates :

Mg and Na $0 \equiv 3F$ but NF, $6F > 0$ ($p = <0.02$)
Al and Cu $0 \equiv 6F$ but NF, $3F > 0$ ($p = <0.02$)

Thus, for all geochemicals considered, the maximum flow of geochemicals through the Stockless field ecosystem was greater than through the Organic field, despite a greater "availability" of some geochemicals in the soil of the latter management type.

:4.4.9 Location of geochemicals in the stems, pods and seeds

The effect of the plant imprint type and treatment upon the chemical composition of the stems, pod cases and seeds were investigated during the penultimate six weeks of the crop's life. The full results from these analyses are shown in Table A11.

.9-1 Neither the imprint type nor the soil treatment affected the main location of any geochemical during the final weeks in the life cycle of the *V. faba* plants. The concentrations of each geochemical were significantly greater in certain plant parts, and the difference increased as the plants dried out :

(1) Concentration in stem > pod cases > seeds for Ca, Na, Al, Cu, Zn, Pb
(2) " " pod cases > seed > stem for Mg, K
(3) " " seed > pod cases > stem for P, Org N

but with no particular location for the concentrations of NO_3-N.

.9-2 The effect of the soil treatments upon the chemical composition of the separate plant parts during the last three weeks of the season was statistic-

Table 4-9 Results of the statistical comparison of the effect of soil treatment upon the concentrations of geochemicals in the dying bean plant

Time and plant part H-3 weeks	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
Stem	O>N,3	O>S	O>N,3*	O>N,3	O N,3	NS	NS	O>N,3*	NS	O>N	-
	*	*	6>3 *	*	*			6,3>N*		*	-
Pod + seed	O>N	NS	N>O	O>3,6	NS	O>3,6	3>N	NS	NS	6,3>N	-
	*		*	**		**	**			**	
Harvest											
Stem	O>N,3	O>N	S>O **	O>S	O>S	O>3,6	NS	NS	O>S	S>O**	S>O*
	*	*	6>N	**	**	*			**	3>N.6*	3>6*
Pod cases	O>6	NS	S>O **	NS	O>S *	O>S	6>O *	O>S**	S>O	S>O	NS
	*		6>3,N*		6>3,N*	**	6>3,N*	6>3,N**	*	*	
Seeds	NS	O>S	NS	NS	S>O	O>S	NS	O>S**	N>O*	N>O*	6>O
		**			**	**		6>3**	N>3>6*	N>3>6*	

Key : H-3 = 3 weeks prior to harvest

NS = No significant differences

P = Organic

N = No fertilizer (Stockless)

S = all Stockless treatments

* = significant to p = <0.05

** = " " p = <0.01

3 = 375 Kg fertilizer/ha

6 = 625 Kg fertilizer/ha

\- = no measurement made

ally determined from the treatment means (Table 4-9). The effect of the soil treatments increased in severity as the plants dried out :

(1) The rate of fertilizer had no effect upon the concentrations of P, Org N, Ca, Na in the plant tissues. Increasing the rate of application of fertilizers increased the plant concentrations of NO_3-N, Mg, K, Al, but decreased that of Cu, Pb and Zn.

(2) 0 > S for P, Org N, Ca, Mg, Na, Al and Cu (stem)
S > 0 for NO_3-N, An, Pb, Mg (seeds), K (pods), Cu (pods).

These results showed almost no overlap with the effects of the soil treatment shown to act upon the concentrations of geochemicals in the separate plant parts at five weeks of age. The discussion has demonstrated how dependent the chemical composition of the plants was, upon the particular stage in the growth cycle at which the plants were sampled.

.9-3 The heavy metal content of the crop was only briefly investigated in 1971. From Table A 11 it was seen that very high concentrations of lead were present in the dead plants at the final harvest. The mean values for each variety were calculated from the three imprint types :

Concentrations of lead in the dead plants Tic and Throws 1971

Treatment	Plant part	Tic μ gm Pb/gm dry plant material	Throws μ gm Pb/gm dry plant material
	Initial seed	40.0	56.3
0	Whole plant	203.3	29.0
	Pod case + stem	301.0	41.6
	Seed	20.0	6.0
S	Whole plant	200.0	108.3
	Pod case + stem	375.0	231.3
	Seed	19.3	36.7
S + 375	Whole plant	95.0	93.3
	Pod case + stem	250.7	145.0
	Seed	23.0	40.0
S + 625	Whole plant	66.6	56.7
	Pod case + stem	108.0	88.0
	Seed	36.0	30.0

Although the concentrations varied widely between the varieties and treatments, in all plants analysed the main concentration of lead was found in the dead stem and pod cases. The concentrations in the live seeds were considerably lower (below the levels found in the seeds shown).

When the analysis for lead was made on the plants of 5 - 20 weeks of age, the concentrations were always below 5 μgm Pb/gm dry plant material. Although there was a reduction in the total plant dry weight during the final four weeks of the season, the resulting concentration of the lead already in the plant tissues was not sufficient alone to explain the high levels found in the stems and pod cases at final harvest. These could only have resulted from an increased uptake of lead from the soil after the death of the plant. During the final stages of senescence, to the dry and blackened state in which the plants were harvested, there would have been a strong upward movement of water through the plant drawn by the evaporation from the dead stem surface.

TABLE4-10 CROP GEOCHEMISTRY

REMOVAL OF GEOCHEMICALS FROM FIELD SYSTEM IN FINAL HARVEST OF WHOLE PLANTS 1971.

Plant Type	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
	Expressed in Kilogrammes/hectare										
NO FERTILIZER.											
Tic O	16.1	202.7	0.78	37.5	6.35	8.26	36.3	2.62	3.56	2.17	2.02
Tic M	14.3	178.6	0.68	33.2	5.80	10.40	45.4	5.43	5.07	3.09	0.53
Tic S	17.9	247.8	1.00	50.1	6.50	19.7	37.7	5.67	2.87	1.00	0.87
Thro O	61.3	174.8	0.73	26.3	2.89	9.75	21.8	0.54	5.26	3.28	0.64
Thro M	24.6	199.3	0.89	26.6	3.89	19.4	28.1	1.19	2.68	1.90	0.91
Thro S	17.3	263.8	1.03	42.3	3.83	17.4	28.3	2.81	4.58	2.29	0.61
Mean	17.8	211.1	0.85	36.0	4.9	14.2	32.9	3.0	4.0	2.3	0.93
SD	3.6	36.6	0.14	9.3	1.5	5.2	8.5	2.1	1.1	0.8	0.6
375 Kg.FERTILIZER / HECTARE.											
Tic O	18.7	223.4	0.76	30.7	4.37	13.7	34.6	0.43	2.98	2.05	0.63
Tic M	18.0	180.0	0.95	37.5	4.46	13.9	34.5	0.27	5.93	3.57	1.18
Tic S	21.2	244.9	0.57	12.8	5.20	5.9	35.1	0.30	5.02	2.97	0.36
Thro O	15.2	170.6	0.65	25.5	3.40	6.91	19.2	0.54	5.57	3.41	0.39
Thro M	18.9	323.2	1.32	55.1	6.00	13.0	38.9	6.94	9.11	5.56	0.84
Thro S	12.9	183.3	0.73	28.6	2.59	7.4	3.3	2.84	4.27	2.65	0.33
Mean	17.5	220.9	0.83	31.7	4.3	10.1	27.6	1.9	5.5	3.4	0.62
SD	3.0	58	0.3	14.1	1.2	3.8	13.7	2.7	2.0	1.2	0.3
625 Kg.FERTILIZER / HECTARE.											
Tic O	19.4	263.2	1.10	31.6	8.00	8.94	43.4	1.27	0.41	0.32	0.82
Tic M	18.4	177.7	0.62	23.5	6.05	6.64	27.7	0.51	1.02	1.29	0.28
Tic S	15.1	175.2	0.89	33.4	4.16	18.7	29.0	0.65	1.42	1.00	0.85
Thro O	30.1	303.5	1.30	31.8	5.10	8.10	33.9	2.84	3.15	1.77	0.47
Thro M	37.0	365.0	1.32	38.3	5.91	13.91	47.3	5.51	2.59	1.35	1.86
Thro S	17.0	257.6	0.92	16.3	4.70	10.20	35.2	1.30	1.05	0.65	0.31
Mean	22.8	257.0	1.0	29.1	5.7	11.1	36.1	2.0	1.6	1.1	0.77
SD	8.7	73	0.3	7.9	1.4	4.5	7.8	1.9	1.1	0.5	0.59
ORGANIC											
Tic O	19.2	210.4	0.60	54.5	7.30	22.7	32.3	3.70	1.28	0.64	1.04
Tic M	7.9	103.1	0.27	26.1	3.11	12.5	12.0	1.11	0.20	0.08	0.52
Tic S	10.7	144.2	0.38	26.8	4.83	13.5	17.2	2.30	0.73	0.42	0.43
Thro O	13.5	160.9	0.45	46.4	6.40	17.6	18.1	4.10	0.06	0.14	0.14
Thro M	7.13	136.9	0.30	29.8	4.35	9.3	15.6	2.32	0.40	0.16	0.46
Thro S	10.12	134.2	0.30	36.5	3.54	11.4	11.4	2.05	0.03	0.06	0.16
Mean	11.4	148.3	0.38	36.7	4.9	14.5	17.8	2.6	0.45	0.25	0.46
SD	4.4	35.8	0.13	11.6	1.6	4.9	7.6	1.1	0.5	0.23	0.33

:4.4.10 Loss of geochemicals from the system in the final harvest

.10.1 One of the most important factors which will limit the productivity of an arable farm ecosystem is the loss of the nutrient geochemicals in the harvested crop. The magnitude of the loss will depend upon the total dry weight of the standing crop, its chemical composition, and the harvesting techniques. At Haughley, the beans were harvested by combine which left most of the roots in the soil, but removed seed, stems and pod cases, the latter to be burned elsewhere.

.10.2 Table 4-10 presents the values of the geochemical loss in the whole plants from the four treatments, expressed in Kg/ha, using the estimate of 270,000 plants per hectare. The imprint types showed no influence over the loss from the system. Therefore to determine the treatment effect, means were calculated from the six plant types within each treatment. The high values of the standard deviations for the losses of heavy metal demonstrated the great variability in tissue concentration, between the plants within each treatment.

.10.3 The results of the statistical analysis of the losses from the four treatments are shown below :

Geochemical	P	Org N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
Significant Result	S>O	S>O	S>O	NS	NS	NS	S>O	NS	S>O	S>O	NS
									NF,3F>6F	NF,3F>6F	
p value	*	*	**				*		**	**	

Where * p = <0.05 ** p = <0.01 NS = no significant difference

(1) Because of the significantly lighter plants on the Organic section (p = <0.05), no geochemical was lost in greater quantity from that section, despite higher tissue concentrations in some of the Organic plants.

(2) Because of the higher tissue concentrations in the Organic plants, despite lower biomass in the field $O \equiv S$ loss for Ca, Mg, Na, Al and Pb, but $S > O$ loss for P, N, NO_3-N, K, Cu and Zn.

(3) The rate of fertilizer application only showed a significant effect upon the loss of copper and zinc, according to the previously noted inverse relationship.

4:4.11 Summary of results and conclusions from the 1971 Geochemical Analysis

.11-1 Effect of imprint type

(1) The greenhouse trial showed some indications that each imprint type was able to obtain more nitrogen from its own farm management soil, but this trend was not confirmed by the field trial for any geochemical. Thus it is concluded that there was no physiological adaptation of any imprint type to its own farm management section - this correlated with the observations of crop growth (Section 3).

(2) The imprint type never significantly influenced the chemical composition of the bean plants at any stage in the growth cycle.

.11-2 Effect of fertilizer application rate

(1) The location of the main concentrations of geochemicals in the plant tissues followed a set seasonal pattern, which was never significantly altered by the rate of fertilizer application.

(2) The apparent effect of the fertilizer application rate upon the chemical composition of the plants depended upon the stage in the growth cycle at which the plants were sampled, and the plant part considered, agreeing with the work on wheat by Boatwright and Haas (1961). A summary of the effect of increasing the level of fertilizer, upon the concentration of geochemicals in the plants, is shown overleaf :

Stage in the growth cycle	P	N	NO$_3$-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
Seasonal mean	-	-	-	-	-	-	-	-	-	-	-
5 week old plants	↓	-	↓	-	-	-	↓	↑	↑	↑	-
Maximum ion conc.	-	-	-	-	-	-	-	-	↓	↓	-
Maximum Dry Weight	-	-	-	-	-	-	-	-	|	-	-
Maximum LAI	↑	-	↓	-	-	-	↑	-	-	↑	-
Maximum flow	-	-	-	-	-	↓	↑	-	↓	↓	-
21-24 week plants	-	-	↑	-	↑	-	↑	↑	↓	↓	↓
Harvest loss	-	-	-	-	-	-	-	-	↓	↓	-

where ↑ = increase in concentration with increasing fertilizer rates

↓ = decrease " " " " " "

\- = no effect

Thus the uptake of most geochemicals was unaffected for most of the growing season by the rate of fertilizer application, except for that of the heavy metals, copper and zinc, which were usually absorbed in inverse proportion to the rate of the fertilizer application.

Although the growth studies (Section 3) showed that the crop yield was strongly influenced by the rate of fertilizer application, this was not found to be true for the loss of geochemicals in the final harvest. The uptake of geochemicals from the Stockless field did not accurately reflect the rate of the addition of nutrients in the fertilizers. This may have been due to an already more than adequate supply of plant nutrients in the unfertilized soil plots.

.11-3 Effect of farm management

(1) The farm management never significantly altered the seasonal pattern shown by the main locations for the concentrations of each geochemical.

(2) Whenever plant weight was used in the comparison of geochemical uptake between the two sections (Max flow and harvest loss), S > 0 due to the larger plants on the Stockless section. Apart from this, the relationship between the farm management sections depended upon each particular geochemical as shown below :

Growth stage	P	N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
Greenhouse	S>0	0>S	0>S	-	0>S	0>S	-	-	-	S>0	-
Field :											
Seasonal mean	S>0	-	S>0	0>S	0>S	0>S	-	-	-	-	-
5 week plants	-	S>0	S>0	0>S	0>S	0>S	-	S>0	S>0	S>0	-
Max Ion conc	S>0	-	-	-	-	-	0>S	S>0	S>0	S>0	-
Max Dry Wt	-	-	S>0	-	0>S	0>S	-	0>S	S>0	-	-
Max LAI	-	-	S>0	-	0>S	0>S	-	0>S	S>0	-	-
Max Flow	S>0	S>0	S>0	S>0	S>0	S>0	S>0	S>0	S>0	S>0	-
21-24 week	0>S	0>S	S>0	0>S	0>S	0>S	-	0>S	S>0	S>0	S>0
Harvest loss	S>0	S>0	S>0	-	-	-	S>0	-	S>0	S>0	-

Except where the patterns were confounded by the differences in plant dry weight, the plant chemical content was directly proportional to the supply in the soil, shown by chemical means (Section 1) e.g. for the alkaline earths. However, despite higher NPK content in the organic soil, the plants grown on that system contained lower concentrations of these geochemicals, possibly due to the Kirkby-Mendel effect.

.11-4 A death reaction was observed whereby the uptake of the heavy metals, especially lead, increased during senescence to produce very high concentrations in the dead stems and pod cases.

4:5 1972 Field Trial

:5.1 Aim

To determine the effect of the three farm management types upon the chemical composition of *V. faba* var Throws (not previously imprinted) under normal agricultural conditions, which included a more detailed study of the heavy metal content of the plants.

:5.2 Method

Five plants were randomly sampled from each of the Organic, Mixed and Stockless farms upon six occasions during the growing season. They were dried as previously described, before being analysed for fourteen geochemicals by the methods in the Appendix.

The plant and soil treatments used for this trial are shown below :

Measurements	Plant material	Treatment
Crop geochemistry - plants analysed for : P, N, NO_3-N, NH_4-N, Na, K, Ca, Mg, Al, Fe, Mn, Cu, Zn, Pb at intervals throughout the season	Commercially obtained *V. faba* var. Throws	Organic farm - field - lysimeter Mixed farm - field - lysimeter Stockless farm - field - lysimeter (normal fert) - lysimeter (high fert)

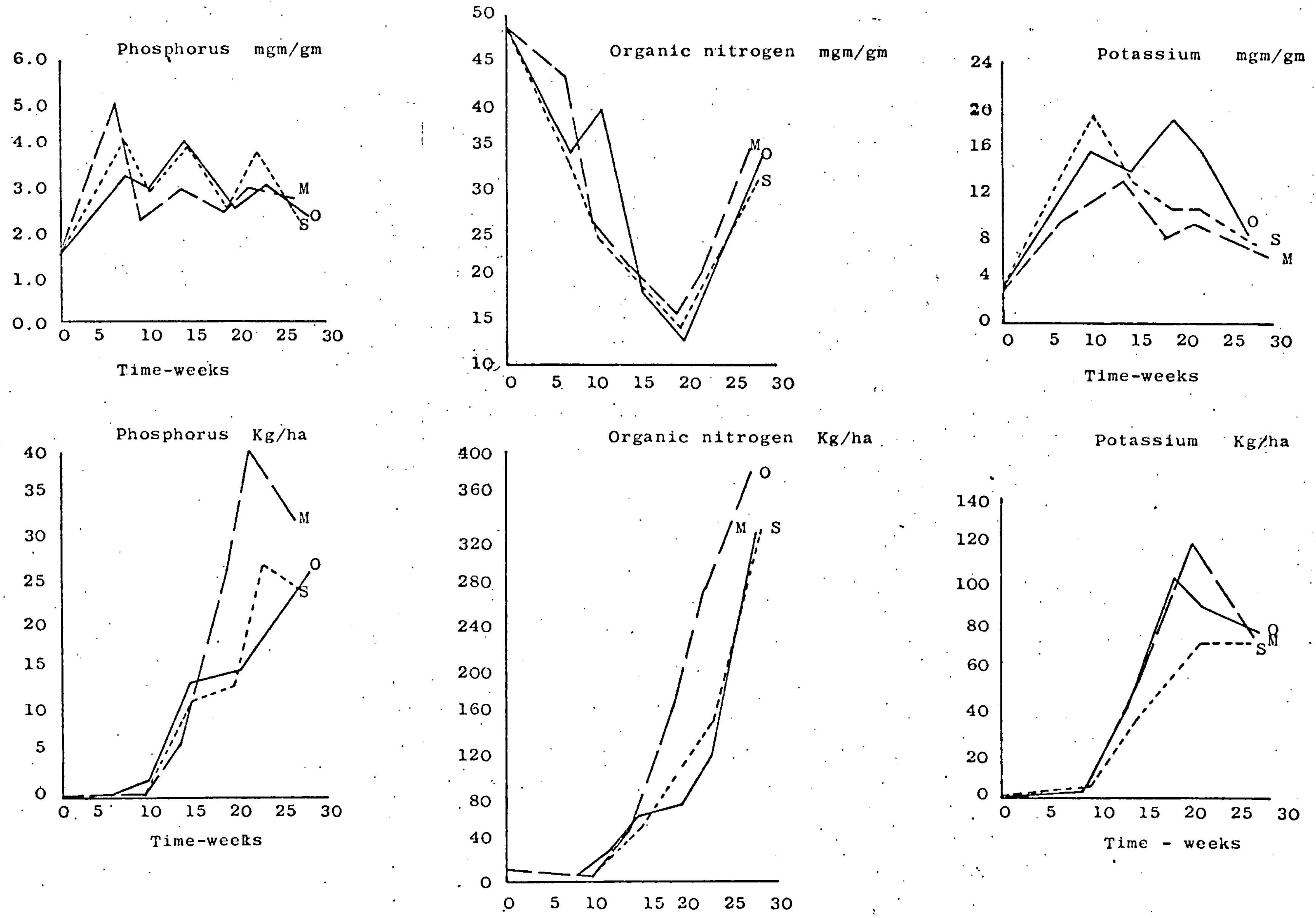
:5.3 Results

The results are presented in graph form - Graphs 4-10 to 4-16.

GRAPH 4-10.

The Seasonal Change in the Chemical Composition of the bean plants, growing on the Organic, Mixed and Stockless farms 1972.

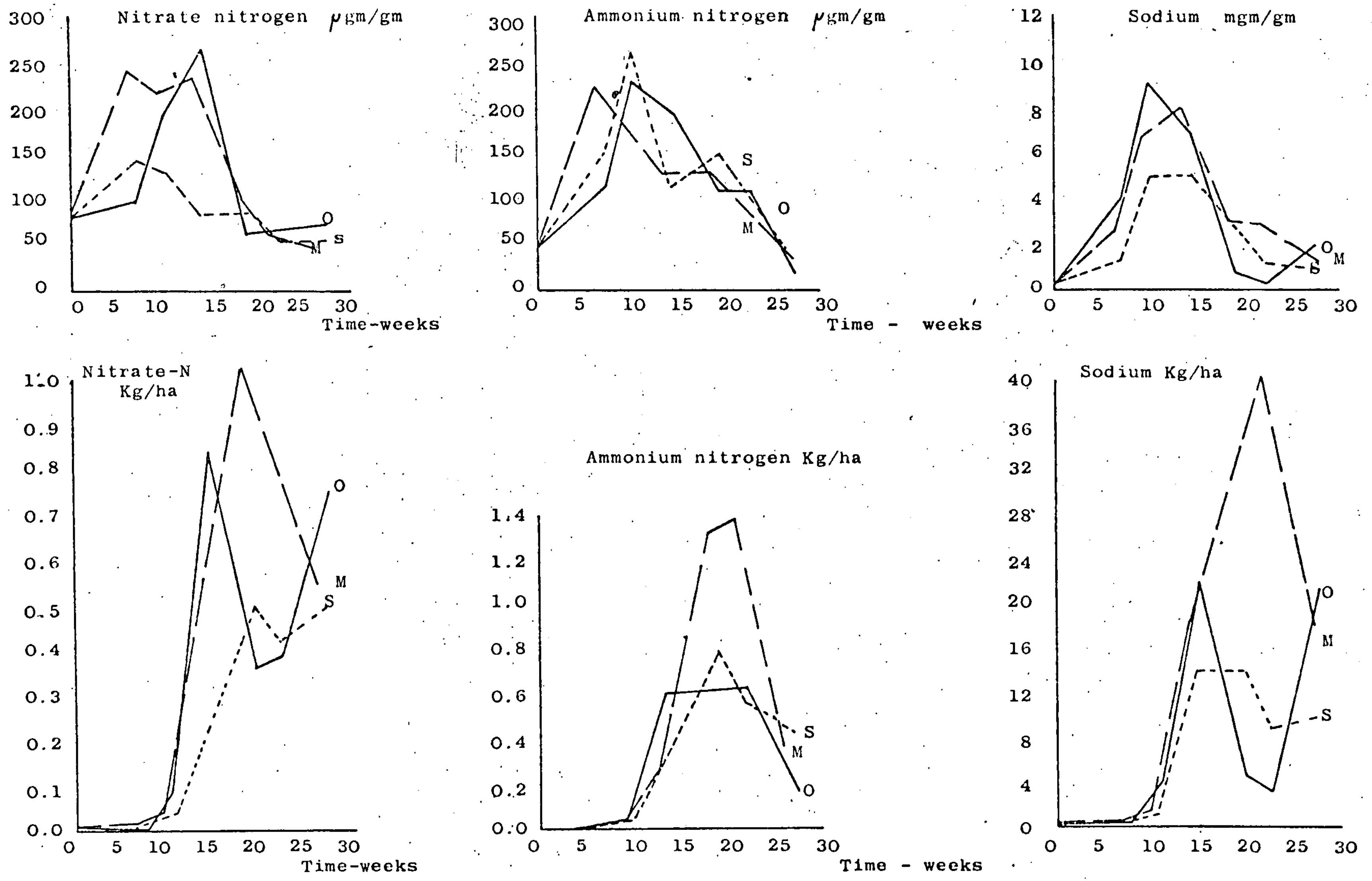
(Concentrations of geochemicals expressed as mgm/gm dry weight whole plant, and as Kg/ha in standing crop)



GRAPH 4-11.

The Seasonal Change in the Chemical Composition of the bean plants, growing on the Organic, Mixed and Stockless Farms 1972.

(Concentrations of geochemicals expressed in mgm or μgm/gm dry weight whole plant, and as Kg/ha in standing crop)



:5.4 Discussion

:5.4.1 Seasonal changes in the geochemical concentrations

.4.1-1 The graphs 4-10 to 4-13 show the pattern of the seasonal change in the chemical composition of the 1972 plants on the three farm sections, expressed as the concentration of geochemicals/gm dry weight, and the total concentration/plant. When these are compared with the 1971 results (Graph 4-9), most geochemicals followed the same seasonal pattern in both years. Only the graphs of nitrate-nitrogen, copper and zinc differed - the latter two reached their maxima earlier in 1972.

.4.1-2 The graphs demonstrate the effect of farm management upon the plant chemical composition - summarizing :

:the management had no sustained effect upon N, NH_4-N, P, K or Ca concentrations.

O ≡ M for tissue concentrations of NO_3-N, Na, Mg, Mn and Zn
O > S " " " " NO_3-N, Na, Zn
S > O " " " " Mg, Al, Mn and Pb
M > O ≡ S for tissue " " Fe and Cu

.4.1-3 The graphs of the total weight of geochemicals per plant indicate that most followed the pattern, where the total increased to a maximum at 19-22 weeks (Maximum dry weight 22-27 weeks) and then decreased during the final five weeks of senescence. The only exception to this rule was shown by the Organic nitrogen values - the total quantity per plant continued to increase throughout the season on all three farm sections. The Organic system exhibited a markedly different influence over several geochemicals, when compared with the effects seen on the other two farms. The total quantities of P, Ca, Mg, Mn, Cu and Pb in the organically grown plants continued to increase throughout the growth cycle, and that of NO_3-N and Na showed two maximum peaks - the second occurred after the death of the plants.

.4.1-4 Because of the significantly greater dry weights of the plants on the Mixed section these showed the greatest flow of geochemicals into the standing crop, for almost all the geochemicals measured. Very high concentrations, in terms of mgm/plant, of Mg in the Stockless plants, resulted in a maximum flow of this cation into the standing crop on that section, despite the lower dry weights of the Stockless-grown plants.

Considering the relationship shown by the flow of geochemicals in the other two systems :

O > S for total plant content of K, NO_3-N and Zn
S > O " " " " " Ca, Mg and Mn
O ≡ S " " " " " P, N, NH_4-N, Na, Al, Fe, Cu and Pb

.4.1-5 The results of the chemical analysis of the plants grown in the lysimeters showed lower concentrations than found in the field-grown plants, for all geochemicals considered, but the relationships between the farm sections outlined above were maintained.

:5.4.2 Mean seasonal geochemical concentrations

All the geochemicals showed marked seasonal fluctuations in their concentrations and therefore the statistical comparison of the seasonal means from the three farm sections would have incurred using large standard deviations, which would have masked any differences between them (as illustrated for the 1971 trial).

:5.4.3 Heavy metal analysis

In the 1971 trial there were indications that the level of lead, copper and zinc increased in the senescing plants to give high concentrations, particularly in the stem and pod cases. One aim of the 1972 research was to determine, in greater detail, the magnitude of the flow of heavy metals into the bean plants on the three farm systems, during the whole of the growing season.

Table 4-11

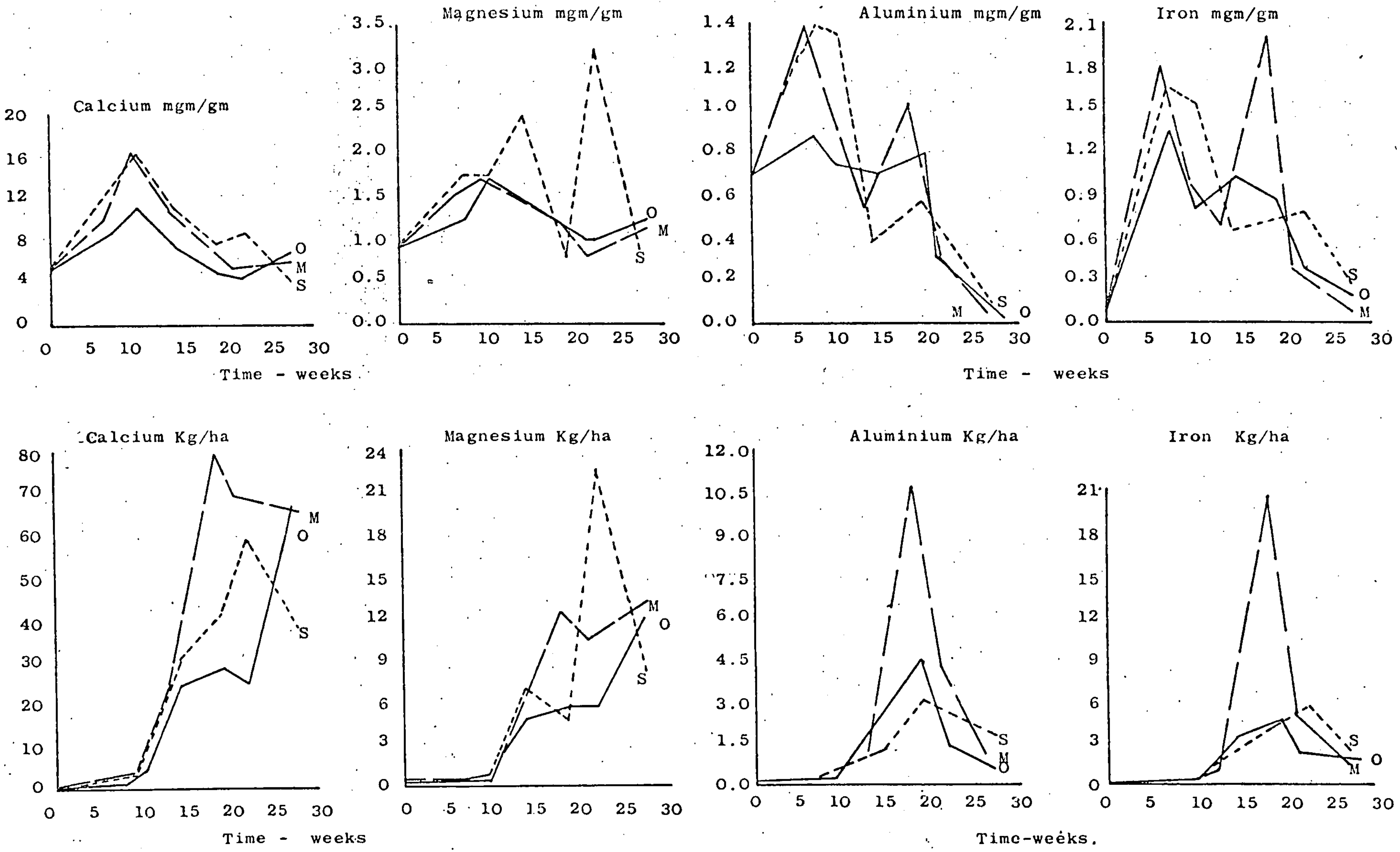
Concentrations of Copper, Zinc and Lead in the 1972 *V. faba* plants

		COPPER		ZINC		LEAD	
Age (weeks) and plant part	Dry weight plant (gms)	Concent-ration µgm/gm	Total/ plant µgm	Concent-ration µgm/gm	Total/ plant µgm	Concent-ration µgm/gm	Total/ plant µgm
Organic section							
Seed sown	0.24	15.0	3.6	10.0	2.4	29.0	7.0
7 weeks	0.42	22.0	9.2	67.0	28.1	3.3	1.4
10	1.60	4.0	6.4	45.0	72.0	10.2	16.3
14	11.72	6.0	70.3	56.0	656.3	15.3	179.3
19	20.40	30.0	612.0	61.0	1244.4	182.5	3723.0
22	21.00	35.0	735.0	67.0	1407.0	263.5	5534.0
27	36.70	38.2	1402.0	29.4	1079.0	256.1	9399.0
27 stem	12.60	41.0	516.6	39.0	491.4	222.5	2803.5
podcases	4.90	67.0	328.3	61.0	298.9	39.2	192.6
seed	19.2	29.0	556.8	15.0	288.0	333.5	6403.2
Mixed section							
Seed sown	0.26	15.0	3.9	10.0	2.6	70.0	18.2
7 weeks	0.34	10.0	3.4	56.0	19.0	3.0	1.0
10	0.87	5.0	4.4	56.0	48.7	20.4	17.8
14	8.07	6.0	48.4	61.0	492.3	10.2	82.3
19	37.83	152.0	5750.0	40.0	1513.2	326.6	12355.3
22	47.90	46.0	2203.0	72.0	3448.8	100.5	4814.0
27	41.80	37.2	1555.0	25.7	1074.2	133.0	5559.4
27 stem	12.70	51.0	647.8	50.0	635.0	60.5	768.4
podcases	6.50	28.0	184.0	33.0	214.5	121.5	789.8
seed	22.60	32.0	723.2	10.0	226.0	142.9	3230.0
Stockless section							
Seed sown	0.28	15.0	4.2	10.0	2.8	70.0	19.6
7 weeks	0.49	14.0	6.9	56.0	27.4	2.0	1.0
10	1.28	15.0	19.2	28.0	35.8	20.4	26.1
14	10.20	3.0	30.6	17.0	173.4	20.4	208.1
19	20.70	81.0	1677.0	50.0	1035.0	355.0	7350.0
22	25.90	26.0	673.4	39.0	1010.0	116.5	3017.4
27	36.60	35.1	1285.0	22.3	816.3	265.4	9714.2
27 stem	13.50	28.0	378.0	33.0	445.5	84.5	1140.8
podcases	4.80	21.0	100.0	39.0	187.2	70.5	338.4
seed	18.30	44.0	805.2	10.0	183.3	450.0	8235.0

GRAPH 4-12.

The Seasonal Change in the Chemical Composition of the bean plants, growing on the Organic, Mixed and Stockless Farms. 1972.

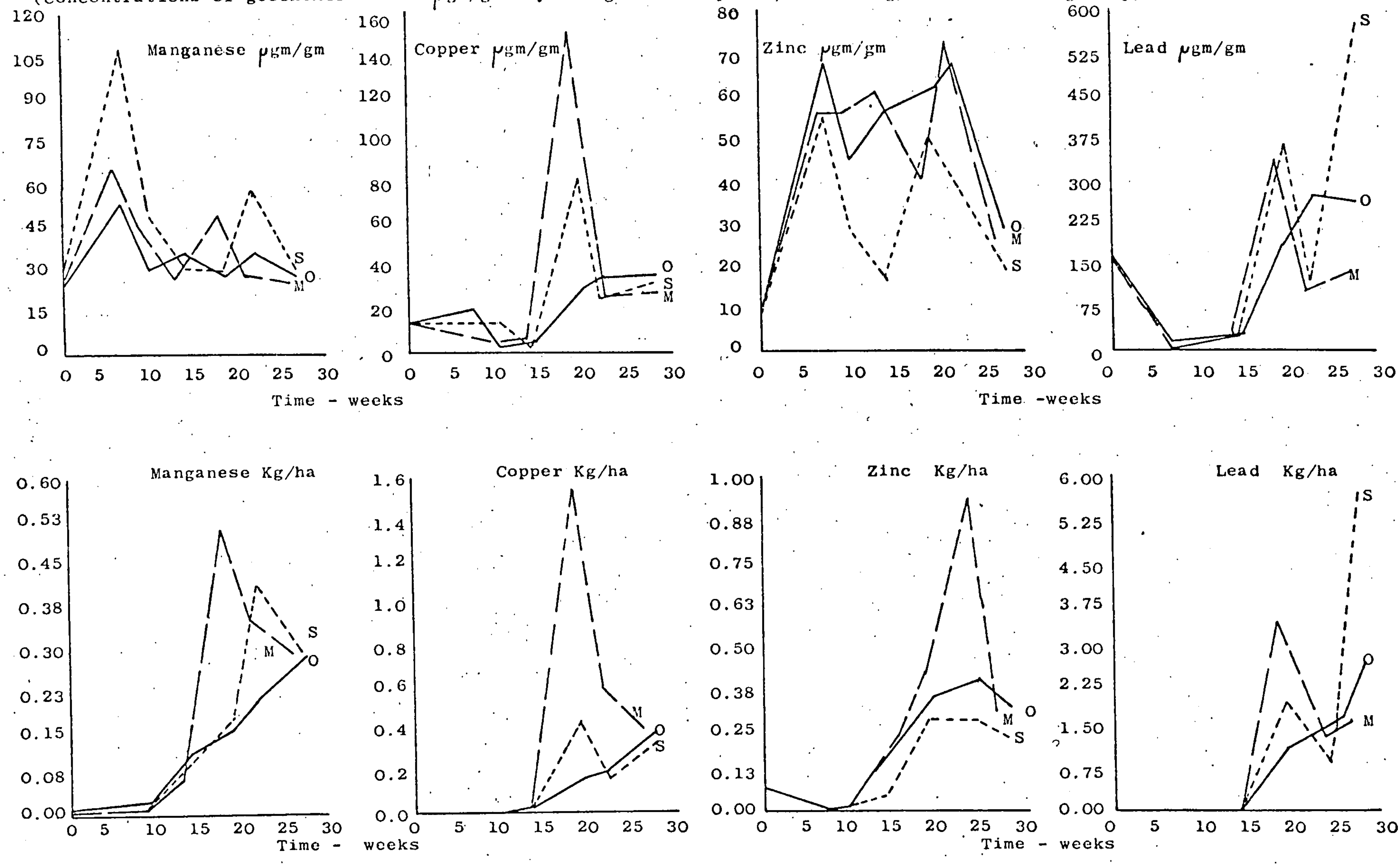
(Concentrations of geochemicals expressed in mgm/gm dry weight whole plant, and in Kg/ha in standing crop)



GRAPH 4-13.

The Seasonal Change in the Chemical Composition of the bean plants, growing on the Organic, Mixed and Staockless Farms. 1972.

(Concentrations of geochemicals in μgm/gm dry weight whole plant, and as Kg/ha in standing crop)



The results shown on Table 4-11 and Graph 4-13 demonstrate that the concentrations and total quantities of copper and zinc reached a maximum before the plant was completely dead, but those of lead did not attain that stage until the final harvest.

.3-1 Copper The total level of copper per plant changed with the season according to a pattern which differed for each farm management section. Very high concentrations of this cation only occurred briefly, and only in the Mixed section plants. At the final harvest most of the total copper/plant was found in the bean seeds, although the highest concentrations were in the dead pod cases, or stems, on the Organic and Mixed sections (Graph 4-14).

.3-2 Zinc On each farm section, two concentration maxima occurred, one in the young plant, the second at week 22 after most of the leaves were dead. The total level then decreased as the abscission of the leaves took place. At final harvest most of the zinc was located in the dead stems, with much lower quantities and concentrations found in the live bean seeds. Throughout the year, the concentrations of zinc in the plant tissues were within the range suggested to be normal for cereals in Britain - 38-54μgm Zn/gm dry weight by Dolar et al. (1971).

.3-3 Lead The quantity of lead present in the seeds sown became "diluted" into the body of the plant during the first seven weeks of growth. Over the following seven weeks the uptake of lead from the environment increased at about the same rate as that of the dry weight, so that there was scarcely any change in the net concentration. It was between the weeks 14-19 that a massive intake of lead occurred on all farm sections, but particularly on the Mixed farm where a five-fold increase in plant dry weight was accompanied by a more than 100-fold increase in lead content, and a 30-fold increase in lead concentration. Thus at the age of 19 weeks the plants, which were just starting to lose more leaves through senescence than were being formed (Max LAI), contained lead in concentrations of 182-355 ppm dry weight.

On the Organic farm both the concentration and the total quantity of lead in the plants continued to increase until the final harvest, when the seeds contained the very high level of 333 ppm lead. On both the other farms, the total quantity, and tissue concentration of lead, fell during the period of maximum leaf fall (weeks 19-22), but by the final harvest, uptake had again increased. Thus, as on the Organic section, the seeds contained most of the lead, with a massive level of 450 ppm on the Stockless section. The individual histograms on Graph 4-14 show that in the lysimeter-grown plants the relationship between the farm sections differed from the situation in the fields, but the main location of lead was still in the live seeds. The observation made by Haar (1970), that there was a great variability in the lead content of biological material within a single treatment, applies here.

It is very difficult to explain the origin of the very high concentration of lead in the live bean seeds in the harvested *V.faba* plants. The differences in plant tissue concentrations did not correlate with the lead levels in the soils, which showed no significant differences between the farms. Jones et al. (1973) showed that only the lead level in the plant roots was proportional to the soil supply, but these were not analysed from the field-grown plants. The level of 20-60 ppm lead in the soil was low by the standards of Swaine (1955) who stated that concentrations of 1 - 500 ppm Pb could be considered normal for arable soils. The analysis of the rain at Haughley showed only 90 gms of lead/ha to be added annually to the soil. From the analysis of the drainage water there were no significant differences in the annual loss of lead from the three farm systems.

In order to check the concentrations of lead found, several of the samples exhibiting high values were analysed independently at Liverpool University - the results found at Durham were confirmed. The high values were not the result of spectral interference (from the alkaline earths) on the atomic absorption spectrophotometer, and the addition of known quantities of lead standards to the plant digests did not result in distorted readings. It is unlikely that any of the processes involved in sample preparation resulted in an increase in lead levels - indeed Sommer (1972) found that oven drying of fresh plant material reduced the lead content by 50%. The seeds were separated into testa and endosperm, both of which were analysed for lead to determine if any contamination of the seed surface was producing the observed results. However, in the samples tested, 95% of the lead content was found in the endosperm, implying that the lead had been transported into the seed through the plant.

It is well documented that airborne dust particles contain lead, and it is therefore possible that the concentrations found in the stem and leaves were due to adhering particles - the plants were not washed prior to analysis. Day et al. (1975) found that dust could contain 85-10,000μgm Pb/gm, although the lower levels were more common in rural areas. Patterson (1970), Bryce-Smith (1971) and Glater (1972) all reported abundant lead upon the leaf surfaces of plants due to industrial fallout, with concentrations of up to 5000 ppm in elm leaves due to lead smelter pollution (Little and Martin 1972). However, Haughley is situated in a predominantly agricultural region, which does not suffer from high traffic densities (lead in vehicular exhausts) nor from obvious industrial pollution, and it is unlikely that aerial pollution should have been so much worse during the final weeks of crop senescence, than at any other time of the year.

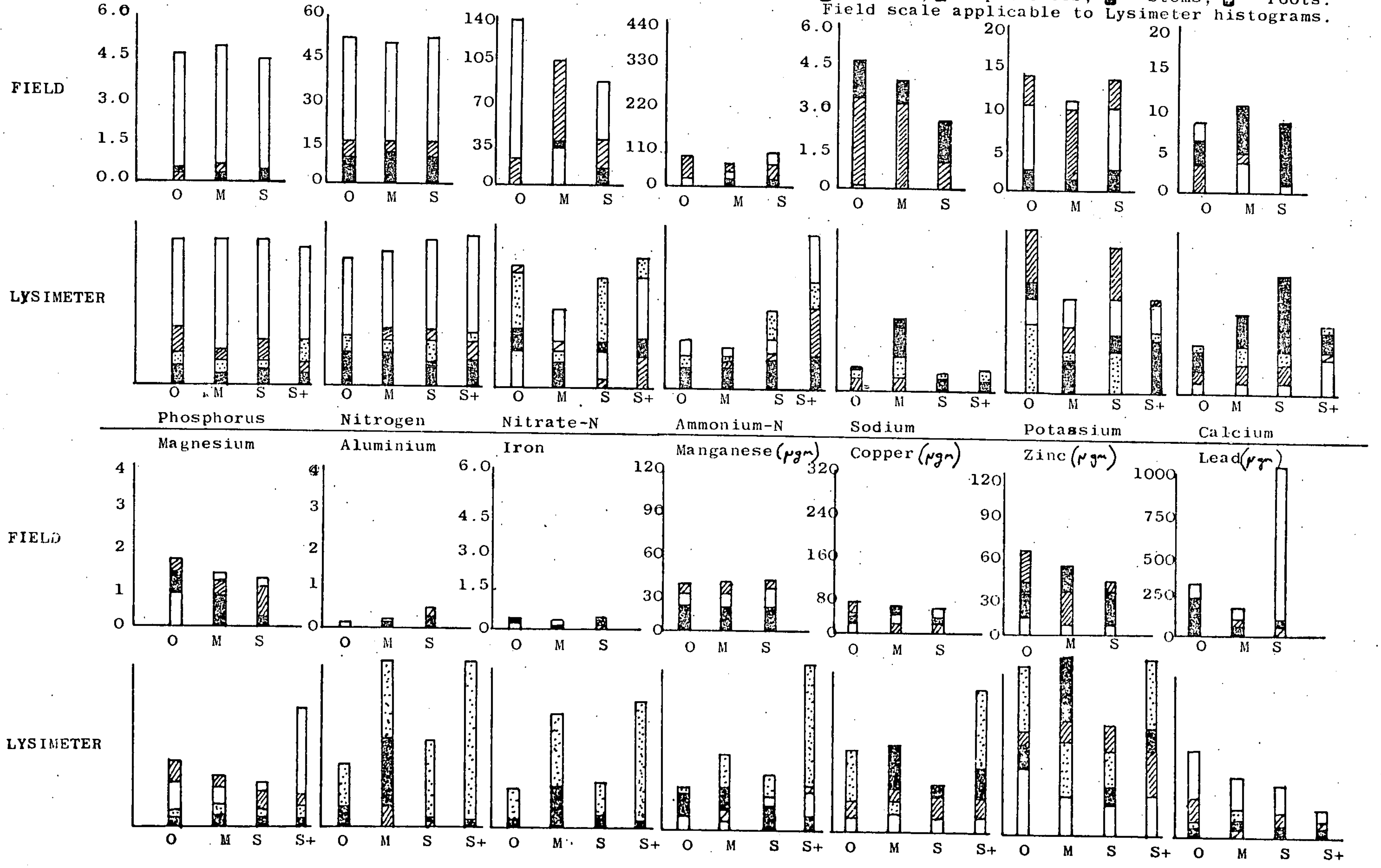
It has been shown in several studies that the permeability of membranes within the plant alters during senescence, so that in, for example, ageing bean leaves, there is an increased export of solutes to the stem (Burg et al., 1964; Jacoby and Dagan 1969), although the deteriorating condition of the phloem (Thrower 1967) will prevent leakage of all the leaf contents. Indeed, geochemicals such as calcium may be selectively moved into the leaves prior to abscission, thus ridding the plants of various excesses (Rieley 1967). However, none of these explanations show why the concentrations of lead in the Haughley bean plants should have increased during the final five weeks of the season; — the total quantity in the plants was also seen to increase in that period. It is possible that this was partly or wholly due to the effect shown by Mitchell and Reith (1966), where the concentration of lead in the plant shoot was increased by translocation from the accumulated levels in the roots after these had died. In all the analyses at Haughley (except for the lysimeter-grown plants), due to the difficulty of removing the roots from the soil, only the shoot from soil level upwards was used. Jones et al. (1973) showed that the roots of plants usually contained the main supplies of lead in the plants, and that during active plant growth this did not pass into the shoots. Thus a possible explanation of the observed levels,would be that upon the death of the roots, the strong upward translocation of water caused by the development of the bean seeds and the drying out of the stem,would have carried any accumulated lead from the roots to the site of active metabolism. Certainly the only roots analysed (lysimeter plants) at the final harvest had low levels of lead within them (Graph 4-14). Upon death, the roots would lose any ability to restrict the entry of solutes and water from the soil, and thus solutes could become concentrated in the senescing plants, as water was drawn through the plant to be lost by the large evaporating surface. The soil did not contain high levels of lead, thus, as observed by Broyer et al. (1972), the lead recoveries in the plants exceeded the levels of the known supplies.

