A STUDY OF THE EFFECTS OF SOIL MOISTURE
ON
FERTILISER RESPONSE IN CROPS

BY

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PLATES

INTRODUCTION

Large seasonal differences in yield of potatoes occur.

Mc Dermott and Ivins (1957) examined the relationship between May to September rainfall and yield of Majestic potatoes and found that rainfall during the growing period exerted a considerable effect on yield. This, they hoped, might indicate possible increases which could be anticipated from efficient irrigation. North (1964) reported yields of potatoes in Staffordshire of 7.4 tons per acre in 1959 when the June to August rainfall was 4 in. and 19.2 tons per acre in 1960 when rainfall over the corresponding period was 9.6 in. Many workers, e.g. North (1962), Penman (1962) and Wellings (1969), have reported increases in yield of potatoes following irrigation in dry years.

Yield of potatoes can also be affected considerably by application of fertilisers. However, the response varies from year to year (Simpson and Crooks, 1961), the tendency being for a greater response to fertiliser in a wet year than a dry year (Simpson, 1970).

Work carried out by Simpson (1956), in the South East of Scotland, showed a highly significant correlation between apparent recovery of phosphorus by crops andsummer rainfall. Further studies with potatoes (Simpson, 1960) showed that increasing the soil moisture content gave an increase in the concentration of phosphorus in the shoots and roots early in the season and he associated this with an increase in the final yield of tubers.

Simpson (1962) noted that the most remarkable effects on growth and yield of potatoes were those of applied nitrogen and their interactions with soil moisture level. Lowering soil moisture tension had a marked effect on the uptake of N,P and K. He suggested that "increased nutrient 'availability' at low moisture tension, whether it occurred simply by increased root penetration or by some other mechanism, quite possibly explains the effect of irrigation on yield".

It was the aim of this investigation to study the effect of soil moisture on fertiliser response in crops. For this, three field experiments were carried out using different levels of nitrogen fertilisers at different soil moisture tensions, with potatoes as a test crop.

REVIEW OF LITERATURE

This review has been divided into four sections.

1. The effects of soil moisture and nitrogen on growth and yield of potatoes.
2. The effects of the interactions of soil moisture and nitrogen on the growth of other grops.
3. The effects of soil moisture and nitrogen on the composition of the potato plant.
4. Possible causes of the effects of soil moisture on the response of potatoes to nitrogen.

1. The effects of soil moisture and nitrogen on growth and yield of potatoes.

Unfortunately the majority of workers have studied these two variables in separate experiments.

Cowie (1945) found that of the three major nutrients (N,P,K), nitrogen gave the largest response, as measured by yield, when added in fertilisers. The effect of nitrogen, in the presence of sufficient phosphorus and potassium, is to increase the size of haulm and the leaf area of the plant by stimulation of the apical and lateral meristems and by the stimulation of the development of branches (Burton, 1966). However, very high levels of nitrogen stimulate very extensive leaf growth at the expense of tuber formation early in the season (Ivins, 1967). Excessive leaf growth does not however give rise to higher bulking rates because of shading of the lower leaves, although leaf persistence is usually longer with higher levels of leaf area index and so bulking continues for a longer period, giving rise to higher yields. However, where the growing season is shortened by blight or early harvest the delaying of tuber formation by large applications of nitrogen can result in low yields.

Russell and Garner (1941) suggested that the increase in yield of tubers by nitrogen is strongly influenced by an increase in tuber number, although there may be some slight increase in size of tubers. Birch et al. (1967) found that most of the yield response to nitrogen occurred as an increase in the yield of large tubers with a small increase in yield of medium tubers up to 60 lb N per acre and negligible effect on small tuber yield. Hanley et al. (1965) described the main effect of nitrogen as an increase in the number of tubers and provision for this increased number to grow just as rapidly as a smaller number would without nitrogen fertiliser.

The effect of soil moisture on potatoes has usually been studied by the addition of water as irrigation.

At Efford (Rep. Efford Expt. Hort. Sta. for 1961), in two years when rainfall in May and June was small, yield increases of up to 4 tons per acre were reported from maintenance of a deficit of 0.75 in.

On the light sandy soils at Gleadthorpe (Gleadthorpe Expt. Husb. Farm Report and Guide, 1970) during a 15 year period there were no responses to irrigation in 7 years, limited responses in 5 years and large responses in 3 years. The average yield increase over the period was 2.0 tons ware per acre and the average water application was 3.5 in. a year.

In a review of the soil-moisture relationships in potatoes, mostly dealing with work in the U.S.A., Singh (1969) concluded that "it is evident that a high soil moisture content should be maintained at all stages of plant growth to obtain high yields of potatoes. The soil moisture should never be allowed to drop below 50% of the available range of moisture". In the experiments reviewed yield increases came from larger tubers rather than an increase in tuber numbers.

In a very comprehensive review of the literature on crop response to water at different stages of growth, Salter and Goode (1967) came to the following conclusions. "It can be concluded that an adequate supply of water is required by potato plants from the time of tuber initiation almost until the tubers are mature if good yields of high quality potatoes are to be obtained. The results of experiments also show that a plentiful supply of water before tuber initiation increases the number of tubers per plant, whereas a plentiful supply after this stage of growth results in an increase in tuber size". The effect of soil moisture at these two stages on tuber yield is variable and may possibly be explained in terms of differential varietal response. If a variety produces a small number of tubers it will benefit from irrigation before tuber initiation but if the variety produces a large number of tubers it will not benefit ~~for~~ from irrigation at this stage, as too many tubers will be produced to reach saleable size. Shortage of water after the tubers have been formed reduces tuber size. The onset of tuber formation and rapid tuber growth creates an additional strain on the water economy of the plant, making it more dependent on favourable soil moisture conditions. With early potatoes irrigation is started early to hasten vegetative growth and tuber initiation. Thus by manipulation of soil moisture conditions at different stages of growth,it is possible to influence earliness, tuber number and tuber size.

On the coast of Peru, Bravo _et al_. (1968) found a close relationship between leaf area index and yield at four different moisture levels. Maintenance of 75% available water gave a yield significantly superior to the other treatments. There was little difference in maintaining available water at 50% or 25%, although both these treatments were significantly superior to maintenance at 0% available water. There was also a tendency for a reduction in size of tubers through lack of water.

Birch et al. (1967) thought that dry conditions in the spring might reduce nitrogen response and more particularly retard growth and depress yields at high rates of nitrogen, but they found no overall effect of spring rainfall on nitrogen response. There was however a low response to nitrogen and a depression in yield from high rates of nitrogen in a dry year.

In West Bengal, Choudhuri and Ray (1964) found significant yield increases from irrigation in dry years but not in wet years. The yield differences due to increases of nitrogen fertiliser were ~~was~~ significant in wet years but not in dry years. There was however no significant nitrogen-irrigation interaction in a given year.

Price and Harvey (1962), at Gleadthorpe, found that irrigated potatoes did not respond better to increased rates of nitrogen than the unwatered crop. In fact, if anything, the reverse was the case. They concluded from their experiments that there was no evidence that potatoes needed more fertiliser or made greater demands on available soil nutrients when irrigated than when not irrigated.

However, also at Gleadthorpe, Wellings (1969), with Pentland Crown grown after sugar beet after peas, at three levels of nitrogen (75, 150, 225 units N per acre) and watered with 1 in. of irrigation whenever the deficit reached 1 in. (2 irrigations applied), found that total yield and yield of ware of the unirrigated crop, but not the irrigated crop, was reduced by increasing the application of nitrogen. This reduction in yield when no irrigation was applied was brought about by a decrease in yield of the 2.25 in. to 3.25 in. size fraction. Under the same conditions, with early potatoes, irrigation increased the yield of ware tubers but nitrogen, with and without irrigation, decreased yield due to reduced tuber numbers. Also with early potatoes in another season the application of 4.45 in. of water (4 irrigations) more than doubled the yield of ware. Increasing the nitrogen application from 80 to 158 units N per acre did not increase the yield of the unirrigated crop but did that of the irrigated crop. Irrigation increased tuber numbers per plant and average tuber weight.

In agreement with this Fulton and Finlay (1964), in S.W. Ontario, obtained maximum yield of potatoes with 400 lb of a 5-10-13 fertiliser per acre when no irrigation was applied but with irrigation 1600 lb per acre was required for maximum yield.

Ellison and Jacob (1954), in the U.S.A., obtained a large response to nitrogen between 60 and 120 lb N per acre and a moderate response between 120 and 180 lb N per acre, when irrigation (approximately 1 in. a week minus rainfall) was applied. Without irrigation there was a moderate response to 120 lb N per acre but no further increase to 180 lb N per acre. It was concluded that adequate moisture must be maintained in order for plants to utilize large amounts of nitrogen.

In a growth analysis experiment, Simpson (1962) found that the effects of applied nitrogen on growth and yield were closely linked with soil moisture. Irrigation gave rise to earlier tuber production when nitrogen was used, at 12 weeks it resulted in more tubers of a greater mean weight. There were also significant interactions on shoot growth at 12 weeks and on uptake of N,P and K.

Holliday and Draycott (1968) studied, by growth analysis techniques, the effect of deep and shallow placement of liquid fertilisers and of placement of solid fertilisers around the tuber on the growth and yield of potatoes. A further experiment tested shallow and deep liquid placement at three moisture levels. They found that shallow placement supplied nutrients for early growth but when the soil surface became dry during the summer nutrients placed deeply resulted in more rapid growth of the crop than shallow placement. By the end of the season yields were largest from deep placement. Deep placement gave a larger leaf area index, an indication that the supply of nutrients was greater from deep placement. Deep placement also sustained leaf area until later in the season with the dry treatment. They concluded that the magnitude of the response to deep placement was related to the soil-moisture regime and that deep placed fertiliser was in a region of the soil which remained moist, whereas the shallower fertiliser was in drier soil where it was less available to potato roots.

2. The effects of the interactions of soil moisture and nitrogen on the growth of other crops.

Unfortunately the potato is unique in its growth habit and so it is difficult to draw true comparisons from other crops. In this country the study of the soil moisture-nitrogen interaction has mainly been on the sugar beet crop and on grassland.

The deep rooting character of sugar beet enables it to recover to a remarkable degree after a period of dry weather, even when moisture deficits of 1.5 in. to 2.0 in. have built up during this time (Rep. Gleadthorpe Expt. Husb. Farm for 1966).

Price and Harvey (1962), in two dry years in the presence of F.Y.M., found there was no yield response to additional nitrogen on irrigated plots when large yield responses to irrigation were recorded.

At Brooms Barn, Draycott and Webb (1971) found that on a 5 year average with o.6 cwt N per acre, irrigation had little effect on response to nitrogen, but with 1.2 and 1.8 cwt N per acre there was an interaction between nitrogen and irrigation; as nitrogen levels increased the response to irrigation increased. The increase was not due to increased sugar content. They reported that other workers had found very small effects of irrigation on response to nitrogen and that Penman suggested a negative interaction between irrigation and nitrogen, though he tested a relatively narrow range of nitrogen treatments and it was at the high nitrogen levels that Draycott and Webb found a positive interaction. Garner (1950) also found that nitrogen was less effective on watered plots than on dry ones, but this may have been due to overwatering (up to 13 in. of irrigation was applied).

Working on small plots Owen (1958) found that a high water regime produced a very high yield of sugar beet. This he attributed to differences in leaf area rather than differences in net assimilation rate.

In contrast to sugar beet, most grasses are shallow rooted and so are particularly sensitive to prevailing weather conditions and respond well to frequent irrigations (North, 1964). The majority of work on the soil moisture-nitrogen interactions on grassland has been complicated by the use of swards containing grass and clover (D'Aoust and Tayler, 1968), when one factor has influenced the growth of one species and the other factor the growth of the other species. The interactions of nitrogen and soil noisture have thus been complicated by changes in botanical composition of the sward. A further complication is that, usually, fertiliser is broadcast on grassland and so water is needed to carry the fertiliser into the soil. Surface applications may also lead to high losses due to volatilization.

In reviewing work on pure grass swards, D'Aoust and Tayler (1968) reported that the results (although not all were in agreement) indicated that irrigation will frequently increase the response to nitrogen, particularly at high levels of application. They also suggested that data for whole seasons may conceal important interactions occurring over short periods within the season. In their own experiments (D'Aoust and Tayler, 1968) they found that between 100 and 200 units N per acre the response to nitrogen over the whole season was not increased by irrigation. Between rates of 200 and 400 units N per acre irrigation (to maintain a deficit less than 2 in.) substantially increased the response to nitrogen. The results for individual short growth periods indicated that irrigation increased the response to nitrogen through improving the moisture status of the upper few inches of soil. There were periods during which the differences in surface horizon moisture appeared to have a critical influence on response to nitrogen. Positive irrigation-nitrogen interactions were small or non-existent at other times when differences in surface horizon moisture were smaller.

The pattern of nitrogen recovery for any one period was similar to that of dry matter accumulation and D'Aoust and Tayler proposed that irrigation may have increased the dry matter response to nitrogen by increasing the uptake of nitrogen, and that this increased uptake was not just due to increase in growth resulting from irrigation.

In a further paper, D'Aoust and Tayler (1969) showed that the influence of irrigation was largely due to an increase in the leaf area index. Responses to nitrogen were due to increases in both leaf area index and net assimilation rate. This, they state, is in contrast to work of Watson who considered that mineral nutrients increased yield by the effect on leaf area index alone, and that net assimilation rate was independent of nutrient supply, except in the case of acute deficiencies. They found no consistent relationship between leaf area index or net assimilation rate and the irrigation-nitrogen interaction.

At Hurley, Garwood and Williams (1967) found that although there was no response of cut grass swards to surface applied nutrients, when the upper soil horizons were dry, by injecting nutrients at depth into the moist subsoil, grass showed a response to the nutrients, especially nitrogen. There was also a greater recovery of nitrogen when it was applied to the moist subsoil. They attributed lack of growth of cut swards during dry weather to inadequate nutrient uptake, particularly that of nitrogen. This they suggested may be overcome by placing nutrients in the moist subsoil or by application of minimal quantities of water, sufficient to re-wet the uppermost soil horizon which contains the applied fertilisers. The main source of water for transpiration and growth would still come from the subsoil.

Little work has been done in this country on the effects of soil moisture-nitrogen interactions on cereals. Roebuck and Peeler (1966) found that, in 2 dry years, irrigation raised the nitrogen requirement of winter wheat, there being a strong positive interaction between additional water and nitrogen. The interaction was not however apparent with spring barley.

In Holland, Hellings(1967) reported that the grain yield of spring wheat without irrigation decreased with nitrogen applications greater than 35 kg N per ha. With irrigation the optimum dressing was 108 kg N per ha, when yield was nearly double that at 35 kg N per ha with no irrigation.

Mackay and Eaves (1962), working with sweet corn and snap beans in Nova Scotia, found significant fertiliser-irrigation interactions in 3 out of 4 years. This they attributed mostly to increased nutrient requirements of a larger crop, rather than increased availability of natural or applied nutrients.

3. The effects of soil moisture and nitrogen on the compostion of the potato plant.

The effect of water supply on dry matter content of potato tubers is variable.

Burton (1966) concluded that "in general it is probably true to say that if conditions without irrigation are arid then irrigation will increase the percentage dry matter of the tubers. On the other hand if conditions without irrigation could not be described as arid, irrigation may have little effect or even cause an appreciable decrease in percentage dry matter."

In the East of Scotland, Simpson (1962) found that percentage dry matter in tubers was considerably reduced by lowering soil moisture tension. He also found a decrease in percentage dry matter by additon of nitrogen, in agreement with many more workers e.g. Holliday (1963). However Laughlin (1971) reported a decrease in tuber dry matter content with increase in rates of nitrogen over 100 lb per acre in only 1 year out of 3 in Alaska. In the other two years dry matter contents were little changed.

Carpenter (1963) reported that early in the season, the nitrogen concentration of potato tops increased with nitrogen application but later on in the season there was not much difference between nitrogen treatments. There was not so great an effect on tuber nitrogen, which increased slightly with addition of nitrogen early in the season, but showed no effect later on. Early in the season, phosphorus concentration of the tops was increased by application of nitrogen but later the highest concentration of phosphorus was found when no nitrogen was applied. There was little effect of nitrogen on tuber phosphorus early in the season but later the concentration was higher when no nitrogen was applied. Potassium concentration of the tops was low with no additional nitrogen but there was no effect of amount of nitrogen applied. Tuber potassium was not affected by nitrogen application.

Laughlin (1971), in Alaska, found that each increment of nitrogen fertiliser tended to increase the concentration of nitrogen in both foliage and tubers of potatoes with significant increases ceasing between 120 and 180 lb N per acre. Concentrations of phosphorus and potassium in foliage and tubers however remained constant at different levels of nitrogen fertiliser.

Simpson (1962), with a second early variety, found that the concentration of phosphorus throughout the season in all parts of the plant, except shoot at 16 weeks, was greatly increased by irrigation. Applied nitrogen reduced the phosphorus content of all parts of the plant at 16 weeks and tubers at 12 weeks. Increasing the nitrogen level from 0 to 60 lbs N per acre significantly increased the total uptake of nitrogen, phosphorus andpotassium at 12 weeks. A further increase to 120 lbs N per acre caused only a significant increase in nitrogen uptake. Irrigation significantly increased the total uptake of nitrogen, phosphorus and potassium at 12 weeks. There were also significant interactions between irrigation and nitrogen, each treatment reinforced the other in stimulating uptake of the three nutrients, e.g. 60 lb N per acre gave increases of approximately 9 and 3 lb P_2O_5 per acre, with and without irrigation respectively.

In the U.S.A., Haddock (1961) found that irrigation caused a significant decrease in the nitrogen and phosphorus concentration of potato leaf blades. The effect upon potassium was not so marked and was inconsistent. The nitrate-nitrogen content in potato petioles decreased with increased quantities of irrigation water and this decrease was related to increased yields.

Flocker and Timm (1966) reported that soluble nitrate-nitrogen in the petioles of potatoes decreased with time, but increased with applied nitrogen fertiliser, as did total nitrogen in the tubers. Petiole nitrate-nitrogen and tuber total nitrogen were both greater in plants grown at 0.7 atmospheres soil moisture tension than plants grown at 0.2 atmospheres. This is in agreement with many other workers (e.g. Stewart, 1970) who found increases in nitrate-nitrogen in plants experiencing moisture stress. The soil may be dry enough to cause moisture stress but may not be sufficiently dry to prevent nitrate formation and uptake. It is possible that the rate of nitrate reduction in the plant is slowed down.

Mica (1969) found no significant relationship between the nutrient content of tubers and the application of fertilisers in Czechoslovakia.

Swiniarski andLadenberger (1970), working in Poland, found that potatoes grown at higher nitrogen levels, contained less glucose and fructose in their tubers than those grown at lower nitrogen levels. The effect ~~of~~ on sucrose was not so marked. However, Moll (1967) reported that the content of reducing sugar, of potatoes in East Germany, increased with increasing nitrogen application but that saccharose content was not significantly affected.

4. Possible causes of the effects of soil moisture on the response of potatoes to nitrogen.

The increases in yield associated with high soil moisture content at high nitrogen levels are possibly due to one of two causes:-

(a) the alleviation of a deleterious factor.

(b) the enhancement of a beneficial effect.

Many cases of damage from "scorch" have been observed when fertiliser has been placed close to seed tubers, sprouted seed being more susceptible to damage than unsprouted seed (Baldwin, 1963). Batey and Boyd (1967) suggested that the fertiliser produces a high concentration of salts which may build up in the moisture film adjacent to the plant tissue, disrupting cells and causing "burn" or "scorch" and that this leads to delayed emergence.

In Northern Ireland, McAllister *et al*. (1958) found reduction in plant numbers and consequent reduction in yield due to damage of seed tubers when high rates of fertiliser were applied to the bottom of the drill. Damage was more severe in dry years. In Alaska stands were reduced when high rates of nitrogen fertiliser were band placed. There was less reduction in a wet spring (Laughlin, 1971).

Shotton and Jarvis (1967) reported decreased yields in some years when high fertiliser rates were either side placed or in contact with the seed tuber. In some cases emergence was delayed but the crop recovered and yielded satisfactorily. Cooke (1950) found that band placement of fertiliser with the potato tubers was the best method of application in a wet year but that in a dry year growth was checked when 15 cwt per acre of a 7-7-10.5 fertiliser was applied. When placed fertiliser was inferior it was usually because emergence and early growth of the potato was checked (Widdowson et al., 1967). About 7.5 cwt of a 13-13-20 fertiliser was the largest dressing that could be safely placed in bands beside the seed on the soils tested. Boyd (1961) stated that traditional methods of fertiliser placement carried a real risk of "scorch" with delay in emergence if heavy dressings were applied and dry weather followed planting, particularly if the ridges had been allowed to dry out before planting. Shotton and Jarvis (1967) associated band and contact placement with damage to young plants which led to slow emergence and poor vigour in early growth.

Similar results have been found for many other crops, cereals in particular showing delayed emergence when high rates of fertiliser were placed with the seed. Olson and Dreier (1956) reviewed the literature on fertiliser placement for small grains. There was disagreement and inconsistency in the reports of fertiliser damage to crop stands. They believed soil moisture to be the cause of these differences. In their experiments they found from slight to moderate stand reductions, and consequent yield losses noticeable with as little as 10 lb N per acre, as ammonium nitrate, placed with the seed of winter wheat. Reduced germination was most severe at low levels of available moisture. However fetiliser was less detrimental in very dry soils. They suggested that maximum salt damage to germination occurred when the moisture supply was sufficient to dissolve fertiliser and result in an excessive total stress (i.e. physical + osmotic). They concluded that full germination is not assured at any moisture level unless a moisture increment from the surface leaches some of the soluble fertiliser away from the seed shortly after planting. They found that fertiliser in the proximity of germinating seed was rapidly translocated and concentrated in the vicinity of the moisture imbibing seed. This was especially evident at low moisture regimes with a highly soluble nitrogen fertiliser (e.g. NH_4NO_3), leading to extremely high concentrations of fertiliser adjacent to the seed. As well as emergence being delayed due to inhibition of germination until additional moisture is added, soil micro-organisms (pathogens) are also partly responsible for injury, since they are more tolerant of low moisture supply and high salt concentration than the plant.

Devine and Holmes (1963) found that ammonium sulphate and ammonium nitrate delayed brairding of spring barley only slightly when combine drilled, but the effects of calcium nitrate and urea at equal nitrogen rates, were much more severe. High rates of nitrate round the seed had apparently affected seedling growth. Ammonium nitrate, as the nitrogen source, combine drilled at 70 or 90 lb N per acre did not produce enough nitrate to damage crops.

Widdowson _et al_. (1960) reported that heavy dressings of nitrate fertiliser may produce consistently lower yields of potatoes than ammonium sulphate. The possibility of fertiliser injury with nitrate-nitrogen was increased when dressings were concentrated too close to the "seed". They suggested that damage was due to the high concentration of nitrate ions. The check to growth did not occur in a wet year.

Greenwood and Cleaver (1971) stated that the response of vegetable crops to nitrogen fertiliser can be dominated by the adverse effects of nitrogen fertiliser on seedling emergence and on early growth and by summer leaching of nitrogen. They reported that emergence fell in proportion to application of nitrogen fertiliser, but the extent to which it did so, though negligible in moist soil, was considerable when appreciable drying occurred.

Restricted root development of potatoes early in the season, with high levels of nitrogen, was suggested by Simpson (1962) to be associated with high local acidity produced by the physiologically acid ammonium sulphate. Early root growth was also significantly decreased by application of 60 to 120 lb K per acre.

Isensee and Walsh (1971), in a study of banded fertilisers, found that a combination of ammonium nitrate, monocalcium phosphate and potassium chloride considerably lowered soil pH in the fertiliser band and that the pH of the soil solution was initially reduced to 4.2 by application of 67.2 kg per ha of each of these nutrients. They also found that this treatment initially resulted in over 200 p.p.m. nitrite-nitrogen in the soil solution.

The phytotoxicity of nitrite varies with pH (Chapman and Liebig, 1952), plants being less tolerant at low pH. In solution cultures (Bingham et al., 1954) growth of several species was reduced by approximately 50% at pH 4.0 by less than 2 p.p.m. nitrite in solution. A threshold soil paste pH value of 7.7 ± 0.1 has been suggested (Fuller, 1963) above which nitrification of nitrite to nitrate will not proceed normally.

Another substance which may accumulate after applications of nitrogenous fertilisers to the soil is ammonia. At low pH ammonia is usually toxic only in overwhelming quantities whereas at high pH much smaller amounts may be lethal (Warren, 1962). In the soil there is an equilibrium between ammonia, ammonium ions in solution and ammonium ions adsorbed on to the soil particles. The relative proportions of these are determined primarily by the pH of the soil solution.

Allred and Ohlrogge (1964) associated free ammonia with diammonium phosphate fertiliser, causing it to be toxic to corn. Ammonia at partial vapour pressures as low as 0.125mm Hg was toxic to corn when it was exposed to this environment for 2 days during the initial stages of germination. Since seedlings germinated in sodium hydroxide solutions at pH 10.5 in a similar manner to those in water they did not associate the damage with high pH. Ammonia produced from the hydrolysis of the fertiliser permeated the soil pore spaces at distances as great as 3 in. from the fertiliser, moving in the vapour phase and thus faster in dry than wet soils.

The nitrification of ammonium fertilisers added to the soil does not always take place uninhibited and is governed by chemical and physical properties of the soil especially around the zone of application. Fuller (1963) found that band placement of ammonium fertilisers in high concentrations caused nitrification to be inhibited if the soil was poorly buffered. This he thought may be due to (a) high concentrations of ammonium fertiliser associated with an alkaline soil reaction, (b) a salt effect producing osmotic concentrations too high for optimal activity of nitrifying bacteria, (c) excessively high pH values. Thus addition of water to the soil may reduce these effects by decreasing concentrations and distributing the fertiliser through a larger volume of soil.

Addition of water, by rainfall or irrigation, may also considerably increase losses of nitrogen in the drainage water by leaching of nitrate when the soil moisture content is greater than field capacity. In the experiments conducted in this study it was aimed not to overwater and Cooke (1967) states that leaching can rarely be a serious cause of loss of nitrate under growing crops in summer.

Losses of nitrogen due to volatilisation are also likely to be small since, with potatoes, fertiliser is buried some distance below the surface (Fuller, 1963).

As stated earlier, poor growth may be caused by large concentrationsof nitrate-nitrogen in the soil solution (similar amounts of ammonium-nitrogen applied to the soil have no such effect), often attributed to root damage. Nielsen and Cunningham (1964) however, in their experiments with Italian ryegrass, found little difference in yields of roots grown with nitrate-nitrogen and ammonium-nitrogen, although there was poorer top growth at high levels of nitrate-nitrogen. A possible reason for this, they thought, might be the accumulation of nitrate-nitrogen in the ryegrass, in the range 1.88 to 2.76% where yields were depressed.

The accumulation of nitrate in plants has been very well reviewed by Wright and Davison (1964). Accumulation of nitrate is not injurious to plants, as far as is known, but it appears to indicate that the rate of progress of nitrate reduction to amino-nitrogen and protein synthesis is limited by the initial nitrate to nitrite step. The reduction in the activity of nitrate reductase can be brought about by many factors including lack of moisture and shading. Nitrate accumulation is also enhanced by nitrogen fertilisers, although it can occur without them. It is suggested that the presence of a large supply of nutrient nitrogen stimulates the plant to draw upon its supply of available carbohydrates for reductive energy and carbon skeletons. Eventually reserves might not be sufficient to keep pace with nitrate uptake. Thus high nitrate plants are likely to be low in readily available carbohydrates.

Nowakowski et al. (1965) reported that, with grass grown at different temperatures, accumulation of nitrate was related to growth. Top growth was greatest when, at 19.5°C with 100 p.p.m. nitrate-N added, nitrate-N was 28.7% of the total-N (corresponding to 1.13% of nitrate-N in the dry matter). Above this growth decreased. Because of the comprehensive nature of this paper it is quoted at length.

In their experiments the large accumulations of nitrate could possibly be attributed to interactions between the following:-

a) An increase in uptake of nitrate, possibly because of the effect of soil temperature.

b) Decreased activity of nitrate reductase due to (i) Soil temperature. Work with apple trees at three temperatures (Nightingale, 1935) showed greatest activity of nitrate reductase at 18.3°C and least at 7.2°C and 32.2°C. Although these results may not hold for grass it suggested that accumulation at 19.5°C was not necessarily due to temperature effects upon nitrate reductase activity. (ii) Nitrate accumulation. Although the literature differs between in vitro studies and those on whole plants the authors suggested that, in their experiments, concentration of nitrate was not limiting reductase activity. Increasing soil temperature increased nitrate accumulation in grass similarly with nitrate-N and ammonium-N, despite the greater concentration of nitrate in plants when nitrate was given.

c) Lack of carbohydrate for nitrate reduction. The energy required by enzyme systems which produced triphosphopyridine nucleotide (TPNH) and diphosphpyridine nucleotide (DPNH) is derived from the intermediates of carbohydrate metabolism. It was suggested that lack of energy to produce reduced pyridine nucleotides may have reduced nitrate reductase activity in the experiments (and hence resulted in nitrate accumulation).

d) Decreased rate of photochemical reduction of nitrate. It has been suggested that the rate of reduction of triphosphopyridine (TPN) increases linearly with increasing light intensity. Also that darkness inhibits nitrate reductase activity.

Thus lack of light is a limiting factor either when energy for producing reduced pyridine nucleotides is derived from the intermediates of carbohydrate metabolism or when pyridine nucleotides are reduced photochemically. In the experiments of Nowakowski <u>et al</u>. (1965) light intensity was low and this was probably the main reason for nitrate accumulating in the grass at 19.5°C. Further increase in nitrate content at 28°C probably reflected the effects of a soil temperature above the optimum and limited production of TPNH, both decreasing the activity of nitrate reductase. They conclude that "there was no evidence that the accumulation of nitrate was solelyresponsible for the smaller growth, which was probably caused by an inadequate light intensity. The small amount of carbohydrate associated with low light intensity was no doubt a main cause of the accumulation of nitrate."

Soil moisture content has a pronounced effect on the mobility of nutrients in the soil. It is generally assumed (Cooke, 1967) that only nutrient ions in the soil solution can be taken up by plants (except in theories of "contact exchange" without a water layer providing transport). Dissolved ions are immediately available provided they are accessible to the roots. There are three mechanisms involved in nutrient ions making contact with roots.

a) As roots growth through the soil they meet nutrients.

b) Nutrients are carried in the water used by plants in transpiration, thus they may be transported from large volumes of the soil to the roots (mass flow).

c) Ions diffuse through the soil solution when a concentration gradient occurs (Diffusion).

a) Root-ion contact. Barber et al. (1963) assumed that roots usually occupy 1% or less of the soil. However, they argued that roots grow through soil pores which have a higher than average nutrient content. Assuming a soil with one third pore space then the concentration in soil pores may be three times that of the soil as a whole. Thus the roots would be able to contact a maximum of 3% of the available nutrients in the soil. They calculated that this would allow a corn crop to obtain 6% of its needed nitrogen in an Indiana soil, by root growth.

Although there are some doubts as to the validity of assessing the importance of root interception in this way further work (Wiersum, 1961) has also shown that the volume of soil occupied by roots in most cases was very small, even when allowing a layer around the roots from which nutrients could be absorbed.

b) Mass flow. All nitrate in the soil is dissolved in the soil solution (provided there is enough present) andis thus carried to the root surface. Mass flow supplies almost all of the nitrogen used by a crop provided the soil is moist. Because of the dependence on water, drought could temporarily immobilise nitrate-nitrogen.

Phosphorus and potassium are much less mobile in the soil. Cooke (1967) estimated that in Southern England, during mid-summer, 5% of the P and K needed weekly by potatoes was dissolved in the water used in one week.

c) Diffusion. If root uptake is greater than the supply of nutrients by mass flow and interception, nutrients move to the roots. Back diffusion can also occur if the rate of uptake is too slow and allows accumulation of nutrients at the root surface.

Since almost all nitrate is moved to the roots by mass flow and interception, diffusion is of little importance in the supply of nitrate. However, almost all phosphorus and most of the potassium diffuses to the roots.

The supply of phosphorus and potassium to plants is very dependent on the moisture content of the soil. Danielson and Russell (1957) using ^{86}Rb with corn seedlings found that soil moisture stress appeared to have no direct influence on the uptake of rubidium ions. This was shown by growing seedlings in solutions of different osmotic pressures, which did not alter the ^{86}Rb accumulation. However, in soil, variation of soil moisture tension resulted in a very marked influence on rubidium accumulation. They postulated that the thickness of the moisture film connecting root and soil particles controlled the rubidium concentration at the root surface. The rate of ion diffusion would be decreased as the film thickness decreased. This may possibly explain why Simpson (1960) found such a marked effect of soil moisture on phosphorus uptake.

Poor soil structure affects root growth to nutrients and uptake by mass flow and diffusion. Because nitrate is soluble in water, poor structure will interfere with uptake by mass flow, only when water is unavailable to plants (i.e. in very small pores). As the ratio of available water to total water diminishes the proportion of nitrate that cannot be used will increase.

Wiersum (1962) showed that phosphorus uptake was diminished by coarse rooting whereas nitrate was little affected by rooting density on account of its high mobility. Similarly Cornforth (1968) showed that the weight of roots per unit volume of soil was more related to nutrient uptake with immobile than with mobile nutrients. Nitrate uptake was independent of size of soil aggregates but uptake of phosphorus decreased as aggregate diameter increased.

Reviewing work on deep placement of fertilisers Cooke (1967) reported that experiments with deep placement of phosphorus showed variable results. However, because diffusion of phosphorus is slow adequate uptake depends on large concentrations of roots. Where these occur only in surface soil it is unlikely that sub-soil placement will be beneficial. In an experiment with sorghum (Eck and Fanning, 1961), a rapid deep rooting crop, uptake of phosphorus ceased when moisture in the soil where fertiliser was placed reached wilting point, but absorption of nitrogen continued even from soil which contained 'little or no available moisture'. Placement of nitrogen was not critical, in these greenhouse studies, because uptake continued from dry soil, but uptake of phosphorus increased with increasing depth of placement, probably because deeper soil remained wetter longer.

