THE UNIVERSITY OF HULL

Comparisons of crop yields using semi-organic and inorganic fertilizers

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TABLE OF CONTENTS

Summary of Thesis submitted for Ph.D degree

by Michael David Kerr

on

Comparisons of Crop Yields using a Semi-Organic and Inorganic Fertilizers

A series of experiments is described in which a semi-organic fertilizer is compared to the more widely used inorganic type. A semi-organic fertilizer contains a base of organic materials to which is added a mixture of inorganic salts to make up a suitable analysis. The results from three years field trials and certain greenhouse experiments are presented. Barley was used as the test crop in all experiments. Biomass production and nitrogen accumulation were studied in the field trials.

In the field trials a greater stand density was produced using the semi-organic fertilizer as compared with an inorganic fertilizer and no-fertilizer treatment. This difference was evident from early in the season and was therefore attributed to relative success in germination and/or establishment. A high salt concentration in the soil water surrounding seeds has been shown to reduce the rate and final percentage germination for a wide variety of crops. The superior stand density produced on the semi-organic treatment was probably due to the lower osmotic effect produced by that fertilizer. The results of the greenhouse experiments supported this hypothesis. Field and greenhouse experiments were not analogous with respect to the emergence observed on the no fertilizer treatment.

The pattern of nitrogen uptake was different on the two fertilizer treatments. Proportionally more nitrogen was absorbed later in the season by plants growing on the semi-organic treatment. This led to a greater nitrogen content per head on the semi-organic treatment. Although there were significantly more heads per unit area on the semi-organic treatment there was no difference in the dry weight per head, this could be due to prolonged photosynthesis in the heads on this treatment. Total biomass production was similar on the two fertilized treatments but proportionally more of the weight was in the heads on the semi-organic treatment. There was a strong negative correlation, later in the season, between plant density and a) dry weight per plant and b) nitrogen content per plant on the inorganic fertilizer treatment but this was not so on the ~~semi-organic fer~~tilizer.

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CHAPTER I

INTRODUCTION

1.1 Factors affecting nitrogen in the soil

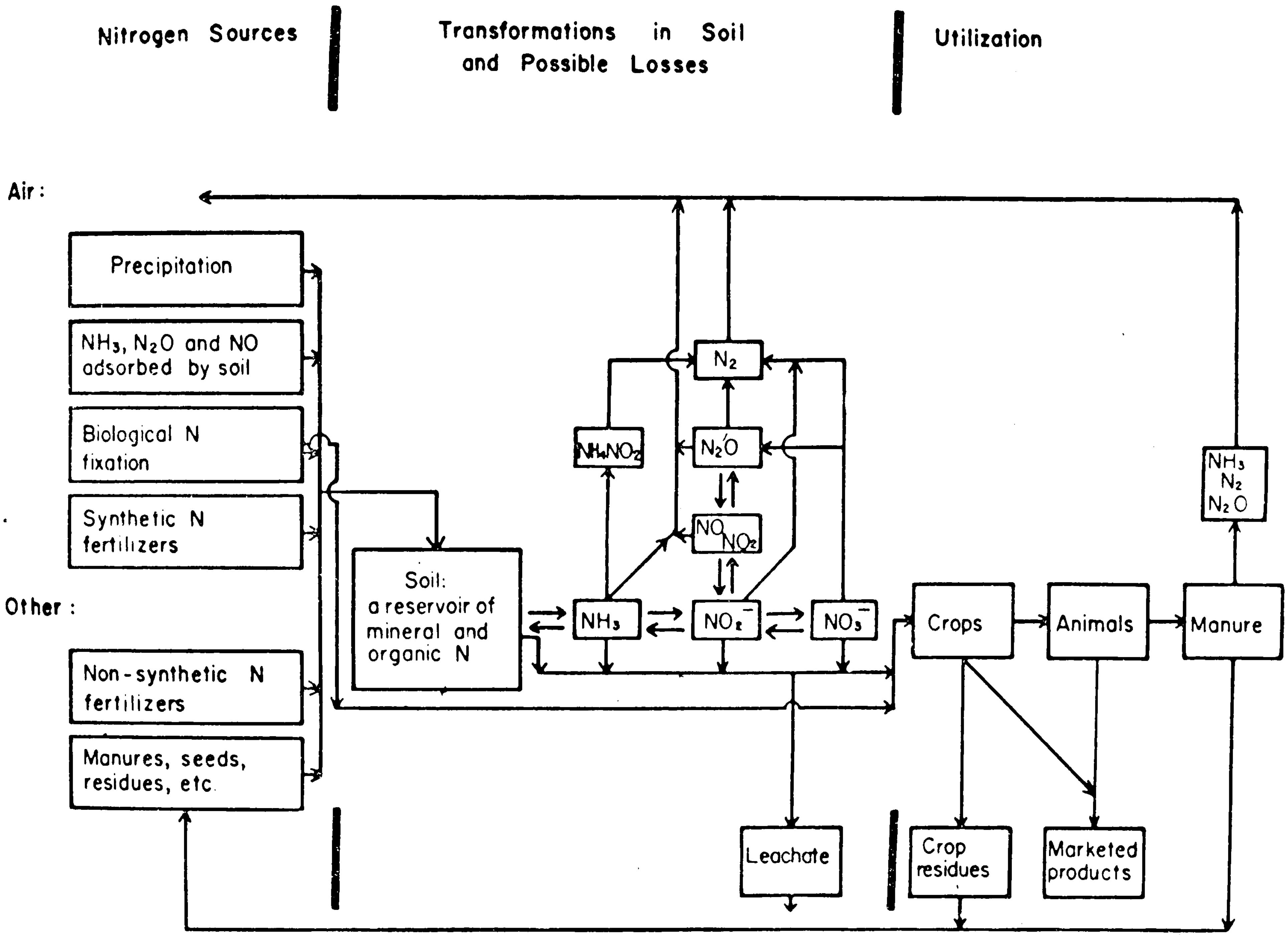
In natural conditions the source of most of the nitrogen absorbed by plants is the organic component of the soil. This organic nitrogen is rendered available by a process of mineralization during which ammonia, nitrite and nitrate are released. Ammonium and nitrate nitrogen constitute the main forms in which nitrogen is taken up by plant roots. Nitrite is taken up in trace amounts only (Scarsbrook, 1965). The soil nitrogen can be supplemented by fertilizer additions, symbiotic and non-symbiotic fixation and rainfall.

The rate of mineralization of soil nitrogen is affected by a wide variety of environmental factors, e.g. soil temperature (Jenny, 1930), soil moisture (Reitemeier, 1946), soil pH (Harmsen and van Schriven, 1955), carbon-nitrogen ratio (Harmsen and van Schriven, 1955), and fertilization and management. Nitrogen can also be lost from the plant/soil system in a number of ways including leaching of nitrates into groundwater, volatalization of ammonia, bacterial denitrifaction and degradation of nitrite from acid soils. The complex of events briefly outlined above can be summarized in what has become known as the Nitrogen Cycle (Figure 1.1)

1.2 The importance and limitations of fertilizers

Until the turn of the century the maintenance of nitrogen levels in farm soils was an urgent problem because agriculture depended entirely upon natural sources of nitrogen. These were mainly from animal and vegetable wastes and by their very nature the supply of these materials was limited. As a fertilizer they were inefficient and expensive in terms of man-hours as the nutrient value was low, making it necessary to apply them in large quantities. Since it first became possible to fix

Fig. 1.1 The Nitrogen Cycle



Soil nitrogen sources and transformations, and fate of end products. (From Allison, 1965.)

atmospheric nitrogen, its use as a fertilizer has roughly doubled every ten years (Cooke, 1964). The changes over the last half-century in the world use of nitrogenous fertilizers have been important in our progress in overcoming natural limitations to food supplies.

However, fertilizer nitrogen, once applied to the plant/soil system is subject to the same processes as that released from soil organic matter. It is exposed to biological immobilization and remobilization, which, like all biological processes are affected by environmental factors such as aeration, water, denitrification, chemical immobilization, leaching and the kind and amount of organic matter present. Too little nitrogen limits yields and reduces quality of a crop, too much can also reduce yields and quality and cause lodging of cereals and sometimes make forage toxic to animals.

It has become increasingly evident that not all applied nitrogen is taken up by the growing crop. From a review of nitrogen balance sheet data collected from a large series of lysimeter experiments in the United States and U.K., Allison (1955) found that nitrogen recovery was between 21-79% of that applied. In pot experiments the recovery rates are usually somewhat higher than in field trials where recovery rates are generally below 50% (Martin and Skyring, 1962). This is certainly not a new discovery, for Russell (1939) reported that cereals usually recovered approximately a third of the nitrogen they received, potatoes, sugar beet, and mangolds about one half, and swedes only a fifth. Recovery of applied nitrogen is generally determined by the difference method, that is, the difference between uptake with and without added nitrogen.

Allison (1966) in a review of his 1955 study summarized the results as follows:-

" 1. Data from lysimeters, located at various state experimental stations, showed that an average of about 15 per cent of the added fertilizer nitrogen could not be accounted for in the crops, soils, and leachates. The magnitude of the deficits were largely independent of the form in which the nitrogen was added.

2. Data from a few greenhouse experiments that supplied adequate information for the calculation of nitrogen balances showed that the unaccounted for nitrogen ranged from near zero to fifty per cent.
3. In long term field experiments, where the leached nitrogen was not determined, the unrecovered nitrogen commonly ranged between fifty and seventy five per cent. The evidence indicated that most of this unrecovered nitrogen was lost through leaching, but frequently gaseous losses appeared to be nearly as large.
4. It was concluded that nitrogen gains through non-symbiotic nitrogen fixation are too small to affect appreciably the nitrogen balance.
5. The unaccounted-for nitrogen, aside from that lost by leaching, was shown to escape as ammonia, chiefly from alkaline soils; as nitrous oxide and nitrogen gas through denitrification; and to a lesser extent as nitric oxide formed by the chemical decomposition of nitrites.
6. The inadequacy of quantitative data on nitrogen loss mechanisms, and on soil nitrogen balances, was emphasized."

Most of the mineral nitrogen lost from the soil by leaching is in the form of nitrate. This is due to the fact that nitrate nitrogen is highly soluble and not markedly absorbed by soil clay or soil organic matter (Bray, 1945). Commoner (1968) in a survey of the nitrate content of the Missouri River, showed that the amount of nitrate acquired from the Nebraska farmlands had increased in parallel with the increasing annual use of nitrogenous fertilizers in Nebraska since 1955 and that high nitrate content of rivers in Illinois farmland was traceable almost entirely to fertilizer that drained into the groundwater.

1.3 Slow release fertilizers

Over the last decade or so, various techniques have been developed for controlling the rate of release or production of nitrate from fertilizers. These include the incorporation of nitrification retarders (Goring, 1962a, b) into the fertilizer and methods of reducing the rate at which nitrate is released (Parr, 1967). The ability of nitrification retarding additives to increase yields has been demonstrated for a variety of crops, such as upland rice (Prasad, 1966), cotton (Swezey and Turner, 1962) and maize (Prasad and Turkhede, 1971). In Louisiana, however, Patrick, Peterson and Turner (1968) observed that although a nitrification inhibitor was very effective in preventing the conversion of ammonium to nitrate under laboratory conditions, no significant increase in yield of rice was obtained under field conditions. There have been many similar reports from various workers on a wide variety of crops (Prasad and Turkhede, 1971).

The slow release of nitrate through a growing season may not, however, supply the plant with enough nitrogen at specific stages of growth. Many experiments have shown that cereals absorb a large proportion of their total nitrogen requirement in the early stages of development. Gregory (1952) states that, "In the developing cereal plant grown at different levels of nitrogen, over 90% of the total nitrogen taken up by the plant has been accumulated when the dry weight is only 25% of the final value". Hanway (1962b) showed that corn grown in Iowa on rotation plots where nitrogen was not limiting had accumulated about 65% of its nitrogen when only 44% of the dry weight had been accumulated.

Although these experiments indicate that the nitrogen component of a cereal fertilizer should be readily available, certain difficulties can occur in practice. Heavy rain soon after fertilization can leach a large proportion of the applied nitrogen out of the rooting layers (Morgan and Street, 1939), while high salt concentrations during periods of drought could damage the roots of seedlings (Carter, 1967). The latter can be particularly severe when combine drills are used (Mason, 1971).

1.4 Semi-organic fertilizers

A possible solution to these problems might be to apply a fertilizer consisting of a combination of readily available and slow release nitrogen sources. Such a combination is provided by the so called 'semi-organic' fertilizers.

The 'semi-organic' type of fertilizer would fall mid-way between the extremes of wholly inorganic and wholly organic fertilizers. Such a fertilizer might be expected to have many advantages, among which would be a readily available source of nutrients to give plants an adequate supply early in their development, and a fraction from which nutrients would be released slowly and which would not be subject to a rapid rate of leaching in wet weather.

The organic fraction would also be a source of minor elements such as iron, copper, zinc, manganese and molybdenum, shortages of which can be serious. These elements are not supplied by high grade inorganic fertilizers. Coupled with this, a semi-organic fertilizer would help to maintain the level of soil organic matter, the importance of which is discussed at great length by Allison (1973).

1.5 Outline of present study

The work to be described consists of a series of experiments in which the relative performances of barley grown with semi-organic and inorganic fertilizers have been assessed. The semi-organic fertilizer used is a product of Humber Manures Ltd. of Hull and consists of an organic base plus a mixture of inorganic additives that make up a suitable analysis. This analysis can be varied according to the type of crop to be fertilized. The basic experiments have been carried out on a field scale but greenhouse trials have also been performed to test certain hypotheses. Barley has been used as the test crop.

CHAPTER II

Preliminary Field Experiments 1970

2.1 Aims

The experiments were designed to compare yields using two types of fertilizer, an inorganic and semi-organic. For this, the first series of experiments, small plots, 2 square yards (1.7 sq.m) in area were used. They were located at two sites, one near Little Humber, about three miles east of Paull on the north bank of the River Humber (grid. ref. 208223), and the other on a farm near Everingham about six miles west of Market Weighton (grid. ref. 823418). Each site was 225 sq. yards (186.3 sq. metres) in total area and was situated at the edge of a large field of the same crop.

The soil at Paull is an alluvial boulder clay and at Everingham a light sandy material derived from the glacial outwash sands of that area. The boulder clay soil is heavy textured and retains water very effectively and is considered to have a good inherent fertility with pH about 7.8. The glacial outwash sands on the other hand are fine textured and free draining. They are generally regarded as low in natural fertility and are susceptible to wind-blow and erosion (pH about 6.8).

The annual rainfall at the two sites is about 25 inches (635mm). This is characteristic of the area to the east of the Pennines. Both fields involved in the trials had been put down to barley the previous season.

2.2 Materials and Methods

Two fertilizers were used, a semi-organic of analysis 6%N, 6% K_2O, 6% P_2O_5 and an inorganic fertilizer of the same analysis. Neither fertilizers were available commercially and both were in powder form. A treatment with no added fertilizer was also included.

The semi-organic fertilizer was a mixture of an organic fraction and an inorganic fraction containing the same salts as were present exclusively in the inorganic fertilizer. The composition of the organic fraction is given in Table 2.1

Table 2.1 - Composition of organic fraction in semi-organic fertilizer

Material	Amount (cwts/ton)	Nitrogen content (% fresh wt.)
Castor meal	2	0.5
Poultry manure	3	0.45
Meat and bone	4	1.08
Skin Meal	3	0.9
Organic base	8	1.2
Organic base:-		
Meat and bone	1.3	1.08
Castor meal	4	0.5
Sewage sludge	15	1.4

The final organic fraction is a dry powder of analysis 4.13% N, 3.61% P_2O_5, 0.24% K_2O. To this is added the requisite amounts of ammonium sulphate, potassium chloride and superphosphate to make up the final 6:6:6 analysis. The inorganic fertilizer is comprised of these three salts alone in a sand base.

Barley (cv. Julia) was used at both sites. This was the variety being sown over the remainder of each field by the farmer.

A standard randomized block design was chosen for both trials. There were three treatments, viz:- semi-organic, inorganic and no fertilizer, two sampling times and four replicates of each treatment arranged in four blocks. There were therefore twenty four plots in each area. Each plot was 2 yds x 1 yd (1.82 x 0.91m) therefore having an area of 2 sq. yds (1.7 sq.m). A 1 yd (0.91m) strip of land was left fallow around each plot and the whole area was separated from the field crop by a two yard strip, weeding of the fallow areas was done by hand. In each plot, three furrows were dug approximately eight inches apart and two yards long. Seed was sown into these furrows by hand at a rate equivalent to 12 stone/acre (188 Kg ha^{-1}) and the seed fertilized with the equivalent of 5 cwts/acre (627.6 Kg ha^{-1}) of the appropriate fertilizer. Soil was then raked over each furrow.

Sowing took place on 2 May 1970 at Little Humber and 7 May 1970 at Everingham. It was noticed that after nearly a month, no growth was evident at the Everingham site and upon examination of the site no seed could be found. It was concluded that the local partridge population had devoured it and resowing took place on 31 May.

At Little Humber the experimental plots were situated at one corner of a large field of barley, and after several weeks it became apparent that those plots nearest to the drain which ran down the side of the field, had been badly nibbled. The damage was such that one block of replicates had to be abandoned. This left three replicates of each treatment.

The first sample was taken from the Little Humber site on 4 August 1970. A sample consisted of the most uniform row from the three rows sown in each plot. All plants in that row were dug up, taking as much rooting material as possible. Individual plants were separated in the laboratory. From each sample twenty five plants were selected at random the roots cut off and the number of tillers and heads noted for each plant. Each plant was then placed in a paper envelope and dried at 90°C for one week (to constant weight). After each plant had been weighed the heads were removed, redried and weighed.

Unfortunately the second sample from this site could not be taken because the whole site was devastated by a severe thunderstorm four days before the final harvest time.

Due to the lateness of the sowing and very uneven growth of the plots, only one sample was taken from the Everingham site. This sample was taken on the 6 September, the day after the remainder of the field had been harvested.

At Everingham, all the plants occupying a plot were harvested. Again, as much root material as possible was taken so as to identify individual plants. Plants from each replicate plot were placed in a large polythene bag and transported back to the laboratory where individual plants were separated out and the number of plants and heads in each plot counted. The root material was cut off and the whole sample dried as before to constant weight. All heads were then cut off and redried and weighed.

2.3 Results

The results are presented in Tables 2.2 and 2.3. All relevant statistical data is presented in Appendix II. The data was analysed by the two way analysis of variance, as shown in Appendix I, the known sources of variation being treatments and blocks. The results have not been transformed.

Yield data for Little Humber

2.2a Mean total dry weight sample^{-1} (g)

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
216.9	167.8	185.3	20.6	34.2

2.2b Mean total number of heads sample^{-1}

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
178.7	128.0	128.0	28.2	46.9

2.2c Mean total dry weight of heads sample^{-1}(g)

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
85.73	67.37	62.12	12.80	21.22

2.2d Mean total number of tillers sample^{-1}

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
207.3	144.0	133.3	40.7	67.5

2.2e Mean dry weight plant^{-1}(g)

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
8.67	6.71	7.41	1.22	2.03

Yield data for Everingham

2.3a Mean total dry weight sample^{-1}(g)

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
269.0	241.4	75.3	62.4	94.5

2.3b Mean total number of plants sample^{-1}

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
255.3	237.0	115.5	45.2	68.5

2.3c Mean total number of heads sample^{-1}

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
307.8	253.0	84.3	81.9	124.0

2.3d Mean total dry weight of heads sample^{-1}(g)

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
113.9	85.7	20.1	28.6	43.4

2.3e Mean dry weight plant^{-1}(g)

Semi-organic	Inorganic	No fertilizer	L.S.D. P=0.05	L.S.D. P=0.01
1.05	1.03	0.59	0.34	0.52

2.4 Discussion

Due to the many mishaps encountered during the course of these preliminary trials, the results obtained were not as complete as would have been desired. The crop at Everingham had to be resown very late in the season (May 31). This would be detrimental to the plants, Kirby (1969a, 1969b) and Kakizaki (1937) having shown that decreases in grain dry matter yields and thousand grain weights occurred at late sowing dates. At both sites only one sample could be taken instead of two, but despite the incompleteness of the results, certain interesting differences emerged from the various treatments at the two sites.

At Little Humber the mean dry weight per sample of the no fertilizer treatments was greater than the inorganic treatments, (Table 2.2a). Although the difference is not significant this is a rather remarkable result and it must be assumed that it was a result of the utilization of nutrients remaining in the soil from previous fertilizer applications. On a dry weight per plant basis (Table 2.2e) and number of tillers per sample (Table 2.2d) there was again, no significant effect of the inorganic fertilizer treatment over the no fertilizer treatment. The mean number of heads per sample (Table 2.2b) was the same in these two treatments but the mean dry weight per sample of heads on the no fertilizer treatment was lower than that on the inorganic treatment although not significantly so ($P>0.05$, Table 2.2c). All these results indicate a high level of residual soil fertility at this site.

The mean dry weight per sample on plots treated with semi-organic fertilizer was significantly higher than either of the other two treatments ($P<0.05$, Table 2.2a). This was a result of a significantly greater number of tillers per sample ($P<0.05$, Table 2.2d) and a greater dry weight per plant ($P<0.05$, Table 2.2e).

At Everingham the effect of fertilizer usage was much more marked.

The inorganic treatment values are significantly greater than the no fertilizer treatment values in all comparisons, at least at the 5% level of probability (Tables 2.3a - 2.3e). Perhaps the most surprising result is the difference in the mean numbers of plants per plot (Table 2.3b). The no fertilizer treatment value is significantly lower than either of the two fertilized treatment values ($P<0.01$). This would indicate either a failure in germination and/or establishment with this treatment, due to very low soil fertility levels. The differences between the semi-organic and inorganic treatments were not so marked at the Everingham site. The mean values for the plots with semi-organic fertilizer were always the higher but the differences were never significant. Both semi-organic and inorganic fertilizer treatments were significantly higher than the no fertilizer treatment in all comparisons ($P<0.05$ Tables 2.3a - 2.3e). It is possible that differences between the inorganic and semi-organic fertilizer treatments were being masked by the extremely low values obtained from the no fertilizer treatment. These low values contribute to an enlarged overall variance and an unduly large error-mean square component in the analysis of variance method. This could be circumvented by transforming the results by some standard method, e.g. log of x or square root of x, but as these were preliminary trials and the results largely incomplete this step was omitted.

A comparison of the performance of the no fertilizer treatment at both sites is quite revealing. On a plant dry weight comparison, (Tables 2.2e and 2.3e), the mean value at Little Humber was 7.41g per plant as compared with 0.59g per plant at Everingham. On a total dry weight basis (Tables 2.2a and 2.3a) the value at Little Humber is 185.3g as against 75.3g at Everingham even though only a random sample of twenty five plants per plot was taken from the Little Humber site and the whole plot value was measured from the Everingham site. This corroborates very well the initial assessment of the inherent soil fertility conditions prevailing at the two sites, although the eventual late sowing date at Everingham would undoubtedly be a major contributing factor.

On examining Tables 2.2b and 2.3c it can be seen that in the semi-organic treatment the number of fertile tillers (i.e. number of heads) was greater in each sample compared with the inorganic and no fertilizer treatments. Aspinall (1961) showed that varying nutrient regimes altered the pattern of tiller production in Barley. Langer (1966) found that tiller production was increased by raising the supply of nitrogen, phosphorus and potassium, and of these elements, nitrogen seemed to be the most important. It seemed, therefore, on the basis of the results of the preliminary trials, that a semi-organic fertilizer might be more efficient than a purely inorganic source in supplying the growing plant with these nutrients. As nitrogen is considered the most important nutrient in this connection, it seemed expedient to concentrate on the uptake of this element in future trials.

CHAPTER III

Field Trials 1971

3.1 INTRODUCTION

As the 1970 trials had been subject to many mishaps and unforseen difficulties, a different approach was adopted for the 1971 series. It was concluded that most of the difficulties had arisen as a result of using a small plot design, where a relatively minor disturbance to the layout had far-reaching effects on the value, completeness and ease of interpretation of the ensuing results. An experimental layout had to be chosen that would circumvent these difficulties in the field.

The 1971 trials were, therefore, on a much larger and more ambitious scale than those attempted previously. The aim of the experiments was as before, viz:- to compare yields of barley when semi-organic (S.O.) and inorganic fertilizers (I.F.) were used. Two methods of determining the amount of each fertilizer applied were used. In the first the fertilizers were applied in equal weights per acre, and in the second in similar 'unit values' per acre. 'Unit value' is a term which incoporates the amount applied and the analysis of the fertilizer in question (1 unit = 1.12 lbs of plant nutrient). A series of nitrogen determinations on samples harvested at different stages of development was undertaken in order to gain some insight into the nutrient releasing properties of the fertilizers used.