It is postulated that the levels of lead found in the *V. faba* seeds at Haughley would exceed the WHO (1972) maximum tolerable limit for human adult ingestion of 3 mg Pb/week, if used extensively in human food. Until 1971, most field bean seed yields were used for direct feeding to stock, but with the awareness of the need for high protein sources for human

GRAPH 4-14.

The Distribution of geochemicals in the dead bean plants at the Final Harvest, from Fields and Lysimeters.1972.

(Concentrations expressed in mgm/gm dry weight plant part)Key:▯ = seeds; ▨ = pod cases; ▩ = stems; ⁙ = roots.
Field scale applicable to Lysimeter histograms.



consumption, since that date most production has been directed towards "artificial meat" processes, and high protein flour additives for sausages and tinned meat. However, it is not known what percentage of the lead in the seeds produced at Haughley would have been biologically active. Haar (1970) found that the average adult daily intake of lead was about 200μgm, of which 5-10% only was absorbed - but lead is an accumulative toxin. It is suggested that further research should be conducted to determine how widespread is this "death reaction" uptake of lead, especially concerning the edible portions of crop plants.

:5.4.4 Distribution of geochemicals in the plants at final harvest

Graph 4-14 shows the results of the chemical analysis of the final harvest plants, considering the seeds, pod cases, stems and roots separately. The composition of the lysimeter-grown plants reflected the pattern found in the field-grown crop, but the inclusion of root analyses of the former plants complicated the comparison.

.4-1 The distribution of the main concentrations of each geochemical through the plants followed a set pattern which was unaffected by the management type, except for copper and zinc. Thus :

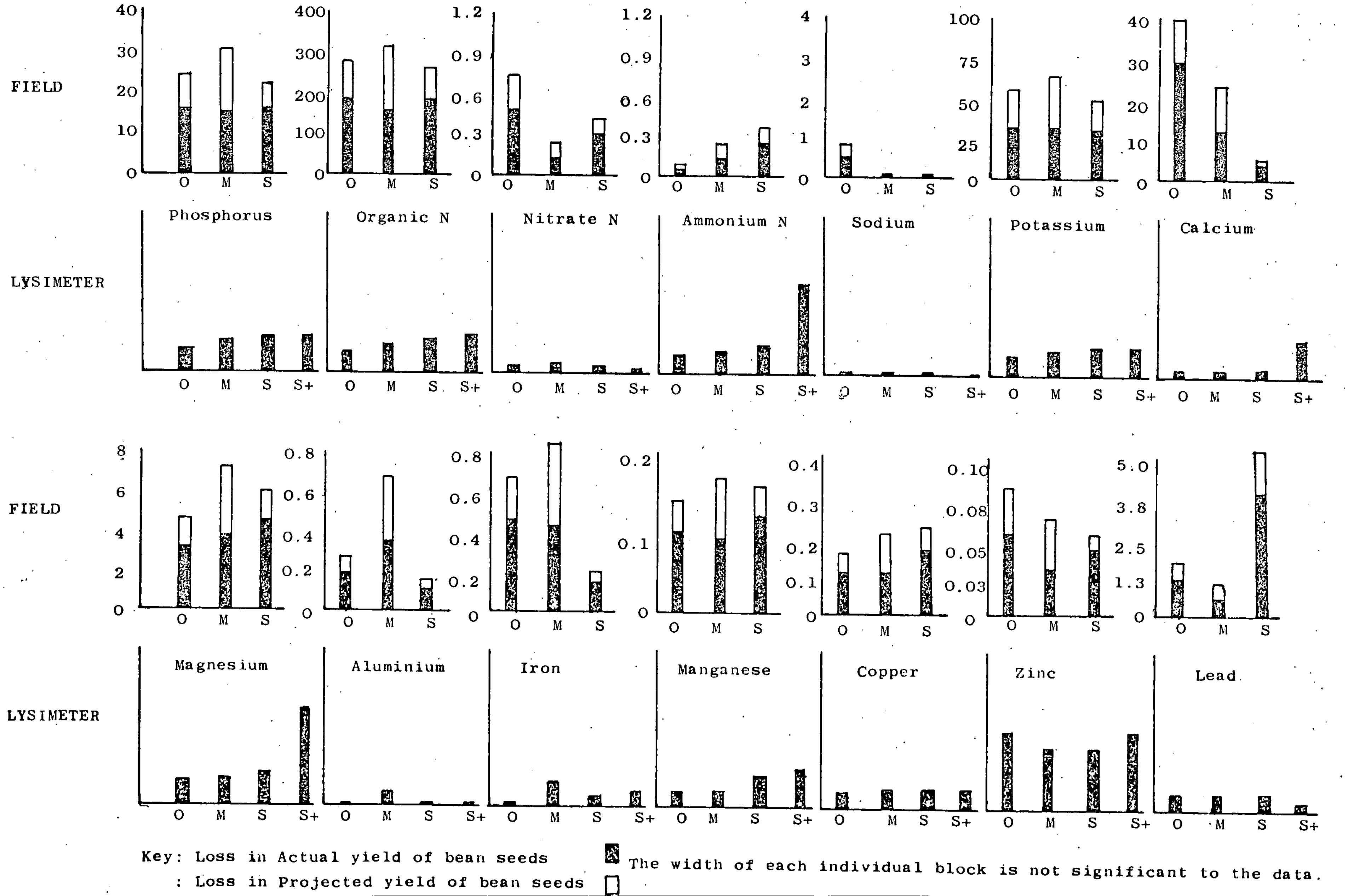
(1) P, N and Pb were located mainly in the seeds
(2) NH_4-N, K, Mg and Zn in the pod cases
(3) Na, Ca, Cu and Zn in the dead stems
(4) NO_3-N, Al, Fe, Mn, Cu and Zn in the dead roots
(5) the main location of copper and zinc varied with management.

It is possible that some of the Al and Fe included in the root analyses was due to adhering soil particles.

.4-2 When the effect of farm management upon the magnitude of geochemical concentrations was investigated it was found that :

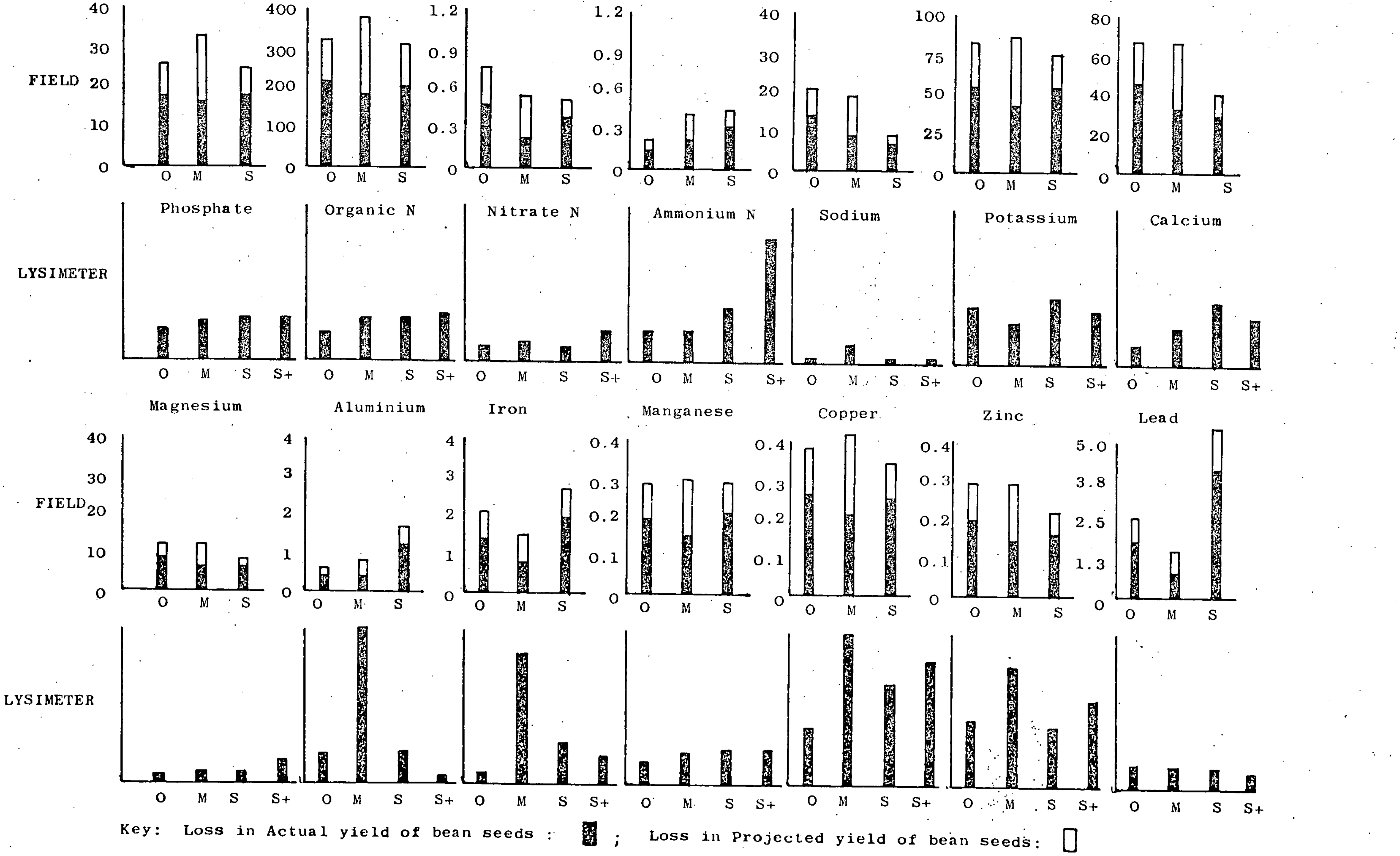
GRAPH 4-15

The Loss of Geochemicals in the Bean Seeds at Final Harvest of the plants growing in the Fields and Lysimeters,1972.(Kg/ha)



GRAPH 4-16

The Loss of Geochemicals in the Whole Plants at Final Harvest of the plants growing in the Fields and Lysimeters, 1972. (Kg/ha)



O ≡ M ≡ S for N, P, K, Fe, Mn and Cu in all plants analysed

O > M > S for Na, Mg and Zn agreeing with the O > S results for 1971

S > M > O for NH_4-N and Al

:the relationship between the farm sections for the concentrations of NO_3-N, Ca and Pb depended upon the particular plant part considered.

:5.4.5 The loss of geochemicals in the final harvest

The histograms on Graphs 4-15 and 4-16 show the loss of the geochemicals in the plants at the final harvest in the bean seeds alone, and in the whole plants. A detailed discussion in Section 3:3.9.5-2 explained the reason for the differences between the predicted and actual yields of seeds from each farm section. The solid blocks represent the loss of geochemicals in the seeds, using the actual bagged yield per hectare, the clear blocks show the losses that would have occurred if the predicted yield of seeds had been achieved.

.5-1 Loss in the bean seeds (Graph 4-15)

Considering only the losses of geochemicals in the actual yield, the effect of the farm management upon the loss varied according to each individual geochemical - there was no overall pattern except that the least influence of management was found for the three major plant nutrients, N, P and K.

.5-2 Loss in the whole plants (Graph 4-16)

The discrepancy between the actual and predicted seed loss can be extrapolated to indicate the probable minimum geochemical losses in the whole plants (solid blocks on histograms). The clear blocks represent the maximum loss which could have occurred - the actual loss would have been between the two levels on the histograms. Thus only where these ranges do not overlap between farm sections can a definite effect of farm management upon loss be postulated. As a result, the only significant effects of farm management which could be determined were :

$O \equiv M \equiv S$ for P, N, NO_3-N, K, Mg, Mn, Cu, Zn

$S \gg M > O$ for NH_4-N and Al - as found in the seed loss alone

$O \gg M > S$ for Na and Ca - corresponding to the soil composition relationship

$S > O > M$ for Fe and Pb

4:6 1973 Field Trial

:6.1 Aim To survey all the fields used for growing beans on the Organic, Mixed, Stockless and Commercial farms to determine the influence of farm management upon the loss of geochemicals from the system in the field harvest. The influence of the rate of NPK fertilizer application upon the loss was also investigated.

:6.2 Method Ten plants were removed at random from each field at the time of final harvest. The plants were divided into green stems, brown stems, pod cases and seeds which were analysed separately for eleven geochemicals as previously described.

The plant and seed treatments used for this trial were :

Measurements	Plant material	Treatment
Crop geochemistry - analysis - for P, N, K, Na, Ca, Mg, Al, Fe, Cu, Zn, Pb at final harvest only	Commercially obtained *V. faba* var. Throws	Organic farm Mixed farm Stockless farm Commercial farm

:6.3 Results

The results are presented in histogram form on Graphs 4-17, 4-18 and 4-19.

:6.4 Discussion

:6.4.1 Distribution of geochemicals in the plants at final harvest

.4.1-1 Graph 4-17 shows the distribution of geochemicals in the plants at final harvest which was unaffected by the farm management, hence :

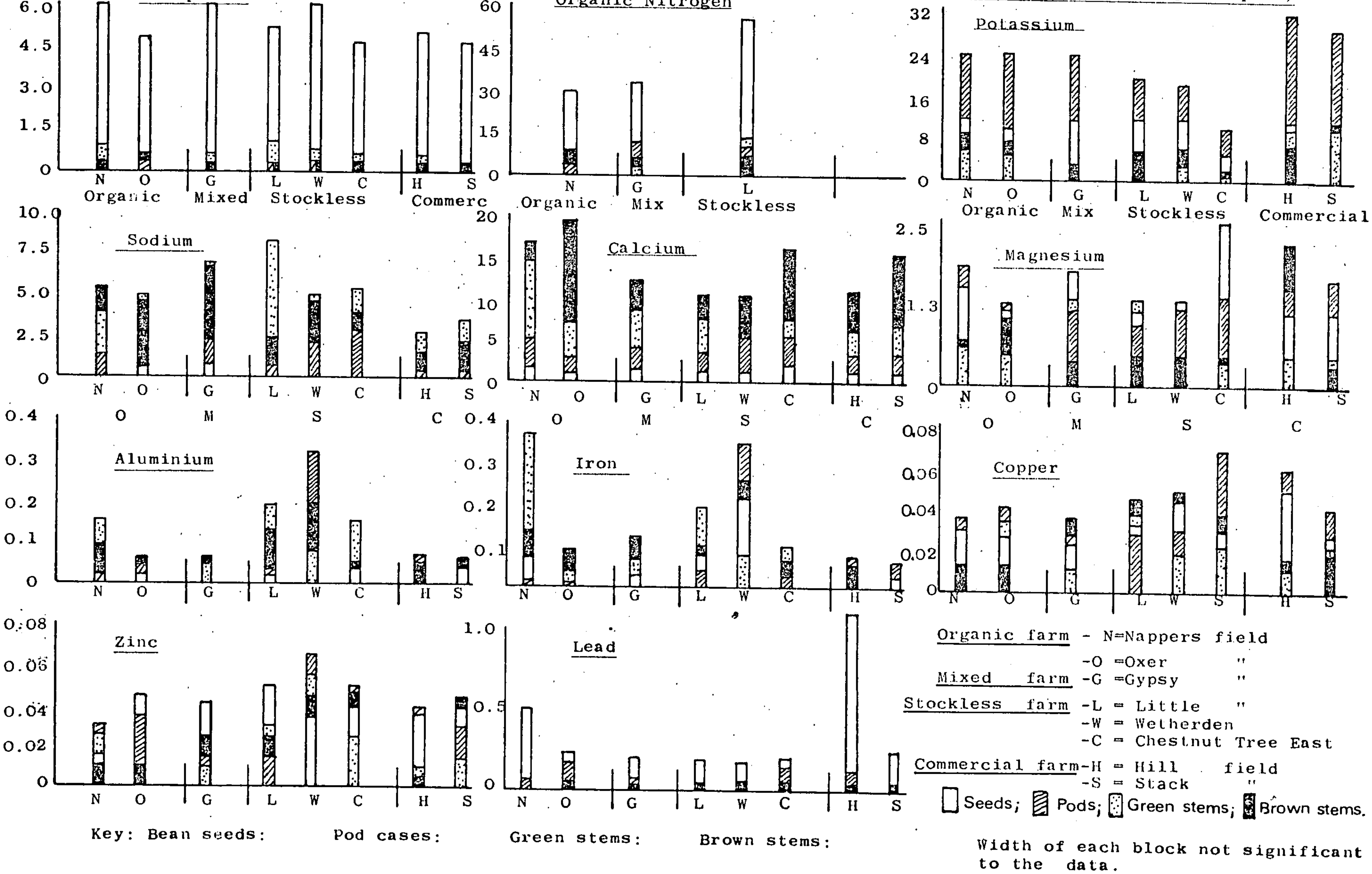
(1) P, N and Pb were located mainly in the seeds

(2) K was located mainly in the pod cases

(3) Na was located mainly in the green stems

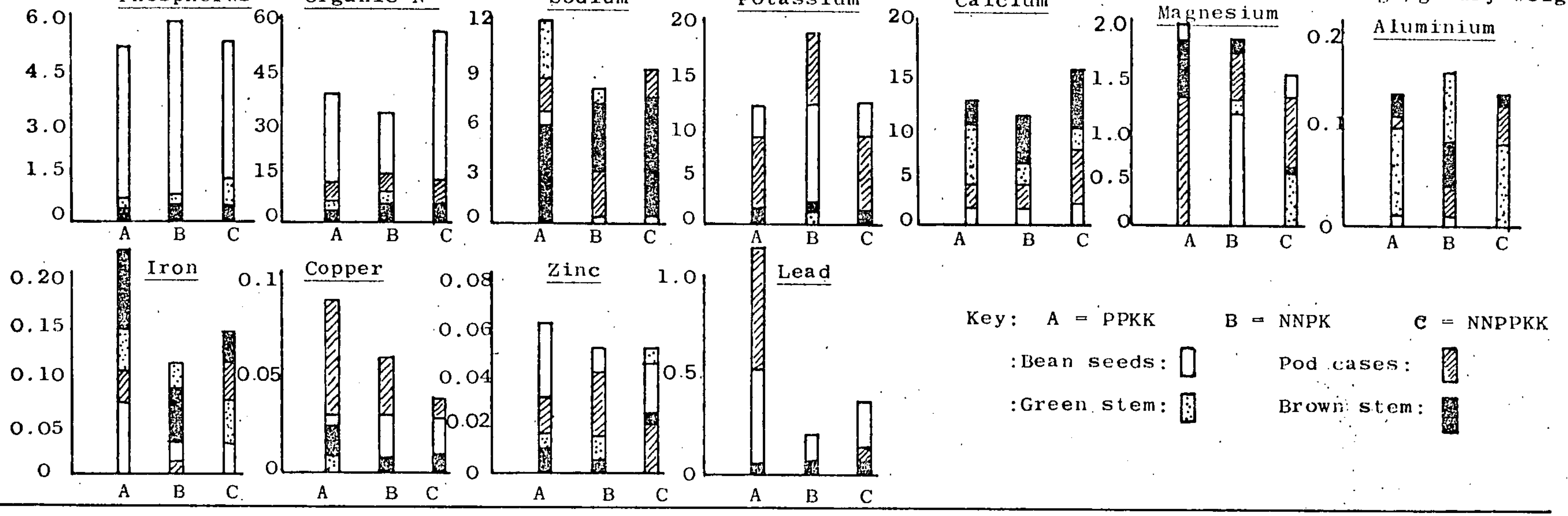
GRAPH 4-17

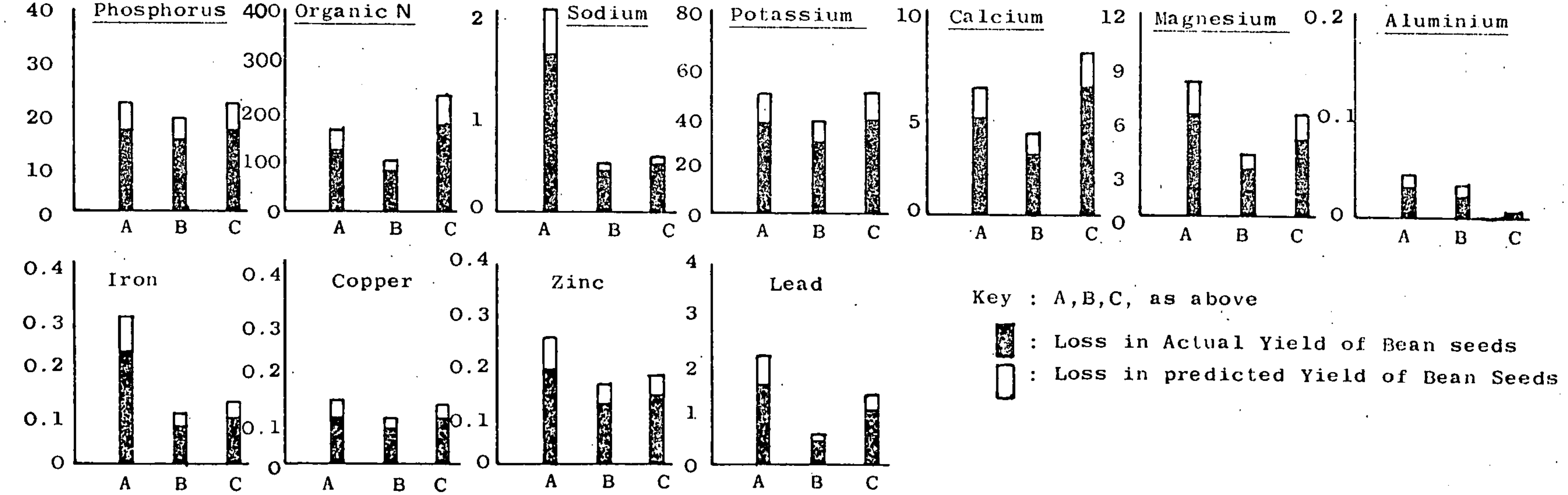
The Distribution of Geochemicals in the dead Bean Plants at the Final Harvest, 1973. (Concentrations in tissues expressed in mgm/gm dry weight of plant part)



GRAPH 4-18

The Distribution of Geochemicals in the Dead Bean Plants at the Final Harvest of the Special Fertiliser Treatments 1973.
(Concentrations in mgm/gm dry weight)

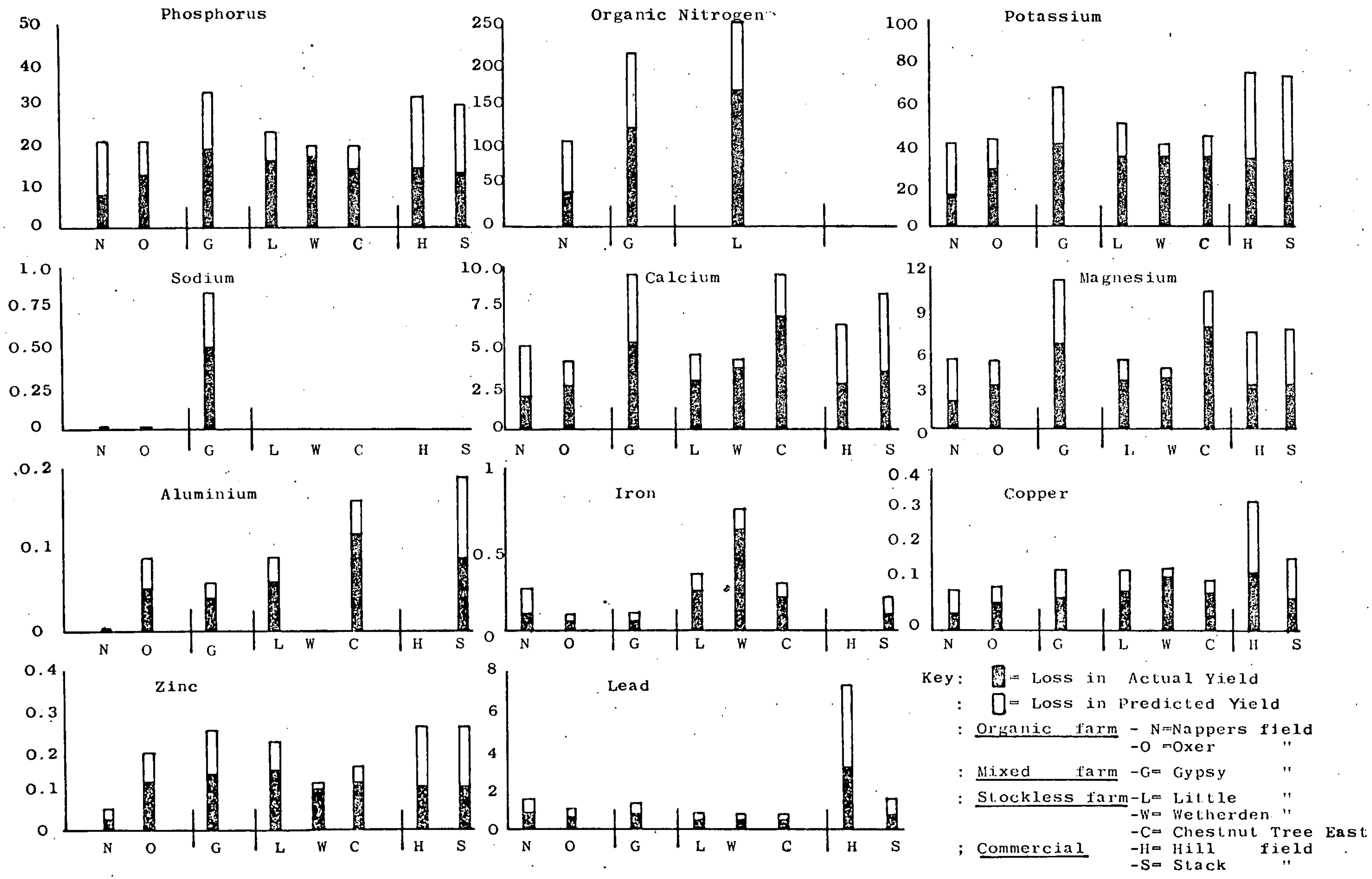




Loss of Geochemicals in the Bean Seeds at Final Harvest of the Special Fertilizer Treatments 1973.Kg/ha

GRAPH 4-19

The Loss of Geochemicals in the Bean Seeds harvested from the four farm types in 1973.(Kg/ha)



Width of each block not significant to the data.

(4) Ca, Al and Fe mainly in the brown stems

(5) The Cu and Zn concentrations varied in location according to the farm management.

These results confirm exactly the pattern determined in the 1972 plants.

.4.1-2 The histograms show that within each farm section, the concentration variation was as great as the variation between farm sections. The relationship showing the effect of soil treatment upon the chemical composition was again different for each geochemical considered, but several generalisations can be made :

the highest concentrations of Ca were found in the Organic grown plants
" " " " Na " " " " Mixed " "
" " " " N, Al, Fe, Cu, Zn " Stockless " "
" " " " K, Mg, Cu, Pb " Commercial "

.4.1-3 Graph 4-18 depicts the distribution of geochemicals in the plants at harvest which were grown on the Special Fertilizer Treatments used for the nitrogen fixation study. The pattern of concentrations in the plants did not follow that of the nutrients supplied to the three plots. Thus :

for P, K and Al - NNPK > PPKK ≡ NNPPKK - a low application resulted in high concentrations of P and K, because of the differences in total plant weight

for N and Ca - NNPPKK > PPKK > NNPK - an application of high nitrogen gave variable results depending on the level of P and K applied

for Na, Fe, Pb, Mg, Cu and Zn - PPKK > NNPPKK ≡ NNPK - the addition of nitrogen to the plots decreased the concentrations of these other cations, possibly by growth dilution, or by the Kirkby-Mendel effect.

.4.1-4 The second part of the graph shows the loss of geochemicals in the harvested bean seeds from the Special Fertilizer Treatments. Considering only the actual yield histograms :

:the loss of phosphorus was unaffected by the rate of fertilizer application;

:NNPPKK > PPKK > NNPK for N and Ca - agreeing with the concentrations of ions in the whole plants;

:PPKK ≡ NNPPKK > NNPK for K - doubling the supply increased the loss of this geochemical;

:the addition of nitrogen decreased the loss of Na, Fe, Pb, Mg, Cu and Zn in the seeds.

:6.4.2 Loss of geochemicals in the bean seeds at final harvest (Graph 4-19)

Considering the losses of the geochemicals in the actual seed yield, considerable variation was found between the fields within the same management section (particularly in the Stockless section) due to a variation in seed yield. Despite this variation, certain patterns emerged, showing the influence of the farm management treatment :

:the loss of all geochemicals from the Organic farm tended to be lower than from any other farm type, mainly because of the lower seed yields;

:the loss of the macronutrients tended to be greatest on the Mixed or Stockless farms;

:the loss of the micronutrients Al, Fe, Cu, Zn was greatest on the Stockless farm;

:the loss of lead was greatest on the Commercial farm, where the soil content was probably the highest (from application of sewage sludge).

4:7 Overall conclusions from the Geochemistry Section

The overall aim of the crop geochemistry study was to determine the influence of plant imprinting and soil management upon the chemical composition of the plants.

4:7.1 The trials showed that the plant ancestry had only a very limited effect upon the chemical composition of the crop, over short periods within the growth cycle, and that this effect never followed a significant pattern. Therefore it must be concluded that the imprinting of the bean crops on the same farm management system for 30 years had not caused any physiological adaptation to take place. Thus no imprint was better suited to its own farm type in preference to any other - no evolved dependence.

This coincided with the findings from the study of the imprint effect upon growth of the plants.

4:7-2 In each season there was a fixed pattern of change in the geochemical concentrations, closely linked to the growth cycle of the plant. The pattern was unaffected by the farm management type or the fertilizer application rate. Therefore the stage in the growth cycle at which the plants were sampled was very important in determining the chemical composition found.

4:7-3 It was shown that the location of the main concentrations of each geochemical in the various plant parts followed a rigid pattern which was unaffected by the soil treatment. The distribution of geochemicals during senescence demonstrated a marked "death reaction", by which the uptake of large quantities of the heavy metals, especially lead, continued after the death of the plants.

4:7-4 The rate of the fertilizer application affected only the concentration of the heavy metals in the crop plants, but the magnitude, and the relationship, varied, depending upon the growth stage, and plant part selected - the uptake of the other geochemicals was rarely affected by the fertilizer application rate.

4:7-5 Although the relationship between crop composition and farm management was confounded by the effect of the soil upon the dry weight of the plant, for many geochemicals the crop content, in concentration/gm and quantity/ha, was directly related to the supply in the soil, which had been quantified by chemical means.

SECTION 5. NITROGEN FIXATION

Section 5. NITROGEN FIXATION

5:1 Introduction

:1.1 One of the main reasons for including a leguminous crop in a farm rotation is that through nitrogen fixation, the symbiotic bacteria are able to draw upon an unlimited supply of atmospheric nitrogen, some of which is released to enrich the soil on the death of the nodules. As artificial and natural nutrient additives for the farm ecosystem become more expensive and in shorter supply, it is considered essential to determine the effect of agricultural management upon the natural improvement of the soil nitrogen, through symbiotic fixation.

:1.2 It has been regularly observed by many research workers that the presence of available inorganic nitrogen in the soil exerts a profound influence upon the fixation of nitrogen by root nodule bacteria (Fred, Baldwin and Mc Coy 1932; Norman and Krampitz 1946; Allos and Bartholomew 1959; Gibson and Nutman 1960; Raggio *et al*. 1965; Moustafa, Ball and Field 1969; Dart and Wildon 1970; Rubeš 1973). In all these reports it has been demonstrated that a high level of available nitrogen in the rooting medium inhibits nodulation and depresses nitrogen fixation. It has also been shown that small amounts of nitrogen may stimulate the fixation of nitrogen by increasing the growth of the host plant, and hence the demand for nitrogen, or by increasing the number of sites available for nodule initiation (Giobel 1926; McConnell and Bond 1957; Burton, Allen and Berger 1961; Dart and Mercer 1965; Moustafa and Hastings 1973).

:1.3 There is considerable controversy concerning the mechanism by which the soil nitrogen acts upon the plant. Orcutt and Wilson (1935) and Cartwright (1967) suggest that the adverse effects are due to the accumulation of nitrogen compounds and a depletion of carbohydrates within the root which would reduce nitrogen fixation. However Tanner and Anderson (1963) and Raggio et al. (1965) believe that the effect is external : the high local concentrations of nitrate in the region of the root hair interfering with indolacetic acid production, and hence reducing nodule initiation.

:1.4 It is clear from the literature that the specific effect of nitrogen upon fixation is strongly influenced by the host plant species and growth rate (Allos and Bartholomew 1959); the bacterial strain infecting the root nodules (Henzell 1962; Dart and Wildon 1970) : the form in which the nitrogen is present in the soil (Diatloff 1967), and the seasonal time of nitrogen application (Pate and Dart 1961). In addition, nitrogen fixation itself is controlled by the host's environment with particular reference to temperature (Gibson 1971; Dart and Day 1971); light intensity (Butler, Greenwood and Soper 1959; Bergesen 1970); diurnal rhythm (Wheeler 1971) and oxygen availability (Virtanen and Hausen 1935; Bergesen 1962). The study of nitrogen fixation is further complicated because all these factors interact, and ideally all should be measured when assessing a particular environment for potential fixation.

5.2 Aim

The chemical analysis of the soils at Haughley (see Section 1) showed that one of the major differences between the farm management sections was the availability of nitrogen. It was decided that a biological evaluation of the soil nitrogen status would be made by studying the phenomenon of symbiotic nitrogen fixation. It was hoped that the study would further elucidate the differences between the soils from the three sections and would show how the long term addition of manures and fertilizers had affected the potential natural addition of nitrogen. In addition to an assay of nitrogen fixation under the normal field conditions, it was planned to investigate the effect of adding high levels of phosphate, potassium and nitrate to one of the Stockless fields (Special Fertilizer treatments PPKK, NNPPKK and NNPK).

5:3 Method

:3.1 Before any attempt could be made to demonstrate the effect of farm management upon fixation, it was deemed necessary to determine in detail the response of fixation by *Vicia faba* (var. Throws) to temperature and diurnal rhythm. This was done in order to prevent ascribing differences caused by these criteria to have been the result of farm practices. As the approach influences the results, this is discussed in the text. The main study of nitrogen fixation comprised a survey of the development and distribution of nodules on the root system through the season, and an estimation of nitrogen fixation by the plants, using acetylene reduction techniques.

:3.2 Nitrogen fixation was measured using the acetylene reduction technique discovered by Dilworth (1966) and Schollhorn and Burris (1966) and developed by Koch and Evans (1966) and Hardy et al. (1968) : "The validity of measuring nitrogen fixation in terms of acetylene reduction has been established by extensive comparison of these activities, using defined systems including purified nitrogenase preparations and pure cultures of nitrogen fixing bacteria." Acetylene acts as a competitive inhibitor for nitrogen fixation, being reduced by nitrogenase to ethylene : both gases are easily detected using gas chromatography. With this assay it becomes possible and practicable to conduct comprehensive surveys of nitrogen fixation and to rapidly evaluate the effects of cultural practices and environmental factors upon nitrogen fixation. Compared with earlier methods, such as $^{15}N_2$ studies, the short incubation periods minimize the changes occurring inside incubation flasks and enable measurement of short term changes, such as diurnal fluctuations, which were previously very difficult to determine.

:3.3 There has been much conflicting evidence concerning the relationship which exists between the amount of acetylene reduced by the bacteria and the quantity of nitrogen which would have been fixed in the absence of acetylene. Factors quoted in the literature for other legumes include :

	C_2H_2	:	N_2
Glycine max	2.3 - 6.6	:	1
Pisum sativum	1.7 - 3.5	:	1
Trifolium sp.	1,5 - 3.7	:	1

No figures were found for *Vicia faba*, therefore the approximations recommended by Hardy and Holsten (1968, 1971) and Stewart et al. (1967) were used. These workers have reasoned that :

1 molecule C_2H_2 reduced to C_2H_4 requires 2 electrons

1 molecule N_2 reduced to $2NH_3$ requires 6 electrons

3 molecules C_2H_2 reduced $\equiv$ 1 molecule N_2 fixed.

Thus to calculate the quantity of nitrogen fixed, the volume of ethylene produced, determined by gas chromatography, must be divided by a factor of three. Throughout the discussion concerning the results of the nitrogen fixation studies at Haughley, all volumes of ethylene measured have been divided by this factor, and are expressed as volumes of nitrogen fixed.

5:4 Development of Technique

:4.1 A Time Course of Fixation

:4.1.1 Aim

In order to perfect field techniques, and to determine the effect of plant decapitation and size of incubation flask upon fixation, an initial time course of fixation was determined. The full details of the field technique used appear in the Appendix.

:4.1.2 Discussion of Results

.1.2-1 Despite the statement by Dart and Day and Harris (1972), that removing the plant shoot has no measurable effect upon the nitrogen fixed by the root nodules during short term assays, Graph 5-1(1)(2) demonstrates that both the total amount of nitrogen, and the rate at which it was fixed, were significantly greater for the whole plants than for the decapitated ones.

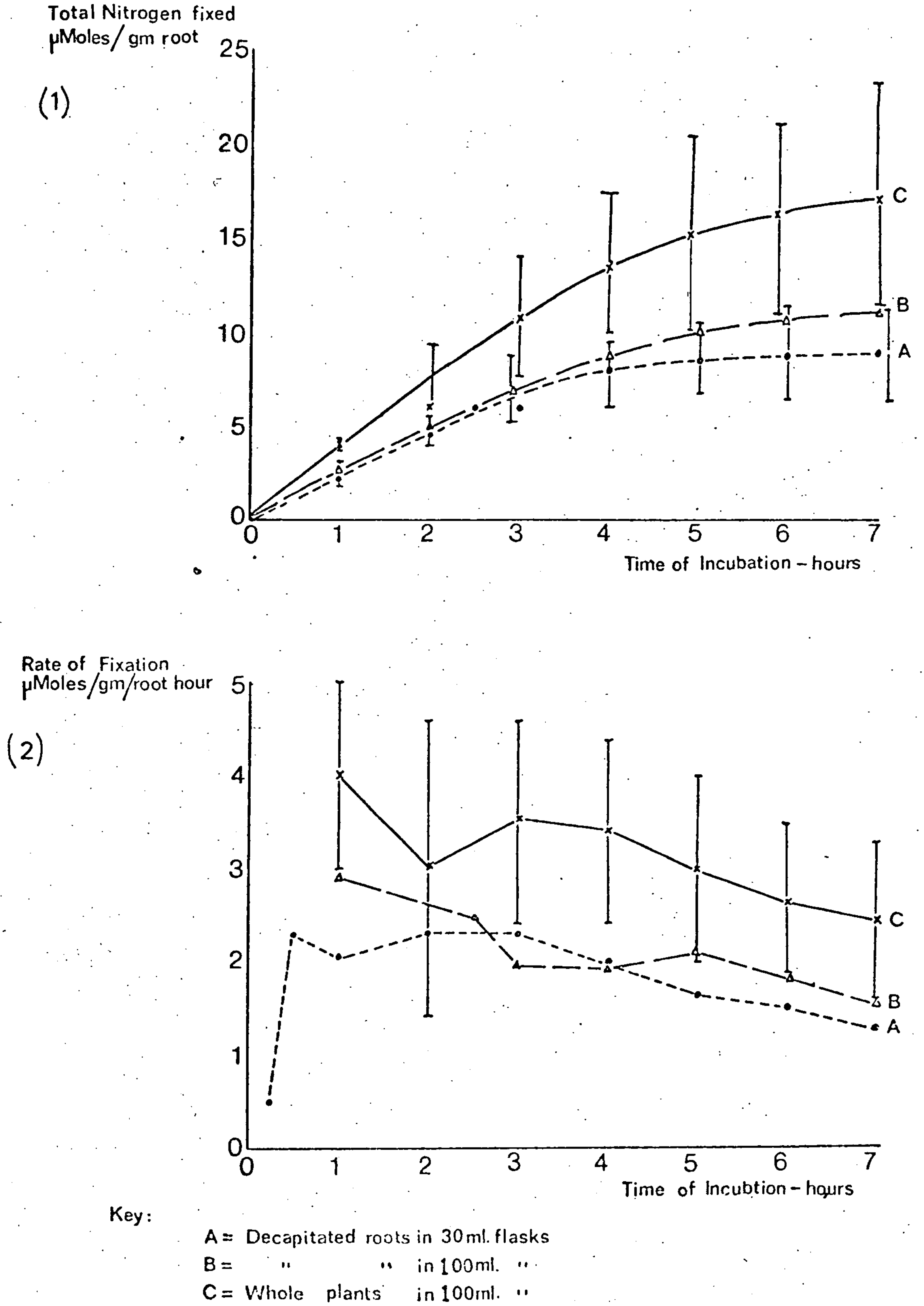
.1.2-2 As nitrogen fixation in the root nodules is affected by the state of the whole plant, it is not unexpected that a drastic action such as decapitation should lower the rate of nitrogen fixation. Moustafa, Ball and Field (1969), working on *Trifolium*, demonstrated that decapitation caused a reduction in fixation rates within half an hour. Hardy and Holsten (1971) proposed that such a reaction to decapitation may be due directly to the injury, or indirectly by removing the supplies of photosynthates which have been shown are necessary (Gibson 1966) for fixation to take place. It is probable that in this study the incubation periods were too short for the lowering of fixation to be caused by lack of carbohydrates. It is far more likely to have been the result of upsetting the physical balances within the whole plant, for example, water tension.

.1.2-3 For all three categories of plant-state and flask size tested, the increase in total nitrogen fixed was linear for three hours (Graph 5-1(1)). Although the difference was not significant, probably due to the small number of replicates used, the rate at which the increase in total nitrogen fixed approached zero was greater in the 30 ml flasks than in the 100 ml flasks. This effect of the incubation volume proportional to the nodule volume can be explained by the sensitivity of the nodules to the partial pressure of oxygen. As the incubation proceeds, the respiring roots and nodules reduce the pO_2 in the flask, and the smaller the volume of the flask, the more quickly the level will become limiting to fixation.

Graph 5-1

Nitrogen Fixation

Initial Time Course



Although the actual reduction of nitrogen (or acetylene) is anaerobic, an adequate pO_2 in the system is required for the production of ATP which energizes the reaction.

.1.2-4 Bergesen (1971) showed that if the pO_2 is too low, the lack of ATP becomes limiting, and if the pO_2 is too high, nodule respiration increases and electrons are diverted from the nitrogen fixing pathway. Graph 5-1(2) demonstrates the falling rate of fixation as time progressed. The flattening out of the curve on graph 5-1(1) correlates closely with the effect shown by Oghoghorie and Pate (1971) where the increase in total nitrogen fixed by the nodulated field pea slackened off due to pO_2 depletion after four hours. The maximum fixation rate appears to have taken place 30 minutes after the incubation was started, as shown by the point on line A (Graph 5-1(2)).

:4.1.3 Conclusions concerning technique

As a result of this initial test it was decided to improve the technique by using a greater number of replicates of whole plants, incubated in larger flasks to reduce oxygen starvation. In later studies, the nodule weight, or number, was used instead of the total dry weight of root, as it was considered that these values would bear a closer relationship to the quantities of nitrogen fixed. It had been observed here that small light roots often bore more nodules than the larger heavier roots. The gas samples would be removed from the incubation flasks after 1-2 hours to ensure that fixation rates were linear when sampled, and the gas would be stored and transported in leakproof Vacutainers (Schell and Alexander 1970).

5:4.2 Temperature Studies

:4.2.1 Aim

It was appreciated in advance that the monitoring of nitrogen fixation by plants from the three farm sections would have to be carried out in a laboratory in Suffolk, where there would be no control over temperature fluctuations. Therefore to prevent fixation differences being attributed to management practices, when they were caused merely by variation in temperature, it was necessary to make a detailed preliminary study of the response of nitrogen fixation of *Vicia faba* nodules to such variations.

:4.2.2 Method

For the first temperature study, 13 week plants were transported from the Stockless section to Durham and decapitated prior to incubation. In order to confirm the results found, during the same season, a second study was performed on pot grown plants in Durham, using both whole and decapitated plants. Full details of these studies appear in the Appendix. The results of the first and second temperature studies appear on Table 5-1 and Graph 5-2.