Cooke (1954) suggested that most crops are stimulated by placed fertiliser but that this may have detrimental effects. The shallow roots induced may be more susceptible to drought. Also if the roots absorb nutrients andwater at the same time then the highly developed root system in the fertiliser zone may dry out the soil and the fertiliser salts may become too concentrated to be used.

EXPERIMENTAL METHODS AND MATERIALS

The experimental programme was conducted during the seasons of 1970 and 1971.

Experiments 1 and 2, 1970. Two factorial field experiments were conducted with different levels of added nitrogen and soil moisture. One experiment was at Saltcoats, Gullane, the other at Langhill, Roslin.

Experiment 3, 1971. One experiment, basically the same as the 1970 experiments but incorporating growth analysis techniques, was carried out at Easter Broomhouse, Dunbar.

A. Field Work

1970 Experiments

Two relatively flat experimental sites were chosen in potato fields on Macmerry soil series. Ease of access and provision of water to the site were limiting factors in the choice of site.

Experiment 1.

This experiment was carried out by courtesy of Mr. R. Trainer, Saltcoats, Gullane, East Lothian.

Site description.

Map ref:- NT 486 822

Elevation:- 15m.

Aspect:- slight south facing slope.

Parent material:- till derived from carboniferous sediments with partially sorted upper horizons.

Soil series:- Macmerry.*

Drainage class:- slightly imperfect.

* See "Soils around Haddington and Eyemouth" J. M. Ragg and D. W. Futty. 1967. H.M.S.O. pp. 99 – 100.

Average annual rainfall:- 630 mm.

Previous cropping:- 1969 - 1966 Barley.
1965 Wheat.
1964 Potatoes.

Soil analysis. The experimental area was sampled to a depth of 0.2m with a soil auger on 13.4.70. The area was divided into three sections, results of soil analysis are shown in table I.

Table I. Experiment 1. Soil analysis data for experimental area.

Section	pH	mg"availableP"/kg soil	mg"availableK"/kg soil
Top	7.0	5.5	68
Middle	6.7	5.5	62
Bottom	6.8	5.5	71
		(moderate)	(moderate)

Subsamples from each section were then bulked for potato cyst eelworm analysis. There was a total of 13 cysts per 200g air-dry soil, but only 1 cyst was viable.

Soil samples and soil cores were taken at various depths from the four corners of the experiment on 30.4.70. On these soil moisture characteristics were determined. They are shown in Figure 1.

Subsamples of soil from the four corners of the experiment were bulked, for each depth sampled, for the analyses shown in Table II. The bottom of the drill was taken as zero. Positive values were above this level, negative values below. Bulk density values were the average for the four corners of the experiment.

Design and treatment. The experiment was a 4 x 3 factorial arranged in 3 blocks of 12 plots, each plot 5.11m^2 (Appendix, Table I). The treatments were:-

Nitrogen - applied as "Nitro-Top", 33.5%N as NH_4NO_3.

Figure 1. Experiment 1. Soil moisture characteristic. Average for all depths.

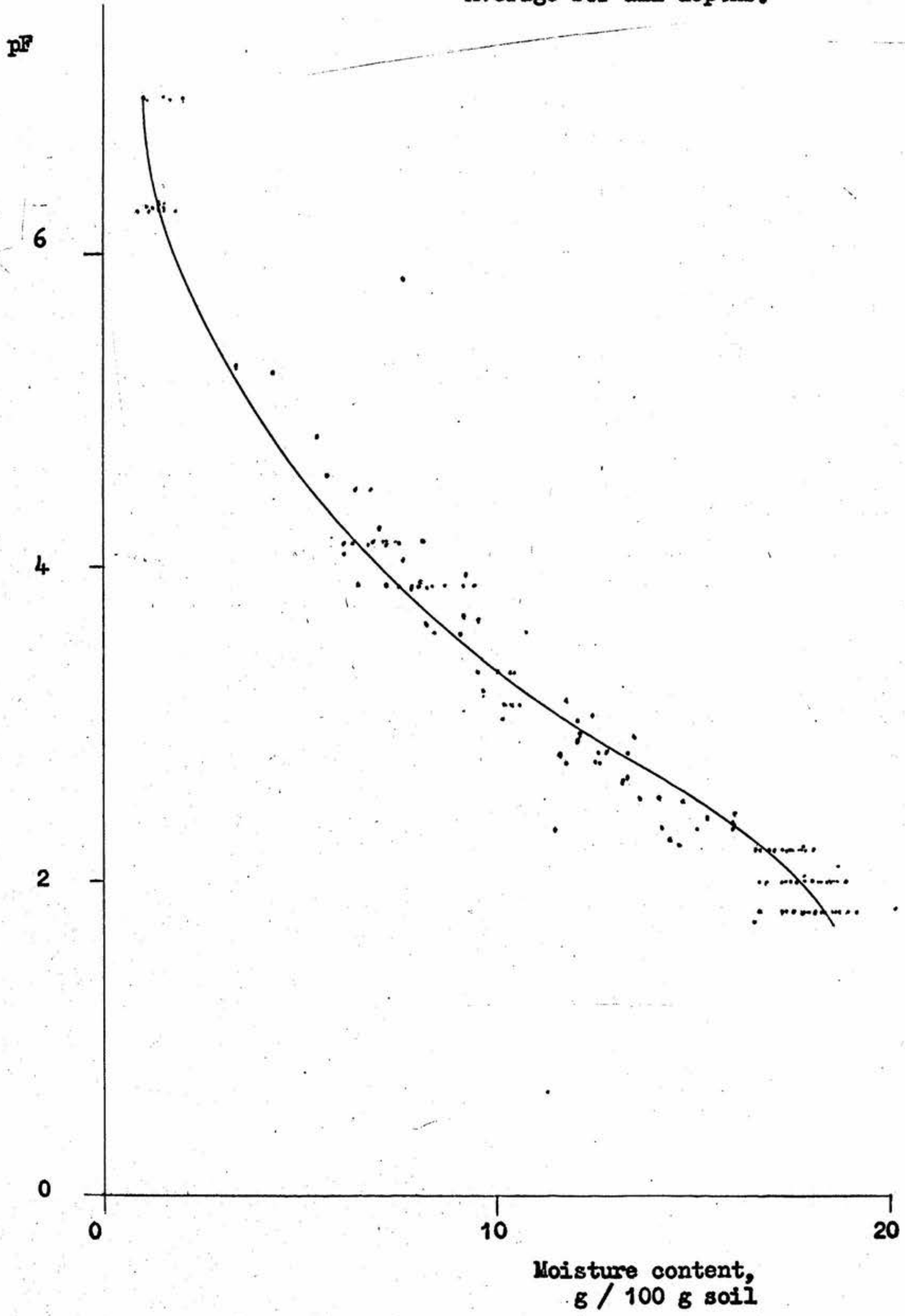


Table II. Experiment 1. Soil analysis data.

Depth of sample m.	+0.05 to +0.10	zero to -0.05	-0.10 to -0.15	-0.20 to -0.25
Cation exchange capacity (me/100g soil)	17.0	16.4	16.1	13.2
% Coarse sand Ø	52.1	55.7	49.0	54.3
% Fine sand Ø	21.5	19.1	24.3	22.6
% Silt Ø	3.8	6.5	7.0	8.0
% Clay Ø	23.3	19.0	19.0	20.5
% Moisture Ø	1.6	1.4	1.5	1.6
Organic carbon (g/100g air dry soil)	2.0	1.8	1.8	1.1
Mineralisable nitrogen (µg NH_4-N/g soil)	63	70	62	43
Bulk density (g cm^{-3})	1.41	1.54	1.56	1.50 ØØ

Ø Expressed as % of air dry soil.

ØØ There was a stony horizon present which was slightly shallower at one end of the experimental area. This prevented cores being taken and so this figure is the average for one end of the experiment.

Design and treatment. (Cont'd)

N_0 No additional nitrogen added.

N_1 100 kg N/ha.

N_2 200 kg N/ha.

N_3 300 kg N/ha.

Soil moisture -

I_0 No supplementary water added.

I_1 Soil moisture maintained between pF 3.0 and 3.5.

I_2 Soil moisture maintained between pF 2.0 and 2.5.

Plate I. Experiment 1. Experimental site, 27.4.1970.

Plate II. Experiment 1. General view of site, 12.8.1970.

A basal dressing of 65 kg P/ha (as superphosphate) and 167 kg K/ha (as K Cl) was applied to all plots. Discard areas received 1250 kg/ha of a 12-12-18 fertiliser.

Each plot was four 0.71 m drills wide and six plants (0.30m spacing) long. The eight inner plants were the harvest plants and the remainder guard plants.

Cultivations and planting. The field was ploughed, sprayed with "Tecane" (for couch control) and reploughed in the autumn of 1969. In the spring of 1970 the seed bed was prepared and the ridges opened on 27.4.70. The experiment was marked out andthe fertiliser applied by hand to the bottom of the drill. The fertiliser was then mixed into the soil using a hand cultivator and the seed potatoes planted on 28.4.70. They were then covered using a rear ridger on a crawler tractor.

The seed potatoes were Foundation Stock Pentland Crown, riddled to the size limit 46-55mm and weighed into two categories (61-70g and 71-80g). They were carefully examined and all damaged, diseased or mis-shapen tubers removed. The tubers were sprouted in trays under artificial lighting, giving strong, uniform sprouts about 10mm long. The two weight categories were planted alternately in the drill.

Moisture sampling. Soil samples were taken from each plot at frequent intervals, usually every week. Two depths of sample were taken in the ridge, an upper (0.20m above the bottom of the drill) and a lower (0.20m below the bottom of the drill), at two different places in the guard rows of each plot. The samples were taken with a screw auger and a piece of tubing. The tubing was placed over the auger and pushed into the gound while taking the upper sample. This prevented soil falling into the hole and contaminating the lower sample. The samples were placed in tins and soil moisture content determined.

Soil moisture changes during the growing season are shown in Figures 2 and 3 and in Appendix, Table 3.

Maintenance of different soil moisture levels. From the soil moisture determinations the amount of water required to return the soil moisture to its required level was calculated. The required amount of water was then added, on a plot basis, using specially constructed equipment.

This consisted of a trolley, on which were mounted two "Vibra-jets", which moved on two rails. The trolley was powered by a motor driving two sprockets, which were engaged in chains fitted to the rails. At each end of the rails was a stop, with which a micro-switch on the trolley came in contact, operating a relay and reversing the motor. The rails were supported on a framework which was moveable from plot to plot.

The apparatus was calibrated by passing it over collecting cans (80mm diam). The rate of water application was 0.6mm per pass and the distribution varied by less than ± 5% along the length of travel of the trolley and less than ± 20% across the direction of travel.

Rainfall and Rainfall+Irrigation during the growing season, averaged over all nitrogen treatments, are shown in Figure 4. The amount of water added to each nitrogen treatment, averaged over replicates is shown in Appendix, Table 4. Samples of irrigation water were taken for chemical analysis (Appendix, Table 5).

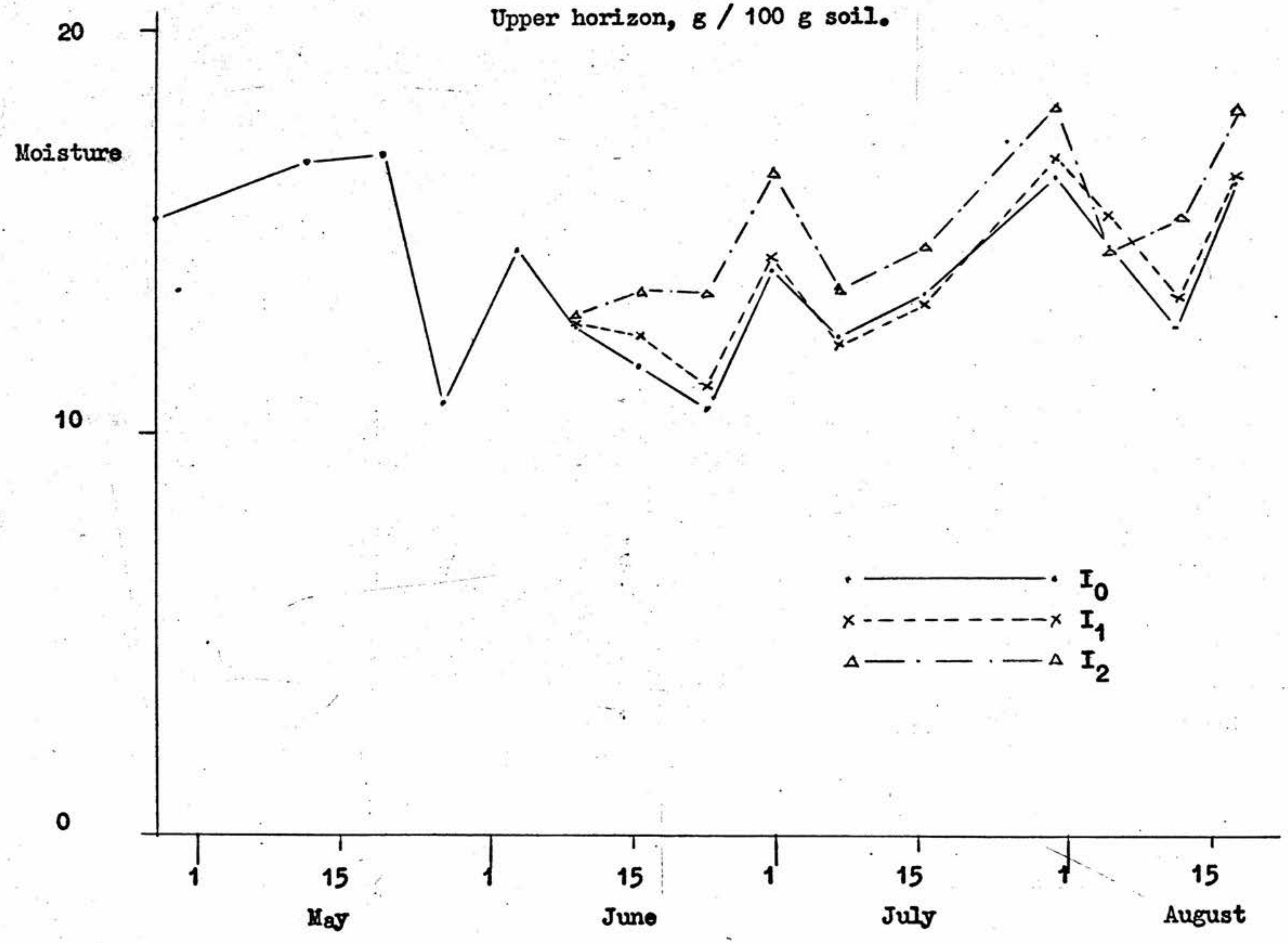
Meteorological Recording. Rainfall was measured using a Meteorological Office rain-gauge Mk 2. Readings were taken whenever the site was visited, at least once a week.

Soil temperature, 0.30m below the top of the ridge, was measured with an earth thermometer (Appendix, Table 6).

Air temperature and humidity were continuously monitored using a thermohygrograph housed in a small thermometer screen.

Figure 2. Experiment 1. Soil moisture changes during the season, average for all N levels.

Upper horizon, g / 100 g soil.



<u>Figure 3</u>. Experiment 1. Soil moisture changes during the season, average for all N levels.

Lower horizon, g / 100 g soil.

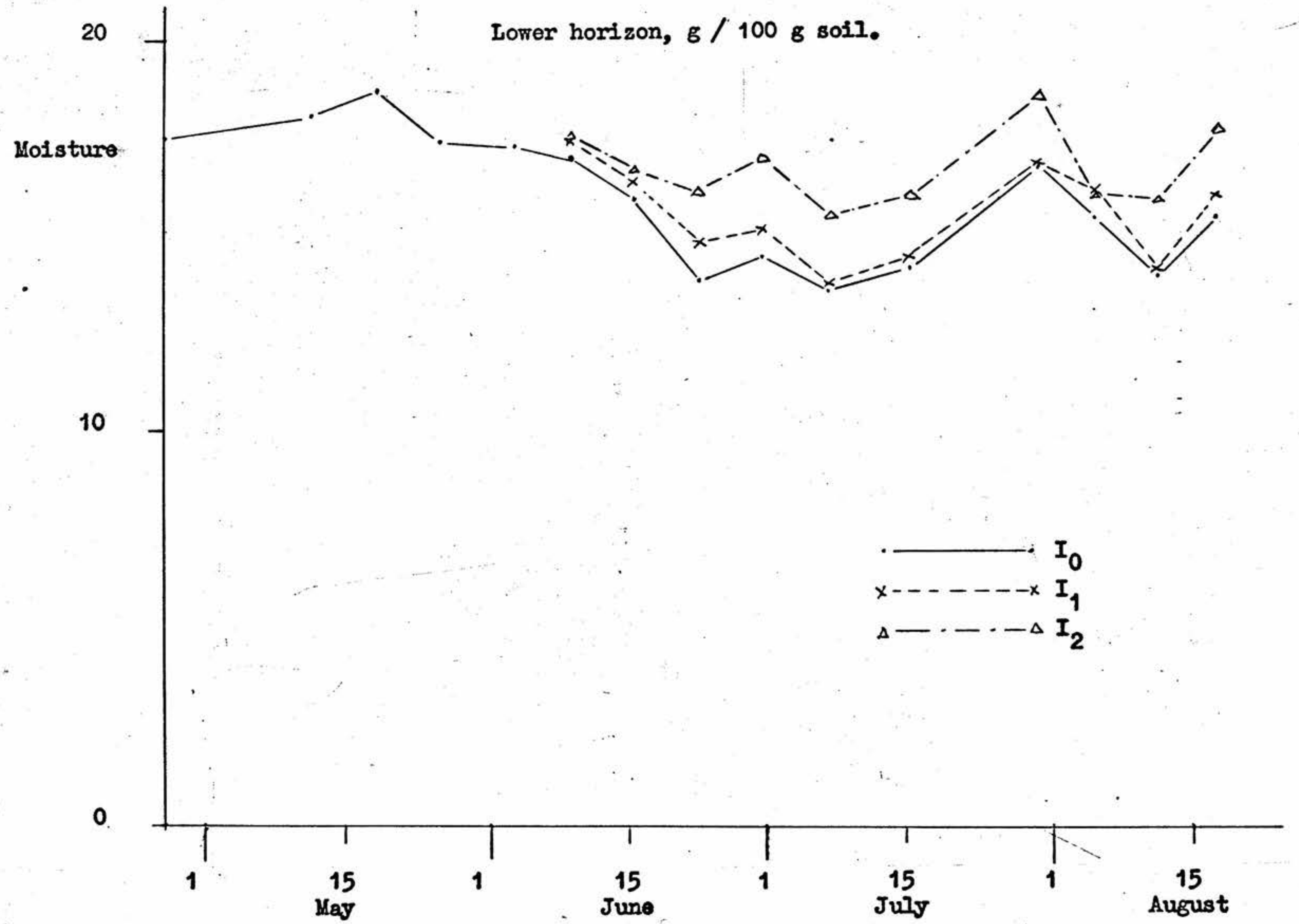
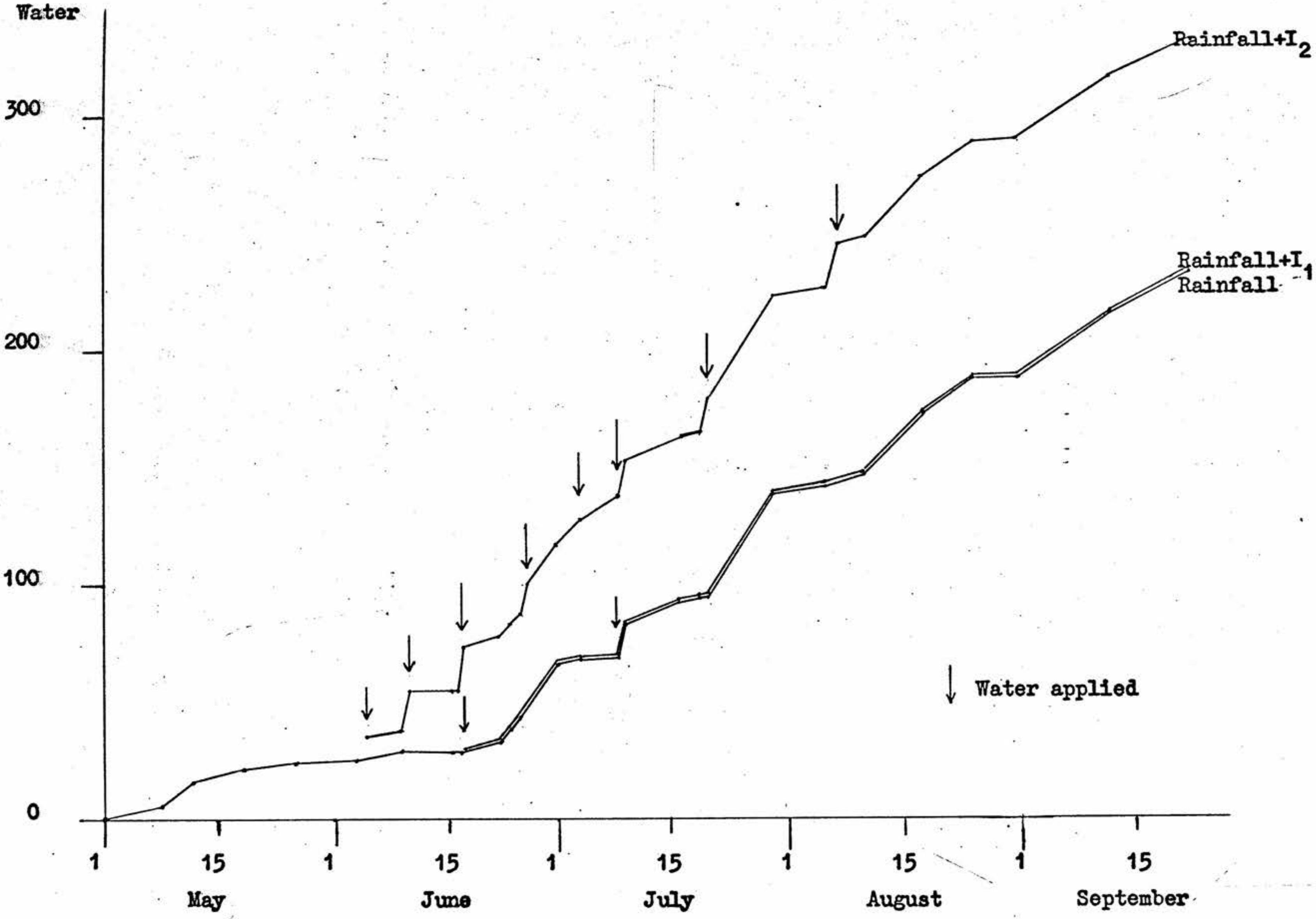


Figure 4. Experiment 1. Rainfall and water applied during the season, mm.



Diary

Emergence counts were made on :- 27.5.70.

Haulm height was measured on :- 3.7.70, 9.7.70, 19.7.70, 7.8.70.

Haulm colour was estimated on :- 3.7.70.

Beaumont periods were recorded on :- 30.7.70-1.8.70, 1.8.70-4.8.70.

Sprayed for blight (with "Dithane") on :- 20.7.70, 31.7.70, 10.8.70, 18.8.70, 27.8.70.

Haulm senescence was estimated on :- 1.9.70.

Haulms were cut down on :- 1.9.70.

Sampling. Eight plants per plot were harvested on 23.9.70. The tubers were washed, riddled into 5 mm size gradings and each tuber was weighed individually. The degree of cracking of the tubers was assessed into four categories:- slight (tuber surface slightly cracked), moderate (cracks in the tuber flesh up to approximately 5mm deep), bad (bad cracks in tuber flesh) and very bad (deep cracks, often more than one third the depth of the tuber). Tubers from each plot were then grouped into the following sizes for analysis.

A.	0 - 30mm	Chats.
B.	31 - 45mm	Small seed.
C.	46 - 60mm	Large seed.
D.	61 - 75mm	Small ware.
E.	76 - 100mm	Large ware.

Each size grouping was sampled for dry matter, N, P and K determinations. When there was sufficient material, samples were also taken for reducing sugar and total sugar determinations.

Experiment 2.

The experiment was carried out on the College Farm, Langhill, Roslin, Midlothian.

Site description.

Map ref. :- NT 273 647.

Elevation:- 150m

Aspect :- slight north west facing slope.

Parent Material:- till derived from carboniferous sediments with partially sorted upper horizons.

Soil series :- Macmerry.*

Drainage class :- imperfect.

Average annual rainfall:- 840mm.

Previous cropping :- 1969 Barley.
1968-1966 Grass.

Soil analysis. The proposed experimental area was soil sampled on 11.3.70, results of analysis are shown in Table III.

Table III. Experiment 2. Soil analysis data for experimental area.

	pH	mg"availableP"/kg soil	mg"availableK"/kg soil
Average of 8 samples	6.3	3.3	58
Maximum	6.5	4.0	71
Minimum	6.2	2.5 (moderate-low)	36 (moderate-low)

Soil samples and soil cores were taken at various depths from the four corners of the experiment on 4.5.70. On these soils moisture characteristics were determined. They are shown in Figure 5.

At low tensions there was a considerable range of results. Since the three results for each core were all comparable this indicates that variation was either due to a non representative core, possibly because of disruption during sampling, earthworm activity before or after sampling or natural soil

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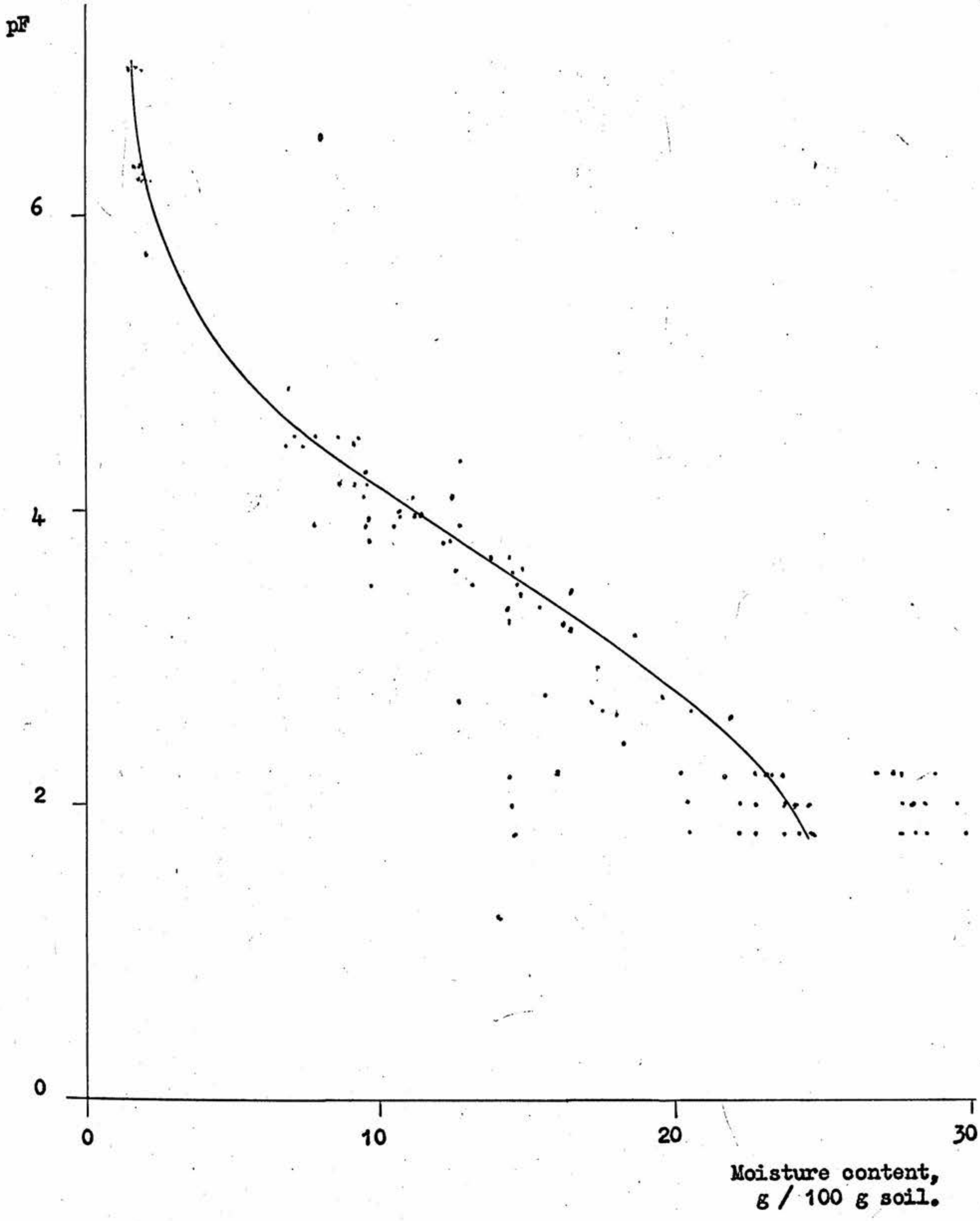
* See "Soils round Haddington and Eyemouth" J.M. Ragg and D.W. Futty. 1967. H.M.S.O. pp 99-100.

Figure 5. Experiment 2. Soil moisture characteristic. Average for all depths.



variability.

Subsamples of the soil were bulked for the analyses shown in Table IV. Bulk density values were the averages for the four corners of the site.

Table IV. Experiment 2. Soil analysis data.

Depth of sample m.	+0.05 to +0.10	-0.05 to -0.10	-0.30 to -0.35
Cation exchange capacity (me/100g soil)	19.4	19.2	15.9
% Coarse sand ∅	31.0	26.4	36.6
% Fine sand ∅	35.9	41.1	33.7
% Silt ∅	14.3	12.8	11.5
% Clay ∅	19.3	21.0	19.8
% Moisture ∅	1.6	1.9	1.6
Organic carbon (g/100g air dry soil)	3.5	3.2	2.2
Mineralisable nitrogen (μg NH_4-N/g soil)	211	127	87
Bulk density (g cm^{-3})	1.20	1.27	1.34

∅ Expressed as % air dry soil.

Design and treatments. Design and treatments were the same as for Experiment 1 (Appendix, Table 20). The basal dressing was 83 kgP/ha (as superphosphate) and 167 kg K/ha (as K Cl).

Cultivations and planting. The field was ploughed in the spring and the seed bed prepared with a rotary cultivator prior to the ridges being opened. The fertiliser was applied to the bottom of the drill and the potatoes planted 29.4.70. The ridges were closed with a front end coverer. Row width, spacing and seed specification were the same as for Experiment 1.

Plate III. Experiment 2. Experimental site, 29.4.1970.

Plate IV. Experiments 1 and 2. Irrigation framework.

Soil moisture measurement and maintenance. This was carried out in the same manner described for Experiment 1. Rainfall and Rainfall+Irrigation during the growing season, averaged over all nitrogen treatments are shown in Figure 6. The amount of water added to each different nitrogen treatment averaged over replicates, is shown in Appendix, Table 21.

Soil moisture changes during the season are shown in Figures 7 and 8 and in Appendix, Table 23.

Meteorological recording. Rainfall was measured using a Meteorological Office rain gauge Mk 2.

Diary

Vigour estimations were made on:- 15.6.70.

Haulm height was measured on:- 14.7.70, 21.7.70.

Sprayed for blight on:- 15.7.70, 29.7.70, 10.8.70, 19.8.70.

Haulm senescence was estimated on:- 13.9.70.

Haulms were cut down on:- 15.9.70.

Sampling. Eight plants per plot were harvested on 8.10.70 and the tubers treated in the manner described for Experiment 1.

1971 Experiment

Choice of site was limited by many factors. These included the necessity for the site being in a relatively dry area, but not too far from the College, and with an adequate water supply. The site was to be relatively uniform, flat and in a potato field.

Experiment 3

This experiment was carried out by courtesy of Mr. M. Robertson, Easter Broomhouse, Dunbar, East Lothian.

Figure 6. Experiment 2. Rainfall and water applied during the season, mm.