3.2 MATERIALS AND METHODS

Three sites were available. Two in the Yorkshire Wolds near Wharram-le-Street (grid ref. 845657) and the other near Aldborough on the Yorkshire Coast (grid ref. 235374). The soil at Wharram-le-Street was classified in 1971 by the Agricultural Advisory Council as, "well drained, naturally calcareous, medium or heavy textured soils often shallow over chalk or limestone". The soils at the two sites were indeed extremely shallow (depth never exceeding four inches) and almost black in colour.

The Aldborough site was on boulder clay and the soil in this area was in all respects similar to that described for Little Humber in Chapter II. All three sites were essentially flat and all had been sown with barley the previous season.

All the fertilizers used in these experiments were commercially available in 1971. The semi-organic (S.O.) fertilizer used was a hard, compact pellet, slightly fibrous in nature. The composition of the organic and inorganic fractions was the same as the S.O. fertilizer used in the 1970 trials, but they were mixed in different proportions to give a final analysis of 9.6.6. (N.P.K.). The analysis of the inorganic fertilizers (I.F.) used at Wharram-le-Street and at Aldborough was 15.10.10. and 20.14.14. respectively. The choice of inorganic fertilizer was left to the farmer concerned and was in keeping with his usual fertilizer practices. The rates of application of the fertilizer were as follows:-

Aldborough (similar unit value per acre) Site I

Semi-organic (S.0): 3 cwts acre^{-1} (376.5 Kg ha^{-1}) giving 27 units N 18 units P_2O_5 and 18 units K_2O per acre.

Inorganic: (I.F.) 1.5 cwts acre^{-1} (188.3 Kg ha^{-1}) 20.14.14. giving 30 units N, 21 units P_2O_5 and 21 units K_2O per acre.

Wharram-le-Street (similar unit value acre^{-1}) Site II

Semi-organic: 2.5 cwts acre^{-1} (313.8 Kg ha^{-1}) 9.6.6. giving 22.5 units N, 15 units P_2O_5, 15 units K_2O per acre.

Inorganic: 1.7 cwts acre^{-1} (213.4 Kg ha^{-1}) 15.10.10. giving 25.5 units N, 17 units P_2O_5 and 17 units K_2O per acre.

Wharram-le-Street (same fertilizer weight $acre^{-1}$) Site III

Semi-organic: 2.5 cwts $acre^{-1}$ (313.8 Kg ha^{-1}) 9.6.6. giving 22.5 units N, 15 units P_2O_5, 15 units K_2O per acre.

Inorganic: 2.5 cwts acre (313.8 Kg ha^{-1}) 15.10.10. giving 37.5 units N, 25 units P_2O_5, 25 units K_2O per acre.

Twelve stone of Sultan barley per acre (188 Kg ha^{-1}) were sown at each site. The seed and fertilizer were sown using a precalibrated combine drill, giving twenty, seven-inch rows. Sowing took place on 6 April 1971 at Aldborough (Site I) and 25 March and 26 March 1971 at Wharram-le-Street. At each site, strips were incoporated where no fertilizer (N.F.) was applied. There were therefore three treatments at each site.

The basic plan of the experiment was a system of strips, nine in all, at each site. Semi-organic and inorganic fertilizers were each applied to three strips and the remaining three were left unfertilized. Each strip was then subdivided into three blocks in a direction at right angles to the orientation of the strips. Altogether therefore there were nine blocks of each treatment (Figure 2.1).

Each strip consisted of eighty rows of plants and each strip was approximately one acre (0.4 ha) in area. Three samples were taken from each block during the growing period. A sampling unit consisted of a 3ft (0.91m) length of one row and the row to be sampled and the position of the unit within the row was determined by means of a table of random numbers.

Plants were dug up from the sampling units to include as much rooting material as possible, in order that individual plants could be distinguished. Subsequent measurements were carried out on the shoot systems only. The samples were placed in polythene bags for transportation to the laboratory.

Figure 2.1

a_3	b_3	c_3	a_6	b_6	c_6	a_9	b_9	c_9
a_2	b_2	c_2	a_5	b_5	c_5	a_8	b_8	c_8
a_1	b_1	c_1	a_4	b_4	c_4	a_7	b_7	c_7

Diagrammatic representation of experimental layout at each site. Letters refer to treatments, numerals refer to sample number.

a = S.O.

b = I.F.

c = No fertilizer

Sampling took place at 8, 16 and 21 weeks after sowing. The 21 week sample was taken just before the crop was harvested. Measurements were taken of the number of plants in a unit, their dry weight, the number and dry weight of fruiting heads and the nitrogen content of heads and vegetative parts.

The eight week samples were small enough to dry *en masse*. The plants were dried to constant weight in an oven at 80°C. The subsequent samples were so large, however, that it was necessary to take subsamples for the determination of dry weights. Each subsample consisted of ten plants chosen at random from the sample. The air dry and oven dry weights of each batch of ten plants were determined and the air dry weight of the whole sample corrected accordingly. From each sample, thirty heads were selected at random and air dry and oven dry weights determined. The oven dry weight of the heads for a full sample was calculated from the air dry weight as before.

Nitrogen determinations were carried out using the standard semi-micro-Kjeldahl sulphuric acid digestion technique followed by Markham distillation into boric acid as described by Humphries (1956).

Data were examined by means of analysis of variance. For practical reasons it was necessary for the blocks to be arranged in a regular pattern. There was no visible variation in slope of any of the fields however, indeed, this was one of the criteria taken into consideration when choosing them. There was also no noticeable variation in soil colour or texture over the fields, certainly there were never any wide divergences in pH within any of the three fields used. It was therefore considered that a comparison of the results using analysis of variance was valid. The results were not transformed.

The number of replicate blocks of each treatment at Site II had to be reduced to six because of shortage of fertilizer.

3.3 RESULTS

The analysis of variance data relevant to each table is presented separately in Appendix II. The least significant difference (L.S.D.) values derived from the analyses of variance are presented with each table (N.S. = No Significant Difference between treatments).

Table 3.1 shows the mean dry weight per sampling unit for the three sites at the three harvest times. This gives an assessment of the performance of the treatments in terms of total yield of dry matter produced.

Table 3.1 - Mean Total Dry Weight Unit^{-1}(g)

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
8 week	22.5	23.7	13.5	6.2	8.5
16 week	136.3	119.2	88.3	35.9	49.5
21 week	149.3	131.6	109.4	25.3	34.9
Site II - Wharram-le-Street					
8 week	37.8	37.4	20.6	9.5	13.5
16 week	101.7	95.4	71.1	N.S.	N.S.
21 week	114.4	97.9	72.3	13.0	18.5
Site III - Wharram-le-Street					
8 week	38.0	34.9	22.5	8.9	12.3
16 week	105.1	119.5	78.1	18.9	26.1
21 week	145.3	106.1	96.5	27.7	38.2

As can be seen from the data presented in Table 3.1, significant treatment differences emerge at all sites and at all sampling times except the 16 week sample at Site II. At Sites II and III (both at Wharram-le-Street) the S.O. treatment gave significantly higher yields over both the I.F. and no fertilizer treatments in the final (21 week) sample. At Site I (Aldborough) the S.O. and I.F. treatments were not significantly different from each other but only the S.O. treatment was significantly greater than the no fertilizer treatment ($P<0.05$). These results largely bare out the 1970 results but in this chapter the increase in yield will be analysed more critically.

Examination of the results showing mean dry weight per plant (Table 3.2) shows that there was very little variation in the final values at the 21 week stage regardless of treatments.

Table 3.2 - Mean Dry Weight Plant^{-1} (g)

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
8 week	0.41	0.46	0.30	0.11	0.15
16 week	2.10	2.40	1.60	0.50	0.70
21 week	2.30	2.40	2.10	N.S.	N.S.
Site II - Wharram-le-Street					
8 week	0.72	0.78	0.56	N.S.	N.S.
16 week	1.70	2.20	1.80	N.S.	N.S.
21 week	2.20	2.50	1.60	0.30	0.50
Site III - Wharram-le-Street					
8 week	0.59	0.70	0.49	0.11	0.16
16 week	1.70	2.00	1.40	0.27	0.37
21 week	2.00	2.50	2.00	N.S.	N.S.

From these results it can be seen that only at Site II were there any significant differences between treatments ($P<0.01$). This is due to the large difference between the I.F. treatment ($\bar{x}$=2.50g) and the N.F. treatment ($\bar{x}$=1.60g). So, the higher total yield obtained using S.O. (Table 3.1) must be attributable to the differences in mean number of plants per unit rather than the mean dry weight per plant. This aspect will be fully dealt with later.

In a comparison of the total dry weight of heads produced per sampling unit (Table 3.3) an insight into the composition of the total dry weight yield can be gained.

Table 3.3 - Mean Total Dry Weight of Heads Unit^{-1}(g)

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
16 week	64.2	49.2	41.1	15.7	21.7
21 week	71.9	47.3	43.7	9.2	12.6
Site II - Wharram-le-Street					
16 week	62.8	54.8	49.0	N.S.	N.S.
21 week	56.6	39.8	39.0	9.4	13.4
Site III - Wharram-le-Street					
16 week	50.5	51.4	34.9	7.5	10.3
21 week	62.8	46.4	43.7	9.3	12.8

At the 21 week stage, the treatments were significantly different at all three sites. On inspection of the L.S.D. values it can be seen that the S.O. treatment produced a superior total dry weight of heads over the I.F. and N.F. treatments ($P<0.01$). It is interesting to note here the relatively poor performance of the I.F. treatment compared with the N.F. treatment. At the 21 week stage there was no significant differences between the I.F. and N.F. treatments at any of the sites. The relative performance of these two treatments will be discussed more fully later in this chapter.

The results from Table 3.3 indicate a superior head yield using S.O. but as shown in Table 3.4 only at Site I (21 week stage) was the mean dry weight per head significantly different under the three treatments.

Table 3.4 - Mean Dry Weight Head^{-1}(g)

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
16 week	0.54	0.52	0.52	N.S.	N.S.
21 week	0.74	0.62	0.61	0.06	0.09
Site II - Wharram-le-Street					
16 week	0.67	0.67	0.68	N.S.	N.S.
21 week	0.71	0.68	0.67	N.S.	N.S.
Site III - Wharram-le-Street					
16 week	0.54	0.53	0.49	0.04	0.05
21 week	0.69	0.70	0.67	N.S.	N.S.

Again, therefore, it seems that the superior yield of heads per unit must be attributable to the number, rather than the dry weight of individual heads. Data on the mean number of plants per unit are presented in Table 3.5

Table 3.5 - Mean Number of Plants Unit^{-1}

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
8 week	61.0	50.8	44.9	8.9	12.4
16 week	65.5	51.6	54.8	10.8	14.8
21 week	64.8	54.3	52.2	9.3	12.8
Site II - Wharram-le-Street					
8 week	53.0	47.5	39.0	N.S.	N.S.
16 week	59.6	44.8	42.2	N.S.	N.S.
21 week	52.7	38.8	47.3	7.2	10.2
Site III - Wharram-le-Street					
8 week	65.0	50.7	46.0	9.2	12.7
16 week	62.0	61.1	54.8	N.S.	N.S.
21 week	66.0	43.0	49.7	10.7	14.8

Taking the average number of plants present over the three sampling times at each site the results shown in Table 3.6 are obtained.

Table 3.6 - Number of plants present unit^{-1} (Mean of three harvests)

	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I	63.8	52.2	50.6	6.8	9.1
Site II	55.1	43.7	42.8	8.4	11.3
Site III	64.3	51.6	50.2	6.1	8.4

As can be seen from the data in Table 3.6 the mean number of plants per unit area present in the S.O. treated samples is significantly higher ($P<0.01$) than either the I.F. or N.F. treatments at all sites.

From Table 3.5 it appears that inequalities in plant density were present at the 8 week stage so it is likely that they can be attributed to differences in percentage germination and/or establishment. This problem was investigated and the results will be presented later.

The mean numbers of heads per sampling unit (Table 3.7) reflects the increase in plant numbers enumerated in Tables 3.5 and 3.6. At all sites the numbers of heads per sample were significantly greater on the strips where S.O. treatment was used, than on either of the other treatments at the 21 week stage ($P<0.01$). This would account for the increased total yield of heads per unit shown in Table 3.3.

Table 3.7 - Mean Number of Heads $Unit^{-1}$

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
16 week	117.6	96.2	78.4	15.7	21.7
21 week	97.3	74.4	72.2	11.0	15.2
Site II - Wharram-le-Street					
16 week	93.8	83.2	72.2	N.S.	N.S.
21 week	79.7	58.2	58.3	10.6	15.0
Site III - Wharram-le-Street					
16 week	94.1	97.8	73.3	12.5	17.2
21 week	90.2	65.1	64.1	13.0	17.9

Data on the mean total Nitrogen taken up per sampling unit and per plant at 8 and 21 weeks are presented in Tables 3.8 and 3.9 respectively.

Table 3.8 - Mean Total Nitrogen Uptake $Unit^{-1}$ (mg)

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
8 week	859.20	869.40	455.00	220.40	303.34
21 week	1569.91	1293.48	1053.78	326.27	449.54
Site II - Wharram-le-Street					
8 week	672.47	622.16	421.58	204.29	290.57
21 week	1212.29	997.36	801.57	152.31	216.63
Site III - Wharram-le-Street					
8 week	732.00	813.20	464.10	233.62	321.89
21 week	1293.21	945.21	861.96	199.45	274.81

Table 3.9 - Mean Nitrogen Uptake Plant^{-1}(mg)

HARVEST	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I - Aldborough					
8 week	13.85	17.11	10.13	3.60	4.97
21 week	24.56	23.82	20.19	N.S.	N.S.
Site II - Wharram-le-Street					
8 week	12.68	13.10	10.94	N.S.	N.S.
21 week	23.00	25.71	16.95	2.85	4.06
Site III - Wharram-le-Street					
8 week	11.26	16.03	10.09	3.10	4.26
21 week	19.59	21.99	17.34	2.67	3.68

The variation due to treatments was significant at all three sites at both sampling times with regard to the total nitrogen uptake per unit (Table 3.8). At the eight week stage there seems to be little difference in the total amount absorbed by the S.O. and I.F. treatments, and in general both absorbed more nitrogen than the N.F. treatment ($P<0.05$). At the 21 week stage, however, the S.O. treatment is seen to have absorbed significantly more than the I.F. and N.F. treatments (P 0.05) at sites II and III. At Site I plants on the S.O. treatment recovered more nitrogen on average but the difference was not significant (P 0.05). Only at Site II did the I.F. treated crop recover significantly more nitrogen in total than the N.F. treatment, whereas the nitrogen uptake from the S.O. treatment was invariably significantly greater than the N.F. treatment ($P<0.05$).

The total nitrogen uptake was a reflection of the total number of plants in the sample, for as inspection of Table 3.9 shows, the difference in nitrogen uptake per plant was never significant between I.F. and S.O. treatments at the 21 week stage. The nitrogen recovery per unit on the S.O. strips was always greater than on I.F. treatment strips and considering that the total nitrogen uptake per plant in the two treatments was never significantly different between the two treatments at the 21 week stage it is again the differences in plant density which are responsible for the differences in total uptake. At the eight week stage plants in the I.F. treated units had recovered significantly more nitrogen per plant than those in the S.O. treatment at Site III. This might lend support to the hypothesis that a wholly inorganic source of nitrogen would be more readily available early on in the growing season than would a semi-organic source. However, it is more likely that this difference is due to the greater quantity of inorganic fertilizer applied at this site. This question will be discussed at greater length in the next section of this chapter.

The total nitrogen contained in the fruiting heads, shows differences at all three sites and for all treatments (Table 3.10). Significantly more nitrogen was found in the heads of the semi-organic treatment than in either the I.F. or N.F. treatments ($P < 0.01$).

Table 3.10 - Total Nitrogen Uptake in Heads Unit^{-1} (mg) 21 week harvest

	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.001
Site I	1145.26	794.36	670.61	162.60	224.04
Site II	830.58	607.88	578.72	154.08	219.17
Site III	857.44	637.17	598.38	130.28	179.35

This again shows the influence of the increased numbers of fruiting heads (Table 3.7) as at none of the sites were there significant differences between S.O. and I.F. treatments with regard to the nitrogen content per head (Table 3.11)

Table 3.11 - Nitrogen Uptake Head^{-1} (mg) 21 week harvest

	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I	11.78	10.68	9.29	1.25	1.72
Site II	10.42	10.45	9.93	N.S.	N.S.
Site III	9.51	9.79	9.34	N.S.	N.S.

The total nitrogen contents of vegetative parts at the 21 week stage are given in Table 3.12. At Site II the total nitrogen contents of both the S.O. and I.F. treatments were significantly higher than the N.F. treatment ($P<0.05$) while at Site III the S.O. treatment recovered significantly more nitrogen in total than either the I.F. or N.F. treatments ($P<0.05$).

Table 3.12 - Total Nitrogen Content of Vegetative Parts (mg) 21 week harvest

	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
Site I	424.65	499.12	383.17	N.S.	N.S.
Site II	381.64	389.48	222.93	128.42	182.66
Site III	435.80	308.46	263.58	118.13	162.76

3.4 DISCUSSION

3.4.1 Dry Matter production - comparisons of treatments and sites

The previous history of fertilizer practice at all three experimental sites was a long period of inorganic fertilization. It would seem reasonable therefore to use the inorganic fertilizer (I.F.) treatment strips as 'controls' and use the ratios

$$\frac{\text{N.F.value}}{\text{I.F.value}} \quad \text{and} \quad \frac{\text{S.O.value}}{\text{I.F.value}}$$ expressed as percentages

to give a picture of the relative performances of the plants on the three treatments over the season. Expressed in this form, the results from Table 3.1 (mean total dry weight g per unit) for all three sites are represented in Table 3.13.

Table 3.13 - Total dry weight, unit^{-1} relative to I.F. treatment (I.F. = 100)

	Site I		Site II		Site III	
HARVEST	S.O.	N.F.	S.O.	N.F.	S.O.	N.F.
8 week	107	57	100	55	109	64
16 week	114	74	106	75	88	65
21 week	114	83	115	73	136	94

The most striking feature of these comparisons is the gradual improvement with time in the performance of the N.F. treated strips as compared to the I.F. strips. This may reflect the high level of residual fertility at all three sites but probably also reflects the relatively low level of fertilization that was employed. The amounts of fertilizer used were decided upon by the farmer concerned in accordance with his normal practice and were lower than the A.D.A.S. recommendations for the spring of 1971 (approximately 40 units N per acre for spring sown cereals). According to the review published by the Ministry of Agriculture, Fisheries and Food in 1972 (M.A.F.F. 1972) the average unit quantities per acre of a 15.10.10. fertilizer or equivalent, applied to spring cereals was 57 units N, 37 units P_2O_5 and 38 units K_2O. In this respect therefore the quantity of fertilizer used throughout these trials was somewhat low.

There is a steady increase in $\frac{S.O.}{I.F.}$ ratio over the season at Sites I and II and the 21 week figure is the highest at each site. At

Site III, 16 week harvest, the number of plants in the I.F. sample was exceptionally high with the result that the total dry weight exceeded that of the S.O. treatment. This is indicated in Table 3.14 where the number of plants per sampling unit for each harvest time at each site is expressed as a percentage of the number in the I.F. sample.

Table 3.14 - Mean Numbers of Plants unit^{-1} Compared with the I.F. Treatment (I.F. = 100)

	Site I		Site II		Site III	
HARVEST	S.O.	N.F.	S.O.	N.F.	S.O.	N.F.
8 week	120.1	88.4	111.6	88.4	128.2	90.7
16 week	127.1	106.2	133.0	94.2	101.5	89.7
21 week	119.3	96.1	135.8	121.9	153.5	115.6

As can be seen, there is considerable variation in these figures and no apparent trends.

The mean dry weight per plant at each site and at each harvest time can be "corrected" for the variation in mean plant numbers per sample using the following formula:-

$$W_e = W_o + b(n_m - n_s) \qquad \text{Formula I}$$

Where W_e is the expected mean dry weight per plant,
W_o is the observed mean dry weight per plant,
b is the regression coefficient between mean stand density and mean dry weight per plant,
n_m is the mean number of plants per unit over the whole season and
n_s is the mean number of plants per sample

More complicated forms of the above equation are to be found in the literature (Holliday 1960) but these refer to very wide ranges of plant density and it is felt that the simpler formula presented is adequate in this case.

Using the "corrected" values and also the raw data values for mean dry weight per plant (Table 3.2) the pattern of dry weight accumulation in the three treatments can be re-examined using ratio percentages, the information is presented in Table 3.15 ("corrected" values in brackets)

Table 3.15 - Mean Dry Weight Plant^{-1} Relative to I.F. Treatment (I.F. = 100)

	Site I		Site II		Site III	
HARVEST	S.O.	N.F.	S.O.	N.F.	S.O.	N.F.
8 week	89(89.1)	65(60.9)	92(92.3)	72(55.1)	84(84.3)	70(70.0)
16 week	88(90.5)	67(66.7)	77(85.0)	82(74.1)	85(82.4)	70(73.5)
21 week	96(97.9)	87(87.5)	88(102.8)	64(75.1)	80(86.8)	80(83.5)

As can be seen from Table 3.15, although virtually all the values are below 100 showing that with the I.F. treatment dry weight per plant was greater than with either S.O. or N.F. treatments, there was a gradual increase in these two treatment values relative to I.F. over the season. This relative increase in dry weight per plant, together with the relative numbers of plants per sample produces the trends in total dry weight per unit seen in Table 3.13. It was felt that the variation seen in these dry matter estimates was due to sampling error and that a similar experiment must be attempted the next year.

Total dry matter production on N.F. strips at the three sites (Table 3.1) illustrates the differences between the two soil types. At 21 weeks the mean dry weight per sample at Sites I, II and III was 109.4g, 72.3g and 96.5g respectively. These results suggest that the boulder clay soil has a greater fertility than the chalk soils though whether this is a result of inherent properties or previous fertilizer policy is not known. It is interesting to note, however, that at the 8 week stage the samples from Sites II and III showed appreciably higher dry weight than Site I for all treatments. At Sites I, II and III mean dry weights on the N.F. treatment were 13.5g, 20.6g and 22.5g respectively. So initially at least, growth and dry matter production was faster on the chalk soil than on boulder clay. Certainly it would be expected that the temperature of the surface soil would increase at a faster rate over the first few months of the year in the shallow soils over chalk than in the boulder clay soil and this could be a contributory factor.

It would seem from the figures presented for dry matter production that the S.O. treatment is more likely to give a higher total dry matter yield per unit area than either I.F. or N.F. treatments. This difference is due in large part to the greater stand density observed with the S.O. treatment. Plants grown with S.O. of N.F. treatments either accumulated dry matter for a longer period or at a faster rate later in the season as compared to the I.F. treatment.

3.4.2 Comparisons of Nitrogen Uptake Values and Nitrogen Distribution in the Plant Under the Various Treatments

In all treatments the pattern of nitrogen uptake was similar to that which has been reported for cereal crops by many other investigators (Knowles and Watkin, 1931; Sayre, 1948; Hanway, 1962b). For combine drilled cereal crops the nitrogen supply from soil and fertilizer sources is usually greatest at sowing and gradually diminishes as the plants develop. The result is that the nitrogen percentages on both a green and dry weight basis decline as the plant grows. At the eight week harvest the nitrogen content of the plants was between 2 and 4%, but as growth and development proceeded this gradually declined until at 21 weeks it was only about 1% (Table 3.16). Comparative figures for wheat (Knowles and Watkin, 1931) were a decrease from 3.6% to 0.8%.

Table 3.16 - Nitrogen Content Unit^{-1} (mg. N/g of sample)

	S.O.	I.F.	N.F.
Site I - Aldborough			
8 week	38.19	36.70	33.70
21 week	10.52	9.83	9.63
Site II - Wharram-le-Street			
8 week	17.79	16.63	20.47
21 week	10.59	10.19	11.09
Site III - Wharram-le-Street			
8 week	19.26	23.30	20.62
21 week	8.90	8.91	8.93

As can be seen the 8 week values at Site I are uniformly greater than those at Sites II and III, but this difference disappears by the 21 week stage. Reference to Table 3.9 (Mean Nitrogen Content Plant^{-1}) shows that there was no marked difference in the nitrogen content of the plants at Wharram-le-Street (Sites II and III) and at Aldborough (Site I) at the 8 week stage. It would seem, therefore, that over the initial period of growth, dry matter production is unrelated to nitrogen content. The plants growing on the Aldborough soil although accumulating nitrogen quite rapidly compared to Sites II and III were slower to accumulate dry matter, presumably as a result of a deficiency in some external factor, e.g. water supply.