:4.2.3 Discussion of Results

.2.3-1 For the first temperature study (Table 5-1(1) and Graph 5-2(1)) a statistical comparison of the effect of changing the temperature on nitrogen fixation rates demonstrated that within the range of 14°C - 22°C there was a significant decrease in the rate of fixation per root, and per nodule, after attaining a maximum rate at 14°C. The effect of an intermediate temperature was not possible to determine due to a malfunction of equipment. The fixation rates at 8 - 14°C were not significantly higher than the rates at 22 - 30°C. At 26°C there was a temporary rise in

Table 5-1

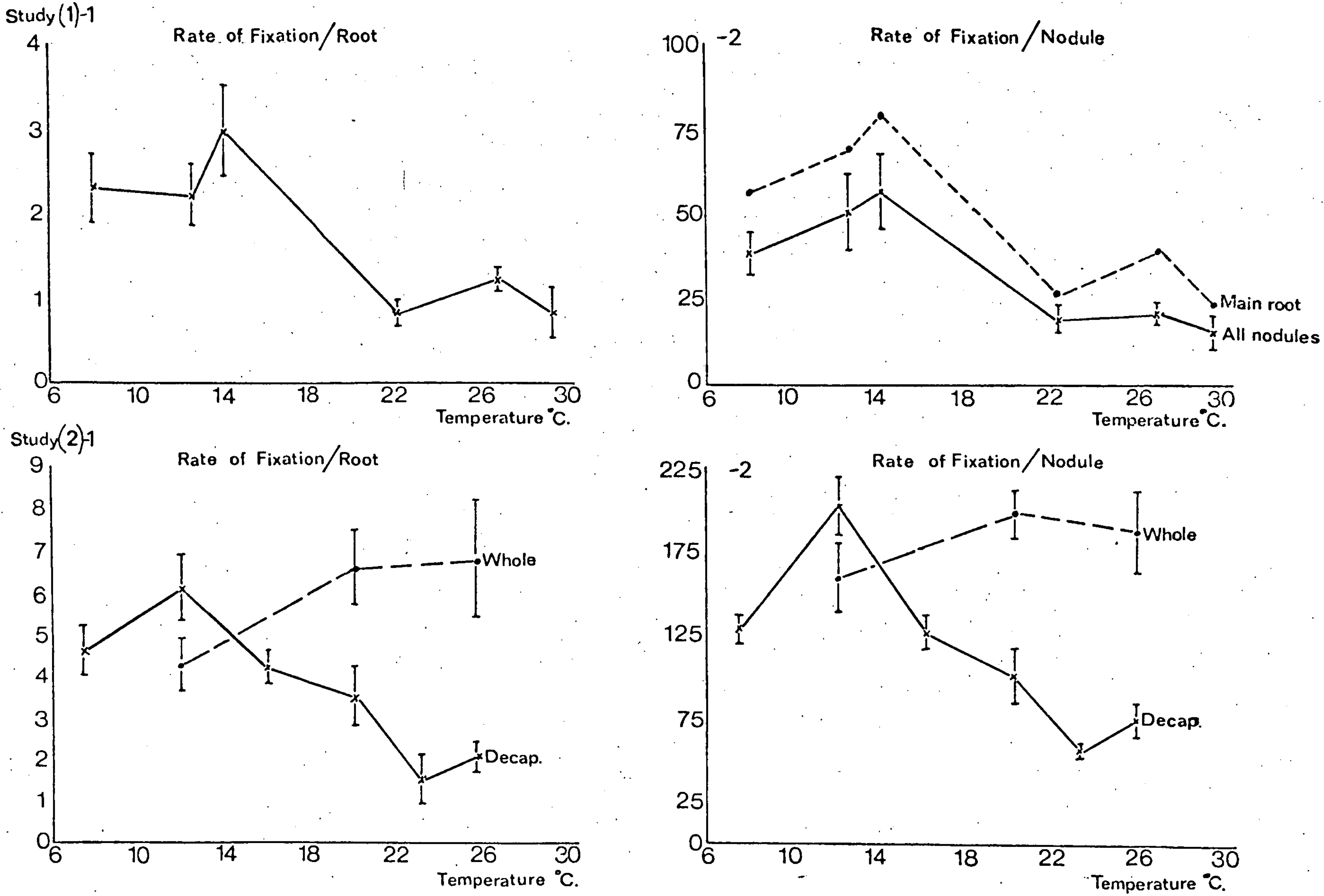
NITROGEN FIXATION

Temperature Study I

Temperature of incubation	Nodule Statistics						Rate of Nitrogen Fixation								
	Main Root			Total Root			Fixation/root/ hr nM			Fixation/main root nodule/hr nM			Fixation/nodule/ hr nM		
°C	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
8.0	41.2	6.0	1.9	59.4	14.9	4.7	2.33	1.47	0.47	57.7	35.3	11.2	39.0	22.6	7.1
12.5	31.8	11.1	3.5	44.6	13.1	4.2	2.21	1.33	0.43	70.3	48.3	15.2	51.6	36.9	11.7
14.0	36.9	6.5	2.1	53.8	10.7	3.4	3.00	1.76	0.57	79.6	38.1	12.0	57.7	40.0	11.7
22.0	30.4	5.3	1.7	45.0	29.7	9.4	0.84	0.50	0.17	27.0	16.2	5.1	19.6	12.8	4.0
26.5	34.6	13.6	4.3	59.8	18.3	5.8	1.25	0.53	0.17	40.4	20.1	6.4	21.5	8.4	2.7
29.0	31.5	6.0	2.1	44.5	21.9	7.7	0.85	0.83	0.30	24.5	23.8	8.4	16.1	13.8	4.9
Temperature Study II															
Whole Plants															
12.0	14.3	8.0	2.5	25.6	7.1	2.2	4.26	1.97	0.63	368.2	357.1	112.9	158.8	63.8	20.2
20.0	20.7	6.4	2.1	32.9	5.7	1.9	6.61	2.60	0.87	354.4	186.6	62.2	197.3	49.9	16.7
25.5	19.7	9.6	3.0	33.8	11.1	3.7	6.80	4.50	1.43	357.2	183.3	58.3	189.2	78.8	24.9
Decapitated															
7.5	20.3	9.0	3.0	34.9	8.0	2.7	4.60	1.80	0.60	235.5	55.4	18.5	128.9	24.5	8.2
12.0	19.7	7.0	2.2	29.4	7.9	2.5	6.10	2.40	0.80	319.5	125.9	39.8	201.9	53.8	17.0
16.0	22.6	5.9	2.0	33.1	5.1	1.7	4.20	1.30	0.40	204.1	51.5	17.2	127.2	29.6	9.9
20.0	17.8	8.0	2.7	34.6	8.8	2.9	3.50	2.10	0.70	288.8	145.3	48.4	101.5	49.4	16.5
23.0	14.9	6.9	2.3	26.2	7.3	2.5	1.49	0.60	0.20	113.9	51.4	17.1	56.4	10.7	3.6
25.5	21.0	7.6	2.4	27.4	8.6	2.7	2.11	1.00	0.30	98.3	40.1	12.7	75.1	28.8	9.1

Graph 5-2

Nitrogen Fixation - Temperature Studies



fixation rates which was almost significant at the 95% level, and this occurrence tallied with the form of graphs for *Medicago truncatula* and *Glycine* (Merit) shown by Dart and Day (1971) and the figures for *Glycine max.* (Hardy et al. 1968). In these studies, prior to a final decrease in fixation rates with increasing temperatures caused by enzyme denaturation, there was a short lived rise in the rate of fixation due to stimulation of nitrogenase activity.

Statistical comparison to demonstrate the significance of change in the rate of nitrogen fixation with changing temperatures

Temperature Compared	Rate of nitrogen fixation							
	Mean total/root μ Moles N_2/hr				Mean Total/nodule n Moles N_2/hr			
°C	df	d	p	R	df	d	p	R
8.0-12.5	17.8	0.19	>0.1	NS	14.9	0.92	>0.1	NS
12.5-14.0	16.8	1.13	>0.1	NS	17.9	0.35	>0.1	NS
16.0-22.0	10.5	3.72	<0.01	Decrease	10.8	2.86	<0.02	Decrease
22.0-26.5	17.9	1.78	>0.1	NS	15.5	0.39	>0.1	NS
26.5-29.0	15.5	1.29	>0.1	NS	14.8	1.06	>0.1	NS

On Table 5-1(1) the great variation in nodule numbers within a single field type was demonstrated for both the main taproot and the total root system. This variability was repeated even under the much more uniform conditions of the pot grown plants (Table 5-1(2)). On graph 5-2(1)-2 the upper line shows the rate of fixation per nodule when only the main taproot nodule numbers were considered (i.e. the fixation by lateral nodules was considered to be zero). The solid line shows the rate of fixation per nodule when all nodules were included. The difference between the lines is attributable to the effect of the lateral root nodules which fix less nitrogen than those on the main tap root.

.2.3-2 The results of the second temperature study statistically compared in the table overleaf, confirm those of the first, but show more detail within the range of 12 - 22°C (Table 5-1(2) and Graph 5-2(2)). The shape of the graphs for decapitated plants correlated well with each other as the temperature increased. The slight difference between maxima at 14°C in the first study, and at 12°C in the second, can be accounted for by the difference in nodule age between the two studies. The rate of fixation by the bean roots in the second study was double that found in the first study, and the respective differences in fixation rates by individual nodules was even greater. This difference was probably due to the variation in nodule age, and to the length of time incurred between the removal of the plants from the soil and the initiation of incubation. In the first study the time lag was about eight hours, but in the second study it was only twenty minutes.

Nitrogen Fixation - Temperature Study 2

Statistical comparison to show the significance of change in the rate of fixation with changing temperatures

Temperatures Compared °C	Rate of nitrogen fixation							
	Mean total root μ Moles/hr				Mean total/nodule nM/hr			
	df	d	p	R	df	d	p	R
Whole Plants								
12.0 - 20.0	14.9	2.20	<0.05	Increase	16.9	1.47	>0.1	NS
20.0 - 25.5	14.6	0.11	>0.1	NS	15.4	0.27	>0.1	NS
12.0 - 25.5	12.3	1.59	>0.1	NS	17.2	0.95	>0.1	NS
Decapitated								
7.5 - 12.0	16.5	1.55	>0.1	NS	12.8	3.86	<0.01	Increase
12.0 - 16.0	14.2	2.16	<0.05	Decrease	14.3	3.80	<0.01	Decrease
16.0 - 20.0	13.4	0.85	>0.1	NS	13.0	1.34	>0.1	NS
20.0 - 23.0	9.2	2.75	<0.05	Decrease	8.8	2.69	<0.05	Decrease
23.0 - 25.5	14.9	1.68	>0.1	NS	11.7	1.91	>0.1	NS
Comparison of whole plants with decapitated plants								
12.0	18.1	0.41	>0.1	NS	11.6	1.38	>0.1	NS
20.0	14.7	2.83	<0.02	W > D	18.0	4.32	<0.001	W > D
25.5	9.8	3.21	<0.01	W > D	11.4	4.31	<0.01	W > D

Key : W = Whole D = Decapitated NS = No significant difference

.2.3-3 Graph 5-2(1) shows that the decapitation of plants markedly increased the susceptibility of root nodule bacteria to the damaging effect of increasing temperature. Only at 12°C was the rate of fixation/decapitated plant slightly greater than that of fixation/whole plant, but the difference was not significant at the 95% level. This bears out the earlier proposal made, that isolated roots are more vulnerable to changes in external conditions, than are whole plants, in which systems such as water tension within xylem and phloem, are complete. It was interesting to discover how the fixation by nodules of whole plants was only marginally affected by temperature changes, the effect only being significant per root between 12 - 20°C, and not significant at all when considering fixation per nodule. The maximum rate of fixation for whole plants was achieved at 20 - 26°C compared with 12 - 14°C for decapitated plants.

.2.3-4 Many times in the literature it is stated that the particular plant species, variety, and strain of infecting bacteria, control the symbiotic response to temperature in each individual environment. However the optimum nitrogen fixation temperatures of 20 - 25°C for the whole *Vicia faba* plants at Haughley agree well with the figures published for other nodulated plants :-

Pisum sativum	- maximum	20°C	(Vincent 1965)
Glycine max	- "	20° - 30°C	(Hardy)
Alnus glutinosa	- "	20° - 25°C	(Hardy)
Vicia faba	- "	20° - 30°C	(Dart and Day 1971)
Trifolium subterraneum	- "	24°C	(Hardy)

The results found at Haughley correspond to those found by Gibson (1971) who wrote in his review that high and low temperatures affect nodulation and fixation, the effect of these on whole plants being less marked than for similar temperatures on roots alone. Meyer and Anderson (1959) also found that high temperatures of the root specifically inhibit fixation.

.2.3-5 The maintenance of maximum fixation activity by whole plants in the temperature range 20 - 30°C is dependent upon an adequate supply of oxygen which enables the production of a constant supply of ATP (Bergesen

1970). The pO_2 in an incubation flask decreases more quickly at the higher temperatures due to the increasing rate of respiration by the roots and nodules (Nutman 1970). However Sprent (1971) believes that one of the main factors controlling root-nodule nitrogen fixation under laboratory and field conditions is the degree of dehydration of the roots. This increases proportionally to the temperature and the length of time since decapitation. She showed that once the turgidity of the nodules decreased below 80% of the maximum fresh weight, acetylene reduction ceased altogether. Thus she warns against the extrapolation of the results of a single assay of acetylene reduction to a weekly fixation figure, as daily fluctuations of water stress in the soil will cause similar variation in fixation rates. Such water stress also affects respiration rate, sugar and amino acid content of the root sap, and phosphorylation. To avoid this hazard, several investigators (Dart and Day 1971) have recommended the use of moist filter papers in the incubation flasks, but due to the great solubility of both acetylene and ethylene it was considered in this study that this would provide a further source of error. It would appear from the observations made on the roots used for the temperature studies, that those which were decapitated dehydrated more quickly than those of whole plants. The severing from the stem, plus the breaking off of distal parts of the main and lateral roots, produced a faster loss of turgidity than in the whole plants which continued active transpiration.

:4.2.4 Conclusions

The nitrogen fixation by root nodules on decapitated roots was more sensitive to increasing temperatures than that by nodules on the whole plants, where scarcely any significant effect was shown by increasing the temperatures from 16°C to 26°C. Due to this lack of variation in fixation rates, wherever possible, when comparing rates for plants from different management sections, whole plants were used. Although the laboratory temperatures could not be controlled, the fixation studies were usually made within the optimum temperature range.

5:4.3 Diurnal Study

:4.3.1 Aim

The aim of the diurnal study was to determine the most suitable time of day at which a single assay of acetylene reduction could be extrapolated to account for fixation over a twenty-four hour period, with the minimum of inaccuracy.

:4.3.2 Method

Ideally the diurnal study should have been made at a constant temperature as variations in this have been shown to have some effect on fixation rates, but convenient facilities were not available. It has been demonstrated by the temperature studies that nodules on whole plants are less susceptible to temperature changes than on decapitated plants. Therefore to minimize the interference of the diurnal rhythm by temperature, whole plants were used for this study. Twelve replicates of ten week old plants were removed from the field (Stockless section), at intervals throughout a 24 hour period and incubations were performed as previously described.

:4.3.3 Results

The results of this study appear in Table 5-2 and Graph 5-3. A statistical comparison of the fixation rates is shown overleaf :-

Table 5-2

NITROGEN FIXATION

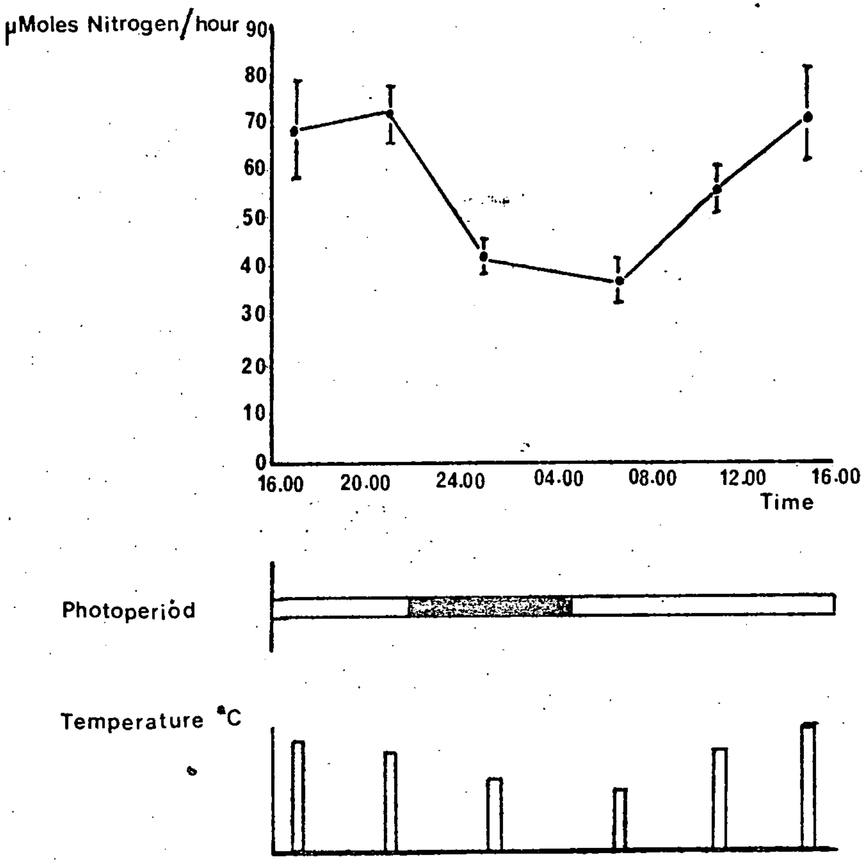
Diurnal Study

Incubation period 24 hour system	Field Temperature ^{o}C	Laboratory Temperature ^{o}C	Nodule Statistics						Rate of fixation of Nitrogen μMoles/hr								
			Main Root			Total Root			Total fixation/ root			Total fixation/ main root nodule			Total fixation/ nodule		
			Mean No.	SD	SE	Mean No.	SD	SE	Mean No.	SD	SE	Mean No.	SD	SE	Mean No.	SD	SE
16.00 - 18.00	19.0	23.0	36.2	12.4	3.6	50.5	15.0	4.3	68.4	34.7	10.1	1.93	0.80	0.23	1.33	0.50	0.13
20.00 - 22.00	18.0	20.0	36.5	11.9	3.3	45.5	10.9	3.0	72.1	18.1	5.2	2.17	0.83	0.23	1.63	0.47	0.13
00.20 - 02.20	11.0	15.0	35.4	9.2	2.6	41.0	11.2	3.1	42.3	12.5	3.5	1.27	0.43	0.13	1.13	0.47	0.13
05.45 - 07.45	10.0	12.0	31.9	5.7	1.6	36.6	7.3	2.1	37.2	13.4	3.8	1.20	0.43	0.13	1.07	0.43	0.13
10.00 - 12.00	18.0	20.0	47.3	14.3	4.8	56.2	16.5	5.5	57.0	16.0	5.3	1.27	0.50	0.17	1.07	0.37	0.13
13.45 - 15.45	23.5	25.0	37.9	15.4	4.6	48.7	15.8	4.8	72.3	31.4	9.5	2.03	0.83	0.23	1.57	0.67	0.20

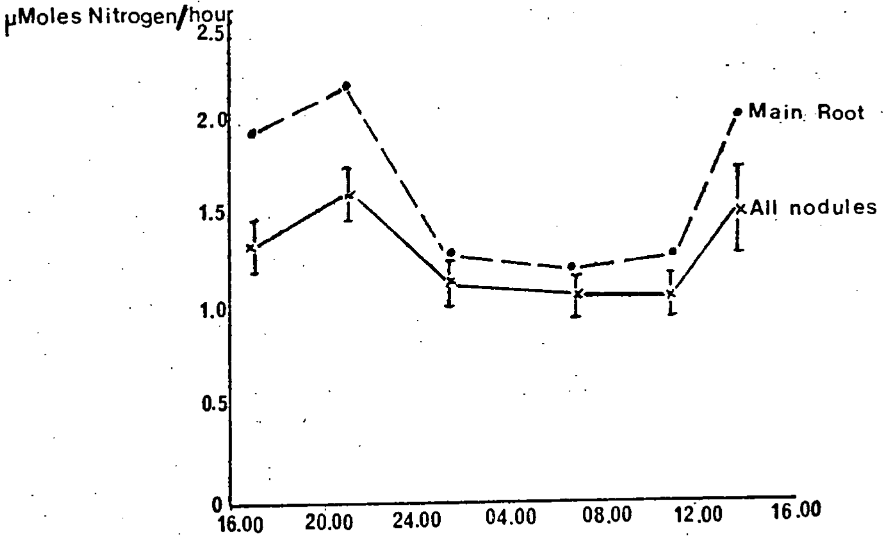
<u>Graph 5-3</u>

Nitrogen Fixation

Diurnal Study



Rate of Fixation/Root



Rate of Fixation/Nodule

Table to show the statistically significant differences in the rate of nitrogen fixation with the time of day

Times Compared (24 hour clock) Hours	Rate of nitrogen fixation μ Moles N_2 fixed/hour							
	Mean fixation/root				Mean fixation/nodule			
	df	d	p	R	df.	d	p	R
17.00-21.00	16.4	0.33	>0.1	NS	21.9	1.52	>0.1	NS
21.00-01.20	19.6	4.66	<0.001	Decrease	22.0	2.64	<0.02	Decrease
01.20-06.45	22.1	0.96	>0.1	NS	21.9	0.33	>0.1	NS
06.45-11.00	21.5	3.29	<0.01	Increase	21.7	0.00	>0.1	NS
11.00-14.45	16.3	1.50	>0.1	NS	17.4	2.27	<0.05	Increase

:4.3.4 Discussion

.3.4-1 This table indicates that a significant drop in fixation rates per root took place between 21.00 and 01.20, and a significant rise between 06.45 and 11.00 hours. The pattern was reflected by the rate of fixation per nodule, except that the significant increase due to the start of the photoperiod was not exhibited until after 11.00 hours. The graph shows the length of darkness and the variation in temperatures over the twenty four hour period. Although the temperature fluctuation followed approximately the same diurnal pattern as that of fixation, the latter variation was not due to temperature alone. Whole plant fixation has been shown to vary only slightly at different temperatures, whereas the changes in this study were large and significant. Also between 17.00 and 21.00 hours the fixation rates continued to increase despite a drop in temperature. From graph 5-3(2) it would appear from the difference between the dotted and solid black lines that the lateral nodules played a proportionately more important part in fixation during the late photoperiod than at any other time, but further investigation of this is required before firm conclusions can be drawn.

.3.4-2 The maximum fixation rate in *Vicia faba* occurred toward the end of the photoperiod when maximum photosynthates were available (Virtanen, Moisio and Burris 1955; Nutman 1968; Hardy et al. 1971). Although it has been observed (Wheeler 1971) that translocation of photosynthates can occur within ten minutes of formation, a time lag is required to allow sufficiently large quantities of carbohydrates to be transported to the nodules. It is probable too that the light intensity in the morning was not sufficient for photosynthesis until about 07.00 hours, which would explain why this time lag is so long. As the light intensity decreases in the evening, photosynthesis will diminish, and hence a drop in the rate of nitrogen fixation occurs before nightfall. Although the diurnal fluctuation in fixation of nitrogen is not caused by temperature variation, this will add magnitude to the changes which occur in the field.

.3.4-3 Other research workers have found similar diurnal fluctuations to occur in other crops studied e.g. :-

Glycine - Maximum fixation 15.00-20.00 (Hardy 1968)
- Minimum fixation 00.00-08.00

Alnus - Maximum fixation 13.30 (Wheeler 1971)

Trifolium - Maximum fixation 08.00-16.00 (Bergesen 1970)
- Minimum fixation 04.00

Nutman (1970), studying clover, vetch and soybean, showed that active nitrogen fixation per nodule decreased at the beginning of the photoperiod prior to an increase to maximum - this concurred with the findings for *Vicia faba* at Haughley.

:4.3.5 Conclusion

A marked diurnal fluctuation in nitrogen fixation rates was observed. The mean rates of fixation for each twenty-four hour period occurred at 23.30 and 10.00 hours. Therefore wherever possible the fixation rates for field samples were measured at 09.00-11.00 hours to lend maximum accuracy to the consequent extrapolation of the figures gained, to estimate daily fixation.

5:5 Effect of farm management upon nodulation

:5.1 Aim

To conduct a survey of the development and distribution of nodules on the root system of *Vicia faba* through the growing season, and to make a comparison of these features on plants from the three farm management sections.

:5.2 Discussion of Results

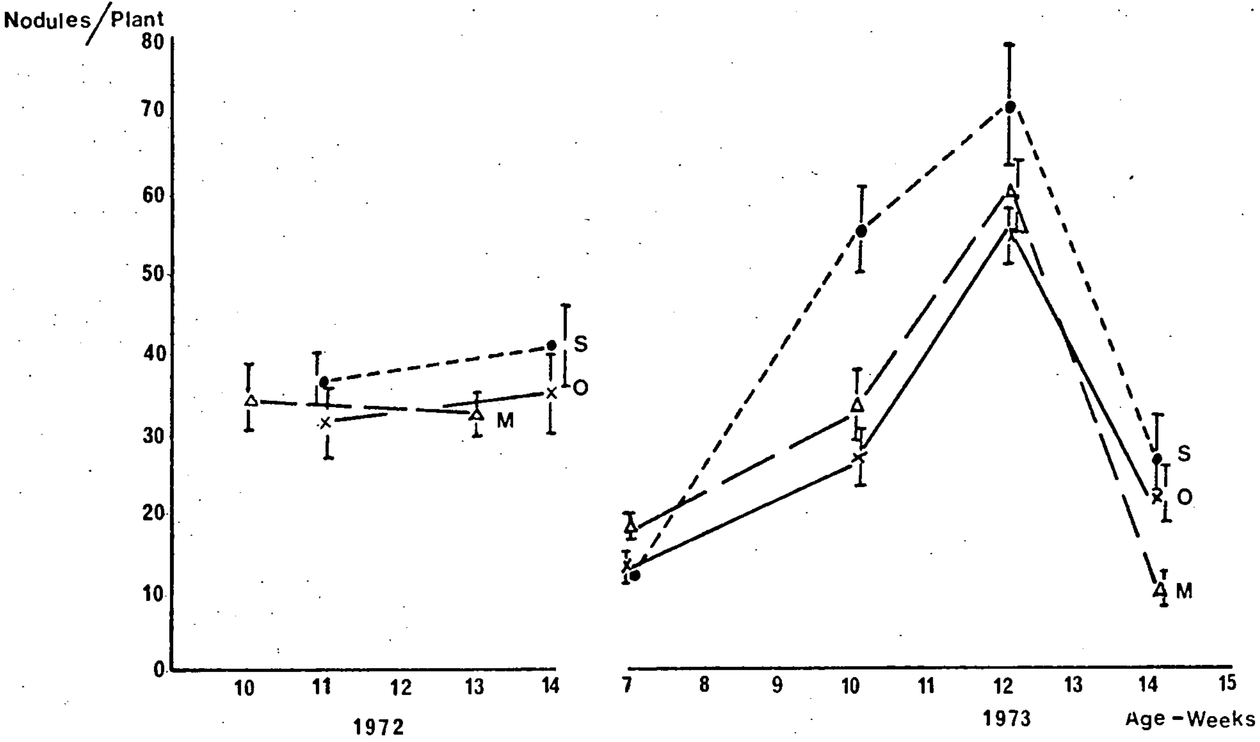
:5.2.1 The development of the root nodules during each season followed a set pattern on all three farm sections studied. The differences between sections are described on the basis of nodule numbers, on the roots used for the nitrogen fixation study. The first nodules to form were always situated within 15 cm of the soil surface on the main tap root, with the largest nodules nearest to the surface (up to 5 mm in diameter). This location was probably due to the influence of oxygen diffusing into the soil, which is better near to the surface and encourages nodule initiation (Loveday 1963). These primary nodules quickly became pink with leghaemoglobin and actually fixed nitrogen before the development of nodules on the lateral roots. The acetylene reduction studies showed a direct relationship to exist between the rate of acetylene reduction and the size and pinkness of the nodule. This has been demonstrated by Bergesen (1969), Schwinghamer, Evans and Dawson (1970) and Ellfolk (1973). A visual assessment of the nitrogen fixing potential of the nodules was therefore possible by cutting the nodules open to observe the intensity of the leghaemoglobin colouration. Storage of the roots used for nitrogen fixation studies, in the deep freeze prior to the estimation of nodule numbers, increased the intensity of colour which aided in its assessment. The progress of the development of nodules during 1972-3 is shown on Graph 5-4 and the statistical comparison of numbers on plants from different sections on Table 5-3.

Graph 5-4

Nitrogen Fixation

Number of Nodules per Plant

Plants from the three Farms



Plants from the Special Fertilizer Treatment

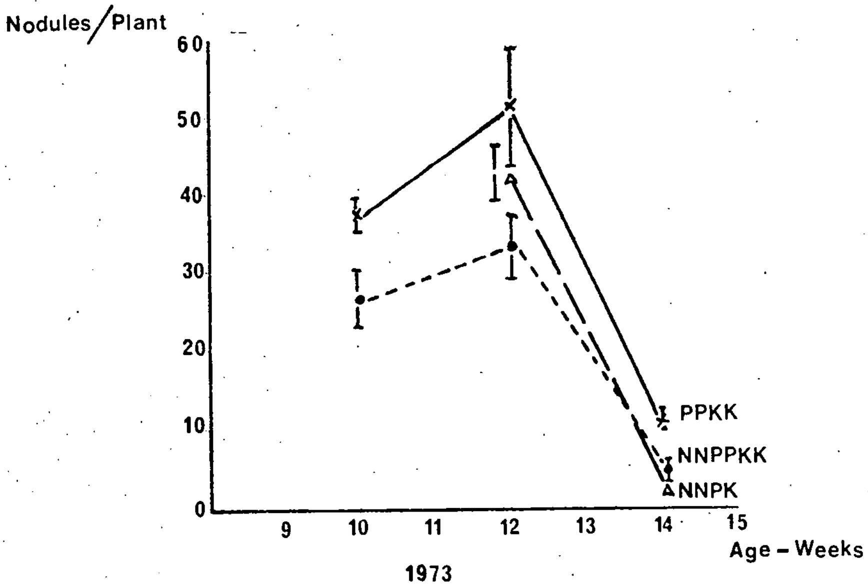


Table 5-3 NITROGEN FIXATION

Statistical comparison of nodulation through the season.

Management Types compared		Total nodules				Main root nodules			
		df	d	p	R	df	d	p	R
2/6/72	O-M	15.8	0.46	>0.1	NS				
	O-S	15.9	0.90	>0.1	NS				
	M-S	12.8	0.27	>0.1	NS				
22/6/72	O-M	10.4	0.47	>0.1	NS				
	O-S	13.9	0.72	>0.1	NS				
	M-S	10.9	1.42	>0.1	NS				
30/4/73	O-M	23.9	2.33	<0.05	M>O				
	O-S	21.5	0.45	>0.1	NS				
	M-S	23.0	2.55	<0.02	M>S				
22/5/73	O-M	12.4	1.25	>0.1	NS	16.0	0.21	<0.1	NS
	O-S	12.2	4.74	<0.001	S>O	8.7	4.65	>0.01	S>O
	M-S	14.6	3.21	<0.01	S>M	11.2	4.07	>0.01	S>M
PPKK - NNPPKK		17.3	2.61	<0.02	PP>NN	16.7	3.03	>0.01	PP>NN
7/6/73	O-M	19.5	0.75	>0.1	NS	20.4	1.71	>0.1	NS
	O-S	16.9	2.30	<0.05	S>O	20.9	2.33	<0.05	S>O
	M-S	20.8	1.50	>0.1	NS	22.0	0.79	>0.1	NS
PPKK - NNPPKK		15.2	2.34	<0.05	PP>NN	18.8	2.51	<0.05	PP>NN
PPKK - NNPK		16.1	1.09	>0.1	NS	19.7	0.82	>0.1	NS
NNPK - NNPPKK		21.8	2.02	0.1	NS	21.9	2.14	<0.05	NN NNPK>PP KK
20/6/73	O-M	22.1	3.30	<0.01	O>M	18.5	3.73	<0.01	O>M
	O-S	23.3	0.49	>0.1	NS	22.5	1.33	>0.1	NS
	M-S	17.5	2.76	<0.02	S>M	15.6	3.83	<0.01	S>M
PPKK - NNPPKK		26.7	2.85	<0.01	PP>NN	-	-	-	-
PPKK - NNPK		20.8	4.38	<0.001	PP>NN	-	-	-	-
NNPK - NNPPKK		20.8	0.94	>0.1	NS	-	-	-	-

In 1972 a preliminary survey of nodulation was carried out when, due to the small number of roots collected, none of the differences between the sections were significant at the 95% level. However at the 90% confidence level the trend in June was clearly S > M and S > 0 with M >< 0 as far as nodule numbers were concerned. In 1973, at seven weeks after sowing, development of primary nodules was found to be most rapid on the M plants but most efficient on the S section plants :-

Development at 7 weeks

Section	Mean number of nodules per root	Location of nodules	Proportion of total nodules which were pink and > 2 mm diam	Proportion of total nodules which were white and < 2 mm diam
0	13.2	Main root	25%	75%
M	17.4	Main root	29%	71%
S	12.3	Main root	75%	25%

The number of nodules on the M section plants were significantly greater than on the 0 or S section.

:5.2.2 Within the following two weeks secondary nodules on the top 10 cm of the lateral roots were initiated. At all times during the primary nodulation the largest and most efficient nodules were found on the tap root, whilst nodules on the laterals were less efficient and smaller (diameter 0.5 - 2.0 mm). Roughley and Dart (1969) suggest that this is because the lateral roots receive less photosynthate than the tap root. As many of the lateral root nodules remain ineffective, the value of the total nodule number does not always reflect actual fixation (Gibson 1971).

:5.2.3 By the tenth week, the numbers of nodules per plant, and the weight of nodules per gramme fresh weight of root, were significantly higher on S section plants on the tap root alone, and on the whole root system. Plants on the 0 and M sections showed no important differences. On the Special Fertilizer Treatment, the effect of adding a double quantity of nitrogen fertilizer to part of the PPKK trial was already evident. This addition, which occurred after the tap root nodules had been initiated, caused widespread death and decay of the nodules.

:5.2.4 At twelve weeks of age, the plants on all sections achieved the maximum numbers of root nodules, which coincided with the point in the plant life cycle at which the maximum numbers of inflorescences were produced. Heavy infestations of white larvae of the bean weevil *Sitonia lineatus* also reached their maximum density at this time. The larvae feed upon the root nodules, causing widespread death and loss of nitrogen fixing ability. The larvae were particularly abundant on the M section, but absent on the O section.

Development at 12 weeks

Section	Mean number of nodules per root decayed, or eaten by *Sitonia*	Mean number of healthy nodules per root
O	0.0	55.9 ± 3.3
M	10.3 ± 2.2	60.3 ± 4.9
S	6.3 ± 1.6	72.2 ± 6.3

Despite the difference in larval density, the S section plants maintained a significantly higher number of healthy root nodules than either of the other sections.

:5.2.5 On the Special Fertilizer Treatment the differences exhibited at ten weeks between PPKK and NNPPKK were maintained, but there was no significant difference between nodule numbers on PPKK and NNPK. This suggests that the depressant effect of double nitrogen is exacerbated if the levels of phosphate and potassium are increased too. This is supported when comparing nodule numbers on NNPK and NNPPKK, the value of the former being significantly higher than on the latter, at the 90% level.

NITROGEN FIXATION

TABLE 5-4. Nodule Survey 1973.

Summary Table of Mean Nodule Numbers

Management Type	Nodules on Tap root				Nodules on lateral roots				Nodules on complete root		
	Size mm diam.	Mean No.	SD	SE	Size mm diam.	Mean No.	SD	SE	Mean No.	SD	SE
ORGANIC	1-2	24.4	14.4	2.2	1	25.2	16.1	2.4	49.6	14.8	2.2
MIXED	2-3	32.8	10.4	1.5	1-2	20.4	11.6	1.7	53.2	18.2	2.6
STOCKLESS	1-3	34.8	9.2	1.2	1-2	17.5	13.3	1.8	52.4	17.4	2.3

Statistical Comparison

Management Types compared	Tap root				Lateral roots				Complete root			
	df	d	p	R	df	d	p	R	df	d	p	R
O-M	88.7	3.35	<0.01	M>O	88.8	1.71	>0.1	NS	95.1	1.09	>0.1	NS
O-S	83.3	4.30	<0.001	S>O	95.1	2.61	<0.02	O>S	94.6	0.88	>0.1	NS
M-S	96.8	1.02	>0.1	NS	96.8	1.16	>0.1	NS	97.9	0.22	>0.1	NS

:5.2.6 The main survey comparing nodulation of plants from the three sections was performed when the plants were at twelve weeks from sowing. In addition to sampling the fields used for the nitrogen fixation studies, all the other bean fields within each section were included. Fifty roots were removed at random from each field and the nodules on the tap root and laterals were counted separately. The results are listed on Table 5-4 and show a close correlation between the management sections, the distribution of the nodules on the root system, and the nitrogen fixation rates. The Organic plants had the smallest nodules, the lowest number of tap root nodules, the highest number on the lateral roots, and the lowest overall rates of fixation. The Stockless plants had the largest range in nodule size, the largest number of tap root nodules, the lowest number on the lateral roots, and the highest fixation rates. The Mixed plants possessed the largest nodules, an intermediate number of tap and lateral nodules, and an intermediate nitrogen fixation rate.

:5.2.7 It is clear from these statements that the fixation rates recorded did not depend upon the total number of nodules on the root system, but upon the size and number of nodules on the tap root. The observations of nodulation on the Organic section fit the statements of Munns (1968) and Dart and Wildon (1970), who found that high levels of available nitrogen in the soil delayed the appearance of primary nodules on the main root and reduced their numbers, but did not affect the formation of secondary nodules on the lateral roots, except by reducing their size. In 1952 Nutman demonstrated that the first nodules established tend to inhibit the formation of secondary nodules - this would explain why the plants on the Stockless section have a large number of tap root nodules, but less on the laterals.

:5.2.8 At the age of fourteen weeks the nodule numbers on all sections had decreased due to widespread death of both roots and nodules. Most were blackened and empty, or contained pupating *Sitonia* larvae. Estimates of the actual numbers of dead nodules per root was difficult as many sloughed off when the roots were extracted from the soil. The trend shown in the table below continued on tap and lateral roots, so that the significantly lowest number of live nodules per root was found on the M section plants. Although nodule numbers on sections O and S showed no significant difference, fixation rates were still higher on S. On all sections it was observed that a few, very small, white nodules had formed on the lateral roots. These were not included in the numbers in this table, due to their diminutive size.

Development at 14 weeks

Section	Mean number of dead nodules per root	Mean number of live nodules per root
O	26.1 ± 2.2	21.3 ± 3.2
M	48.8 ± 1.8	9.1 ± 1.8
S	35.3 ± 4.5	24.3 ± 5.2

:5.2.9 A similar decrease in nodule numbers was observed to occur on the Special Fertilizer Treatments. The difference seen earlier was maintained, with nodule numbers being significantly higher where no nitrogen had been applied. However the previous lack of difference between PPKK and NNPK, and the difference between NNPK and NNPPKK were not evident at this time. This suggests that earlier indications of a possible exacerbating effect of increasing phosphate on input of nitrogen was probably a factor resulting from too few replicates. If guidance is sought from the nitrogen fixation studies, it can be seen that far from increasing the effect, addition of double PK compensates partly for the depressant effect of double nitrogen, so that fixation on NNPPKK is higher than on NNPK.

:5.2.10 After flowering, which reached a maximum at 12 weeks, the development of the bean pods caused a great increase in the plants' demand for nitrogen. Weber et al. (1972) have shown that for soybean this increase

NITROGEN FIXATION

TABLE 5-5. Renodulation Survey 1973.

Summary Table of Mean Nodule numbers per root

Management Type	Size (mm diam.)	Number	Standard Deviation	Standard Error
Standard fields:-				
ORGANIC	1.4	28.5	18.9	4.3
MIXED	0.5	4.6	4.5	1.0
STOCKLESS	0.7	7.7	5.2	1.2
Special Treatments:-				
PPKK	0.5	14.2	14.4	3.2
NNPPKK	0.5	9.0	5.7	1.3
NNPK	0.8	12.1	11.5	2.6

Statistical Comparison

Management Types Compared	Degrees of Freedom	d	p	R
O-M	21.1	5.56	<0.001	O>M
O-S	21.9	4.73	<0.001	O>S
M-S	37.3	2.07	<0.05	S>M
PPKK-NNPPKK	24.7	1.49	>0.1	NS
PPKK-NNPK	36.1	0.51	>0.1	NS
NNPPKK-NNPK	27.8	1.07	>0.1	NS

in the requirement for nitrogen stimulates the nitrogen fixation of the root nodule bacteria to a maximum for the season, between flowering and pod expansion. Therefore to determine whether or not this occurred in *Vicia faba*, a second nodule survey was made on the plants at 16 weeks of age. It was found that extensive renodulation, the initiation of which had been seen at week 14, had taken place,to a differing extent under the three sections of farm management. The results are presented in Table 5-5.

:5.2.11 At this stage many of the tap roots were found to be dead, the new nodules forming on the lateral roots only. They tended to lack leghaemoglobin and had a highly developed reticulate surface. As can be seen from the table, on renodulation, the Organic plants produced a significantly greater number of larger nodules than were found on either the Mixed or Stockless sections. As has already been discussed, Nutman (1952) found that primary nodules tended to restrict the growth of secondary nodules so that the Stockless plants, which previously had a larger number of nodules than on the Organic section, may now renodulate to a lesser extent for this reason. Also Munns (1968) showed that secondary nodules were not affected by high nitrogen levels, so, that the depressant effect of high levels of available nitrogen on the Organic section would not affect renodulation. A combination of these two ideas may explain the observations made upon renodulation.

:5.2.12 There were no differences in renodulation on the Special Fertilizer Treatments which were significant. This may be because by this stage in the crop's growth most of the added nitrogen had been utilized or leached away. The lack of difference is probably more likely to have been due to the masking effect of the very high variability in nodule numbers within each treatment, and the samples consequently being too small to reveal differences. Unfortunately, due to a malfunction of equipment, it was not possible to measure the nitrogen fixation by the new nodules, but as the numbers observed were much less than at maximum nodulation, it is unlikely that the high levels of fixation recorded at that time were exceeded by the new nodules. Thus Weber's results for soybeans were not found to relate to renodulation of *Vicia faba*, particularly as the plants with the largest number of new nodules (O) eventually produced the lowest bean yield and would therefore have had the smallest increase in nitrogen demand.

5:5.3 Conclusions from nodulation studies

:5.3.1 The nodule development and distribution, on roots of *Vicia faba*, was seen to be strongly influenced by season and by the farm management practices. Roughley and Dart (1970) showed that low soil temperatures, as would be experienced early in the season, encourage the slow formation of large nodules on the primary root. Later in the year, the higher temperatures encourage faster initiation of nodules on the lateral roots. These statements fully explain the pattern of development observed to occur at Haughley.

:5.3.2 It was demonstrated that the most important guide to the nitrogen fixation potential of any root was the number, size and colour of the nodules on the main tap root, during the main nodulation. The timing of the maximum number of nodules coincided exactly with the time at which the maximum number of inflorescences were produced. This agreed with the findings of Masefield (1961) who worked on *Vicia faba* plants. He also demonstrated that the infestations of *Sitonia* larvae could be reduced by increasing the soil moisture content. The fact that no larvae were to be found on the Organic section, compared with heavy infestations on the other sections, indicates that possibly on the former section, a much higher soil moisture content existed. This suggestion was borne out by the studies on soil water content (see Soils section), but it is unlikely that this factor alone would explain the absence of larvae on the Organic section.

:5.3.3 Each farm section influenced the rate of formation of the initial plant nodules, the rate of their decay, and the rate of renodulation. For each management type there was a characteristic rate for these processes. Thus the roots of plants on the Mixed section were the quickest to initiate nodules, and also lost their nodules more rapidly than on the other sections; the Organic plants nodulated slowly, but tended to lose their nodules slowly too.

:5.3.4 With reference to the findings by many research workers (see 5:1) that a high level of available nitrogen in the rooting medium decreases nodulation, it is concluded that the low level of nodulation on the Organic section was caused by this factor. It has been shown by other researchers that several geochemicals can influence the nodulation of legumes, but these factors are unlikely to have been operating at Haughley to produce the results obtained. Acidity of soil has been shown to depress nodulation (Loneragan and Dowling 1958; Munns 1970), but all the fields at Haughley showed pH values in the range 7.0 - 7.4. The presence of calcium and magnesium has been found to stimulate nodulation (Hellriegel 1894; Albrecht and Davis 1929; Dobereiner 1966), but at Haughley, where soil analysis showed the Organic section to have significantly higher concentrations of both these geochemicals, that section had the plants with the least nodules. Thus the influence of available soil nitrogen was the most likely cause of poorer nodulation on the Organic section.

It was considered that the climatological impact would have been the same on all fields studied. It is possible that the differences in nodulation between sections were caused by the infection of the roots by different bacterial strains, but this was not investigated.

:5.3.5 The number of large pink, effective tap root nodules provided a good assay for the availability of nitrogen in the soil, correlating by inverse proportion to the levels of available nitrogen determined by chemical analysis. The addition of high levels of nitrate-nitrogen to bean plants which had already initiated the formation of nodules, caused widespread death and decay of the nodules, and the reduced number on these plants was maintained throughout the growing season, agreeing with the observations of Oghoghorie and Pate (1971).

5:6 The effect of farm management upon nitrogen fixation

:6.1 Aim

To compare the rates of nitrogen fixation by plants from the three farm management sections upon a number of occasions during the growing season.

:6.2 Results

The full field results are shown on Table A12 and an account of the problems encountered and methods used in the field, appears with it in the Appendix. A summary of these results is presented on Table 5-6 and depicted on Graphs 5-5 and 5-6. A statistical comparison of the fixation under different farm management sections is shown in Table 5-7.

:6.3 Discussion of Results

:6.3.1 The seasonal effect upon nitrogen fixation is clearly demonstrated for 1972 and 1973 in Graphs 5-5 and 5-6. Although the pattern of fixation per root, and fixation per nodule, closely followed the variation in air temperature at which the incubations were performed, it was demonstrated earlier that the response of whole plants to temperature changes between 18 - 25°C was small. Therefore the seasonal change in nitrogen fixation rate was probably due entirely to nodule age and the demand by the plant for nitrogen, which will vary as it grows. The fixation rates recorded for the O, M and S sections at week 14 in 1972 were probably a more accurate estimate of the actual rates found at week 14 in 1973 than the values shown. Due to the large size of the shoot and dryness of the soil, 1973 plants at this age

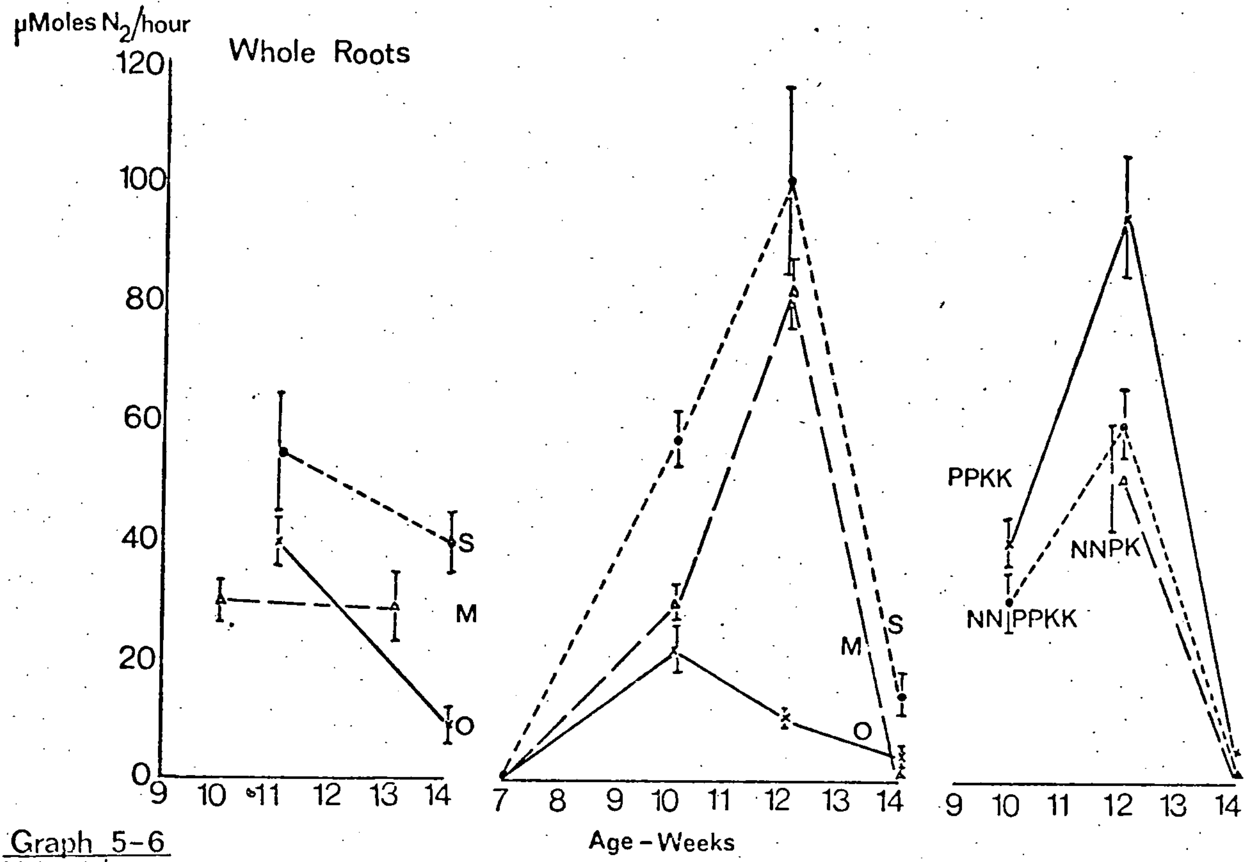
TABLE 5-6. Summary of field sampling data through 1972/73.