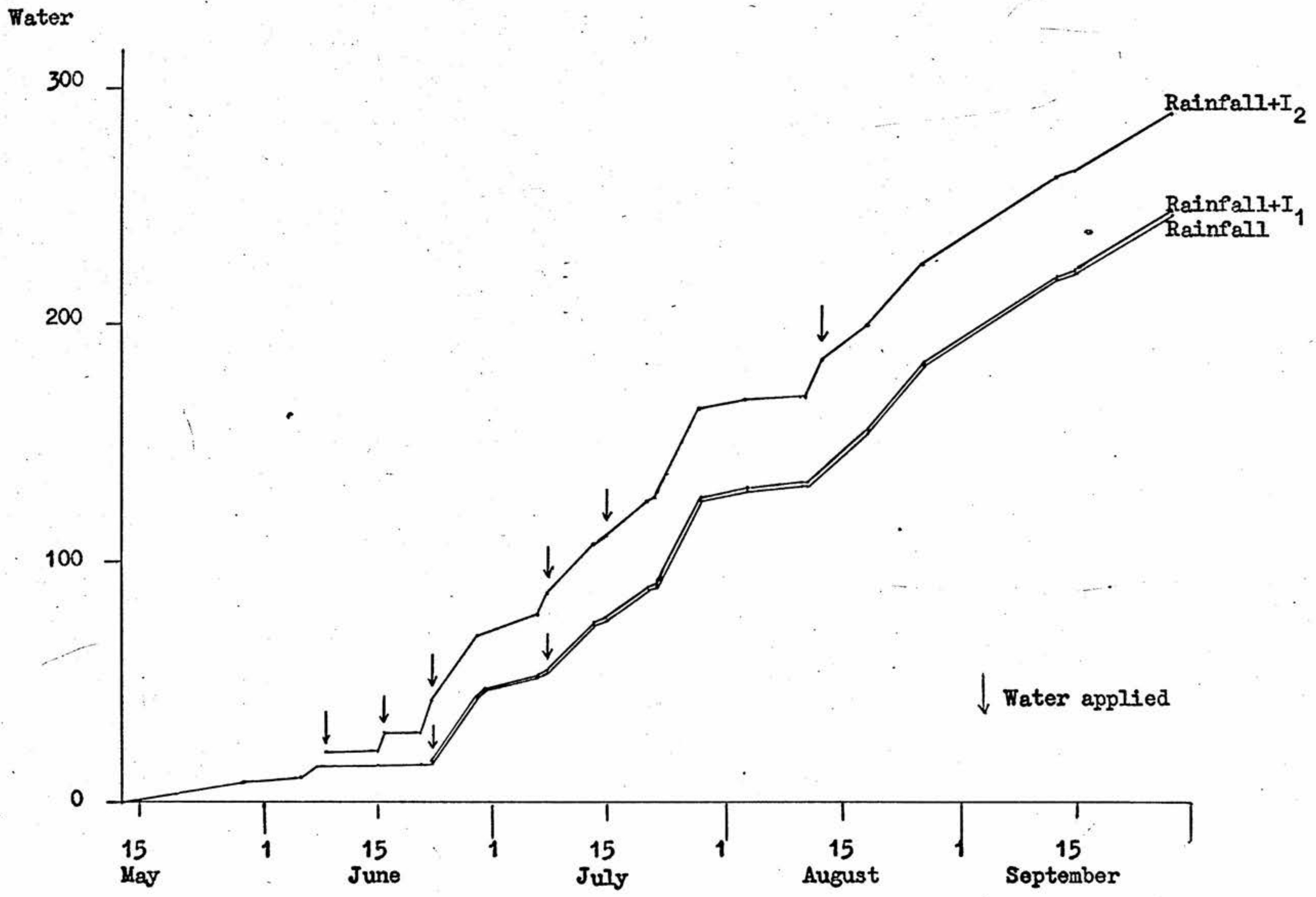


Figure 7. Experiment 2. Soil moisture changes during the season, average for all N levels. Upper horizon, g / 100 g soil.

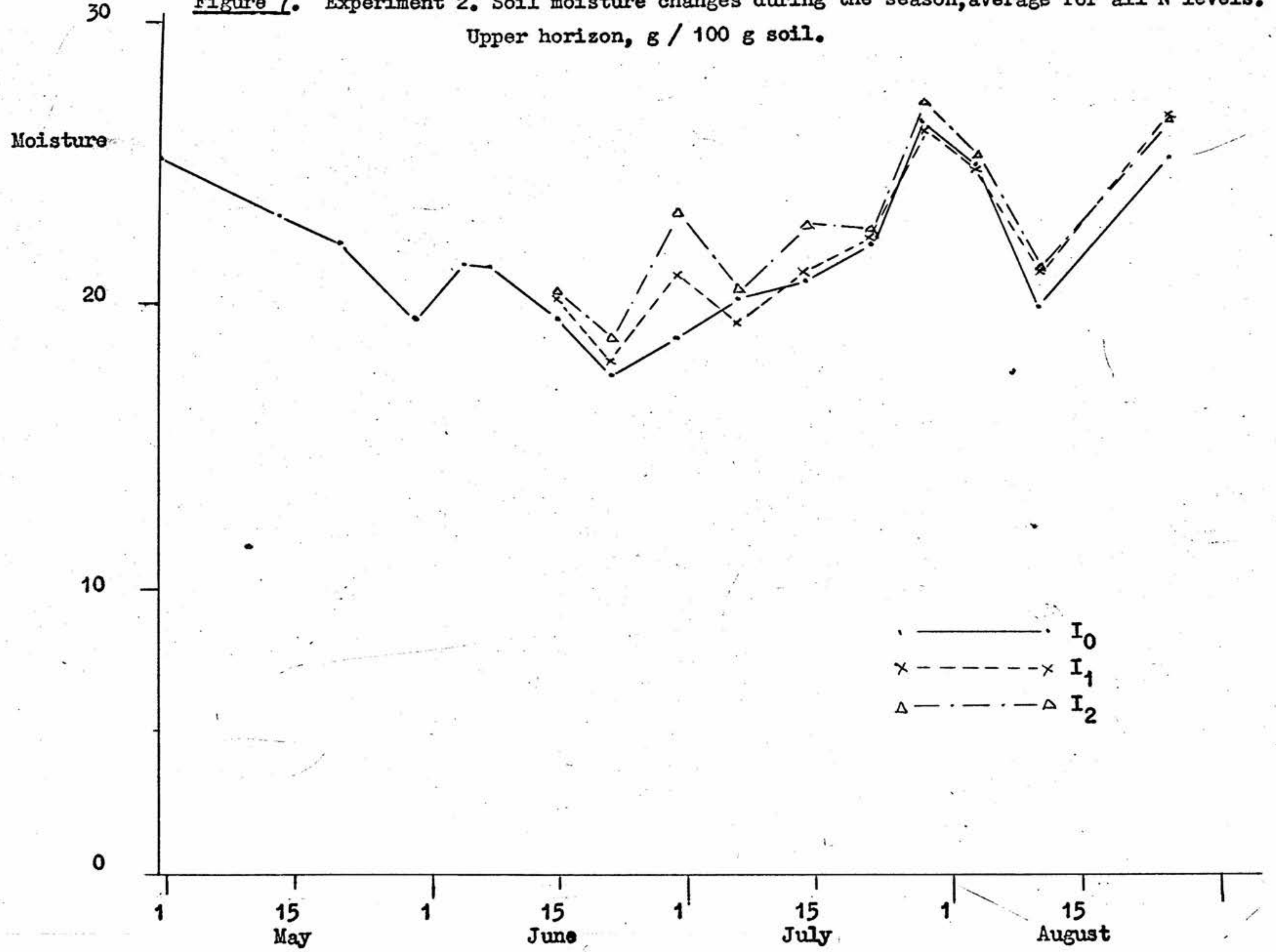
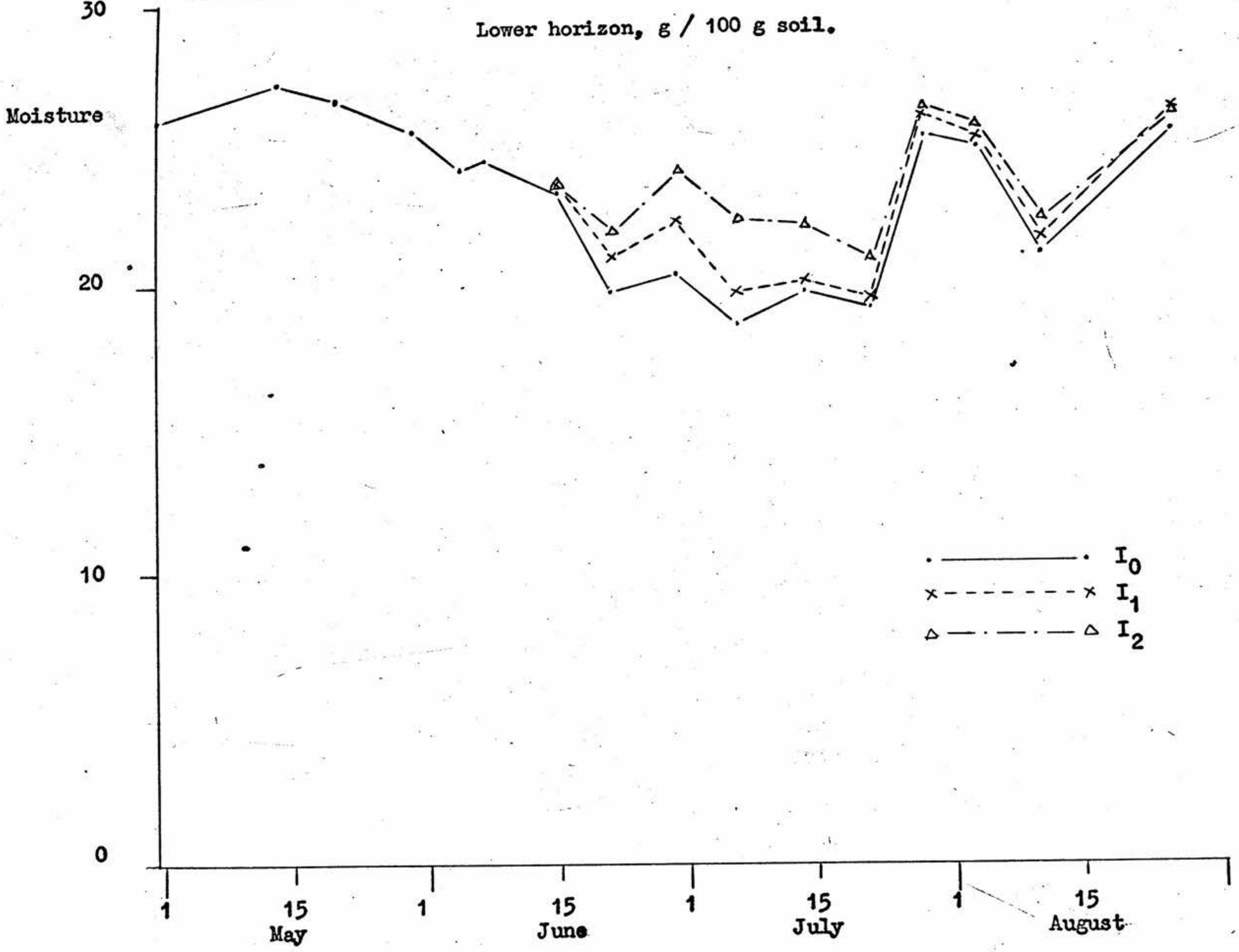


Figure 8. Experiment 2. Soil moisture changes during the season, average for all N levels.

Lower horizon, g / 100 g soil.



Site description.

Map ref:- NT 683 765.

Elevation:- 53m.

Aspect:- nil.

Parent material:- till derived from marls and shales.

Soil series:- Pressmennan.*

Drainage class:- imperfect.

Average annual rainfall:- 600mm.

Previous cropping:- 1970 - 1967 Barley
1966 Potatoes.

Soil analysis. The experimental area was divided into four sections and soil sampled on 22.3.71, results of soil analysis are shown in Table V.

Table V. Experiment 3. Soil analysis data for experimental area.

Section	pH	mg"available P"/kg soil	mg"available K"/kg soil	Potato cyst eelworm No. cysts/200g soil Total	Viable
1	7.0	45	185	1	1
2	6.9	45	191	2	0
3	6.9	55	257	1	0
4	6.8	55 (very high)	244 (very high)	3	1

Soil samples and soil cores were taken at various depths from the four corners of the experiment on 3.5.71. On these soil moisture characteristics were determined. They are shown in Figure 9.

Subsamples of soil from the same depth were bulked for the analyses shown in Table VI. Bulk density values were averaged for the four corners of the site.

* See "Soils around Haddington and Eyemouth" J.M. Ragg & D.W. Futty. 1967. H.M.S.O. pp. 75-76.

Figure 9. Experiment 3. Soil moisture characteristic.
Average for experimental area.

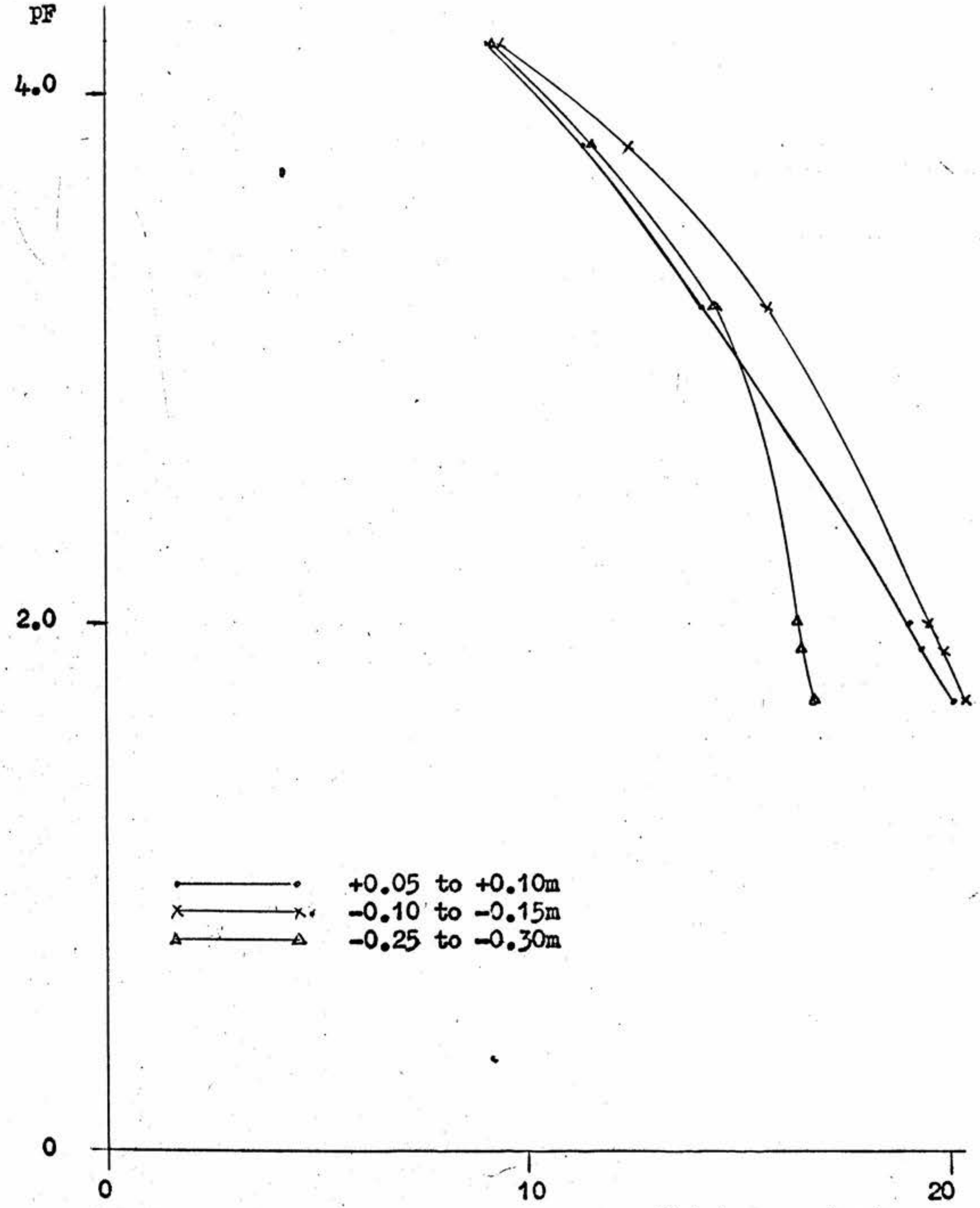


Table VI. Experiment 3. Soil analysis data.

Depth of sample m.	+0.05 to +0.10	-0.10 to -0.15	-0.25 to -0.30
Cation exchange capacity (me/100g soil)	15.4	15.2	14.9
% Coarse sand ∅	24.6	24.2	26.8
% Fine sand ∅	37.8	37.8	35.0
% Silt ∅	13.5	12.5	8.5
% Clay ∅	26.3	25.5	25.8
% Moisture ∅	1.6	1.4	1.4
Organic carbon (g/100g air dry soil)	1.8	1.9	1.4
Mineralisable nitrogen (μg NH_4-N/g soil)	32	70	43
Bulk density (g cm^{-3})	1.65	1.69	1.75

∅ Expressed as % air dry soil.

Design and treatments. The experiment was a 4 x 2 factorial arranged in four blocks of eight plots, each plot 22.15m^2 (Appendix, Table 37).

The treatments were:-

Nitrogen - applied as "Nitro-Top", 33.5%N as NH_4NO_3.

N_0 No additional nitrogen added.

N_1 100 kg N/ha.

N_2 200 kg N/ha.

N_3 300 kg N/ha.

Soil moisture -

I_0 No supplementary water added.

I_1 Soil moisture maintained between pF 2.0 and 2.5

A basal dressing of 30 kg P/ha (as superphosphate) and 167 kg K/ha (as K Cl) was applied to each plot. Discard areas received 1000 kg/ha of a 13-13-20 fertiliser.

Samples were taken from each plot, throughout the growing season, for growth analysis. To accomodate this the plot design was as shown in Figure 10.

Figure 10. Experiment 3. Typical plot design.

```
X X X X X X X X

X 0 0 X X 0 0 X
*  4       5
X 0 0 X X 0 0 X

X X X X X X X X

X 0 0 X X 0 0 X
   3       6   *
X 0 0 X X 0 0 X

X X X X X X X X

X 0 0 X X 0 0 X
*  2       7   *
X 0 0 X X 0 0 X

X X X X X X X X

X 0 0 X X 0 0 X
   1       8   *
X 0 0 X X 0 0 X

X X X X X X X X
```

0 Sampling plants

X Guard plants

3 Sampling number

* Resistance blocks

Samplings 1 to 4 were consecutive on one side of each plot and samplings 5 to 8 consecutive on the other side. The position of sampling 1 was randomised in each plot, both in respect to side of plot and end of plot. The position of sampling 5 was randomised with respect to end of plot.

Cultivations and planting. The field was ploughed in the autumn of 1970 and seed-bed preparations carried out prior to opening the ridges (row-width 0.71m) on 20.4.1971. The experiment was marked out and the fertiliser applied to the bottom of the drill and mixed with the soil using a hand cultivator. The seed potatoes were placed (0.30m spacing) into the rather cloddy seed bed on 21.4.71 and covered with a front end ridger.

The seed potatoes were Foundation Stock Pentland Crown riddled to the size limit 41-50mm and in the weight range 60-69g. They were carefully examined and all damaged, diseased or mis-shapen tubers removed. The tubers were sprouted in trays under artificial lighting, giving strong uniform sprouts about 10mm long.

Soil moisture recording. In 1970 soil moisture changes had been followed only at two depths within the ridge. In 1971 changes of soil moisture between the ridges and at an additional depth within the ridge were to be investigated. Since time would not be available during the growing season to handle this number of samples for gravimetric analysis on a weekly basis it was decided to use stainless-steel/nylon resistance blocks. Seven hundred and fifty of these blocks were constructed to the specifications of Farbrother (1957). They were not coated with gypsum.

The position of the resistance blocks in theplot is shown in Figure 10. At each of the 5 positions, one resistance block was placed between the ridges, i.e. in the bottom of the drill, 0.10m below the surface, in a vertical position. There were three blocks in and below the ridge itself. Two blocks were in vertical positions, 0.10m and 0.30m below the level of the bottom of the drill, and one horizontal, 0.10m above the bottom of the drill.

Holes for the blocks were made with a Jarrett type auger. The blocks were smeared with a slurry of soil and water and placed in the holes, which were then filled with the slurry.

The electrical leads were colour coded for depth and each position was

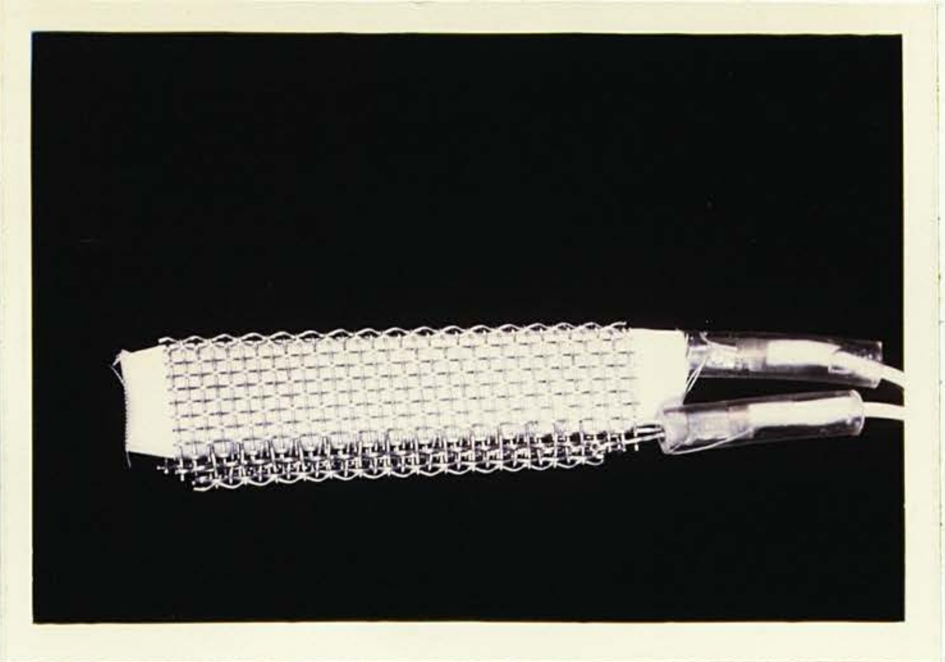


Plate V. Experiment 3. Details of resistance block.

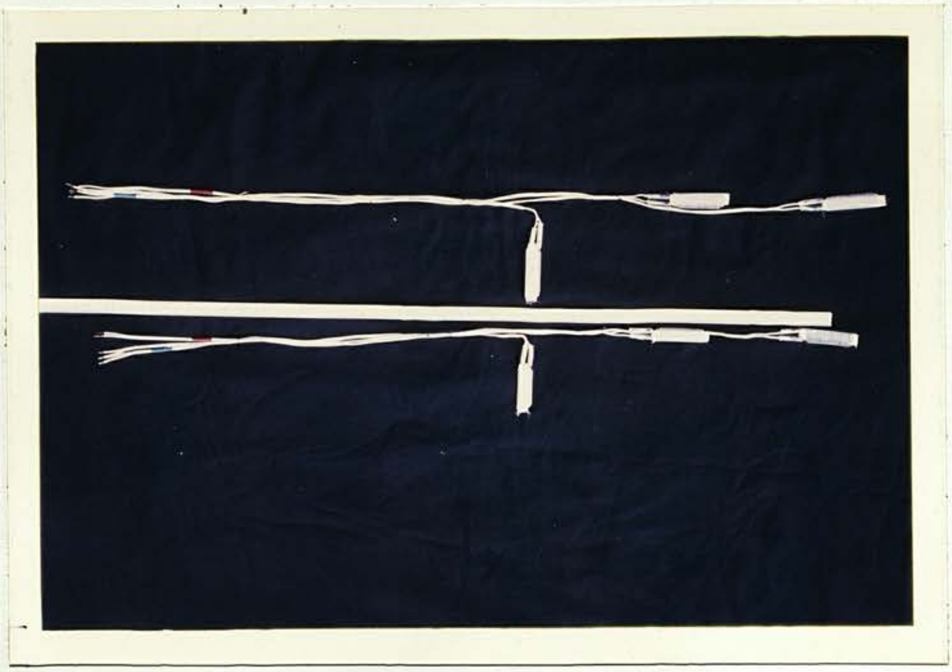


Plate VI. Experiment 3. Resistance blocks layout.

numbered. Readings of resistance were taken weekly using a resistance meter.

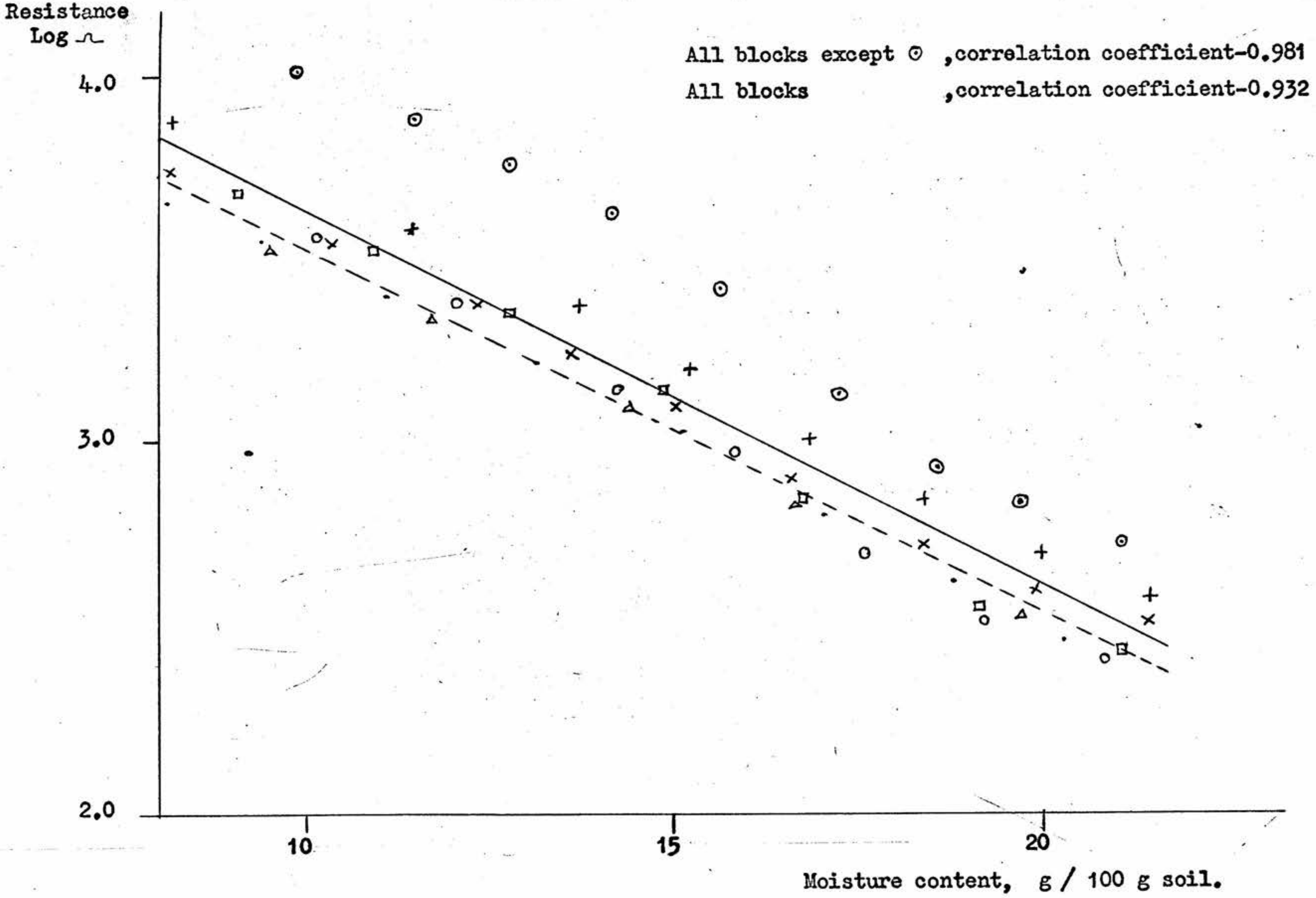
Calibration of resistance blocks. A random sample of resistance blocks was retained for calibration in the laboratory. The method used was that of Kell~~e~~y (1964). A small wire mesh basket was lined with nylon cloth and a resistance block placed centrally in it, completely surrounded by approximately 20mm of soil. The basket was stood in a tray of water for 24h to wet the soil by capillarity, then removed and allowed to complete one drying cycle before being rewetted. The basket was then placed in a humidity cabinet (relative humidity 95%) for 48h to drain. The basket and contents were then weighed and the resistance of the block measured. The soil was then allowed to dry in the laboratory for 4-5h before being placed back in the cabinet for 19-20h. After this period resistance and weight were again measured. The procedure was repeated until the soil was dry, when soil moisture content was determined by oven drying. This allowed moisture content to be determined for each time the resistance had been measured.

The soil for the calibration was taken from two depths at each corner of the site. The top-soil was from 0-0.3m and the sub-soil from 0.3-0.6m. The soil was sieved (12.5mm mesh) to remove large stones.

Figure 11 shows calibration curves for seven blocks in top-soil from one corner of the site. The curves are limited to the range 8-22g moisture/100g dry soil since this was considered to be the working range of the experiment and also, over this range, the calibration curve approximated to a straight line. The calibration curves of five of the blocks were almost identical, and that of a sixth very similar. One calibration curve showed considerable variation from the others, which was possibly due to slight differences in construction of the block.

Figure 11. Experiment 3. Resistance blocks calibration curve for one sample of soil.

Different symbols represent different blocks.



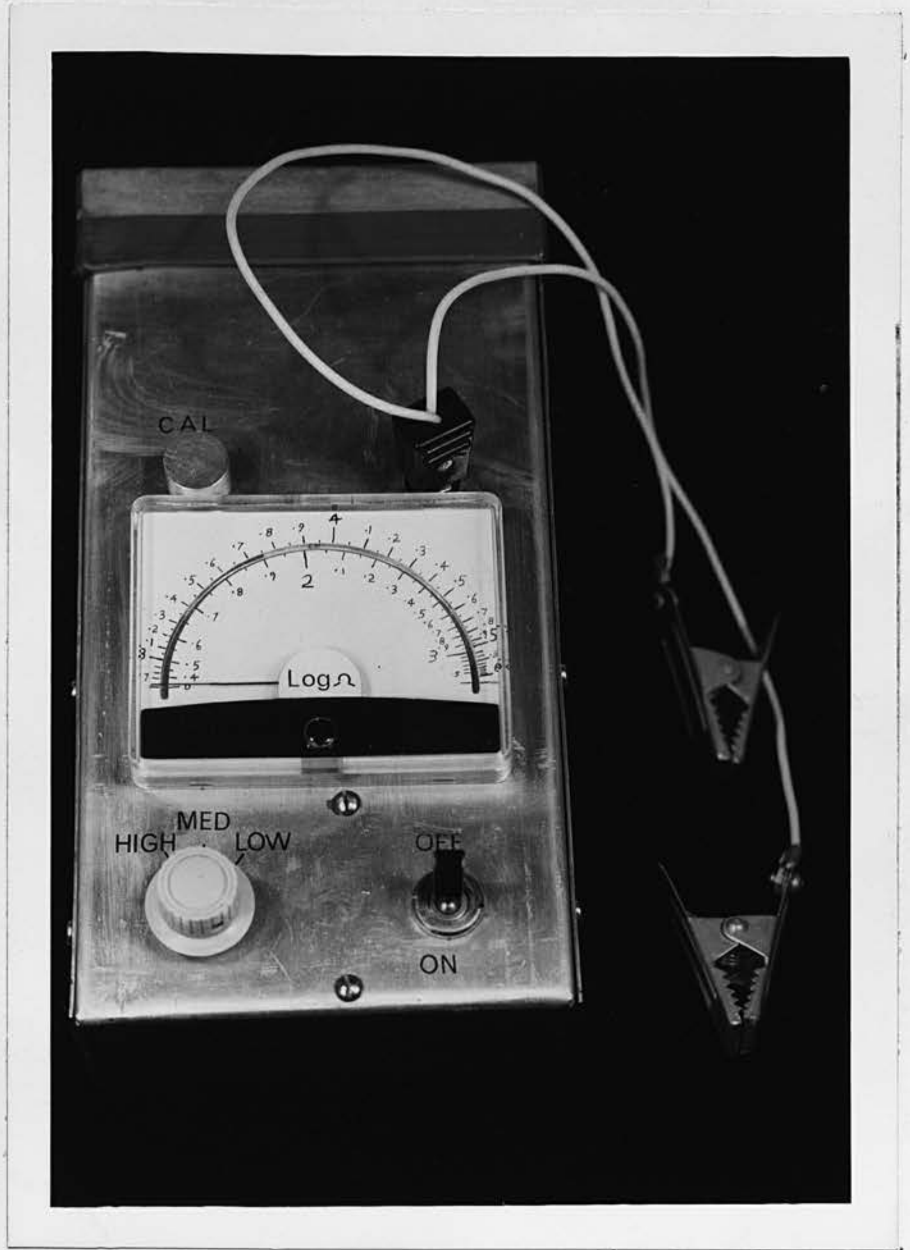


Plate VII. Experiment 3. Resistance meter.

Since it was not practical to calibrate separately each block used in the field, an average calibration curve was constructed (Figure 12). This was obtained with different blocks in top-soil and sub-soil from the four corners of the site. Although calibration curves for top-soil and sub-soil were slightly different an average curve was used to determined moisture content of the soil from resistance readings taken in the field.

Maintenance of different soil moisture levels. The equipment used in 1970 was slightly modified to accommodate the larger plots. Aluminium rails, which were moveable from plot to plot, were used to support the trolley. The rails were placed on lengths of tubing supported on posts driven into the ground at the sides of the plots.

Each plot was watered in two separate halves. To minimise the effect of wind on the distribution of water the plots were surrounded during watering by wooden frameworks covered with polythene sheeting.

Rainfall and Rainfall+Irrigation during the season are shown in Figure 13.

Soil moisture changes during the season are shown in Table VII and in Figure 14.

Meteorological recording. The equipment used in Experiment 1 was again utilised.

Diary.

Sprayed with weedkiller ("Gramanol") on :- 14.5.71.

Emergence counts made on :- 28.5.71.

Height and colour assessments made on :- 12.7.71.

Beaumont period recorded :- 22.8.71-24.8.71.

Sprayed for blight ("Dithane") on :- 28.7.71, 11.8.71, 25.8.71.

Haulm cut down on :- 22.9.71.

Plate VIII. Experiment 3. Experimental site showing plot layout.

Plate IX. Experiment 3. General view of site during irrigation.

Plate X. Experiment 3. General view of experiment.

Plate XI. Experiment 3. Side view of irrigation trolley.

Plate XII. Experiment 3. End view of irrigation trolley.

Figure 12. Experiment 3. General calibration curve for resistance blocks.