The relative levels of nitrogen recovery between the two soil types can be seen in Table 3.8 where, at the 21 week stage, plants grown on N.F. treated strips had recovered 1053.78 mg.N per unit at Site I and 801.58 mg. and 861.96 mg.N per unit at Sites II and III respectively. On a nitrogen content per plant basis (Table 3.4) the

Site I values at 21 weeks are seen to be much higher than at Sites II and III (20.19 mg.N plant^{-1} at Site I as against 16.95 mg and 17.34 mg.N plant^{-1} at Sites II and III respectively). Since there is no such pattern in the dry weight per plant values presented in Table 3.2 it seems quite likely that the crop at Site I suffered a water shortage at some stage during the season.

From the economic viewpoint, the percentage recovery of the applied nitrogen is of importance. Using the formula:-

$$\text{N recovery (\%)} = \frac{\text{Total N. uptake unit}^{-1} - \text{Total N uptake unit}^{-1}\text{(N.F.)}}{\text{N. applied unit}^{-1}} \times 100$$

the data for total percentage recovery (heads and vegetative parts) and percentage recovery in the heads only are presented in Table 3.17.

Table 3.17 - Percentage of Nitrogen Applied Unit^{-1} Recovered in Heads and in Whole Plant (Heads + Vegetative Parts)

	TOTAL		HEADS	
	S.O.	I.F.	S.O.	I.F.
Site I	93.8	39.1	86.3	20.2
Site II	87.2	38.6	55.0	6.4
Site III	87.4	11.5	52.3	5.8

Using data from experiments at Rothamsted, Woburn and Commercial Farms, Cooke (1964) quotes recovery rates ranging between 22-47% for spring barley (heads only). The values for S.O. recovery percentages are therefore somewhat in excess of what would have been expected and the I.F. figures somewhat lower. Kirby (1969) and Puckeridge and Donald (1967) have shown that, over the lower ranges at least, the total nitrogen recovery for a variety of cereals increases with increasing population density. Taking this into consideration and the values presented in Table 3.5 (Mean Number of Plants Per Unit) the figures obtained for S.O. recovery rates are not so surprising. The recovery of nitrogen on the I.F. treatment was very low and it is interesting to note that this appears to be linked with a very low rate of uptake in the later stages of growth. At the 8 week stage plants on the I.F. treatment had taken up more than 60% of the total amount of the nitrogen absorbed, whereas on the other two treatments the proportion was invariably less than 60% (Table 3.18). Possible reasons for these differences in the pattern of nitrogen uptake are:-

(1) That considerable losses of the readily available nitrogen occurred in the I.F. treatment through leaching;

(2) That mineralization of organic nitrogen on the S.O. and N.F. treatments maintained a relatively high supply of nitrogen throughout the growth period; and

(3) The presence of relatively large quantities of available nitrogen at an early stage in the season suppressed the mineralization of existing organic nitrogen or plant utilization of this source, later in the season.

These problems will be discussed in more detail in Chapter IV.

Table 3.18 - Percentage of the Total N Uptake Unit^{-1} Present at the Eight Week Stage

	S.O.	I.F.	N.F.
Site I	56.2	67.2	43.2
Site II	56.0	62.4	52.6
Site III	56.6	86.0	53.8

At Site III the high figure for I.F. recovery rate (86%) might be a result of the higher level of inorganic fertilizer applied at this site, but also reflects the low final value for total nitrogen uptake per unit (Table 3.8).

As was pointed out in the Introduction (1.3) an early supply of nitrogen may well be an ideal situation in that it reduces the risk of nitrogen loss from the system due to leaching, etc. It might be expected that nitrogen losses through leaching could be reduced by supplying part of the nitrogen in a form that only becomes available slowly, e.g. as organic matter. It is important to note, however, that the uptake of nitrogen per plant is similar on the S.O. and I.F. treatments and differences in total and percentage recovery are dependent upon the density of plants. Thus, although the pattern of uptake on the I.F. and S.O. treatments was somewhat different, it seems likely that the plants on both treatments were able to satisfy their requirements and the apparent under utilization of nitrogen on the I.F. treatment was a result of the lower degree of germination or establishment. This problem will be explored further in the next chapter where the experiment was repeated at Site I with a higher rate of fertilizer supply.

3.5 SUMMARY

As a general summary to this chapter the following points could be made:-

(1) The semi-organic fertilizer treatment supported a higher stand density than either the inorganic fertilizer or no fertilizer treatments. This occurred at all three experimental sites and the differences were significant ($P<0.05$).

(2) This difference in density was largely responsible for differences in total dry matter production, total nitrogen uptake and percentage recovery of applied nitrogen as the performance of individual plants was similar on both fertilizer treatments.

CHAPTER IV

FIELD TRIALS 1972

4.1 INTRODUCTION

In the 1971 experiments the relative performance of the no fertilizer (N.F.) treatment was surprisingly high at all sites and it is likely that this high performance was achieved at the expense of fertilizer retained in the soil from previous applications. It has been suggested by numerous workers (Patterson and Watson, 1960; Viets, 1960; Gasser, 1971; Berryman, 1971; Clement, 1971) that fertilizer materials, especially organics might have a residuum which can be used the next season. It was felt necessary to investigate this possibility in the 1972 trials. An experiment was set up at Site I (Aldborough) only, with the treatment replicates in exactly the same positions as in the 1971 experiments. This had the advantage that the effect of leaving strips unfertilized for two consecutive years could be investigated. Once again the Inorganic fertilizer (I.F.) treatment could be used as a 'control' since for several years previously these strips had been fertilized with inorganic fertilizer.

In the 1971 experiments it was felt that the frequency of sampling was insufficient to give a clear picture of the pattern of growth of the plants in the different treatments. In the present experiment more samples were taken to try to reduce the error component in the statistical analyses, and sampling was carried out at more regularly spaced intervals, in order to investigate the growth patterns more thoroughly.

4.2 MATERIALS AND METHODS

The experimental layout and procedure was exactly the same as in 1971. The site chosen was at Aldborough (Site I). The amount of fertilizer applied was increased and a different variety of barley was sown. The rate of application of the fertilizers was as follows:-

Semi-Organic (S.O.) 6 cwts acre^{-1} (753 Kg ha^{-1}) analysis 9.6.6. giving 54 units N, 36 units P_2O_5, and 36 units K_2O acre^{-1}.

Inorganic (I.F.) 2.75 cwts acre^{-1} (345 Kg ha^{-1}) analysis 20.14.14. giving 55 units N, 38.5 units P_2O_5 and 38.5 units K_2O acre^{-1}.

Strips with no fertilizer additions were left as before (N.F. treatment)

It can be seen therefore that the rate of application was approximately double that of the previous year's experiment at this site. Twelve stone acre^{-1} (188 Kg ha^{-1}) of Proctor barley was sown on 19 April 1972. The seed and fertilizer were again sown using a precalibrated combine drill giving twenty, seven inch rows. As in 1971 there were nine blocks of each treatment (S.O., I.F., and N.F.) arranged in parallel strips (Fig. 2.1). At four times throughout the growing season two samples were taken at random from each block. Each sample consisted of three foot (0.91m) length of barley plants taken from a randomly selected row at a randomly selected point along that row. These samples were returned to the laboratory for analysis. Assessment of total dry weight and nitrogen content were made for each sample as in 1971. Sampling took place 5, 11, 17 and 19 weeks after sowing. The last sample was taken just before the entire crop was harvested. Subsampling was performed on the 2nd, 3rd and 4th harvests as in 1971. Each replicate value was taken as the mean of the two samples taken from each replicate block. There were thus nine replicates of each treatment. Data were examined by means of analysis of variance. The results were not transformed.

4.3 RESULTS

Table 4.1 shows the mean total dry weight produced per sample.

Table 4.1 - Mean Total Dry Weight Unit^{-1}(g)

Harvest	S.O.	I.F.	Control	L.S.D. P=0.05	L.S.D. P=0.01
5 weeks	4.51	4.49	2.18	0.87	1.20
11 weeks	89.30	86.60	40.00	12.20	16.80
17 weeks	204.8	187.0	90.4	23.9	33.0
19 weeks	190.3	191.2	102.0	22.5	31.1

Both fertilizer treatments were superior to the N.F. treatment at all sample times ($P<0.01$) but, as in 1971 the total yield per sample on the S.O. treatment was not sifnificantly different from that on the I.F. treatment. The variation due to replication was insignificant as in 1971.

In comparison of the mean dry weight plant^{-1} produced under the three treatments (Table 4.2) the N.F. values are markedly lower than either of the two fertilizer treatment values at all sampling times ($P<0.01$) and the S.O. and I.F. treatments showed no significant differences at any sampling time. Reference to Table 3.2 will show that this result is the same for both years at this site. The final values for the mean dry weight per plant on the fertilized strips were higher than in 1971, perhaps because larger quantities of fertilizer were applied.

Table 4.2 - Mean Dry Weight Plant^{-1}(g)

Harvest	S.O.	I.F.	Control	L.S.D. P=0.05	L.S.D. P=0.01
5 weeks	0.063	0.068	0.039	0.011	0.015
11 weeks	1.11	1.22	0.63	0.16	0.23
17 weeks	2.74	2.83	1.51	0.34	0.47
19 weeks	2.47	2.79	1.46	0.34	0.47

It can be seen from Table 4.1 that the mean total dry weight per sample at the final harvest with the N.F. treatment was very similar to that obtained the previous year (c.f. Table 3.1). The mean dry weight per plant at this stage, however, in 1972 was markedly lower, the two values for 1971 and 1972 being 2.10g and 1.46g respectively. The stability in total dry weight is the result of a general increase in the stand density in all treatments in 1972. The figures for 1972 are presented in Table 4.3

Table 4.3 - Mean Number of Plants $Unit^{-1}$

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
5 weeks	71.4	65.6	58.4	N.S.	N.S.
11 weeks	80.8	71.3	63.7	7.3	10.0
17 weeks	74.7	67.1	61.2	8.1	11.1
19 weeks	79.1	69.7	71.4	4.7	6.5

As in 1971 the S.O. treatment supported a consistently higher stand density ($P<0.05$) than either I.F. or N.F. treatment over the whole season but the differences between the S.O. and I.F. treatments were significant only at 11 and 19 weeks. The mean number of plants per sample using the figures from all harvests were 76.5, 68.6 and 63.7 for S.O., I.F. and N.F. treatments respectively. At the five week stage the variation was relatively high and the differences of means were not significant. It can be seen from Table 4.3 that the figures for the 5 week harvest are below the seasonal average value for all treatments so it is possible that the reason for the relatively high variability of this sample was that it was taken before all seedlings had emerged.

The mean number of heads per sample at 17 and 19 weeks is shown in

Table 4.4. The number per sample on the S.O. treatment was higher than on the I.F. treatment at both the 17 weeks (P=0.05) and the 19 week (P< 0.05) stage.

Table 4.4 - Mean Number of Heads Unit^{-1}

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. 0=0.01
17 weeks	120.2	109.8	67.8	11.4	15.7
19 weeks	129.1	119.3	81.6	8.9	12.3

The differences presented in Table 4.4 result in a significantly higher total dry weight of fruiting heads per sample on the S.O. treatment than on the I.F. treatment.

Table 4.5 - Mean Total Dry Weight of Heads Unit^{-1}(g)

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
17 weeks	87.5	73.2	44.1	9.8	13.6
19 weeks	90.7	81.2	49.7	8.7	12.0

In Table 4.6 the mean dry weight per head for the 17 and 19 week harvests are presented. The N.F. values are significantly lower than either S.O. or I.F. values at both sampling times (P<0.05). Only at the 17 week harvest was the S.O. value significantly greater than the I.F. figure (P<0.05).

Table 4.6 - Mean Dry Weight Head^{-1}

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
17 weeks	0.72	0.67	0.61	0.04	0.06
19 weeks	0.71	0.68	0.60	0.07	0.09

The total nitrogen uptake per unit as shown in Table 4.7 portrays an almost parallel set of results to those of the previous season at this site. There was no significant difference between the total amount recovered from the two fertilizer treatments but in 1972 both values were far in excess of that on the N.F. treatment.

Table 4.7 - Mean Total Nitrogen Uptake Unit^{-1}(mg.)

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
5 weeks	209.7	209.5	72.2	44.9	61.9
11 weeks	1392.0	1345.0	503.4	267.2	368.1
17 weeks	1508.0	1264.0	654.4	163.9	225.9
19 weeks	1606.4	1475.7	800.4	207.4	285.7

Values for the mean nitrogen content per plant are presented in Table 4.8 and for mean total nitrogen taken into the heads in Table 4.9

Table 4.8 - Mean Nitrogen Uptake Plant^{-1}(mg)

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
5 weeks	2.93	3.22	1.31	0.63	0.87
11 weeks	17.15	18.93	7.81	4.03	0.87
17 weeks	20.10	19.08	10.70	2.37	3.27
[illegible]	[illegible]	[illegible]	11.27	3.03	4.18

Table 4.9 - Mean Total Nitrogen Uptake in Heads $Unit^{-1}$ (mg)

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
17 weeks	1045.0	822.9	480.8	133.5	183.9
19 weeks	1198.1	991.5	570.1	146.5	201.8

The results presented in Table 4.9 show significant differences between all three treatments ($P<0.01$) at both sampling times. The S.O. treatment was found to be markedly superior to either I.F. or N.F. treatments in this respect. This difference in total uptake is a result of the greater number of heads per sample with the S.O. treatment and also as the results presented in Table 4.10 show, a significantly greater nitrogen content per head.

Table 4.10 - Mean Nitrogen Uptake $Head^{-1}$ (mg)

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
17 weeks	8.62	7.48	7.01	0.98	1.34
19 weeks	9.25	8.25	6.98	1.00	1.40

The total accumulation of nitrogen in the vegetative parts and the amount of nitrogen per vegetative shoot, i.e. the whole plant minus the roots and the heads, are shown in Tables 4.11 and 4.12 respectively.

Table 4.11 - Mean Total Nitrogen Uptake $Unit^{-1}$ in Vegetative Parts (mg)

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
17 weeks	463.1	441.1	169.2	88.2	121.5
19 weeks	408.3	484.3	228.9	84.4	116.3

Table 4.12 - Mean Nitrogen Uptake Vegetative Shoot^{-1}(mg)

Harvest	S.O.	I.F.	N.F.	L.S.D. P=0.05	L.S.D. P=0.01
17 weeks	5.97	6.54	2.83	1.39	1.92
19 weeks	5.17	6.98	3.11	1.29	1.78

As can be seen in Table 4.11 the differences in nitrogen uptake between the two fertilizer treatments are not significant either at 17 or 19 weeks, but at the 19 week stage the I.F. treatment contains significantly more nitrogen per vegetative shoot than either S.O. or N.F. treatments.

4.4 DISCUSSION

As in the previous chapter, the I.F. values can be used as 'controls' because of the continued use of inorganic fertilizer on exactly the same areas in the experimental site. It is still possible therefore to use $\frac{N.F.}{I.F.} \times 100$ and $\frac{S.O.}{I.F.} \times 100$ ratio percentage values as indicators of relative performance.

4.4.1 Factors affecting dry matter production

In Table 4.13 mean densities on the S.O. and N.F. treatments are expressed as a percentage of the I.F. values and although the values obtained for the N.F. treatment cover approximately the same ranges as in 1971 those obtained for the S.O. treatment are markedly lower (Table 3.14, Site I). Nonetheless, at two of the four sampling times the difference in density between S.O. and I.F. treatments were still significant (Table 4.3), probably because the error variance in 1972 was lower than in 1971. This was achieved by increasing the number of samples.

Table 4.13 - Mean Number of Plants Unit^{-1} Relative to I.F. Treatment I.F. Treatment (I.F. = 100)

Harvest	S.O.	N.F.
5 weeks	108.8	89.0
11 weeks	113.3	89.3
17 weeks	111.3	91.2
19 weeks	109.2	102.4

In Table 4.14 the sample dry weights are expressed as a percentage of the I.F. values and again the S.O. treatment results tend to be lower than those obtained in 1971 (Table 3.13, Site I).

Table 4.14 - Mean Total Dry Weight Unit^{-1} (I.F. = 100)

Harvest	S.O.	N.F.
5 weeks	100.4	48.5
11 weeks	103.1	46.2
17 weeks	109.5	48.3
19 weeks	99.5	53.3

There is no firm indication of late season benefit from the use of a semi-organic fertilizer from these figures and there is no apparent trend in the N.F. values which remained at approximately 50% for the whole season.

The two components of total dry matter per unit area are:

(1) Number of plants per unit area and

(2) The mean dry weight per plant.

In Table 4.15 values for the latter variable are expressed as a percentage of the I.F. value and for both the S.O. and the N.F. treatments are consistently less than 100%. though for the S.O. treatment none of the differences are significant (P>0.05, Table 4.2). No seasonal trends are apparent in the values presented in Table 4.15.

Table 4.15 - Mean Dry Weight Plant^{-1} (I.F. = 100)

Harvest	S.O.	I.F.
5 weeks	93	57
11 weeks	91	52
17 weeks	96.5	53.5
19 weeks	88	52.5

Since stand density was consistently higher on the S.O. treatment, it might be expected that the plants growing under these conditions would experience greater competition than those on other treatments. To investigate this, the regression of dry weight per sample upon density was calculated for each treatment at each sampling time and the results are presented in Figs. 4.1, 4.2, 4.3 and 4.4 In Table 4.16 the correlation coefficients are presented and those which are significantly different from the I.F. coefficients are marked * (P<0.05). Coefficients significantly different from zero correlation are marked †(P<0.05).

Figure 4.1

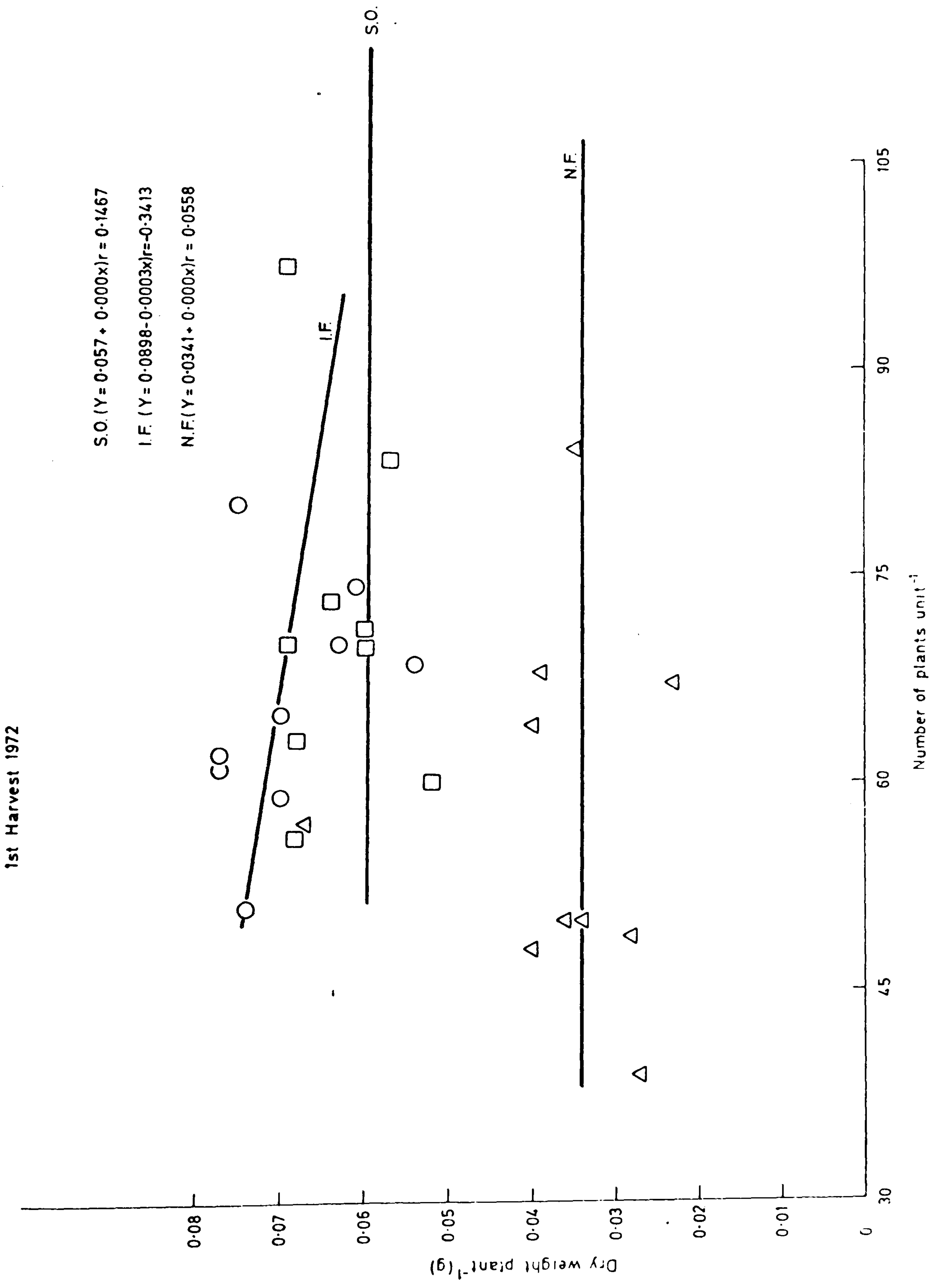

1st Harvest 1972
S.O. (Y= 0·057 + 0·000x)r = 0·1467
I.F. (Y= 0·0898-0·0003x)r=-0·3413
N.F.(Y= 0·0341+ 0·000x)r = 0·0558
S.O.
I.F.
N.F.
Dry weight plant^{-1} (g)
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0
Number of plants unit^{-1}
30
45
60
75
90
105

Figure 4.2

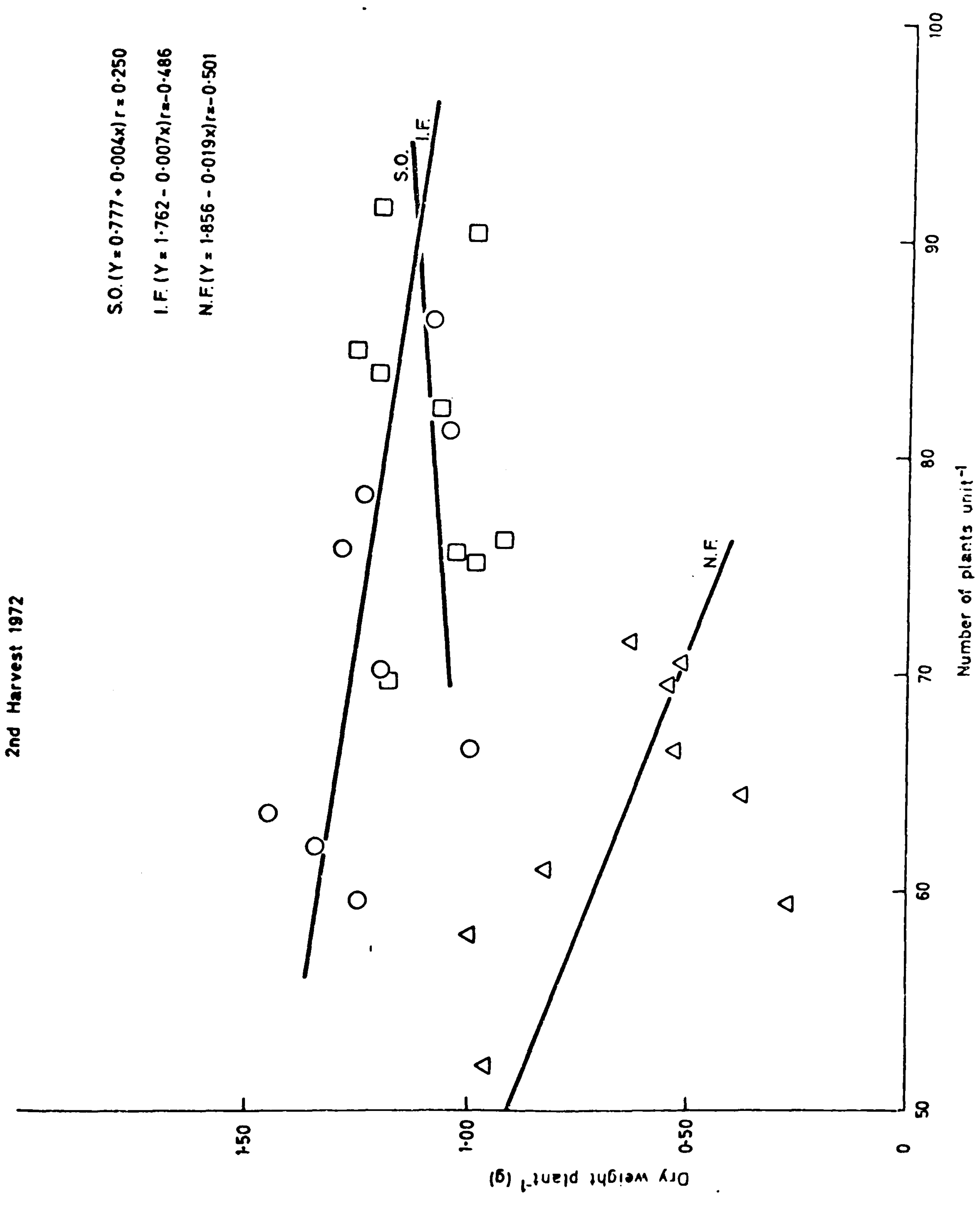

2nd Harvest 1972
S.O. (Y = 0·777 + 0·004x) r = 0·250
I.F. (Y = 1·762 - 0·007x) r = -0·486
N.F. (Y = 1·856 - 0·019x) r = -0·501
S.O.
I.F.
N.F.
Dry weight plant-1 (g)
0
0·50
1·00
1·50
Number of plants unit-1
50
60
70
80
90
100