Treatment	Date	Age	Mean number live nodules	Rate of nitrogen fixation μM	
				root/hr.	nod./hr.
Organic	2/6/72	11	31.5 ± 4.2	40.0 ± 4.0	1.33 ± 0.13
	22/6/72	14	35.6 ± 5.9	9.0 ± 2.9	0.25 ± 0.06
	30/4/73	7	13.2 ± 1.3	0.073 ± 0.030	0.012 ± 0.003
	22/5/73	10	26.8 ± 2.9	22.2 ± 3.9	0.80 ± 0.10
	7/6/73	12	55.9 ± 3.3	12.4 ± 1.3	0.23 ± 0.02
	20/6/73	14	21.3 ± 3.2	4.1 ± 1.4	0.16 ± 0.03
Mixed	2/6/72	10	34.5 ± 4.9	30.1 ± 3.3	1.33 ± 0.33
	22/6/72	13	32.5 ± 2.9	30.9 ± 5.5	0.97 ± 0.13
	30/4/73	7	17.4 ± 1.3	0.34 ± 0.08	0.023 ± 0.007
	22/5/73	10	33.4 ± 4.5	29.9 ± 3.2	0.93 ± 0.17
	7/6/73	12	60.3 ± 4.9	82.0 ± 5.9	1.43 ± 0.17
	20/6/73	14	9.1 ± 1.8	1.3 ± 0.3	0.14 ± 0.02
Stockless	2/6/72	11	36.1 ± 3.0	54.7 ± 10.2	1.53 ± 0.23
	22/6/72	14	41.3 ± 5.4	39.9 ± 4.9	1.07 ± 0.17
	30/4/73	7	12.3 ± 1.5	0.51 ± 0.08	0.042 ± 0.009
	22/5/73	10	56.5 ± 5.5	57.0 ± 5.3	1.07 ± 0.13
	7/6/73	12	72.2 ± 6.3	100.9 ± 16.4	1.43 ± 0.27
	20/6/73	14	24.3 ± 5.2	14.5 ± 3.3	0.57 ± 0.07
PPKK	22/5/73	10	37.2 ± 2.5	40.0 ± 4.2	1.07 ± 0.07
	7/6/73	12	52.0 ± 7.0	95.2 ± 10.3	1.97 ± 0.17
	20/6/73	14	11.4 ± 1.3	4.0 ± 1.6	0.31 ± 0.11
NNPPKK	22/5/73	10	26.5 ± 3.2	30.0 ± 5.0	1.10 ± 0.07
	7/6/73	12	34.2 ± 3.1	60.1 ± 6.6	1.47 ± 0.20
	20/6/73	14	5.9 ± 1.3	2.2 ± 0.6	0.36 ± 0.08
NNPK	7/6/73	12	43.5 ± 3.5	51.4 ± 9.2	1.10 ± 0.13
	20/6/73	14	4.4 ± 0.8	1.1 ± 0.3	0.21 ± 0.04

Graph 5-5

Nitrogen Fixation

The Rates of Fixation by Whole Roots and Individual Nodules



Graph 5-6

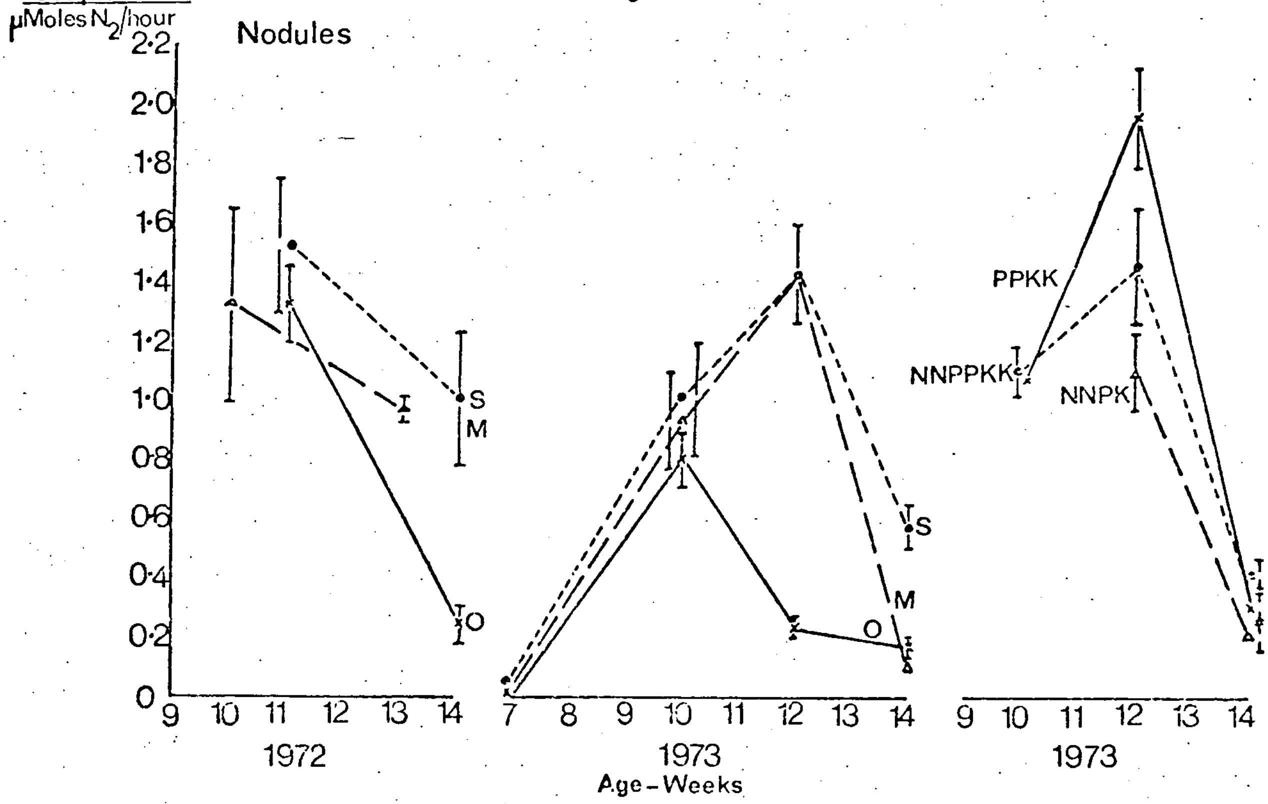


Table 5-7

NITROGEN FIXATION

Statistical comparison of nitrogen fixation rates.

Management types compared		Rate of fixation/root/hr				Rate of fixation/nodule/hr			
		df	d	p	R	df	d	p	R
2/6/72	O-M	16.8	1.90	0.1	NS	10.1	0.00	>0.1	NS
	O-S	10.4	1.35	>0.1	NS	13.4	0.77	>0.1	NS
	M-S	9.7	2.28	<0.05	S>M	13.9	0.50	>0.1	NS
22/6/72	O-M	13.6	3.54	<0.01	M>O	11.2	4.80	<0.001	M>O
	O-S	11.6	5.43	<0.001	S>O	8.3	4.56	<0.01	S>O
	M-S	15.9	1.23	>0.1	NS	14.6	0.46	>0.1	NS
30/4/73	O-M	14.9	4.19	<0.001	M>O	16.3	1.84	0.1	NS
	O-S	12.2	6.13	<0.001	S>O	12.5	3.88	<0.01	S>O
	M-S	23.0	1.88	0.1	NS	20.5	2.11	<0.05	S>M
22/5/73	O-M	13.7	1.19	>0.1	NS	10.0	0.68	>0.1	NS
	O-S	15.0	5.27	<0.001	S>O	15.6	1.69	>0.1	NS
	M-S	15.0	3.61	<0.01	S>M	12.8	0.67	>0.1	NS
PPKK - NNPPKK		10.6	2.27	<0.05	PP>NN	16.8	0.25	>0.1	NS
7/6/73	O-M	12.1	11.40	<0.001	M>O	11.2	7.06	<0.001	M>O
	O-S	11.1	5.36	<0.001	S>O	11.1	4.62	<0.001	S>O
	M-S	13.8	1.08	>0.1	NS	19.0	0.00	>0.1	NS
PPKK - NNPPKK		18.8	2.88	<0.01	PP>NN	21.3	1.85	>0.1	PP>NN
PPKK - NNPK		21.9	3.20	<0.01	PP>NN	18.4	4.35	<0.001	PP>NN
NNPK - NNPPKK		20.3	0.77	>0.1	NS	14.3	1.48	>0.1	NS
20/6/73	O-M	15.5	1.96	0.1	NS	26.9	0.50	>0.1	NS
	O-S	18.9	2.89	<0.01	S>O	16.9	6.12	<0.001	S>O
	M-S	14.3	4.00	<0.01	S>M	14.0	0.49	>0.1	NS
PPKK - NNPPKK		17.9	1.08	>0.1	NS	25.3	0.39	>0.1	NS
PPKK - NNPK		15.2	1.81	0.1	NS	19.3	0.87	>0.1	NS
NNPK - NNPPKK		19.8	1.57	>0.1	NS	20.9	1.67	>0.1	NS

were decapitated and washed prior to incubation. Both these factors would have served to depress the fixation rates, as observed earlier.

:6.3.2 The influence of farm management which caused differences between fixation rates per root for Organic, Mixed and Stockless section plants was effective both by causing differences in the fixation rate per nodule, and by the modification of root nodule numbers. Thus the significant differences shown between the fixation rates per root for Mixed and Stockless plants in Graph 5-5 were due entirely to a difference in nodule numbers - the curves on Graph 5-6 showed no significant differences except at week 7. But the differences between S and O plants on Graph 5-5 are reflected in 5-6 due to a genuinely lower fixation rate per nodule in the latter treatment, coupled with lower nodule numbers.

:6.3.3 Maximum fixation occurred at twelve weeks of age on the Mixed and Stockless sections which coincided with the maximum nodulation, and with maximum flowering, of the bean plants. However on the Organic section maximum nitrogen fixation per root and per nodule occurred two weeks earlier (two weeks prior to the achievement of maximum nodulation). It is possible that in fact this earlier maximum occurred at 11 weeks of age when no sample was taken, as indicated by the higher rate of fixation at this time in 1972. This indicates that many of the nodules on the Organic plants were ineffective at fixing nitrogen, which concurs with the conclusions reached in the nodulation section.

:6.3.4 Summarising the results of the statistical comparisons of the treatment effect upon nitrogen fixation rates by individual nodules and whole roots in Table 5-7 - out of 36 pairs tested :-

At the 95% confidence level M > O five times
S > O nine times
S > M four times

Out of the 18 tests in which no significant differences were found, the lack of differences segregated as follows :-

O not significantly different from M - seven times
M " " " " " " " S - eight times
S " " " " " " " O - three times

From these statistical tests the conclusions are that the Organic section plants had a significantly lower ability to fix atmospheric nitrogen than those on either the Mixed or Stockless section, and it is suggested that this was a direct effect of the farm management on the O section. There was no single instance in which the fixation rate on the Organic section was greater than that on the Stockless section, and only on three occasions out of 36 were there no significant differences between these sections. The trend for the relationship between the Mixed section and the other two, was :-

M fixation > O fixation
S " > M " although seven and eight times respectively out of 36 comparisons, these pairs showed no significant differences.

:6.4 Special Fertilizer Treatment Results

:6.4.1 The measurement of nitrogen fixation by plants from the special fertilizer treatments was first made just one week after the addition of double nitrogen to part of the PPKK and PK plots. Within such a very short time the effect of the nitrogen was to significantly reduce the nodule numbers, and hence the fixation per root, but the fixation rate per nodule was unaffected. After a further two weeks had elapsed, the added nitrogen had lowered the rate of fixation per nodule significantly, on both single, and double, phosphate and potassium plots (NNPK and NNPPKK). Although the fixation per nodule per hour was significantly PPKK > NNPPKK > NNPK, this difference did not hold completely true for the fixation rates per plant.

The NNPK treatment caused less death of nodules than the NNPPKK plot, and hence there was no significant difference in the total fixation per root between these treatments. At the end of the season there were no differences in fixation between any of the special fertilizer plots, although the trend was for PPKK plants to have the highest number of nodules per root. This indicates that either the nitrogen applied had been leached away or used up by this time, or that its effect upon fixation wore off as the nodules aged, possibly because the secondary nodules which are less sensitive to nitrogen became more important for the fixation of nitrogen (Munns 1968).

From Table 5-7 out of a total of 14 pairs compared, fixation was significantly different for :-

PPKK > NNPPKK three times

PPKK > NNPK twice, the remaining nine showing no differences at the 95% level, which may have been due to the use of samples which were too small in number. In general, the results gained from the special fertilizer treatment were those expected from the work of Bell and Nutman (1971); Moustafa, Ball and Field (1969); and Vincent (1965).

6.4.2 Nitrogen fertilizer in the form of ammonium nitrate was applied to the special fertilizer plots immediately after the primary nodules had been initiated, but before fixation had started. Oghoghorie and Pate (1971) suggest that combined nitrogen supplied to plants at this stage may well enhance later fixation by causing greater growth of the shoot, and hence increased nitrogen demand. This effect was not seen to occur on the trial plots in this study, when comparing NNPK plants with the standard PK plants on the Stockless section. It is assumed that the quantities used here were too great, and therefore the depressant effect too long lasting, for this benefit to be shown.

:6.4.3 It is interesting to compare the maximum rate of fixation by plants on the special fertilizer treatments with the maximum rate of those plants on the O, M and S sections.

.3-1 When comparing fixation PK (S) with PPKK, the effect of doubling the phosphate and potassium significantly enhanced the fixation potential per nodule. However the same addition so reduced the nodule numbers that the resulting nitrogen fixation per plant showed no overall effect to distinguish between the two treatments.

.3-2 When double nitrogen was added to the PPKK plot, the effect on nodule fixation was equivalent to that found on the M and S sections. But again the reduction in nodule numbers caused the overall fixation rate per plant to fall significantly below that of the M section plants.

.3-3 When double nitrogen was added to the PK plants, both the fixation per nodule, and the fixation per root, were depressed below that of NNPPKK, but this was not significant for the whole root as there was no commensurate increase in nodule numbers.

Thus for nodules : PPKK > NNPPKK ≡ M ≡ S > NNPK > O

and for roots : PPKK ≡ S > M > NNPPKK ≡ NNPK > O

Therefore even the addition of a high level of nitrate fertilizer to the bean plants on the Stockless field could not depress the whole plant fixation to a level as low as the normal rate of fixation on the Organic section.

:6.4.4 The doubling of the application of phosphorus and potassium to the Stockless system in the special fertilizer treatments severely restricted the formation of new nodules, but the effect was compensated for by a considerable enhancement of the rate of nitrogen fixation per nodule. Addition of nitrate-nitrogen in the form of a top dressing of fertilizer after the initiation of nodules caused an immediate reduction in the number of nodules, followed by a reduction in the nitrogen fixing ability of each nodule. This depressant effect by inorganic nitrogen was not as severe as was shown by the nitrogen derived from the manurial treatment,on the Organic section.

:6.5 Estimation of nitrogen fixed/hectare/year

:6.5.1 Although Hardy et al. (1968) extrapolated single readings of acetylene reduction, which had been measured at a set time once per week, to an estimation of the nitrogen fixed by a symbiotic legume association per season, this can only give a very rough guide, due to the large number of changing factors which influence the rate of fixation. The light intensity, temperature, time of day, water stress, availability of soil nitrogen, the nutritional state of the plant, and the age and growth of nodules and plants all interact to control nitrogen fixation by the root nodule bacteria. As the daily fluctuations in these factors cannot be assessed by a single measurement of acetylene reduction, great care must be exercised when quoting the potential annual nitrogen fixation for a particular plant, if it is obtained in this way. However, as these variations cannot be controlled under field conditions, any such estimate may prove useful in the context of a nitrogen balance sheet for a particular ecosystem. Thus, although the fixation rates measured at Haughley were only valid for the time and conditions of the assay, these figures have been extrapolated to cover the fixation over the growing season.

:6.5.2 As described previously, all the acetylene reduction incubations in the 1973 season were performed between 09.00 - 11.00 hours because this coincided with the time of the mean fixation rates over the diurnal period studied. For the determination of the potential nitrogen fixed in 1973, figures for the 14th week were used from 1972 so that all the means used would be derived from a study of whole plants.

Calculation :-

Age of plants (weeks)	Number of days	Mean fixation rates µ Moles nitrogen/root/hour		
		Organic	Mixed	Stockless
7 - 10	21	11.06	15.12	28.76
10 - 12	14	17.30	55.90	78.95
12 - 14	14	10.69	56.47	70.42
14 - 15.5	9	4.49	15.47	19.97

Then :-

µgm N_2 fixed = Mean fixation rate x number of days x weight of 1 µ M Nitrogen x Number of plants per hectare

The number of plants per hectare was estimated to be 270,000. Bell and Nutman (1971) stated that when the nitrogen content of a harvested crop is quoted as a measure of the total nitrogen fixed, this was seldom an overestimate. But the figures for the annual removal of nitrogen at Haughley bore little resemblance to this estimation of nitrogen fixation, except on the Mixed section.

Section	Organic	Mixed	Stockless	Special Fertilizer Treatments PPKK	Special Fertilizer Treatments NNPPKK
KgN_2 fixed/ha/season	120.6	368.4	521.6	334.0	231.7
KgN_2 removed/ha/season	321.0	381.0	311.0		

The estimation of values for fixation on the special fertilizer treatments was probably an underestimate because at week 14 only the figures for decapitated plants were available; but the difference between PPKK and NNPPKK demonstrated the effect of adding inorganic nitrogen.

:6.5.3 No figures for the annual fixation of nitrogen were found in the literature to relate to field beans, but the figures calculated at Haughley lie within the range round for other crops elsewhere :-

Lucerne	0 - 300 KgN/ha/year	Bell and Nutman (1971)
Soybean	30 - 120 " " "	Hardy (1968), Weber (1966)
Clover	150 - 600 " " "	Munro (1969), Sears et al. (1965)

:6.5.4 The assessment of nitrogen fixation for the Haughley farm sections suggests that the depressant effect of the Organic manurial treatments upon symbiotic nitrogen fixation, resulted in the removal of nearly three times as much nitrogen in the crop as was fixed by the root nodules. If further studies which included the measurement of nitrogen fixation over the whole season corroborated these results, there would be a strong indication that the organic management system employing expensive manures was defeating part of the aim of using legumes in the farm rotation, to improve the nitrogen status of the soil. Conversely, the Stockless system appears to permit the fixation of much more nitrogen than is removed annually by the crop. The loss of nitrogen from all three systems could be lessened if the dead stems of the plants were ploughed back into the ground, instead of being removed from the field and burned, or used as fodder.

:6.6 Nitrogen content of the nodules

Standard Kjeldahl analysis of the dried and ground root nodules was carried out through the 1973 season, to determine the organic nitrogen content of these structures. In order to provide sufficient material for analysis, nodules from all three sections were homogenized together.

Date	Age of plant (weeks)	N_2 content of nodules Ngm/gm dry weight
30/4/73	7	38.4
21/5/73	10	64.3
7/6/73	12	48.2
24/7/73	19	49.1
2/8/73	20	47.3

This indicates that even after the root systems were dead, and long after fixation had ceased, the root nodules retained their high levels of nitrogen, which would be released to the soil as they gradually decayed. The maximum nitrogen content occurred at the time at which plants on the Organic section were undergoing maximum fixation.

:6.7 Overall conclusions of the Nitrogen fixation study

:6.7.1 The nitrogen fixation by *Vicia faba* plants was found to be strongly influenced by season and by the farm management practices.

The seasonal effect causing variations in the rate at which nitrogen was fixed, acted through day length, the age of nodules, and the changing demand for nitrogen by the plant as the crop matured. It is possible that the greater fixation rates recorded on the Stockless section were due to the large demand for nitrogen for the high yield of bean seed, whereas on the Organic section low seed yield caused, or was the effect of, low nitrogen fixation rates.

:6.7.2 The effect of farm management controlled the total amount of nitrogen fixed per plant through the combination of two partially independent factors :-

- by modifying the number of effective nodules initiated on each root
- by altering the efficiency of nitrogen fixation per nodule.

The severe depression of nitrogen fixation found on the Organic farm section is considered to have been caused by the high levels of available nitrogen which had resulted from the long-term use of organic manures. The response of the symbiotic legume association to the level of available nitrogen in the soil can be used as a biological assay to confirm or replace chemical soil analyses.

FINAL DISCUSSION

FINAL DISCUSSION

The aim of the research project conducted at Haughley was to evaluate and compare the dynamics of the agricultural ecosystem, under three contrasting patterns of farm management. In each of the five main sections of the text the methods of investigation used to determine the rate of energy fixation (crop growth and yield), and the magnitude of the flow of geochemicals through the system, are described, and the results discussed. Thus the influence of farm management upon each of several individual components of the ecosystem has been identified. The purpose of this Final Discussion is :

1. To draw together the individual conclusions from the previous sections of the text, to provide an overall picture of the agricultural ecosystem.

2. To emphasize the most important findings of the research project.

3. To suggest future spheres of intensified research, designed to examine more closely some of the results of this broad-based screening operation.

1. The overall picture of the agricultural ecosystem

The theme of investigation in this research has been to define the seasonal dynamics of the flow of geochemicals through the plant-soil-soil water system. In order to provide a basis for quantifying most of the sources and sinks for plant nutrients within a finite closed system, lysimeters were constructed for the second year field trial. As described in Section 2 (2:2.4) the lysimeters provided only a very crude approach to the problem, for due to several limitations of construction, conditions within them tended to be dissimilar from those operating in the open field. However, the use of this equipment enabled the inexpensive monitoring of the rate of outflow of the soil-water percolate - this information proved to be impossible to collect from the whole-field studies. Using the results from the lysimeter study, crude balance sheets were constructed for the plant macronutrients - the magnitude of the annual flow through the system was expressed in Kilogrammes/hectare/year.

For the purpose of the formulation of these tables, analytical values gained from different seasons have been collated with the lysimeter results. For example, the comparative study of symbiotic nitrogen fixation by the legume crop was performed in 1973 - the fixation values have been inserted into the appropriate columns on the Gain sheet for the 1972 situation. The estimate for the high fertilizer (S^+) fixation was taken to be equivalent to the fixation recorded on the NNPPKK plot in 1973.

Thus a composite picture has been produced to show the balance of the Gain and Loss of Nutrients to, and from, the system, in which all the values are necessarily only very approximate, but which allows some comparison of the effects of the three management patterns to be made.

(1) Gains to the system

The addition of geochemicals to each system were supplied in :

:1. the precipitation
:2. the manures and fertilizers
:3. the seeds sown
:4. the nitrogen fixed by the legume symbionts
:5. the nitrogen fixed by the free soil microflora

(The numbers refer to those additions listed in Table D:1).

The values for the non-symbiotic fixation of nitrogen were taken from the results of Basahy (1974), and are inserted as a guide to the influence of farm management upon this process. The pattern followed was

FINAL BALANCE SHEET

Table D:1 Gains to the Farm Systems (Kg/ha/year)

Geochemical	Input	Cropped				Fallow			
		O	M	S	S^+	O	M	S	S^+
Nitrate-N	1	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
	3	0.02	0.02	0.02	0.02				
	Total	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Organic N	1	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
	2	398.0	103.0	50.0	112.0	398.0	103.0	50.0	112.0
	3	10.2	10.2	10.2	10.2				
	4	120.6	368.4	521.6	232.0				
	Total	537	490	590	363	406	111	58	120
	5	40	26	74	50	40	26	74	50
Org. N + NO_3-N	Total	579	518	666	415	448	139	134	172
Phosphorus	2	68.0	46.0	35.0	120.0	68.0	46.0	35.0	120.0
	3	0.3	0.3	0.3	0.3				
	Total	68	46	35	120	68	46	35	120
Potassium	1	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
	2	80.0	35.0	35.0	198.0	80.0	35.0	35.0	198.0
	3	0.6	0.6	0.6	0.6				
	Total	89	44	44	207	88	43	43	206
Calcium	1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
	2	253.0	28.0	6.0	1.7	253.0	28.0	6.0	1.7
	3	1.1	1.1	1.1	1.1				
	Total	272	47	25	21	271	46	24	20
Magnesium	1	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
	2	49.0	10.0	0.5	1.7	49.0	10.0	0.5	1.7
	3	0.2	0.2	0.2	0.2				
	Total	64	25	15	16	63	24	15	16
Sodium	1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
	2	12.0	-	1.2	4.4	12.0	-	1.2	4.4
	3	0.1	0.1	0.1	0.1				
	Total	25	13	14	18	25	13	14	18

Key : Input 1 = Precipitation over one year
2 = Fertilizer/Manure
3 = Seed content
4 = Nitrogen fixed by legumes
5 = Nitrogen fixed by free bacteria

Totals expressed to nearest whole number similar to that found for the fixation in the legume root nodules, with a maximum in the soil where no organic manures had been supplied (Stockless farm) and a minimum on the Organic farm. However it is unlikely that this level of non-symbiotic fixation would have occurred in the field as the values were only obtained after massive enrichment of the soil with glucose.

Table D:1 depicts the situation for both sizes of lysimeter, because, although these differed in their surface areas, the additions are expressed in weight per unit area. The differences between the cropped and fallow additions were due to the chemical content of the seeds sown, and to crop nitrogen fixation. Thus, except for nitrogen, the total gains of geochemicals by the cropped and fallow lysimeters were equal, ± 1 Kg/ha. As all the values on the table are approximate, this allows further simplification :

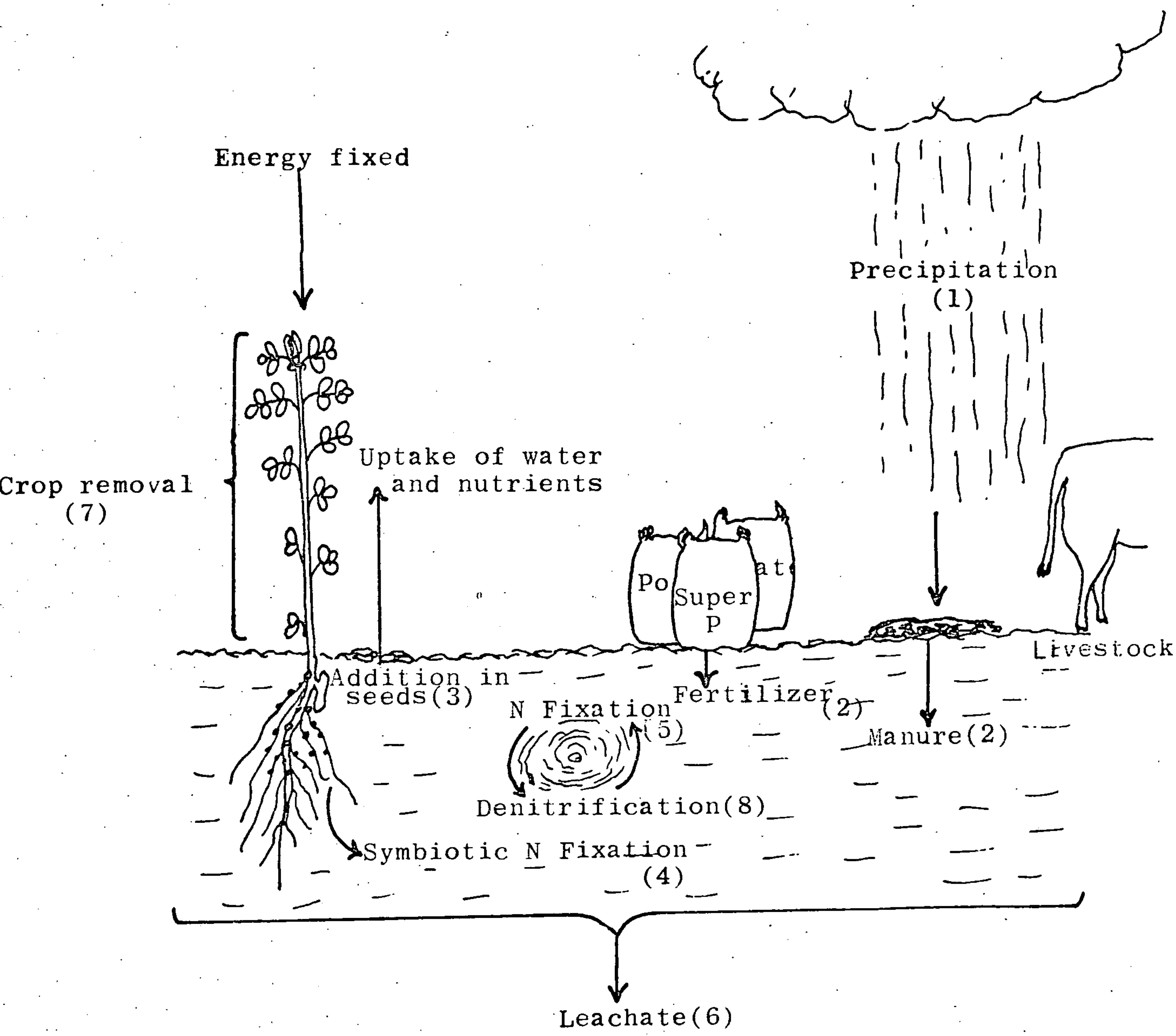
Total Gains of geochemicals in Kg/ha/year :

Geochemical	Lysimeter type	O	M	S	S^+
$N + NO_3$-N	Fallow	448	139	134	172
	Cropped	579	518	666	414
P	Fallow + Cropped	68	46	35	120
K	Fallow + Cropped	89	44	44	207
Ca	Fallow + Cropped	272	47	25	21
Mg	Fallow + Cropped	64	25	15	16
Na	Fallow + Cropped	25	13	14	18

Although the flow of a greater range of geochemicals had been investigated during the field studies, complete nutrient balance information was not available in a form easily related to the lysimeter situation, and therefore only the macronutrient values have been presented in these tables.

A diagram to illustrate the eight components which were considered when constructing the Net Annual Geochemical Balance Sheet for the agricultural ecosystem at Haughley.

(The numbers in brackets refer to the categories used on the Gain and Loss Tables D-1 and D-2, from which figures the annual balance was calculated).



There were two limitations which further restricted the accuracy of the figures shown on Table D:1 :

: Due to the very large concentrations of nitrogen in the fertilizers and manures the sensitive methods of analysis used for the plant and soil samples were swamped - no accurate estimation was possible. Therefore all the nitrogen in these additives has been included into the table under the one heading of Organic nitrogen.

: It was impossible to estimate accurately the level of nutrients remaining in the Organic farm soil from the application of manure which had been made in the previous year. As it was necessary to provide a figure on the table for each geochemical considered, an arbitrary figure of 75% of the initial nutrient value (Section 1:2.3.2) of the manure supplied,was used to represent the probable remaining level.

An indication of the beneficial value of including a leguminous crop in the farm rotation is shown by the difference between the Gains in Organic nitrogen,for the cropped and fallow lysimeters. A significant relationship can be seen to have been operating between the level of nitrogen applied by man, and the resulting fixation of nitrogen by bacteria :

Source of nitrogen	O	M	S	S^+
Fertilizer/Manure	398	103	50	112
Legume symbiosis	121	368	522	232

Clearly the higher the prior addition of nitrogen, the lower the fixation rates. It is noted from Section 5 (5:6.4.3-2) that despite a massive application of inorganic nitrogen to the plot NNPPKK, the resulting depression of fixation was still not as severe as was experienced on the Organic farm.

(2) Losses from the system

Although it was possible to simplify the presentation of the Gain sheet (D:1) by equating the values for shallow and deep, cropped and fallow lysimeters, no similar simplification of the Loss sheet (D:2) can be made - the loss of geochemicals in the leachate (6) and in the harvested crop (7) were considerably different, depending closely upon the lysimeter size, depth and use of soil. With the exception of denitrification (figures from Basahy 1974), the only loss assumed to be suffered by the fallow lysimeters was through leaching of the soil by the percolating rainfall.

If a comparison is made between the losses from the deep and shallow containers, it can be seen that for all geochemicals except phosphorus, the leachate loss was greatest from the former type. Except for potassium, which is a relatively immobile ion like phosphorus (Cooke and Williams 1970), the extent to which the loss from Deep > Shallow differed was very large. For the relative depth of soil, less rain fell onto the deep lysimeters, but the lower evaporation rate, and the inclusion of the lower soil horizons, enabled the leaching of greater quantities of the alkaline earths (especially calcium) from this type. As discussed in Section 2 (2:6.2.2.6), the loss of geochemicals from the deep lysimeters was probably more closely akin to that found in the field than that shown by the shallow type. However, the loss would still be an overestimate of the actual nitrate loss, and probably a slight underestimate of the loss of the alkaline earths.

Comparing the losses of geochemicals in the leachate alone,from the cropped and fallow lysimeters, these were always greater from the latter type, due to a combination of factors. Where there was no crop, the unprotected soil surface would have been more vulnerable to leaching, and where plants were growing, some of the geochemicals otherwise available for leaching would have been taken up into the plant biomass. The only exception to this

FINAL BALANCE SHEET

Table D:2 Losses from the Farm Systems (Kg/ha/year)

Geochemical	Output	Shallow lysimeters				Deep lysimeters			
		O	M	S	S^+	O	M	S	S^+
1. CROPPED									
Nitrate-N	6	1.5	1.5	1.5	1.5	6.0	4.6	5.3	9.0
	7	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
	Total	2.0	2.0	2.0	2.0	6.0	5.0	5.0	9.0
Organic N	6	7	7	8	7	44	30	51	65
	7	80	105	115	120	80	105	115	120
	Total	87	112	123	127	124	135	166	185
	8	55	24	5	4	55	24	5	4
Org. N + NO_3-N	Total	144	138	130	133	185	164	176	198
Phosphorus	7	8	10	12	12	8	10	12	12
Potassium	6	0.7	0.3	0.6	0.7	3.0	0.9	0.9	0.9
	7	37	27	45	35	37	27	45	35
	Total	38	27	46	36	41	28	46	36
Calcium	6	15	18	15	9	75	84	105	99
	7	12	20	34	25	12	20	34	25
	Total	27	38	49	34	87	104	139	124
Magnesium	6	1.0	0.8	0.5	0.4	3.6	3.7	3.3	3.0
	7	2.0	3.0	3.0	6.0	2.0	3.0	3.0	6.0
	Total	3	4	4	6	6	7	6	9
Sodium	6	2.1	1.7	0.9	0.8	9.3	7.5	7.5	6.6
	7	1.0	5.0	1.0	1.0	1.0	5.0	1.0	1.0
	Total	3	7	2	2	10	13	9	8
2. FALLOW									
Nitrate-N	6	3.0	1.8	1.5	1.5	9.0	2.8	7.5	12.0
Organic N	6	12	9	6	12	45	12	75	86
	8	55	24	5	4	55	24	5	4
Org. N + NO_3-N	Total	70	35	13	18	109	39	88	102
Potassium	6	1.7	0.4	1.2	0.7	1.2	0.3	2.1	1.5
Calcium	6	30	30	15	21	126	36	150	108
Magnesium	6	1.3	1.0	0.7	0.7	3.8	1.1	4.8	3.5
Sodium	6	3.3	2.1	1.5	1.5	14.1	2.0	7.5	9.3

Key : Output 6 = Lysimeter leachate over one year
7 = Crop removal at final harvest
8 - Denitrification by soil bacteria

rule was shown by the deep lysimeters of the Mixed section where the the values of geochemical loss were greatest for the cropped soil, but this was due entirely to an internal blockage of the outflow pipe from the fallow containers, effective from September 1972 - March 1973. Except for sodium, where the difference of loss in leachate and crop was small, the major loss of nutrients from the cropped lysimeters was contained in the plant material removed at the time of the final harvest. Although the bean seed yields in the lysimeters were considerably below those recorded in the field, in order to retain the situation found within the containers, the field data were not substituted into this table. Therefore the actual field loss of geochemicals in the plant biomass was generally above that indicated here (see Section 4:5.4.5).

(3) Net annual geochemical change

By subtracting the values of the annual losses from the system (Table D:1), from the values of the annual gains to the system (Table D:2), the net annual geochemical change in each farm system can be defined (Table D:3).

As mentioned in the discussion of Table D:1, the nitrate-nitrogen figures are not truly representative of the values for the actual gains and losses of this ion because of the exclusion of the fertilizer and manure content. Therefore the negative values, showing a net annual loss of nitrate, must be passed over, except to reiterate how much greater the loss of geochemicals was from the deep lysimeters.

It is significant that, despite a greater content of easily exchangeable, and therefore potentially leachable, plant nutrients in the Organic soil (Section 1:3.2.2), that system did not demonstrate a net annual loss of any of the main geochemicals considered. By contrast, all sections receiving inorganic fertilizers showed such losses, particularly of calcium, potassium and nitrogen, under both cropped and fallow conditions. Except

Final Balance Sheet

Table D:3 Net annual geochemical change (Kg/ha/year)

The figures indicate the net annual gain, and the net annual loss
(with minus sign)

Geochemical	Shallow lysimeters				Deep lysimeters			
	O	M	S	S+	O	M	S	S+
1. Cropped :								
Nitrate-N	0.4	0.3	0.4	0.3	-4.1	-2.8	-3.4	-7.2
i. Organic N	450	378	467	236	413	355	424	178
ii. Nitrogen	395	354	462	232	354	328	416	167
iii. Nitrogen	435	380	536	282	394	354	490	217
Phosphorus	60	36	23	108	60	36	23	108
Potassium	51	17	-2	171	48	16	-2	171
Calcium	245	9	-24	-13	185	-57	-114	-103
Magnesium	64	21	11	10	58	18	9	7
Sodium	22	6	12	16	15	0	5	10
2. Fallow :								
Nitrate-N	-1.1	0.1	0.4	0.4	-7.1	-0.9	-5.6	-10.1
i. Organic N	394	102	52	108	361	99	-17	34
ii. Nitrogen	338	78	47	104	299	74	-28	20
iii. Nitrogen	378	104	121	154	339	100	46	70
Phosphorus	68	46	35	120	68	46	35	120
Potassium	86	43	42	205	87	43	41	205
Calcium	241	16	9	-1	145	10	-126	-88
Magnesium	62	23	14	15	59	23	10	13
Sodium	22	11	13	17	11	11	7	9

Key : Nitrogen i. = soil fixation, denitrification, and nitrate-nitrogen figures omitted
ii. = denitrification and nitrate included
iii. = denitrification, nitrate and soil fixation included.

for sodium, where the Mixed plants demonstrated a very high uptake, the maximum loss (or minimum gain) of geochemicals was always found on the Stockless section where there were no remains of organic manures to stabilize the availability of the soil geochemicals. Organic material serves to bind certain compounds into its matrix (1:1.3) and will also only gradually decompose to release the initially unavailable nutrients into an available form. In comparison, when artificial inorganic fertilizers are added to the soil, most of the contained nutrients are immediately available, for plant uptake or leaching by the percolating soil-water.

The extent of the loss of the calcium, magnesium and sodium from the normal Stockless system was closely copied by that from the high fertilizer treatment (S^+), and the loss over the year was much greater than from the Organic and Mixed systems. However, due to their relative immobility, the levels of phosphorus and potassium, which were supplied at a greater rate in the S^+ lysimeters, remained at levels 300-500% higher than in S, throughout the season. Thus, the use of significantly greater quantities of fertilizer than is normal did not greatly increase the threat to water system eutrophication, except marginally so for total nitrogen.

The most realistic of the nitrogen figures listed is probably ii. which included the denitrification and nitrate-nitrogen estimates, and the legume fixation values, but omitted the probably inflated values of the non-symbiotic fixation figures. Using this category, it can be seen that the most advantageous system (where most nitrogen was conserved) was the Stockless system, due to the maximum level of symbiotic fixation. Most of the gain in nitrogen on this system was obtained without any financial investment by the farmer, whereas most of the apparently large gain in nitrogen on the Organic farm originated from the heavy application of expensive animal manures. Despite a high investment in nitrogen fertilizers on the S^+ plot, the net annual gain was the lowest for all systems, due to the depression of fixation. The Mixed system showed a lower net annual nitrogen gain than either of the other normal systems, but a greater proportion of the gain was derived from legume fixation than on the Organic system and, additionally, the Mixed farm gave the highest bean seed yields. Thus, with the exception of nitrogen, the net annual gain of most geochemicals followed the pattern O > M > S, no matter whether the soil volume considered was deep or shallow, cropped or fallow.

2. The most important features of the research results

The findings shown by the construction of the balance sheets must be considered in conjunction with the conclusions drawn from each section of the total investigation, as many of these are not referred to by the figures on these tables.

(1) The research was conducted against the background of differences found in the rooting medium, which had been brought about as a result of the different farm management systems practised over a period of thirty years. The chemical and physical analysis of the soil showed that the use of organic manures on the Organic and Mixed farms had improved the level of organic matter, and the soil's potential moisture content. There was a close relationship between the amount of nutrients supplied to the soil in the manures and fertilizers, and the concentrations found in the soil during the season; with the maxima of most geochemicals occurring where organic manures had recently been applied.

The organic manures were shown to be a better source of exchangeable nitrogen, phosphorus and potassium than artificial fertilizers as, in addition to a high intrinsic nutrient content, they encouraged soil stability, and they only gradually released their own nutrients to the developing crop plants, during the season. In theory therefore, the Organic and Mixed farms should have provided the best rooting medium for the healthy growth of crop plants. It was shown that per unit weight, the organic manures actually provided less nutrient additions to the soil than the highly concentrated inorganic salts, but due to the massive rates of application of manures, the availability of nutrients on the Organic and Mixed farms was maximal. For this reason the Organic system posed a possible threat of eutrophication to the water draining from the land. The most serious threat, however, came from the Mixed farm where nutrients were supplied in the form of both organic manures, and annual artificial fertilizer applications. Even so, the WHO preferred safe limit for nitrate-nitrogen concentrations in water,was never exceeded, even where leaching of this ion had been artificially increased by the construction of lysimeters.

Only the concentrations of heavy metals and phosphorus in the soil were unaffected by farm management. It has been shown that due to great immobility, the annual addition of phosphorus to the soil of each system tended to cause a progressive accumulation in the soil horizons, so that adequate supplies were available for crop growth,even where no fertilizer was applied in the experimental season. The loss of phosphorus by leaching was found to be negligible when the analysis of the percolate was made.

(2) A study of the chemical composition of the water draining from the lysimeters and fields,revealed that the maximum concentrations of leached geochemicals did not occur during the same season as the maximum total weight loss of the geochemicals from the soil. The maximum concentrations occurred during the three months following the application of manures (November), and fertilizers (March), but the maximum total losses occured during the season of maximum rainfall (September - December), especially after the disturbance of the soil during the harvesting of the crop. This seasonal pattern of loss was independent of the farm management type - the only exception was found to be the shallow fallow lysimeters where, due to an unprotected soil surface, maximum loss occurred during the summer. In general, the magnitude of the leaching losses followed the pattern of the

total volume of water draining through the soil, and the rate of nutrient application to the soil, within the framework of Ca > Na > N > Mg > K > P, a pattern which closely mimicked that of the supply of geochemicals in the rainwater. Analysis of the rain showed that a greater quantity of potassium, magnesium and sodium were supplied per unit area of field, than was lost in the drainage water, even from areas where high potash fertilizer had been applied.

(3) The main evaluation of the long-term effects of the three management systems, and varying application rates of fertilizers was made using the crop *Vicia faba* L. as a phytometer. Despite the differences in nutrient availability on the three systems, the growth performance of the bean plants showed almost no significant differences on any of the farms,at any level of fertilizer application. It must therefore be assumed that on all the farms the background level of plant nutrients was adequate for efficient crop growth, and that any further application of geochemicals was surplus to the crop's requirements. The only apparent effect of varying the rate of nutrient input was to reduce or extend the length of time required for the plant to achieve its growth maxima.

The only major effect of farm management upon any aspect of the performance by the phytometer was upon its yield, where increasing the fertilizer application rate caused an increase in the bean seed yield. When comparing the fields where organic manures had been applied during the previous year to each of the Organic, Mixed and Commercial fields studied, the yield followed the pattern $M \equiv C > O \equiv S$. The practice on the Commercial fields was to supply heavy applications of manures every year, so that although not measured by soil analysis, the nutrient availability on that section would probably have been the maximum to be found anywhere at Haughley. However, the nutrient input, and hence the financial investment, was less on the Mixed section. Thus the Mixed farm would be the most economically rewarding for the farmer to use, with a lower nutrient input than on the Commercial farm, but with the same yields.

Before the phytometer was used to evaluate the effect of farm management systems upon the soil, an investigation had been made into the possible long-term effects of imprinting the crop on each farm system. The hypothesis was made that the continued growth of a crop (in rotation) upon farms differing in their nutrient availability might have caused a physiological adaptation of each imprint type to be able to grow more efficiently upon its own system. However, this hypothesis was largely disproved by a greenhouse and field trial. Although there were some differences in the growth performance of the three imprint types, these were largely non-significant, and could have been purely due to natural within-population variability, which had been emphasized by the use of very small samples. Because of the observed lack of differences in the growth of the plants on the three farm management sections (referred to in the previous two paragraphs), it was probably the high background level of plant nutrients on all the farms which prevented the process of imprinting from having any 'evolutionary' effect upon the physiological requirements of the *Vicia faba* crop.