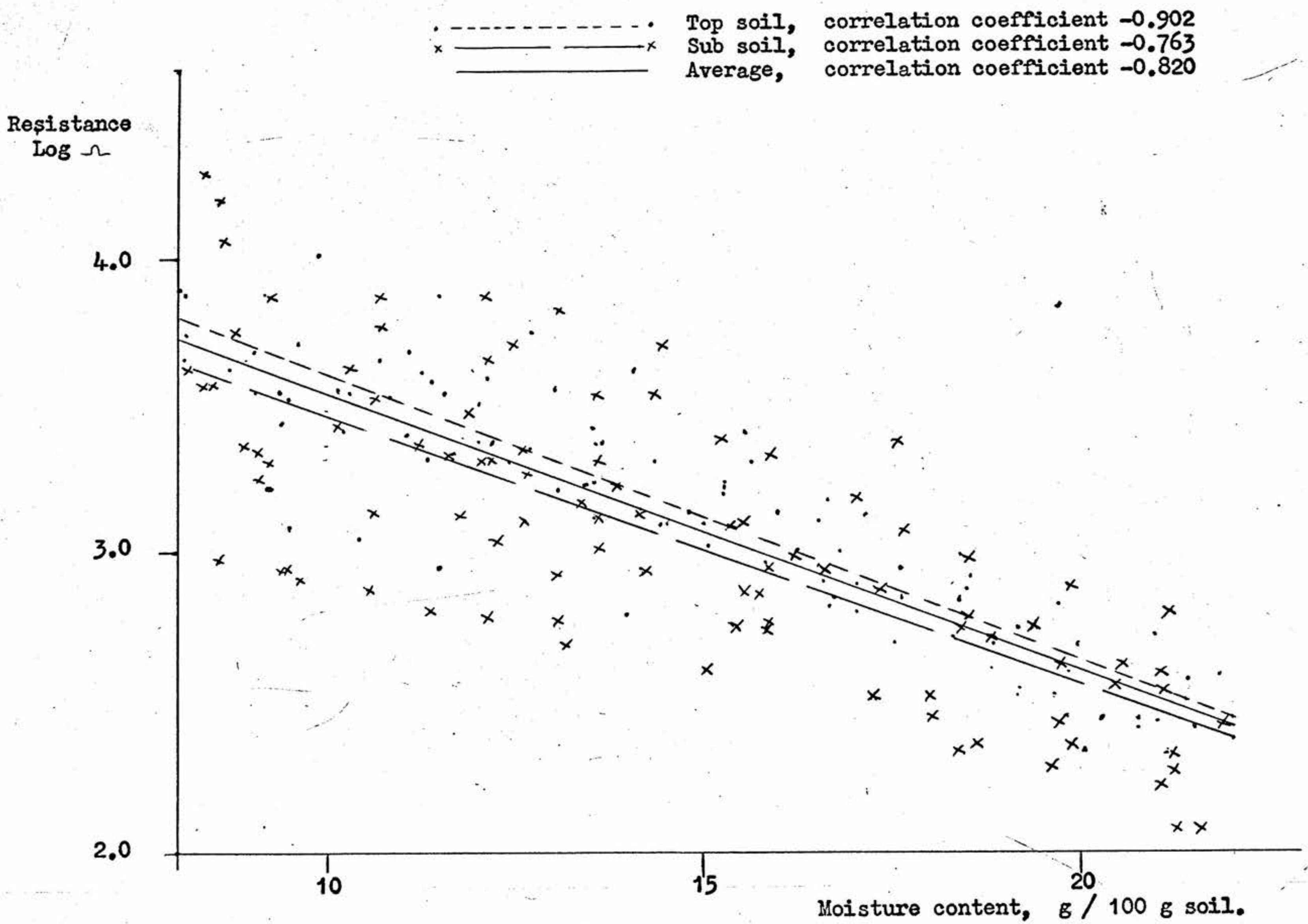


Figure 13. Experiment 3. Rainfall and water applied during the season, mm.

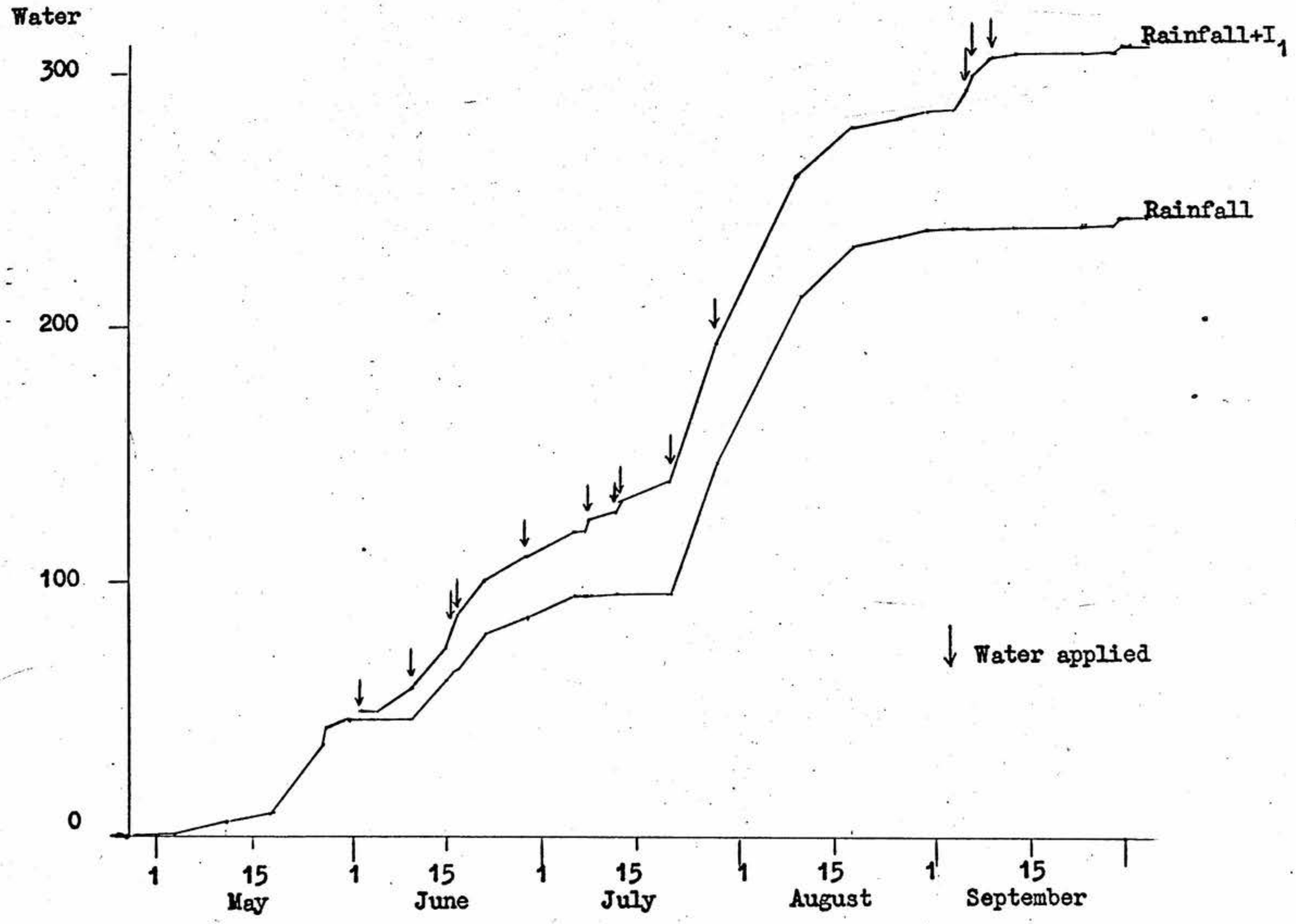


Figure 14. Experiment 3. Example of soil moisture changes during the season at -0.30m. g / 100 g soil.

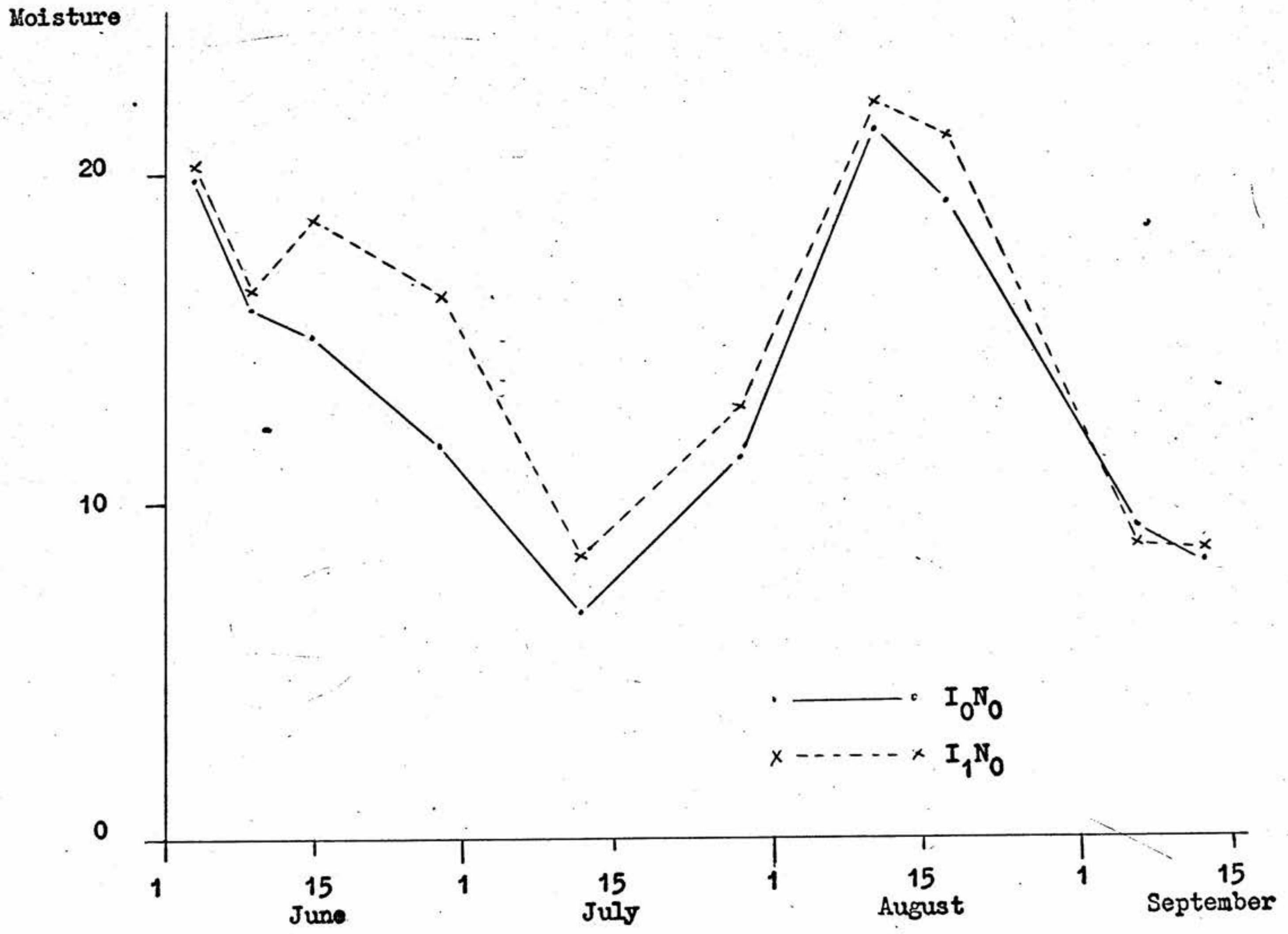


Table VII. Experiment 3. Soil moisture, g/100g soil.

Treatment	Position	3.6.71		9.6.71		15.6.71		28.6.71		12.7.71	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
I_0N_0	Red	14.0	0.52	11.1	0.54	14.9	0.53	12.3	0.37	8.8	0.42
	White	15.7	0.42	11.5	0.50	11.9	0.63	9.9	0.59	6.7	0.27
	Blue	19.8	0.53	15.9	0.51	15.1	0.55	11.8	0.66	6.7	0.40
	Yellow	19.9	0.44	16.3	0.54	22.2	0.50	16.2	0.57	9.7	0.72
I_0N_1	Red	14.4	0.71	11.6	0.56	14.3	0.80	10.4	0.53	7.2	0.48
	White	15.7	0.61	11.4	0.68	11.9	0.82	8.9	0.67	7.2	0.49
	Blue	20.5	0.72	15.4	0.59	14.7	0.67	10.7	0.66	7.7	1.00
	Yellow	19.1	0.49	15.1	0.67	21.6	0.50	15.7	0.84	9.6	0.59
I_0N_2	Red	15.3	1.02	11.8	0.90	14.8	1.03	12.7	1.20	8.7	0.55
	White	16.6	0.78	12.3	0.91	12.9	0.90	11.4	0.78	8.3	0.92
	Blue	20.1	0.55	15.8	0.50	15.8	0.55	12.5	0.49	7.2	0.39
	Yellow	18.0	0.37	14.0	0.38	20.9	0.40	15.7	0.64	7.9	0.45
I_0N_3	Red	18.3	0.98	15.8	1.01	18.8	0.92	15.1	0.98	11.5	0.91
	White	16.4	0.87	13.5	0.84	14.2	0.85	11.3	0.75	7.6	0.91
	Blue	20.3	0.58	16.5	0.62	15.9	0.65	12.6	0.59	7.2	0.40
	Yellow	19.2	0.44	14.6	0.50	22.3	0.47	16.1	0.65	8.6	0.48
I_1N_0	Red	13.0	0.58	10.7	0.49	16.7	0.52	12.2	0.72	8.3	0.39
	White	16.3	0.72	12.6	0.61	15.3	0.63	12.5	0.75	7.5	0.67
	Blue	20.3	0.59	16.6	0.51	18.6	0.56	16.3	0.74	8.5	0.65
	Yellow	19.0	0.48	15.5	0.56	23.9	0.33	19.1	0.72	9.3	0.56
I_1N_1	Red	14.1	0.99	12.2	0.90	17.6	0.98	11.9	0.77	8.8	0.52
	White	15.9	0.77	12.5	0.68	15.5	1.07	10.5	0.72	7.9	1.37
	Blue	20.5	0.47	16.5	0.44	18.7	0.48	14.7	0.66	8.6	0.81
	Yellow	18.0	0.39	14.7	0.38	22.8	0.59	19.3	0.74	7.9	0.37
I_1N_2	Red	15.6	0.75	13.8	0.92	19.2	0.73	13.4	0.93	8.7	0.64
	White	16.6	0.63	14.2	0.85	17.4	0.68	12.3	0.80	7.4	0.43
	Blue	20.1	0.54	16.2	0.46	18.5	0.66	14.6	0.74	7.2	0.55
	Yellow	19.0	0.33	15.7	0.44	23.8	0.33	20.2	0.66	9.4	0.60
I_1N_3	Red	15.3	0.93	12.9	0.87	19.8	0.62	14.2	1.03	9.5	0.80
	White	15.5	0.73	13.4	0.64	17.3	0.80	12.8	0.92	7.8	1.11
	Blue	20.1	0.57	16.2	0.51	19.0	0.70	15.9	0.81	8.2	0.83
	Yellow	18.1	0.38	14.9	0.45	22.9	0.42	18.7	0.92	9.2	0.60

Within ridge:- Red + 0.10m, White - 0.10m, Blue - 0.30m

Between ridges:- Yellow - 0.10m

Table VII cont'd. Experiment 3. Soil moisture, g/100g soil.

Treatment	Position	28.7.71		11.8.71		18.8.71		6.9.71		13.9.71	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
I_0N_0	Red	21.9	0.73	18.8	0.72	16.6	0.89	8.3	0.58	7.9	0.53
	White	15.3	1.44	21.1	0.45	19.4	0.81	9.3	0.60	8.0	0.58
	Blue	11.4	1.81	21.3	0.87	19.1	1.24	9.3	0.47	8.2	0.53
	Yellow	20.6	0.38	18.1	0.43	18.0	0.44	9.7	0.64	8.4	0.63
I_0N_1	Red	22.3	0.74	17.2	0.87	16.0	0.93	7.7	0.79	7.3	0.72
	White	16.1	1.61	20.3	0.59	19.7	0.66	7.5	0.59	7.2	0.77
	Blue	14.1	2.52	21.4	0.61	20.6	0.78	8.6	1.17	8.4	1.08
	Yellow	22.0	0.39	19.5	0.56	18.8	0.60	10.2	0.79	8.9	0.77
I_0N_2	Red	21.0	1.19	18.5	1.08	16.7	1.25	7.6	0.43	6.3	0.30
	White	14.9	1.27	20.1	0.81	18.1	1.19	8.3	0.81	6.8	0.51
	Blue	7.9	0.79	20.1	0.98	16.8	1.39	7.9	1.39	7.9	1.96
	Yellow	21.5	0.49	18.2	0.32	16.9	0.48	7.7	0.51	7.9	0.64
I_0N_3	Red	22.3	0.96	18.6	1.65	16.6	1.90	11.8	1.55	12.1	1.08
	White	16.9	1.78	20.2	1.11	18.5	0.83	8.7	1.10	7.9	1.15
	Blue	11.9	1.70	21.8	1.03	19.0	1.34	8.5	0.90	7.9	0.72
	Yellow	22.4	0.45	18.7	0.65	16.7	0.70	8.3	0.22	7.4	0.27
I_1N_0	Red	22.0	0.64	16.7	0.80	16.8	0.80	7.4	0.52	8.5	0.70
	White	17.9	1.26	19.8	0.53	20.0	0.55	9.3	0.79	9.0	0.82
	Blue	12.9	1.64	22.2	0.58	21.1	0.60	8.7	0.77	8.5	0.73
	Yellow	22.8	0.40	19.2	0.47	19.4	0.47	9.9	0.74	15.9	0.58
I_1N_1	Red	22.5	0.60	16.8	0.75	16.2	0.72	7.3	0.78	7.9	0.78
	White	18.8	1.42	20.0	0.90	19.6	1.05	7.9	0.86	8.7	1.01
	Blue	14.4	1.85	21.8	0.82	20.9	1.04	9.3	0.79	9.4	0.85
	Yellow	22.2	0.30	18.9	0.49	18.2	0.56	8.7	0.50	14.1	0.64
I_1N_2	Red	24.0	0.48	17.8	1.01	16.3	1.03	8.1	0.79	9.0	0.94
	White	19.3	1.46	20.0	0.50	17.9	0.99	9.6	0.90	9.7	0.85
	Blue	15.4	1.93	20.4	0.54	16.6	1.35	7.2	0.90	6.7	0.69
	Yellow	21.6	0.28	17.7	0.67	16.2	0.77	8.6	0.79	12.7	0.68
I_1N_3	Red	23.6	1.22	18.8	0.97	16.1	1.10	9.0	1.26	9.7	1.63
	White	16.3	1.45	20.0	0.63	16.9	1.01	7.0	1.31	8.0	0.74
	Blue	13.3	1.48	21.4	0.67	18.9	1.13	8.8	1.12	8.5	1.12
	Yellow	21.7	0.45	17.2	0.72	15.7	0.75	8.3	0.58	11.8	0.70

Sampling. Sampling was carried out at two-week intervals early in the season and later at three-week intervals.

Field procedure. The two guard plants nearest the end of the plot were carefully lifted out of the way. For samplings 1 to 5 a soil sample was then taken from just below the fertiliser band, in each ridge, between the guard plant and the first sampling plant. At the first sampling the samples from the two ridges were kept separate, but for later samplings they were combined in one polythene bag for each plot.

The aerial parts of the four sampling plants were cut just above soil level and placed in a polythene bag. The below-ground parts were dug and placed in a separate bag.

Samplings planned as 7 and 8 were combined into one sampling (sampling 7).

Laboratory procedure. The soil was analysed for NO_3-N, NH_4-N, soil moisture, pH (in water and Ca Cl_2), "available P", "available K" and conductivity. In addition the NO_2-N concentration of the soil extract was determined at the first sampling.

The leaves were removed from the stems and both leaves and stems weighed and sub-sampled for dry matter determination and chemical analysis. A sub-sample of leaves was also taken for leaf-area determination. This was done with a cork borer (Watson and Watson, 1953), 50 complete leaf discs (Spencer, 1962) being dried and weighed.

The below-ground parts of the plant were washed and separated into stems, stolons and developing tubers, roots and tubers. These fractions were weighed and sampled for dry matter determination and chemical analysis.

At the last sampling tubers only were taken. These were riddled into four size fractions, counted and weighed.

A.	0 - 30mm	Chats.
B.	31 - 45mm	Small seed.
C.	46 - 60mm	Large seed.
D.	Greater 61mm	Ware.

Subsamples of fractions B, C and D were washed for dry matter determination and N, P and K analysis. Subsamples of fractions C and D were combined for reducing sugar and total sugar determination.

The analyses carried out, on each fraction, at each sampling, are summarised in Table VIII.

Growth characteristics. Growth characteristics were calculated, for intervals between samplings, using the following formulae.

Relative growth rate, g/g/day $= \dfrac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$

Net assimilation rate, g/m^2/day $= \dfrac{W_2 - W_1}{A_2 - A_1} \times \dfrac{\log_e A_2 - \log_e A_1}{t_2 - t_1}$

Economic assimilation rate, g/m^2/day $= \dfrac{T_2 - T_1}{A_2 - A_1} \times \dfrac{\log_e A_2 - \log_e A_1}{t_2 - t_1}$

Crop growth rate, g/m^2/day $= \dfrac{W_2 - W_1}{P(t_2 - t_1)}$

Relative leaf growth rate, m^2/m^2/day $= \dfrac{\log_e A_2 - \log_e A_1}{t_2 - t_1}$

Relative tuber growth rate, g/g/day $= \dfrac{\log_e T_2 - \log_e T_1}{t_2 - t_1}$

W = total dry weight, g.

A = leaf area, m^2.

T = tuber dry weight, g.

P = ground area, m^2.

Subscript$_1$ = start of time interval.

Subscript$_2$ = end of time interval.

t = time, days.

Table VIII. Experiment 3. Summary of plant analyses.

Sampling number and date	Roots	Stolons and developing tubers	Tubers	Stems and petioles	Leaves
1 21.6.71	N.P.K. NO_3-N	DM.	DM.	N.P.K. NO_3-N. DM.	N.P.K. DM. LA.
2 5.7.71	N.P.K. NO_3-N	DM.	N.P.K. DM.	N.P.K. NO_3-N. DM.	N.P.K. DM. LA.
3 19.7.71	N.P.K. NO_3-N	DM.	N.P.K. DM.	N.P.K. NO_3-N. DM.	N.P.K. DM. LA.
4 9.8.71			N.P.K. DM.	N.P.K. NO_3-N. DM.	N.P.K. DM. LA.
5 31.8.71			N.P.K. DM.	N.P.K. NO_3-N. DM.	N.P.K. DM. LA.
6 21.9.71			N.P.K. DM.	N.P.K. NO_3-N. DM.	N.P.K. DM. LA.
7 4.10.71			N.P.K. DM. RS. TS.		

N.	Nitrogen.	NO_3-N.	Nitrate-nitrogen	R.S.	Reducing sugar.
P.	Phosphorus.	DM.	Dry matter.	T.S.	Total sugar.
K.	Potassium.	L.A.	Leaf area.		

B. Analytical Methods

Plant analysis.

Dry matter determination and preparation of samples for analysis of dry matter.

Plant material was dried overnight at 90°C in a forced draught oven, dry matter content being determined by weighing. A sub-sample was then ground in a mill and stored in a poly-pot until required for analysis.

Digestion of plant material for determination of P and K. Digestion was carried out according to the method described by Alston (1964) using a mixture of nitric and perchloric acids. The digest was not filtered but was shaken and allowed to settle. The aliquot for analysis was taken from the supernatant liquid.

Determination of P and K. Potassium was determined using a flame photometer (Collins and Polkinhorne, 1952) and P determined by measuring the colour produced on formation of the phosphovanadomolybdate complex (Hanson, 1950).

Determination of total N. A modified Kjeldahl method was used to determine the total N content of dry plant material.

Reagents:- Catalyst tablets, 2.5g(1.875g K_2SO_4, 0.625g $CuSO_4$).

H_2SO_4, concentrated (1.84g/ml).

H_2O_2, 100 volume (0.30kg/l).

Zn, granulated.

Na OH, solution (0.60kg/l).

Boric acid/mixed indicator.

A.400g H_3BO_3 made up to 10l with distilled water.

B.0.98g bromo cresol green indicator, 0.70g methyl red, made up to 1 l with absolute alcohol.

200 ml solution B added to solution A.

H_2SO_4, 0.05N.

Procedure:- 0.5g oven-dry plant material was placed in a 50 ml Kjeldahl flask and approximately 5 ml distilled water added. After addition of a catalyst tablet, 10 ml concentrated H_2SO_4 and 2 ml H_2O_2, the solution was digested and the heating continued for 1h after the solution had cleared. The contents of the flask were transferred to a 500 ml distillation flask and then were added some granulated Zn, 30 ml NaOH and approximately 250 ml distilled water. This was distilled into 20 ml boric acid/mixed indicator in a 500 ml conical flask. When distillation was complete the distillate was titrated against 0.05N H_2SO_4.

$$1 \text{ ml } 0.05N\ H_2SO_4 \equiv 0.7\text{mgN}$$

Modification:- Because of the high concentrations of nitrate-nitrogen in the stems and roots, digestion was modified to "trap" nitrate-nitrogen (Vogel, 1961). To 0.5g of plant material, 15 ml concentrated H_2SO_4 containing 0.5g salicylic acid was added and shaken, left for at least 0.5h, and then 1.25g sodium thiosulphate added, shaken and left for 15min. The flask was heated on a low flame until frothing had ceased, then a catalyst tablet was added. Heating was increased and continued for 1h after the solution had cleared.

Determination of NO_3'-N. Nitrate content of dried plant material was determined by the phenol disulphonic acid method described by Johnson and Ulrich (1959). The Cl' content of the material was first determined by Mohr's method (Johnson and Ulrich, 1959). There was less than 10g Cl'/kg dry material and therefore it was not necessary to destroy Cl' before the determination of NO_3'-N.

Reagents:- Ca CO_3, suspension. 1g Ca CO_3 suspended in 200 ml distilled water.

H_2O_2, 50 volume (0.15kg/l).

Phenol disulphonic acid (B.D.H.).

NH_4OH solution (0.251 0.880 NH_4OH/1).

Nitrate stock standard solutions. (500µg NO_3'-N/ml)

3.6090g KNO_3 made up to 1 l with distilled water.

Working standard solutions. 0,5,10,15 and 20 ml stock standard made up to 100 ml with distilled water.

Contains 0,25,50,75 and 100µg NO_3'-N/ml.

Procedure:- 0.25g oven dry plant material was weighed into a 100 ml shaking jar, 75 ml distilled water added and shaken for 15min. After filtering through a Whatman N°42 paper, a 10 ml aliquot of the filtrate was pipetted into a 50 ml beaker. Two ml Ca CO_3 suspension and 2 ml H_2O_2 were added and the beaker placed on a steam bath for 2h with a watch glass on top to prevent evaporation. The watch glass was then removed and the contents of the beaker evaporated to dryness and left on the steam bath for an additional 30min to destroy any residual H_2O_2. After cooling, 2 ml phenol disulphonic acid was added and then 10min later approximately 10 ml distilled water followed by excess NH_4OH solution was added. The solution was allowed to cool and made up to 50 ml. The intensity of the yellow colour was then measured in an E.E.L. absorptiometer using a 10mm cell and a 601 filter (425nm).

To obtain a standard curve 10 ml aliquots of the working standards were treated in the same manner.

Preparation of tubers for sugar determinations. The tubers were chipped and separate subsamples taken for dry matter determination and extraction for sugar determinations.

Extraction of tubers for sugar determinations. About 150g chipped tubers (weighed accurately) were added to 200 ml industrial methylated spirits in a Sunbeam blender and macerated for 5min. The slurry was then filtered through a Whatman N^{o}1 paper and the filtrate collected. One ml of this filtrate corresponded to $\frac{a}{200+a(1-d)}$ g fresh tuber when 200 ml alcohol was macerated with a g fresh tuber of d kg drymatter/kg fresh material.

Determination of reducing sugar. Reducing sugar concemtration of the alcoholic extract was determined using a modified dinitrophenol method (Ross, 1959).

Reagents:- Dinitrophenol reagent.

A. 8g sodium 2.4 - dinitrophenolate and 2.5g phenol dissolved in 200 ml NaOH solution (50g/1).

B. 100g sodium potassium tartrate dissolved in about 500 ml distilled water.

Solutions A and B were mixed together and made up to 1 1 with distilled water.

Reducing sugar stock standard solution (10mg reducing sugar/ml). 1.000g glucose made up to 100 ml with distilled water.

Working standard solutions. 0,1,2,3,4 and 5 ml stock standard pipetted into 100 ml volumetric flasks, 15 ml industrial methylated spirits added and made up with distilled water. Contains 0,0.1, 0.2,0.3,0.4,0.5mg reducing sugar/ml.

Procedure:- Ten ml alcoholic extract was diluted to 50 ml with distilled water. Two ml diluted extract was pipetted (in duplicate) into a test-tube and 6 ml dinitrophenol reagent added. The test-tube was then placed in a boiling water bath for 6min. and then transferred to a cold water bath for 3min. The intensity of the orange colour, which is stable only in cold water for 20min, was read in an E.E.L. absorptiometer using a 5mm cell and a 604 filter (520nm).

Each of the working standards was treated in the same manner to give a calibration graph. The concentration of reducing sugar in the alcoholic extract could then be calculated.

Determination of total sugar. Total sugar concentration of the alcoholic extract was determined (as invert sugar), after inversion of sucrose to glucose and fructose by acid hydrolysis (Vliet and Muller, 1968), by the dinitrophenol method as given above. From the difference between total and reducing sugar the sucrose concentration was calculated. Sucrose concentration plus reducing sugar concentration gave the total sugar concentration of the tubers.

Reagents:- Methyl orange indicator.

H Cl, approximately 4N.

H Cl, 0.1N.

NaOH, 0.1N.

Standard solution. 1.190g sucrose, plus 20 ml industrial methylated spirits made up to 250 ml with distilled water. Contains 5mg invert sugar/ml.

Procedure:- To 10 ml undiluted extract in a boiling tube 4 drops methyl orange indicator were added and 4N H Cl drop-by-drop until the solution turned red. After addition of 7.5 ml 0.1 N H Cl the tube was placed in a boiling water bath for 30min, then cooled rapidly. 7.5 ml 0.1 N NaOH was added and the solution made up to 100 ml with distilled water. The invert sugar concentration of this was determined by the dinitrophenol method described above.

A standard curve was prepared by taking 2,4,6,8 and 10 ml stock solution and treating as above.

Soil analysis

Preparation of samples. Where air-dry samples were required the soil was placed in trays in a heated room (approximately 25°C) until dry. The samples were ground, passed through a 2mm sieve and stored in paper bags until required.

Where analysis on fresh moist soil was required the samples were mixed thoroughly before subsampling for analysis.

Determination of soil moisture content. Soil moisture was determined by weighing about 200g of moist soil, drying it overnight at 105°C in a forced draught oven, and reweighing. Unless otherwise stated soil moisture is always expressed as g moisture/100g oven dry soil.

Determination of soil reaction. Soil pH was measured in a 1:2.5 suspension of soil and water on a Pye pH meter using a glass electrode and calomel half cell.

Soil pH was also measured in a 1:2.5 suspension of soil and 0.01 M $Ca\ Cl_2$ using the same apparatus.

Extraction of "available P" and "available K". Soil extracts were obtained using a modified Morgan's reagent (pH 4.5) as described by Hende etal. (1953).

Determination of "available P" and "available K". The extracts were analysed for "available P" by measuring the intensity of the blue colour produced after reduction of ammonium phosphomolybdate by $Sn\ Cl_2$, using the method described by Alston (1964).

"Available K" was determined on the soil extract using the flame photometer method (Collins and Polkinhorne, 1952).

Determination of cation exchange capacity. The cation exchange capacity was determined by NH_4^+ saturation of the soil and displacement by Na Cl (Chapman, 1965). The NH_4^+ was determined using the method described in the determination of total N in plant material.

Determination of particle size distribution. Mechanical analysis was carried out using the pipette method described by Kilmer and Alexander (1949) and particles separated according to the I.S.S.S. limits.

Determination of organic C. Organic carbon was determined by the modified Tinsley method (Bremner and Jenkinson, 1960) using 0.5g soil ground to pass through a 0.2mm sieve.

Determination of conductivity. A saturated soil paste was prepared (U.S.D.A. Handbook N°60, 1954), using fresh soil, and the conductivity measured using a Pye conductivity cell.

Extraction of soil NO_3'-N. Soil NO_3'-N was extracted using 0.0044N $Ca\ SO_4$ solution (Roller and McKaig, 1939).

Determination of soil NO_3'-N. The brucine method (Robinson et al., 1959) was tried but the results were not found to be very reproducible. It was superseded by the phenol disulphonic acid method (Bremner, 1965) which although tedious is much more reliable.

Extraction of soil NH_4^+-N. Soil NH_4^+-N was extracted using sodium acetate-acetic acid solution (Morgan, 1941).

Determination of soil NH_4^+-N. Ammonium-N in the extracts was determined by measuring the intensity of the yellow colour produced by Nesslerisation (Peech and English, 1944).

Determination of soil NO_2'-N. The NO_2'-N content of the $Ca\ SO_4$ extract was determined using a modified Griess-Ilosvay method (Bremner, 1965).

Determination of N availability. Ammonium produced under anaerobic conditions was determined using the method described by Waring and Bremner (1964). The NH_4^+ was estimated using the distillation technique described for total N content of plant material.

Determination of bulk density. Cores of soil were taken from the field using the sampler described by Dagg and Hosegood (1962). The cores were dried at 105°C for 48h and the weight of dry soil determined. The volume of the core was calculated and the bulk density calculated as g oven dry soil/cm^3.

Determination of soil characteristics. Soil moisture contents at tensions less than pF 3.0 were determined using undisturbed field cores, at greater tensions than this air dried sieved (2mm) soil was used (Broadfoot, 1954).

Tensions less than pF 3.0:- Cores of undisturbed soil were taken using the same sampler used for bulk density determinations. The moisture contents at various tensions were then determined using the Dutch designed sand- and kaolin-sand-box apparatus (Stakman *et al.*, 1969).