Figure 4.3

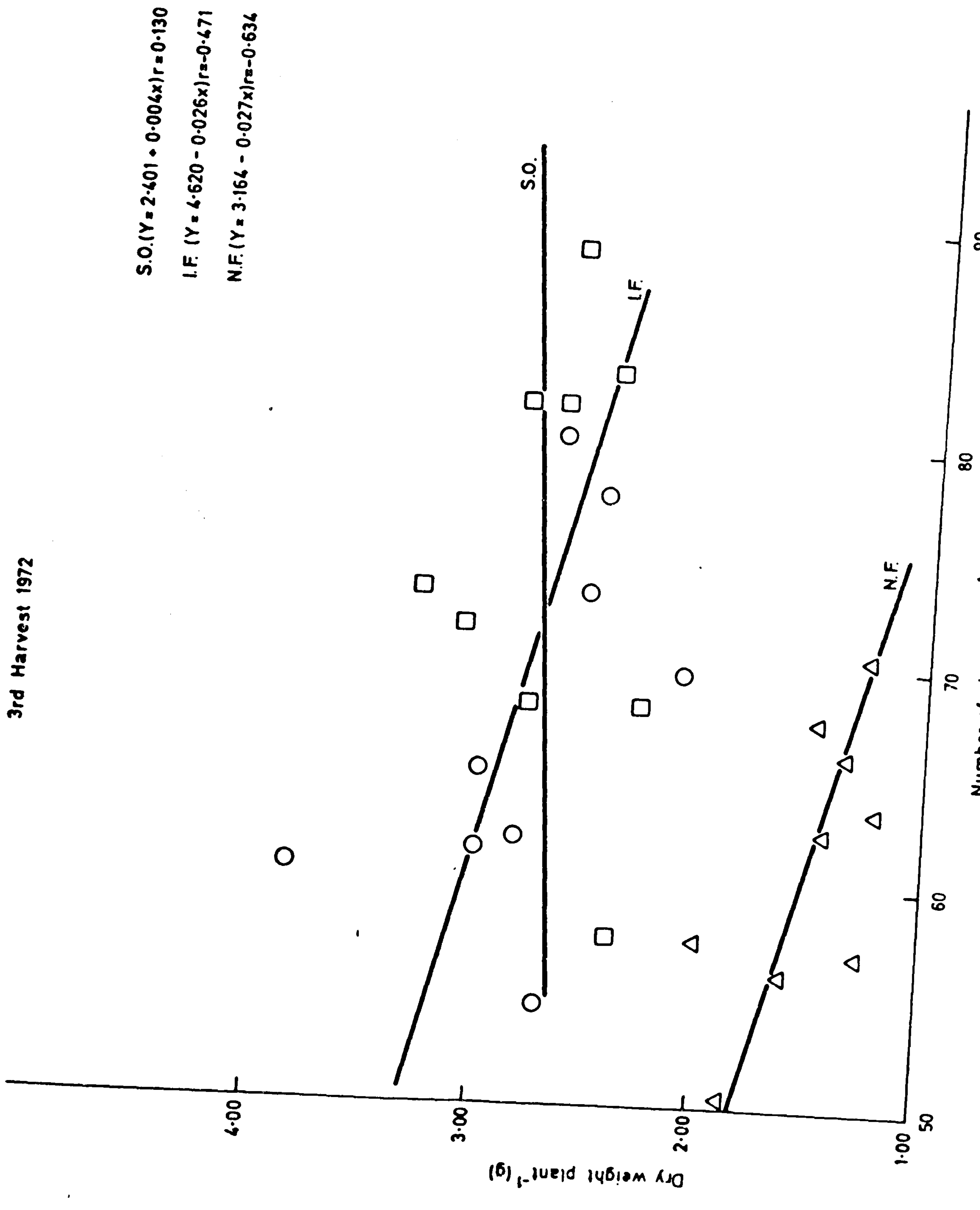

3rd Harvest 1972
S.O.(Y= 2·401 + 0·004x) r = 0·130
I.F. (Y= 4·620 - 0·026x) r=-0·471
N.F. (Y= 3·164 - 0·027x) r=-0·634
S.O.
I.F.
N.F.
Dry weight plant^{-1} (g)
1·00
2·00
3·00
4·00
Number of plants unit^{-1}
50
60
70
80
90

Figure 4.4

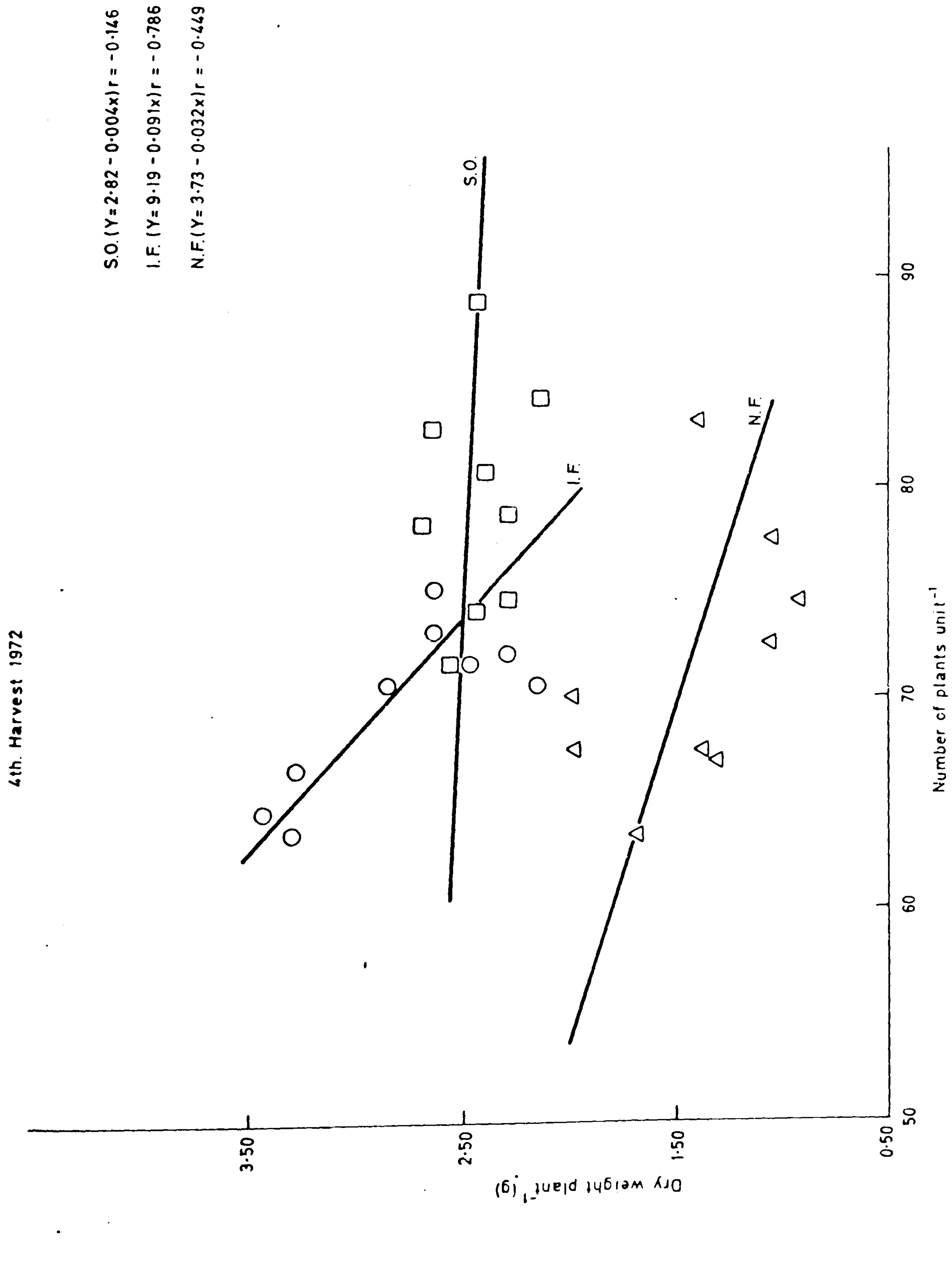

4th. Harvest 1972
S.O.(Y=2·82 - 0·004x) r = -0·146
I.F. (Y= 9·19 - 0·091x) r = -0·786
N.F.(Y= 3·73 - 0·032x) r = -0·449
S.O.
I.F.
N.F.
Dry weight plant⁻¹(g)
3·50
2·50
1·50
0·50
50
60
70
80
90
Number of plants unit⁻¹

Table 4.16 - Summary of Figures 4.1 - 4.4 inclusive

Harvest	Treatment	Correlation Coefficient
1st (5 week)	S.O.	0.1467
	I.F.	-0.3414
	N.F.	0.0558
2nd (11 weeks)	S.O.	0.250 *
	I.F.	-0.486 †
	N.F.	-0.501 †
3rd (17 weeks)	S.O.	0.130 *
	I.F.	-0.471 †
	N.F.	-0.634 †
4th (19 weeks)	S.O.	-0.146 *
	I.F.	-0.786 †
	N.F.	-0.449

(* = treatment significantly different from I.F. $P \leq 0.05$)
(† = correlation coefficient significant $P \leq 0.05$)

The correlation coefficients shown in Table 4.16 indicate that density had no significant effect on the mean dry weight per plant on the S.O. treated strips. As the season progressed an increasingly negative correlation and therefore an increasingly severe effect of density was observed in the I.F. treatment and to a slightly lesser extent with the N.F. treatment. This could be due to nutrient deficiency occurring in the N.F. and I.F. treatments but not in the S.O. treatments despite the greater density of plants on the S.O. treatment. This problem will be discussed again in section 4.4.3.

4.4.2 Distribution of dry matter in the developing plants

Although there were no significant differences between the I.F. and S.O. treatments in terms of total dry matter produced per unit area, the total dry weight of heads was seen to be significantly greater with the S.O. treatment (Table 4.5). This leads to the conclusion that relatively more vegetative growth took place with the I.F. treatment. The mean percentage contributions of the vegetative material to the mean total dry weight per unit were 52.3%. 57.5% and 51.3% for S.O., I.F. and N.F. respectively. The ratio of vegetative weight to head weight in cereals is often related to nitrogen supply especially early in development. This point will be discussed later. (Section 4.4.3).

In a recent paper Gallagher J.N., Biscoe P.V., and Scott R.K. (1975) showed that over a wide range of grain yields in a large number of experiments and N.I.A.B. trials, mean weight per grain in Proctor barley was relatively stable. Grain yield was thus strongly dependent on the number of grains per unit ground area that a crop was able to produce. They considered that stability of grain weight could be achieved by:

"(a) The number of grains per unit ground area developing during the grain filling period may be governed by the amount of assimilate which the crop is able to supply,

(b) The crop may somehow be able to regulate the dry matter it can supply to permit the grains to reach a nearly constant weight irrespective of the extent of grain set, and

(c) A combination of both (a) and (b) may occur."

From their experiments they conclude that the number of grains per unit ground area is determined before filling of the grain begins and that neither (a) or (c) can therefore occur. The crop may therefore be able to adjust the amount of assimilate it can supply to meet the requirements of the number of grains that are to be filled. Once the number of grains per unit ground area has been determined it appears that if the amount of photosynthate produced by the crop is insufficient to fill these grains, translocation will occur to compensate. Conversely if crop dry matter production exceeds that required to fill the grains then stem dry weight will increase rather than mean weight per grain.

In 1972 at the Aldborough site the 2nd harvest (11 week) was taken just before (about 2 weeks) anthesis and comparisons between the mean dry weight per plant at this stage and the final mean dry weight of heads per plant and between mean dry weight per plant and mean dry weight of vegetative material (stem) per plant shows that photosynthesis was not limiting in any of the three treatments because stem dry weight continued to increase up to the final harvest. The amount of increase however varied between the treatments. (Table 4.17).

Table 4.17 - Measurements of mean dry weight plant^{-1}(Wp), stem^{-1}(Ws) and head wt. plant^{-1}(W_H) at the 2nd (2) and 4th (4) harvests and the change in weight (Δ) of these plant parts from 2 to 4 for the three treatments (g)

	2	4		2	4		2	4	
	Wp	Wp	ΔWp	Ws	Ws	ΔWs	W_H	W_H	ΔW_H
S.O.	1.11	2.47	+1.36	1.11	1.32	+0.21	-	1.15	+1.15
I.F.	1.22	2.79	+1.57	1.22	1.66	+0.42	-	1.17	+1.17
N.F.	0.63	1.46	+0.83	0.63	0.76	+0.13	-	0.70	+0.70

The figures for Ws show that under the N.F. treatment between the 2nd and 4th harvests most of the photosynthetic input (84%) was transported to, or a product of the developing heads. The correspond-ing proportions for the S.O. and I.F. treatments were 84% and 74%

respectively. From Table 4.6 it can be seen that there was no significant difference between the mean dry weight per head on the S.O. and I.F. treatments and both of these were significantly higher than the N.F. values. If grain weight was stable between the three treatments then differences in mean dry weight per head must be attributable to numbers of grains per head. In this respect heads produced in the N.F. treatment would be expected to contain less grains. Mean dry weight per head was not significantly different between S.O. and I.F. treatments although there were significantly more heads per unit area in the S.O. treatment (Table 4.4). From Table 4.17 it was noted that the proportion of photosynthetic input transferred to or produced by the heads was greater for S.O. treatment (84%) than for I.F. treatment (74%). This difference in input could lead to the equality in mean dry weight per head noted previously. This problem will be discussed later.

4.4.3 Nitrogen uptake, distribution in the plant and relation to dry matter production

The percentage recovery of applied nitrogen for the two fertilizer treatments was 72.3% (53.9% in heads) and 59.9% (40.2% in heads) for S.O. and I.F. respectively. Information on the pattern of nitrogen uptake and re-distribution in the crop is presented in Table 4.18, where estimates of the total uptake of nitrogen per plant at the second and fourth harvests and of the nitrogen accumulated in the heads and in the vegetative material (stem) over that period of growth are shown.

Table 4.18 - Measurements of the total nitrogen uptake plant^{-1} (N_T) vegetative material (Ns) and heads (N_H) plant^{-1} at the 2nd (2) and 4th (4) harvests and the changes in total nitrogen content (Δ) of the fractions from 2-4 for the three treatments (mg)

	2	4		2	4		2	4	
	N_T	N_T	ΔN_T	Ns	Ns	ΔNs	N_H	N_H	ΔN_H
S.O.	17.15	20.36	+3.21	17.15	5.19	-11.96	-	15.17	+15.17
I.F.	18.93	21.31	+2.38	18.93	7.12	-11.81	-	14.19	+14.19
N.F.	7.81	11.27	+ 3.46	7.81	3.24	- 4.57	-	8.03	+ 8.03

Figures for ΔN_T show that nitrogen was being absorbed by the plants in all treatments during this period although there were differences between the treatments. The allocation of absorbed nitrogen and the redistribution of both this and the nitrogen already contained in the plant can be assessed using the ΔNs and ΔN_H figures. During this period the vegetative material (ΔNs) showed a net loss of nitrogen and the heads showed a net increase (ΔN_H). The proportion $\frac{\Delta N_H}{N_T(4)}$ is found to be 74.5%. 67.2% and 71.2% for S.O., I.F. and N.F. respectively. It seems therefore that proportionally more nitrogen is being transferred to the heads in the S.O. and N.F. treatments than in the I.F. treatment during the period 11-19 weeks. There is also more nitrogen absorbed from the environment in the S.O. and N.F. treatments during this period relative to I.F. (ΔN_T).

Gregory (1952) and Hanway (1962b) showed that nitrogen accumulation was rapid over the initial period of growth in cereals, especially when nitrogen supply was not limiting. On Table 4.19 dry weights and nitrogen contents per sample at the various sampling times are expressed as a percentage of the 19 week values.

Table 4.19 - Percentage of final values for Total dry weight (D.W.) and Total nitrogen uptake (N) unit^{-1} at various stages in development

HARVEST	TREATMENT S.O.		I.F.		N.F.	
	D.W.	N	D.W.	N	D.W.	N
5 week	2.4	13.1	2.4	14.2	2.1	9.6
11 week	46.9	86.7	45.3	90.5	39.2	62.9
17 week	107.6	93.9	97.8	86.3	88.6	81.8
19 week	100	100	100	100	100	100

It can be seen from Table 4.19 that for the S.O. and I.F. treatments nitrogen uptake was rapid up to the eleven week harvest and then levelled off, by which time less than half the total dry weight had been accumulated. In the N.F. treatment, nitrogen was absorbed at a relatively steady rate throughout the season. In Table 4.20, nitrogen content per sample on the S.O. and N.F. treatments is expressed as a percentage of that in the I.F. treatment and it is particularly noticeable that as the plants develop there is a steady increase in the relative amount of nitrogen in the N.F. treatment.

Table 4.20 - Mean Total Nitrogen content unit^{-1} (I.F. = 100)

Harvest	S.O.	N.F.
5 week	100.0	36.9
11 week	103.5	37.4
17 week	119.3	51.8
19 week	108.9	54.2

The corresponding values for the S.O. treatment also show a rise during the season up to 17 weeks then a decrease. It could be argued that variations in total dry matter per unit and the total nitrogen content per unit over the season may be due to the fluctuating sample size at each harvest (c.f. Table 4.13). The trends observed in Table 4.20 could therefore be artifacts produced by sampling error. Estimates were therefore made (Formula I, Chapter III) of whole plant dry weight and whole plant nitrogen content at densities corresponding to the seasonal mean for each treatment. These figures were calculated for each treatment at each harvest and then multiplied by the seasonal mean number of plants per unit for each treatment. A series of 'corrected' figures is thereby produced for mean total dry weight per unit and mean total nitrogen content per unit at the various harvests. These figures are presented in Table 4.21 and expressed as percentages of the 19 week values for each treatment in Table 4.22.

Table 4.21 - Mean total dry weight g. unit^{-1} (D.W.) and mean total nitrogen uptake mg. per unit (N) at various harvests (Values at mean seasonal density)

TREATMENT

HARVEST	S.O.		I.F.		N.F.	
	D.W.	N	D.W.	N	D.W.	N
5 week	4.8	241.7	4.7	216.1	2.5	84.7
11 week	84.2	1315.0	85.1	1333.6	40.1	497.5
17 week	209.6	1529.2	192.8	1284.9	93.6	659.9
19 week	189.7	1597.3	198.3	1510.6	108.3	793.7

Table 4.22 - Percentage of 19 week values for mean total dry weight unit^{-1} (D.W.) and mean total nitrogen uptake unit^{-1} (N) at various harvests (data from Table 4.21)

HARVEST	S.O.		I.F.		N.F.	
	D.W.	N	D.W.	N	D.W.	N
5 week	2.5	15.1	2.3	14.3	2.3	10.7
11 week	44.4	82.3	42.9	88.3	37.0	62.7
17 week	110.5	95.7	97.2	85.1	86.4	83.1
19 week	100	100	100	100	100	100

The results in Table 4.21 and 4.22 are presented graphically in Figs. 4.5 and 4.6 respectively. Reworking Table 4.20 using the figures presented in Table 4.21 (and thereby eleiminating fluctuations due to sample size) for mean total nitrogen uptake per unit, Table 4.23 is produced.

Table 4.23 - Mean total nitrogen uptake unit^{-1} (data from Table 4.21) I.F. = 100

Harvest	S.O.	N.F.
5 week	119.9	39.2
11 week	98.6	37.3
17 week	119.0	51.4
19 week	105.7	52.4

It can be seen from Fig. 4.5 that plants on the N.F. treatment continued to absorb nitrogen and accumulate dry matter at a fairly steady rate throughout the season. From Table 4.23 it appears that over the latter half of the season nitrogen accumulation was greater on the N.F. treatment than I.F. treatment, because the ratio values increase

Figure 4.5

Mean total dry weight (g) unit^{-1} and mean total nitrogen (mg) unit^{-1} at various harvests.

△ = S.O.
□ = I.F.
○ = N.F.