(4) In order to investigate the flow of geochemicals from the soil into the standing biomass of the crop, the plants used for the measurement of the growth parameters were subjected to chemical analysis. Because this study was designed to be a comparative one, and not to define the absolute values for crop chemical composition, the main text section did not discuss the actual chemical concentrations except where these were of particular interest.

It was found that neither the process of imprinting, nor the farm management type, nor fertilizer application rate, altered the main location of the geochemical concentrations in the plants. The treatment also showed no effect upon the seasonal pattern of the variation of concentrations in each separate plant part. There was no evidence of any 'eutrophication' of any part of the plant by an accumulation of nitrates, but a marked death reaction occurred by which there was a dramatic increase in the uptake of heavy metals, in particular lead, after the death of the roots. The magnitude of the flow of lead into the plant was considered to be at a possibly dangerous level, particularly if large quantities of the bean seed were consumed. The accumulation of this toxin did not appear to be related to any particular farm management practice.

Due to the presumed-adequate level of plant nutrients in the non-fertilized soil, the uptake of geochemicals from the various treatments on the Stockless section did not accurately reflect the rate of addition of the extra quantities of fertilizer. This lack of response corresponded well with the results found from the comparative growth studies. However, except in young plants, there was a direct relationship between the rate of application of inorganic fertilizers and the uptake of potassium and aluminium by the plants. For some reason, possibly due to complexing between the added nutrients and the heavy metal ions in the soil, the greater the application of fertilizer, the lower the uptake of copper and zinc by the crop.

When the geochemical composition of the crop plants from the three main management sections was compared, the concentrations of the alkaline earth macronutrients were found to be directly proportional to the soil content. Although the potential supply of the three most important plant nutrients (N, P, K) was greater in the soils treated with organic manures, the concentrations of these tended to be greater in the plants grown on the Stockless farms. This could possibly have been due to the greater initial availability of these elements in the inorganic salts, or the uptake may have been influenced by the Kirkby-Mengel effect (4:1.3).

As soon as the plant weight was taken into consideration, to evaluate the effect of farm management upon the total geochemical content of the standing crop, the maximum content was always found on either the Mixed or Stockless fields. This was due to the characteristically low dry weight of the plants on the Organic section, which in the open field resulted from the great competition with the high population of weeds, especially charlock.

This factor could have only been avoided within the constraints of the Organic management, by prodigious hand hoeing, as no chemical herbicides were allowed. Thus weed competition reduced the potential yield of the otherwise ideal rooting medium to a level far below that of the other farm sections. Although the chemical composition of the crop on the Mixed field was only studied during one field trial, it is concluded that due to a lack of competition from weeds on the Mixed and Stockless sections, the maximum geochemical content of the standing crop always followed the pattern of M > S > O. This demonstrates that a complex of interacting factors influences the uptake of nutrients into the plants, which cannot be predicted by the chemical analysis of the soil alone.

(5) The Gain sheet (Table D:1) demonstrated the value of including a legume in the crop rotation - resulting in a great input of naturally-fixed nitrogen, beneficial to the succeeding crops. It is well-documented in the literature that the level of available nitrogen in the soil strongly influences the symbiotic fixation of nitrogen. This research project confirmed that high soil nitrogen inhibits the formation of nodules, and reduces the fixation rates of those that do form. The responses of nitrogen fixation are governed by many factors (5:1.3) but it was considered that this phenomenon provided a means of biologically assaying the nitrogen levels in the soil of the three farm sections.

It was found that nodulation development and distribution on the root were strongly influenced by season, farm management and the rate of application of nitrogenous fertilizers. Each particular farm section influenced the rate of decay of the initial nodules, and the rate of re-nodulation of the bean plants according to a predictable pattern. The number of large pink nodules which developed upon the tap root was determined to be a good assay of the level of available nitrogen in the soil - the results indicated the same relationship between the farm sections as had been found by chemical analysis of the soils. A strongly seasonal effect upon nitrogen fixation was found, presumed to be due to a changing demand for nitrogen by the developing plant, and to changing temperature and daylength. The timing of the maximum fixation and nodulation was found to coincide with the time of maximum flowering, and that of renodulation with the initiation of bean seed formation.

The farm management effect shown on Table D:1 was for an increasing rate of nitrogen fixation to occur as the available nitrogen content of the soil fell. However, the demand for nitrogen by the plant also influenced the rate of fixation - thus the low bean seed yield on the Organic section may have been partially caused by, or have been the effect of, low fixation, and vice-versa on the Stockless section.

Having discounted the possibility that the low fixation rates on the Organic section were due to any other recognised factors (5:5.3.4), it is concluded that the measurement of potential nitrogen fixation provides a worthwhile biological assay of the level of available nitrogen in the soil. It was this character of the soil which was one of the major differences between the farm management sections, assumed to be the main result of adding organic manures to the soil over a thirty year period.

Now that agricultural economists are aware of the problems of the increased costs of farm management, it is somewhat of a contradiction to closely combine the use of a legume crop with the application of organic manures, as the second practice defeats part of the object of the first. Yet, at Haughley, the bean fields on the Organic section selected for the nitrogen fixation studies had all received heavy applications of organic manures during the preceding winter. This ensured the maximum level of available soil nitrogen during the growth of the bean crop, causing a maximum reduction in the nitrogen fixation potential of the bean root nodules.

FINAL CONCLUSIONS

The conclusion from the ecological evaluation of the three systems of farm management at Haughley, using the field bean as a phytometer, is that the methods of management have caused changes to occur in the availability of nutrients in the soil, which strongly influence the yield and nitrogen fixation potential of the crop. The most economical and geochemically viable system was shown to be that of the Mixed farm where both organic manures and inorganic fertilizers were employed. Upon this system there was a maximum availability of soil nutrients for crop growth, and hence a maximum yield of bean seeds. Provided that the addition of manures to the system did not occur within less than two years of the planting of a bean crop, an adequate natural symbiotic fixation of nitrogen was possible, which would greatly benefit the following cereal crop.

The only problem which could be associated with the widespread use of this system of farm management would be that, parallel to the maximum availability of soil nutrients for the crop growth, there would be a high risk of water system eutrophication. Even so, the levels of nitrate suggested to be dangerous by the World Health Organization were not approached, even where the loss of this ion was artificially increased. On the basis of the results from the lysimeter study, none of the systems investigated would appear to pose a serious threat of nitrogen or phosphorus eutrophication.

3. Recommendations for future research

From the results and conclusions derived from the research project at Haughley several recommendations can be made for more detailed research to be conducted, to determine how widespread the occurrence of these phenomena are :

(1) In order to complete the information and balance sheets from Haughley, automatic monitoring systems of the field drainage outflow points should be set up, to enable a more accurate estimation of the actual loss of water and geochemicals from each farm management system under normal field conditions. This would indicate the possible severity of a eutrophication threat from the Mixed farm system.

(2) Exhaustion studies on the soil at Haughley could be conducted to determine the extent to which the natural background level of nutrients is adequate for crop growth.

(3) A full investigation could be made into the physical structure of the soil from the three farm systems to determine whether changes had been caused over the past thirty years which could explain the differential availability of the major plant nutrients. It would also be interesting to further elucidate the exact form in which the geochemicals exist in each soil.

(4) On a wider scale it is considered important that a survey should be made to determine how common the phenomenon of lead accumulation is, particularly in the seeds of cereals and grain legumes, where the crop is harvested after the death of the plants. Additional research should try to identify the source of the lead, and the form in which it occurs in the plants - i.e. whether or not it is biologically active, and therefore toxic, to consumers.

(5) A survey should be made of the farm management practices used where legumes are included in crop rotations, to determine to what extent the natural nitrogen fixation potential of the crop is being lost by inefficient farm systems which supply high levels of available nitrogen to the soil, immediately prior to the growth of the legumes.

(6) An investigation could be made into the possible sources of the high levels of geochemicals in the rainfall which could pose problems of eutrophication to the water systems.

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APPENDIX

SOIL

Soil characteristics of the Haughley Research Farm

The Haughley Research Farm lies in gently undulating countryside on Kimmeridgian chalky boulder clay at an altitude of 200 feet above sea level.

In 1961 Williams and Cooke at Rothamsted described a soil profile from each farm management type, and a complete soil survey of the farm was completed by the Soil Survey of England and Wales in 1968. These reports are combined with observations made during the course of the current research to determine the soil patterns in the fields used for this project.

Four local phases (1, 2, 2A, 3) of the Beccles series (Corbett and Tatler 1970) are distinguishable over the area of the farm, but a complete map has not been made due to the very complex mosaic of the phases. All phases show a slight impedance below 25 cms to a variable degree, which is indicated by the mottled colouration of the lower horizons. All contain calcium carbonate throughout the profile, and in the upper layers have a moderate organic matter content, though very little in the lower horizons. The surface horizon is reported to be similar over all fields, consisting of an olive-brown clay-loam of a consistent texture. However during the course of this study, it was noted that the surface soil of the Organic section fields had a firm structure where the crumbs were easily detached, with many earthworms, whereas that of the Stockless section fields had little structure, the clods being difficult to break apart, and with few earthworms. The Mixed section soil was similar in structure to that of the Organic section, but had few earthworms. The colour too was seen to vary, the Stockless soil being a lighter brown than that of the Organic section. However these qualitative differences were only evident by observation, and were not found to be quantifiable in scientific terms, with the exception of the measured variation in the organic matter content, which could account for some of the observed structural differences. The main distinctions between the profiles occur in the lower horizons.

Phase 1 :- occurs as a discontinuous W - E band across the farm, and of the fields used for this research only Oxer (Organic) and Seven Acres (Mixed) lie fully within this soil type. The part of Chestnut Tree East (S), used for the investigation of the effect of the special fertilizer treatment upon nitrogen fixation in 1973, also lies within this phase. The soil is derived from calcareous clay, the upper horizon of 25 cms of olive brown sandy clay-loam being sharply distinguished from a variable thickness (13-46 cm) of bright yellow-brown sandy clay with no chalk particles. Below this lies a pale yellow-brown clay mottled with grey and white due to a high proportion of chalk, and intense gleying. Large and small particles of chalk occur in this layer of prismatic structure.

Phase 2 :- is the most extensive, and all the fields (whole/in part), used in the three year study, other than those mentioned above, occur within this soil type. The parent material of phase 2 is also derived from a calcareous clay, but contains more clay and less fine sand than phase 1. The top two layers are similar to phase 1, although the lower one is more consistent in its extent (25 cms). The lowest layer is much darker than in phase 1, but still contains abundant chalk particles.

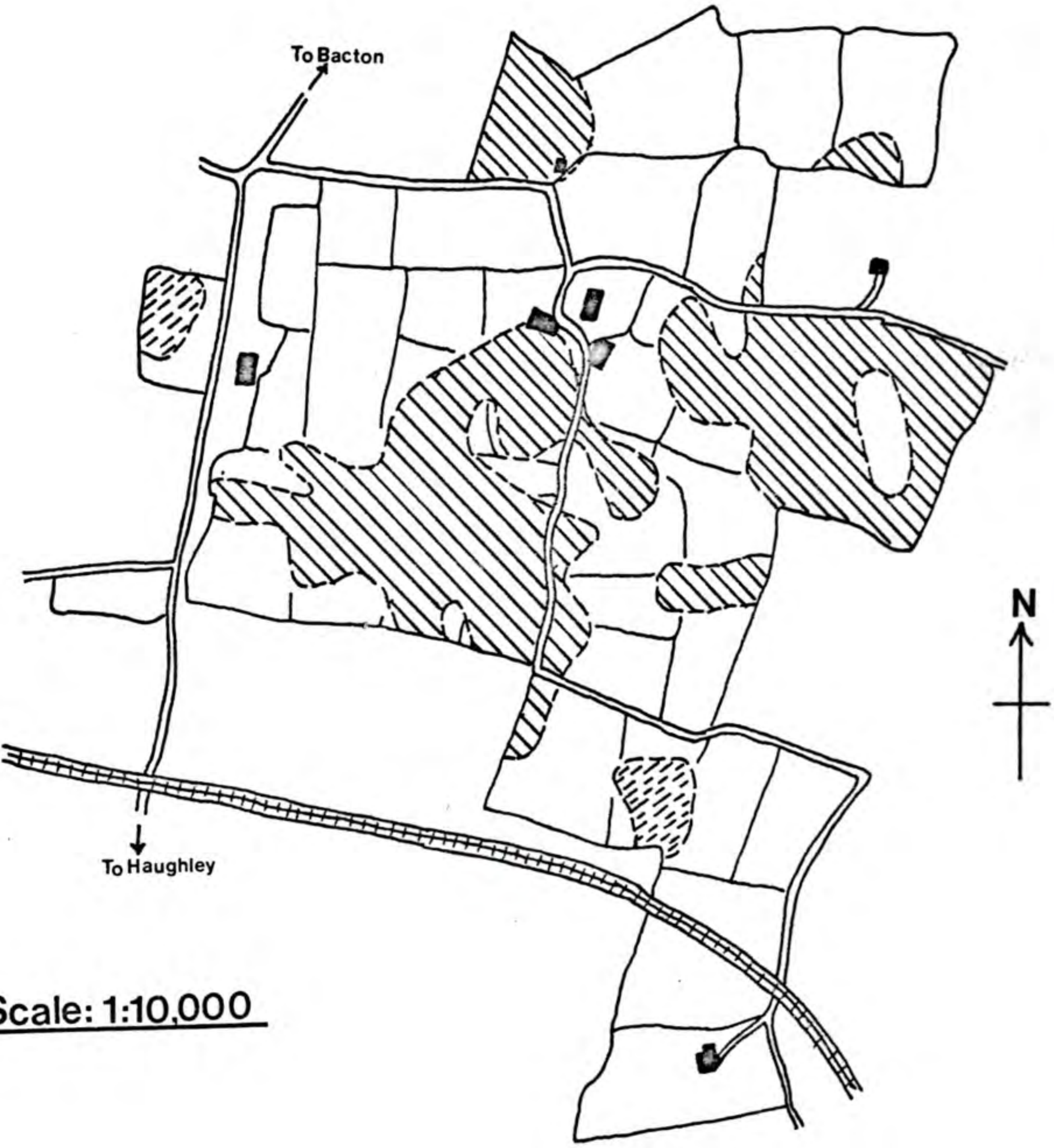
Phase 2A :- in some fields on the farm, in the lower layers an additional gravelly layer may be found. This occurs in Road (S) and Gypsey (M) which were used in 1971 and 1973 respectively, but the local areas chosen in these fields were outside the boundaries of phase 2A, so that the drainage through the soil profile would be similar to the other fields studied.

Soil map of the Haughley Research Farm.

Key: ▧ = Beccles Series – Phase 1

☐ = " " – Phase 2

▨ = " " – Phase 2A



Scale: 1:10,000

Phase 3 :- derived from a calcareous sand, occurs sporadically in the form of sandy pockets scattered over the whole farm, but not in any of the fields used. The upper horizon is similar to those of phases 1 and 2, but below 25 cms a sandy loam occurs which is always wet, and often waterlogged below 60 cms. The colour of this layer is a bright orange-yellow, but grey-green where waterlogged, and occurs down to 100 - 150 cms from the surface.

The mean particle sizes for a profile through phase 2 are as follows :-

Size of particle	% of particles	
	Top	Base
< 2 µ	26	40
2 - 50 µ	14	47
50 - 100 µ	10	4
100 - 200 µ	30	4
200 - 500 µ	18	3
500µ - 2 mm	2	2

The results of Williams and Cooke (1961) investigation are summarized below :-

Section	pH	% $CaCO_3$	% org C	% Total N	Density gm/ml	% Water holding capacity
Organic	7.8	2.6	2.27	0.27	2.42	66.2
Mixed	8.1	5.2	1.70	0.27	2.46	55.8
Stockless	7.8	5.6	1.24	0.18	2.51	47.3

There would appear to be a direct correlation between water-holding capacity and percentage organic Carbon, but these results can only act as a guide to the Haughley situation as no details concerning the location of sampling sites were given.

From the soil survey discussion, and the map, it can be seen that all the fields used for this research, with the exception of Oxer, Seven Acres and Chestnut Tree East, are composed of the same basic soil phase. The pH of a 1:1 soil:water measurement, ranged between 7.6 - 7.8 on all fields used, in all sections, except for Road field (S) which read 6.8.

WATER CHEMISTRY

Construction of Lysimeters

In March 1972 a series of filled, shallow and deep, lysimeters were constructed in one field of each farm section, in order that the drainage water from the soil could be collected, and analysed, at monthly intervals throughout the year. On the Organic and Mixed sections two lysimeters of each depth were made, so that one pair (shallow and deep), could be planted with beans, and the other pair maintained in a weed-free, fallow condition. On the Stockless section four lysimeters of each depth were used in order that two rates of fertilizer could be applied.

Both types of lysimeter consisted of a container with slightly sloping walls, an open top, and a base which provided for the collection of the water percolate. The containers were filled with the soil which had been removed from the hole excavated to accommodate the lysimeter. Care was taken to replace the layers in the order in which they naturally occurred. The top was completely covered with soil, level with the surrounding area, to permit natural runoff, and to eliminate the border effect resulting from a raised rim.

Shallow lysimeters

The lysimeters were constructed from heavy gauge polythene sheeting, lining a hole 1.2 metres square and 25 cms deep. The base was sloped towards the middle from both sides, where a channel containing coarse gravel was made to facilitate the flow of water. From the lower end of the channel, a brass connector was attached to a 1.5 cm diameter clear polythene tube, which drained into the ditch where the water was collected in a 5 litre black polythene bottle. No space was left between the tube and bottle-neck, thus preventing entry by dust and insects. The use of black polythene prevented the growth of algae.

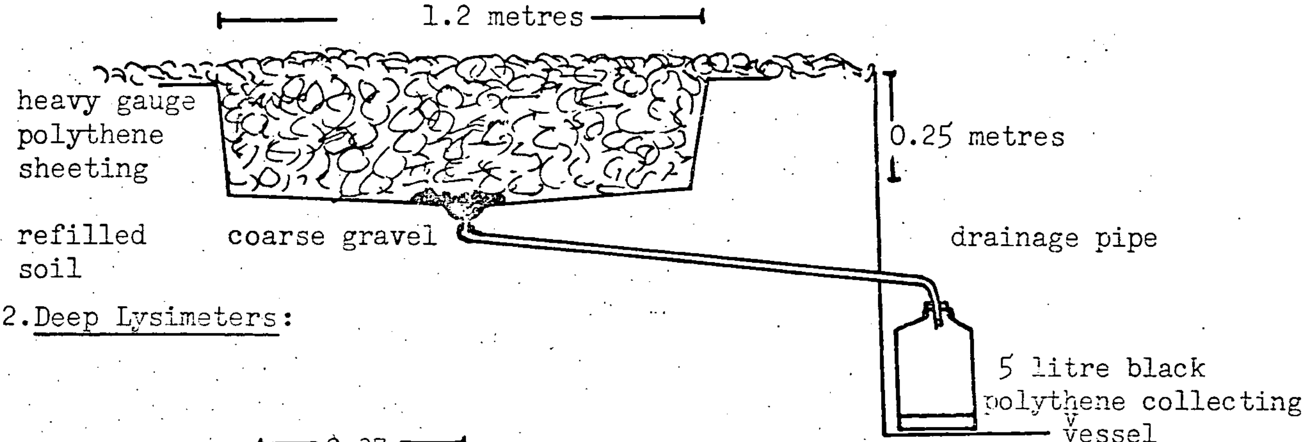
Deep lysimeters

The deep lysimeters were constructed from commercial plastic dustbins which were sunk into the ground and refilled with the soil. Brass connectors, with lengths of clear polythene tubes, drained from the base of the dustbins into the polythene collecting vessels. The dustbins were 0.37 metres in diameter at the top (surface area 0.108 square metres) and 0.47 metres deep.

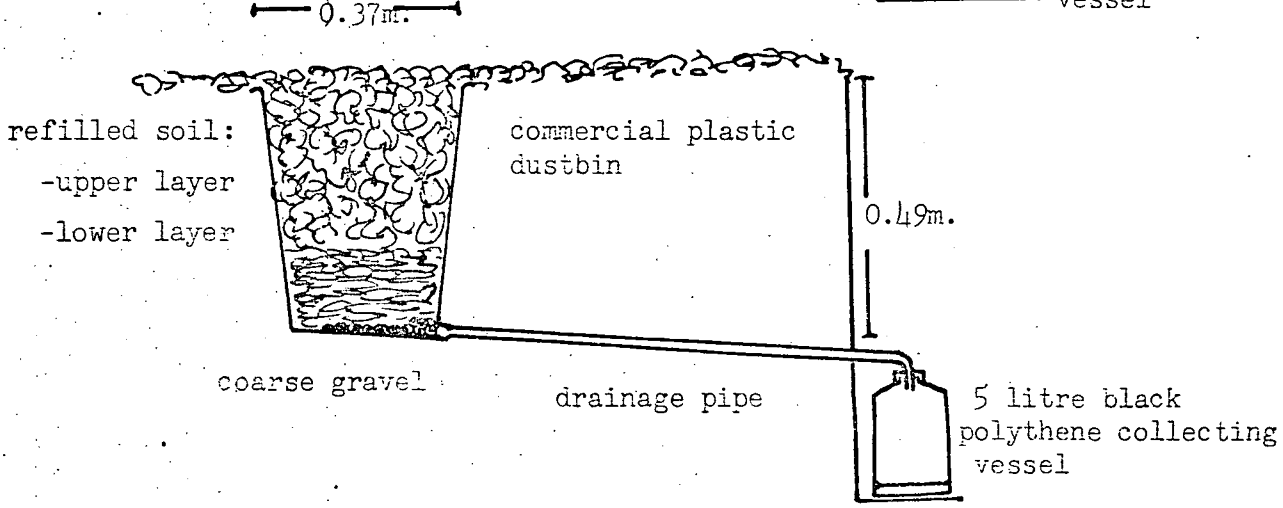
The spaces between the lysimeters in the field were sown with barley, to minimize the edge effects on the crop stands within the lysimeters, and to camouflage the isolated bean areas from the birds.

The diagrams below show the cross-sections of the lysimeter constructions.

1. Shallow Lysimeters:



2. Deep Lysimeters:



Collection and storage of water samples

The total volume of the lysimeter leachate draining into the polythene containers was measured at monthly intervals, when a sample of 125 mls of the agitated total was collected in a small polythene bottle. These samples were filtered before being placed in the deep freeze to await chemical analysis.

Samples of water draining out of the field tile-drains were collected when these were at peak flow rate, the water being similarly filtered prior to freezing. There have been several reports concerning the chemical alteration of water samples on storing in glass and polythene containers (Rainwater and Thatcher 1960; Struempler 1973), due to adsorption or release of compounds (particularly phosphates) by the container walls or the associated bacteria. It has been shown that this can be avoided by the addition of small volumes of various organic compounds, or by deep freezing the samples (Heron 1962).

CROP GROWTH

1. Preliminary Growth Analysis - Greenhouse Pot Trial

The flower pots were arranged in nine Latin squares over the benches in the greenhouse, which meant that the slightly variable conditions of light and temperature were averaged out over all treatments. The Latin squares ensured a maximum ordered disorder of the different combinations of the seed imprint type (Tic O, Tic M, Tic S), and soil type (Organic and Stockless).

Arrangement of Latin square :-Where capital letters indicate seed type *Vicia faba* var. Tic) and lower case letters indicate soil types :-

Os	Ms	Ss	Oo	Mo	So
Ss	Oo	Mo	So	Os	Ms
Mo	Ss	Os	Ms	Ss	Oo
Ms	Ss	Oo	Mo	So	Os
Oo	Mo	So	Os	Ms	Ss
So	Os	Ms	Ss	Oo	Mo

The light was provided by eight Phillips 400 watt mercury vapour horticultural lamps, to give a photoperiod of 17 hours from midnight to 5 p.m. The additional heat provided by these lamps helped to prevent any undue fall in temperature in the early morning. The temperature was maintained at 19 - 21°C, and the relative humidity at 80%.

The seeds were initially planted at the rate of three per 10 cm pot, and were covered by black polythene for one week to stimulate germination. Later in the experiment this rate of planting proved too dense, and the plants were thinned to one plant per pot. Samples were taken twice per week, pots being removed at random from the Latin squares. The pots were watered as evenly as possible on every second day, with a distilled water sprinkler.

Measurement of plants

(1) Shoot length - measured by metre rule from the point at which the soil surface occurred, to the base of the youngest leaf in the apical shoot.

(2) Leaf area - measured as described by Blade (1943), and modified by Blackman and Wilson (1951). The leaves were removed from the stem and were placed between two sheets of glass illuminated from below. The outline of each leaf was drawn upon paper of uniform thickness, the weight of which had been calibrated against area (in square centimetres). The paper leaf-outlines were cut out, and collectively weighed for each plant, their area being calculated from the calibration table. This method proved more accurate than the use of the leaf area meter.

(3) Dry weight - adhering soil particles were washed from the roots with tap water, followed by distilled water. The plants were separated into leaf, shoot and root fractions which were dried at 105°C for 24 hours, by which time a constant weight had been attained. The samples were cooled in a dessicator prior to weighing and chemical analysis.

(4) Leaflet pairs - the leaves of *Vicia faba* are compound, each being composed of several elliptical leaflets arranged in pairs along a central axis. When the number of leaves was used as a growth parameter (1973), the results were expressed in terms of the leaflet pairs per plant.

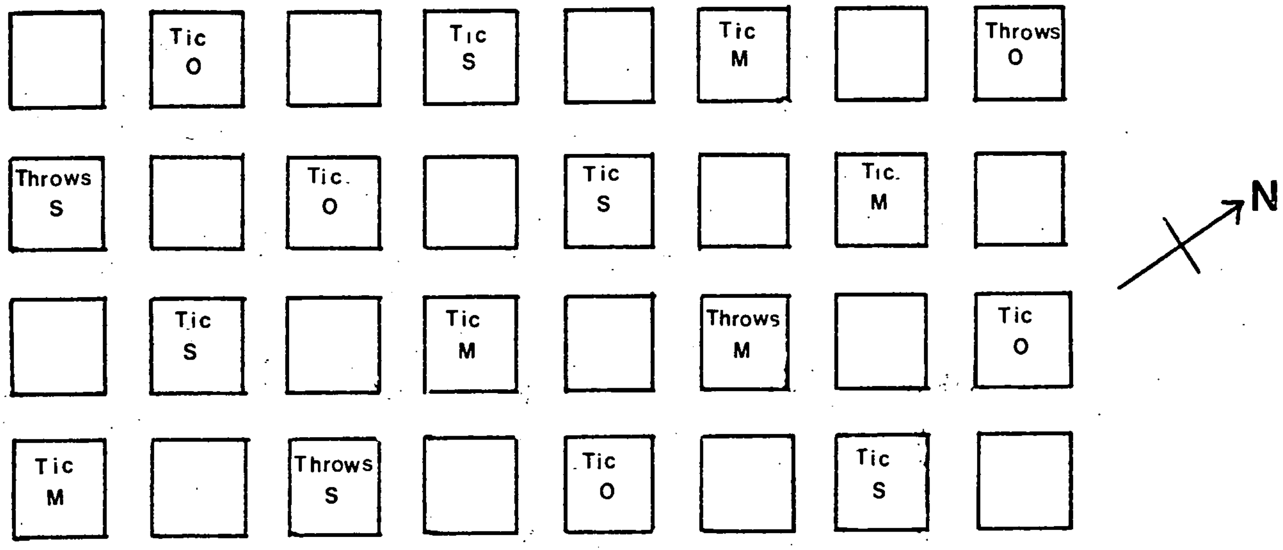
2. 1971 Field Trial

The plots used for this field trial were shared with A.Y. Basahy who was carrying out a similar growth study on barley under the four treatments. The plan of the plots is shown overleaf - the blank plots were used for the barley study.

1971 Field Trial Plots

Organic Field

Scale : 1mm.= 10cms.

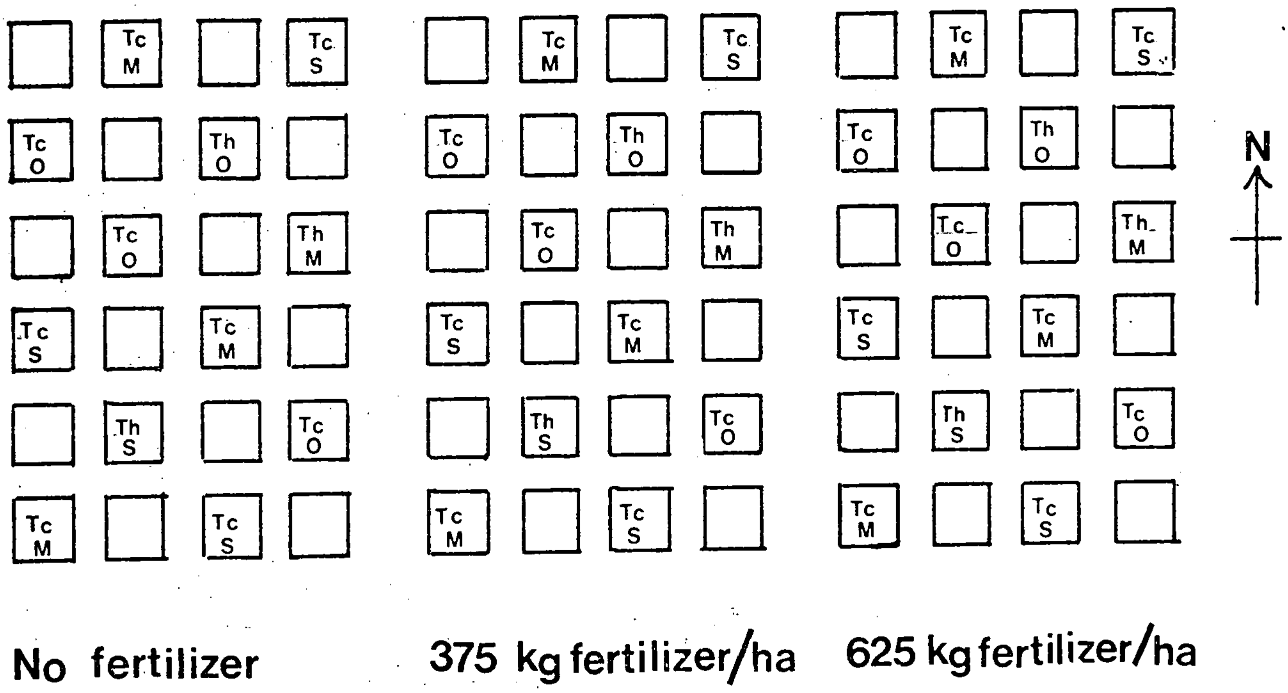


	Tic O		Tic S		Tic M		Throws O
Throws S		Tic O		Tic S		Tic M	
	Tic S		Tic M		Throws M		Tic O
Tic M		Throws S		Tic O		Tic S	

Stockless Field

Tc = Tic variety
Th = Throws variety

Scale : 1mm = 15cms.



No fertilizer				375 kg fertilizer/ha				625 kg fertilizer/ha			
	Tc M		Tc S		Tc M		Tc S		Tc M		Tc S
Tc O		Th O		Tc O		Th O		Tc O		Th O	
	Tc O		Th M		Tc O		Th M		Tc O		Th M
Tc S		Tc M		Tc S		Tc M		Tc S		Tc M	
	Th S		Tc O		Th S		Tc O		Th S		Tc O
Tc M		Tc S		Tc M		Tc S		Tc M		Tc S	

Methods of Chemical Analysis

During the research project, samples of soil, water and plant material were subjected to chemical analysis for a wide range of geochemicals. The methods of analysis used are described below, but are only discussed in detail where modifications to the standard methods were made. As some of the initial methods used incurred major disadvantages, these were improved or replaced, where possible, for later analyses.

Preparation of samples prior to chemical analysis

1. Soil - when the soils sampled from the fields were to be analysed for their "total geochemical" content, the samples were homogenized by hand, before being dried to a constant weight in a forced-draught oven. A period of forty-eight hours at 105°C was sufficient to achieve this state. After drying, the samples were cooled in a dessicator, and ground with a pestle and mortar until the soil passed through a 1 mm gauge sieve. The samples were stored in paper bags within a dessicator.

- when the soils sampled were to be analysed for their "exchangeable geochemicals" the homogenized soil was dried for five days at 30°C in a forced-draught oven to simulate air drying, before grinding and sieving.

2. Plant material - the replicate plants were divided into their component parts where separate analysis was desired, the roots were washed in distilled water and all parts were dried in an oven at 105°C until a constant weight was attained (a period of twenty four hours was adequate). After cooling in a dessicator, the samples were ground to a fine powder in a Moulinex electric coffee grinder to facilitate digestion/extraction, and to homogenize the samples. The material was stored in glass tubes sealed with polythene caps prior to analysis, when three replicate subsamples were taken from each sample. The small coffee grinder was found to be more convenient than a conventional mill, due to the small bulk of many of the dried samples.

3. Water - upon collection of the samples from the field drains, lysimeter bottles and rain gauge, the water was filtered and stored for analysis in a deep freeze. The samples were used for analysis immediately after thawing out.

1. Nitrogen

1:1 Nitrate-nitrogen

1:1.1 Phenoldisulphonic acid method - used for water, soil and plant extracts in 1970-1972.

Nitrate was quantitatively extracted from the ground dried plant material, and sieved, dried soil, by a short period of agitation in water (Roller and McKaig 1939). The phenoldisulphonic acid method depends on the nitration of the acid by the nitrates in the aqueous solution. Under alkaline conditions this results in a yellow colour, the intensity of which is directly proportional to the concentration of nitrate in the sample. The colour was measured at 420 mμ in a spectrophotometer cell. The procedure used was described by Johnson and Ulrich (1950) and Bremner (1965).

Disadvantages : (1) This method of nitrate analysis is subject to interference from organic matter, nitrites, chlorides and the colour of the aqueous extracts. The organic matter was successfully oxidized by the use of 100 volume hydrogen peroxide. The samples from Haughley contained very small quantities of the two main interfering anions and therefore these did not constitute a problem. Tests using the decolourizing agent of activated charcoal resulted in a loss of colour, but an increase in the nitrate level of the extract. It was found necessary to increase the quantity of hydrogen peroxide used when extracts were coloured, or to use the correction method described by Berge (1941) and recommended by Metson (1956).

(2) The method is tedious and time-consuming, and the equipment required does not enable large numbers of samples to be analysed simultaneously.

(3) The reaction mixture is made alkaline by the addition of ammonium hydroxide solution. The concentration of the commercially available phenodisulphonic acid may be variable within a single batch - sometimes the addition of ammonia caused violent spitting from the evaporating basins. It was not desirable to use a concentrated ammonia solution in the same laboratory in which Kjeldahl analyses for total nitrogen were being undertaken.

1:1.2 <u>2-6 Xylenol</u> - used for filtered water samples in 1972-1973.

This method depends upon the reaction between nitrate and 2-6 xylenol in sulphuric acid in the presence of ammonium chloride. The optical density of the solution so produced was measured using a Perkin Elmer (402) spectrophotometer at 310 mμ wavelength. The method used was as described by Lewis (1961) and Montgomery and Dymock (1962).

1:2 Nitrate-nitrogen and Ammonium nitrogen by a cold distillation method

Used for determining the exchangeable nitrogen in the soil and manure samples, and the inorganic nitrogen content of the plant material, in 1973.

The method is based upon the displacement of ammonia by magnesium oxide and the reduction of nitrate to ammonia by titanous sulphate. The technique used was a modification of that used by Etherington and Morrey (1967), based upon the microdiffusion principles described by Conway (1947). The ammonia, which is liberated from the aqueous extract of the soil or plant sample, is separated by microdiffusion, ideally at 25°C, instead of by the steam distillation method which is more traditional (Bremner 1965).

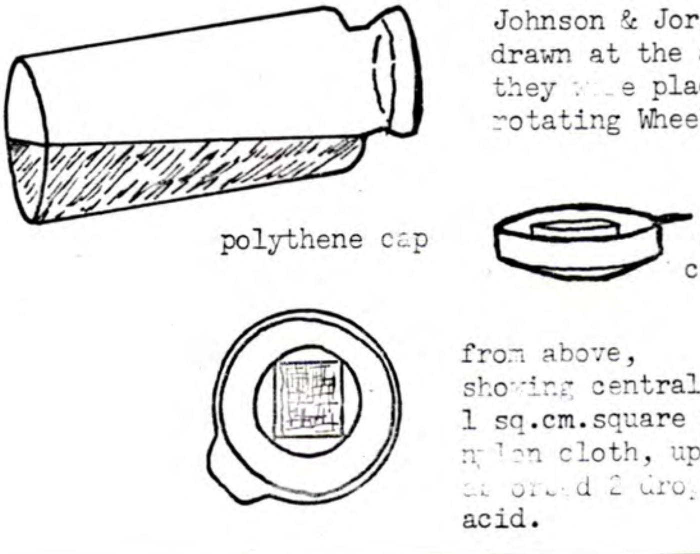
Reagents

1. Plant and soil extractant, see below.
2. Magnesium oxide suspension - 12 grammes light MgO in 100 ml distilled water.

Methods of Chemical Analysis Appendix Plate 1

A photograph of the Wheel used for rotating the Cold Distillation vials.

A diagram of the J. & J. vials used for cold distillation.



3. Titanous sulphate solution - this must be technical grade, as Analar purity prevents the reaction taking place. 5 mls $Ti_2(SO_4)_3$ in 100 mls distilled water.
4. N Analar sulphuric acid.
5. Analar $(NH_4)_2 SO_4$ for construction of the calibration curve.
6. Phenol sodium nitroprusside solution - 12 gm phenol dissolved in 1 litre of water plus 200 ml 1.7% NaOH, plus 0.06 gm sodium nitroprusside dissolved in 10 ml water - made up to 2:1 and stored in a dark bottle. The sensitivity of this reagent was found to increase dramatically within 24 hours of preparation and was therefore always freshly prepared for each batch of samples.
7. Alkaline sodium hypochlorite solution - 10 ml of sodium hypochlorite solution (containing 10% available Cl_2^- - the domestic bleach, Domestos, was found to be ideal) added to 250 ml 1.7% NaOH. (6 and 7 from Allen and Whitfield 1965).

Procedure

Disposable plastic syringes were used throughout the technique for the transfer of solutions, and the application of acid to the caps.

2 mls of the extract was injected into a 15 ml Johnson and Jorgensen plastic capped glass specimen vial, followed by 1 ml of 12% MgO suspension which had been freshly prepared. The plastic cap, which had previously had a 1 sq cm. square of industrial nylon cloth fitted into the central well and moistened with two drops of N H_2SO_4, was immediately replaced on the vial (see diagram). The ammonia within the extract was slowly displaced by the MgO and was absorbed by the sulphuric acid on the nylon square. The vial was then placed at an angle on the rotary wheel shown in the photograph, so that the contents were allowed to spread to a

maximum surface area without entering the cap. The wheel was rotated for 24 hours. The cap of the vial was removed, and placed upon a second vial containing 10 ml phenol sodium nitroprusside solution plus 2 ml alkaline sodium hypochlorite solution. The vial was shaken until the nylon square was dislodged into the solution, the colour was developed in the dark for one hour, and the intensity of the blue colour was determined at 680 mμ on a spectrophotometer. The phenol-hypochlorite reaction has been described by Russell (1944), and Lubochinsky and Zalta (1954). The vial on the wheel had 1 ml of 5% titanous sulphate solution injected into it, and a new cap with nylon square placed on top. The vial had to be gently swirled by hand to prevent the separation of the MgO from the $Ti_2(SO_4)_3$, before being replaced on the wheel for 48 hours. The nitrates in the extract were reduced to ammonia which was then liberated as before onto the nylon square. The ammonia in the sulphuric acid was evaluated as described previously. Triplicate determinations of every sample were made.

A calibration curve using various concentrations of Analar Ammonium sulphate in the extractants,was constructed - it was found to be linear to a concentration of 5 μg NH_4-N/ml. It was found that the distillation could be successfully performed at normal room temperature provided this did not fall below 20°C. Below that temperature, condensation droplets tended to form on the neck of the vials. These tended to absorb some of the liberated ammonia and the complete recovery was very slow. At lower temperatures it was necessary to extend the time allowed for distillation. Blanks and standards were run with every batch of samples because of the variable sensitivity of the phenol-sodium nitroprusside reagent.

The advantages of using this method were that a total of 102 samples could be distilled simultaneously on the wheel, which was all the equipment required. The method enabled the use of coloured plant and soil extracts, and no interferences from other compounds were found. Although the distillation time was lengthy, the actual work contact-time with the samples was very short. In samples having a low NH_4-N content, but high NO_3-N content, it was shown that if one vial was used directly for the determination of nitrate + ammonia, and another was used for ammonia alone, the nitrate content could be determined by subtraction. This method reduced the amount of time required on the wheel for each sample. However where the ammonia content was high, the two drops of sulphuric acid on the nylon square were insufficient to absorb all the gaseous ammonia liberated, and hence recoveries by this method tended to be low.

Extraction of samples

(i) Soil - The soil was dried at 30°C in a forced draught for 5 days to simulate air drying, prior to extraction. The drying of soil samples simplifies their preparation for analysis, but tends to change the ammonium and nitrate content (Cooke and Cunningham 1958; Allen and Grimshaw 1962). Storage after drying tends to increase the exchangeable nitrogen concentrations (Gasser 1961) even when the soils are stored in airtight containers (Cunningham 1962).

Thus, where feasible, soil samples were dried and analysed within 24 hours of collection. It has been shown that several extractants are suitable for the determination of the exchangeable nitrogen in the soil. The use of KCl or NaCl solutions was proposed by McLean and Robertson (1924), which were acidified by HCl by Olsen (1929), and the form of the extractant was further modified by Richardson (1938) who used K_2SO_4 acidified with H_2SO_4. As the literature does not provide clear evidence as to which of these extractants provides results which are the closest to the plant-available nitrogen levels, all were tested upon the Haughley soils.

In order that the extract could be used for the analysis of nitrite-nitrogen too, the non-acidified extractants of N KCl and N K_2SO_4 were evaluated for their effectiveness. It was found that the intrinsic levels of both nitrate-nitrogen and ammonium-nitrogen in KCl were very high, and the recovery of a known standard was only 63%. For K_2SO_4 the intrinsic nitrogen levels were slightly lower, and the recovery was 102% of the standard - the low solubility of the sulphate caused difficulties in the preparation of the extractant.

Because of the appreciable intrinsic nitrogen content even in the K_2SO_4, experiments were run using 2N NaCl as the extractant. It was found that the recovery rate of the known additions of nitrogen was always above 90%, and usually above 95%, and that the nitrogen content was negligible, but solubility high. Therefore throughout the investigation of the levels of exchangeable nitrogen in the soils, 2N NaCl was successfully used as the extractant. 5 gms of air-dry soil were shaken with 100 mls 2N NaCl for two hours, and filtered through a Whatman No. 42 filter paper prior to analysis. The standards and blanks were also made up in sodium chloride solution. As the wheel distillation had to be run overnight, the laboratory temperature frequently fell below 20°C. Therefore, to ensure full recovery of the soil nitrogen, it was calculated from the time course that the distillation time for ammonium nitrogen should be 48 hours, and that for nitrate-nitrogen 72 hours. This was adopted as the standard procedure.

(2) Plant material - the plant material was prepared as previously described. Water and 0.1N H_2SO_4 were tried as extractants for the cold distillation determination of nitrogen. The recovery results showed that both these were satisfactory, but that there were no significant differences between the extracts. For simplicity, water was used, shaking 100 mg plant material with 20 ml water for 10 minutes, before filtering the extract through a Whatman No. 42 filter paper.

1:3 Nitrite-nitrogen - used for soils 1972-1973.

Because the 2N NaCl extractant was not acidified, the extract which was prepared for the determination of nitrate- and ammonium-nitrogen could be used for the analysis for nitrite nitrogen by the modified Griess-Ilosvay method (Griess 1879; Ilosvay 1889). The method depends upon the reaction of nitrite with primary aromatic amines in acidic solution to produce diazonium salts which react with aromatic compounds containing amino or hydroxyl groups to form coloured azo compounds which are suitable for photometric measurement (Snell and Snell 1949). The diazotization is brought about by sulfanilamide, and the coupling reaction by N-(1-naphthyl) ethylenediamine. The colour is measured at 520 mμ. The method used in this research was described by Barnes and Folkard (1951). Because the values for nitrite-nitrogen in the soils at Haughley were very low, it was not necessary to remove the nitrite prior to the cold distillation determination of nitrate- and ammonium-nitrogen.

1:4 Total nitrogen - used for plant, water and soil samples 1970-73.

Since Kjeldahl (1883) first proposed his method for the determination of total nitrogen by the digestion of organic matter with sulphuric acid, many modifications have been developed by different research workers to extend the scope of the method. The method used in this research was based on that outlined by Allen and Whitfield (1965), and later modified by Allen (personal comm.). The temperature of the digestion was raised, using Se metal powder, and hydrogen peroxide was used to complete the oxidation of the organic matter.

Reagents
1. Phenol sodium nitroprusside - prepared as described in A 1:2.6
2. Alkaline sodium hypochlorite - " " " " A 1:2.7
3. 0.1 gm Se metal powder dissolved, whilst heating, in 100 mls Analar H_2SO_4
4. 30 volume hydrogen peroxide.

Procedure - The digestion was performed on a micro scale which enabled the simultaneous treatment of sixty samples of soil, plant material or water. The digestion used 100 mg of dried plant material, or 0.5 gms dried soil, or 4 ml of water, which were placed in the micro Kjeldahl flasks which had been made by pinching in the walls of a thick-walled test tube 4 cms from the base. 2 ml of the selenium solution was added, followed slowly by 1 ml of hydrogen peroxide. The tubes were placed in the mild steel digestion block (constructed at East Malling) and heated for 1½ hours. To prevent bumping, two unglazed porcelain insulating beads were added to each tube.

After digestion, the solution was made up to 20 ml with distilled water. 2.5 ml of this solution was diluted to 100 ml, and 1 ml used for the colour reaction. 5 mls of the phenol sodium nitroprusside were added to the 1 ml of diluted digest, followed by 1 ml of alkaline sodium hypochlorite. The colour was developed in the dark for one hour, prior to reading of the colour intensity at 680 mμ A calibration curve was made by using standards of ammonium sulphate added to blank digests. The colour reaction followed Beer's law up to 5 μgm NH_4-N/ml.

The salicylic acid and sodium thiosulphate modification suggested by Bremner and Shaw (1958) was experimented with, but it was found very difficult to use on the microscale described above, as the tube contents tended to froth out. Recovery tests suggested that less than 10% of the nitrate-nitrogen, but more than 90% of the ammonium-nitrogen, in the soil and plant samples were recovered by the unmodified Allen method. Therefore in this research the nitrate-nitrogen levels were analysed separately and were then added to the Kjeldahl digest results to give the total nitrogen values.