Tensions greater than pF 3.0:- In 1970 the filter paper method was used (Fawcett and Collis-George, 1967) with a slight modification. Three Whatman N°42 filter papers were equilibrated with the soil, a 55mm diam paper sandwiched by two 70mm diam papers. This ensured that the middle paper was not contaminated with soil. In 1971 a "15 Bar" Ceramic Plate Extractor (Soil Moisture Equipment Company, Santa Barbara, California, U.S.A.) was purchased. This allowed direct variation of soil moisture tension.

EXPERIMENTS 1 AND 2

Treatments

N_0 - No additional nitrogen

N_1 - 100 kg N/ha

N_2 - 200 kg N/ha

N_3 - 300 kg N/ha

I_0 - No supplementary water added.

I_1 - Soil moisture maintained between pF 3.0 and 3.5

I_2 - Soil moisture maintained between pF 2.0 and 2.5

Tuber size fractions.

A - 0 - 30mm Chats

B - 31 - 45mm Small seed

C - 46 - 60mm Large seed

D - 61 - 75mm Small ware

E - 76 - 100mm Large ware

EXPERIMENT 3

Treatments

N_0 - No additional nitrogen

N_1 - 100 kg N/ha

N_2 - 200 kg N/ha

N_3 - 300 kg N/ha

I_0 - No supplementary water added.

I_1 - Soil moisture maintained between pF 2.0 and 2.5

Tuber size fractions.

A - 0 - 30mm Chats

B - 31 - 45mm Small seed

C - 46 - 60mm Large seed

D - > 60mm Ware

EXPERIMENT 3

Sampling 1	21. 6.71	61 days after planting
2	5. 7.71	75
3	19. 7.71	89
4	9. 8.71	110
5	31. 8.71	132
6	21. 9.71	153
7	4.10.71	166

RESULTS, EXPERIMENTS 1 AND 2

EXPERIMENT 1.

Growth record (Figures 15-21).

Emergence, 29 days after planting, was slightly reduced by high levels of nitrogen.

At 66 days the haulm colour of the high moisture treatment (I_2) tended to be lighter than the lower moisture levels at N_0, but darker at N_2 and N_3. At this time haulm height was greater with the addition of nitrogen (N_1) and decreased at higher rates of nitrogen. The decrease was most prominent when no additional water was added (I_0) and this treatment gave a maximum height at N_1. At the high moisture level (I_2) haulm height was the same at N_1 and N_2, with only a slightly shorter haulm than this at N_3. This trend was also shown at 72 days, but at 82 days the deleterious effects of high nitrogen levels at low soil moisture was not as marked. This was also the case at 101 days. In all cases haulm height was greatest at the high moisture level (I_2) for each nitrogen treatment, except N_0 where I_2 and I_1 were the same.

Senescence at 126 days was more advanced at low nitrogen levels. There was no marked effect of soil moisture, except a slightly more advanced senescence at N_0 at the high moisture level (I_2).

Yield of tubers. (Appendix, Tables 7 and 9)

The interaction between soil moisture and applied nitrogen on tuber yield was statistically significant for all size fractions and groupings of size fractions except fraction D, where only the main soil moisture effect was significant, and fraction E, where only nitrogen had a significant effect on the weight of tubers.

Plate XIII. Experiment 1. Plots on 12.8.70.
Left I_2N_0, right I_0N_0.

Plate XIV. Experiment 1. Plots on 12.8.70.
Left I_0N_3, right I_0N_0.

Figure 15. Experiment 1. Emergence at 29 days, number of plants

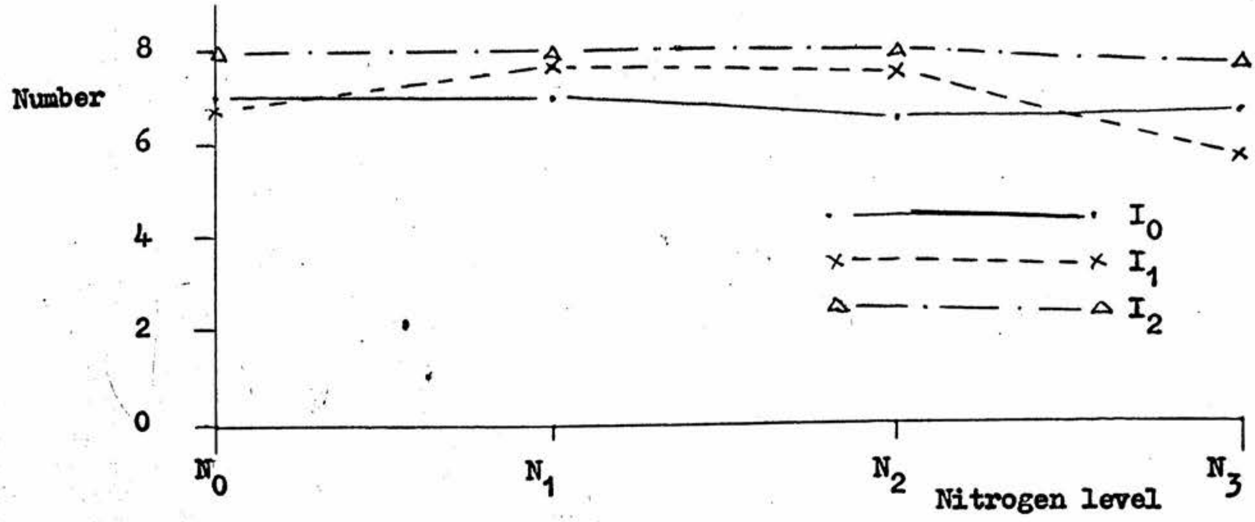


Figure 16. Experiment 1. Haulm colour estimate at 66 days.

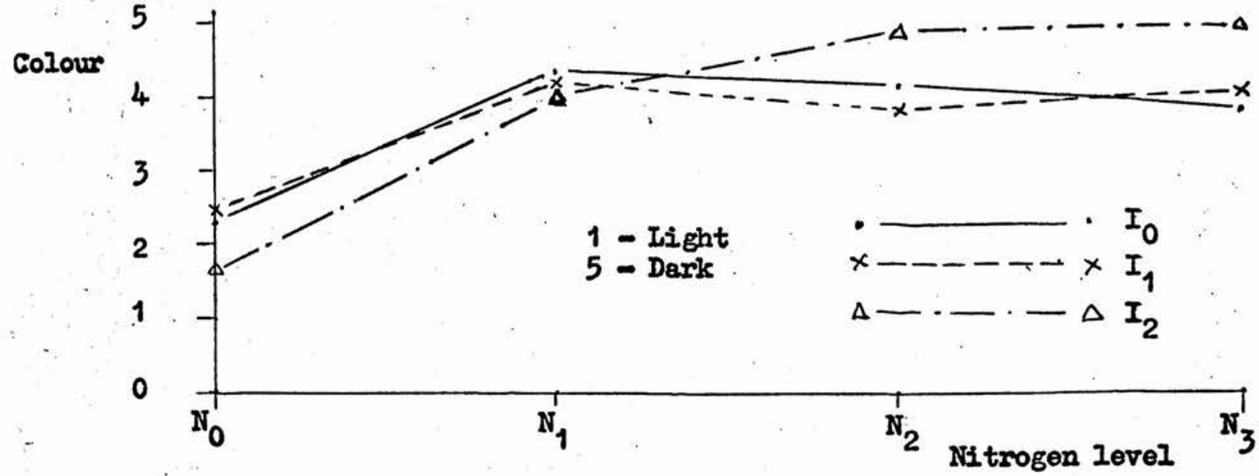


Figure 17. Experiment 1. Senescence estimate at 126 days.

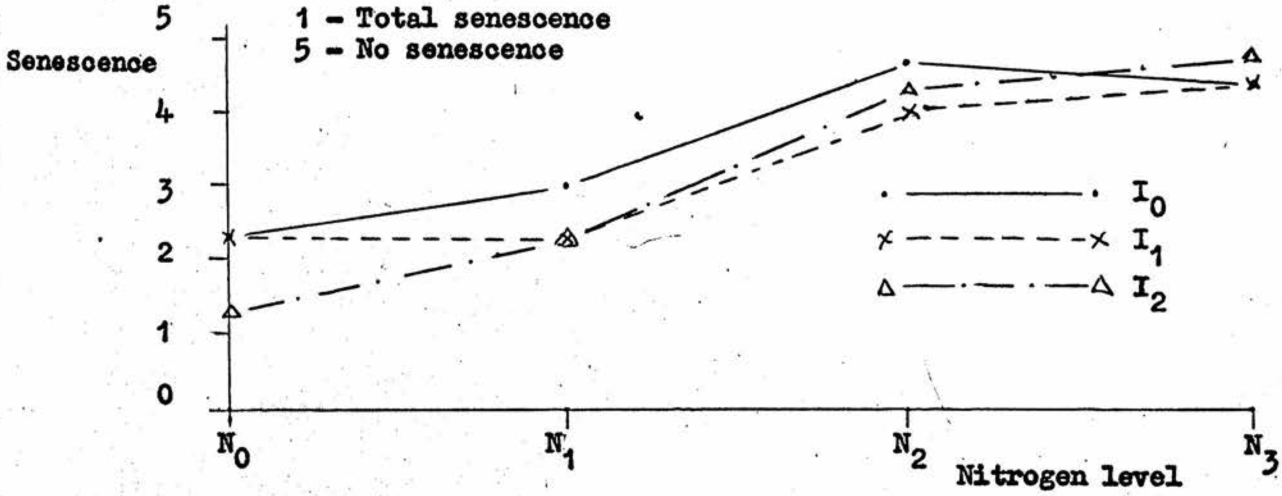


Figure 18. Experiment 1. Haulm height estimate at 66 days.

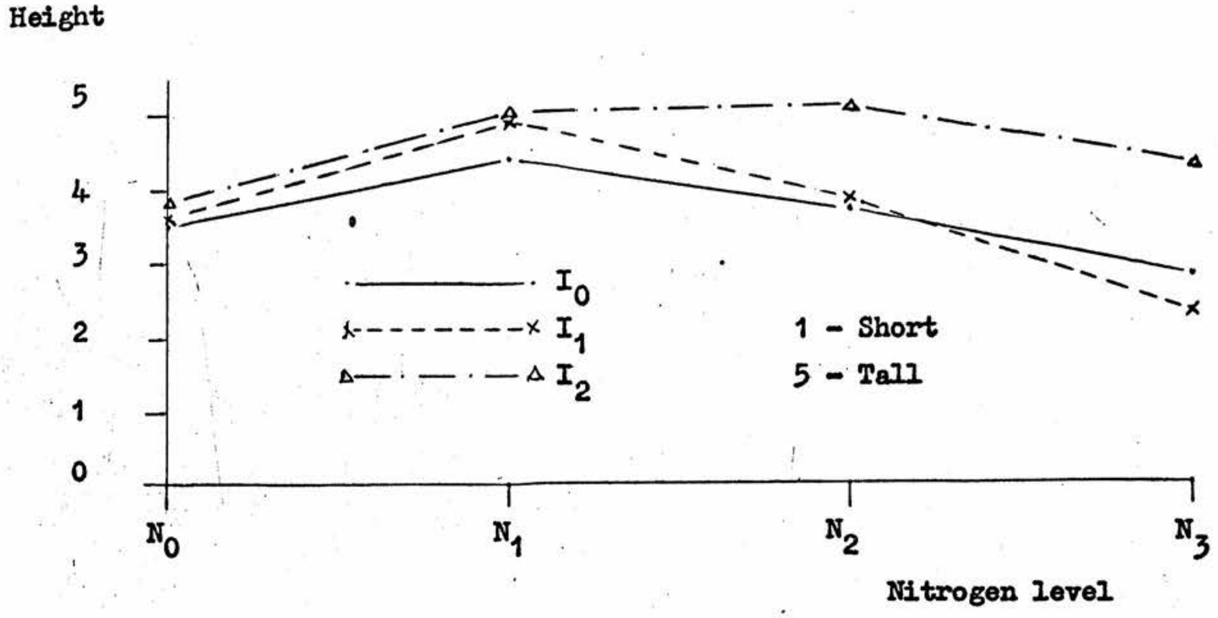


Figure 19. Experiment 1. Haulm height at 72 days, m.

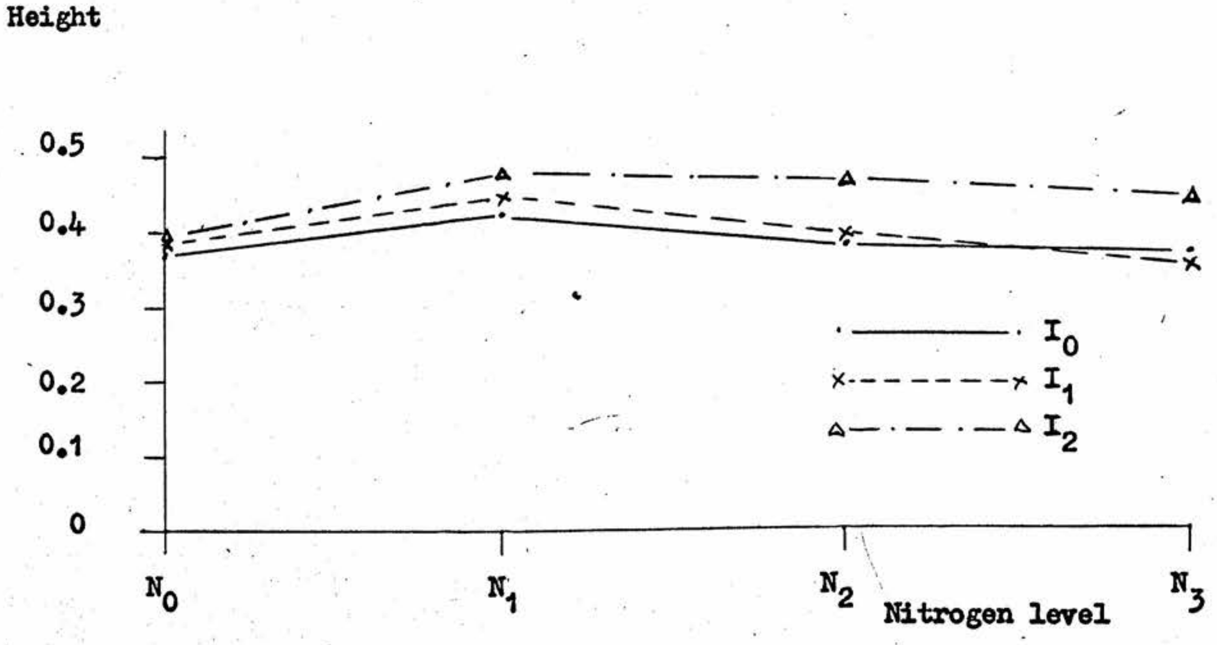


Figure 20. Experiment 1. Haulm height at 82 days, m.

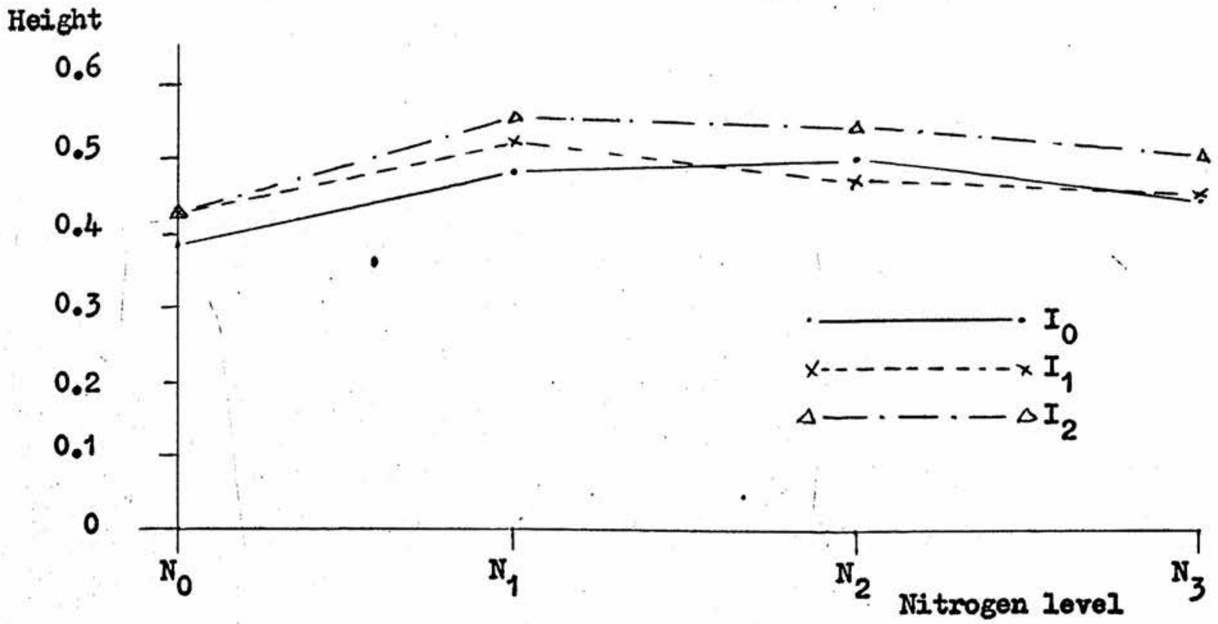
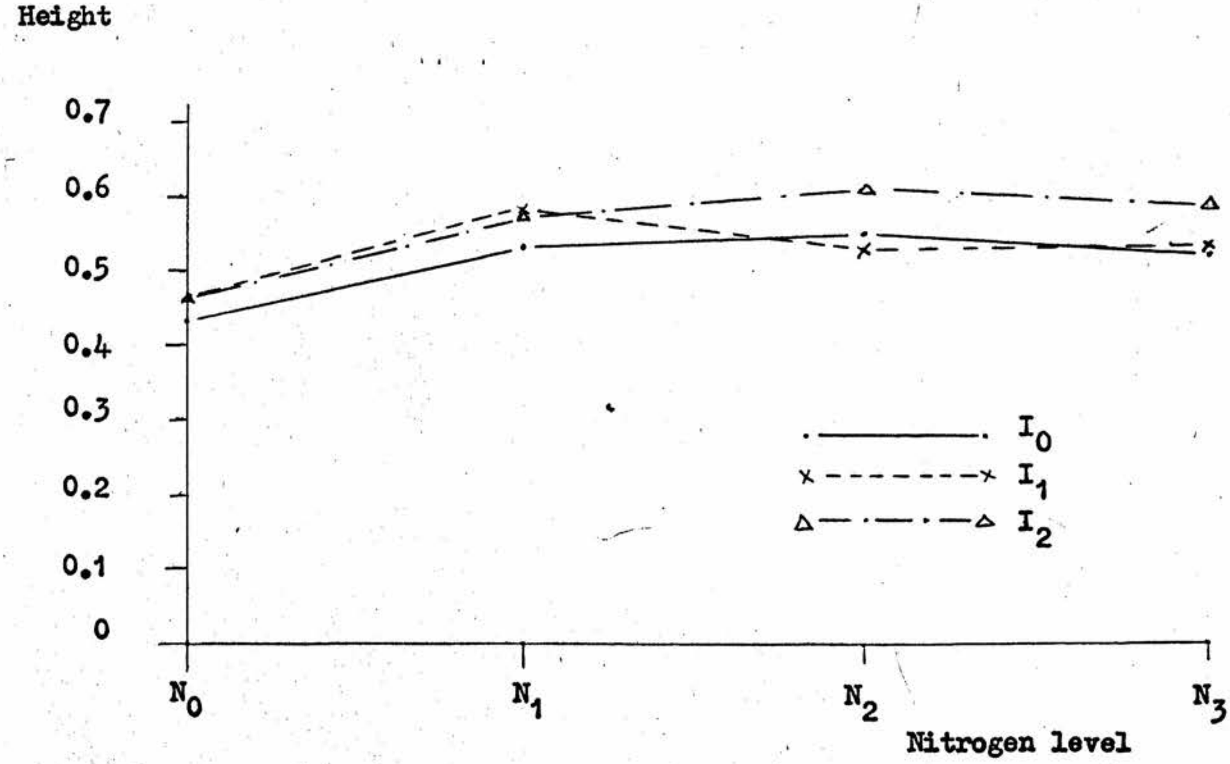


Figure 21. Experiment 1. Haulm height at 101 days, m.



Total yield. (Figure 22). The yield of fraction A tubers was very small and had very little effect on total yield. Thus total yield (fraction A+B+C+D+E) and saleable yield (fraction B+C+D+E) are not discussed separately.

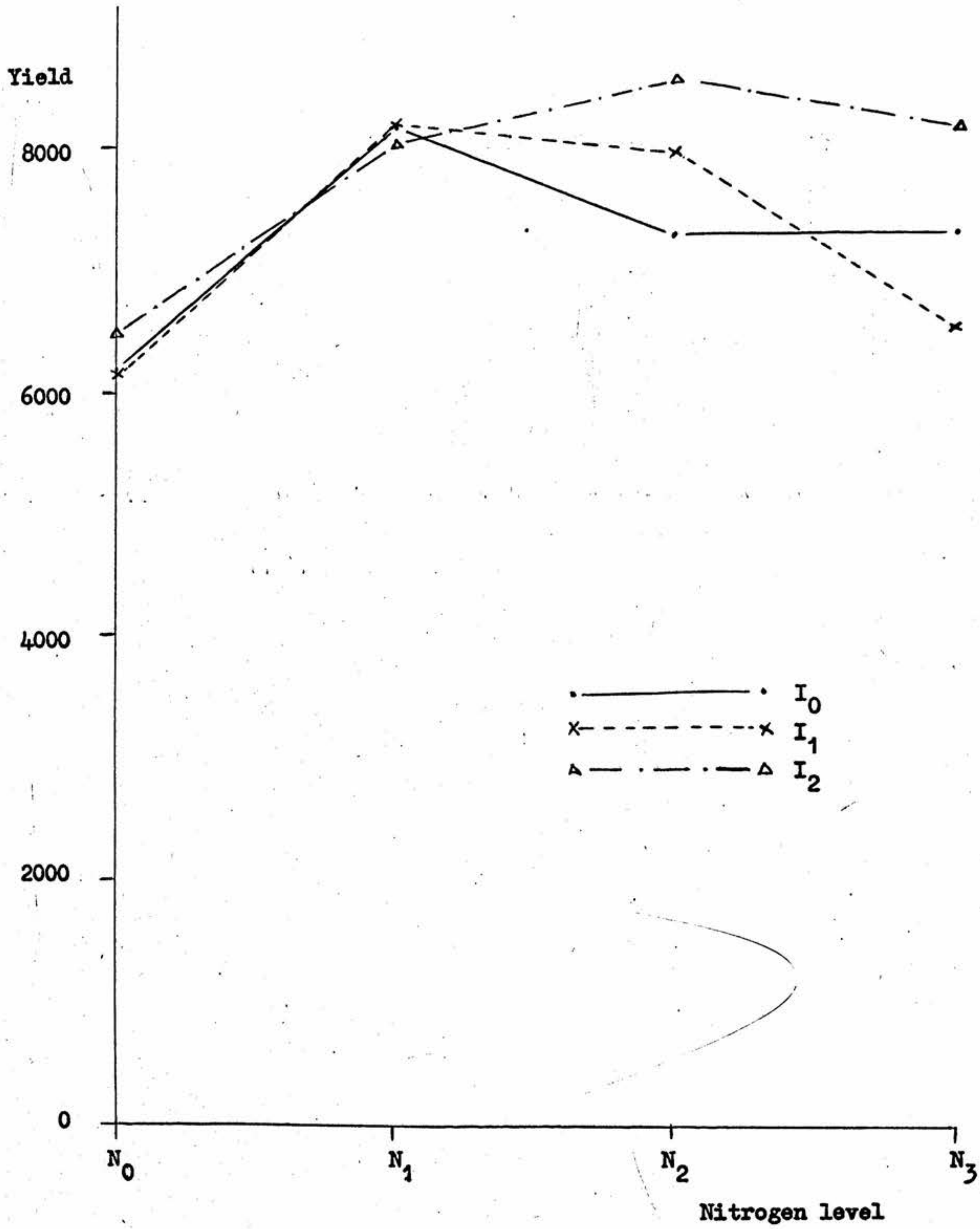
Regardless of soil moisture level the total yield of tubers was increased very significantly by application of nitrogen at the N_1 level. There were no significant differences between soil moisture levels at N_0 or N_1.

The interaction between nitrogen and soil moisture was apparent at higher levels of nitrogen. At the low moisture level (I_0) total yield of tubers was significantly less at N_2 and N_3 than at N_1, there being no significant difference between N_2 and N_3. At the high moisture level (I_2) yield of tubers increased with an increase in nitrogen to the N_2 level and was slightly lower than N_2 at N_3. There were however no significant differences between yields at N_1, N_2 and N_3 at the high moisture level (I_2). Yield was significantly greater with the high moisture level (I_2) than with the low moisture level (I_0) at N_2 and at N_3. The intermediate soil moisture level (I_1) showed a slightly, but not statistically, lower yield at N_2 than at N_1. At N_3 yield was significantly lower, even below the yield with no additional water (I_0).

The overall trend was that yield of tubers was increased by addition of small quantities of nitrogen but that in the absence of sufficient moisture yield was reduced by further additions of nitrogen.

Yield of different size fractions. Fractions B and C, separately and when combined, gave a higher yield with additional water than without it when no nitrogen (N_0) was applied. Addition of nitrogen decreased the yield of fractions C and B+C. However, at the highest nitrogen level yield of fractions C and B+C was increased by addition of water, giving larger yields than at N_1 and N_2. The high moisture level (I_2) gave a significantly higher yield at N_3 than did the low moisture level (I_0).

Figure 22. Experiment 1. Total tuber yield, g/8 plants.



Fraction D gave a larger yield with the high moisture level (I_2) than with the other moisture levels, there was no significant effect of nitrogen.

Fraction E showed a significant increase in yield with addition of nitrogen to the N_1 level but further additions of nitrogen had no significant effect. At low nitrogen levels (N_0 and N_1) the high soil moisture level (I_2) gave lower yields, the difference being significant at N_1.

When fractions D and E were combined the high yield of fraction D with thehigh moisture treatment (I_2) and the low yield of fraction E with the same treatment at N_0 and N_1 cancelled each other out and thus gave no difference between moisture levels at N_0 and N_1. N_1 was significantly greater than N_0. The high yield of fraction D at the high moisture level (I_2) was apparent in fraction D+E at N_2 and N_3, yield being greater than at lower moisture levels. The high moisture level (I_2) gave a significantly greater yield at N_2 than did the low moisture level (I_0) but the difference was not significant at N_3.

Summary. (Figures 23-26). Thus when size fractions were combined important interactions were masked. Although at N_0 the weight of individual fractions, except E, was increased at the high moisture level (I_2), the reduction in yield of fraction E resulted in only a small increase in total yield from the higher moisture level.

At N_1 the high moisture level (I_2) gave a significantly higher yield of fraction D than did the low moisture level (I_0). However, yield of fraction E was less at the high moisture level (I_2) and so moisture level had no effect on yield of fraction D+E. Thus, since there was also no effect of moisture treatment on yield of fraction B+C at N_1, there was no significantly effect on total yield. Yield at N_1 was significantly greater than yield at N_0.

Total yield at high nitrogen levels was dominated by the effects on fractions C and D. At N_2 the greater effect was on the D fraction, high

Figure 23. Experiment 1. Yield of tubers of different fractions. g/8 plants.

Low moisture level, I_0.

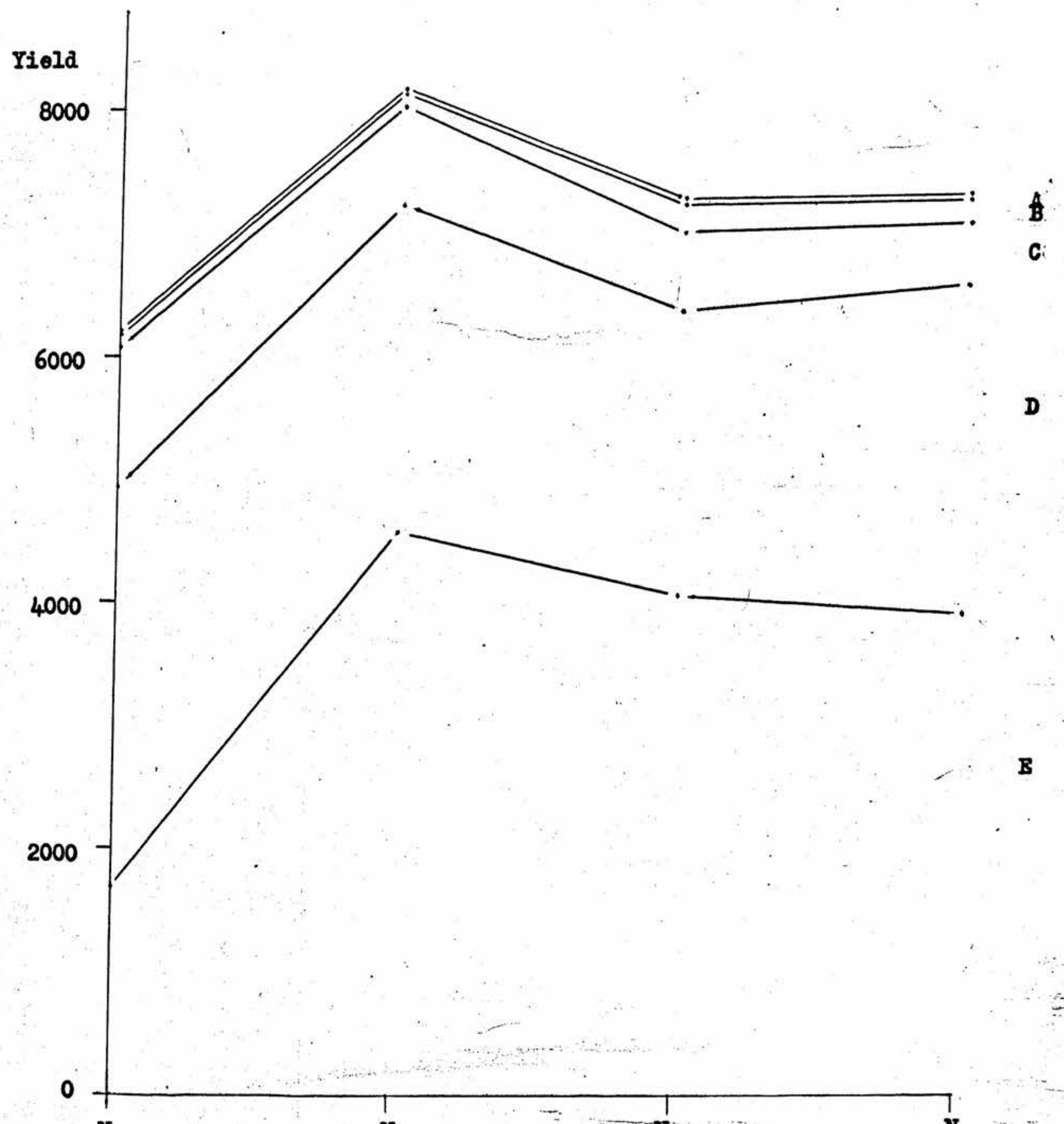


Figure 24. Experiment 1. Yield of tubers of different fractions, g/8 plants.

Intermediate moisture level, I_1.

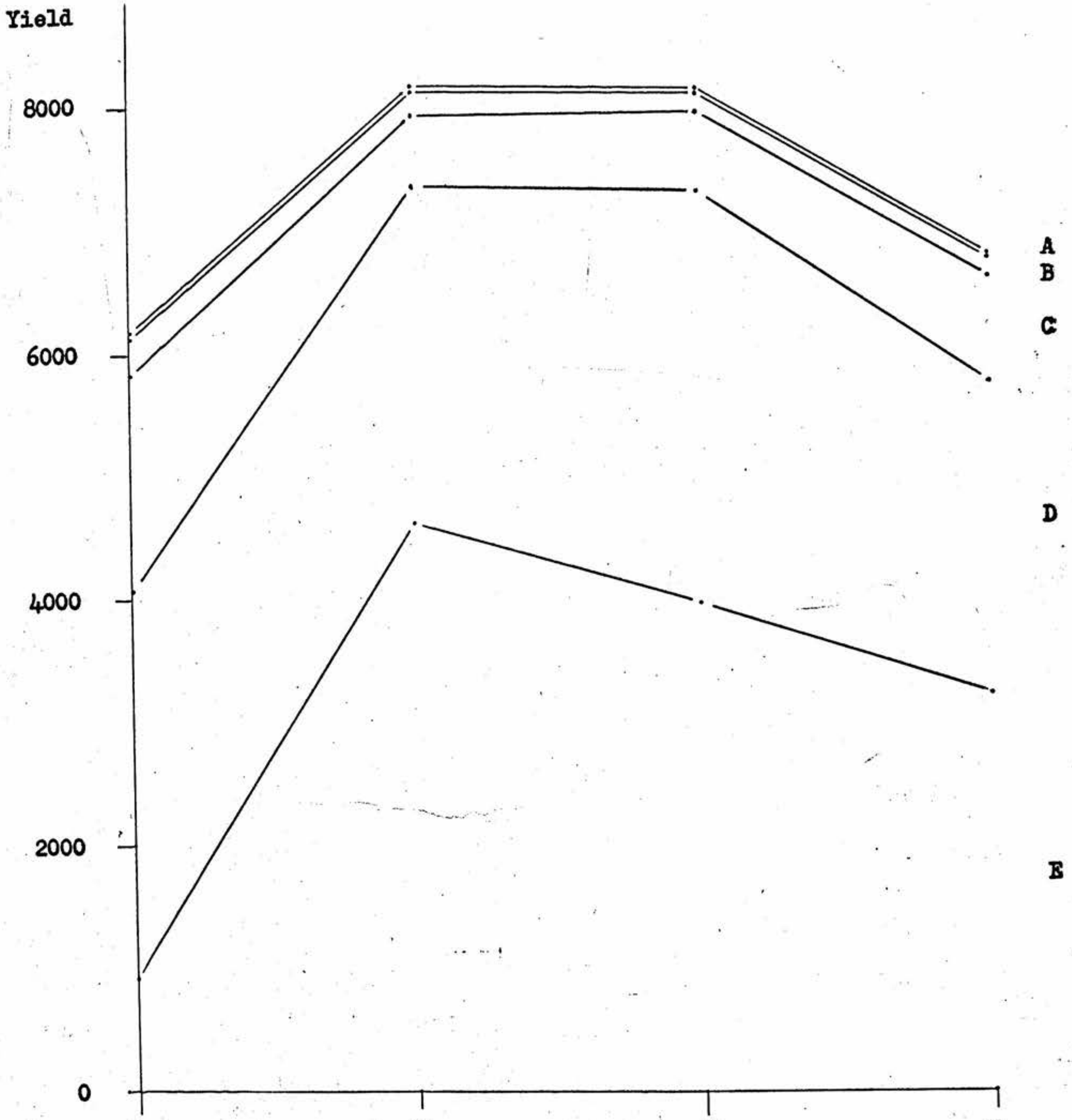


Figure 25. Experiment 1. Yield of tubers of different fractions, g/8 plants.