Closed symbols = Dry weight
Open symbols = Nitrogen uptake

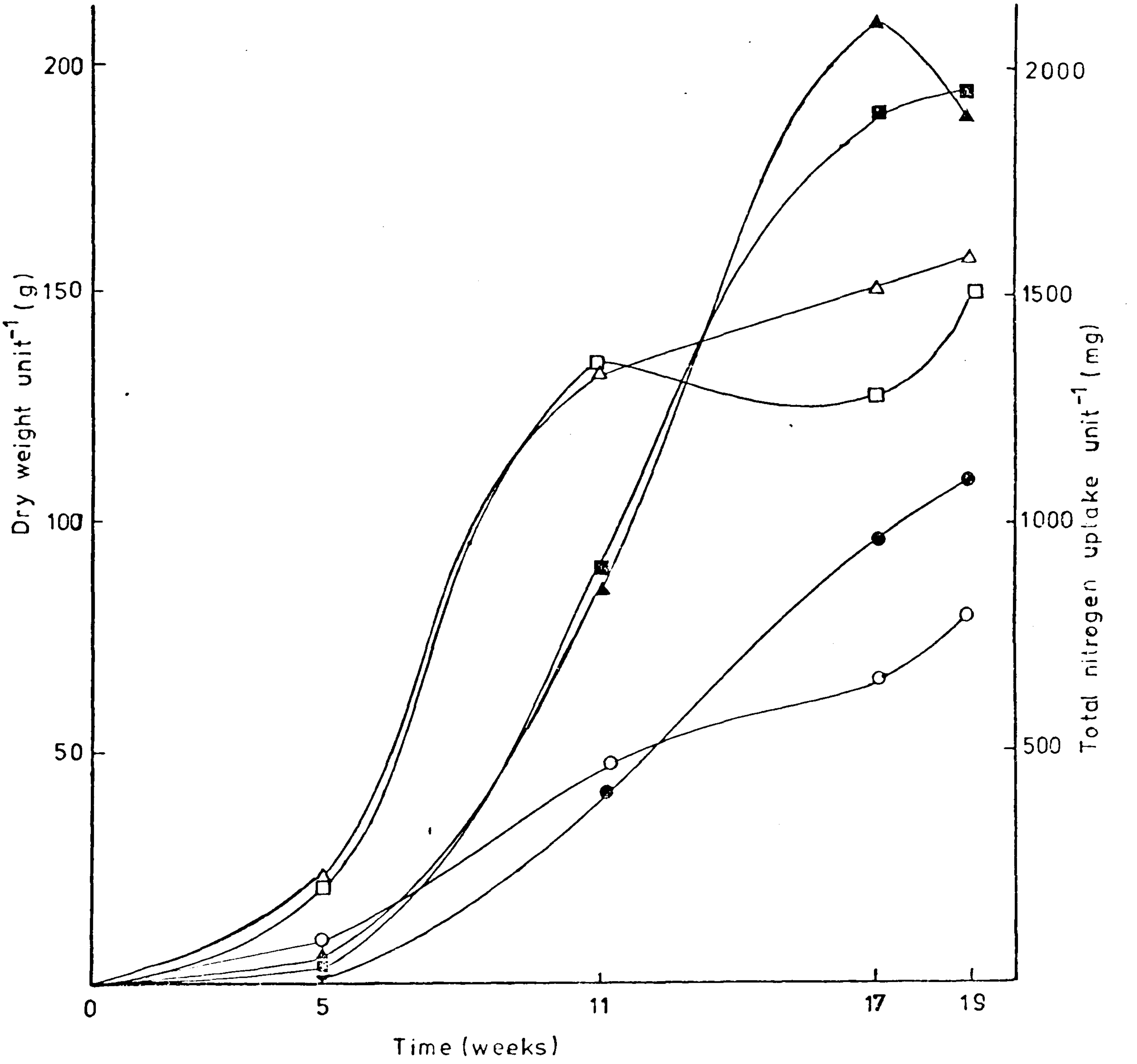
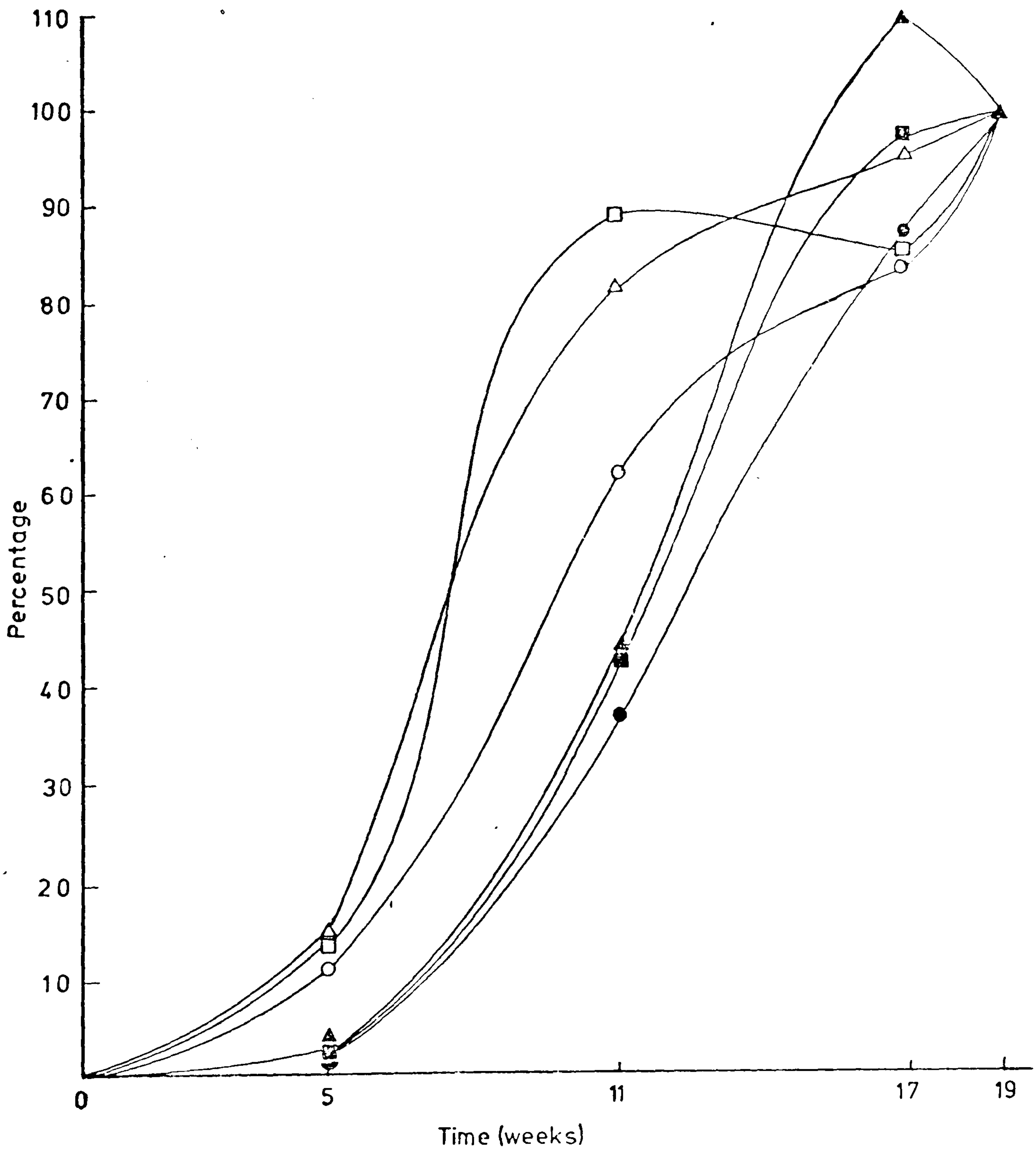


Figure 4.6

(1972) Percentage of final dry weight and percentage of final total nitrogen uptake at various harvests.

△ = S.O.
□ = I.F.
○ = N.F.

Closed symbols = Dry weight
Open symbols = Nitrogen uptake



steadily from the 11 week harvest onward. Thorne (1962) found in pot experiments with Proctor and Plumage Archer barley that nitrogen uptake from unfertilized soil continued slowly until maturity, whereas uptake from pots fertilized at sowing (inorganic fertilizer) was complete at ear emergence. Over the last four weeks of her experiment, plants in the non fertilized plots absorbed 10% of their final nitrogen content whereas there was no net income from the fertilized pots over the same period.

In a field experiment using several varieties of barley, Watson, Thorne and French (1958) found that nitrogen uptake continued throughout the season (0.46 cwts N applied as 'Nitrochalk' broadcast at sowing). After ear emergence nitrogen in the ear increased at the expense of the shoot, so that at the final harvest the major part of the nitrogen occurred in the grain. Over the last eight weeks of their experiment the difference in total nitrogen content between fertilized and non-fertilized treatments decreased showing that nitrogen content on the no fertilizer treatment was increasing relative to the fertilized treatment. They offer no satisfactory explanation for this phenomena but cite rate of mineralization of soil organic matter as a contributory factor.

Addition of fertilizer nitrogen has been shown (Aleksic, Broeshart and Middelboe, 1968) to have very little effect upon the rate of mineralization of soil organic nitrogen. It seems likely therefore that the performance of the N.F. treatment plants is due to continued plant uptake of, and requirement for, nitrogen relative to plants on the I.F. treatment.

Gregory (1952) stated that in the developing cereal plant grown at different levels of nitrogen, over 90% of the total nitrogen taken up by the plants has been accumulated when the dry weight is only 25% of the final value. Watson et al (1958) found substantially lower values for rate of nitrogen uptake relative to dry weight accumulation. In their experiments only 60% of the maximum nitrogen content was present at 25% maximum dry weight. The corresponding values for S.O., I.F. and N.F. treatments are as follows:- 61%, 75% and 52% respectively (c.f. Fig 4.6). It appears from these figures that the rate of nitrogen uptake was faster with the I.F. treatment that either S.O. or N.F. treatments over the early stages of growth. The ratio of head weight to vegetative weight in cereals is often related to early nitrogen uptake. Halliday (1948) observed that with small grain cereal crops the maximum ratio of grain to straw usually occurred in the range of marked deficiency of nitrogen. Hence the ratio of grain to straw usually decreases with an increase in nitrogen supply. He concluded that increases in ratio of grain to straw from nitrogenous fertilization could be obtained by delayed application of the fertilizer. From the figures presented for the rates of nitrogen uptake as percentage of the final value it would be expected that proportionally more of the total weight would be present in the heads in the S.O. and N.F. treatments compared to the I.F. treatment. Reference to Table 4.17 shows that the value $\frac{W_H 4}{Wp4}$ is 46.6%, 41.9% and 47.9% for S.O., I.F. and N.F. respectively. These figures are from the raw data and it seems important therefore to rework Tables 4.17 and 4.18 using estimates of plant dry weight and nitrogen content per plant at densities corresponding to the seasonal mean for each treatment. Table 4.24 corresponds to Table 4.17 and Table 4.25 corresponds to Table 4.18.

Table 4.24 - Measurements of mean dry weight plant^{-1}(Wp), stem^{-1} (Ws) and head wt. plant^{-1}(W_H) at the 2nd (2) and 4th (4) harvests and the change in weight (Δ) of these plant parts from 2 to 4 for the three treatments. All estimated at densities equal to seasonal mean for each treatment

	2	4		2	4		2	4	
	Wp	Wp	ΔWp	Ws	Ws	ΔWs	W_H	W_H	ΔW_H
S.O.	1.10	2.48	+1.38	1.10	1.29	+0.19	-	1.19	+1.19
I.F.	1.24	2.89	+1.65	1.24	1.68	+0.44	-	1.21	+1.21
N.F.	0.63	1.70	+1.07	0.63	0.91	+0.28	-	0.79	+0.79

Table 4.25 - Measurements of the total nitrogen uptake plant^{-1}(N_T) stem (Ns) and heads plant^{-1} (N_H) at the 2nd (2) and 4th (4) harvests and the changes in total nitrogen content (Δ) of the fractions from 2-4 for the three treatments. All estimated at densities equal to seasonal mean for each treatment

	2	4		2	4		2	4	
	N_T	N_T	ΔN_T	Ns	Ns	ΔNs	N_H	N_H	ΔN_H
S.O.	17.19	20.80	+3.61	17.19	5.29	-11.9	-	15.51	+15.51
I.F.	19.44	22.02	+2.58	19.44	7.36	-12.08	-	14.66	+14.66
N.F.	7.81	12.46	+4.65	7.81	3.30	- 4.51	-	9.16	+ 9.16

Certain comparisons have been extracted from Tables 4.24 and 4.25 and these are presented in Table 4.26.

Table 4.26 - Ratios calculated from data presented in Table 4.24 and 4.25 (percentages)

	$\frac{W_H(4)}{W_s(4)}$	$\frac{W_H(4)}{W_p(4)}$	$\frac{N_H(4)}{N_T(4)}$	$\frac{\Delta N_T}{N_T(4)}$	$\frac{N_T(2)}{N_T(4)}$	$\frac{\Delta N_s}{N_s(2)}$
S.O.	92.2	48.0	74.6	17.4	82.6	69.2
I.F.	72.0	41.9	66.6	13.3	88.3	62.1
N.F.	86.8	46.5	73.0	37.3	62.7	57.7

The grain to straw ratios ($\frac{W_H(4)}{W_s(4)}$) for the three treatments are 92.2%, 72.0% and 86.8%, and the proportion of the dry weight per plant present in the heads ($\frac{W_H(4)}{W_p(4)}$) is 48.0%, 41.9% and 46.5% for S.O., I.F. and N.F. respectively. This shows that the contribution to the total dry weight found in the heads is the least on the I.F. treatment. As was mentioned previously (Halliday 1948) abundant early nitrogen supply is associated with lower grain to straw ratios. The ratios ($\frac{N_T(2)}{N_T(4)}$) show that 88.3% of the final total nitrogen content per plant was present at the 2nd harvest for plants on the I.F. treatment. The corresponding values for S.O. and N.F. treatments were 82.6% and 62.7% respectively.

From Table 4.24 it can be seen that ΔW_s increased during the 11 to 19 week period in all treatments. This suggests that photosynthetic input during this period was not limiting and that favourable conditions existed for grain filling. Gallagher et al (1975) in their paper on the stability of grain weight in barley (c.v. Proctor) demonstrated that large decreases in ΔW_s occurred in two out of the three seasons studied. They associated these large amounts of translocation to drought conditions during the period of grain filling. Under these conditions the rate of photosynthesis in the ear, awns and upper leaves of the canopy was found to be very low from anthesis to maturity. In their experiments, 2.3%, 74.2% and 33.3% of the final grain weight was attributable to translocation from the stem (1969, 1970 and 1972 seasons respectively). Other workers, however, have found little or no translocation from the vegetative material (stem) to the heads in barley. Watson and Norman (1939) found no loss of stem dry weight as the ears matured and similar results were presented by Watson et al (1958) and Thorne (1965). It would appear that translocation of dry matter from the stem to aid grain filling only occurs when photosynthesis in the ears is prevented or reduced by external factors such as water supply.

Watson and Norman (1939) in experiments where certain parts of the barley plant were shaded to prevent photosynthesis were able to estimate the contribution to ear dry weight made by the various plant fractions. Material for ear growth appeared to be derived as follows:- 25% from leaves and sheaths before ear emergence, 45% from the flag leaf and top internode and 30% from assimilation by the grain itself. Watson et al (1958) reported broadly similar values. Both of these papers showed no close dependence of the rate of translocation of nitrogen compounds into the ear on the rate of increase in carbohydrate in the ears. The dry matter contribution to grain yield by assimilation in the shoots was, however, increased by nitrogenous fertilization and this increase was wholly ascribable to increase in leaf area duration. Increase in dry matter production by the ears was associated with an increase in the photosynthetic capacity of the ears. In a field experiment, Thorne (1962) showed that application of fertilizer nitrogen at the time of ear emergence had no effect on the production of new tillers but senescence of the leaves and of the existing shoots was delayed and grain yield increased correspondingly.

From table 4.25 it can be seen that the amount of nitrogen absorbed from the environment during the 11-19 week period was greatest on the N.F. treatment ($\Delta N_T = 4.65$) and least on the I.F. treatment ($\Delta N_T = 2.58$). This intake of nitrogen was also proportionally greatest on the N.F. treatment ($\frac{\Delta N_T}{N_T(4)}$) and least on the I.F. treatment. Translocation of nitrogen from the stem to the heads took place in all three treatments but was greatest on the S.O. treatment and least on the N.F. treatment ($\frac{\Delta Ns}{N_s(2)}$). In view of Thorne's (1962) findings that late nitrogen uptake prevented senescence of photosynthetic surfaces it might be expected that head weight would continue to accumulate to a later date in the S.O. and N.F. treatments compared to the I.F. treatment. Certainly the proportion of nitrogen found in the heads ($\frac{N_H(4)}{N_T(4)}$) was greatest on the S.O. and N.F. treatments as was the proportion of the whole plant weight found in the heads ($\frac{W_H(4)}{W_P(4)}$).

The greater degree of translocation of nitrogen to the head and the greater absorption of nitrogen from the soil on the S.O. treatment compared to the I.F. treatment could account for the fact that although total nitrogen content per plant was not significantly different (Table 4.8) there was significantly more nitrogen per head on the S.O. treatment (Table 4.10). This pattern of nitrogen distribution could lead to prolonged photosynthetic activity in the heads on the S.O. treatment and equivalence of dry weight per head (Table 4.6) even though the number of heads per unit area on the S.O. treatment was significantly higher than on the I.F. treatment (Table 4.4).

4.4.4 Relationship between stand density and nitrogen content per plant

The relationship between stand density and mean dry weight per plant at the four harvest times has been shown in Figs. 4.1 - 4.4.

These graphs indicate that there is no significant relationship between density and mean dry weight per plant on the S.O. treatment, but that as the season progressed there was an increasingly negative correlation on the I.F. treatment and to a lesser degree on the N.F. treatment. A similar relationship is found to occur between stand density and the mean nitrogen content per plant over the season. This is illustrated in Figs. 4.7, 4.8, 4.9 and 4.10. Table 4.28 gives a summary of the information presented in these figures.

Table 4.28 - Summary of Figures 4.7 - 4.10 inclusive

Harvest	Treatment	Correlation coefficient
1st (5 week)	S.O.	0.385 *
	I.F.	-0.269
	N.F.	0.061
2nd (11 week)	S.O.	-0.024
	I.F.	-0.468 †
	N.F.	-0.323
3rd (17 week)	S.O.	0.249 *
	I.F.	-0.564 †
	N.F.	-0.599 †
4th (19 week)	S.O.	-0.367
	I.F.	-0.627 †
	N.F.	-0.287

(* = treatment significantly different to I.F. $P \leq 0.05$)
(† = correlation coefficient significant $P \leq 0.05$)

The correlation coefficients between mean dry weight per plant and density, and mean nitrogen content per plant and density are plotted against time in Fig. 4.11. As can be seen these two variables

1st Harvest 1972

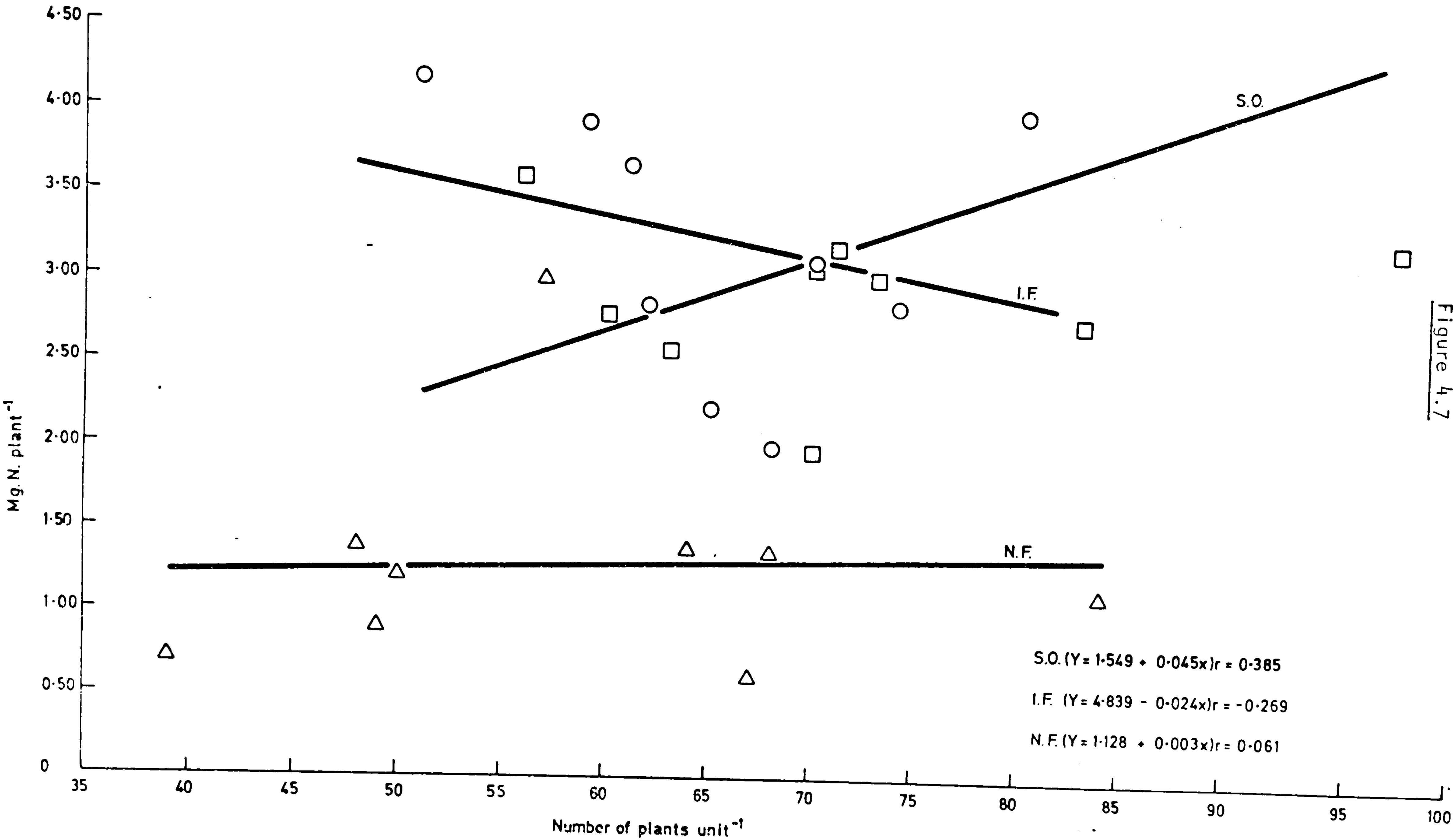


Figure 4.7

Figure 4.8

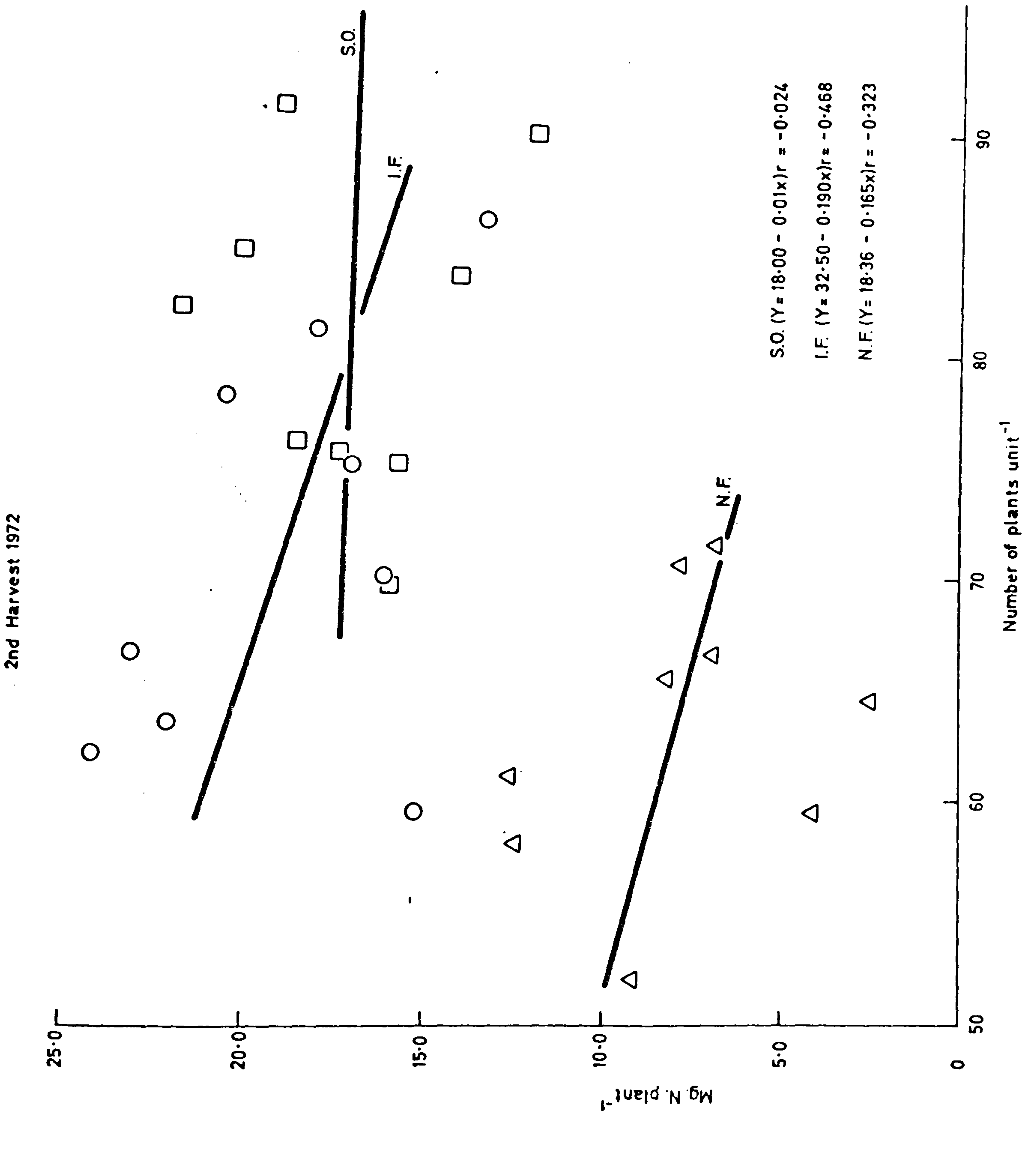

2nd Harvest 1972
S.O.
I.F.
N.F.
S.O. (Y= 18·00 - 0·01x) r = -0·024
I.F. (Y= 32·50 - 0·190x) r = -0·468
N.F. (Y= 18·36 - 0·165x) r = -0·323
Number of plants unit^{-1}
Mg. N. plant^{-1}
0
5·0
10·0
15·0
20·0
25·0
50
60
70
80
90