2. Acid Digestion for total cations - used for plants, soil and water, 1970-1973.

The technique used to digest the soil, plant material and water for the determination of total cations was a modification of those described by Piper (1950) and Mackereth (1963). Initially, the digest mixture consisted of hydrochloric acid, nitric acid and perchloric acid. It was later found that the omission of HCl improved the determination of phosphorus.

Reagents 1. Concentrated Analar nitric acid

2. Concentrated Analar perchloric acid

Plant analysis - 0.5 - 1.0 gm plant material used for digestion.

Soil analysis - 2.0 gms were used for digestion.

Water analysis - 100 ml samples were evaporated down to 5 mls prior to digestion.

Digestion

The material to be digested was placed in a 125 ml glass digestion beaker on a sand bath in a fume cupboard. 20 mls conc. HNO_3 were added and allowed to stand cold overnight. This allowed most of the organic material to be digested prior to the addition of perchloric acid, which can react explosively in contact with organic matter. 5 ml perchloric acid was added and the samples heated, gradually at first, and then more strongly for about 2 hours, until ignition was obtained (dense white fumes). Distilled water was carefully added, heating being continued until the acidity was appreciably reduced. After filtration, the samples were made up to 250 ml with distilled water, and stored for analysis in polythene bottles.

An improved method described by Adrian (1973) allows digestion to take place at room temperature in closed plastic bottles, which is considerably safer than the method used here.

3. Phosphorus

3.1 Total phosphorus - used for plant material, soil and water 1970-1973.

The determination was made upon the acid digest, obtained as described previously. The colorimeter method used was found on the Unicam Instrument Method Sheet No. 53 (1960), described by Yarwood (Ph.D. Thesis).

Reagents
1. 1.25 gm ammonium metavanadate dissolved in 400 mls 1:1 HNO_3 : water
2. 50 gm ammonium molybdate dissolved in 400 ml distilled water

Solution 2 was added to Solution 1, and made up to 1 l. with distilled water. The solution was usable for one month.

3. Standard : 4.393 gm potassium dihydrogen phosphate made up to 1 l. contains 1000 μgm PO_4-P/ml

Procedure 12 mls of the sample digest + 4 mls reagent, made up to 20 mls with water. After 10 minutes, the intensity of yellow colour was read in an Ultraviolet spectrophotometer at 490 mμ wavelength.

3.2 Exchangeable phosphorus - used for soil analysis 1972-73.

Phosphorus was extracted from the soil using 0.5 M $NaHCO_3$ at a pH of 8.5 and detected using ammonium molybdate and stannous chloride. The method used was that described by Olsen et al. (1954), without modification.

3.3 Dissolved phosphorus - used for water analysis 1972-73.

The method used required the use of ammonium molybdate, sulphuric acid and ascorbic acid, exactly as described by Fogg and Wilkinson (1958).

4. Potassium

4.1 Total potassium - used for plant material, soil and water samples 1970-1973.

The determination of total potassium was made upon the acid digest using a Perkin Elmer 403 Atomic absorption spectrophotometer.

4.2 Exchangeable potassium - used for soil samples 1972-73.

The exchangeable fraction of potassium in the soils was determined using the method described by Pratt (1965), extracting the potassium with 1 N Ammonium Acetate at pH 7.0 and reading the concentrations from the previously calibrated Eel Flame photometer, according to the principles outlined by Dean (1960).

5. Total cations of Ca, Mg, Na, Al, Fe, Mn, Cu, Zn, Pb - used for plant material, soil and water samples 1970-1973.

The determination of the concentrations of the above cations were made upon the acid digest using a Perkin Elmer 403 Atomic absorption spectrophotometer. The machine was calibrated against known standards for each cation, and the reading of blank digests were subtracted from those of the samples.

Absorption interference

It was found that high concentrations of the alkaline earth cations in the digests caused an interference in the determinations of the concentrations of the heavy metals, copper, zinc and lead. The effect of each alkaline earth became accumulative in the digest and served to increase the heavy metal readings above that due to these ions alone. This phenomenon was reported on by Koirtyohann and Pickett (1965). Because of this interference, a correction factor was calculated, according to the formulae below. In each case the apparent concentrations of each heavy metal in the plant tissue or soil sample was calculated from the machine readings, and then the value of I was subtracted :-

$$\text{For Pb} \quad I = \frac{0.15\text{x Ca}}{10^3} + \frac{0.15\text{x Mg}}{10^3} + \frac{0.12\text{x K}}{10^4} + \frac{0.19\text{x Na}}{10^4}$$

where Ca = concentration of calcium in sample used.

$$\text{For Cu} \quad I = \frac{0.22\text{x Ca}}{10^4} + \frac{0.012\text{x Mg}}{10^3} + \frac{0.03\text{x K}}{10^4} + \frac{0.04\text{x Na}}{10^4}$$

$$\text{For Zn} \quad I = \frac{0.13\text{x Ca}}{10^4} + \frac{0.10\text{x Mg}}{10^3} + \frac{0.02\text{x K}}{10^4} + \frac{0.01\text{x Na}}{10^4}$$

These approximate formulae were calculated from exhaustive tests performed at Durham by G.J. Waughman. All the figures for heavy metal concentrations referred to in the text (Section 4) and listed in the Appendix Tables have undergone these corrections for alkaline earth interferences.

NITROGEN FIXATION

Field Technique

An initial time course of nitrogen fixation by *Vicia faba* was performed in order to perfect field techniques and the use of equipment. This was conducted upon both whole and decapitated plants which were used seven weeks after sowing. The plants were removed from the nearest field to the laboratory half an hour prior to incubation. The roots used were standardized to include only the top 12 cms of tap root, and the connected lateral roots up to 8 cm in length; this section of the total root system bore 95% of the root nodules. The whole plants were incubated in 100 ml Büchner flasks, the stem being sealed into the neck of the flask at the junction between shoot and root, using plasticine and parafilm. The side arm was fitted with a No. 25 suba seal to allow penetration with a syringe needle (see photograph). The decapitated plants were incubated in 30 ml and 100 ml flasks, to determine whether increasing the volume proportional to that of the root system increased the length of time for which fixation proceeded linearly, as observed by Sprent (1969). Prior to incubation, the soil was shaken gently from the roots, but these were not washed, as it has been shown that a film of moisture over the nodules reduces their ability to fix nitrogen (Schwinghamer, Evans and Dawson 1970).

Most research workers using the acetylene reduction technique have evacuated the incubation vessels and then flushed with an "inert gas : oxygen" mixture to remove the nitrogen present in the air. In order to reduce the amount of equipment to be transported to the field, no evacuation or flushing was done. Hardy and Holsten (1968) stated that a failure to replace the air with argon : oxygen could result in a 10-20% reduction in the acetylene conversion to ethylene. However the affinity of nitrogenase for acetylene far exceeds that for nitrogen (Dart and Day 1972), and it has been shown (Stewart 1971; Sprent 1971) that the error involved by having nitrogen present is marginal during short incubation periods, especially where the acetylene concentration is increased to 20% $^{v}/v$. Acetylene gas was transported to the field in football bladders (Waughman 1971), each fitted with a short length of high pressure tubing closed with a spring clip, from which acetylene gas was easily removed in hypodermic syringes. Due to a shortage of acetylene, the time course was performed using only a 10% $^{v}/v$ concentration of acetylene in the incubation flasks. Glass beads were included in the flasks to aid the mixing of acetylene with air.

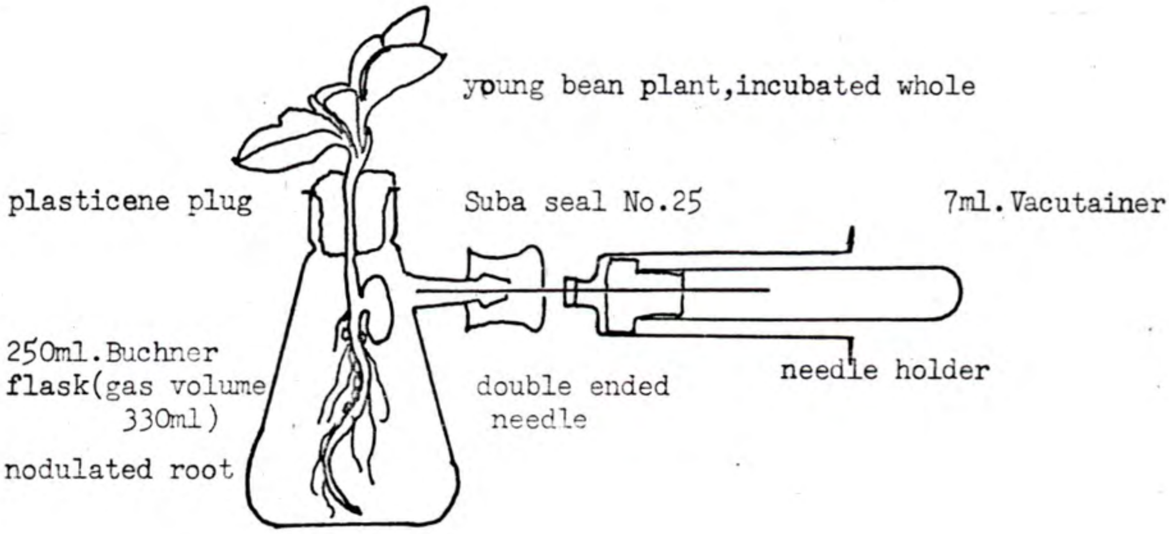
The necessary volume of gas was injected into the flask, which was then shaken, and after two minutes the gas mixture was equilibrated to atmospheric pressure by piercing the seal with another needle. Four replicates of each treatment were made, together with four control flasks : two containing decapitated roots, but not injected with acetylene, to determine whether or not endogenous ethylene was produced : two empty flasks injected with acetylene to determine the effect of the suba seal rubber, and the amount of ethylene in the industrial acetylene gas. There have been reports that as ethylene is soluble in the silicone rubber, used seals may contain adsorbed ethylene which will later be released, enhancing sample readings on the gas chromatograph (Kavanagh and Postgate 1970). This possible error source was confirmed by the present work, and therefore only new suba seals were utilized for each incubation.

The plants were incubated for seven hours, two 1 ml samples of gas being withdrawn from each flask every hour, into disposable 1 ml syringes. In the first experiment, the gas samples were transported back to the laboratory for analysis, in the syringes - the needles firmly lodged into a rubber bung (Dart and Day 1971). The acetylene itself was used as an internal standard to detect leakage or erroneous injection. If the acetylene reading of the sample on the gas chromatograph was more than 5%

Nitrogen Fixation Appendix Plate 2

A photograph of the apparatus used for the incubation of the samples with acetylene, together with the Vacutainer assembly for collecting and storing the gas mixture.

A diagram to explain the apparatus seen in the above photograph.



below the reading of the control, the sample was discarded. It was found that the storage of gas in syringes was only satisfactory for about five hours, after which time the leakage prevented any accurate evaluation of acetylene reduction. The gas samples were analysed, using a Varian 1200 Gas Chromatograph fitted with a 360 cm x 0.31 cm steel column filled with Poropak R, operating at 100°C. The carrier gas of nitrogen was used at a flow rate of 10 mls every 25 seconds, and the ethylene and acetylene levels were determined by a hydrogen/air flame ionization detector. These settings allowed fast reading of gas samples at 35 seconds after injection of 1 ml gas. It was essential to test the levels of ethylene in the acetylene cylinders on every occasion of using the gas as this level varied, depending on the partial pressure within the cylinder. Over two years, readings (RAP) on the gas chromatograph of the blank control flask varied between 1x2x10 to 1x32x20, which had to be subtracted from the reading of each sample.

Calculation

The calculation used to estimate the volume of nitrogen which would have been fixed by the bean root nodules, if the acetylene had not been present, was as follows :-

$$\text{n Moles nitrogen fixed} = \frac{(RAP/M)\,(V_I/V_s)\,(V_v+V_s/V_v)}{F}$$

where :-

RAP - Range x Attenuation x Peak height - readings taken from gas chromatograph

M - Machine factor - A one ml sample of gas is injected into the gas chromatograph from a one litre bottle which has been injected, one hour previously, with 0.5 ml sample of industrial ethylene. Using the gas constant - one mole of gas occupying 22.4 litres at standard temperature and pressure, and the reading above, a factor is calculated to determine the number of nMoles of gas in a 1 ml sample injected. Hence 1 RAP unit is defined : for this machine M = 25.

V_I - Volume of incubation flask

V_s - Volume of syringe

V_v - Volume of vacutainer

F - Conversion factor of 3 (Hardy and Holsten 1968)

The calculation was further modified, when necessary, to produce values for nitrogen fixation per unit weight of root or nodules, fixation per nodule, or fixation per unit time. The results calculated from the initial time course experiment appear in the table below. They are presented graphically (Graph 5-1) and are discussed in the main text (Section 5:4.1). The figures are the mean values of four replicates ± Standard errors, and show Total Nitrogen fixed, expressed in μM N_2/gm roots and Rate of nitrogen fixation expressed in μM N_2/gm/hr.

Incubation time (hours)	Decapitated plant 30 ml flask		Decapitated plant 100 ml flask		Whole plant 100 ml flask	
	Total N_2 fixed	Rate of fixation	Total N_2 fixed	Rate of fixation	Total N_2 fixed	Rate of fixation
0.25	0.125±0.04	0.50±0.15	-	-	-	-
0.50	1.164±0.15	2.33±0.56	-	-	-	-
1.00	2.060±0.63	2.06±0.63	2.92±0.51	2.92±0.51	4.00±1.40	6.00±1.40
2.00	4.641±1.18	2.32±0.59	-	-	5.97±3.21	2.99±1.61
2.50	-	-	6.13±0.85	2.47±0.34	-	-
3.00	7.07 ±1.80	2.36±0.60	5.88±1.00	1.97±0.33	10.67±3.45	3.56±1.15
4.00	8.06 ±2.06	2.02±0.51	7.50±1.07	1.87±0.27	13.53±4.23	3.38±1.06
5.00	8.35 ±2.19	1.67±0.44	10.70±1.25	2.13±0.25	15.00±5.33	3.00±1.07
6.00	9.13 ±2.46	1.52±0.41	11.04±1.59	1.83±0.27	15.90±5.10	2.65±0.86
7.00	8.93 ±2.40	1.28±0.34	-	-	17.00±6.30	2.43±0.90

The values for nitrogen fixation were based upon the dry weight of the roots incubated.

Having found that the safe storage time for transporting gases from the field to the laboratory was rather limited, all the nitrogen fixation studies after the construction of the time course used B-D Vacutainers for this purpose, as proposed by Schell and Alexander (1970). These pre-evacuated blood sampling tubes were found to be ideal for the purpose (although expensive), and, using the apparatus shown in the photograph, enabled collection and transport of the gases with negligible leakage. It was discovered by other workers in the University Department that some of the vacutainer stocks, with an increased amount of glycerine in the rubber septa, tended to release ethylene when samples were stored for several weeks. This phenomenon was investigated, using 240 Vacutainers injected with a known mixture of acetylene/ethylene similar to levels experienced in the nitrogen fixation study. Batches of 40 tubes were analysed each week, for five weeks.

Time (weeks)	Mean RAP readings Acetylene	Mean RAP readings Ethylene
0	100x512x40	1x8x30
1	x40	1x8x65
2	x40	1x16x50
3	x39	1x16x70
4	x38	1x16x96
5	x38	1x16x96

A significant increase in the level of ethylene was recorded over the first four weeks. Changing the temperature for further batches made no difference to the increase. To ensure that this error source did not affect the results in the research study, an older stock of tubes with less glycerine was employed, and all samples were read on the gas chromatograph within 48 hours of collection of gases.

TEMPERATURE STUDIES

Although the conclusions made from the initial time course experiment stated that whole plants would be used for all subsequent fixation studies, it was found necessary to use decapitated plants for the first temperature study. To provide a wide range of temperatures, growth cabinets without lights had to be used for some temperatures. Plants of the age of 13 weeks from sowing were removed from the Stockless section, being transported whole to Durham, in rolls of wet newspaper and plastic bags. The plants were decapitated, and to standardize conditions, ten replicates in 100 ml flasks were placed in the dark into each temperature cabinet to equilibrate for one hour prior to incubation. Sufficient acetylene to give a concentration of 21.3% was injected, and the flasks incubated for one hour, after which gas samples were analysed on the gas chromatograph. The results are tabulated and discussed in the text (Section 5:4.2).

In the second temperature study both whole and decapitated plants were utilized. A mixture of OMS Throws variety seed was sown in pots containing S soil, in open cold frames in Durham, at the end of June. This enabled younger and more active plants to be tested, and these were removed from the soil immediately before incubation. The whole root system was recoverable in the study, and the average length of the main tap root was found to be 25 cms. All the root nodules were located within the top 12 cms length, 95% within the top 8 cms. This confirmed that the previous decision to only use the top 12 cms of tap root in the plants removed from the field, had included almost all the root nodules formed. Plants were removed from the pots at the age of five weeks when, due to later planting than normal, faster growth rates had enabled them to develop to a stage equivalent to eight weeks of growth in the field. Ten replicates for each temperature were used, as previously described. Where lights were available, the activity of nodules on whole plants was estimated, using 330 ml flasks, injected with 90 mls of acetylene to give a 21.3% concentration. Incubations of all plants were maintained for two hours. The results of the second temperature study confirm those of the first, and appear in the text - Table 5-1(2) and Graph 5-2(1).

FIELD COMPARISONS

Table A12 summarizes all the measurements taken during this study; the methods used were those which have been previously described.

On the first occasion, in order to maintain the field environment during incubation with acetylene, the plants were dug from the soil and sealed into the flasks standing in the field. The flasks were replaced in the holes from which the plants had been removed, the shoots being exposed to the wind and sun. This technique was not repeated,as excessive wilting resulted. Also the spatial separation of the fields on the three farm sections prevented simultaneous incubation of replicates from different fields. After this experience, all incubations were performed in the laboratory where humidity, temperature, light intensity and time of day were uniform for all samples to be compared. During 1972, both incubations were performed for three hours, but due to excessive wilting, which caused variation in the linearity of acetylene reduction, this period was cut to two hours in 1973, to minimize the effect of oxygen and water stress.

Comparison of 2 and 3 hour incubations :

Section	2 hrs incub:Fix Rate	μ MN$_2$/hr	3 hrs incub:Fix Rate	μMN$_2$/hr
	/root	/nodule	/root	/nodule
O	10.4	0.3	8.9	0.25
M	30.9	0.97	28.9	0.93
S	37.2	1.03	38.9	1.07

As the diurnal study showed that the daily mean of fixation occurred at 23.00 and 10.00 hours, incubations were standardized for 09.00 - 11.00 hours. Thus the rates of fixation measured at these times may be multiplied by 24 to give the probable net fixation/day. Whole plants were used for incubations throughout both seasons until the stem height became too large, at which time decapitated roots had to be used.

Table A12 refers to fixation rates of "selected" and "all" roots on 30/4/73. Within the replicates used for field comparison on this date, several roots with small white nodules showed no greater reduction of acetylene than could be accounted for by experimental error. When the results of these samples are included in a total ("all" roots), the great variation within one treatment causes very large standard deviations to occur. The pattern of fixation S > M > O is retained. Graphs 5-5 and 5-6 use the results of the "selected" roots - comparison of the management effect being made from the roots with actively fixing nodules only.

Table A1(1)

WATER ANALYSIS

Concentration of Geochemicals in Lysimeter Leachate.

Concentrations expressed as mg/litre.

ORGANIC

Date	ORGANIC N				NITRATE N				K				Na				Ca				Mg			
	Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
1972																								
11/4	21.2	26.5	25.6	31.8	11.1	9.7	10.9	5.8	13.3	3.1	6.8	2.5	14.7	13.8	12.9	21.4	67.5	76.1	65.0	177.5	5.5	5.0	3.5	3.1
1/5	41.3	31.8	42.4	42.4	7.3	6.1	4.7	3.2	6.5	1.5	7.5	1.3	13.5	11.0	10.2	11.8	89.0	88.0	69.0	63.0	6.3	4.3	5.0	2.0
22/5	100.7	90.1	109.2	95.4	6.8	-	10.6	10.2	7.5	-	8.5	1.0	13.3	-	12.2	13.7	104.5	-	84.5	69.0	7.3	-	5.5	3.0
22/6	31.8	37.0	32.7	33.9	8.4	2.9	8.4	5.9	10.5	0.9	10.8	0.7	13.5	11.0	12.0	14.3	108.5	95.0	108.0	90.0	9.3	9.0	7.0	3.5
25/7	26.5	26.5	25.4	26.5	3.1	8.7	9.3	7.3	3.8	8.0	9.8	1.3	5.3	6.4	11.6	16.7	42.0	40.5	86.0	117.0	2.8	2.0	6.0	3.3
19/8	29.7	-	26.5	26.5	2.0	-	40.0	37.6	3.5	-	3.5	0.6	6.8	-	12.2	14.3	44.0	-	137.5	112.0	2.3	-	5.8	1.8
19/9	21.2	24.3	22.3	21.2	3.3	3.2	8.7	5.5	0.5	9.3	5.0	1.3	14.1	12.9	17.1	19.2	60.5	70.0	98.5	132.0	4.0	4.5	6.3	4.3
10/12	95.4	49.8	42.4	47.7	14.3	12.8	5.3	7.5	0.6	6.0	4.3	1.0	13.1	9.3	10.8	8.1	77.0	62.5	77.0	111.5	6.3	2.8	3.0	3.0
1973																								
6/1	30.7	49.8	47.7	-	3.5	7.5	2.9	-	0.7	4.8	7.0	-	15.9	12.2	10.0	-	71.5	62.0	116.5	-	4.0	3.8	3.5	-
26/2	24.4	32.9	31.8	31.8	8.9	4.4	1.2	5.3	6.5	0.6	4.5	1.3	9.7	10.2	9.1	10.2	108.5	106.0	76.0	121.5	7.7	2.2	3.4	3.1
6/3	31.8	29.7	32.9	30.7	11.9	6.3	1.3	4.8	6.8	1.0	3.8	0.6	10.9	7.3	7.3	7.5	113.5	95.5	70.5	61.0	5.8	2.6	3.2	3.9
Mean	41.3	39.8	39.9	38.8	7.3	6.8	9.4	9.3	5.5	3.9	6.5	1.2	11.9	10.5	11.4	13.7	80.6	77.3	89.9	105.5	5.6	4.0	4.8	3.1
SD	28.6	19.9	24.4	21.3	4.1	3.2	10.8	10.1	4.2	3.3	2.5	0.6	3.4	2.5	2.5	4.5	26.0	20.8	22.8	36.1	2.1	2.2	1.5	0.8
SE	8.6	6.3	7.4	6.8	1.2	1.1	3.2	3.2	1.3	1.1	0.8	0.2	1.0	0.8	0.8	1.4	7.9	6.9	6.9	11.4	0.7	0.7	0.4	0.2

MIXED

Date	ORGANIC N				NITRATE N				K				Na				Ca				Mg			
	Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
1972																								
11/4	31.8	44.5	30.7	30.7	10.6	2.2	2.2	-	1.8	2.2	1.3	-	9.4	8.8	11.0	-	73.5	38.3	67.0	-	3.5	1.9	5.3	-
1/5	38.3	30.7	31.8	38.2	4.8	6.8	3.9	6.9	1.0	0.5	1.0	2.5	7.0	5.8	7.2	6.6	72.5	63.0	81.5	77.0	3.8	3.5	4.5	3.8
22/5	58.3	-	79.5	58.3	3.9	-	6.4	7.1	1.2	-	1.1	-	7.7	-	6.0	-	95.5	-	67.5	-	3.8	-	4.0	-
22/6	29.7	-	27.6	28.6	7.0	-	9.7	6.7	1.1	-	1.3	0.4	3.4	-	7.4	5.6	99.0	-	136.5	95.5	5.5	-	5.8	3.8
25/7	-	-	26.5	25.4	-	-	10.3	8.5	-	-	1.3	0.6	-	-	7.4	7.9	-	-	112.0	127.5	-	-	2.3	2.0
19/8	26.5	-	21.2	25.4	1.8	-	8.1	8.1	0.8	-	4.3	1.0	2.8	-	6.0	5.7	44.0	-	106.5	99.5	-	-	4.5	4.0
19/9	21.2	21.2	23.3	-	5.5	5.0	8.4	-	4.3	4.8	2.5	-	-	7.2	5.3	-	80.0	238.5	78.0	-	5.8	10.0	3.8	-
10/12	42.4	35.0	42.4	-	15.1	8.3	5.7	-	1.1	0.7	0.4	-	6.2	13.7	6.5	-	85.5	65.5	101.0	-	3.5	4.0	3.0	-
1973																								
6/1	44.5	39.2	35.0	-	13.4	5.6	7.7	-	1.0	1.8	0.7	-	6.7	7.3	5.0	-	60.5	109.0	57.5	-	3.5	9.8	3.3	-
26/2	42.4	31.8	31.8	-	13.4	2.8	2.4	-	0.6	0.8	0.4	-	4.5	4.4	2.0	-	115.0	117.5	63.5	-	3.0	2.5	2.7	-
6/3	23.3	24.4	-	-	4.4	5.1	-	-	1.1	0.2	-	-	4.2	4.4	-	-	71.0	57.5	-	-	2.9	2.3	-	-
Mean	35.8	32.4	35.0	34.4	8.0	5.1	6.5	7.5	1.4	1.6	1.4	1.1	5.8	7.4	6.4	6.5	79.7	98.5	87.1	99.9	3.9	4.9	3.9	3.4
SD	11.5	8.1	16.8	12.6	4.7	2.1	2.9	0.8	1.1	1.6	1.2	1.0	2.2	3.2	2.3	1.1	20.3	67.9	25.7	20.9	1.0	3.5	1.1	0.9
SE	3.6	3.1	5.3	5.1	1.5	0.8	0.9	0.4	0.3	0.6	0.4	0.5	0.7	1.2	0.7	0.5	6.4	25.7	8.1	10.4	0.3	1.3	0.7	0.5

Symbols:
S = Shallow lysimeter
D = Deep lysimeter
- = No drainage from lysimeter/insufficient volume sample.

Table A1(2)

WATER ANALYSIS.

Concentrations of Geochemicals in Lysimeter Leachate.

(Concentrations expressed as mgm/litre)

STOCKLESS - NORMAL FERTILIZER

1972																				
11/4	33.9	42.4	21.2	30.7	6.1	5.4	6.1	3.9	3.0	3.0	5.3	4.5	8.2	10.0	10.6	14.7	58.5	51.5	67.5	54.0	2.8	2.0	4.8	5.0
1/5	42.4	44.5	41.3	31.8	5.0	2.2	2.2	7.8	2.8	1.0	4.5	0.8	4.8	6.2	6.0	6.0	87.5	61.0	74.0	70.5	3.0	2.3	3.8	2.3
22/5	53.0	90.1	53.0	90.1	1.8	2.9	10.4	1.3	2.5	1.9	5.5	0.9	5.3	8.1	6.4	6.3	73.5	92.0	74.0	88.5	1.5	2.5	4.0	4.0
22/6	36.4	31.8	21.2	30.7	0.5	10.1	1.0	2.9	1.8	0.6	7.0	0.7	1.9	6.2	5.9	6.5	61.0	80.0	74.0	90.0	2.8	2.8	3.5	3.3
25/7	-	-	21.2	27.6	-	-	2.2	6.7	-	-	8.0	1.0	-	-	6.6	7.3	-	-	91.0	106.5	-	-	3.3	3.8
19/8	26.5	-	27.4	31.8	0.7	-	1.1	3.3	6.3	-	4.5	5.0	3.5	-	6.2	12.2	46.0	-	68.0	202.5	1.3	-	2.8	5.8
19/9	25.4	-	24.3	21.2	0.3	-	0.3	4.1	6.0	-	12.0	0.7	6.1	-	7.5	9.4	127.0	-	110.5	241.5	4.5	-	3.8	7.5
10/12	47.7	42.4	58.3	49.8	2.1	15.4	1.7	6.2	2.3	1.5	3.0	-	7.7	14.9	6.5	-	93.5	184.0	57.5	-	4.0	6.0	4.5	-
1973																								
6/1	43.5	35.0	-	38.3	1.1	2.4	-	5.7	2.5	1.1	-	1.0	5.2	5.2	-	6.3	61.5	124.0	-	120.0	1.8	4.0	-	6.8
26/2	44.5	33.9	-	31.8	1.9	2.6	-	2.1	1.0	0.7	-	3.3	1.7	3.0	-	3.8	48.5	68.0	-	108.5	1.3	1.8	-	2.5
6/3	24.4	31.8	-	25.4	0.6	5.7	-	0.5	1.5	0.5	-	0.9	3.6	4.1	-	4.2	62.0	75.0	-	74.5	1.8	1.8	-	2.5
Mean	37.7	44.0	33.5	37.2	2.0	5.8	3.1	4.1	3.0	1.2	6.2	1.9	4.8	7.2	7.0	7.7	71.9	91.9	77.1	115.7	2.4	3.4	3.8	4.4
SD	10.0	19.3	15.3	19.0	2.0	4.7	3.4	2.3	1.8	0.8	2.8	1.7	2.2	3.8	1.6	3.5	24.7	43.3	16.5	60.1	1.1	1.3	0.6	1.9
SE	3.2	6.8	5.4	5.7	0.6	1.7	1.2	0.7	0.6	0.3	1.0	0.5	0.7	1.3	0.6	1.1	7.8	15.3	5.8	19.0	0.4	0.5	0.2	0.6

STOCKLESS - HIGH FERTILIZER

1972																								
11/4	42.4	35.0	31.8	37.1	4.7	7.3	8.9	6.1	2.3	2.0	5.0	0.6	8.2	12.0	11.2	7.2	45.0	79.0	53.0	46.5	2.3	3.0	2.8	2.0
1/5	41.3	31.8	33.9	28.6	6.2	11.4	6.6	4.7	2.8	0.5	3.1	0.4	5.1	5.8	5.0	3.1	83.0	83.5	90.0	47.2	3.3	3.0	4.4	1.7
22/5	92.2	61.4	83.7	77.4	3.5	13.4	7.9	5.4	3.0	0.9	3.3	0.7	6.4	5.4	5.9	6.4	87.5	98.5	68.0	77.0	3.3	4.0	2.5	2.3
22/6	37.1	-	33.9	25.4	13.8	-	2.8	4.9	5.5	-	4.3	0.5	5.9	-	6.0	6.5	113.5	-	74.5	98.0	5.0	-	3.3	2.8
25/7	-	-	25.4	24.4	-	-	0.6	5.5	-	-	5.0	0.5	-	-	6.6	7.0	-	-	100.0	97.5	-	-	4.3	3.5
19/8	25.4	-	23.3	24.4	2.6	-	4.0	2.4	6.5	-	3.3	1.1	3.9	-	6.6	7.2	51.5	-	113.0	104.0	1.8	-	3.5	2.8
19/9	24.3	24.3	24.3	25.4	1.8	10.6	2.4	12.4	6.5	1.3	0.6	2.3	6.1	10.4	5.0	6.6	49.5	118.0	73.5	76.5	1.8	4.5	2.8	2.8
10/12	58.3	42.4	56.2	42.4	5.9	14.9	2.4	18.8	3.3	0.9	1.8	1.8	5.9	6.4	7.6	7.0	43.5	52.0	105.0	67.0	1.8	3.0	3.3	2.0
1973																								
6/1	46.6	42.4	47.7	46.6	3.1	7.8	0.9	1.1	2.5	1.3	0.4	0.9	5.5	6.8	5.2	5.4	55.0	127.5	50.5	66.0	1.5	1.8	1.8	2.0
26/2	42.4	42.4	42.4	40.3	1.7	1.5	2.1	2.0	5.6	0.6	-	0.1	4.7	4.5	-	2.8	63.0	115.0	-	45.0	2.5	3.0	-	1.5
6/3	18.6	18.6	30.0	27.6	0.7	5.1	0.2	0.4	1.8	0.9	1.0	0.3	3.6	4.8	3.3	4.2	50.5	76.0	51.0	56.0	2.1	2.0	1.9	1.6
Mean	42.9	37.3	39.3	36.3	4.4	9.0	3.5	5.8	4.0	1.1	2.8	0.8	5.5	7.0	6.3	5.8	64.2	93.7	77.9	62.1	2.5	3.0	3.1	2.3
SD	21.0	13.2	17.9	15.8	3.8	4.4	3.0	5.4	1.8	0.5	1.7	0.7	1.3	2.7	2.1	1.7	23.0	25.6	23.2	28.6	1.1	0.9	0.9	0.6
SE	6.6	4.7	5.4	4.8	1.2	1.6	0.9	1.6	0.6	0.2	0.6	0.2	0.4	1.0	0.7	0.5	7.3	9.1	7.3	8.6	0.3	0.3	0.3	0.2

Table A1(3)

WATER ANALYSIS

Concentrations of some Minor Geochemicals in Lysimeter Leachate measured at the beginning and end of the 1972 Season. Concentrations in mg/litre.

Management & Date	Fe				Al				Cu				Zn				Pb			
	Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow		Cropped		Fallow	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
ORGANIC																				
1/5/72	0.63	2.25	0.25	2.50	0.70	0.66	0.02	0.64	0.08	0.03	0.03	0.06	2.48	0.01	0.12	0.17	0.05	0.05	0.03	0.05
19/9/72	0.50	1.13	0.25	0.88	0.02	0.35	0.00	0.14	0.01	0.39	0.02	0.05	0.07	0.07	0.03	0.03	0.06	0.05	0.07	0.05
MIXED																				
1/5/72	0.38	0.25	0.38	-	0.16	0.00	0.04	-	0.03	0.01	0.02	-	0.05	0.01	0.04	-	0.03	0.04	0.06	-
19/9/72	1.00	2.95	0.25	-	0.18	0.30	0.07	-	0.08	0.57	0.01	-	0.19	0.09	0.03	-	0.03	0.03	0.04	-
STOCKLESS - NF																				
1/5/72	0.75	0.75	2.63	1.38	0.33	0.10	0.53	0.18	0.04	0.06	0.04	0.27	0.03	0.37	0.05	0.63	0.04	0.04	0.01	0.02
19/9/72	0.38	-	0.75	1.25	0.06	-	0.26	0.26	0.02	-	0.02	0.06	0.03	-	0.04	0.54	0.02	-	0.05	0.09
STOCKLESS - HF																				
1/5/72	0.88	0.25	1.25	0.42	0.33	0.00	0.40	0.00	0.04	0.04	0.06	0.06	0.02	0.32	0.26	0.21	0.05	0.05	0.05	0.03
19/9/72	0.63	3.41	0.38	0.88	0.13	0.51	0.06	0.26	0.02	0.09	0.02	0.08	0.01	0.12	0.03	0.16	0.04	0.08	0.20	0.06

Table A2(1)

WATER ANALYSIS

Chemical Analysis of Drainage Water collected from Field Tile Drains
Concentration of geochemicals in mg/litre

(A) Fields Under Specific Study

(1) ORGANIC

Date	Field	Org N	NO_3-N	Total N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1/1972	L.W.S.	40	4.8	45	0.4	7.5	17.3	126.5	6.0	0.07	0.13	0.022	0.40	0.05
2/1972	L.W.S.	28	1.2	29	0.3	0.9	14.3	83.5	3.5	0.12	0.02	0.016	0.12	0.03
	Nappers	33	5.4	38	0.2	0.9	20.6	124.4	4.7	0.12	0.19	-	0.06	0.06
4/1972	L.W.S.	38	0.7	39	0.01	0.4	13.3	86.1	4.4	0.11	-	-	0.01	0.05
	Nappers	36	0.2	36	0.3	3.4	29.1	120.6	6.9	0.37	0.46	-	0.11	0.21
5/1972	L.W.S.	32	2.9	35	0.2	1.1	12.5	75.0	3.3	0.06	0.16	0.011	0.13	0.02
11/1972	L.W.S.	44	5.3	49	0.3	4.7	19.1	103.1	5.6	0.59	1.90	0.075	0.29	0.14
4/1973	L.W.S.	-	-	-	0.6	9.5	24.1	102.0	8.3	0.27	0.17	0.007	0.23	0.05
Mean ± SE		35.9 ± 2.0	2.9 ± 0.9	38.7 ± 2.5	0.29 ± 0.06	3.6 ± 1.2	18.8 ± 2.0	102.7 ± 7.0	5.3 ± 0.6	0.21 ± 0.07	0.43 ± 0.25	0.026 ± 0.013	0.19 ± 0.04	0.08 ± 0.02
SD		5.4	3.4	6.6	0.17	3.4	5.7	19.9	1.7	0.19	0.70	0.028	0.11	0.07

(2) MIXED

Date	Field	Org N	NO_3-N	Total N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1/1972	7 Acres	32	0.3	32	0.5	1.1	20.4	102.1	2.5	0.22	0.63	-	1.16	0.04
	Cottage	34	1.7	36	0.4	6.5	37.8	70.0	4.5	0.06	0.16	0.020	0.04	0.06
2/1972	7 Acres	34	4.2	38	0.2	0.5	15.1	102.0	2.8	0.12	0.18	0.021	0.12	0.06
	Cottage	33	0.3	33	0.2	1.0	13.7	34.5	1.3	0.21	0.60	0.011	0.11	0.06
4/1972	7 Acres	32	5.8	38	0.3	0.4	6.9	92.5	2.5	0.22	0.31	-	0.02	0.10
	Cottage	42	4.1	46	0.5	5.0	18.1	85.0	5.6	0.25	0.60	0.010	0.04	0.05
5/1972	7 Acres	41	1.0	42	2.5	6.8	26.8	115.0	5.4	1.11	2.39	0.039	0.45	0.09
4/1973	7 Acres	-	-	-	0.4	11.5	34.5	140.5	12.0	-	0.52	0.009	0.32	0.11
Mean ± SE		35.4 ± 1.6	2.5 ± 0.8	37.9 ± 1.9	0.63 ± 0.27	4.1 ± 1.4	21.7 ± 3.5	92.7 ± 11.1	4.6 ± 0.4	0.31 ± 0.14	0.67 ± 0.25	0.018 ± 0.005	0.28 ± 0.14	0.07 ± 0.009
SD		4.2	2.2	4.9	0.77	4.0	9.9	31.4	1.0	0.36	0.72	0.011	0.39	0.03

(3) STOCKLESS

Date	Field	Org N	NO_3-N	Total N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1/1972	Little	-	-	-	0.4	6.4	25.4	92.2	5.3	0.06	0.15	0.022	0.12	0.06
2/1972	ChTE	26	0.5	27	0.2	0.4	15.9	80.6	3.1	0.21	0.43	0.013	0.36	0.09
	Little	33	0.3	33	0.3	5.7	23.6	78.3	4.7	0.42	0.36	0.011	0.07	0.07
4/1972	ChTE	26	2.0	28	0.5	1.4	28.0	125.0	5.4	0.50	0.66	-	1.23	0.03
	Little	44	1.8	46	0.3	5.8	20.6	82.0	6.0	0.08	0.21	0.009	0.11	0.04
2/1973	ChTE	-	-	-	0.4	5.0	24.9	117.5	5.8	0.34	0.48	0.009	0.15	0.06
4/1973	ChTE	-	-	-	0.3	4.5	18.2	125.5	7.3	0.55	0.95	0.009	0.02	0.07
Mean ± SE		32.3 ± 4.3	1.2 ± 0.4	33.5 ± 4.4	0.34 ± 0.04	4.2 ± 0.9	22.4 ± 1.6	100.2 ± 8.2	5.4 ± 0.5	0.31 ± 0.07	0.46 ± 0.10	0.012 ± 0.002	0.29 ± 0.16	0.06 ± 0.004
SD		8.5	0.9	8.7	0.10	2.3	4.3	21.7	1.3	0.20	0.27	0.005	0.43	0.02

Table A2(2)

WATER ANALYSIS

Chemical Analysis of Drainage Water Collected from Field Tile Drains
Concentration of geochemicals in mg/litre

(B) Bulked Samples from all other Fields

(1) ORGANIC

Date	Org N	NO_3-N	Total N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1/1972	38	2.7	41	0.2	1.5	13.3	65.0	4.8	0.11	0.12	-	0.04	0.01
2/1972	24	2.2	26	0.04	1.0	22.9	48.5	4.0	0.12	0.46	0.007	0.09	0.02
4/1972	40	1.7	42	0.2	0.8	15.3	71.5	6.0	0.19	0.33	-	0.10	0.09
5/1972	44	2.6	47	0.4	4.0	26.9	51.5	5.0	0.23	0.81	0.019	0.70	0.02
11/1972	48	2.9	51	0.6	6.3	17.6	83.5	6.3	0.19	0.54	0.019	0.31	0.07
2/1973	-	-	-	0.7	16.0	17.1	109.0	7.8	0.19	0.15	0.007	0.16	0.06
4/1973	-	-	-	0.5	6.7	20.1	95.4	7.8	0.58	0.36	0.007	0.41	0.05
Mean ± SE	37.1 ± 2.0	2.7 ± 0.5	39.8 ± 2.2	0.33 ± 0.05	4.3 ± 1.1	18.9 ± 1.3	89.7 ± 6.4	5.6 ± 0.4	0.22 ± 0.04	0.41 ± 0.13	0.019 ± 0.007	0.21 ± 0.05	0.06 ± 0.01
SD	6.9	1.7	7.7	0.2	4.3	5.1	24.9	1.6	0.17	0.48	0.021	0.19	0.05

(2) MIXED

Date	Org N	NO_3-N	Total N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1/1972	33	2.1	35	0.2	1.0	10.2	68.5	3.8	-	0.05	0.018	0.03	0.05
2/1972	33	3.4	36	0.3	0.6	17.6	67.0	4.8	-	0.23	-	0.09	0.04
4/1972	38	4.5	43	0.2	1.0	12.4	92.0	5.3	-	0.31	-	0.14	0.09
5/1972	44	1.4	44	2.3	4.2	26.9	68.0	6.5	-	0.67	0.021	0.07	0.06
11/1972	39	0.6	40	1.0	10.8	21.6	101.0	6.5	-	0.48	0.021	0.23	0.11
2/1973	-	-	-	1.1	24.2	34.2	89.8	8.2	-	0.26	0.009	0.16	0.05
4/1973	-	-	-	0.4	11.7	14.2	85.0	6.1	-	0.68	0.009	0.11	0.08
Mean ± SE	36.3 ± 1.2	2.5 ± 0.5	38.6 ± 1.3	0.7 ± 0.2	5.8 ± 1.7	20.7 ± 2.4	87.5 ± 6.4	5.2 ± 0.7	0.31 ± 0.14	0.54 ± 0.14	0.017 ± 0.003	0.21 ± 0.08	0.07 ± 0.006
SD	4.3	1.9	4.5	0.7	6.6	9.5	24.7	2.6	0.36	0.55	0.009	0.29	0.025

(3) STOCKLESS

Date	Org N	NO_3-N	Total N	P	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Pb
1/1972	31	0.6	32	0.3	2.5	13.3	42.5	2.3	0.31	0.63	0.016	0.61	0.03
2/1972	29	0.4	29	0.2	5.8	26.5	71.0	5.3	0.16	0.13	-	0.01	0.08
4/1972	33	1.7	35	0.3	12.0	13.7	147.5	6.5	0.25	0.50	-	0.02	0.46
5/1972	42	0.9	43	0.3	1.3	14.7	66.0	3.3	0.09	0.39	0.021	0.12	0.03
11/1972	37	5.9	43	0.5	3.8	14.3	83.5	4.0	0.21	0.50	0.021	0.09	0.05
2/1973	-	-	-	0.4	5.0	26.1	131.5	6.0	0.29	0.37	0.009	0.13	0.05
4/1973	-	-	-	0.8	9.4	25.0	104.5	9.1	0.25	0.70	0.009	0.03	0.07
Mean ± SE	33.4 ± 2.2	1.6 ± 0.6	35.1 ± 2.4	0.40 ± 0.04	4.9 ± 0.8	20.7 ± 1.5	96.3 ± 7.9	5.3 ± 0.5	0.27 ± 0.04	0.46 ± 0.06	0.014 ± 0.002	0.21 ± 0.09	0.09 ± 0.03
SD	6.5	1.8	7.2	0.15	3.1	5.5	29.7	1.8	0.15	0.23	0.006	0.34	0.11

Each reading on a bulked sample of 10 fields.

Means calculated from bulked samples plus fields under specific study.

WATER ANALYSIS

Table A3(1) Monthly loss of geochemicals in lysimeter leachate.