High moisture level, I_2.

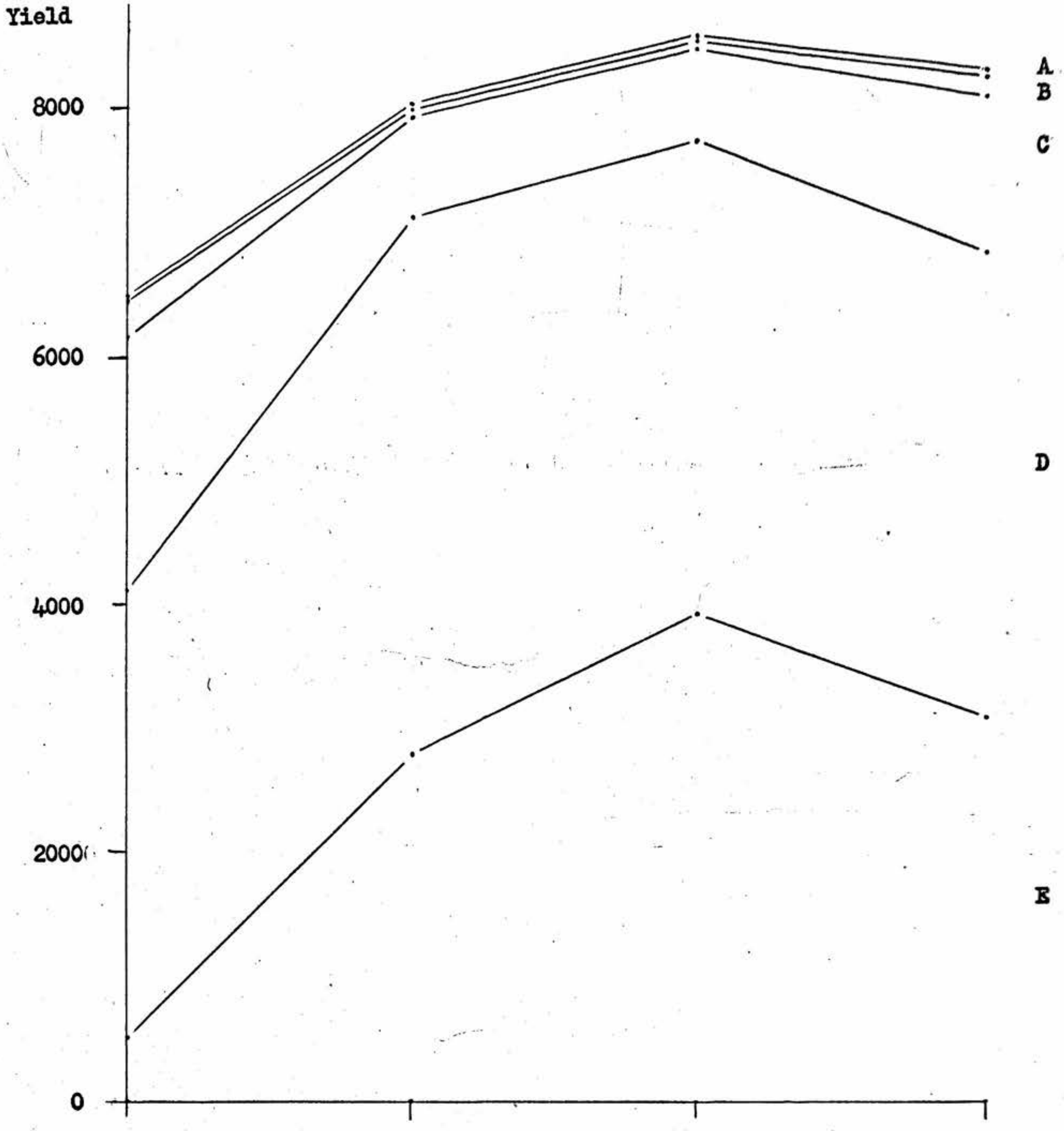
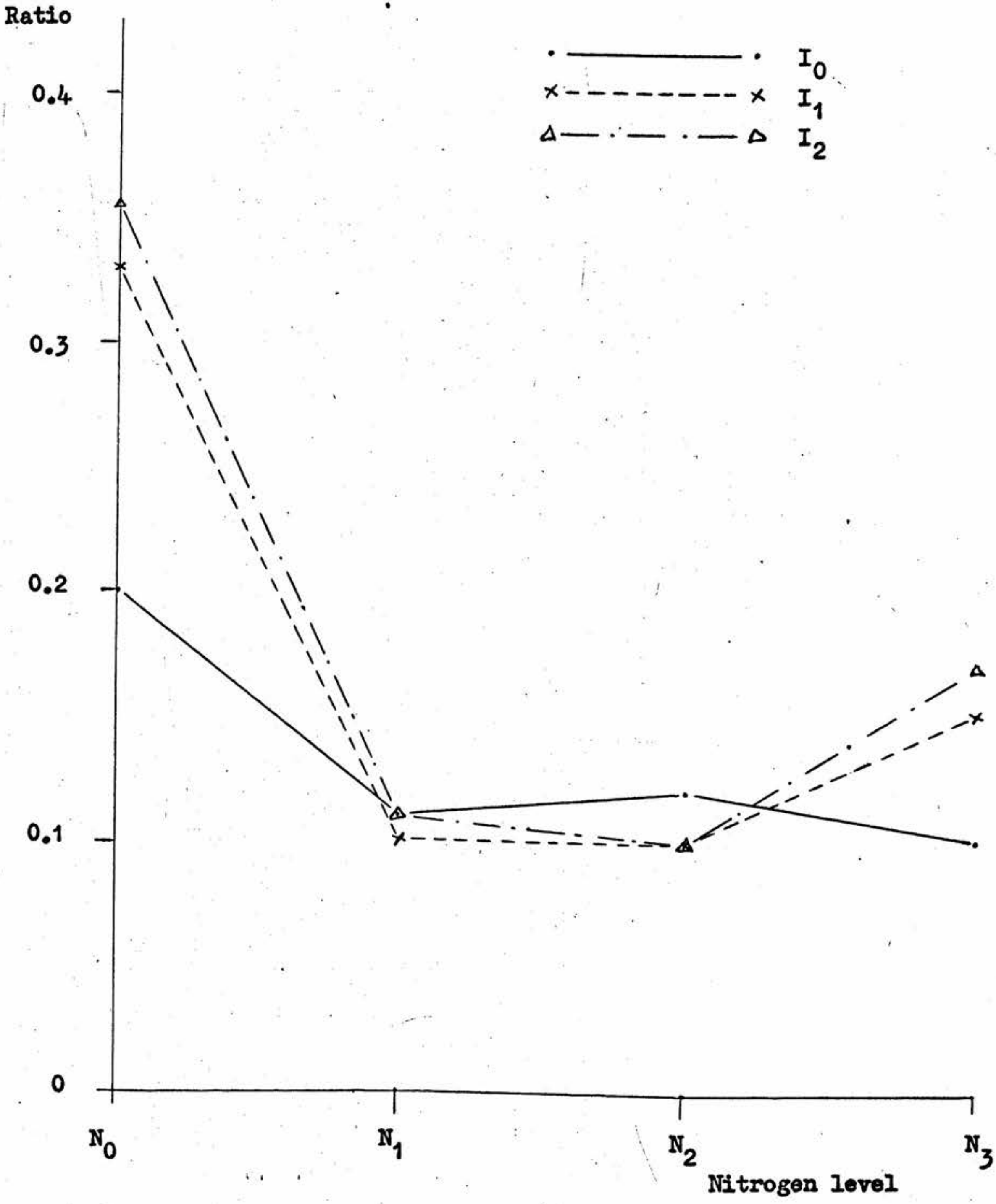


Figure 26. Experiment 1. Seed / Total ratio for weight of tubers.



moisture (I_2) giving a higher yield than low moisture (I_0) with the intermediate level (I_1) between the two. At N_3 the high yield of the D fraction at the high moisture level (I_2) was further enhanced by the high yield of the C fraction.

Addition of nitrogen reduced the seed/total ratio (B+C/A+B+C+D+E) because of the increase in large tubers. This reduction was more marked when additional water was applied as the ratio was greater with these treatments at N_0. There were no differences between N_1, N_2 and N_3 when no additional water was applied. At the higher moisture levels, although N_1 and N_2 were the same as the low moisture level (I_0), at N_3 addition of water increased the ratio because of the increase in fraction C tubers.

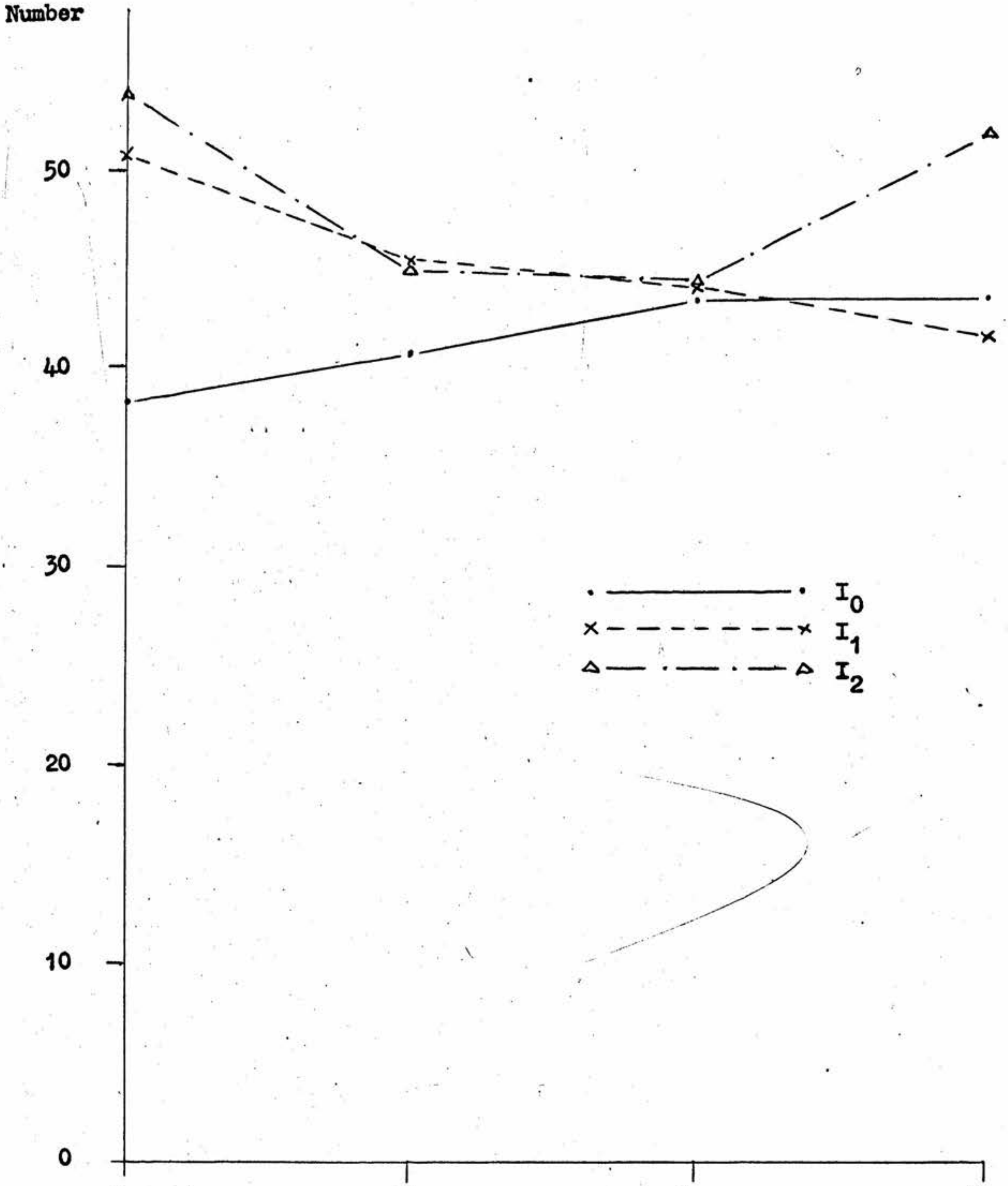
Tuber number. (Appendix, Tables 8 and 10)

Statistical analysis was carried out by logarithmic transformation using $\log_e$ (number tubers + 1). As with tuber weight there were significant interactions of soil moisture and nitrogen on tuber number for all except the D and E fractions. Fraction D gave a significant soil moisture effect and fraction E showed significant nitrogen and soil moisture effects.

Total number of tubers. (Figure 27). When no additional nitrogen was applied the total number of tubers present at harvest was significantly greater when the soil moisture had been supplemented. With addition of nitrogen at the N_1 and N_2 levels there was no effect of soil moisture, but at the highest nitrogen level (N_3) the number of tubers was much greater at the high moisture level (I_2).

Without additional water (I_0) the number of tubers increased with increase in nitrogen, but at the intermediate soil moisture level (I_1) the number of tubers decreased with increasing nitrogen level. The main difference was however, at N_0 where I_1 was significantly greater than I_0. The high soil moisture level

Figure 27. Experiment 1. Total tuber number / 8 plants.



(I_2) showed the same effect as I_1 at all except the highest nitrogen level (N_3), where a greater number of tubers remained at harvest.

Number of tubers in different fractions. The number of tubers of the A fraction showed little effect of nitrogen when additional water was added. With no extra water however, the number of tubers was lower at low nitrogen levels (N_0 and N_1) but at the highest nitrogen level (N_3) all moisture levels were the same.

There was an increase in the number of B fraction tubers at the low moisture level (I_0) with increase in nitrogen from (N_0, N_1) to (N_2, N_3). Additional water gave a greater number of tubers at N_0 but less at N_3.

Fraction C showed a slight decrease in number of tubers with increase in nitrogen at the low soil moisture level (I_0). Although the higher soil moisture levels showed little difference from the low moisture level (I_0) in number of tubers at N_1 and N_2, at N_0 and N_3 additional water increased the number of tubers.

When combined fractions B and C showed little effect of nitrogen on the number of tubers at the low soil moisture level (I_0). Addition of water however, increased the number of tubers at N_0, as did the high moisture level (I_2) at N_3.

Fraction D showed an increase in the number of tubers at the high soil moisture level (I_2) over the other moisture levels (I_0, I_1) at all nitrogen levels, but showed no significant effect of nitrogen.

The number of tubers of fraction E was significantly increased by addition of nitrogen at the N_1 level but further additions had no significant effect. The number of tubers at low nitrogen levels (N_0 and N_1) was smaller with the high moisture level (I_2).

When combined fractions D and E showed no effect of soil moisture on tuber number at N_0 and N_1, although the latter gave a higher number of tubers than the former. At higher nitrogen levels (N_2 and N_3) the largest number of tubers was at the high moisture level (I_2), as was evident in fraction D.

Summary. (Figures 28-31). Considering saleable tubers (B+C+D+E) nitrogen had no significant effect on tuber number when no additional water (I_0) was added. At higher soil moisture levels the number of tubers was much higher when no nitrogen (N_0) was applied. This was because of the larger number of small tubers, particularly fraction C, since fraction E showed a smaller number of tubers with I_2 at N_0, than with I_0 at N_0. At N_1 and N_2 there were no marked effects of soil moisture on tuber number, except for a slight difference in ratio between fractions D and E at N_1 with high soil moisture and a greater number of fractions A and B at N_2 with I_0 than I_2, but compensated by a smaller number of fraction D.

At the highest nitrogen level (N_3) the number of tubers was greatest at the high moisture level (I_2) because of a greater number of tubers of fractions C and D.

The effect of the addition of fraction A, i.e. giving total yield, was mainly to increase the number of tubers, except at low nitrogen levels with no additional water (I_0), where a lower number of tubers were present compared with the higher nitrogen levels. It also accentuated the rise in tuber number at N_3 with high soil moisture.

The addition of nitrogen decreased the seed/total (B+C/A+B+C+D+E) ratio for tuber number because of the increase in number of large tubers. Without the addition of nitrogen the ratio was higher with additional water. At N_3 the addition of water increased the ratio above that without water by increasing the C fraction.

Figure 28. Experiment 1. Number of tubers of different size fractions / 8 plants.

Low moisture level, I_0.

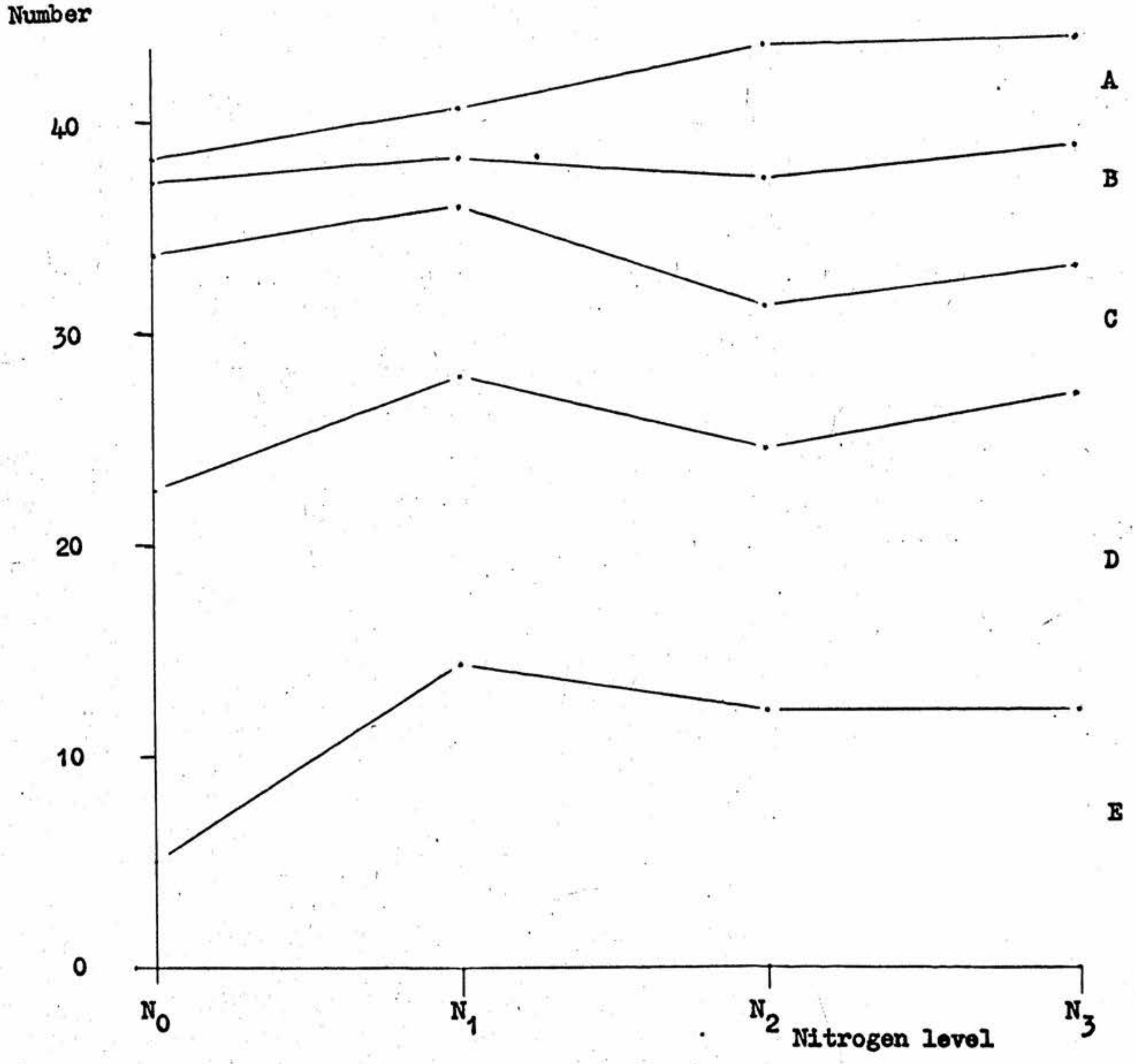


Figure 29. Experiment 1. Number of tubers of different size fractions / 8 plants.

Intermediate moisture level, I_1.

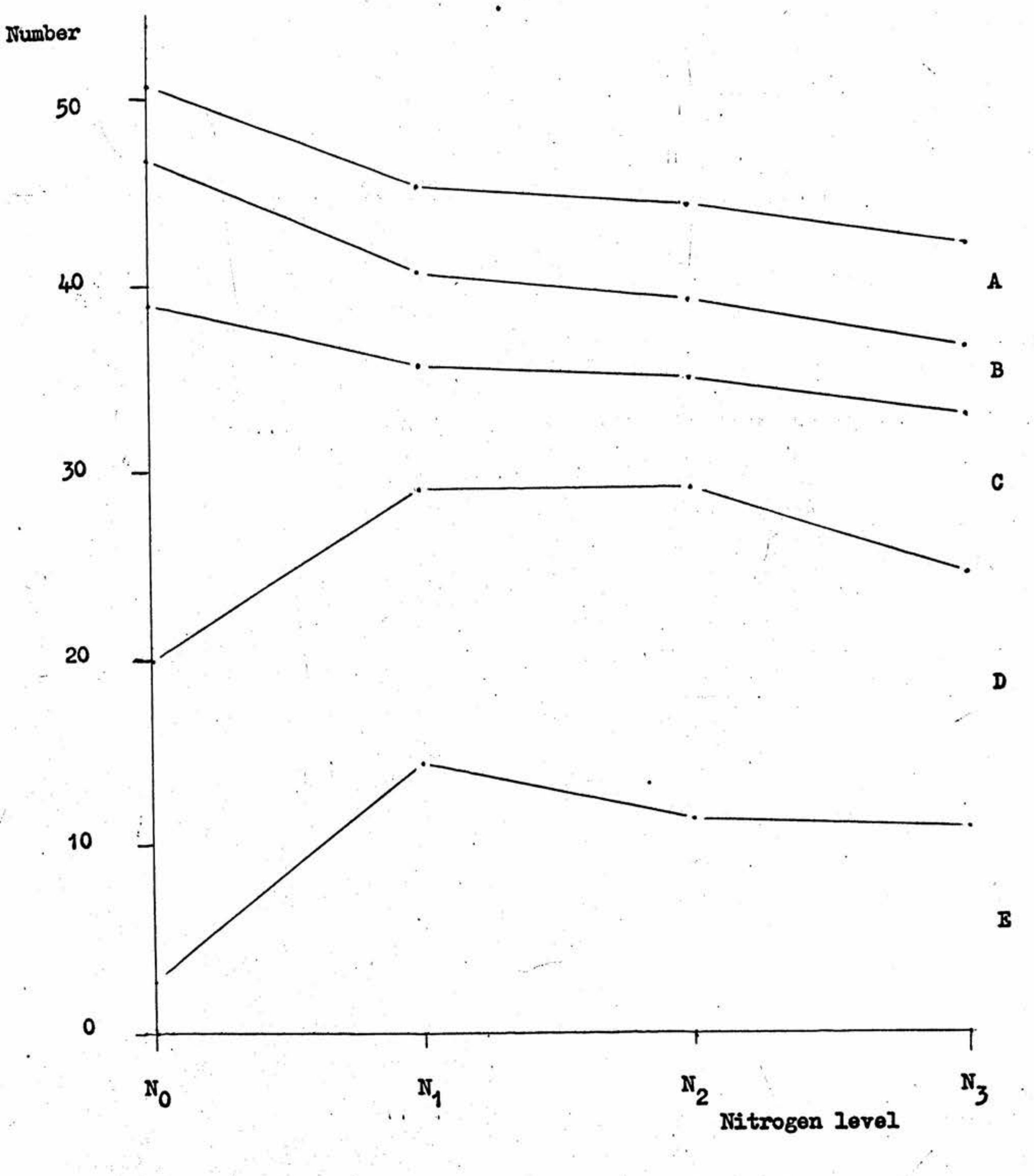


Figure 30. Experiment 1 Number of tubers of different size fractions / 8 plants.

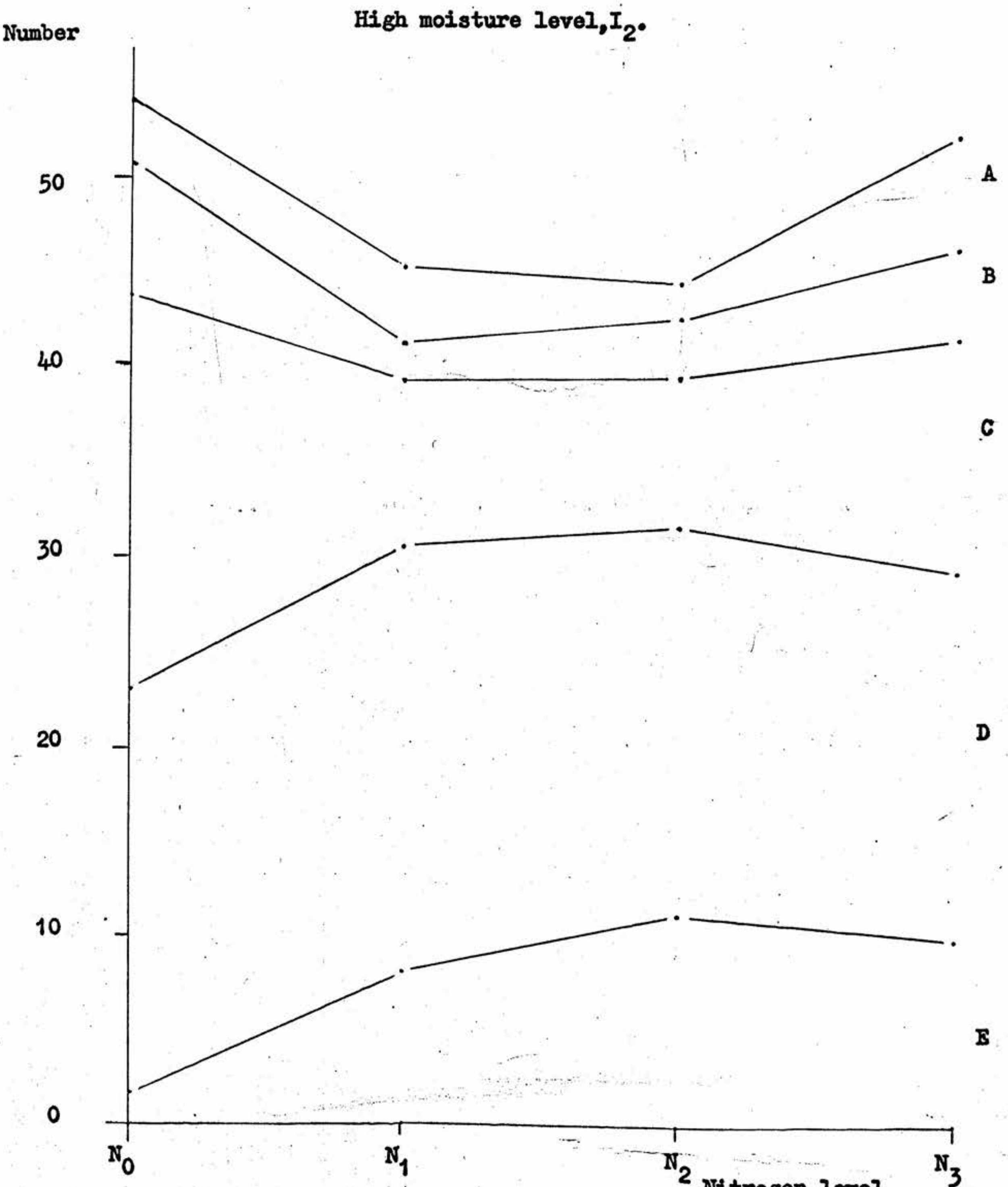
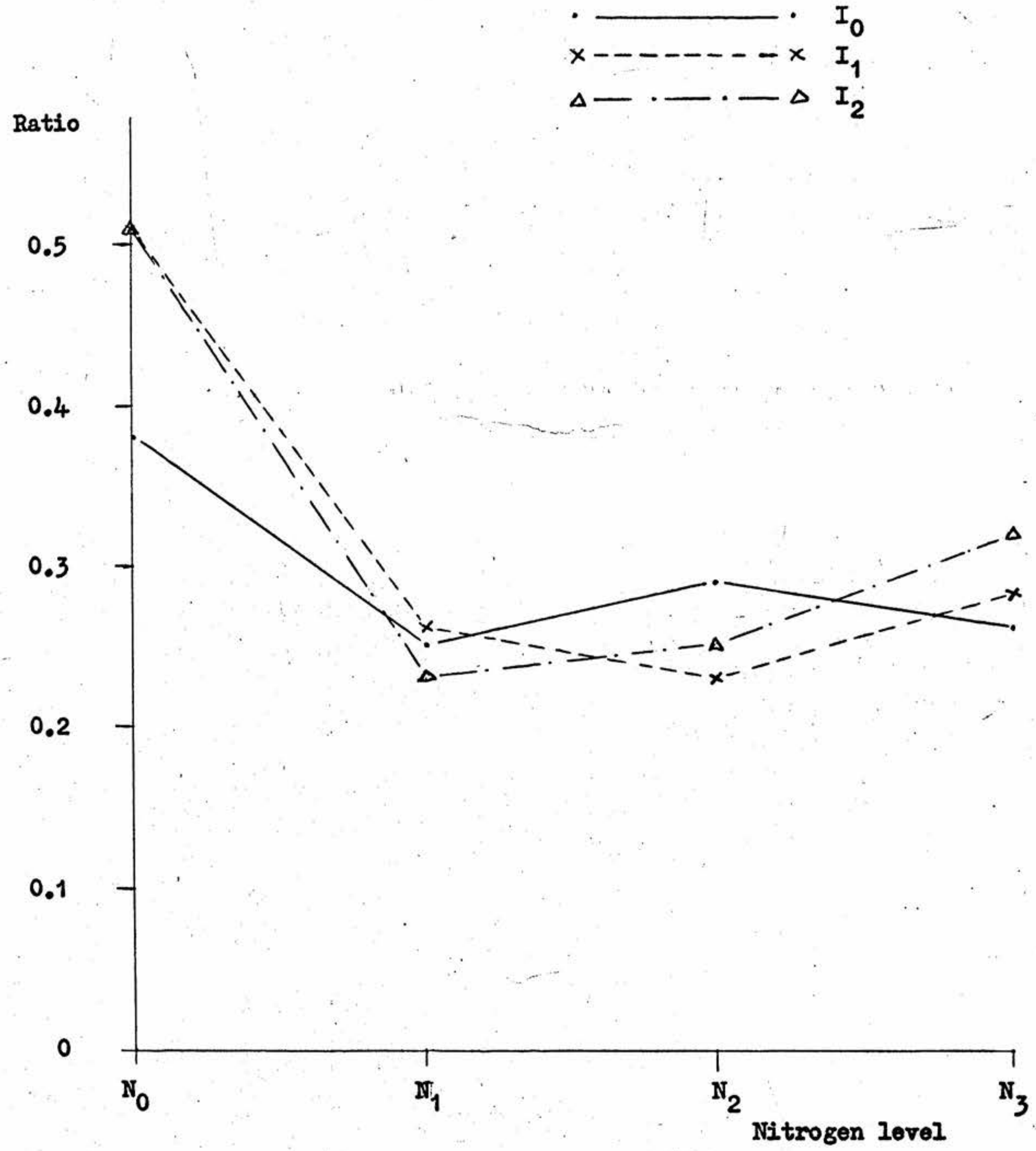


Figure 31. Experiment 1. Seed / Total ratio for tuber number.



Average tuber fresh weight. (Appendix, Table 11)

The addition of nitrogen at the N_1 level increased the average tuber weight but there was little extra effect with higher levels of nitrogen (Figure 32). At low nitrogen levels (N_0 and N_1) average tuber weight was greater where no additional water was applied.

Average weight of tubers of different fractions. As was expected the average weight of an individual fraction did not vary greatly, but when fractions were combined the effect of treatment on size distribution was evident. Fractions A and E were expected to show most effect as they had a larger size range.

The average tuber weight of fraction A decreased with addition of nitrogen except at the high nitrogen level (N_3) with high soil moisture (I_2), when average tuber weight was greater than at lower soil moisture levels.

There were no significant effects on fraction E.

The average tuber weight of fraction B+C showed no significant effect of nitrogen when additional water was added, but at the low moisture level (I_0) average tuber weight decreased at high nitrogen levels.

Fraction D+E showed no effect of moisture. Average tuber weight was increased by addition of nitrogen to the N_1 level, but not by further additions. This effect was also apparent in the B+C+D+E fraction with a slight decrease in average tuber weight at N_3. At low nitrogen levels, the low soil moisture level (I_0) gave slightly heavier tubers. The overall effect was dominated by the large tubers.

Dry matter content of tubers. (Appendix, Table 12).

The only major significant effect on the dry matter content of the tubers was that of the nitrogen treatment. The overall effect was a decrease in dry matter content with increase in nitrogen to the N_2 level (Figure 33).

Figure 32. Experiment 1. Average tuber fresh weight, g / tuber. Fraction B+C+D+E.