Figure 4.9

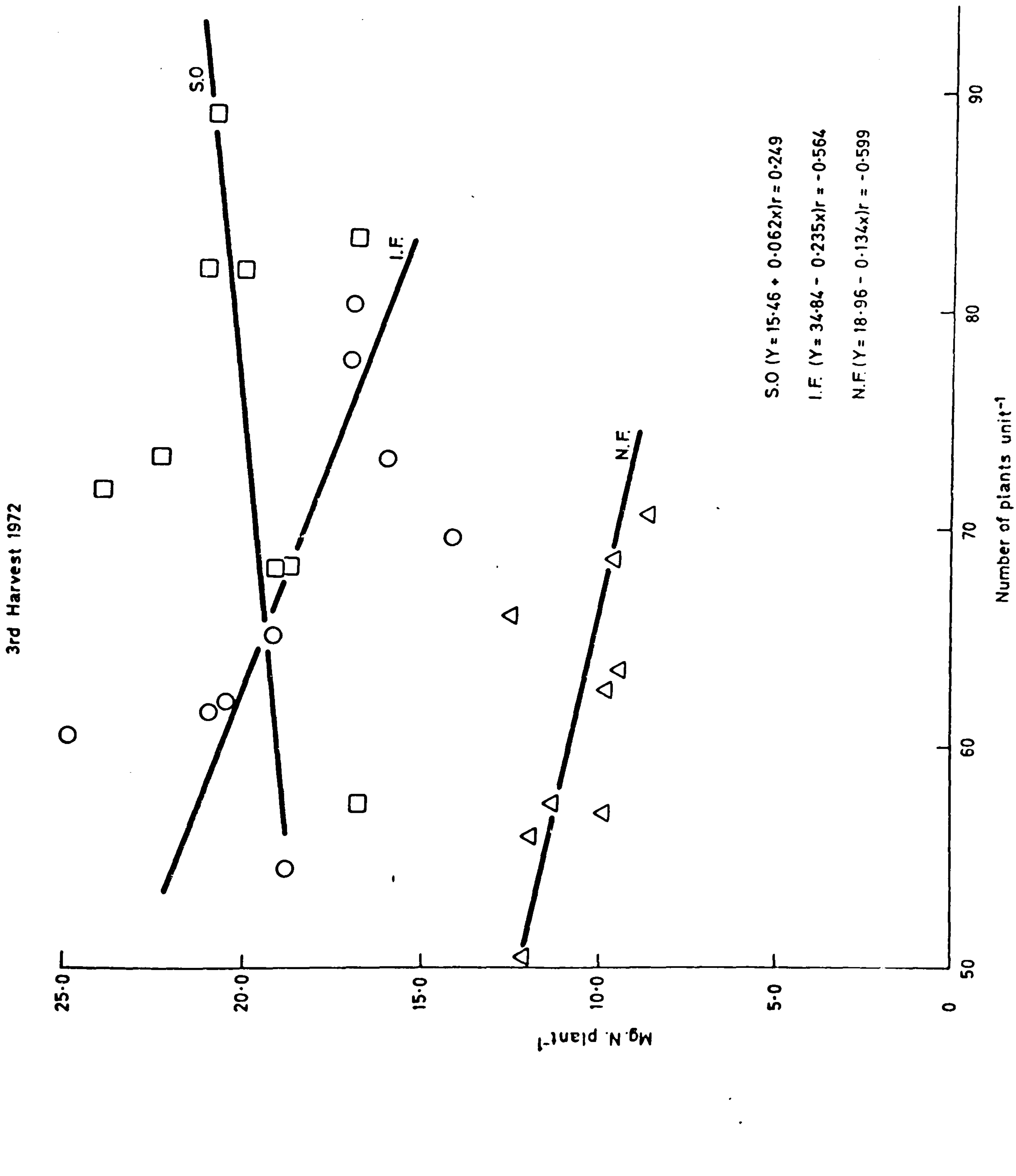

3rd Harvest 1972
S.O
I.F.
N.F.
S.O (Y = 15·46 + 0·062x) r = 0·249
I.F. (Y = 34·84 - 0·235x) r = -0·564
N.F. (Y = 18·96 - 0·134x) r = -0·599
Mg. N. plant⁻¹
25·0
20·0
15·0
10·0
5·0
0
50
60
70
80
90
Number of plants unit⁻¹

Figure 4.10

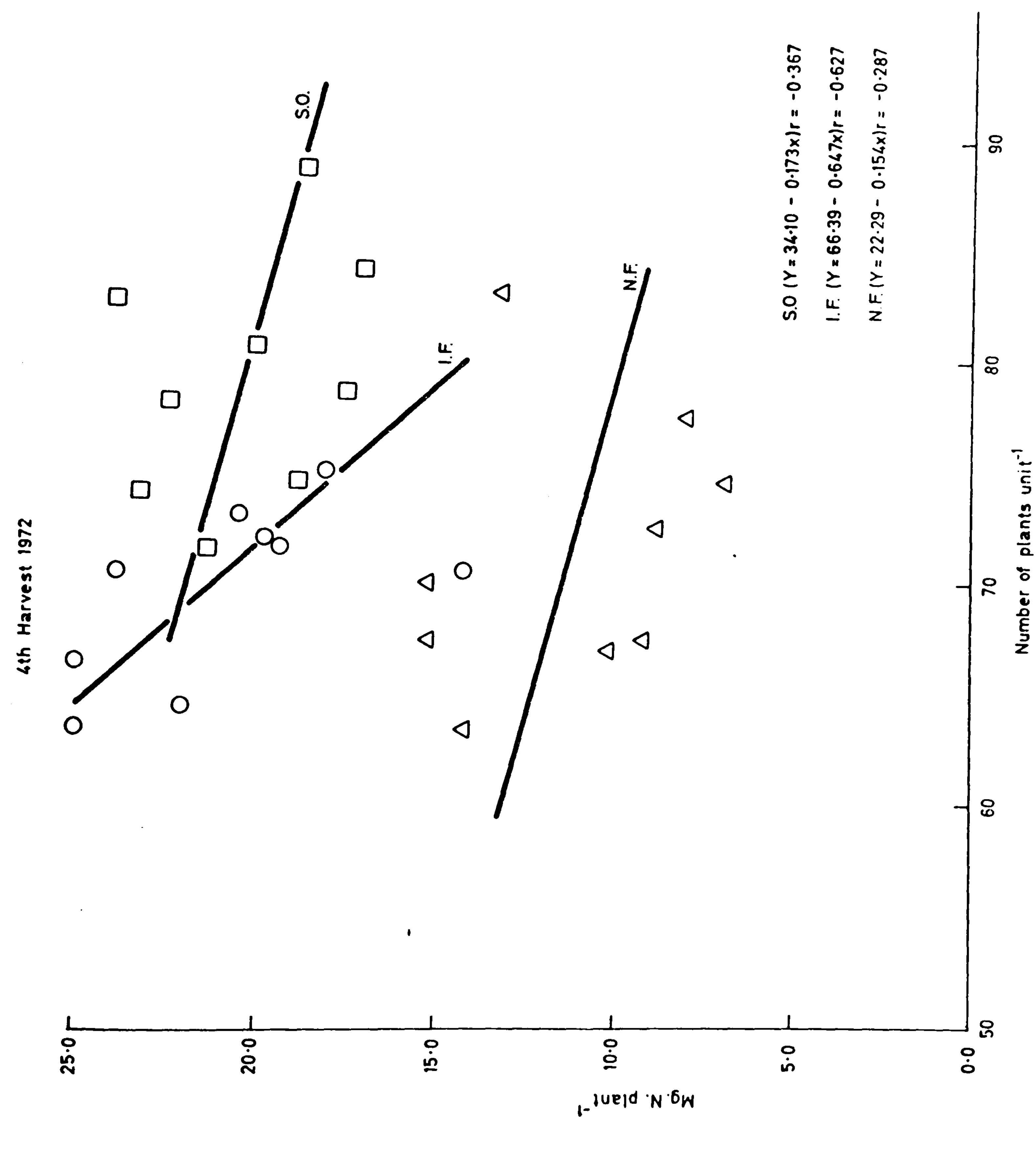
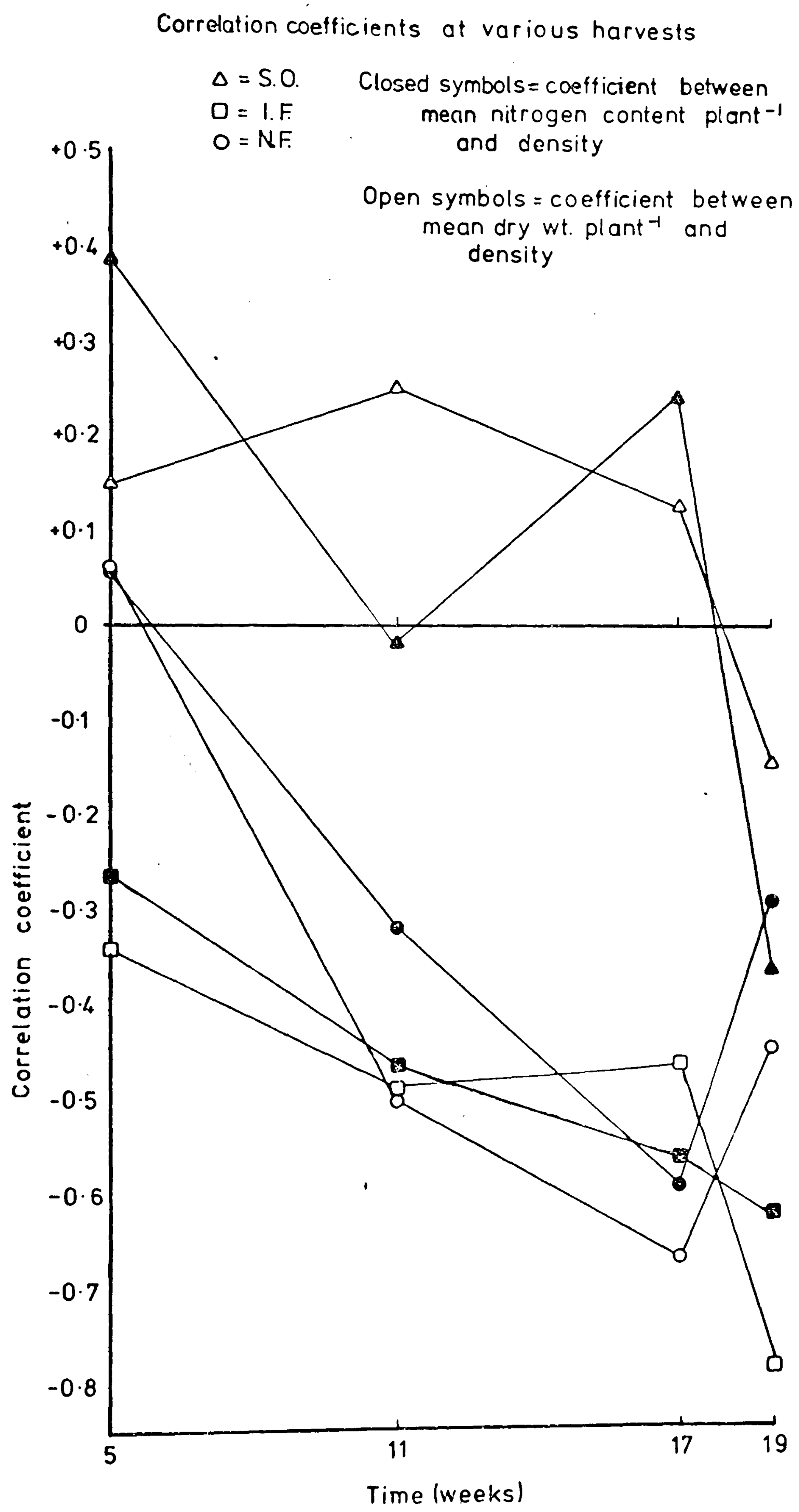

4th Harvest 1972
S.O.
I.F.
N.F.
S.O (Y = 34·10 - 0·173x) r = -0·367
I.F. (Y = 66·39 - 0·647x) r = -0·627
N.F. (Y = 22·29 - 0·154x) r = -0·287
Mg. N. plant⁻¹
25·0
20·0
15·0
10·0
5·0
0·0
50
60
70
80
90
Number of plants unit⁻¹

Figure 4.11


Correlation coefficients at various harvests
Δ = S.O.
□ = I.F.
○ = N.F.
Closed symbols = coefficient between mean nitrogen content plant⁻¹ and density
Open symbols = coefficient between mean dry wt. plant⁻¹ and density
+0·5
+0·4
+0·3
+0·2
+0·1
0
-0·1
-0·2
-0·3
-0·4
-0·5
-0·6
-0·7
-0·8
Correlation coefficient
5
11
17
19
Time (weeks)

follow a very similar course throughout the season on the I.F. and N.F. treatments. In the S.O. treatment, however, the two variables change in a similar way only between the 17 and 19 week harvests. This suggests that competition for nitrogen might be responsible for the inverse relationship between dry weight and density on the I.F. and N.F. treatments and that it becomes effective on the S.O. treatment only late in the season.

4.5 SUMMARY

The following points are made as a general summary to this chapter:-

1. The S.O. treatment supports a higher stand density than either I.F. or N.F. treatments.
2. Only in the I.F. and N.F. treatments was there a significant (negative) correlation between stand density and mean dry weight per plant over the course of the season.
3. The correlation between mean dry weight per plant and density is very marked on both the I.F. and N.F. treatments, but not so on the S.O. treatment. This could indicate that nitrogen was not limiting dry matter production to such an extent on the S.O. treatment.
4. The percentage recovery of applied nitrogen was greater on the S.O. treatment than on the I.F. treatment.
5. There was no significant difference in the total dry matter produced per unit area on the two fertilized treatments. A greater proportion of this weight was in the heads on the S.O. treatment compared with the I.F. treatment.
6. The mean total nitrogen uptake per unit was not significantly different between the S.O. and I.F. treatments but the mean

total nitrogen uptake per unit in heads and the mean nitrogen content per head was significantly greater in the S.O. treatment.

7. Plants grown with the semi-organic fertilizer absorb proportionally more nitrogen later in the season than those grown with the inorganic fertilizer. More nitrogen is also transferred from the vegetative material to the heads. This could lead to prolonged photosynthetic activity in the heads on the S.O. treatment thereby compensating for the greater number of heads per unit area found on this treatment.

CHAPTER V

THE EFFECT OF FERTILIZER MATERIALS ON THE GERMINATION OF BARLEY GRAINS

5.1 INTRODUCTION

Numerous workers have recorded the effects of fertilizer salts upon the rate and completeness of germination in a wide variety of seeds and grains. Olson and Dreier (1956) tested the effects of fertilizer placement on the germination and eventual stand density of a variety of small grains under field conditions and in the greenhouse. They found that severe stand reductions in the field crop resulted from only moderate levels of fertilization (10lbs N $acre^{-1}$) when the water content of the soil approached the permanent wilting point.

In laboratory experiments to determine the effects of ammonium nitrate and muriate of potash on germination when placed in contact with wheat seeds, Chapin and Smith (1960) concluded that:-

"(a) variation in soil moisture percentage, from just below the permanent wilting point to field capacity, caused but slight variation in germination of wheat seeds when fertilizer was not used.

(b) fertilizer salts placed with seed at planting time in soil that was at or near field capacity had little effect upon final germination. There was some delay in seedling emergence, however, with the heavier rates of application causing the greatest delay.

(c) if fertilizers were placed in direct contact with the seed and if the soil moisture was at or near the permanent wilting point, germination was reduced greatly or even prevented by heavy applications of fertilizers.

(d) a given amount of nitrogen from ammonium nitrate delayed germination more and caused greater final losses in germination than did the same amount of K_2O supplied by muriate of potash."

Stand reduction and germination retardation of wheat both in the field and the greenhouse using a variety of fertilizers was recorded by Brage, Zich and Fine (1960). Much of the work done on this problem has incorporated two variables, the amount of fertilizer applied and the level of soil moisture at the time of sowing. Much work has been done on this second variable (Doneen and MacGillivray, 1943; Hunter and Erikson, 1952; Dasberg and Mendel, 1971; Uhvits, 1946; Hadas, 1970). In all cases low soil moisture level and/or high salt concentration of the soil solution led to a reduced germination rate.

In some of the experiments referred to above the amounts of fertilizer used were less than those applied in the experiment described in Chapter III, and it is possible that the concentrations of salts in the soil solution of the I.F. treatment were responsible for the relatively low densities of plants on this treatment compared with the S.O. treatment. A series of greenhouse experiments were set up to investigate this possibility.

5.2 MATERIALS AND METHODS

5.2.1 Experiment I

In the first experiment the method employed was similar to that used by Chapin and Smith (1960). Five inch (17.8cm) plant pots were filled with soil from the field at Aldborough (Site I). The soil was air dried and sieved (½" mesh) to remove large particles. A circular furrow 3.5 inches (8.9cm) in diameter was drawn in the soil surface of each pot. This gives an area equivalent to 1.2×10^{-5} acres

(0.49×10^{-5} ha) assuming 7 inches (17.8cm) between adjacent rows. At a sowing density equivalent to twelve stone per acre (188 $Kg.ha^{-1}$) the number of seeds required per pot was found to be twenty five. Therefore twenty-five grains of dressed Proctor barley were sown at a depth of ¾" (1.9cm) in each furrow. Fertilizer was also placed in the furrow in a quantity calculated to give a rate of application of 3 cwts per acre (376.5 Kg ha^{-1}) or 1.9g per pot. Eight pots were treated with S.O. fertilizer (analysis 9.6.6.) eight with I.F. (9.6.6.) and eight received no fertilizer (N.F.), giving twenty four pots in all. Two watering regimes were used viz:- 100 and 200 cm^3 of distilled water every two days. This is equivalent to 0.08 inches (2.0mm) and 0.16 inches (4.1mm) of rain respectively. The pots were arranged in the greenhouse in a standard randomized block design there being four replicates of six treatments as follows:

Treatment Number	Treatment
1	No Fertilizer (N.F.), $100cm^3$ H_2O/2 days
2	" " " , $200cm^3$ " "
3	Semi-organic (S.O.), $100cm^3$ H_2O/2 days
4	" " " $200cm^3$ " "
5	Inorganic (I.F.), $100cm^3$ H_2O/2 days
6	" " $200cm^3$ " "

The number of seedlings per pot was counted and recorded every twenty four hours.

5.2.2 Experiment II

This experiment was basically similar in overall design to Experiment I, but grains were sown at different times, a greater water stress was applied and a different watering regime was used.

The Chapin and Smith (1960) method was retained and the same two fertilizers at the same rates were used. The plant pots were filled as before with air dried and sieved Aldborough soil. Each soil sample was then brought to field capacity (water content = 31.5% dry weight) then left to dry out gradually. Three days after water had ceased to drain out of the pots, when the water content of the soil was 18.4% dry weight, half of them were sown and fertilized as before. The remaining pots were sown and fertilized three days later when the water content had dropped to 10.2% dry weight. Air dry soil had a water content of 4.2% dry weight.

There were therefore six treatments:-

Treatment No.	Treatment		
1	N.F. sown	day	0
2	" "	"	3
3	S.O. sown	day	0
4	" "	"	3
5	I.F. sown	day	0
6	" "	"	3

There were four replicates of each treatment as in Expt. I. The number of seedlings per pot was counted every 24 hours. No water was added at the time of sowing. After eleven days from day 0 no seedlings had appeared and the soil was extremely dry. Two hundred cm^3 of distilled water was added to each pot on that day and a further 100 cm^3 was added when the seedlings showed signs of wilting.

5.2.3 Experiment III

The same basic method used in Experiment I and II was retained. Whereas in these two previous experiments the Inorganic fertilizer (I.F.) was a specially prepared powdered compound of analysis 9.6.6. the fertilizer used in Expt. III was the standard commercially available prilled compound (analysis 20.14.14.) used in the 1972 field trials. The rates of application were also the same as in the 1972 field trials, viz:- 6 cwts per acre (753 $Kg.ha^{-1}$) Semi-organic (S.O.) and 2.75 cwts per acre (345 $Kg.ha^{-1}$) Inorganic (I.F.) This rate of application was equivalent to 3.8g per pot (S.O.) and 1.74g per pot (I.F.). A treatment with no added fertilizer (N.F.) was included as before. The twenty-four plant pots were filled with air dried and sieved Aldborough soil, brought to field capacity then left to drain. Half the pots were sown and fertilized when the soil moisture content had dropped to 17.3% dry weight, the remaining pots were set up when the level had dropped to 7.7% dry weight (day 5). There were therefore six treatments as before, viz:-

Treatment No.	Treatment
1	N.F. sown day 0
2	" " " 5
3	S.O. sown day 0
4	" " " 5
5	I.F. sown day 0
6	" " " 5

No water was applied to the pots at the time of sowing. The first watering (200 cm^3 per pot) took place on day 12 and 100 cm^3 was added to each pot whenever there were signs of wilting.

5.3 RESULTS AND DISCUSSION

The results of Experiment I are presented in Fig. 5.1 (N.F. = Control). A high percentage germination was achieved in all treatments in the first experiment, but there was a maximum difference of five days in the time taken to reach 90% germination between the six treatments. Emergence of seedlings was recorded for both N.F. treatments and for the S.O. treatment at the higher watering regime (Treatment nos.

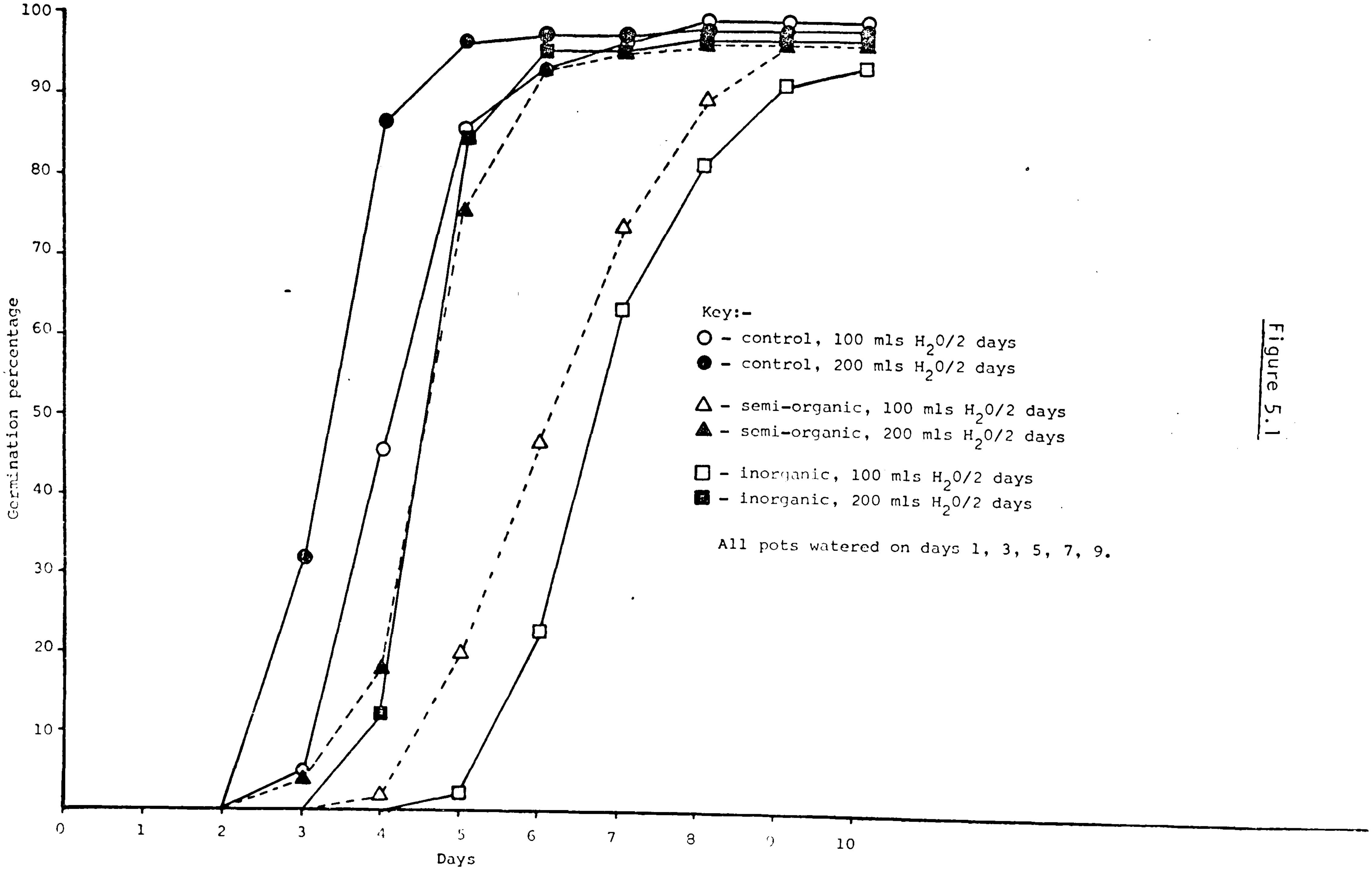

100
90
80
70
60
50
40
30
20
10
Germination percentage
0
1
2
3
4
5
6
7
8
9
10
Days
Key:-
○ - control, 100 mls H_2O/2 days
● - control, 200 mls H_2O/2 days
△ - semi-organic, 100 mls H_2O/2 days
▲ - semi-organic, 200 mls H_2O/2 days
□ - inorganic, 100 mls H_2O/2 days
■ - inorganic, 200 mls H_2O/2 days
All pots watered on days 1, 3, 5, 7, 9.