Expressed in Milligrams/Lysimeter

Treatment and date	Organic Nitrogen				Nitrate Nitrogen				Potassium				Sodium				Calcium				Magnesium			
	Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
ORGANIC																								
11/4/72	1.06	1.28	1.32	1.59	0.56	0.55	0.49	0.29	0.67	0.34	0.16	0.13	0.74	0.65	0.7	1.07	3.4	3.3	3.8	8.9	0.28	0.18	0.25	0.16
1/5/72	16.5	127.2	19.1	10.2	2.9	14.1	3.7	0.8	2.6	22.5	0.90	0.31	5.4	30.6	6.6	2.8	35.6	207.0	52.8	15.1	2.5	15.0	2.6	0.48
22/5/72	62.4	255.5	69.4	55.3	4.2	24.8	-	5.9	4.7	19.9	-	0.60	8.3	28.6	-	8.0	64.8	197.7	-	40.0	4.5	12.9	-	1.7
22/6/72	77.0	157.0	58.5	26.4	20.3	40.3	4.6	4.6	25.4	51.8	1.4	0.60	32.7	57.6	17.4	11.2	262.6	518.4	150.1	70.2	22.5	33.6	14.2	2.7
25/7/72	103.4	45.7	4.0	20.1	12.1	16.7	1.3	5.6	14.8	17.6	1.2	1.0	20.7	20.9	1.0	12.7	163.8	154.8	6.1	88.9	10.9	10.8	0.30	2.5
19/8/72	41.9	124.8	-	23.9	0.90	51.8	-	9.3	4.9	16.5	-	0.50	9.6	57.5	-	12.9	62.0	647.6	-	100.8	3.2	27.3	-	1.6
19/9/72	56.4	59.3	8.3	34.8	8.8	40.4	1.1	9.0	1.3	23.2	3.2	2.1	37.5	79.3	4.4	31.5	160.9	457.0	23.8	216.5	10.6	29.2	1.5	7.1
10/12/72	376.8	195.9	155.4	220.4	56.5	24.5	39.9	34.7	2.4	19.9	18.7	4.6	51.8	49.9	29.0	37.4	304.2	355.7	195.0	515.1	24.9	13.9	8.7	13.9
6/1/73	114.5	214.7	57.8	-	13.1	13.1	8.7	-	2.6	31.5	5.6	-	59.3	45.0	14.2	-	266.7	524.3	71.9	-	14.9	15.8	4.4	-
26/2/73	94.2	146.9	76.0	76.3	34.4	5.5	10.2	12.7	25.1	20.8	1.4	3.1	37.4	42.0	23.6	24.5	4.8.8	351.1	244.9	291.6	29.7	15.7	5.1	7.4
6/3/73	104.3	158.2	21.1	23.3	39.0	6.3	4.5	3.7	22.3	18.3	0.70	0.50	35.8	35.1	5.2	5.7	372.3	339.1	67.8	46.4	19.0	15.4	1.9	3.0
TOTAL	1049	1487	471	492	193	229	75	87	107	242	33	13	299	447	102	148	2115	3756	816	1394	143	190	39	41
MIXED																								
11/4/72	1.59	1.54	2.23	1.54	0.53	-	0.11	-	0.10	0.07	0.11	-	0.47	0.55	0.44	-	3.7	3.4	1.9	-	0.18	0.27	0.10	-
1/5/72	187.7	157.1	8.6	9.9	23.5	19.3	1.9	1.8	4.9	4.9	0.14	0.65	34.3	35.6	1.6	1.7	355.3	402.6	17.6	20.0	18.6	22.2	1.0	1.0
22/5/72	12.8	211.5	-	26.8	0.90	17.0	-	3.3	0.26	2.9	-	-	1.7	16.0	-	-	21.0	179.6	-	-	0.80	10.6	-	-
22/6/72	28.2	138.0	-	28.6	6.7	48.5	-	6.7	1.1	6.5	-	0.40	3.2	37.0	-	5.6	94.1	682.5	-	95.5	5.2	29.0	-	3.8
25/7/72	-	108.7	-	36.1	-	42.2	-	12.1	-	5.3	-	0.90	-	30.3	-	11.2	-	459.2	-	181.1	-	9.4	-	2.8
19/8/72	42.9	103.5	-	22.9	2.9	39.5	-	7.3	1.3	21.0	-	0.90	4.5	29.3	-	5.1	71.3	519.7	-	89.6	3.2	22.0	-	3.6
19/9/72	95.4	90.9	5.1	-	24.8	32.8	1.2	-	19.4	9.8	1.2	-	35.0	20.7	1.7	-	360.0	304.2	57.2	-	26.1	14.8	2.4	-
10/12/72	195.5	198.0	129.9	-	69.6	26.6	30.8	-	5.1	1.9	2.6	-	28.6	30.4	50.8	-	394.2	471.7	243.0	-	16.1	14.0	14.8	-
6/1/73	205.6	141.8	37.2	-	61.9	31.2	5.3	-	4.6	2.8	1.7	-	31.0	20.3	6.9	-	279.5	232.9	103.6	-	16.2	13.4	9.3	-
26/2/73	190.0	153.0	115.8	-	10.8	-	10.2	-	2.7	1.9	2.9	-	20.2	9.6	16.0	-	515.0	305.4	427.7	-	13.4	13.0	10.2	-
6/3/73	97.9	-	22.9	-	18.5	-	4.8	-	4.6	-	0.20	-	17.6	-	4.1	-	298.2	-	54.1	-	12.2	-	2.2	-
TOTAL	1058	1304	322	126	220	257	54	31	44	57	9	3	177	230	82	24	2392	3560	904	387	112	149	40	11

Table A3(2)

WATER ANALYSIS.

Monthly loss of geochemicals in the Lysimeter leachate.

(Loss expressed in mgm/Lysimeter)

Treatment and date	Organic Nitrogen				Nitrate Nitrogen				Potassium				Sodium				Calcium				Magnesium			
	Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
STOCKLESS - NORMAL FERTILIZER																								
11/4/72	1.7	1.06	2.12	1.54	0.31	0.31	0.27	0.2	0.15	0.27	0.15	0.23	0.41	0.53	0.5	0.74	2.9	3.4	2.6	2.7	0.14	0.24	0.10	0.25
1/5/72	206.1	186.7	16.0	11.1	24.3	9.9	0.80	2.7	13.6	20.3	0.36	0.28	23.3	27.1	2.2	2.1	425.3	334.5	22.0	24.7	14.6	17.2	0.83	0.80
22/5/72	18.6	104.9	45.1	43.2	0.60	20.6	1.5	0.6	0.9	10.9	0.60	0.43	1.9	12.7	4.3	3.0	25.7	146.5	46.0	42.5	0.50	7.9	1.3	1.9
22/6/72	35.7	106.0	20.4	39.0	0.50	5.0	6.5	3.7	1.8	35.0	0.40	0.90	1.9	29.5	4.0	8.3	59.8	370.0	51.2	115.2	2.7	17.5	1.8	4.2
25/7/72	-	71.2	-	33.1	-	7.4	-	8.0	-	26.9	-	1.2	-	22.2	-	8.8	-	305.8	-	127.8	-	11.1	-	4.6
19/8/72	78.4	133.2	-	48.3	2.1	5.4	-	5.0	18.7	21.9	-	7.6	10.4	30.1	-	18.5	136.2	330.5	-	307.8	3.9	13.6	-	8.8
19/9/72	74.2	97.7	-	39.4	0.90	1.2	-	7.6	17.5	48.2	-	1.3	17.8	30.2	-	17.5	370.8	444.2	-	449.2	13.1	15.3	-	14.0
10/12/72	212.7	284.5	147.6	203.4	9.4	8.3	53.6	24.8	10.3	14.6	5.2	-	34.3	31.7	51.9	-	417.0	280.6	640.3	-	17.8	22.0	20.9	-
6/1/73	191.4	-	39.9	48.6	4.8	-	2.7	7.2	11.0	-	1.3	1.3	22.9	-	5.9	8.0	270.6	-	141.4	152.4	7.9	-	4.6	8.6
26/2/73	182.9	-	89.5	89.7	7.8	-	6.9	5.9	4.1	-	1.9	9.3	7.0	-	7.9	10.7	199.3	-	179.5	306.0	5.3	-	4.8	7.1
6/3/73	98.6	-	25.4	19.8	2.4	-	4.6	0.4	6.1	-	0.40	0.7	14.5	-	3.3	3.3	250.5	-	60.0	58.1	7.3	-	1.4	2.0
TOTAL	1100	985	386	577	53	50	77	66	84	178	10	23	134	184	80	81	2158	2216	1143	1586	73	105	36	52
STOCKLESS - HIGH FERTILIZER																								
11/4/72	2.12	1.59	1.75	1.86	0.24	0.45	0.37	0.31	0.12	0.25	0.10	0.03	0.41	0.56	0.60	0.36	2.3	2.7	4.0	2.3	0.12	0.14	0.15	0.10
1/5/72	38.8	88.1	13.4	17.5	5.8	17.2	4.8	2.9	2.6	8.1	0.21	0.24	4.8	13.0	2.4	1.9	78.0	234.0	35.1	28.8	3.1	11.4	1.3	1.0
22/5/72	33.2	88.7	17.2	48.0	1.3	8.4	3.8	3.4	1.1	3.5	0.25	0.43	2.3	6.3	1.5	4.0	31.5	72.1	27.6	47.7	1.2	2.7	1.1	1.4
22/6/72	82.4	167.1	-	35.1	30.6	13.8	-	6.8	12.2	21.2	-	0.70	13.1	29.6	-	9.0	252.0	367.3	-	135.2	11.1	16.3	-	3.9
25/7/72	-	124.5	-	63.4	-	2.9	-	14.3	-	24.5	-	1.3	-	32.3	-	18.2	-	490.0	-	253.5	-	21.1	-	9.1
19/8/72	41.2	114.6	-	22.5	4.2	19.7	-	2.2	10.5	16.2	-	1.0	6.3	32.5	-	6.6	83.4	556.0	-	95.7	2.9	17.2	-	2.6
19/9/72	67.6	28.7	22.4	41.2	5.0	2.8	9.8	20.1	18.1	0.70	1.2	3.7	17.0	5.9	9.6	10.7	137.6	86.7	108.6	123.9	5.0	3.3	4.1	4.5
10/12/72	284.5	251.8	157.3	173.8	28.8	10.8	55.3	74.4	16.1	8.1	3.3	7.1	28.8	34.1	23.7	27.7	212.3	470.4	192.9	265.3	8.8	14.8	11.1	7.9
6/1/73	134.2	233.7	106.9	62.4	8.9	4.4	19.7	1.5	7.2	2.0	3.3	1.2	15.8	25.5	17.1	7.2	158.4	247.5	321.3	88.4	4.3	8.8	4.5	2.7
26/2/73	198.4	206.9	122.1	107.2	8.0	10.3	4.3	-	26.2	-	1.7	0.30	22.0	-	13.0	7.5	294.8	-	331.2	119.7	11.7	-	8.6	4.0
6/3/73	48.4	144.0	12.7	20.4	1.8	1.0	3.5	0.30	4.7	4.8	0.6	0.20	9.4	15.8	3.3	3.1	131.3	244.8	51.7	41.4	5.5	9.1	1.4	1.2
TOTAL	931	1450	454	593	95	92	102	126	99	90	11	16	120	196	71	96	1382	2772	1072	1202	54	105	32	38

Table A3(3)

WATER ANALYSIS

Loss of metals in lysimeter leachate at beginning and end of season.
milligrams/lysimeter.

Date and Treatment	Aluminium				Iron				Copper				Zinc				Lead			
	Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
ORGANIC																				
1/5/72	0.28	0.06	0.40	0.15	0.25	0.75	1.35	0.60	0.03	0.08	0.02	0.01	0.99	0.36	0.00	0.04	0.02	0.09	0.03	0.01
19/9/72	0.05	0.00	0.12	0.23	1.33	1.16	0.38	1.44	0.01	0.09	0.13	0.08	0.19	0.14	0.02	0.05	0.16	0.37	0.02	0.10
MIXED																				
1/5/72	0.78	0.20	0.00	-	1.86	1.88	0.07	-	0.14	0.07	0.00	-	0.25	0.20	0.00	-	0.15	0.30	0.01	-
19/9/72	0.81	0.27	0.07	0.00	4.50	0.98	0.71	0.13	0.37	0.05	0.14	0.04	0.86	0.12	0.02	0.02	0.14	0.16	0.01	0.05
STOCKLESS - NORMAL FERTILIZER																				
1/5/72	1.60	2.40	0.04	0.06	3.70	11.90	0.27	0.48	0.18	0.18	0.00	0.09	0.15	0.23	0.13	0.22	0.24	0.05	0.01	0.01
19/9/72	0.18	1.05	-	0.48	1.11	3.02	-	2.33	0.06	-	0.09	0.10	0.09	0.16	-	1.00	0.06	0.20	-	0.17
STOCKLESS - HIGH FERTILIZER																				
1/5/72	0.31	1.04	0.00	0.00	0.83	3.25	0.11	0.26	0.04	0.17	0.02	0.04	0.02	0.68	0.13	0.13	0.05	0.13	0.02	0.02
19/9/72	0.36	0.07	0.47	0.42	1.75	0.45	3.14	1.43	0.04	0.02	0.09	0.13	0.01	0.04	0.11	0.26	0.11	0.26	0.07	0.11

WATER ANALYSIS

Table A4(1) Monthly loss of geochemicals in lysimeter leachate. Expressed in Kg/ha.

Treatment and date	Organic Nitrogen				Nitrate-Nitrogen				Potassium				Sodium				Calcium				Magnesium			
	Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
ORGANIC																								
11/4/72	0.01	0.01	0.12	0.15	0.00	0.00	0.05	0.03	0.00	0.00	0.02	0.01	0.00	0.00	0.07	0.10	0.02	0.02	0.35	0.82	0.00	0.00	0.02	0.02
1/5/72	0.12	0.88	1.77	0.95	0.02	0.10	0.34	0.07	0.02	0.16	0.08	0.03	0.04	0.21	0.61	0.26	0.25	1.44	4.89	1.40	0.02	0.10	0.24	0.04
22/5/72	0.43	1.77	6.42	5.12	0.03	0.17	-	0.55	0.03	0.14	-	0.06	0.06	0.19	-	0.74	0.45	1.37	-	3.70	0.03	0.09	-	0.16
22/6/72	0.53	1.09	5.42	2.45	0.14	0.28	0.43	0.43	0.18	0.36	0.13	0.06	0.23	0.40	1.61	1.04	1.83	3.60	13.90	6.50	0.16	0.23	1.32	0.25
25/7/72	0.72	0.32	0.37	1.86	0.08	0.12	0.12	0.52	0.10	0.12	0.11	0.09	0.14	0.15	0.09	1.18	1.14	1.08	0.57	8.23	0.08	0.08	0.03	0.23
19/8/72	0.29	0.87	-	2.21	0.00	0.36	-	0.86	0.03	0.12	-	0.05	0.07	0.40	-	1.20	0.43	4.50	-	9.33	0.02	0.19	-	0.15
19/9/72	0.39	0.41	0.77	3.22	0.06	0.28	0.10	0.83	0.00	0.16	0.30	0.20	0.26	0.55	0.41	2.92	1.12	3.18	2.20	20.05	0.07	0.20	0.14	0.66
10/12/72	2.62	1.36	14.39	20.41	0.39	0.17	3.70	3.21	0.02	0.14	1.73	0.43	0.36	0.35	2.69	3.46	2.11	2.47	18.06	47.70	0.17	0.10	0.81	1.29
6/1/73	0.80	1.49	5.35	-	0.09	0.09	0.81	-	0.02	0.22	0.52	-	0.41	0.31	1.32	-	1.85	3.64	6.65	-	0.10	0.11	0.41	-
26/2/73	0.65	1.02	7.04	7.07	0.24	0.04	0.95	1.18	0.17	0.15	0.13	0.29	0.26	0.29	2.19	2.27	2.91	2.44	22.70	27.00	0.21	0.11	0.47	0.69
6/3/73	0.72	1.10	1.95	2.16	0.27	0.04	0.42	0.34	0.16	0.13	0.07	0.05	0.25	0.24	0.48	0.53	2.59	2.36	6.28	4.30	0.13	0.11	0.18	0.30
TOTAL.	7.3	10.3	43.6	45.6	1.3	1.7	6.9	8.0	0.7	1.7	3.1	1.3	2.1	3.1	9.5	13.7	14.7	26.1	75.6	129.0	1.0	1.3	3.6	3.8
MIXED																								
11/4/72	0.01	0.01	0.21	0.14	0.00	-	0.01	-	0.00	0.00	0.01	-	0.00	0.00	0.04	-	0.03	0.02	0.18	-	0.00	0.00	0.01	-
1/5/72	1.31	1.09	0.80	0.92	0.16	0.13	0.18	0.17	0.03	0.03	0.01	0.06	0.24	0.25	0.15	0.16	2.47	2.80	1.63	1.85	0.13	0.15	0.09	0.09
22/5/72	0.09	1.47	-	2.48	0.00	0.12	-	0.31	0.00	0.02	-	-	0.01	0.11	-	-	0.15	1.25	-	-	0.00	0.07	-	-
22/6/72	0.20	0.96	-	2.65	0.05	0.34	-	0.62	0.01	0.05	-	0.04	0.02	0.26	-	0.52	0.65	4.74	-	8.84	0.04	0.20	-	0.35
25/7/72	-	0.76	-	3.34	-	0.29	-	1.12	-	0.04	-	0.08	-	0.21	-	1.04	-	3.19	-	16.77	-	0.07	-	0.26
19/8/72	0.30	0.72	-	2.12	0.02	0.28	-	0.68	0.01	0.15	-	0.08	0.03	0.20	-	0.47	0.50	3.61	-	8.30	0.02	0.15	-	0.33
19/9/72	0.66	0.63	0.47	-	0.17	0.23	0.11	-	0.14	0.07	0.11	-	0.24	0.14	0.16	-	2.50	2.11	5.30	-	0.18	0.10	0.22	-
10/12/72	1.36	1.38	12.03	-	0.48	0.19	2.85	-	0.04	0.01	0.24	-	0.20	0.21	4.70	-	2.74	3.28	22.50	-	0.11	0.10	1.37	-
6/1/73	1.43	0.99	0.26	-	0.43	0.22	0.50	-	0.03	0.02	0.16	-	0.22	0.14	0.64	-	1.94	1.62	9.59	-	0.11	0.10	0.86	-
26/2/73	1.32	1.06	10.72	-	0.07	-	0.95	-	0.02	0.01	0.27	-	0.14	0.07	1.48	-	3.57	2.12	39.78	-	0.09	0.09	0.95	-
6/3/73	0.68	-	2.12	-	0.13	-	0.45	-	0.03	-	0.02	-	0.12	-	0.38	-	2.07	-	5.01	-	0.09	-	0.20	-
TOTAL.	7.4	9.1	26.6	11.7	1.5	1.8	5.1	2.9	0.3	0.4	0.8	0.3	1.2	1.6	7.6	2.2	16.6	24.7	83.9	35.8	0.8	1.03	3.7	1.0

WATER ANALYSIS

Table A4(2) Monthly loss of geochemicals in lysimeter leachates. Expressed in Kg/ha.

Treatment and date	Organic Nitrogen				Nitrate-Nitrogen				Potassium				Sodium				Calcium				Magnesium			
	Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
STOCKLESS - NORMAL FERTILIZER																								
11/4/72	0.02	0.00	0.20	0.14	0.00	0.00	0.03	0.02	0.00	0.00	0.01	0.02	0.00	0.00	0.05	0.07	0.02	0.02	0.24	0.25	0.00	0.00	0.01	0.02
1/5/72	1.43	1.30	1.48	1.03	0.17	0.07	0.07	0.25	0.09	0.14	0.03	0.03	0.16	0.19	0.21	0.20	2.96	2.33	2.04	2.29	0.10	0.12	0.08	0.07
22/5/72	0.13	0.73	4.17	4.00	0.00	0.14	0.14	0.06	0.01	0.08	0.06	0.04	0.01	0.09	0.40	0.28	0.18	1.02	4.26	3.94	0.00	0.06	0.12	0.13
22/6/72	0.25	0.74	1.89	3.61	0.00	0.04	0.60	0.34	0.01	0.24	0.04	0.08	0.01	0.21	0.37	0.77	0.42	2.57	4.76	10.67	0.02	0.12	0.17	0.39
25/7/72	-	0.50	-	3.07	-	0.05	-	0.74	-	0.19	-	0.11	-	0.15	-	0.82	-	2.13	-	11.83	-	0.07	-	0.43
19/8/72	0.55	0.93	-	4.47	0.02	0.04	-	0.46	0.13	0.15	-	0.70	0.07	0.21	-	1.71	0.95	2.30	-	28.50	0.03	0.10	-	0.82
19/9/72	0.52	0.68	-	3.65	0.01	0.01	-	0.70	0.12	0.34	-	0.12	0.12	0.21	-	1.62	2.58	3.09	-	41.60	0.09	0.11	-	1.29
10/12/72	1.48	1.98	13.67	18.84	0.07	0.06	4.96	2.30	0.07	0.10	0.48	-	0.24	0.22	4.81	-	2.90	1.95	59.6	-	0.12	0.15	1.94	-
6/1/73	1.33	-	3.70	4.50	0.03	-	0.25	0.67	0.08	-	0.12	0.12	0.16	-	0.55	0.74	1.88	-	13.09	14.11	0.06	-	0.43	0.80
26/2/73	1.27	-	8.28	8.30	0.05	-	0.64	0.55	0.03	-	0.18	0.86	0.05	-	0.73	0.99	1.39	-	16.62	28.34	0.04	-	0.44	0.66
6/3/73	0.69	-	2.35	1.83	0.02	-	0.43	0.04	0.04	-	0.04	0.07	0.10	-	0.31	0.31	1.74	-	5.58	5.38	0.05	-	0.13	0.19
TOTAL.	7.7	6.9	35.7	53.4	0.4	0.4	7.1	6.1	0.6	1.2	1.0	2.1	0.9	1.3	7.4	7.5	15.0	15.4	106.2	146.9	0.5	0.7	3.3	4.9
STOCKLESS - HIGH FERTILIZER																								
11/4/72	0.02	0.01	0.16	0.17	0.00	0.00	0.03	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.06	0.03	0.02	0.02	0.37	0.21	0.00	0.00	0.01	0.01
1/5/72	0.27	0.61	1.24	1.62	0.04	0.12	0.44	0.27	0.02	0.06	0.02	0.02	0.03	0.09	0.23	0.18	0.54	1.63	3.25	2.67	0.02	0.08	0.12	0.09
22/5/72	0.23	0.62	1.59	4.45	0.01	0.06	0.35	0.32	0.00	0.02	0.02	0.04	0.02	0.04	0.14	0.37	0.22	0.50	2.56	4.42	0.01	0.02	0.10	0.13
22/6/72	0.57	1.16	-	3.25	0.21	0.10	-	0.63	0.09	0.15	-	0.07	0.09	0.21	-	0.83	1.75	2.55	-	12.52	0.08	0.11	-	0.36
25/7/72	-	0.87	-	5.87	-	0.02	-	1.32	-	0.17	-	0.12	-	0.23	-	1.69	-	3.41	-	23.47	-	0.15	-	0.84
19/8/72	0.29	0.80	-	2.08	0.03	0.14	-	0.20	0.07	0.11	-	0.09	0.04	0.23	-	0.61	0.58	3.86	-	8.86	0.02	0.12	-	0.24
19/9/72	0.47	0.20	2.07	3.82	0.04	0.02	0.91	1.86	0.13	0.00	0.11	0.34	0.12	0.04	0.89	0.99	0.96	0.60	10.06	11.47	0.04	0.02	0.38	0.42
10/12/72	1.98	1.75	14.57	16.09	0.20	0.08	5.12	6.89	0.11	0.06	0.31	0.66	0.20	0.24	2.20	2.57	1.48	3.27	17.86	24.57	0.06	0.10	1.03	0.73
6/1/73	0.93	1.62	9.89	5.78	0.06	0.03	1.82	0.14	0.05	0.01	0.31	0.11	0.11	0.18	1.58	0.67	1.10	1.72	29.75	8.19	0.03	0.06	0.42	0.25
26/2/73	1.38	1.44	11.31	9.92	0.06	0.07	0.40	-	0.18	-	0.16	0.03	0.15	-	1.20	0.70	2.05	-	30.67	11.09	0.08	-	0.60	0.37
6/3/73	0.33	1.00	1.18	1.89	0.01	0.00	0.32	0.03	0.03	0.03	0.06	0.02	0.07	0.11	0.31	0.30	0.91	1.70	4.78	3.83	0.04	0.06	0.13	0.11
TOTAL.	6.5	10.1	42.0	55.0	0.7	0.6	9.4	11.7	0.7	0.6	1.0	1.5	0.8	1.4	6.6	8.9	9.6	19.3	99.3	111.3	0.4	0.7	3.0	3.6

WATER ANALYSIS

Table A4(3) Loss of metals in lysimeter leachate at beginning and end of season.
Expressed as Gms/ha.

Treatment and date	Aluminium				Iron				Copper				Zinc				Lead			
	Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
ORGANIC																				
1/5/72	1.94	0.42	37.04	13.89	1.74	5.21	125.0	55.6	0.21	0.56	1.85	0.93	6.88	2.50	0.00	3.70	0.14	0.63	2.78	0.93
19/9/72	0.35	0.00	11.11	21.30	9.24	8.06	35.2	133.3	0.07	0.63	12.0	7.4	1.32	0.97	1.85	4.63	1.11	2.57	1.85	9.3
MIXED																				
1/5/72	5.42	1.39	0.00	-	12.92	13.06	6.48	-	0.97	0.49	0.00	-	1.74	1.39	0.00	-	1.04	2.08	0.93	-
19/9/72	5.63	1.88	6.48	0.00	31.25	6.81	65.7	12.0	2.57	0.35	13.0	3.70	5.97	0.83	1.85	1.85	0.97	1.11	0.93	4.63
STOCKLESS - NORMAL FERTILIZER																				
1/5/72	11.11	16.70	3.70	5.56	25.69	82.63	25.0	44.4	1.25	1.25	0.00	8.33	1.04	1.60	12.0	20.4	1.67	0.35	0.93	0.93
19/9/72	1.25	7.29	-	44.4	7.70	21.00	-	215.7	0.42	-	8.33	9.3	0.63	1.11	-	92.6	0.42	1.39	-	15.7
STOCKLESS - HIGH FERTILIZER																				
1/5/72	2.15	7.22	0.00	0.00	5.76	22.56	10.2	24.1	0.28	1.18	1.85	3.70	0.14	4.72	12.0	12.0	0.35	0.90	1.85	1.85
19/9/72	2.50	0.49	43.5	38.9	12.15	3.13	290.7	132.4	0.28	0.14	8.33	12.0	0.07	0.28	10.2	24.1	0.76	1.81	6.48	10.2

DYNAMICS OF CROP GROWTH

Table A5. Raw growth data - 1971 Greenhouse Trial. Each reading a mean of three samples.

Age (days)	O seeds - O soil			O seeds - S soil			M seeds - O soil			M seeds - S soil			S seeds - O soil			S seeds - S soil		
	Shoot length (cms.)	Leaf area (cms^2)	Total dry wt. (gms)	Shoot length (cms)	Leaf area (cms^2)	Total dry wt. (gms)	Shoot length (cms)	Leaf area (cms^2)	Total dry wt. (gms)	Shoot length (cms)	Leaf area (cms^2)	Total dry wt. (gms)	Shoot length (cms)	Leaf area (cms^2)	Total dry wt. (gms)	Shoot length (cms)	Leaf area (cms^2)	Total dry wt. (gms)
9	9.8	4.2	0.523	10.5	7.2	0.640	7.3	5.3	0.486	6.5	4.6	0.553	4.7	0.0	0.628	3.9	1.2	0.652
12	15.8	19.5	0.610	13.0	14.0	0.577	17.5	20.5	0.444	13.5	22.8	0.521	9.9	10.0	0.672	12.7	6.2	0.696
16	24.8	27.1	0.485	24.3	37.7	0.467	26.8	39.3	0.505	27.6	40.8	0.511	20.8	31.4	0.592	12.9	7.0	0.464
19	27.9	39.2	0.523	28.6	43.6	0.627	24.6	28.7	0.377	27.2	39.9	0.471	26.3	47.9	0.482	20.3	32.5	0.442
23	29.9	51.9	0.522	32.5	35.1	0.531	32.2	44.7	0.534	33.3	58.0	0.528	23.2	33.3	0.484	23.3	37.7	0.662
26	38.9	52.4	0.504	30.4	50.2	0.506	33.5	52.7	0.432	36.3	52.0	0.519	38.0	45.3	0.552	36.5	71.5	0.721
29	44.5	68.7	0.700	37.9	39.5	0.571	45.6	56.8	0.603	33.4	70.1	0.596	41.5	54.7	0.729	38.9	51.4	0.523
45	46.6	58.9	0.667	41.8	61.5	0.602	49.8	74.3	0.682	51.3	97.2	0.877	45.5	92.6	0.655	54.8	108.8	0.841
47	62.5	108.8	0.718	55.0	83.4	0.772	45.5	61.9	0.677	53.3	105.8	0.806	60.3	101.5	0.823	52.8	85.8	0.552
51	55.6	71.7	0.859	52.8	74.3	0.679	51.4	54.4	0.630	59.9	96.3	0.956	46.4	93.1	0.598	62.3	91.4	0.836
54	50.5	56.7	0.859	42.1	55.7	0.737	56.0	116.9	0.962	57.4	54.6	0.764	60.0	69.7	0.593	40.7	33.1	0.662
58	66.3	67.6	1.024	47.7	43.0	0.703	59.2	46.6	0.740	44.8	49.5	0.657	60.6	73.6	0.878	56.6	62.8	0.937
65	61.4	71.3	0.850	63.5	56.1	0.783	64.0	96.5	0 772	60.7	44.6	0.840	61.3	58.9	0.833	71.0	69.9	0.780
73	52.4	35.0	0.763	41.3	32.7	0.583	49.8	28.6	0.483	59.7	42.7	0.647	65.5	61.5	1.001	66.8	46.2	0.650

Table A6(1).

DYNAMICS OF CROP GROWTH

1971 Greenhouse Trial - Computed Data

(a) Fitted Log Weight with Standard Error

Age	O seed - O soil		O seed - S soil		M seed - O soil		M seed - S soil		S seed - O soil		S seed - S soil	
(days)	F Log W	SE	F Log W	SE	F Log W	SE	F Log W	SE	F Log W	SE	F Log W	SE
9	6.327	0.121	6.416	0.092	6.172	0.125	6.267	0.103	6.426	0.131	6.454	0.140
12	6.279	0.085	6.347	0.065	6.138	0.088	6.233	0.070	6.389	0.093	6.383	0.100
16	6.247	0.066	6.286	0.052	6.124	0.068	6.217	0.060	6.354	0.073	6.322	0.080
19	6.243	0.069	6.261	0.053	6.133	0.068	6.224	0.060	6.338	0.074	6.298	0.080
23	6.260	0.076	6.250	0.059	6.166	0.074	6.254	0.060	6.327	0.081	6.290	0.080
26	6.288	0.080	6.257	0.062	6.203	0.078	6.290	0.070	6.328	0.084	6.300	0.090
29	6.325	0.081	6.274	0.062	6.248	0.079	6.333	0.070	6.335	0.085	6.322	0.090
45	6.596	0.078	6.454	0.057	6.510	0.075	6.607	0.070	6.466	0.081	6.531	0.090
47	6.628	0.080	6.477	0.057	6.533	0.077	6.635	0.070	6.491	0.083	6.558	0.090
51	6.685	0.085	6.516	0.059	6.564	0.081	6.680	0.070	6.545	0.086	6.607	0.090
54	6.717	0.088	6.538	0.061	6.572	0.084	6.701	0.070	6.588	0.088	6.635	0.090
58	6.742	0.090	6.552	0.062	6.555	0.086	6.707	0.070	6.650	0.089	6.658	0.100
65	6.724	0.092	6.521	0.065	6.434	0.089	6.642	0.070	6.763	0.113	6.643	0.110
73	6.575	0.147	6.371	0.111	6.118	0.147	6.418	0.120	6.895	0.235	6.508	0.200

(b) Fitted Log Area with Standard Error

9	2.072	0.641	2.098	0.270	2.105	0.300	1.970	0.200	-2.728	0.710	-2.280	0.890
12	2.516	0.451	2.574	0.190	2.617	0.211	2.600	0.140	-0.673	0.500	-0.670	0.630
16	3.057	0.354	3.100	0.150	3.177	0.162	3.280	0.110	+1.506	0.400	+1.100	0.490
19	3.419	0.365	3.418	0.160	3.515	0.162	3.690	0.110	2.759	0.410	2.150	0.500
23	3.841	0.405	3.750	0.180	3.861	0.177	4.100	0.120	3.980	0.440	3.220	0.550
26	4.107	0.425	3.935	0.180	4.050	0.185	4.320	0.130	4.600	0.460	3.810	0.580
29	4.329	0.430	4.070	0.180	4.185	0.187	4.470	0.130	5.000	0.460	4.230	0.590
45	4.634	0.416	4.147	0.160	4.200	0.179	4.450	0.130	4.666	0.440	4.500	0.550
47	4.556	0.428	4.100	0.170	4.143	0.183	4.390	0.140	4.478	0.450	4.400	0.560
51	4.316	0.454	3.987	0.180	4.008	0.193	4.230	0.140	4.106	0.470	4.150	0.580
54	4.057	0.470	3.880	0.180	3.894	0.200	4.110	0.140	3.865	0.480	3.960	0.590
58	3.604	0.479	3.746	0.180	3.734	0.204	3.950	0.140	3.655	0.480	3.740	0.600
65	2.495	0.490	3.502	0.190	3.468	0.213	3.720	0.140	3.795	0.610	3.570	0.690
73	0.697	0.784	3.291	0.330	3.261	0.351	3.640	0.240	4.120	1.200	4.000	1.260

Table A6(2).

DYNAMICS OF CROP GROWTH.

1971 Greenhouse Trial - Computed Data.

(c) Relative Growth Rate

Age (days)	O seed - O soil		O seed - S soil		M seed - O soil		M seed - S soil		S seed - O soil		S seed - S soil	
	RGR	SE	RGR	SE	RGR	SE	RGR	SE	RGR	SE	RGR	SE
9	-0.019	0.019	-0.027	0.014	-0.015	0.018	-0.015	0.016	-0.014	0.020	-0.027	0.021
12	-0.012	0.015	-0.020	0.011	-0.008	0.015	-0.008	0.012	-0.011	0.016	-0.020	0.017
16	-0.004	0.011	-0.011	0.008	0.000	0.011	0.000	0.009	-0.007	0.011	-0.011	0.012
19	+0.001	0.008	-0.006	0.006	0.006	0.008	+0.005	0.007	-0.004	0.008	-0.005	0.009
23	0.007	0.005	+0.000	0.004	0.011	0.005	0.010	0.005	-0.001	0.007	+0.001	0.006
26	0.011	0.004	+0.004	0.003	0.014	0.004	0.013	0.004	+0.001	0.005	0.005	0.005
29	0.014	0.004	0.007	0.003	0.016	0.004	0.016	0.004	0.003	0.005	0.009	0.005
45	0.017	0.006	0.012	0.004	0.013	0.005	0.015	0.004	0.012	0.006	0.014	0.006
47	0.016	0.005	0.011	0.004	0.010	0.005	0.013	0.004	0.013	0.006	0.013	0.006
51	0.012	0.005	0.009	0.004	0.005	0.005	0.009	0.004	0.014	0.005	0.011	0.006
54	0.009	0.005	0.006	0.004	0.000	0.005	0.005	0.004	0.015	0.006	0.008	0.006
58	0.004	0.006	0.001	0.004	-0.009	0.005	-0.002	0.005	0.016	0.008	0.003	0.007
65	-0.009	0.009	-0.010	0.008	-0.027	0.009	-0.017	0.009	0.017	0.015	-0.008	0.013
73	-0.029	0.019	-0.028	0.014	-0.053	0.018	-0.040	0.016	0.016	0.026	-0.026	0.023
(d) Leaf Area Ratio												
9	0.014	0.009	0.013	0.003	0.017	0.005	0.014	0.002	0.000	0.000	0.000	0.000
12	0.023	0.009	0.023	0.004	0.030	0.006	0.026	0.003	0.001	0.000	0.001	0.001
16	0.041	0.014	0.041	0.006	0.053	0.007	0.053	0.005	0.007	0.003	0.005	0.002
19	0.059	0.020	0.058	0.008	0.073	0.010	0.079	0.007	0.028	0.011	0.016	0.007
23	0.089	0.034	0.082	0.013	0.100	0.016	0.116	0.011	0.096	0.042	0.046	0.024
26	0.113	0.045	0.098	0.016	0.116	0.019	0.139	0.014	0.177	0.080	0.083	0.045
29	0.136	0.055	0.110	0.018	0.127	0.021	0.155	0.016	0.262	0.119	0.123	0.068
45	0.141	0.055	0.099	0.015	0.100	0.016	0.116	0.012	0.165	0.072	0.132	0.068
47	0.126	0.051	0.093	0.014	0.092	0.015	0.105	0.011	0.134	0.060	0.115	0.060
51	0.094	0.040	0.080	0.013	0.078	0.013	0.086	0.010	0.087	0.040	0.086	0.047
54	0.070	0.031	0.071	0.012	0.069	0.012	0.075	0.008	0.066	0.031	0.069	0.038
58	0.043	0.020	0.061	0.010	0.060	0.011	0.063	0.007	0.050	0.024	0.054	0.030
65	0.015	0.007	0.049	0.008	0.052	0.010	0.054	0.006	0.051	0.031	0.046	0.029
73	0.003	0.002	0.046	0.013	0.057	0.018	0.062	0.012	0.181	0.227	0.081	0.096
(e) Net Assimilation Rate												
9	-1.37	1.40	-1.99	1.12	-0.87	1.09	-1.09	1.13	-	-	-	-
12	-0.53	0.64	-0.85	0.50	-0.26	0.50	-0.30	0.47	12.44	19.74	-22.82	21.90
16	-0.09	0.26	-0.27	0.20	+0.01	0.20	0.00	0.17	-0.88	1.47	-2.05	2.42
19	+0.02	0.13	-0.09	0.10	0.08	0.11	+0.06	0.08	-0.15	0.30	-0.34	0.61
23	0.08	0.06	+0.01	0.05	0.11	0.06	0.09	0.04	-0.01	0.06	+0.03	0.13
26	0.09	0.05	0.04	0.03	0.12	0.04	0.10	0.03	+0.01	0.03	0.06	0.07
29	0.10	0.05	0.07	0.03	0.13	0.04	0.10	0.03	0.01	0.02	0.07	0.05
45	0.12	0.06	0.12	0.04	0.13	0.06	0.13	0.04	0.07	0.05	0.11	0.07
47	0.12	0.06	0.12	0.05	0.11	0.06	0.13	0.04	0.10	0.06	0.12	0.08
51	0.13	0.07	0.11	0.05	0.06	0.06	0.10	0.05	0.16	0.10	0.13	0.09
54	0.13	0.09	0.08	0.05	0.00	0.07	0.06	0.05	0.23	0.14	0.12	0.11
58	0.08	0.13	0.02	0.07	-0.14	0.10	-0.03	0.07	0.31	0.22	0.06	0.14
65	-0.64	0.75	-0.22	0.16	-0.52	0.22	-0.32	0.17	0.32	0.35	-0.18	0.31
73	-10.32	10.94	-0.61	0.37	-0.93	0.44	-0.64	0.30	0.09	0.19	-0.32	0.53

Table A 7(1).

DYNAMICS OF CROP GROWTH.

1971 Field Trial - Computed Data.

(1) Fitted Log Weight with Standard Errors

Treatment & Age (weeks)	Tic O	Tic M	Tic S.	Throw O	Throw M	Throw S
Stockless - No Fertilizer						
3	-0.76 ± 0.21	-0.71 ± 0.21	-0.75 ± 0.23	-1.72 ± 0.32	-1.62 ± 0.27	-1.49 ± 0.35
5	-0.19 ± 0.14	-0.13 ± 0.13	-0.17 ± 0.14	-0.95 ± 0.20	-0.77 ± 0.17	-0.66 ± 0.22
7	+0.58 ± 0.14	+0.64 ± 0.14	+0.58 ± 0.14	+0.00 ± 0.20	+0.19 ± 0.17	+0.28 ± 0.23
10	1.71 ± 0.13	1.76 ± 0.13	1.68 ± 0.14	1.34 ± 0.20	1.45 ± 0.17	1.53 ± 0.22
12	2.48 ± 0.12	2.53 ± 0.12	2.43 ± 0.13	2.23 ± 0.18	2.27 ± 0.16	2.34 ± 0.20
14	3.18 ± 0.13	3.21 ± 0.13	3.11 ± 0.13	3.01 ± 0.19	2.97 ± 0.16	3.05 ± 0.21
18	4.07 ± 0.16	4.05 ± 0.16	4.00 ± 0.17	3.98 ± 0.24	3.91 ± 0.21	4.00 ± 0.27
21	4.05 ± 0.15	3.99 ± 0.15	4.06 ± 0.16	3.94 ± 0.22	4.02 ± 0.19	4.11 ± 0.25
24	3.22 ± 0.23	3.09 ± 0.22	3.38 ± 0.24	3.00 ± 0.34	3.48 ± 0.29	3.56 ± 0.38
Stockless - 375 Kg Fertilizer/ha.						
3	-0.81 ± 0.17	-0.73 ± 0.30	-0.68 ± 0.20	-1.78 ± 0.30	-1.80 ± 0.20	-1.52 ± 0.17
5	-0.33 ± 0.11	-0.33 ± 0.19	-0.45 ± 0.13	-1.02 ± 0.19	-0.86 ± 0.13	-0.86 ± 0.11
7	+0.73 ± 0.11	+0.63 ± 0.20	+0.38 ± 0.13	+0.34 ± 0.20	+0.56 ± 0.13	+0.40 ± 0.11
10	1.55 ± 0.10	1.39 ± 0.19	1.13 ± 0.13	1.28 ± 0.19	1.46 ± 0.13	1.32 ± 0.10
12	2.38 ± 0.10	2.18 ± 0.17	1.94 ± 0.12	2.18 ± 0.17	2.24 ± 0.11	2.22 ± 0.09
14	3.14 ± 0.13	2.92 ± 0.18	2.72 ± 0.12	2.97 ± 0.18	3.00 ± 0.12	3.02 ± 0.10
18	4.12 ± 0.13	3.93 ± 0.23	3.85 ± 0.16	3.96 ± 0.23	3.92 ± 0.15	4.03 ± 0.13
21	4.09 ± 0.12	4.01 ± 0.21	3.98 ± 0.14	3.92 ± 0.21	4.05 ± 0.14	3.99 ± 0.12
24	3.12 ± 0.18	3.22 ± 0.32	3.17 ± 0.22	2.95 ± 0.32	3.55 ± 0.22	2.98 ± 0.18
Stockless - 625 Kg Fertilizer/ha						
3	-0.75 ± 0.25	-0.77 ± 0.22	-0.85 ± 0.26	-1.78 ± 0.29	-1.77 ± 0.35	-1.60 ± 0.26
5	-0.27 ± 0.16	-0.30 ± 0.14	-0.29 ± 0.16	-0.89 ± 0.18	-0.92 ± 0.23	-0.82 ± 0.17
7	+0.76 ± 0.16	+0.73 ± 0.14	+0.83 ± 0.17	+0.52 ± 0.19	+0.48 ± 0.23	+0.50 ± 0.17
10	1.54 ± 0.15	1.53 ± 0.14	1.66 ± 0.16	1.46 ± 0.18	1.41 ± 0.22	1.40 ± 0.16
12	2.33 ± 0.14	2.33 ± 0.13	2.47 ± 0.15	2.32 ± 0.16	2.29 ± 0.20	2.24 ± 0.15
14	3.04 ± 0.15	3.05 ± 0.13	3.20 ± 0.15	3.08 ± 0.17	3.06 ± 0.21	2.99 ± 0.16
18	4.01 ± 0.19	3.94 ± 0.17	4.11 ± 0.20	4.05 ± 0.22	4.08 ± 0.27	3.97 ± 0.20
21	4.05 ± 0.18	3.85 ± 0.16	4.05 ± 0.18	4.12 ± 0.20	4.18 ± 0.25	4.05 ± 0.19
24	3.27 ± 0.27	2.81 ± 0.24	3.09 ± 0.27	3.43 ± 0.31	3.53 ± 0.38	3.37 ± 0.28
Organic						
3	-0.69 ± 0.11	-0.47 ± 0.17	-0.46 ± 0.11	-1.43 ± 0.21	-1.37 ± 0.20	-1.21 ± 0.22
5	-0.03 ± 0.07	+0.12 ± 0.11	-0.17 ± 0.07	-0.59 ± 0.13	-0.39 ± 0.13	-0.54 ± 0.13
7	+0.70 ± 0.08	0.87 ± 0.12	+0.49 ± 0.08	+0.27 ± 0.15	+0.54 ± 0.14	+0.24 ± 0.15
9	1.43 ± 0.08	1.68 ± 0.11	1.36 ± 0.08	1.08 ± 0.14	1.39 ± 0.14	1.06 ± 0.14
13	2.70 ± 0.09	3.00 ± 0.13	3.04 ± 0.09	2.42 ± 0.16	2.63 ± 0.15	2.47 ± 0.16
16	3.27 ± 0.09	3.30 ± 0.13	3.57 ± 0.09	2.99 ± 0.17	3.00 ± 0.16	3.03 ± 0.17
19	3.33 ± 0.12	2.58 ± 0.18	2.85 ± 0.12	3.03 ± 0.22	2.74 ± 0.22	2.86 ± 0.22

(2) Fitted Log Area with Standard Errors

Stockless - No Fertilizer						
3	-4.15 ± 2.67	-3.04 ± 2.09	-4.15 ± 2.70	-3.14 ± 2.01	-4.19 ± 2.60	-3.18 ± 1.98
5	+1.06 ± 1.67	+0.65 ± 1.30	+1.07 ± 1.70	+0.25 ± 1.26	+1.14 ± 1.60	+0.40 ± 1.23
7	4.88 ± 1.72	3.90 ± 1.34	4.90 ± 1.70	3.40 ± 1.30	5.03 ± 1.70	3.66 ± 1.27
10	7.47 ± 1.69	6.90 ± 1.32	7.50 ± 1.70	6.59 ± 1.30	7.64 ± 1.70	6.91 ± 1.25
12	7.80 ± 1.55	8.21 ± 1.21	7.85 ± 1.60	8.00 ± 1.17	7.94 ± 1.50	8.30 ± 1.15
14	7.10 ± 1.59	8.61 ± 1.24	7.15 ± 1.60	8.61 ± 1.20	7.20 ± 1.60	8.86 ± 1.18
18	3.22 ± 2.03	6.66 ± 1.58	3.27 ± 2.00	7.01 ± 1.53	3.22 ± 1.90	7.12 ± 1.50
21	-1.24 ± 1.89	2.58 ± 1.48	-1.21 ± 1.90	2.94 ± 1.42	-1.27 ± 1.90	2.95 ± 1.40
24	-6.43 ± 2.86	-3.97 ± 2.23	-6.44 ± 2.90	-3.97 ± 2.16	-6.43 ± 2.80	-4.02 ± 2.12
Stockless - 375 Kg Fertilizer/ha.						
3	-4.04 ± 2.80	-3.21 ± 1.90	-4.05 ± 2.70	-4.18 ± 2.60	-3.16 ± 2.00	-4.05 ± 2.78
5	+0.93 ± 1.78	+0.33 ± 1.20	+0.80 ± 1.70	+0.82 ± 1.60	+0.32 ± 1.30	+0.83 ± 1.77
7	5.69 ± 1.81	4.56 ± 1.20	5.44 ± 1.80	5.54 ± 1.70	4.51 ± 1.30	5.52 ± 1.80
10	7.25 ± 1.72	6.55 ± 1.20	6.96 ± 1.70	7.04 ± 1.60	6.50 ± 1.30	7.07 ± 1.71
12	7.69 ± 1.58	7.81 ± 1.10	7.36 ± 1.50	7.40 ± 1.50	7.78 ± 1.20	7.50 ± 1.57
14	7.11 ± 1.65	8.25 ± 1.10	6.78 ± 1.60	6.75 ± 1.50	8.25 ± 1.20	6.93 ± 1.64
18	3.42 ± 2.13	6.42 ± 1.40	3.17 ± 2.10	3.03 ± 2.00	6.50 ± 1.60	3.32 ± 2.11
21	-1.05 ± 1.97	2.38 ± 1.30	-1.18 ± 1.90	-1.31 ± 1.80	2.54 ± 1.40	-1.09 ± 1.96
24	-6.55 ± 2.99	-4.21 ± 2.00	-6.46 ± 1.90	-6.45 ± 2.80	-3.99 ± 2.20	-6.49 ± 2.97
Stockless - 625 Kg Fertilizer/ha						
3	-4.05 ± 2.77	-3.05 ± 2.08	-3.40 ± 1.80	-3.41 ± 1.70	-3.44 ± 1.66	-3.26 ± 1.94
5	+0.85 ± 1.76	+0.29 ± 1.32	+0.10 ± 1.20	+0.18 ± 1.10	+0.17 ± 1.06	+0.19 ± 1.24
7	5.56 ± 1.80	4.40 ± 1.35	4.40 ± 1.20	4.54 ± 1.10	4.53 ± 1.10	4.49 ± 1.26
10	7.13 ± 1.71	6.49 ± 1.28	6.48 ± 1.10	6.63 ± 1.00	6.61 ± 1.00	6.61 ± 1.20
12	7.57 ± 1.56	7.85 ± 1.18	7.85 ± 1.00	7.98 ± 1.00	7.94 ± 0.90	8.04 ± 1.10
14	7.02 ± 1.63	8.42 ± 1.22	8.41 ± 1.00	8.49 ± 1.00	8.44 ± 1.00	8.65 ± 1.14
18	3.40 ± 2.10	6.82 ± 1.58	6.73 ± 1.40	6.68 ± 1.30	6.60 ± 1.30	7.03 ± 1.48
21	-1.05 ± 1.95	2.79 ± 1.47	2.68 ± 1.30	2.1 ± 1.20	2.41 ± 1.20	2.93 ± 1.37
24	-6.54 ± 2.96	-4.02 ± 2.20	-4.10 ± 1.90	-4.4 ± 1.80	-4.48 ± 1.80	-4.04 ± 2.08
Organic						
3	3.82 ± 1.13	4.09 ± 1.23	2.43 ± 3.12	4.00 ± 1.30	3.95 ± 1.50	4.22 ± 1.45
5	3.90 ± 0.71	4.06 ± 0.77	5.70 ± 1.94	3.55 ± 0.80	3.54 ± 1.00	3.59 ± 0.90
7	5.09 ± 0.78	5.21 ± 0.65	7.12 ± 2.20	4.51 ± 0.90	4.54 ± 1.00	4.47 ± 1.00
9	6.67 ± 0.76	6.80 ± 0.83	7.01 ± 2.10	6.10 ± 0.90	6.15 ± 1.00	6.05 ± 1.00
13	8.11 ± 0.86	8.31 ± 0.93	3.33 ± 2.40	7.92 ± 1.00	8.00 ± 1.20	7.96 ± 1.11
16	4.85 ± 0.88	5.04 ± 0.96	-1.34 ± 2.40	4.93 ± 1.00	5.03 ± 1.20	5.05 ± 1.12
19	-4.84 ± 1.18	-4.80 ± 1.29	-6.54 ± 3.30	-4.78 ± 1.30	-4.68 ± 1.60	-4.71 ± 1.51

Table A7(2)

DYNAMICS OF CROP GROWTH.