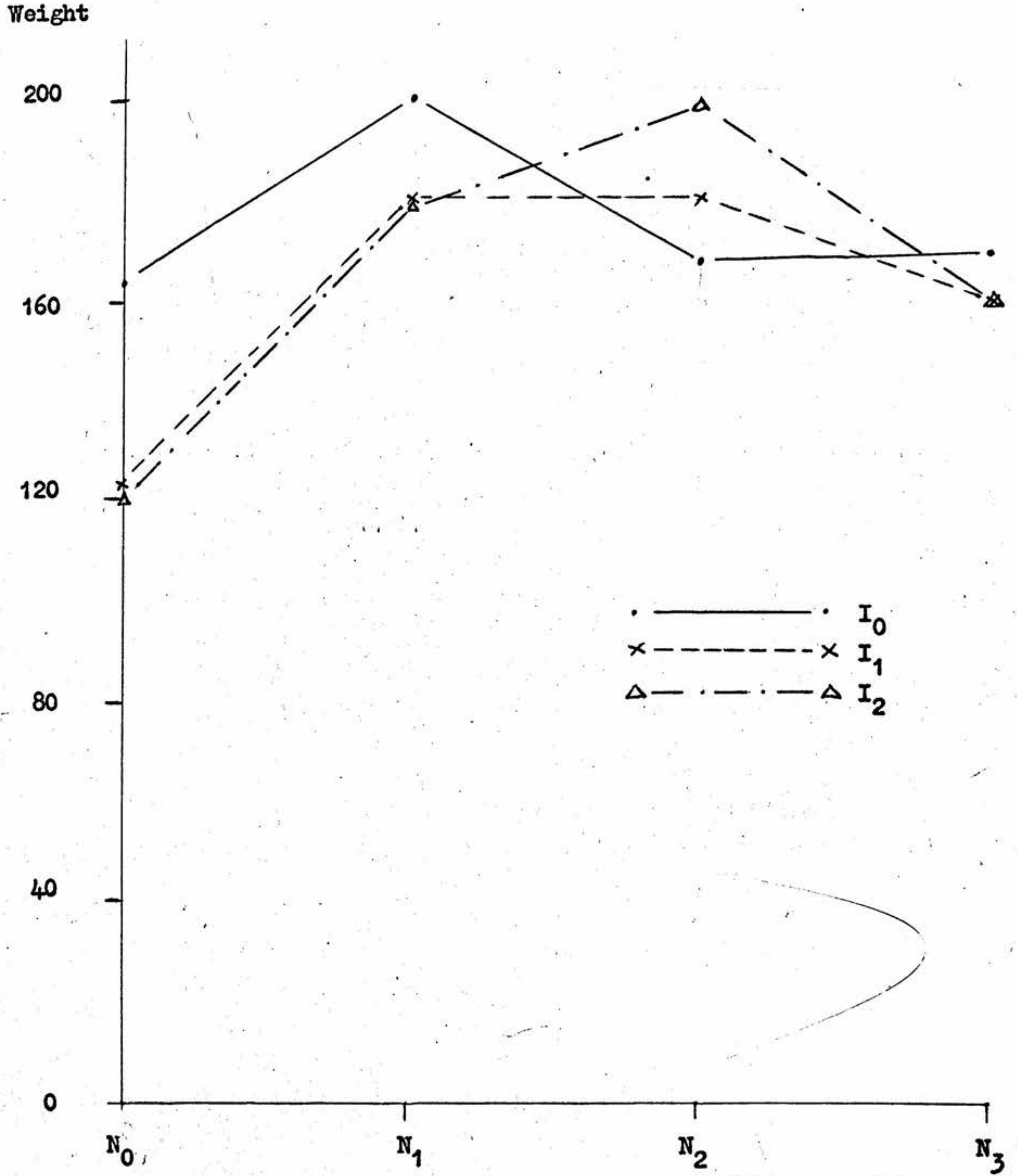
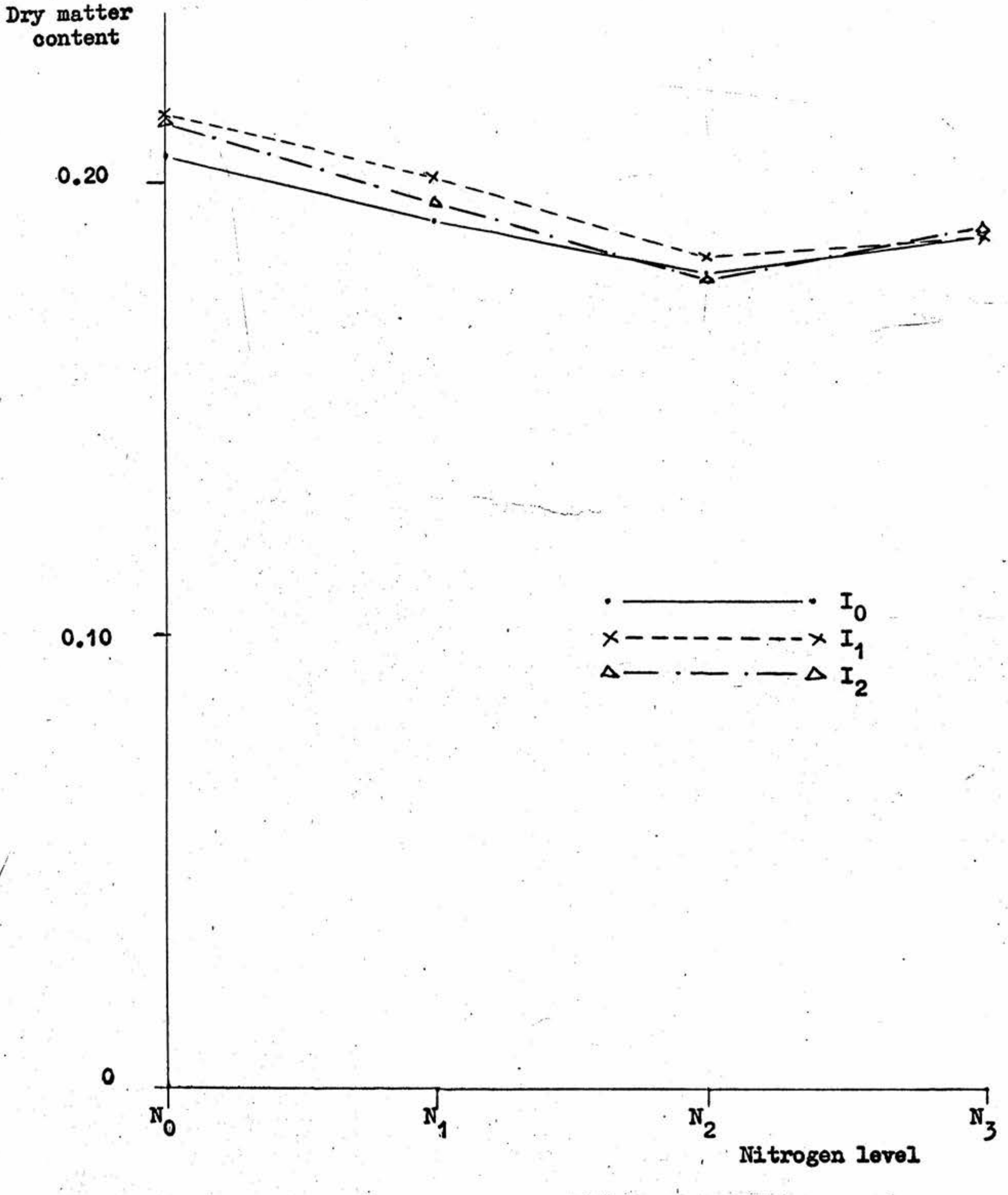


Figure 33. Experiment 1. Dry matter content fraction B+C+D+E, kg dry matter /kg fresh material.



The smaller tubers (fractions B and C) showed little effect of additional nitrogen above this level, but the larger tubers (fractions D and E) showed a slight, but not significant, increase in dry matter content at the highest nitrogen level.

There was little effect of soil moisture on dry matter content of the tubers.

Degree of cracking of tubers. (Appendix, Table 13).

For statistical analysis the number of tubers in each category of cracking was expressed as a ratio of the total number of tubers present.

At the high moisture level (I_2) nitrogen had little effect upon the very badly cracked tubers, but at lower moisture levels the proportion of very badly cracked tubers was increased at high nitrogen levels. This was also the case for badly cracked tubers and for the two categories combined.

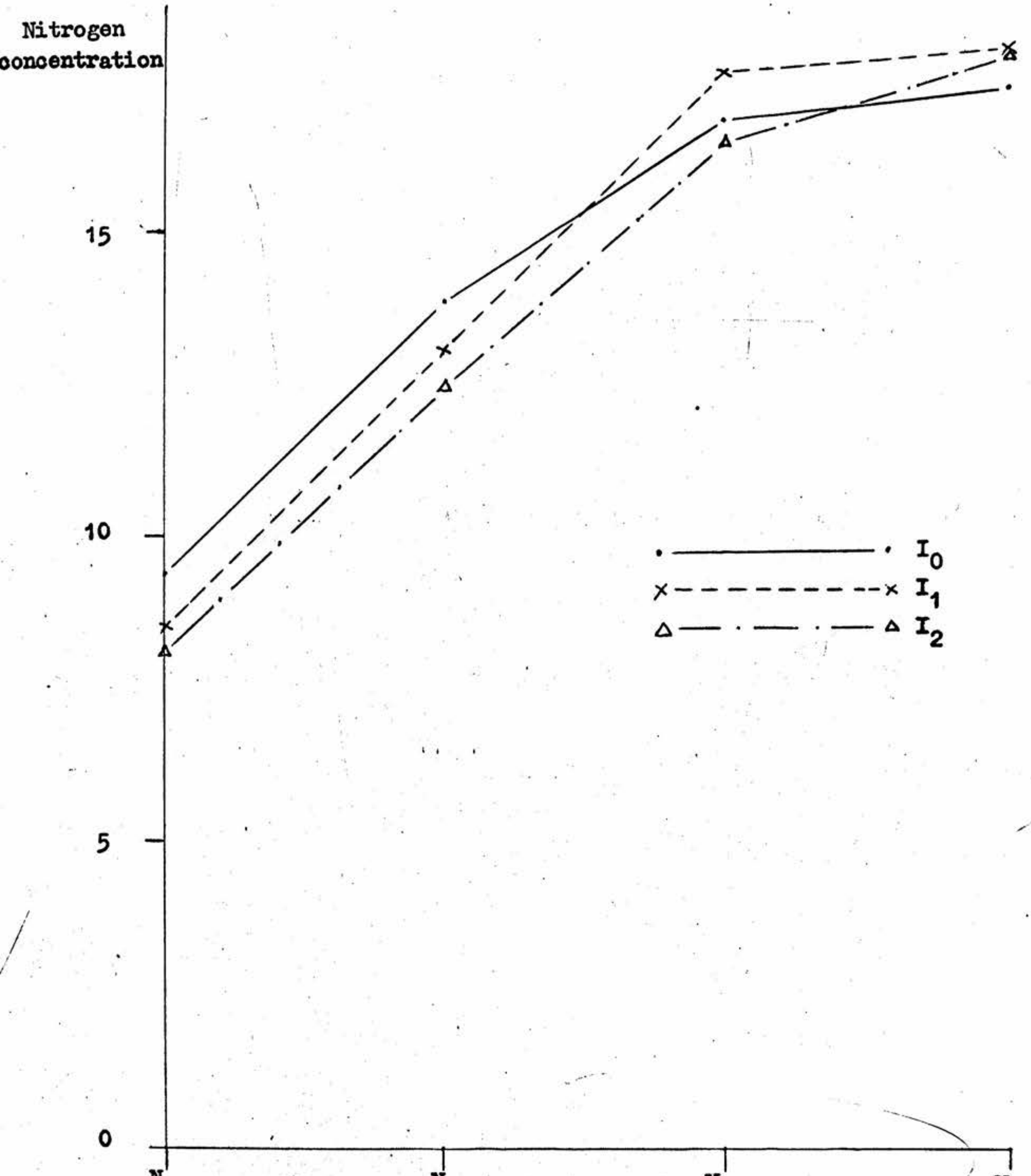
The proportion of tubers in the moderate category with no additional nitrogen (N_0) was greater when no additional water (I_0) was added than at higher soil moisture levels. With the high soil moisture level (I_2), addition of nitrogen increased the proportion of moderately cracked tubers.

With no additional nitrogen (N_0) the proportion of tubers in the slightly cracked category was higher when water was added. The addition of water reduced the number of tubers which cracked to a moderate extent at low nitrogen levels.

N, P and K concentration in tuber dry matter.

Nitrogen (Figure 34; Appendix, Table 14). The nitrogen concentration of the tubers was influenced mainly by the amount of nitrogen applied. With all fractions and groups of fractions the application of nitrogen significantly

Figure 34. Experiment 1. Tuber nitrogen concentration, fraction B+C+D+E, mg nitrogen / g dry material.



increased the nitrogen concentration up to the N_2 level. Above this level, except for the B fraction, the increase in nitrogen concentration was not so marked.

At low nitrogen levels the addition of water appeared to lower the nitrogen concentration of the tubers. At high nitrogen levels however, the effect of soil moisture was more variable. At N_3 addition of water increased the nitrogen concentration of all except the B fraction.

Phosphorus. (Figure 35; Appendix, Table 15). All fractions showed a significant linear nitrogen effect. Application of nitrogen increased phosphorus concentration up to the N_2 level, but in most cases there was little difference between phosphorus concentration at N_2 and N_3.

The E fraction had a significant soil moisture-nitrogen interaction which was apparent in all groupings of fractions where E was present. The phosphorus concentration was lowest where no additional water was added at all nitrogen levels except N_0.

Potassium. (Figure 36; Appendix, Table 16). The application of nitrogen at the N_1 level increased the potassium concentration above that at N_0, except for fraction C at the high moisture level (I_2). There was little difference in potassium concentration with further additions of nitrogen, except at the N_3 level where potassium concentration tended to decrease below that at the N_2 level, especially when soil moisture level was increased.

Sugar concentration in tubers.

Reducing sugar. (Appendix, Table 17). Nitrogen had little effect on the reducing sugar concentration of the C fraction at the low soil moisture level (I_0), but the concentration at the high moisture level (I_2) decreased with added nitrogen. Fractions D and E also showed a decrease in reducing sugar concentration

Figure 35. Experiment 1. Tuber phosphorus concentration, fraction B+C+D+E, mg phosphorus / g dry material.

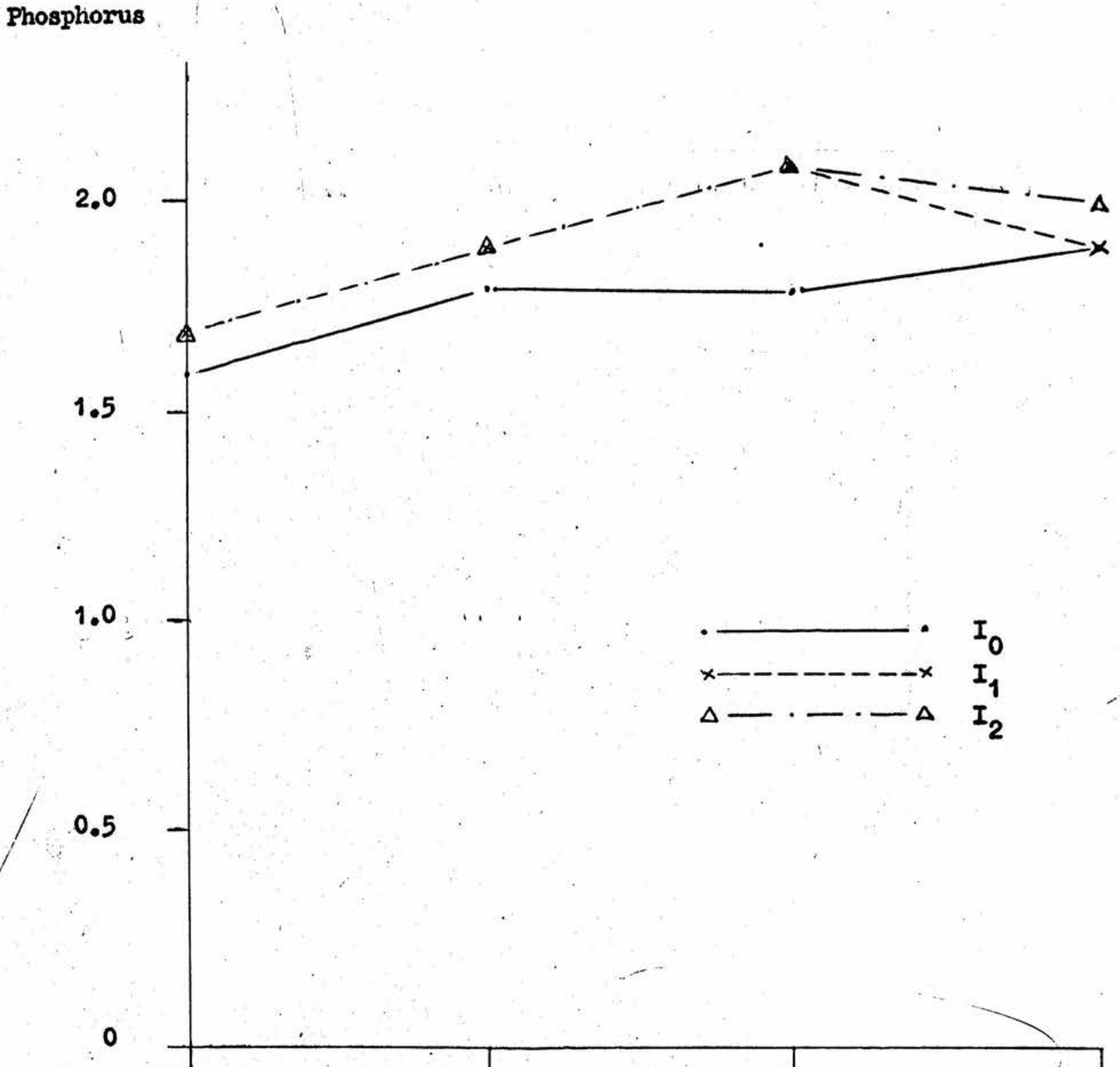
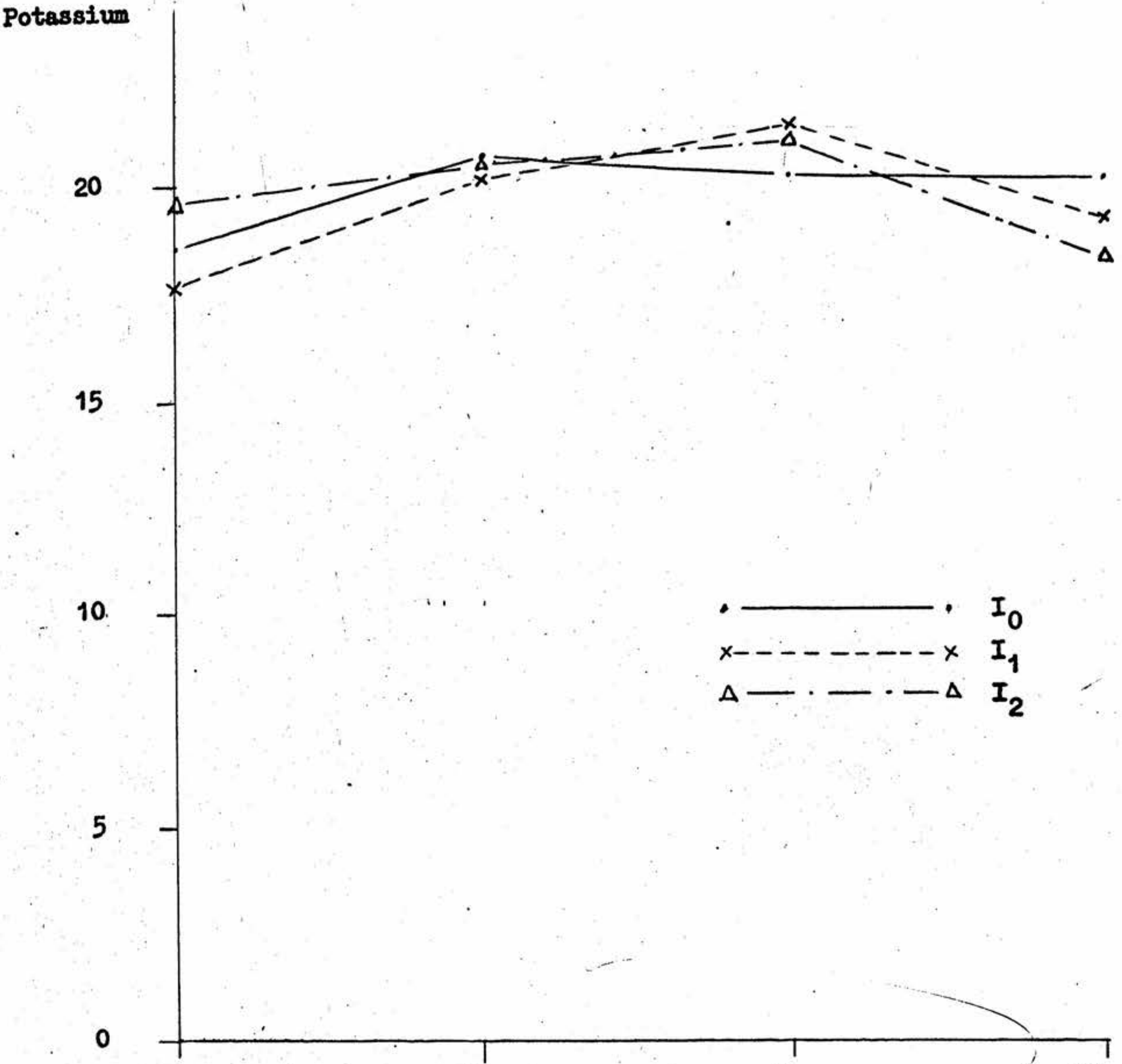


Figure 36. Experiment 1. Tuber potassium concentration,
fraction B+C+D+E,
mg potassium / g dry material.



with increase in nitrogen applied, irrespective of moisture level. The decrease was not as great at higher nitrogen application rates as it was with the increase from N_0 to N_1. Fractions D and E tended to give higher reducing sugar concentrations at N_0 and N_1 when additional water was added.

Sucrose. (Appendix, Table 18). There was little effect of treatment upon sucrose concentration. There was a tendency for the highest moisture level to give lower sucrose concentrations at each nitrogen level except N_1.

Total sugar. (Appendix, Table 19). Total sugar concentration followed the same trends as reducing sugar concentration.

EXPERIMENT 2.

Growth record. (Figures 37-41)

An estimation of vigour of growth, 47 days after planting, showed no effect of moisture level, but a decrease in vigour with increase in nitrogen level.

Haulm height at 76 and 83 days after planting showed little effect of nitrogen at the high moisture level (I_2), where haulm height was generally greater than at lower moisture levels. At low moisture levels haulm height increased with addition of nitrogen and then decreased at higher nitrogen levels. The latter was also shown at 104 days, but then height of the high moisture level (I_2) was rather erratic.

Senescence at 137 days was more advanced at the low nitrogen levels.

Yield of tubers. (Appendix, Tables 24 and 26)

The effect of nitrogen was significant on all except the A fraction, which showed no statistically significant effect of treatment. Fractions C and B+C

Figure 37. Experiment 2. Vigour estimation at 47 days.

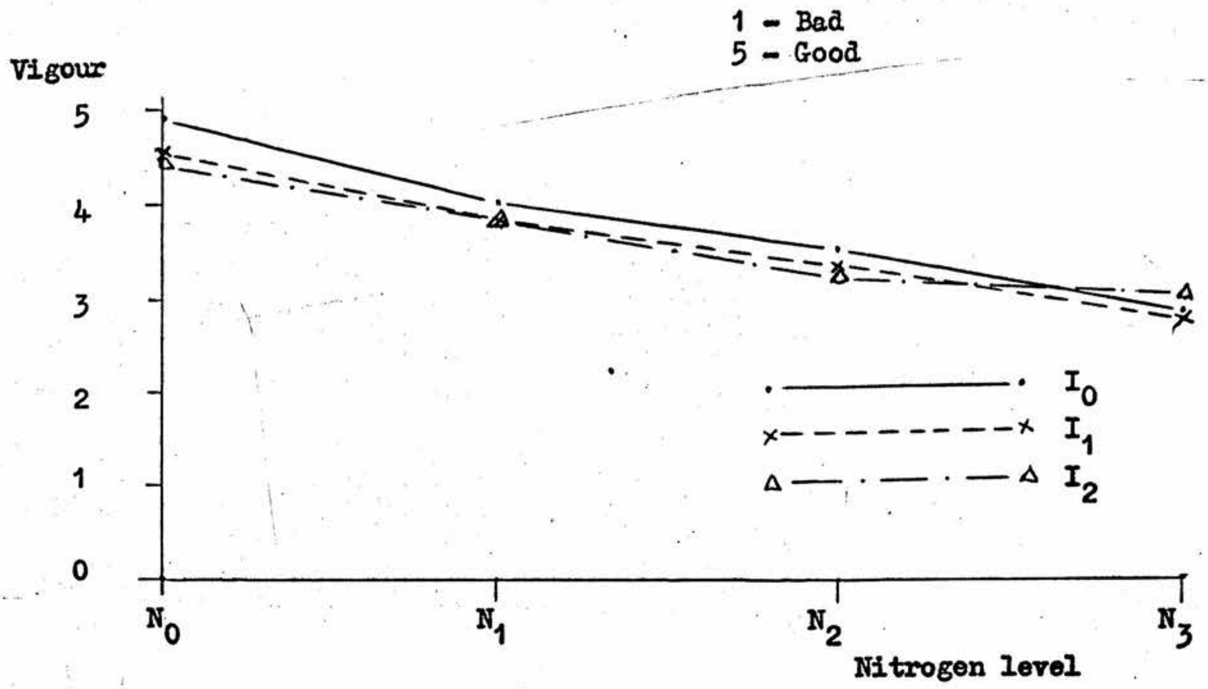


Figure 38. Experiment 2. Senescence estimate at 137 days.

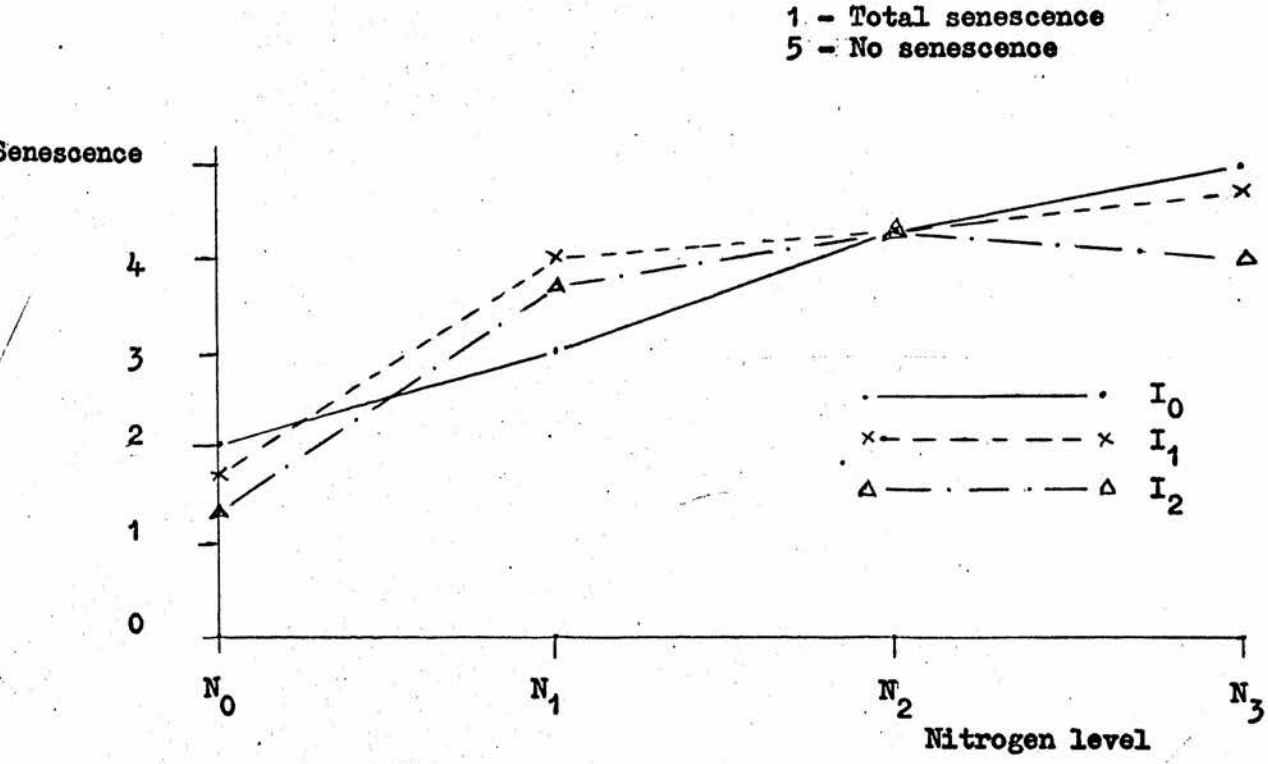


Figure 39. Experiment 2. Haulm height at 76 days, m.

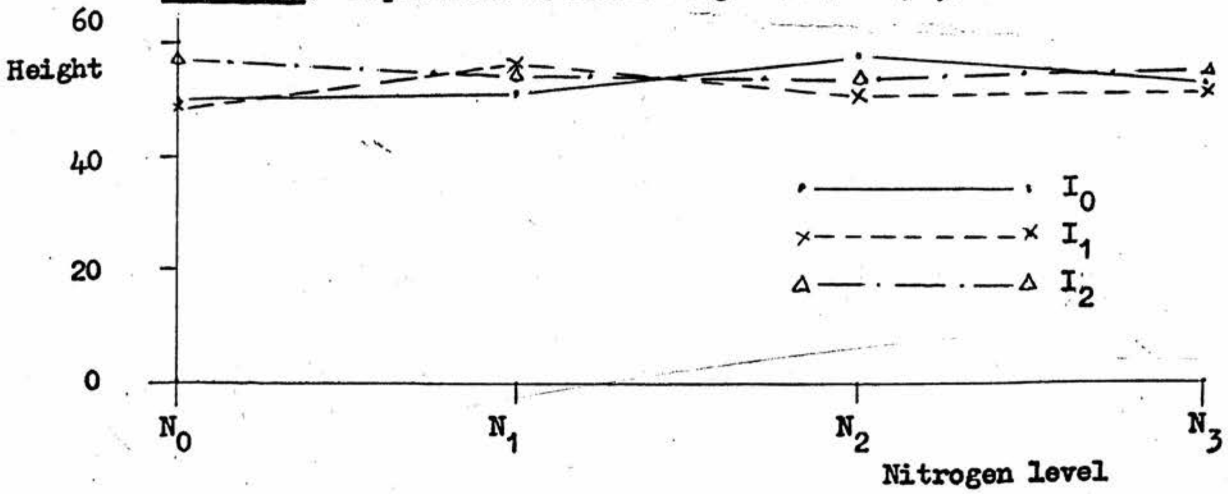


Figure 40. Experiment 2. Haulm height at 83 days, m.

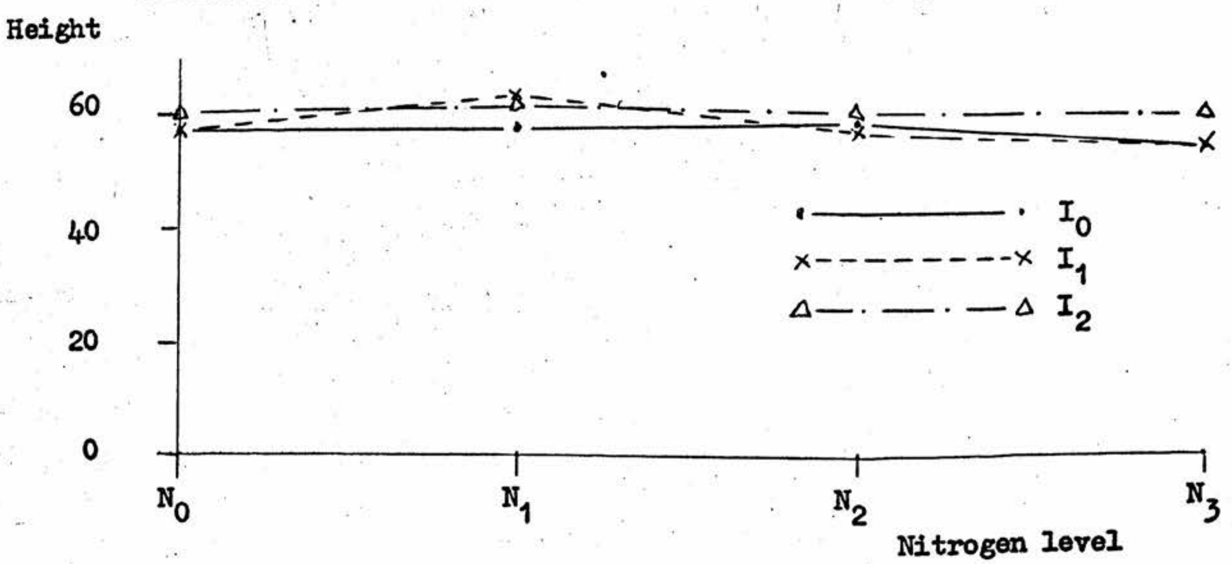
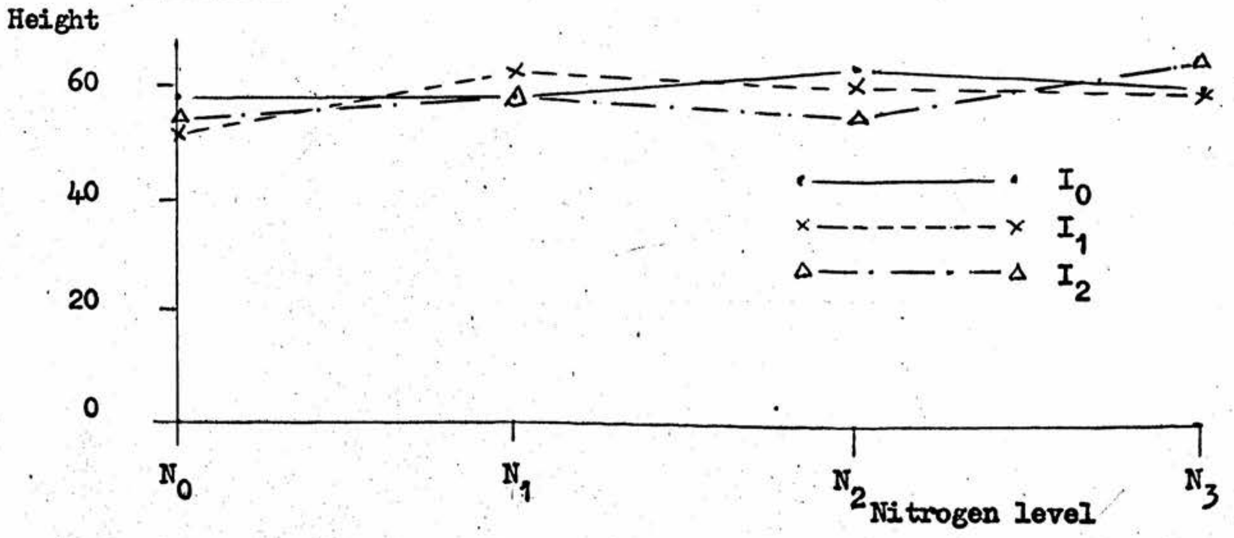


Figure 41. Experiment 2. Haulm height at 104 days, m.



showed significant soil moisture effects. There were significant interactions of nitrogen and soil moisture on fractions B, E, D+E, B+C+D+E and A+B+C+D+E.