Figure 5.1

1, 2 and 4) the first day after the regular watering regime was started. One day later seedlings emerged in the S.O. treatment receiving 100 cm^3 H_2O per day and the I.F. treatment at the higher watering level (Treatment nos. 6 and 3). Twenty four hours later seedlings were present in pots in treatment no. 5 (I.F. low water regime). So it would appear that the presence of the fertilizer materials was reducing the rate of germination even when there was no apparent water shortage. The slowest and most incomplete level of germination was recorded under the I.F. fertilizer at the lower watering level. These results agree with those obtained by Chapin and Smith (1960). Using a silty clay loam soil at soil moisture contents ranging from 20% - 30% dry weight they found that fertilizer materials reduced the rate of germination of wheat seeds but by the end of the experimental period differences in germination had disappeared.

In Experiment I the soil moisture level was not allowed to approach the permanent wilting point at any stage. Experiment II was designed to incorporate the effects of a water shortage on the germination rate. Fig. 5.2 (N.F. = control) shows that following the first watering (day 11) seedlings appeared in some pots the next day, i.e. the pots treated with semi-organic fertilizer and those without fertilizer addition (Treatment nos. 1, 2, 3 and 4). The appearance of seedlings in the pots treated with inorganic fertilizer (Treatment nos. 5 and 6) was delayed by as much as a further three days (Treatment no. 6). Furthermore, there were marked differences in the percentage emergence under the different treatments at the end of the experiment. With the I.F. treatments (5 and 6) 76% and 73% of the seedlings emerged respectively, with the S.O. treatments (3 and 4) 83% and 87% respectively and where no fertilizer was added final percentages were 91% for both treatments (1 and 2). It can be seen therefore that soil moisture content at the time of sowing had an appreciable effect upon the rate and percentage of germination of barley grains

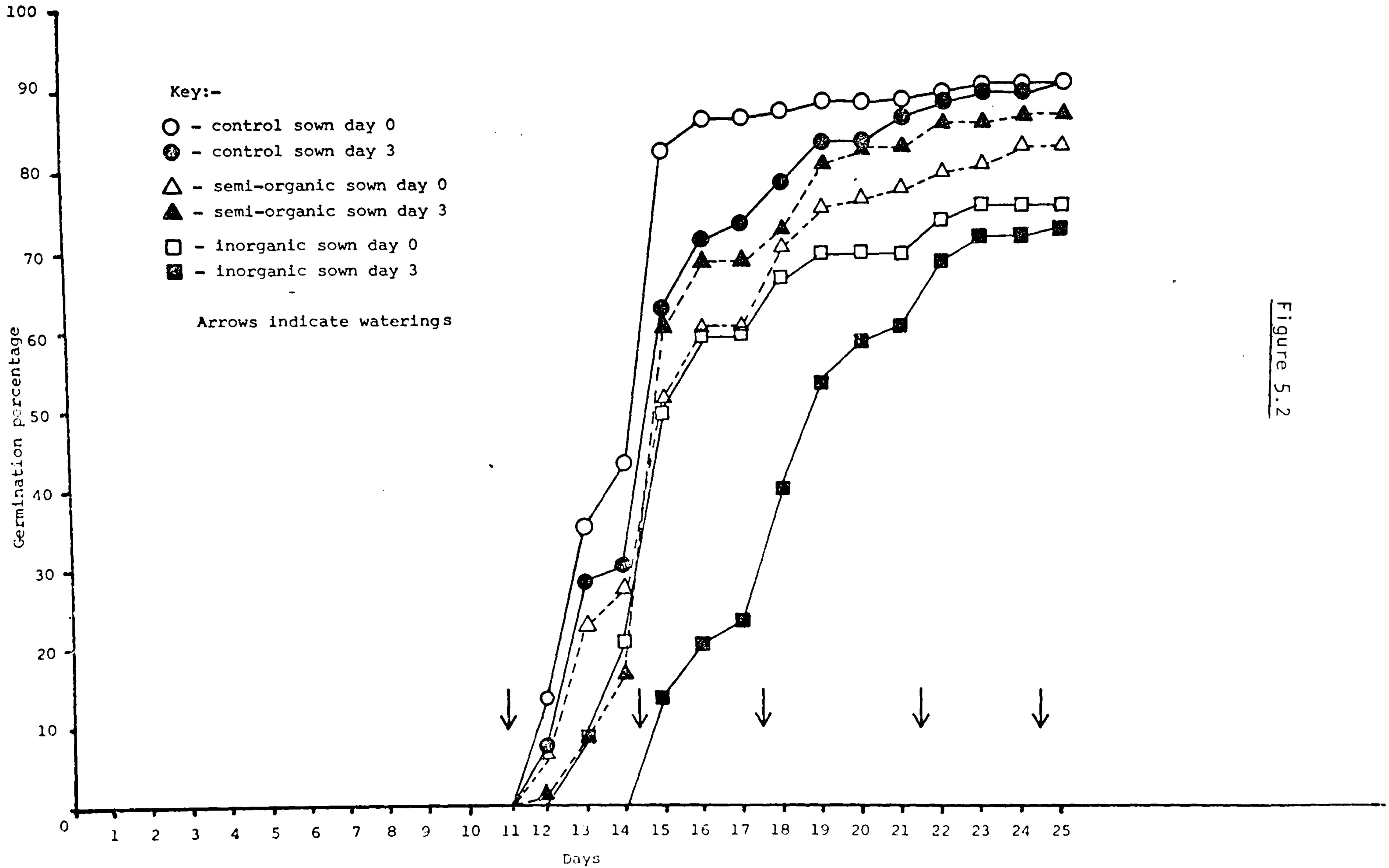

Key:-
○ - control sown day 0
● - control sown day 3
△ - semi-organic sown day 0
▲ - semi-organic sown day 3
□ - inorganic sown day 0
■ - inorganic sown day 3
Arrows indicate waterings
Germination percentage
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Days

Figure 5.2

especially in conjunction with the I.F. fertilizer treatment. The rate and final germination percentage was lowest for the two inorganic fertilizer treatments, treatment 6 being two full days behind treatment 5 in showing seedling emergence.

Experiments I and II had shown that fertilizer materials in conjunction with varying soil moisture levels could reduce both the rate and completeness of germination of barley grains. The aim of Experiment III was to follow the levels of fertilization used in the 1972 field trials at two soil moisture levels at the time of sowing.

The results presented in Figure 5.3 (N.F. = control) show that germinating seedlings were present after three days in treatment no. 1 (N.F.) but the level remained very low until the first waterings took place (day 12). The percentage emergence in the two N.F. treatments (1 and 2) rose sharply to around 80% and thereafter rose gradually to final values of 88% and 93% (Treatments 1 and 2 respectively). Emergence was first recorded for treatments 3 and 4 (S.O.) on days 13 and 14, with final values of 81% and 73% respectively. Treatments 5 and 6 (I.F.) showed seedlings present on days 14 and 15 rising to final values of 47% and 61% respectively. As in Experiments I and II therefore, it would appear that at various soil moisture levels establishment is considerably higher in the presence of a semi-organic fertilizer than an inorganic fertilizer.

Fertilizer salts may be detrimental to crop production in two ways. Firstly a chemical effect through the toxicity of certain of the constituents, e.g. Biuret (Brage et al, 1960) and secondly a physical effect through the attainment of an osmotic concentration greater than that which can be tolerated by crop plants. Banding of seed and fertilizer together increases the efficiency of use of fertilizers but can lead to stand reduction (Lewis and Strickland, 1944; Widdowson, Penny, Williamson

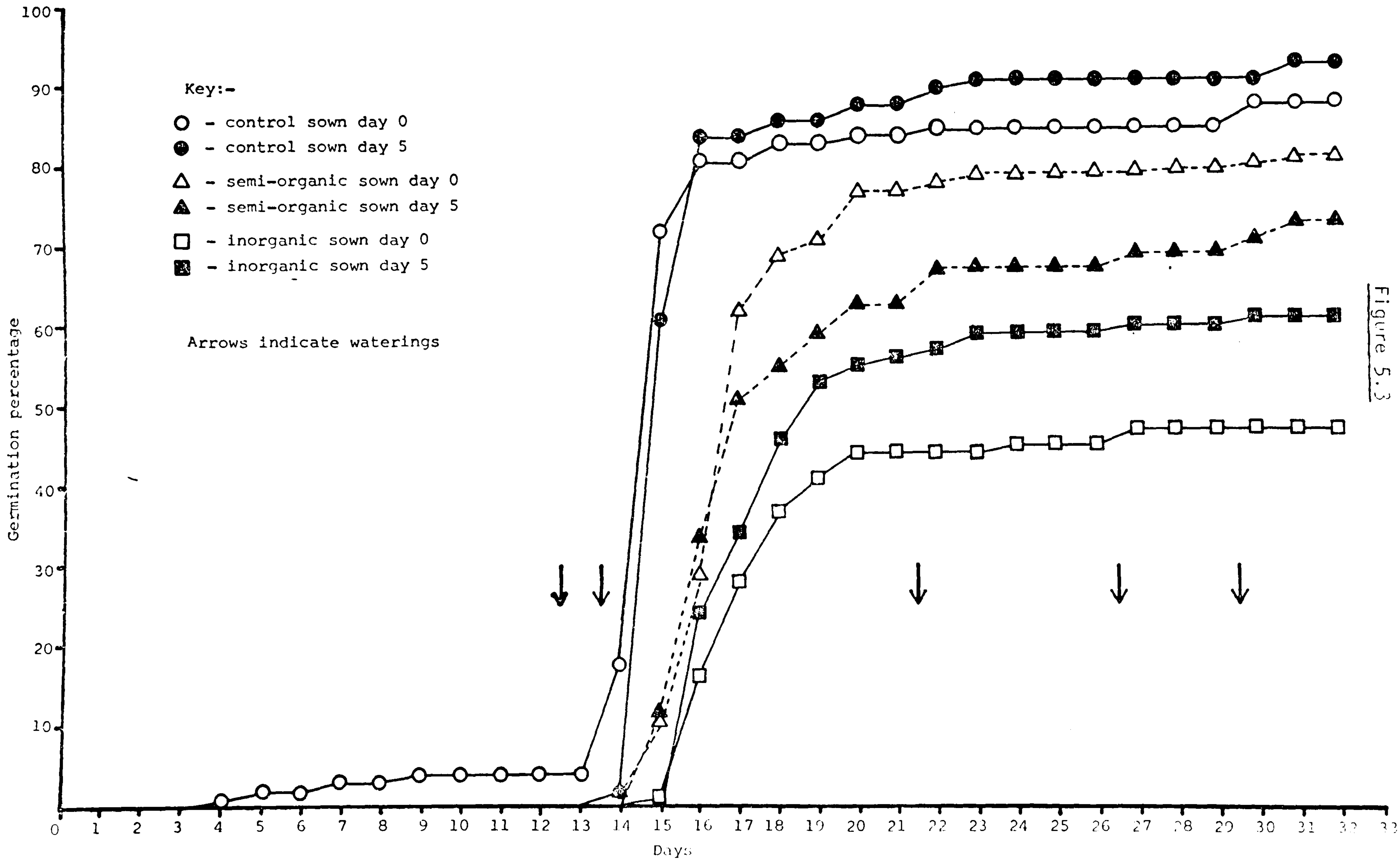

Key:-
- control sown day 0
- control sown day 5
- semi-organic sown day 0
- semi-organic sown day 5
- inorganic sown day 0
- inorganic sown day 5
Arrows indicate waterings
Germination percentage
Days

Figure 5.3

and Cooke, 1959). For a given quantity of fertilizer nitrogen fertilizers are generally most toxic, potassium next and phosphorus next (Carter, 1967).

The relative performance of the plants treated with inorganic and semi-organic fertilizers resembles that obtained in the field experiments but the relative performance of the plants without fertilizer is quite different. This problem will be discussed in Chapter VI.

CHAPTER VI

GENERAL DISCUSSION

This study set out to investigate the efficiency of a semi-organic fertilizer as compared to the more usual wholly inorganic type. Although the semi-organic fertilizer has been commercially available for many years it has never been the subject of any detailed study. The three years of field work presented in this thesis were designed to compare the effects of a semi-organic fertilizer and a wholly inorganic type of fertilizer on the growth of barley and the uptake and subsequent distribution of nitrogen in the crop. Since the first years trials (Chapter II) were subject to so many unforseen difficulties, no further discussion of the results presented in section 2.3 will be attempted here. Special attention will be given here to a comparison of the results from the 1971 (Chapter III) and 1972 (Chapter IV) trials at Aldborough location (Site I).

6.1 COMPARISON OF RESULTS FROM 1971 and 1972 FIELD TRIALS AT SITE I

A selection of the results for various parameters from the two seasons' field trials is presented in Table 6.1. All the figures are those measured at the final harvests (21 week in 1971, 19 week in 1972).

Table 6.1 - Various comparisons abstracted from the 1971 & 1972 results

TREATMENT YEAR	S.O. 1971	S.O. 1972	I.F. 1971	I.F. 1972	N.F. 1971	N.F. 1972
Mean number plants $unit^{-1}$	64.8	79.1	54.3	69.7	52.2	71.4
Mean total dry weight $unit^{-1}$ (g)	149.3	109.3	131.6	191.2	109.4	102.0
Mean dry weight $plant^{-1}$ (g)	2.30	2.47	2.40	2.79	2.10	1.46
Mean dry weight $head^{-1}$ (g)	0.74	0.71	0.62	0.68	0.61	0.60
Mean total N. uptake $unit^{-1}$ (mg)	1569.9	1606.4	1293.4	1475.7	1053.7	800.4

In 1972 the value of every property recorded in Table 6.1 is higher on both the fertilizer treatments than in 1971 with the exception of the mean dry weight per head on the S.O. treatment. On the N.F. treatment however, every value except density is lower in 1972 than in 1971. The overall mean number of plants per unit for 1971 and 1972 is shown for each treatment in Table 6.2 (figures in brackets refer to final harvest values only),

Table 6.2 - Overall mean number of plants $unit^{-1}$

	1971	1972	$\frac{1971}{1972} \times 100$
S.O.	64.3	76.5	84.1 (81.9)
I.F.	54.3	68.6	79.2 (77.9)
N.F.	50.5	63.7	79.3 (73.1)

and it can be seen that there was an increase in stand density over all three treatments in 1972 compared with 1971 though the increase for the S.O. treatment was somewhat less than for the other two treatments. There would therefore appear to be a factor which is responsible for the total number of seeds germinating and/or becoming established. This factor acts to a similar degree across all treatments (as the ratios indicate). If as is suspected the stand density observed with the S.O. treatment in 1971 is very close to a maximum possible value then any factor which increases the overall stand density would affect the S.O. treated stands to a lesser extent. This factor is likely to be a climatic one; it cannot be a nutritional factor as N.F. treatment is affected to the same extent as I.F. treatment.

The average monthly rainfall in this area for the first three months of 1971 and 1972 was 35.5mm per month and 48.2mm per month respectively. For the first five months the corresponding values were 36.4mm per month and 49.5mm per month. Before sowing on 6 April 1971 there had been no appreciable rainfall (max. 2mm) in any one day for the preceeding twenty days. In 1972 prior to sowing on 19 April there had been a rainfall of 11.5mm (recorded in one day) just ten days previously. The soil moisture content at the time of sowing in 1971 was $14.7\% \pm 0.8$ and in 1972 was $17.7\% \pm 0.9$. The differences in plant numbers between 1971 and 1972 could therefore be attributable to more favourable climatic conditions for germination in 1972 though it must be borne in mind that different varieties were sown in the two years.

The substantial increase in biomass production on the fertilizer treatments in 1972 seems to be largely a result of the increase in density, for the increase in dry weight per plant in 1972 is only small in each case (7.4% on the S.O. treatment and 16.2% on the I.F. treatment). Since the increase in density appears to be a result of climatic conditions it might be argued that the increase in amount of fertilizer used in 1972 had little effect on biomass production. It has been shown, however, (Chapter IV) that, especially towards the end of the growth period, there was a highly significant negative correlation between plant dry weight and stand density on the I.F. treatment so had not the fertilizer application been increased it seems unlikely that plant dry weight and therefore biomass production, would have been so high. This does not seem to apply to the S.O. treatment however, for here the correlation was not significant. It follows that a substantial increase in biomass production on this treatment might be achieved by increasing sowing density.

In Table 6.3 estimates of the amounts of nitrogen absorbed by the crop per sampling unit on the two fertilizer treatments and the amounts left in the soil and or lost to the system by drainage, etc. are presented for 1971 and 1972. The first value was obtained by subtracting the uptake of nitrogen on the N.F. treatment from that on the respective fertilizer treatment and the second by subtracting this value from the amount of fertilizer nitrogen applied.

Table 6.3 - Fate of applied nitrogen

	S.O. Treatment		I.F. Treatment	
	1971	1972	1971	1972
Nitrogen applied (mg)	550	1100	612	1120
Absorbed by crop	516	806	240	675
Not absorbed	34	294	372	445

In 1971 the amount of nitrogen absorbed by the crop on the S.O. treatment was equivalent to a very high percentage of that applied (94%) while on the I.F. treatment it was equivalent to less than half (39%) of that applied. In 1972 the amount retained in the soil or lost with the drainage on the I.F. treatment was similar to the 1971 value and it can be estimated that 60% of the applied nitrogen was absorbed. Since the N.F. treatment received no fertilizer for two consecutive years, however, it could be argued that the 1971 value for uptake of nitrogen on the N.F. treatment should be used in the calculations. In this case the amount of fertilizer nitrogen absorbed would be 422mg, 38% of that applied. The corresponding values for the S.O. treatment would be 553mg and 50%. If, in general, a crop is capable of utilising a large proportion of nitrogen supplied as semi organic fertilizer as occurred in 1971, it seems that in 1972 there was a considerable residuum which could have been utilized by increasing sowing density. On the inorganic fertilizer treatment it seems that either there is an approximately constant amount of fertilizer that is not utilized (about 400mg per sample) or a constant proportion (about 60%) depending upon whether 1971 or 1972 values for nitrogen taken up by the N.F. treatment are used.

The mean number of fertile tillers per plant (e.g. number of heads per plant) increased between 1971 and 1972 for both S.O. and I.F. treatments despite the greater mean stand density in 1972. The number of fertile tillers per plant in the N.F. treatment declined from 1.38 in 1971 to 1.14 in 1972. Aspinall (1961) and Langer (1966) ascribe variation in tiller number to levels of nutrient uptake. The relationship between the fertile tiller number and mean total nitrogen uptake per unit between 1971 and 1972 can be seen in Table 6.4

Table 6.4 - Differences in fertile tiller number plant^{-1}(A) and mean total nitrogen uptake unit^{-1}(B) between 1971 and 1972

	A $\frac{1972}{1971} \times 100$	B $\frac{1972}{1971} \times 100$
S.O.	108.6	102.2
I.F.	122.9	114.1
N.F.	82.7	75.9

There was a considerable drop in the mean total nitrogen uptake per unit between 1971 and 1972 in the N.F. treatment. It must be assumed that this is a result of two seasons of unfertilized growth and the effects of this can be seen throughout the results in this treatment. The increase in stand density between the two years does however complicate this relationship considerably.

Due to a combination of increase in stand density and two seasons unfertilized growth the mean dry weight per plant in the N.F. treatment drops from 2.10g in 1971 to 1.46g in 1972. The mean dry weight per head however remains virtually constant (Table 6.1). In fact the proportion (percentage) of the mean dry weight per plant contributed by the fruiting head material is markedly different between the three treatments and the two years (Table 6.5)

Table 6.5 - Proportion (%) of mean dry weight plant^{-1} present in heads

	1971 3rd Harvest	1972 3rd Harvest	1972 4th Harvest
S.O.	32.2	26.3	28.7
I.F.	25.8	23.7	24.2
N.F.	29.1	40.4	41.1

It has already been noted (Halliday, 1948, see section 4.4.3) that high grain to vegetative matter ratios are consistent with low levels of nitrogen availability in barley so the sharp rise in percentage dry weight shown by the N.F. treatment in 1972 supports the view that these plants were suffering from nitrogen deficiency.

This was not the case in 1971 and this leads to the conclusion that there were considerable residual level of fertilizer materials present from preceeding seasons. The results presented here for two consecutive seasons unfertilized barley growth on alluvial boulder clay soil suggest that nitrogen deficiency starts to appear after just one year's crop.

6.2 VARIATION OF STAND DENSITY WITH TREATMENT

Perhaps the most important single factor to emerge from the various field trials was the difference in stand density under the three treatments (S.O., I.F. and N.F.). The mean number of plants per unit over the whole season for each site and year is given in Table 6.6(a) and a summary of the results obtained in the greenhouse experiments in Table 6.6(b)

Table 6.6(a) - Mean number plants unit^{-1}(data from all individual harvests)

	1971			1972
	Site I	Site II	Site III	Site I
S.O.	63.5	55.1	64.3	76.5
I.F.	52.2	43.7	51.6	68.6
N.F.	50.6	42.8	50.1	63.7

Table 6.6(b) - Summary of greenhouse experiments

	Final percentage germination (average)		
	Expt I	Expt II	Expt III
S.O.	97.0	85.0	77.0
I.F.	95.5	74.5	54.0
N.F.	99.0	91.0	90.5

In each greenhouse experiment the N.F. treatment had the greatest number of seedlings present and the rate of germination was also faster than either S.O. or I.F. treatments (c.f. Figs. 5.1, 5.2 and 5.3). This type of effect has been noted many times in greenhouse experiments. Rader, White and Whittaker (1942) stated that "the germination of seeds may be prevented or established crops may be injured by the presence of too much soluble salt in the soil. This effect is connected with the high concentration of the soil solution and the high osmotic pressure that results". White and Ross (1939) had already shown that the addition of a wide variety of fertilizer materials to soil increased the osmotic pressure of the soil solution. Magistad and Reitmeier (1947) observed that growth reduction of several crops in soil culture was linear with increasing osmotic pressure of the substrate.

As can be seen from Table 6.6(b) and in view of the above comments the figures for percentage germination and emergence in the greenhouse experiments are consistent with an osmotic effect between the presence of fertilizer material and germination reduction.

In the field experiments (Table 6.6(a)) it is always the S.O. treatment that supported the greatest number of plants per unit area and this effect is apparent from the earliest samplings (Tables 3.5 and 4.3). If, as in the greenhouse experiments, the differences in stand density were due to osmotic effects at the germination stage then it would be expected that the N.F. treatment would support the greatest stand density. In fact the stand densities were very similar in the N.F. and I.F. treatments and uniformly lower than the S.O. values. It is possible to explain these results in two ways:-

(a) that there was no osmotic effect upon germination and stand density in the field trials on any treatment, but the S.O. treatment promotes germination and establishment of seedlings compared to I.F. and N.F. treatments, i.e. conditions in the greenhouse experiments were not representative of the conditions apertaining in the field experiments.

(b) that the difference in stand density between I.F. and S.O. treatments was due to their effects on the osmotic pressure of the soil solution at the time of germination and the situation in the field is analogous to that observed in the greenhouse with regard to these two treatments only. The potential stand density in the N.F. treatment was reduced by some other factor, e.g. die-back due to lack of nutrients immediately after germination.

In the greenhouse experiments the rate of seedling emergence was always quickest on the N.F. treatment. In the field experiments the number of seedlings present at the first harvest for both 1971 and 1972 was always proportionally lower on the N.F. treatment than the other two treatments at this stage. This is shown in Table 6.7 where the ratio

$$\frac{\text{mean number plants unit}^{-1}\ \text{(1st harvest)}}{\text{" " " " (whole season)}}$$

is expressed as a percentage for each site, treatment and year.

Table 6.7 - Ratio of mean stand density (1st harvest) to mean stand density (whole season) expressed as a percentage

Site and Year	Treatment S.O.	I.F.	N.F.
I 1971	95.6	97.3	88.7
II 1971	96.2	108.6	91.1
III 1971	101.1	98.3	91.6
I 1972	93.3	95.9	91.7

The N.F. values presented in Table 6.7 are seen to be lower than either S.O. or I.F. values at all sites. If the rate of germination and emergence was governed purely by osmotic forces in the soil then the opposite result would have been expected.