1971 Field Trial - Computed Data.

3. Leaf Area Ratio - Observed Values

Treatment &	STOCKLESS - NO FERTILIZER						STOCKLESS - 375 Kg FERTILIZER/ha						STOCKLESS - 625 Kg FERTILIZER/ha					
Age (weeks)	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic S	Tic M	Tic S	Throw O	Throw M	Throw S
3	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.02
5	43.62	50.43	41.14	86.40	79.90	71.33	59.60	52.20	52.46	110.73	99.10	90.44	58.45	60.53	29.74	77.52	88.70	78.30
7	86.77	115.20	102.41	109.70	131.60	100.91	99.85	125.66	92.10	107.90	99.90	105.20	61.92	90.00	86.97	100.70	108.70	119.60
10	79.35	83.50	54.67	78.60	109.20	90.38	82.07	90.53	100.76	109.20	112.20	80.88	78.06	76.01	79.25	91.50	102.00	98.60
12	60.29	67.00	80.56	79.01	72.20	84.60	62.66	69.27	64.33	62.70	69.30	64.33	80.25	77.13	72.06	83.30	69.10	94.50
14	39.84	43.50	59.56	60.36	(103.20)	(117.40)	52.67	53.22	91.10	36.40	32.80	58.97	51.77	43.70	34.83	70.60	55.00	69.80
18	34.11	28.70	31.20	45.89	32.00	32.40	39.27	22.14	28.60	26.40	23.50	38.40	31.19	25.76	17.43	27.10	40.60	30.70
21	0.00	2.50	0.00	3.11	0.00	3.30	0.00	1.57	0.00	0.00	2.30	0.00	0.00	4.24	3.19	1.10	0.70	3.40
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Treatment &	ORGANIC					
Age (weeks)	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S
3	59.15	66.15	48.03	143.70	120.90	133.21
5	90.44	82.33	100.34	116.70	108.40	137.99
7	120.33	108.84	321.09	111.00	83.10	94.98
9	139.48	153.54	359.20	104.60	76.70	107.63
13	62.79	49.16	51.42	64.60	56.90	59.10
16	21.60	26.84	0.00	34.10	39.00	40.30
19	0.00	0.00	0.00	0.00	0.00	0.00

4. Net Assimilation Rate

Treatment &	STOCKLESS - NO FERTILIZER						STOCKLESS - 375 Kg FERTILIZER/ha.						STOCKLESS - 625 Kg FERTILIZER/ha.					
Age (weeks)	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S	Tic S	Tic M	Tic S	Throw O	Throw M	Throw S
3	1.024	0.362	1.070	0.205	0.758	0.304	0.640	0.233	0.140	0.540	0.260	0.495	0.725	0.242	0.422	0.307	0.303	0.270
5	0.013	0.022	0.013	0.018	0.009	0.021	0.012	0.019	0.008	0.010	0.021	0.009	0.014	0.023	0.032	0.022	0.022	0.022
7	0.001	0.002	0.001	0.002	0.001	0.002	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.002	0.001	0.001	0.001
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
18	0.036	0.001	0.036	0.001	0.038	0.001	0.034	0.002	0.050	0.041	0.001	0.035	0.034	0.001	0.001	0.001	0.002	0.001
21	-3.663	-0.087	-2.601	-0.058	-1.840	-0.029	-3.690	-0.080	-2.402	-4.131	-0.036	-3.699	-2.620	-0.072	-0.090	-0.068	-0.069	-0.040
24	$-\infty$	-76.200	$-\infty$	-74.412	$-\infty$	-87.161	$-\infty$	$-\infty$	$-\infty$	$-\infty$	-76.140	$-\infty$	$-\infty$	-69.980	-94.200	$-\infty$	$-\infty$	-88.430

Treatment &	ORGANIC					
Age (weeks)	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S
3	0.000	0.000	0.000	0.000	0.000	0.000
5	0.001	0.001	0.000	0.001	0.001	0.001
7	0.001	0.001	0.000	0.001	0.001	0.001
9	0.000	0.000	0.000	0.000	0.001	0.000
13	0.000	0.000	0.035	0.000	0.000	0.000
16	0.003	-0.001	0.017	0.002	0.001	0.002
19	-43.650	$-\infty$	$-\infty$	-32.470	-50.200	-58.160

Table A7(3)

DYNAMICS OF CROP GROWTH

1971 Field Trial - Computed Data

5. Relative Growth Rate with Standard Errors.

Treatment & Age (weeks)	Tic O	Tic M	Tic S	Throw O	Throw M	Throw S
STOCKLESS - NO FERTILIZER						
3	0.035 ± 0.014	0.035 ± 0.014	0.036 ± 0.015	0.049 ± 0.021	0.059 ± 0.018	0.056 ± 0.023
5	0.047 ± 0.008	0.047 ± 0.008	0.046 ± 0.008	0.060 ± 0.012	0.063 ± 0.011	0.061 ± 0.014
7	0.055 ± 0.004	0.054 ± 0.004	0.053 ± 0.005	0.066 ± 0.005	0.064 ± 0.006	0.063 ± 0.007
10	0.057 ± 0.004	0.056 ± 0.004	0.055 ± 0.004	0.066 ± 0.005	0.061 ± 0.005	0.061 ± 0.006
12	0.053 ± 0.004	0.052 ± 0.004	0.052 ± 0.005	0.060 ± 0.007	0.055 ± 0.005	0.055 ± 0.007
14	0.045 ± 0.005	0.043 ± 0.005	0.044 ± 0.005	0.050 ± 0.007	0.046 ± 0.006	0.046 ± 0.008
18	0.016 ± 0.003	0.013 ± 0.003	0.017 ± 0.003	0.016 ± 0.005	0.018 ± 0.004	0.019 ± 0.005
21	-0.019 ± 0.007	-0.021 ± 0.007	-0.013 ± 0.007	-0.022 ± 0.010	-0.009 ± 0.008	-0.009 ± 0.011
24	-0.062 ± 0.014	-0.066 ± 0.014	-0.053 ± 0.016	-0.070 ± 0.022	-0.044 ± 0.019	-0.044 ± 0.024
STOCKLESS - 375 Kg FERTILIZER/ha						
3	0.025 ± 0.011	0.020 ± 0.020	0.005 ± 0.013	0.049 ± 0.020	0.066 ± 0.013	0.039 ± 0.011
5	0.042 ± 0.006	0.037 ± 0.012	0.027 ± 0.008	0.060 ± 0.011	0.068 ± 0.008	0.053 ± 0.006
7	0.057 ± 0.003	0.052 ± 0.005	0.050 ± 0.003	0.067 ± 0.005	0.066 ± 0.003	0.065 ± 0.003
10	0.060 ± 0.003	0.056 ± 0.005	0.057 ± 0.003	0.067 ± 0.005	0.062 ± 0.003	0.066 ± 0.003
12	0.057 ± 0.003	0.056 ± 0.006	0.058 ± 0.004	0.061 ± 0.006	0.055 ± 0.004	0.062 ± 0.003
14	0.049 ± 0.004	0.049 ± 0.006	0.053 ± 0.004	0.051 ± 0.006	0.046 ± 0.004	0.052 ± 0.004
18	0.017 ± 0.002	0.020 ± 0.005	0.024 ± 0.003	0.016 ± 0.004	0.019 ± 0.003	0.017 ± 0.003
21	-0.022 ± 0.005	-0.015 ± 0.009	-0.014 ± 0.006	-0.022 ± 0.009	-0.008 ± 0.006	-0.023 ± 0.005
24	-0.073 ± 0.012	-0.062 ± 0.021	-0.065 ± 0.014	-0.071 ± 0.021	-0.041 ± 0.014	-0.075 ± 0.012
STOCKLESS - 625 Kg FERTILIZER/ha						
3	0.027 ± 0.016	0.025 ± 0.014	0.033 ± 0.016	0.060 ± 0.018	0.057 ± 0.022	0.052 ± 0.017
5	0.042 ± 0.010	0.041 ± 0.008	0.047 ± 0.010	0.066 ± 0.011	0.064 ± 0.014	0.059 ± 0.010
7	0.054 ± 0.004	0.055 ± 0.004	0.058 ± 0.004	0.068 ± 0.005	0.068 ± 0.006	0.064 ± 0.004
10	0.057 ± 0.004	0.058 ± 0.004	0.059 ± 0.004	0.065 ± 0.005	0.065 ± 0.006	0.063 ± 0.005
12	0.054 ± 0.005	0.055 ± 0.005	0.056 ± 0.005	0.059 ± 0.006	0.060 ± 0.007	0.058 ± 0.006
14	0.047 ± 0.005	0.047 ± 0.005	0.047 ± 0.006	0.049 ± 0.006	0.050 ± 0.008	0.049 ± 0.006
18	0.019 ± 0.004	0.014 ± 0.003	0.015 ± 0.004	0.018 ± 0.004	0.020 ± 0.005	0.019 ± 0.004
21	-0.016 ± 0.008	-0.025 ± 0.007	-0.023 ± 0.008	-0.013 ± 0.009	-0.012 ± 0.011	-0.013 ± 0.008
24	-0.061 ± 0.017	-0.076 ± 0.015	-0.071 ± 0.018	-0.053 ± 0.020	-0.052 ± 0.024	-0.053 ± 0.018
ORGANIC						
3	0.044 ± 0.010	0.033 ± 0.014	0.003 ± 0.010	0.059 ± 0.018	0.071 ± 0.017	0.042 ± 0.018
5	0.050 ± 0.005	0.049 ± 0.007	0.036 ± 0.005	0.061 ± 0.009	0.069 ± 0.009	0.053 ± 0.009
7	0.053 ± 0.003	0.057 ± 0.004	0.057 ± 0.003	0.060 ± 0.005	0.064 ± 0.005	0.058 ± 0.005
9	0.051 ± 0.003	0.057 ± 0.004	0.065 ± 0.003	0.056 ± 0.005	0.056 ± 0.005	0.058 ± 0.005
13	0.037 ± 0.003	0.033 ± 0.004	0.046 ± 0.003	0.038 ± 0.005	0.031 ± 0.005	0.040 ± 0.005
16	0.017 ± 0.003	-0.007 ± 0.005	0.000 ± 0.003	0.016 ± 0.007	0.004 ± 0.006	0.012 ± 0.007
19	-0.012 ± 0.010	-0.065 ± 0.015	-0.073 ± 0.010	-0.013 ± 0.019	-0.030 ± 0.018	-0.030 ± 0.019

Table A8

DYNAMICS OF CROP GROWTH. 1972 Field Trial.

Each reading a mean of 5 samples.

A. Raw Data. Fields.

Age (weeks)	Total Dry Weight (gms)			Leaf Area (cms^2)			Shoot length (cms)			Lysimeters - plants Total Dry Weights (gms)			
	O	M	S	O	M	S	O	M	S	O	M	S	HF S
7	0.42	0.34	0.49	41.7	35.3	58.0	5.6 ± 0.5	7.1 ± 0.6	5.1 ± 0.4				
10	1.60	0.87	1.28	203.0	103.0	161.0	25.5 ± 2.1	19.3 ± 1.4	29.3 ± 0.9				
14	11.72	8.07	10.22	880.0*	587.0	629.0*	-	-	-				
19	20.35	37.83	20.27	588.0	691.2*	453.0	79.5 ± 1.8	81.8 ± 2.3	91.3 ± 1.0				
22	21.00	47.90*	25.91	0.0	0.0	0.0	-	-	-				
27 - total	36.70*	41.80	36.60*	0.0	0.0	0.0	139.8 ± 2.7	140.0 ± 5.4	148.0 ± 8.0	10.56	13.50	15.50	14.80
- pods	4.90	6.50	4.80							1.38	2.11	2.10	2.14
- beans	19.20	22.60	18.30							4.02	5.24	5.90	6.01
- stems	12.60	12.70	13.50							5.16	6.14	7.51	6.63

B. Fitted Data with Standard errors.

Age (weeks)	Fitted Log Weight			Fitted Log Area			Leaf Area Ratio			Net Assimilation Rate		
	O	M	S	O	M	S	O	M	S	O	M	S
7	-0.991 ± 0.17	-1.180 ± 0.15	-0.830 ± 0.18	3.02 ± 1.13	2.81 ± 1.18	3.36 ± 1.12	99.4 ± 3.3	102.9 ± 2.0	117.3 ± 2.6	0.0018	0.0012	0.0012
10	+0.749 ± 0.14	+0.151 ± 0.12	+0.624 ± 0.14	6.88 ± 0.91	6.37 ± 0.95	6.71 ± 0.90	129.9 ± 6.1	124.2 ± 25.0	126.5 ± 11.1	0.0002	0.0001	0.0001
14	2.148 ± 0.15	1.848 ± 0.13	1.971 ± 0.15	7.00 ± 0.98	6.56 ± 1.02	6.62 ± 0.96	77.2 ± 9.2	73.9 ± 5.7	63.3 ± 8.5	0.0003	0.0005	0.0004
19	2.918 ± 0.13	3.468 ± 0.12	2.929 ± 0.14	2.27 ± 0.88	2.26 ± 0.92	2.07 ± 0.86	29.3 ± 2.0	20.3 ± 4.3	24.9 ± 4.6	0.024	0.113	0.044
22	3.127 ± 0.15	3.972 ± 0.13	3.238 ± 0.16	-1.46 ± 0.99	-1.27 ± 1.04	-1.50 ± 0.99	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.843	2.526	1.294
27	3.538 ± 0.19	3.674 ± 0.17	3.524 ± 0.20	-6.05 ± 1.29	-6.09 ± 1.35	-6.04 ± 1.28	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0			

Age (weeks)	Relative Growth Rate		
	O	M	S
7	0.100 ± 0.013	0.063 ± 0.012	0.080 ± 0.014
10	0.067 ± 0.005	0.063 ± 0.005	0.060 ± 0.006
14	0.035 ± 0.004	0.056 ± 0.003	0.038 ± 0.004
19	0.013 ± 0.004	0.034 ± 0.004	0.019 ± 0.004
22	0.009 ± 0.003	0.013 ± 0.003	0.011 ± 0.004
27	0.018 ± 0.013	-0.033 ± 0.011	0.007 ± 0.013

*Maxima

TABLE A9(1). CROP GEOCHEMISTRY

CONCENTRATION OF THE GEOCHEMICALS IN THE THREE PLANT TYPES GROWN ON THE TWO DIFFERENT SOILS IN THE GREENHOUSE. 1970/1971.

All concentrations as mg/gm dry plant material.

ORGANIC SOIL

Age (days)	NO_3-N			Nitrogen			Phosphorus			Potassium		
	O	M	S	O	M	S	O	M	S	O	M	S
7	0.036	0.023	0.053	15.2	8.0	24.8	1.00	1.60	1.33	13.0	16.3	15.8
14	0.040	0.043	0.038	17.3	38.7	18.0	1.00	1.53	2.25	14.0	16.3	16.5
21	0.113	0.128	0.165	14.5	48.3	29.0	1.20	2.85	1.33	20.0	22.5	19.3
28	0.163	0.141	0.133	30.6	26.2	6.2	1.23	1.40	2.13	15.8	18.5	19.3
46	0.143	0.113	0.116	19.1	31.4	19.1	1.13	0.93	1.33	16.5	15.0	20.0
52	0.130	0.154	0.143	2.9	5.9	5.3	0.50	0.85	1.40	13.0	18.5	21.5
58	0.132	0.129	0.194	2.7	3.4	3.2	0.78	1.63	1.08	17.0	20.5	17.5
65	0.182	0.162	0.110	3.6	13.6	3.1	1.05	1.20	0.55	19.3	21.5	15.8
73	0.096	0.148	0.110	5.2	3.1	2.9	0.70	1.05	0.50	14.0	20.5	11.0
Mean	0.115	0.116	0.118	12.3	19.8	12.4	0.95	1.45	1.32	15.8	18.8	17.4
S.D.	0.050	0.050	0.050	9.5	16.8	10.3	0.25	0.60	0.60	2.6	2.6	3.1
STOCKLESS SOIL												
7	0.034	0.036	0.032	8.8	15.6	3.7	1.08	1.48	1.23	13.0	15.8	15.8
14	0.045	0.052	0.025	20.2	28.7	27.0	1.13	2.75	2.23	15.8	19.0	16.5
21	0.068	0.142	0.076	19.2	24.9	39.8	1.15	0.50	3.23	18.5	19.3	21.5
28	0.091	0.133	0.141	8.6	6.8	3.5	1.00	1.75	0.50	18.5	20.5	19.3
46	0.115	0.114	0.145	15.9	17.0	22.9	1.48	1.70	1.05	16.5	17.5	19.3
52	0.166	0.157	0.140	5.1	2.4	7.3	0.68	0.78	0.55	20.5	20.5	20.0
58	0.116	0.133	0.157	4.8	6.1	4.5	1.08	0.88	3.50	15.8	20.5	24.5
65	0.128	0.107	0.174	2.6	4.9	9.6	1.23	1.70	2.15	21.5	19.3	24.5
73	0.123	0.144	0.135	5.3	3.5	2.9	1.78	2.53	2.50	20.5	22.5	30.5
Mean	0.098	0.113	0.113	10.06	12.2	13.5	1.01	1.56	1.88	15.8	19.4	21.3
S.D.	0.043	0.042	0.055	6.7	9.7	13.3	0.48	0.76	1.10	6.5	1.9	4.6
Analysis of seeds used on both soils:-												
Seed	0.019	0.019	0.013	3.7	3.7	4.8	0.70	1.53	1.70	13.0	15.8	15.8

TABLE A9(2). CROP GEOCHEMISTRY

CONCENTRATION OF THE GEOCHEMICALS IN THE THREE PLANT TYPES GROWN ON THE TWO DIFFERENT SOILS IN THE GREENHOUSE. 1970/1971.

All concentrations as mg/gm dry plant material.

ORGANIC SOIL

Age (days)	Calcium			Magnesium			Sodium			Zinc		
	O	M	S	O	M	S	O	M	S	O	M	S
7	7.3	7.0	8.1	0.9	1.0	0.9	2.8	2.3	1.8	1.00	1.50	0.55
14	8.1	8.6	7.6	1.0	1.2	0.9	4.5	3.6	3.1	0.15	0.08	0.15
21	10.9	8.6	9.3	1.2	1.1	1.0	12.1	7.3	7.3	0.15	0.15	0.05
28	10.9	10.1	8.6	1.3	1.3	1.0	5.0	7.6	7.6	0.08	0.05	0.05
46	9.3	11.8	10.5	1.2	1.5	1.2	9.8	9.8	9.8	0.08	0.15	0.08
52	11.7	10.5	9.3	1.5	1.5	1.3	7.3	7.6	11.3	0.05	0.08	0.05
58	9.5	9.3	11.8	1.6	1.3	1.3	8.5	6.3	8.5	0.05	0.15	0.15
65	13.8	9.8	11.3	1.4	1.4	1.3	9.8	8.0	5.0	0.15	0.05	0.08
73	11.8	12.3	8.8	1.4	1.0	0.7	4.0	8.5	6.3	0.08	0.05	0.15
Mean	10.4	9.8	9.5	1.3	1.3	1.1	7.1	6.8	6.7	0.2	0.3	0.2
S.D.	2.0	1.7	1.4	0.2	0.2	0.2	3.2	2.4	3.1	0.3	0.5	0.2
STOCKLESS SOIL												
7	7.3	7.3	8.1	0.8	1.0	0.8	2.3	1.8	1.4	1.35	1.85	0.65
14	8.1	8.1	7.3	1.1	1.0	1.0	3.7	3.6	1.8	0.20	0.15	0.15
21	10.1	8.6	8.1	1.2	1.0	1.0	4.5	3.6	2.8	0.25	0.05	0.15
28	10.1	12.5	9.3	1.1	1.3	1.0	3.6	5.4	4.5	0.08	0.20	0.05
46	9.9	10.5	10.8	1.3	1.2	1.2	5.8	5.8	6.3	0.08	0.08	0.05
52	11.3	10.5	9.8	1.2	1.2	1.2	5.4	5.4	4.5	0.05	0.08	0.05
58	11.3	10.5	11.8	1.0	1.2	1.2	4.0	5.8	4.0	0.05	0.05	0.15
65	12.5	11.3	11.3	1.3	1.1	1.0	5.0	5.0	6.3	0.15	0.08	0.20
73	12.5	11.8	9.8	1.2	1.0	1.3	4.5	5.4	4.0	0.30	0.20	0.30
Mean	10.3	10.1	9.6	1.1	1.1	1.1	4.3	4.6	4.0	0.3	0.3	0.2
S.D.	1.8	1.8	1.6	0.2	0.1	0.2	1.1	1.4	1.7	0.4	0.6	0.2
Analysis of seeds used on both soils:-												
Seed	2.3	2.6	2.6	0.8	0.8	0.8	1.8	1.8	1.4	0.15	0.08	0.08

TABLE A10(1) CROP GEOCHEMISTRY

CONCENTRATION OF THE GEOCHEMICALS IN THE THREE PLANT TYPES GROWN ON TWO DIFFERENT SOILS IN THE GREENHOUSE.

ORGANIC SOIL

All concentrations as. mg/ plant.

Age (days)	NO_3-N			Nitrogen			Phosphorus			Potassium		
	O	M	S	O	M	S	O	M	S	O	M	S
7	0.019	0.012	0.034	8.1	4.1	16.2	0.53	0.83	0.87	6.9	8.5	10.3
14	0.023	0.019	0.024	10.1	17.7	11.3	0.58	0.69	1.42	8.1	7.3	10.4
21	0.059	0.057	0.080	7.5	21.9	14.0	0.62	1.28	0.64	10.4	10.1	9.3
28	0.098	0.073	0.085	18.5	13.6	4.0	0.74	0.73	1.36	9.5	9.6	12.4
46	0.099	0.077	0.081	13.2	21.4	13.3	0.78	0.63	0.93	11.4	10.2	14.0
52	0.104	0.131	0.087	2.5	5.1	3.2	0.40	0.72	0.85	10.4	15.7	13.1
58	0.136	0.096	0.173	2.7	2.6	2.9	0.80	1.21	0.96	17.3	15.2	15.6
65	0.155	0.125	0.092	3.1	10.5	2.6	0.90	0.92	0.46	16.4	16.6	13.1
73	0.074	0.071	0.111	4.0	1.5	2.9	0.54	0.50	0.50	10.8	9.8	11.0
Mean	0.085	0.073	0.085	7.7	10.9	7.8	0.65	0.83	0.89	11.2	11.4	12.1
S.D.	0.046	0.041	0.043	5.5	8.1	5.7	0.16	0.26	0.34	3.5	3.4	2.0
STOCKLESS SOIL												
7	0.019	0.019	0.020	5.0	8.4	2.3	0.61	0.80	0.78	7.4	8.5	10.0
14	0.024	0.029	0.014	10.6	15.7	15.7	0.59	1.51	1.29	8.2	10.5	9.6
21	0.038	0.071	0.042	10.5	12.4	21.9	0.63	0.25	1.78	10.2	9.7	11.8
28	0.049	0.074	0.087	4.6	3.8	2.2	0.54	0.98	0.31	10.0	11.5	12.0
46	0.079	0.096	0.109	10.9	14.3	17.3	1.02	1.43	0.79	11.4	14.7	14.5
52	0.116	0.135	0.105	3.6	2.0	5.5	0.50	0.67	0.41	14.4	17.6	15.0
58	0.082	0.088	0.148	3.4	4.0	4.3	0.76	0.58	3.29	11.1	13.5	23.0
65	0.100	0.090	0.129	2.1	4.1	7.1	0.96	1.43	1.59	16.8	16.2	18.1
73	0.072	0.093	0.088	3.1	2.3	1.9	1.03	1.64	1.63	11.9	14.6	19.8
Mean	0.064	0.077	0.082	6.0	7.4	8.7	0.73	1.03	1.32	11.3	13.0	14.9
S.D.	0.034	0.035	0.047	3.6	5.4	7.6	0.21	0.49	0.91	2.9	3.1	4.6
Analysis of seeds used on both soils:-												
Seed	0.012	0.011	0.009	2.3	2.1	3.1	0.43	0.86	1.10	8.1	8.9	10.3

TABLE A10(2) CROP GEOCHEMISTRY

CONCENTRATION OF THE GEOCHEMICALS IN THE THREE PLANT TYPES GROWN ON TWO DIFFERENT SOILS IN THE GREENHOUSE.

All concentrations in mg/ plant.

ORGANIC SOIL

Age (days)	Calcium			Magnesium			Sodium			Zinc		
	O	M	S	O	M	S	O	M	S	O	M	S
7	3.9	3.6	5.3	0.5	0.5	0.6	1.5	1.2	1.2	0.53	0.78	0.36
14	4.7	3.9	4.8	0.6	0.5	0.6	2.6	1.6	2.0	0.09	0.04	0.09
21	5.7	3.9	4.5	0.6	0.5	0.5	6.3	3.3	3.5	0.08	0.07	0.02
28	6.5	5.3	5.5	0.8	0.7	0.6	3.0	4.0	4.9	0.05	0.03	0.03
46	6.4	8.0	7.4	0.8	1.0	0.8	6.8	6.7	6.9	0.06	0.10	0.06
52	9.4	8.9	5.7	1.2	1.3	0.8	5.8	6.5	6.9	0.04	0.07	0.03
58	9.7	6.9	10.5	1.6	1.0	1.2	8.7	4.7	7.6	0.05	0.11	0.13
65	11.7	7.6	9.4	1.2	1.1	1.1	8.3	6.2	4.2	0.13	0.04	0.07
73	9.1	5.9	8.8	1.1	0.5	0.3	3.1	4.1	6.3	0.06	0.02	0.15
Mean	7.5	6.0	6.9	0.9	0.8	0.8	5.1	4.3	4.8	0.12	0.13	0.10
S.D.	2.6	2.0	2.2	0.4	0.3	0.2	2.6	2.0	2.3	0.16	0.25	0.10
STOCKLESS SOIL												
7	4.2	3.9	5.1	0.5	0.5	0.5	1.3	1.0	0.9	0.77	0.99	0.41
14	4.2	4.5	4.2	0.6	0.6	0.6	1.9	2.0	1.0	0.10	0.08	0.09
21	5.6	4.3	4.5	0.7	0.5	0.6	2.5	1.8	1.5	0.14	0.03	0.08
28	5.5	7.0	5.8	0.6	0.7	0.6	1.9	3.0	2.8	0.04	0.11	0.03
46	6.8	8.8	8.1	0.9	1.0	0.9	4.0	4.9	4.7	0.06	0.07	0.04
52	7.9	9.0	7.4	0.8	1.0	0.9	3.8	4.6	3.4	0.04	0.07	0.04
58	7.9	6.9	11.1	0.7	0.8	1.1	2.8	3.8	3.8	0.04	0.03	0.14
65	9.8	9.5	8.4	1.0	0.9	0.7	3.9	4.2	4.7	0.12	0.07	0.15
73	7.3	7.7	6.4	0.7	0.7	0.9	2.6	3.5	2.6	0.17	0.13	0.20
Mean	6.6	6.8	6.8	0.7	0.7	0.8	2.7	3.2	2.8	0.16	0.18	0.13
S.D.	1.9	2.1	2.2	0.2	0.2	0.2	0.9	1.4	1.5	0.23	0.31	0.12
Analysis of seeds used on both soils:-												
Seed	1.4	1.5	1.7	0.5	0.5	0.5	1.1	1.0	0.9	0.10	0.08	0.05

Table A11(1)

CROP GEOCHEMISTRY

Concentration of Geochemicals in Separate Plant Parts at Final Harvest 1971.

(Concentrations expressed as mg ion/gm dry wt. of plant part)

	FERTILIZER: NONE											FERTILIZER: 375 Kg/ha										
Plant Type	P	N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb	P	N	NO_3-N	Ca	Mg	Na	K	Al	Cu	Zn	Pb
STEMS																						
Tic O	0.5	8	0.14	6.8	0.10	2.0	1.5	0.3	0.99	0.57	0.36	0.6	13	0.17	9.9	0.00	5.2	1.2	0.2	0.99	0.65	0.07
Tic M	1.1	10	0.15	8.9	0.20	3.4	1.9	1.5	1.65	0.98	0.14	0.4	10	0.17	7.9	0.00	3.8	1.6	0.1	1.76	1.07	0.12
Tic S	1.1	9	0.14	9.9	0.02	4.5	0.8	1.3	0.53	0.33	0.10	1.0	7	0.15	3.5	0.00	2.7	0.8	0.0	2.68	1.58	0.10
Thro O	0.5	7	0.17	7.9	0.00	3.3	0.9	0.1	1.72	1.03	0.14	0.5	8	0.12	7.4	0.20	2.1	1.0	0.2	1.72	1.05	0.07
Thro M	0.4	7	0.14	5.2	0.02	4.4	1.0	0.3	0.55	0.39	0.09	0.9	9	0.17	10.4	0.20	2.7	1.7	1.5	1.91	1.16	0.10
Thro S	0.5	8	0.11	8.3	0.07	3.7	0.9	0.6	1.00	0.49	0.10	1.0	10	0.18	9.8	0.00	2.8	0.9	1.1	1.61	0.97	0.11
Mean	0.7	8.2	0.14	7.8	0.07	4.5	1.2	0.7	1.07	0.63	0.15	0.7	9.5	0.16	8.2	0.07	3.2	1.2	0.5	1.78	1.08	0.09
Standard Dev.	0.3	1.2	0.02	1.7	0.01	2.8	0.4	0.6	0.50	0.30	0.10	0.3	2.1	0.02	2.6	0.10	1.1	0.4	0.6	0.50	0.30	0.02
PODS																						
Tic O	3.9	28	0.10	5.0	0.9	0.6	10.4	0.02	0.01	0.20	1.90	2.3	41	0.09	1.9	0.8	0.7	9.2	0.02	0.45	0.36	0.27
Tic M	3.9	39	0.09	3.3	0.7	0.5	7.4	0.02	0.68	0.46	0.36	3.5	25	0.10	4.9	0.7	1.3	7.7	0.02	0.33	0.19	0.39
Tic S	1.7	33	0.09	3.1	0.8	1.2	6.4	0.02	0.41	0.28	0.22	3.9	39	0.10	1.7	0.4	0.8	5.9	0.02	0.13	0.11	0.17
Thro O	2.3	40	0.10	2.2	0.8	0.4	7.4	0.02	0.50	0.41	0.22	1.8	37	0.10	3.1	0.9	0.8	7.9	0.02	0.15	0.12	0.26
Thro M	4.0	47	0.10	1.4	0.8	0.7	6.4	0.02	0.57	0.40	0.59	1.6	47	0.16	3.2	1.0	0.3	7.9	0.02	0.19	0.15	0.11
Thro S	2.0	49	0.12	2.0	0.4	0.8	4.7	0.02	0.06	0.07	0.16	1.8	37	0.09	8.9	0.9	0.4	4.4	0.02	0.02	0.45	0.02
Mean	3.0	39.3	0.10	2.8	0.7	0.7	7.1	0.02	0.37	0.30	0.57	2.5	37.7	0.11	4.0	0.8	0.7	7.2	0.02	0.21	0.23	0.20
Standard Dev.	1.0	8.0	0.01	1.3	0.2	0.3	1.9	0.00	0.28	0.15	0.70	1.0	7.2	0.03	2.7	0.2	0.4	1.7	0.00	0.15	0.14	0.13
SEEDS																						
Tic O	3.3	43	0.07	3.0	1.5	0.20	7.2	0.4	0.01	0.02	0.03	4.6	45	0.08	1.4	1.1	0.04	6.4	0.02	0.009	0.011	0.04
Tic M	3.2	44	0.07	1.8	1.6	0.10	11.9	0.4	0.02	0.03	0.01	3.6	37	0.08	1.4	1.1	0.04	5.2	0.02	0.003	0.000	0.02
Tic S	3.4	47	0.10	2.2	1.5	0.20	6.9	0.3	0.01	0.02	0.01	3.5	43	0.05	1.1	1.0	0.10	6.2	0.05	0.004	0.001	0.01
Thro O	5.3	50	0.08	1.0	0.9	0.08	5.4	0.1	0.02	0.03	0.03	5.3	54	0.10	0.3	1.0	0.03	5.4	0.02	0.007	0.005	0.03
Thro M	5.3	37	0.07	0.9	0.9	0.05	5.2	0.0	0.01	0.01	0.06	3.0	56	0.07	1.0	1.0	0.03	5.9	0.02	0.009	0.005	0.07
Thro S	3.5	50	0.12	0.9	0.8	0.05	5.4	0.0	0.01	0.02	0.02	3.6	54	0.09	0.3	0.9	0.02	5.4	0.05	0.012	0.005	0.02
Mean	4.0	45.2	0.08	1.6	1.2	0.11	7.0	0.2	0.013	0.02	0.03	3.9	48.2	0.08	0.9	1.0	0.04	5.8	0.03	0.007	0.005	0.03
Standard Dev.	1.0	4.9	0.02	0.9	0.4	0.07	2.5	0.2	0.004	0.01	0.02	0.8	7.6	0.02	0.5	0.1	0.03	0.5	0.01	0.003	0.004	0.02

Table A 11(2)

Concentrations of Geochemicals in Separate Plant Parts at Final Harvest 1971.

(Concentrations expressed as mgm geochemical/gm.dry weight)

FERTILIZER: 625 Kg/ha

STEMS											
Tic O	0.9	10	0.17	6.1	0.0	2.6	1.2	0.4	0.05	0.08	0.06
Tic M	0.9	6	0.17	10.5	1.2	3.8	2.3	0.2	0.60	0.78	0.07
Tic S	0.8	5	0.16	8.8	0.3	5.5	1.6	0.2	0.39	0.26	0.07
Thro O	1.8	12	0.17	6.6	0.0	1.9	1.7	0.6	0.72	0.41	0.07
Thro M	1.3	10	0.18	8.4	0.1	3.2	1.5	1.2	0.56	0.30	0.06
Thro S	1.0	11	0.17	4.2	0.1	3.0	1.5	0.3	0.26	0.17	0.04
Mean	1.1	9.0	0.17	7.4	0.3	3.3	1.6	0.5	0.43	0.33	0.06
Standard Dev.	0.4	2.8	0.07	2.2	0.5	1.2	0.4	0.4	0.25	0.25	0.01
PODS											
Tic O	1.7	23	0.16	3.6	1.3	1.5	9.7	0.2	0.17	0.09	0.33
Tic M	2.2	33	0.16	4.9	1.5	1.5	10.9	0.3	0.10	0.07	0.09
Tic S	2.6	38	0.18	1.9	0.6	1.0	6.3	0.0	0.18	0.14	0.59
Thro O	1.3	29	0.17	3.7	1.5	0.6	10.9	0.2	0.25	0.13	0.07
Thro M	2.3	42	0.17	3.6	1.5	0.2	10.4	0.4	0.33	0.17	1.90
Thro S	1.8	35	0.15	3.0	1.6	0.7	10.2	0.2	0.70	0.34	0.17
Mean	2.0	33.3	0.16	3.5	1.3	0.8	9.7	0.2	0.29	0.15	0.52
Standard Dev.	0.5	6.7	0.01	1.0	0.4	0.4	1.7	0.1	0.22	0.09	0.70
SEEDS											
Tic O	3.2	44	0.10	2.4	1.3	0.05	5.7	0.02	0.006	0.000	0.04
Tic M	4.8	46	0.08	1.3	1.0	0.05	5.7	0.05	0.000	0.000	0.04
Tic S	3.6	44	0.09	1.2	0.9	0.05	6.4	0.05	0.000	0.000	0.03
Thro O	4.5	49	0.11	0.5	0.9	0.02	4.4	0.05	0.004	0.000	0.03
Thro M	5.1	50	0.08	0.2	0.8	0.10	5.7	0.05	0.003	0.001	0.03
Thro S	2.8	45	0.07	0.3	0.9	0.01	5.9	0.05	0.002	0.000	0.03
Mean	4.0	46.3	0.09	1.0	1.0	0.05	5.6	0.05	0.003	0.000	0.03
Standard Dev.	0.9	2.6	0.01	0.8	0.2	0.03	0.7	0.01	0.002	0.000	0.01

FERTILIZER: ORGANIC MANURE

STEMS											
Tic O	1.0	8	0.08	12.0	0.8	5.5	1.7	0.9	0.33	0.16	0.27
Tic M	1.0	14	0.09	11.9	0.8	5.8	1.5	0.5	0.09	0.03	0.20
Tic S	1.4	12	0.07	10.5	0.9	5.5	1.5	0.8	0.33	0.18	0.14
Thro O	1.2	11	0.09	14.3	1.2	5.4	1.2	1.2	0.01	0.03	0.01
Thro M	1.1	8	0.06	17.5	1.1	5.5	1.7	1.2	0.24	0.09	0.04
Thro S	1.8	14	0.07	12.0	0.7	3.9	1.2	0.6	0.01	0.01	0.04
Mean	1.3	11.2	0.07	13.0	0.9	5.3	1.5	0.9	0.17	0.08	0.12
Standard Dev.	0.3	2.7	0.01	2.5	0.2	0.7	0.2	0.3	0.15	0.07	0.10
PODS											
Tic O	2.6	33	0.09	4.9	1.7	1.5	9.7	0.2	0.02	0.05	0.02
Tic M	3.4	22	0.08	3.5	1.7	1.6	7.4	0.3	0.10	0.07	0.43
Tic S	3.8	40	0.09	3.7	1.7	1.6	5.7	0.4	0.01	0.04	0.10
Thro O	3.5	36	0.07	4.2	1.6	1.6	5.4	0.5	0.02	0.04	0.07
Thro M	2.0	40	0.09	3.6	1.6	1.3	5.9	0.4	0.05	0.03	0.43
Thro S	2.4	45	0.06	3.0	1.5	1.5	4.4	0.4	0.01	0.02	0.14
Mean	3.0	36.0	0.08	3.8	1.6	1.5	6.4	0.4	0.04	0.04	0.20
Standard Dev.	0.7	8.0	0.01	0.7	0.1	0.1	1.9	0.1	0.03	0.02	0.19
SEEDS											
Tic O	4.4	50	0.07	1.5	0.8	0.2	4.7	0.2	0.008	0.000	0.02
Tic M	3.9	54	0.06	1.1	0.9	0.6	5.4	0.1	0.000	0.000	0.02
Tic S	2.9	54	0.09	0.8	0.9	0.3	5.9	0.2	0.004	0.010	0.03
Thro O	3.2	55	0.09	0.5	0.7	0.2	5.2	0.2	0.008	0.005	0.02
Thro M	2.5	60	0.09	0.8	0.8	0.1	5.2	0.2	0.008	0.002	0.00
Thro S	3.0	54	0.08	1.9	0.8	0.3	4.4	0.3	0.007	0.015	0.00
Mean	3.3	55	0.08	1.1	0.8	0.3	5.1	0.2	0.006	0.005	0.01
Standard Dev.	0.7	3.2	0.01	0.5	0.1	0.2	0.5	0.1	0.003	0.006	0.01

NITROGEN FIXATION

TABLE A12. Summary Table to Demonstrate the Effect of Treatment upon Nodulation and Nitrogen Fixation during 1972 and 1973 seasons

Date	Temperature ^oC		Treatment type	Age of plants (weeks)	No. of replicates	Plant growth-shoot height (cms)	Conc. C_2H_2 used % $^v/v$	Incubation time (hr)	Nodule Statistics						Rate of Nitrogen Fixation								
									Main Root nodules			Total nodules			/root/hr µM			/main root nodule/hr µM			/nodule/hr µM		
	Field Air & soil.	Laboratory							Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
2 /3/72	A 15.0	-	O	11	10	36.0	11.0	3.0	-	-	-	31.5	13.1	4.2	40.0	12.6	4.0	-	-	-	1.33	0.37	0.13
	S 12.0		M	10	9	29.0						34.5	15.5	4.9	30.1	10.0	3.3	-	-	-	1.33	1.00	0.33
Whole			S	11	9	40.0						36.1	8.9	3.0	54.7	30.7	10.2	-	-	-	1.53	0.70	0.23
22/6/72	A 15.0	19.5	O	14	8	79.0	11.0	3.0	-	-	-	35.6	16.6	5.9	8.97	8.43	2.97	-	-	-	0.25	0.18	0.06
	S 13.5		M	13	10	82.0			-	-	-	32.5	9.2	2.9	30.93	17.33	5.47	-	-	-	0.97	0.43	0.13
Whole			S	14	8	91.0			-	-	-	41.3	15.3	5.4	39.93	13.83	4.90	-	-	-	1.07	0.48	0.17
									% Large pink nodules of Total						Selected roots			/root/hr - All roots			Selected roots		
30/4/73	A 8.0	10.5	O	7	12	4.0	19.5	2.0	-	25%	-	13.2	4.4	1.3	0.073	0.057	0.030	0.047	0.047	0.013	0.012	0.007	0.003
			M	7	14	4.0			-	29%	-	17.4	4.9	1.3	0.337	0.227	0.080	0.203	0.230	0.063	0.023	0.020	0.007
Whole			S	7	12	4.0			-	75%	-	12.3	5.3	1.5	0.510	0.240	0.083	0.350	0.307	0.087	0.042	0.026	0.009
22/5/73	A 18.0	20.5	O	10	10	23.0	19.5	2.0	24.5	8.9	2.8	26.8	9.1	2.9	22.2	12.3	3.9	0.87	0.23	0.07	0.80	0.30	0.10
			M	10	8	17.3			25.3	7.4	2.6	33.4	12.6	4.5	29.9	14.8	3.2	1.63	0.97	0.33	0.93	0.47	0.17
Whole			S	10	9	17.7			47.3	14.3	4.8	56.2	16.5	5.5	57.0	16.1	5.3	1.30	0.50	0.17	1.07	0.37	0.13
			PPKK	10	10	26.6	19.5	2.0	32.0	5.9	1.9	37.2	8.0	2.5	40.0	13.2	4.2	1.23	0.32	0.10	1.07	0.30	0.07
			NNPPKK	10	10	18.5			22.6	7.9	2.5	26.5	10.1	3.2	30.0	15.7	5.0	1.30	0.36	0.10	1.10	0.23	0.07
7 /6/73	A 22.5	23.5	O	12	12	69.8	19.5	2.0	38.2	10.6	3.1	55.9	11.6	3.3	12.4	4.5	1.3	0.33	0.13	0.03	0.23	0.07	0.02
	S 17.5		M	12	12	55.2			44.7	8.0	2.3	60.3	17.0	4.9	82.0	20.5	5.9	2.70	1.03	0.30	1.43	0.60	0.17
Whole			S	12	12	55.1			47.3	8.3	2.4	72.2	21.7	6.3	100.9	57.0	16.4	2.77	2.53	0.73	1.43	0.90	0.27
			PPKK	12	12	52.3	19.5	2.0	33.9	10.7	3.1	52.0	24.2	7.0	95.2	35.5	10.3	3.17	0.93	0.27	1.97	0.60	0.17
			NNPPKK	12	12	48.2			24.6	6.9	2.0	34.2	10.7	3.1	60.1	23.0	6.6	2.83	1.13	0.33	1.47	0.70	0.20
			NNPK	12	12	48.8			30.8	7.4	2.1	43.5	12.0	3.5	51.4	31.7	9.2	1.63	0.83	0.23	1.10	0.50	0.13
20/6/73	A 20.0	18.0	O	14	15	107.0	19.5	1.0	7.9	5.2	1.4	21.3	12.5	3.2	4.1	5.4	1.4	0.44	0.35	0.09	0.16	0.13	0.03
			M	14	15	90.0			2.3	2.1	0.5	9.1	7.1	1.8	1.3	1.3	0.3	0.84	1.17	0.35	0.14	0.09	0.02
			S	14	15	86.0			11.5	8.9	2.3	24.3	20.2	5.2	14.5	12.8	3.3	1.30	1.03	0.27	0.57	0.23	0.07
Decapitated	A 14.5	18.0	PPKK	14	15	79.3	19.5	1.0	-	-	-	11.4	5.2	1.3	4.0	6.0	1.6	-	-	-	0.31	0.41	0.11
			NNPPKK	14	14	71.9			-	-	-	5.9	5.2	1.3	2.2	2.2	0.6	-	-	-	0.36	0.29	0.08
			NNPK	14	14	81.1			-	-	-	4.4	2.9	0.8	1.1	1.2	0.3	-	-	-	0.21	0.17	0.04