In an experiment to determine the effects of side-placing urea and other nitrogen fertilizers on spring barley, Widdowson, Penny and Williams (1964) found an average of 255 plants per square yard on no fertilizer treated strips, 6 weeks after sowing. At the same stage strips receiving 0.35cwt/acre ammonium sulphate (combine drilled) had 258 plants per square yard and those receiving 0.7cwt/acre ammonium sulphate had 295 plants per square yard.

Unfortunately no information on soil moisture content is given in this paper, but it does seem that emergence of unfertilized plants can be slower when no fertilizer additions are present in the field. This indicates that in the N.F. treatment field and greenhouse experiments were not analogous.

The differences in germination and establishment between the S.O. and I.F. treatments are roughly comparable between the greenhouse and the field experiments, and the figures for rainfall and soil moisture content mentioned in section 6.1 illustrate the point that the Plain of Holderness is one of the driest areas in the country. It would seem inevitable therefore that soil moisture stresses would develop and at the time of sowing the surface soil could be extremely dry. In fact, farmers will only sow their crops when the soil surface is dry to avoid soil compaction by the heavy machinery. As demonstrated in the greenhouse experiments, under conditions of low soil moisture content, inorganic fertilizers reduce the rate of emergence to a greater extent than a semi-organic fertilizer. The high rate of emergence on the N.F. treatment in the greenhouse could possibly be due to higher soil temperatures than in the field, leading to adequate nutrient uptake from the soil.

There is no evidence from these results of a promoting effect on germination due to the presence of the semi-organic fertilizer. The difference in the stand densities in the field and greenhouse experiments between the S.O. and I.F. treatments is most likely due to their differing effects on the concentration of the soil solution when soil moisture content was very low. Germination and emergence of the grains on the N.F. treatment in the field was delayed and reduced presumably by nutrient deficiency, a condition not repeated in the greenhouse.

6.3 CONCLUSION

Throughout this study various aspects of the growth of barley under three different fertilizer treatments have been discussed. In conclusion the following general comparisons can be made between semi-organic and inorganic fertilizers:-

(a) On the semi-organic fertilizer a higher stand density was produced.

(b) A higher total head weight in proportion to the total dry matter per unit area was produced on the semi-organic fertilizer.

(c) Proportionally more of the total nitrogen absorbed was in the heads on the semi-organic fertilizer.

(d) On the semi-organic fertilizer proportionally less nitrogen was absorbed early in the growth period but later in the season the rate of absorption was higher than from the inorganic fertilizer.

(e) A semi-organic fertilizer was more efficient in supplying nitrogen to the crop. This was especially so when the two fertilizers were applied at low levels per unit area.

(f) Individual plant weight was invariably higher on the inorganic fertilizer.

Therefore it has become apparent that a semi-organic fertilizer has properties which are of great economic and agricultural importance.

APPENDICES

APPENDIX I - Example of method used in analysis of variance computation

The method employed follows Bailey (1959)

Table 3.5 - Mean number of plants unit^{-1} (Site III)

TREATMENTS	REPLICATES									TREATMENT TOTALS	TREATMENT MEANS
	1	2	3	4	5	6	7	8	9		
S.O.	59	67	59	95	63	72	60	68	51	594	66.0
I.F.	36	51	34	38	48	45	54	39	42	387	43.0
N.F.	60	64	49	55	47	29	60	55	28	447	49.7
REPLICATE TOTALS	155	182	142	188	158	146	174	162	121	1428	

The basic calculations are:-

Total number of observations = 27

Grand Total, G = 1428. Correction Factor, $C = \frac{G^2}{27} = 75525.3$

Total sums of squares about the mean = $(59)^2 + (67)^2 \ldots + (28)^2 - C = 5536.7$

Sum of square for treatments = $\frac{1}{9} \quad (594)^2 + (387)^2 + (447)^2 - C = 2520.7$

Sum of squares for replicates = $\frac{1}{3} \quad (155)^2 + (182)^2 \ldots +(121)^2 - C = 1174.0$

The resultant analysis of variance table can now be completed as follows:-

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	VARIANCE RATIO
TOTAL	26	5536.7		
TREATMENTS	2	2520.7	1260.34	10.95
REPLICATES	8	1174.0	146.75	1.28
ERROR	16	1842.0	115.12	

Standard error of the mean $\pm \frac{2 \times 115.12}{9} = 5.28$

Least significant difference (L.S.D.) = $t_{(0.05) \text{ or } (0.01)} \times 5.28$

$\text{L.S.D.}_{0.05} = 2.12 \times 5.28 = 10.73$

$\text{L.S.D.}_{0.01} = 2.92 \times 5.28 = 14.80$

The variance ratio (F) P = 0.05 with 2 and 16 degrees of freedom is read from tables as $F^{2}_{16} = 3.63$

The variance ratio (F) P = 0.05 with 8 and 16 degrees of freedom is read from tables as $F^{8}_{16} = 2.59$

From the analysis of variance table presented we find that $F_{treatments}$ = 10.95 which exceeds 3.63 and the effect of treatments is significant P 0.05

$F_{replicates}$ = 1.28 which is less than 2.59 and therefore the effect of replication is not significant.

In Appendix II the level of significance of the variance ratio (F) is shown as follows:-

N.S.	=	Not significant
*	=	Significant P = 0.05
**	=	Significant P = 0.01
***	=	Significant P 0.01

APPENDIX II - Analysis of variance data for tables in text

Chapter II

2.2a Mean total dry weight sample^{-1} - Little Humber

Source of Variation	d.f.	mean square	Variance Ratio	Level of Significance
Total	8			
Treatments	2	1856.41	22.48	**
Blocks	2	518.83	6.27	N.S.
Error	4	82.59		

2.2b Mean Total Number of Heads Sample^{-1} - Little Humber

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	8			
Treatments	2	2567.11	16.50	*
Blocks	2	227.11	1.46	N.S.
Error	4	155.61		

2.2c Mean Total Dry Weight of Heads Sample^{-1} - Little Humber

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	8			
Treatments	2	461.00	14.47	*
Blocks	2	80.47	2.53	N.S.
Error	4	31.85		

2.2d Mean Total Number of Tillers Sample^{-1} - Little Humber

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	8			
Treatments	2	4800.5	14.9	*
Blocks	2	864.8	2.7	N.S.
Error	4	321.9		

2.2e Mean Dry Weight Plant^{-1} - Little Humber

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	8			
Treatments	2	2.97	10.61	*
Blocks	2	0.83	2.96	N.S.
[illegible]	4	0.28		

2.3a Mean Total Dry Weight of Sample^{-1} - Everingham

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	11			
Treatments	2	43953.82	33.80	***
Blocks	3	6759.24	5.20	*
Error	6	1300.27		

2.3b Mean Total Number of Plants Sample^{-1} - Everingham

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	11			
Treatments	2	23083.59	33.84	***
Blocks	3	5382.97	7.89	*
Error	6			

2.3c Mean Total Number of Heads Sample^{-1} - Everingham

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	11			
Treatments	2	54284.25	24.26	**
Blocks	3	11049.56	4.94	*
Error	6			

2.3d Mean Total Dry Weight of Heads Sample^{-1} - Everingham

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	11			
Treatments	2	9257.67	33.81	***
Blocks	3	1424.74	5.20	*
Error	6	273.87		

2.3e Mean Dry Weight Plant^{-1} - Everingham

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	11			
Treatments	2	0.27	6.75	*
Blocks	3	0.02	0.50	N.S.
Error	6	0.04		

CHAPTER III

3.1 Mean Total Dry Weight Unit^{-1}

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	372.0	9.7	**
	Replicates	8	103.4	2.9	*
	Error	16	38.3		
16 weeks	Total	26			
	Treatments	2	5314.0	4.11	*
	Replicates	8	1054.0	0.82	N.S.
	Error	16	1293.0		
21 weeks	Total	26			
	Treatments	2	3590	5.60	*
	Replicates	8	582.4	0.91	N.S.
	Error	16	641.2		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	17			
	Treatments	2	278.80	10.62	**
	Replicates	5	8.62	0.16	N.S.
	Error	10	54.49		
16 weeks	Total	17			
	Treatments	2	1569.0	3.07	N.S.
	Replicates	5	489.9	0.96	N.S.
	Error	10	511.0		
21 weeks	Total	17			
	Treatments	2	2705.0	26.4	***
	Replicates	5	195.1	1.9	N.S.
	Error	10	102.7		

3.1 Contd.

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Site III - Wharram-le-Street					
8 weeks	Total	26			
	Treatments	2	607.6	7.62	**
	Replicates	8	53.1	0.67	N.S.
	Error	16	79.7		
16 weeks	Total	26			
	Treatments	2	4000.0	11.15	**
	Replicates	8	390.8	1.09	N.S.
	Error	16	358.6		
21 weeks	Total	26			
	Treatments	2	6008.0	7.82	**
	Replicates	8	2052.0	2.67	N.S.
	Error	16	768.2		

3.2 Mean Dry Weight Plant^{-1}

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	0.058	5.95	*
	Replicates	8	0.022	2.22	N.S.
	Error	16	0.010		
16 weeks	Total	26			
	Treatments	2	1.19	5.07	*
	Replicates	8	0.11	0,48	N.S.
	Error	16	0.24		
21 weeks	Total	26			
	Treatments	2	0.24	1.38	N.S.
	Replicates	8	0.06	0.34	N.S.
	Error	16	0.18		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	17			
	Treatments	2	0.085	3.84	N.S.
	Replicates	5	0.009	0.44	N.S.
	Error	10	0.022		
16 weeks	Total	17			
	Treatments	2	0.45	2.16	N.S.
	Replicates	5	0.18	0.91	N.S.
	Error	10	0.21		
21 weeks	Total	17			
	Treatments	2	1.39	21.00	***
	Replicates	5	1.16	2.37	N.S.
	Error	10	0.07		

3.2 Contd.

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Site III - Wharram-le-Street					
8 weeks	Total	26			
	Treatments	2	0.103	7.98	**
	Replicates	8	0.018	1.36	N.S.
	Error	16	0.012		
16 weeks	Total	26			
	Treatments	2	0.669	9.49	**
	Replicates	8	0.031	0.44	N.S.
	Error	16	0.071		
21 weeks	Total	26			
	Treatments	2	0.508	2.63	N.S.
	Replicates	8	0.295	1.53	N.S.
	Error	16	0.193		

3.3 Mean Total Dry Weight of Heads Unit^{-1}

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	26			
	Treatments	2	1234.0	4.9	*
	Replicates	8	276.6	1.1	N.S.
	Error	16	247.6		
21 weeks	Total	26			
	Treatments	2	2119.0	25.3	***
	Replicates	8	101.9	1.2	N.S.
	Error	16	83.8		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	17			
	Treatments	2	286.3	2.46	N.S.
	Replicates	5	161.1	1.38	N.S.
	Error	10	116.5		
21 weeks	Total	17			
	Treatments	2	594.9		
	Replicates	5	39.26	11.11	**
	Error	10	53.54	0.73	N.S.

Site III - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	26			
	Treatments	2	669.99	12.57	**
	Replicates	8	92.02	1.75	N.S.
	Error	16	53.30		
21 weeks	Total	26			
	Treatments	2	966.1	11.20	**
	Replicates	8	272.6	3.16	*
	Error	16	86.3		

3.4 Mean Dry Weight Head^{-1}

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	26			
	Treatment	2	0.001	0.16	N.S.
	Replicate	8	0.003	0.48	N.S.
	Error	16	0.006		
21 weeks	Total	26			
	Treatment	2	0.05	10.6	**
	Replicate	8	0.003	0.53	N.S.
	Error	16	0.005		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	17			
	Treatments	2	0.0004	0.06	N.S.
	Replicate	5	0.0003	0.50	N.S.
	Error	10	0.006		
21 weeks	Total	17			
	Treatments	2	0.0022	0.24	N.S.
	Replicates	5	0.0017	0.19	N.S.
	Error	10	0.0092		

Site III - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	26			
	Treatment	2	0.006	4.04	*
	Replicate	8	0.003	1.68	N.S.
	Error	16	0.002		
21 weeks	Total	26			
	Treatments	2	0.0027	1.96	N.S.
	Replicate	8	0.0064	4.65	*
	Error	16	0.0014		

3.5 Mean Number of Plants $Unit^{-1}$

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	598.1	7.38	**
	Replicates	8	133.4	1.65	N.S.
	Error	16	81.1		
16 weeks	Total	26			
	Treatments	2	438.8	4.16	*
	Replicates	8	193.4	1.70	N.S.
	Error	16	116.2		
21 weeks	Total	26			
	Treatments	2	406.8	4.67	*
	Replicates	8	64.8	0.75	N.S.
	Error	16	87.0		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	17			
	Treatments	2	298.5	3.56	N.S.
	Replicates	5	44.8	0.53	N.S.
	Error	10	84.0		
16 weeks	Total	17			
	Treatments	2	533.4	3.10	N.S.
	Replicates	5	152.9	0.90	N.S.
	Error	10	172.1		
21 weeks	Total	17			
	Treatments	2	292.1	9.43	**
	Replicates	5	34.7	1.12	N.S.
	Error	10	30.9		

Site III - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	879.15	10.44	**
	Replicates	8	138.23	1.64	N.S.
	Error	16	84.23		
16 weeks	Total	26			
	Treatments	2	139.6	1.18	N.S.
	Replicates	8	101.9	0.90	N.S.
	Error	16	118.1		
21 weeks	Total	26			
	Treatments	2	1260.3	10.95	**
	Replicates	8	146.7	1.28	N.S.
	Error	16	115.1		

3.7 Mean Number of Heads Unit^{-1}

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	26			
	Treatments	2	3451.0	5.76	*
	Replicates	8	633.7	1.06	N.S.
	Error	16			
21 weeks	Total	26			
	Treatments	2	1748	14.43	***
	Replicates	8	215.8	1.78	N.S.
	Error	16	121.2		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	17			
	Treatments	2	704.2	2.81	N.S.
	Replicates	5	256.5	1.02	N.S.
	Error	10	251.0		
21 weeks	Total	17			
	Treatments	2	917.4	13.63	**
	Replicates	5	122.1	1.81	N.S.
	Error	10	67.3		

Site III - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
16 weeks	Total	26			
	Treatments	2	1564.0	10.05	**
	Replicates	8	196.0	1.26	N.S.
	Error	16	155.7		
21 weeks	Total	26			
	Treatments	2	1970.0	11.66	**
	Replicates	8	254.6	1.51	N.S.
	Error	16	168.9		

3.8 - Total Nitrogen Uptake Unit^{-1}

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	0.5028×10^6	10.34	**
	Replicates	8	0.1061×10^6	2.18	N.S.
	Error	16	0.4863×10^6		
21 weeks	Total	26			
	Treatments	2	0.5060×10^6	4.75	*
	Replicates	8	0.3393×10^5	0.32	N.S.
	Error	16	0.1066×10^6		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	17			
	Treatments	2	105700	4.19	*
	Replicates	5	4582	0.20	N.S.
	Error	10	25220		
21 weeks	Total	17			
	Treatments	2	0.238×10^6	16.98	***
	Replicates	5	0.116×10^5	0.83	N.S.
	Error	10	0.140×10^5		

Site III - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	0.3005×10^6	5.50	*
	Replicates	8	0.3086×10^5	0.56	N.S.
	Error	16	0.5466×10^5		
21 weeks	Total	26			
	Treatments	2	0.4707×10^6	11.82	**
	Replicates	8	0.1019×10^6	2.56	N.S.
	Error	16	0.3983×10^5		

3.9 - Nitrogen Uptake Plant^{-1}

Site I - Aldborough

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	101.20	7.67	**
	Replicates	8	18.11	1.37	N.S.
	Error	16	13.18		
21 weeks	Total	26			
	Treatments	2	32.8	1.35	N.S.
	Replicates	8	4.12	0.17	N.S.
	Error	16	24.29		

Site II - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	17			
	Treatments	2	4.64	0.46	N.S.
	Replicates	5	3.97	0.40	N.S.
	Error	10	9.90		
21 weeks	Total	17			
	Treatments	2	104.34	34.69	***
	Replicates	5	10.37	3.45	*
	Error	10	3.01		

Site III - Wharram-le-Street

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
8 weeks	Total	26			
	Treatments	2	71.66	7.43	**
	Replicates	8	9.28	0.96	N.S.
	Error	16	9.64		
21 weeks	Total	26			
	Treatments	2	38.23	5.45	**
	Replicates	8	16.95	2.42	*
	Error	16	7.01		

3.10 - Total Nitrogen Uptake in Heads Unit^{-1} 21 Week Harvest

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Site I - Aldborough				
Total	26			
Treatments	2	0.5456×10^6	20.62	***
Replicates	8	0.2536×10^5	0.96	N.S.
Error	16			
Site II - Wharram-le-Street				
Total	17			
Treatments	2	0.114×10^6	7.94	**
Replicates	5	8534.0	0.60	N.S.
Error	10	0.144×10^5		
Site III - Wharram-le-Street				
Total	26			
Treatments	2	0.1757×10^6	10.34	**
Replicates	8	0.4784×10^5	2.82	*
Error	16	0.1699×10^5		

3.11 - Nitrogen Uptake Head^{-1} 21 Week Harvest

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Site I - Aldborough				
Total	26			
Treatments	2	13.55	8.63	**
Replicates	8	0.84	0.54	N.S.
Error	16	1.57		
Site II - Wharram-le-Street				
Total	17			
Treatments	2	0.72	0.32	N.S.
Replicates	5	0.48	0.21	N.S.
Error	10	2.28		
Site III - Wharram-le-Street				
Total	26			
Treatments	2	0.50	1.43	N.S.
Replicates	8	1.04	2.97	*
Error	16	0.35		

3.12 - Total Nitrogen Content of Vegetative Parts

21 Week Harvest

Site I - Aldborough

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	26			
Treatments	2	34990	1.30	N.S.
Replicates	8	26040	0.96	N.S.
Error	16			

Site II - Wharram-le-Street

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	17			
Treatments	2	0.5299×10^5	5.32	*
Replicates	5	6277	0.63	N.S.
Error	10	9967		

Site III - Wharram-le-Street

Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
Total	26			
Treatments	2	0.7333×10^5	5.25	*
Replicates	8	0.3210×10^5	2.30	N.S.
Error	16	0.1397×10^5		

CHAPTER IV

4.1 - Mean Total Dry Weight Unit^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
5 weeks	Total	26			
	Treatments	2	16.18	21.69	***
	Replicates	8	0.73	1.0	N.S.
	Error	16	0.75		
11 weeks	Total	26			
	Treatments	2	6897.0	46.54	***
	Replicates	8	226.6	1.53	N.S.
	Error	16	148.2		
17 weeks	Total	26			
	Treatments	2	0.3414×10^5	59.52	***
	Replicates	8	1085.0	1.89	N.S.
	Error	16	573.6		
19 weeks	Total	26			
	Treatments	2	0.2364×10^5	46.5	***
	Replicates	8	520.6	1.02	N.S.
	Error	16	508.3		

4.2 - Mean Dry Weight Plant^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
5 weeks	Total	26			
	Treatments	2	0.0022	22.08	***
	Replicates	8	0.0001	1.00	N.S.
	Error	16	0.0001		
11 weeks	Total	26			
	Treatments	2	0.880	31.43	***
	Replicates	8	0.044	1.57	N.S.
	Error	16	0.028		
17 weeks	Total	26			
	Treatments	2	4.92	41.51	***
	Replicates	8	0.20	1.61	N.S.
	Error	16	0.12		
19 weeks	Total	26			
	Treatments	2	4.45	37.33	***
	Replicates	8	0.18	1.47	N.S.
	Error	16	0.12		

4.3 - Mean Number of Plants Unit^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
5 weeks	Total	26			
	Treatments	2	381.4	2.4	N.S.
	Replicates	8	102.4	0.65	N.S.
	Error	16	156.7		
11 weeks	Total	26			
	Treatments	2	661.1	12.49	**
	Replicates	8	75.5	1.5	N.S.
	Error	16	52.9		
17 weeks	Total	26			
	Treatments	2	412.6	6.42	*
	Replicates	8	78.9	1.23	N.S.
	Error	16	64.7		
19 weeks	Total	26			
	Treatments	2	226.7	10.36	**
	Replicates	8	37.9	1.73	N.S.
	Error	16	21.9		

4.4 - Mean Number of Heads Unit^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
17 weeks	Total	26			
	Treatments	2	6920.0	53.23	***
	Replicates	8	266.1	2.05	N.S.
	Error	16	130.0		
19 weeks	Total	26			
	Treatments	2	5662.0	71.25	***
	Replicates	8	119.6	1.51	N.S.
	Error	16	79.47		

4.5 - Mean Total Dry Weight of Heads Unit^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
17 weeks	Total	26			
	Treatments	2	4419.0	45.53	***
	Replicates	8	263.6	2.72	N.S.
	Error	16	97.1		
19 weeks	Total	26			
	Treatments	2	4146.0	55.1	***
	Replicates	8	111.7	1.5	N.S.
	Error	16	75.3		

4.6 - Mean Dry Weight Head^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
17 weeks	Total	26			
	Treatments	2	0.0256	14.20	**
	Replicates	8	0.0049	2.70	*
	Error	16	0.0018		
19 weeks	Total	26			
	Treatments	2	0.0301	6.86	*
	Replicates	8	0.0029	0.66	N.S.
	Error	16	0.0044		

4.7 - Mean Total Nitrogen Uptake Unit^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
5 weeks	Total	26			
	Treatments	2	0.5256×10^5	26.03	***
	Replicates	8	3457	1.71	N.S.
	Error	16	2019		
11 weeks	Total	26			
	Treatments	2	0.2227×10^7	31.16	***
	Replicates	8	0.3268×10^5	0.46	N.S.
	Error	16	0.7148×10^5		
17 weeks	Total	26			
	Treatments	2	0.1738×10^7	64.58	***
	Replicates	8	0.6926×10^5	2.57	N.S.
	Error	16	0.2692×10^5		
19 weeks	Total	26			
	Treatments	2	0.1684×10^7	39.11	***
	Replicates	8	0.5777×10^5	1.34	N.S.
	Error	16	0.4305×10^5		

4.8 - Mean Nitrogen Uptake Plant^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
5 weeks	Total	26			
	Treatments	2	9.51	24.09	***
	Replicates	8	0.55	1.39	N.S.
	Error	16	0.39		
11 weeks	Total	26			
	Treatments	2	320.2	19.86	**
	Replicates	8	2.72	0.20	N.S.
	Error	16	16.12		
17 weeks	Total	26			
	Treatments	2	239.46	42.08	***
	Replicates	8	9.10	1.60	N.S.
	Error	16	5.69		
19 weeks	Total	26			
	Treatments	2	276.31	28.66	***
	Replicates	8	14.35	1.49	N.S.
	Error	16	9.64		

4.9 - Mean Total Nitrogen Uptake in Heads Unit^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
17 weeks	Total	26			
	Treatments	2	0.7259×10^{6}	40.67	***
	Replicates	8	0.4823×10^{5}	2.70	*
	Error	16	0.1785×10^{5}		
19 weeks	Total	26			
	Treatments	2	0.9217×10^{6}	42.89	***
	Replicates	8	0.3307×10^{5}	1.54	N.S.
	Error	16	0.2149×10^{5}		

4.10 - Mean Nitrogen Uptake Head^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
17 weeks	Total	26			
	Treatments	2	6.02	6.40	**
	Replicates	8	1.33	1.42	N.S.
	Error	16	0.94		
19 weeks	Total	26			
	Treatments	2	12.42	11.94	**
	Replicates	8	0.96	0.93	N.S.
	Error	16	1.04		

4.11 - Mean Total Nitrogen Uptake in Vegetative Parts

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
17 weeks	Total	26			
	Treatments	2	0.2638×10^{6}	33.89	***
	Replicates	8	0.1191×10^{5}	1.53	N.S.
	Error	16	7783.0		
19 weeks	Total	26			
	Treatments	2	$0.1922c10^{6}$	26.96	***
	Replicates	8	5373.9	0.75	N.S.
	Error	16	7127.6		

4.12 - Mean Nitrogen Uptake Vegetative Shoot^{-1}

Harvest	Source of Variation	d.f.	Mean Square	Variance Ratio	Level of Significance
17 weeks	Total	26			
	Treatments	2	36.02	18.54	***
	Replicates	8	2.41	1.24	N.S.
	Error	16	1.94		
19 weeks	Total	26			
	Treatments	2	33.79	20.48	***
	Replicates	8	1.31	0.79	N.S.
	Error	16	1.65		

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