Total yield. (Figure 42). Total tuber yield (A+B+C+D+E) and saleable yield (B+C+D+E) were considered the same because of the small weight of tubers of fraction A.

With no additional water added (I_0) total tuber weight decreased with addition of nitrogen, although the decrease was not statistically significant.

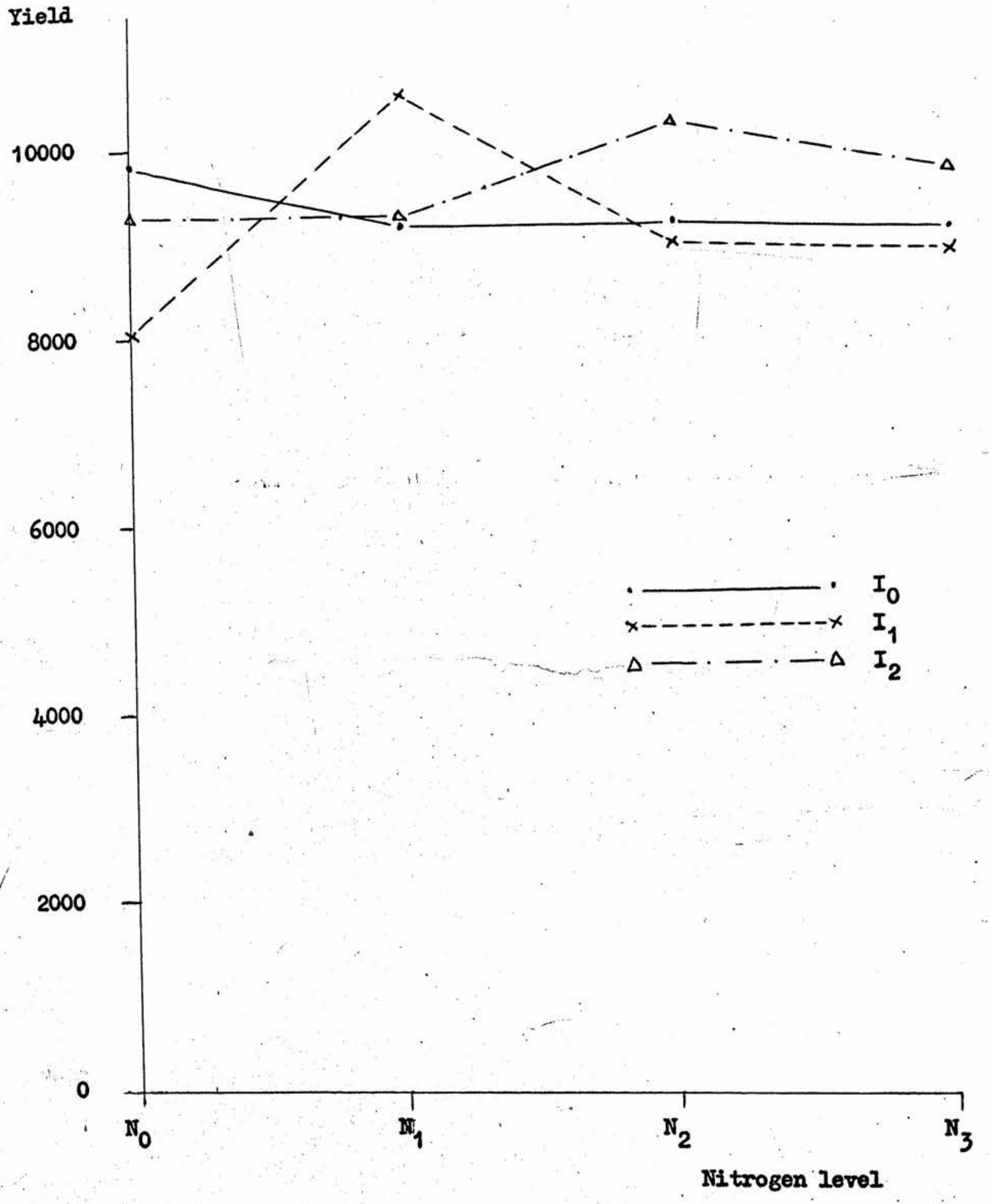
The high moisture level (I_2) gave a slightly lower yield than the low soil moisture level (I_0) when no nitrogen was added (N_0), but at N_1 yields were the same for both high and low moisture treatments. With the high moisture level (I_2) however, yields increased above the N_1 yield when nitrogen was added at the N_2 level, before decreasing slightly at the highest nitrogen level (N_3). Although none of these differences were statistically significant the difference in yield at N_2 with the high and low soil moisture levels was nearly so.

The intermediate moisture level (I_1) gave a very low yield when no nitrogen was added (N_0), but showed an increase in yield with addition of nitrogen at the N_1 level. Further additions of nitrogen gave the same yields as did the low soil moisture level (I_0).

The overall picture was a decrease in yield with addition of nitrogen at the low soil moisture level (I_0), but with an increase in moisture level yield increased to a maximum at N_1 with I_1 and at N_2 with I_2, before decreasing at higher nitrogen levels.

Yield of different size fractions. The yield of fraction B at the high moisture level (I_2) decreased with additions of nitrogen. The low moisture treatment

Figure 42. Experiment 2. Total tuber yield, g / 8 plants.



(I_0) differed from this in giving lower yield at N_0 and higher yield at N_3.

Fraction B+C was dominated mainly by the effects of the C fraction, because of its larger weight in comparison to the B fraction. At the high moisture level (I_2) there was a linear decrease in yield with additions of nitrogen. At the lower moisture levels (I_0 and I_1) the decrease in yield was evident only to the N_2 level, N_2 and N_3 gave the same yields. Yield at N_3 was the same for all moisture levels, but at lower nitrogen levels, yield was greater at the high moisture level (I_2).

Additions of nitrogen decreased the yield of fraction D and yield at each nitrogen level, except N_2, was the same regardless of moisture level. At N_2 however, the high moisture treatment (I_2) gave the same yield as at N_1 and the low moisture level (I_0) the same yield as at N_3. This gave a large difference in yield at N_2 between the high and low moisture treatments.

Yield of fraction E was increased by additions of nitrogen, the increase being linear at the high moisture level (I_2). Yield with no additional water (I_0) was higher than the high moisture level (I_2) at N_0, N_1 and N_2 but yield decreased from N_2 to N_3 and thus gave a lower yield at N_3. The intermediate moisture level (I_1) showed a significant increase in yield with addition of nitrogen at the N_1 level, but yields at N_1, N_2 and N_3 were the same.

When fractions D and E were combined, nitrogen had no effect on yield when no additional water (I_0) was applied. Although yield of fraction E was increased by increasing nitrogen application, yield of fraction D decreased. At the high moisture level (I_2) yield was less than with no additional water (I_0) at low nitrogen levels (N_0 and N_1), but greater at high nitrogen levels (N_2 and N_3). The intermediate moisture level (I_1) gave the same yield as the high moisture level (I_2) at N_0 and the same yield as the low moisture level (I_0)

at N_2 and N_3. At N_1 however, the intermediate moisture level (I_1) gave the highest yield of all treatments, this was due to the high yield of the E fraction. The high yield of tubers with the high moisture level (I_2) at N_2 was due to a high yield of tubers of the D fraction and at N_3 high yield was due to the E fraction.

Summary. (Figures 43-46). Although yield of fraction E was lower with the high moisture level (I_2) than with the low moisture level (I_0) at N_0, N_1, and N_2, yield increased linearly with addition of nitrogen at the high moisture level (I_2) and so was greater at N_3. Yield of fraction D increased with additions of nitrogen, with little effect of moisture except at N_2, where the high moisture level (I_2) gave a much larger yield than the low moisture level (I_0). Thus the overall effect on the D+E fraction was of no effect of nitrogen at the low moisture level (I_0). At the high moisture level (I_2) yield of fraction D+E was lower than the low moisture level (I_0) at the low nitrogen levels (N_0 and N_1), because of the low yield of fraction E. At higher nitrogen levels however, yield was greater because of the high yields of fraction D at N_2 and fraction E at N_3. Although the yield of fraction C at N_0 was greater with the high moisture level (I_2) than with the low moisture level (I_0), the latter had a greater total yield because of the yield of large tubers (fraction D+E). Yield of fraction C at N_1 was greater at the high moisture level (I_2), which compensated for a low yield of fraction D+E and so high and low moisture levels gave the same yield at N_1. Yield of fraction C was also greater with the high moisture level (I_2) at N_2 and this, combined with the high yield of fraction D+E, gave a higher total yield than the low moisture level (I_0) at N_2. Although yield of fraction C was slightly smaller with the low moisture level (I_0) at N_3, a slightly greater yield of

Figure 43. Experiment 2. Yield of tubers of different fractions, g / 8 plants.

Low moisture level, I_0.

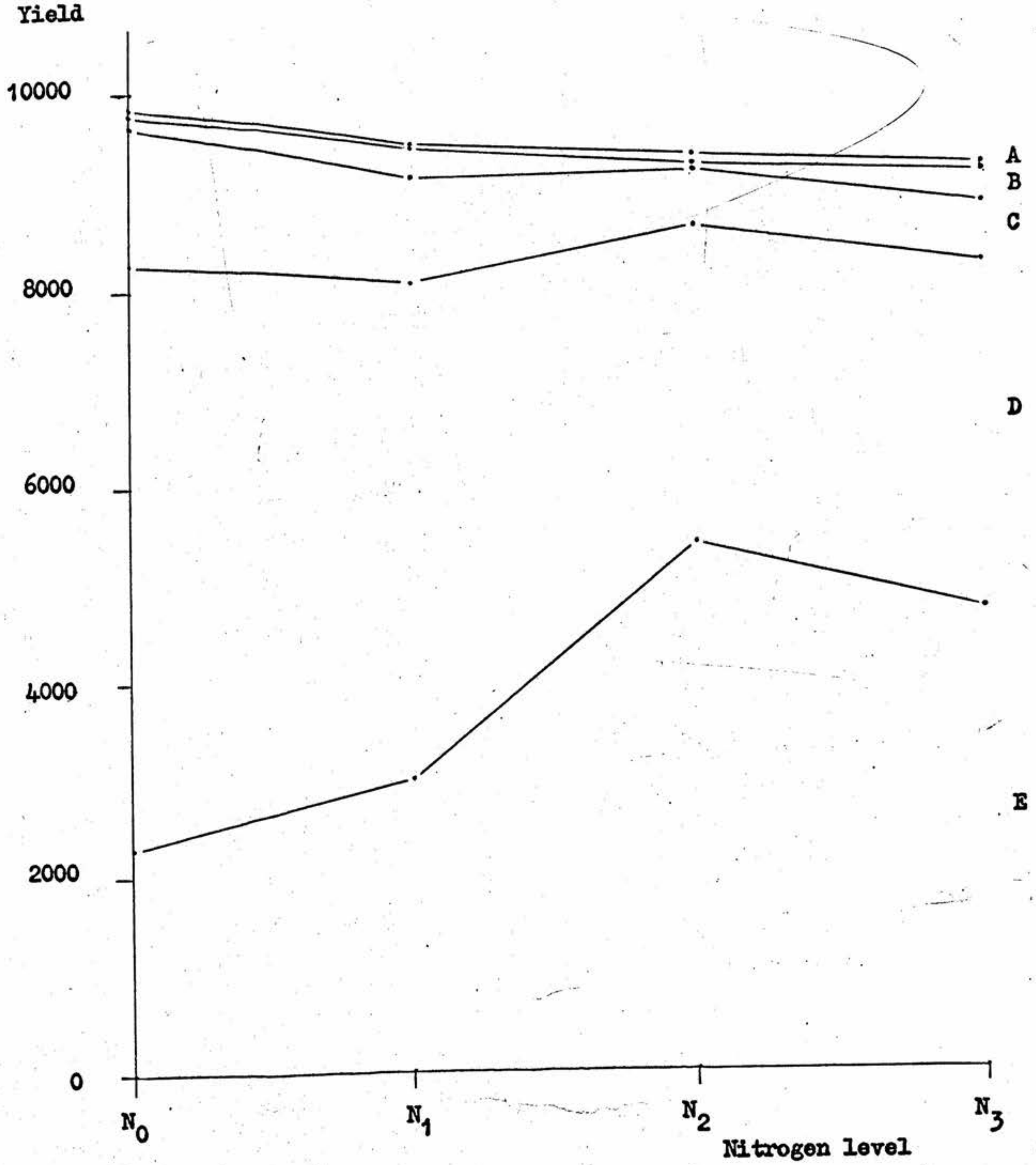


Figure 44. Experiment 2. Yield of tubers of different fractions, g/ 8 plants.

Intermediate moisture level, I_1.

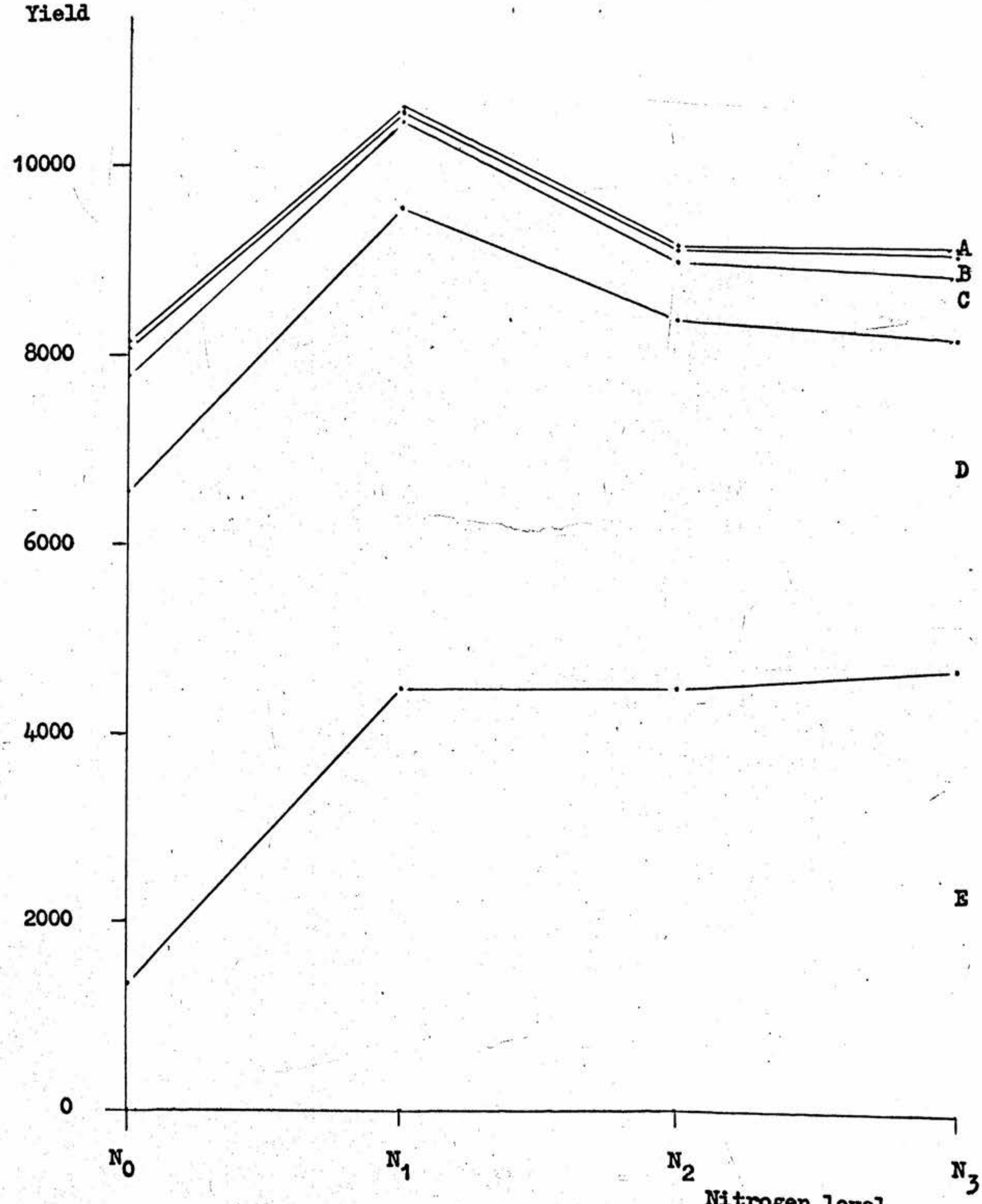


Figure 45. Experiment 2. Yield of tubers of different fractions g / 8 plants.

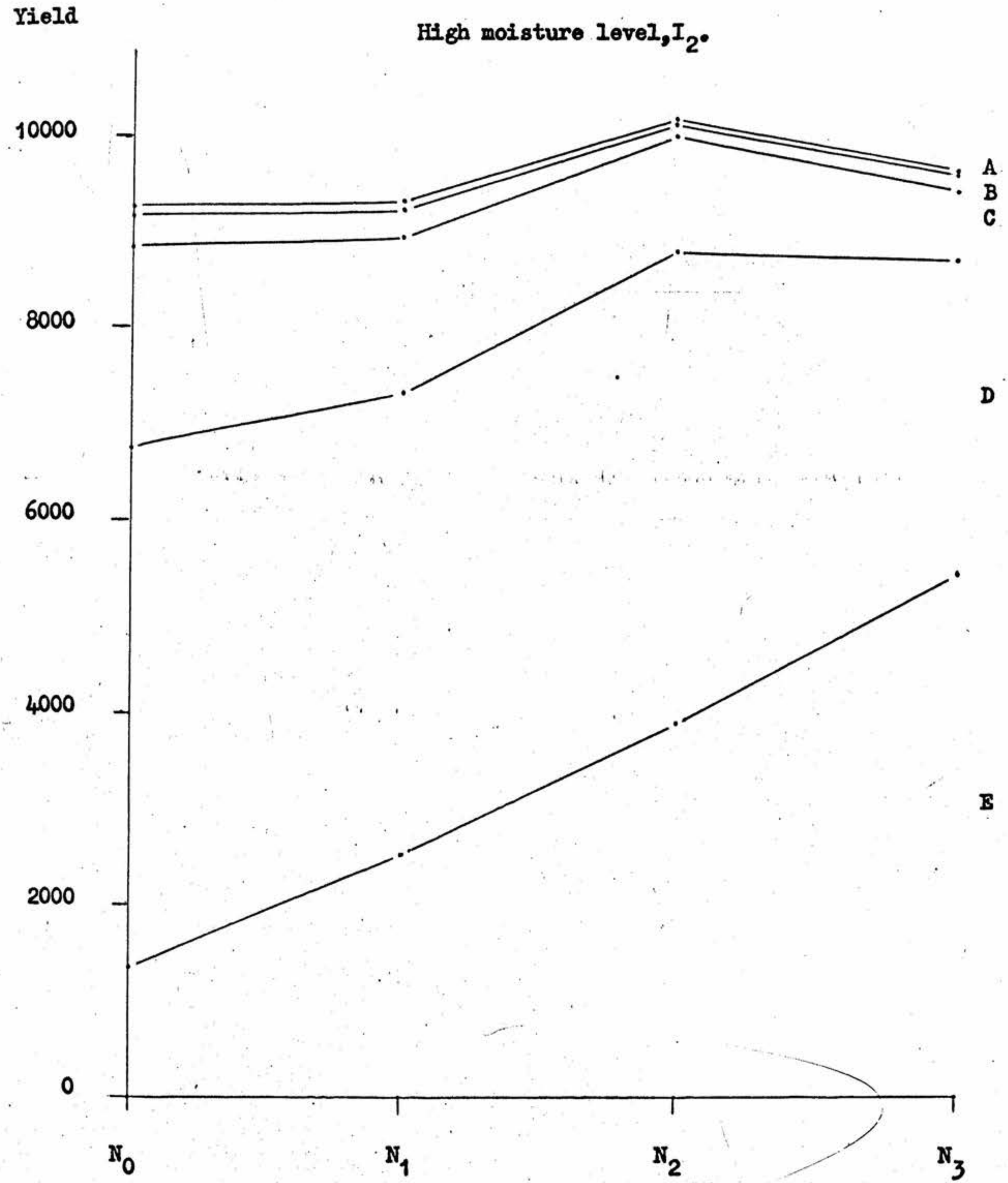
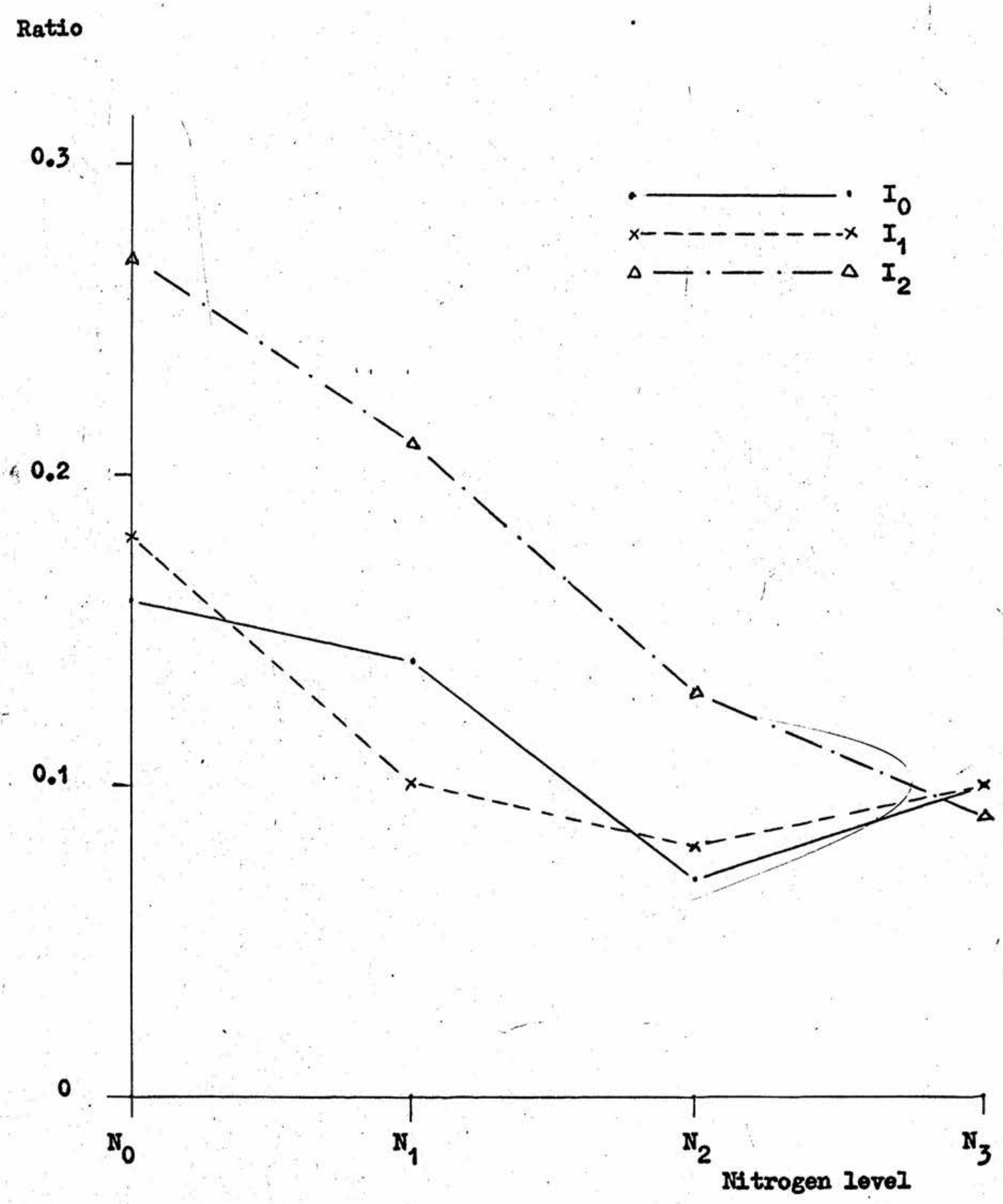


Figure 46. Experiment 2. Seed / Total ratio for weight of tubers.



fraction B resulted in no difference in yield of fraction B+C with the high and low moisture levels. The high yield of fraction E at N_3 gave the high moisture level (I_2) a greater total yield than the low moisture level (I_0). The decrease in total yield with addition of nitrogen from N_2 to N_3 at the high moisture level (I_2) was due to a marked decrease in the D fraction.

Yield of tubers with the intermediate moisture level (I_1) showed basically the same trends as the low moisture level (I_0), except that nitrogen had little effect upon the C fraction and that yield of fraction E did not increase with addition of nitrogen above the N_1 level, where the yield was greater than at the low moisture level (I_0). Thus total yield with I_1 reached a maximum at N_1 and then decreased at higher nitrogen levels. The low yield at N_0 was a cumulative effect of low yield of all except the B fraction.

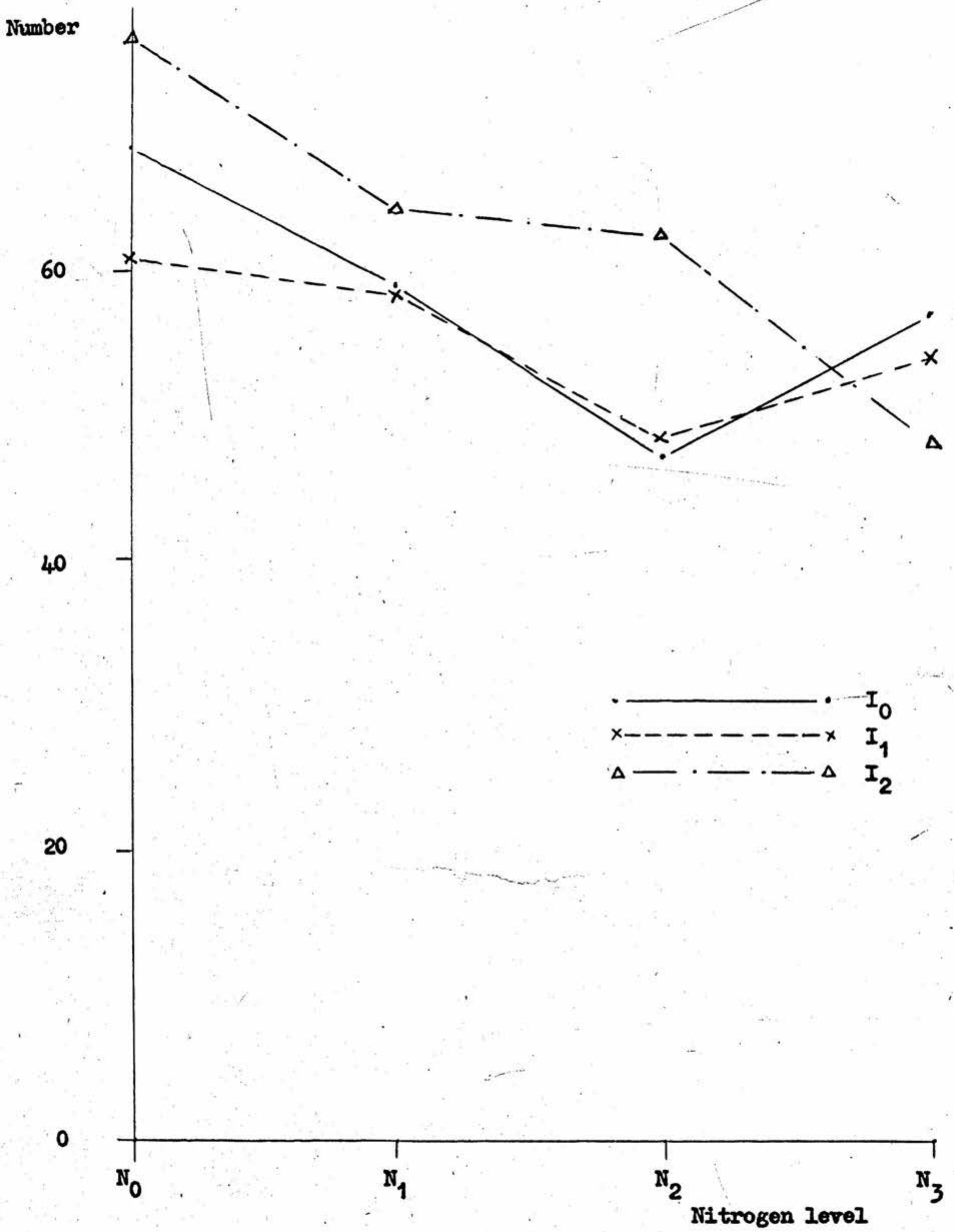
The seed/total ratio at the high moisture level (I_2) decreased with the addition of nitrogen because of the increase in yield of large tubers (fraction D+E). At the low moisture level (I_0) the decrease in the ratio was not so marked. This was because of the yield of large tubers (fraction D+E) remained constant but yield of small tubers decreased as nitrogen level was increased.

Tuber number. (Appendix, Tables 25 and 27).

Statistical analysis was carried out by log transformation.

Total number of tubers. (Figure 47). Increasing nitrogen application reduced the total number of tubers at harvest, except with the low and intermediate moisture levels where the number of tubers increased with addition of nitrogen from N_2 to N_3. At all except the highest nitrogen level (N_3) the high moisture level (I_2) always produced a greater number of tubers. There was little difference between the low and intermediate soil moisture, except at N_0 when there were fewer tubers with the intermediate level.

Figure 47. Experiment 2. Total tuber number / 8 plants.



Number of tubers in different fractions. At the high moisture level (I_2) the number of tubers in fraction A decreased with successive applications of nitrogen. With lower moisture levels the number of tubers also decreased with the application of small quantities of nitrogen, but at higher nitrogen levels the number of tubers increased. It was the high number of tubers in fraction A at N_3 with the intermediate moisture level (I_1) that gave the only difference between number of tubers in fractions A+B+C+D+E and B+C+D+E.

Addition of nitrogen to the N_2 level decreased the number of tubers of the B fraction with the high moisture level (I_2). There was little difference with the high moisture level (I_2) between N_2 and N_3. The low moisture level (I_0) gave a similar number of tubers as the high moisture level (I_2) at N_1 and N_2, but gave fewer tubers at N_0 and more tubers at N_3. There was little effect of nitrogen with the intermediate moisture level (I_1).

The number of tubers in fraction C decreased linearly with additions of nitrogen at the high moisture level (I_2). At lower moisture levels the number of tubers decreased with increased nitrogen to the N_2 level, but there was little difference between N_2 and N_3. The highest nitrogen level (N_3) showed no difference between moisture levels, but at lower nitrogen levels the high moisture level (I_2) gave a greater number of tubers. This was also the general pattern shown by fraction B+C.

The number of tubers in fraction D decreased linearly with additions of nitrogen, except that the high moisture level (I_2) gave the same number at N_1 and N_2 and the low moisture level (I_0) the same number at N_2 and N_3. This gave a large difference in numbers at N_2 between the two moisture extremes.

With the high moisture level (I_2) the number of tubers in fraction E increased linearly with successive additions of nitrogen. The low moisture level (I_0) showed approximately the same pattern with addition of nitrogen up to N_2, but then showed no increase to N_3. The intermediate level of moisture (I_1) gave the same number of tubers at N_1, N_2 and N_3.

The two opposite effects of nitrogen on fractions D and E were combined in fraction D+E. At the low moisture level (I_0) nitrogen application to the N_2 level reduced number of tubers, with little difference between N_2 and N_3. The higher moisture levels gave a lower number of tubers at N_0, but at N_3 all moisture levels gave the same number of tubers. The high moisture level (I_2) showed a maximum number of tubers at N_2, derived from the D fraction, and the intermediate moisture level (I_1) gave a maximum number of tubers at N_1, a result of the high number in the E fraction.

Summary. (Figures 48-51). Overall the low and intermediate moisture levels behaved very similarly.

The high moisture level (I_2) however, showed marked differences, giving a greater number of tubers than the other moisture levels at N_0, N_1 and N_2, but fewer at N_3. With no additional nitrogen (N_0) the low moisture level (I_0) gave a greater number of large tubers (D+E), but a high number of small tubers (B+C) at the high moisture level (I_2) gave, overall, a greater number of tubers at the high moisture level (I_2). At N_1 it was the greater number of tubers in fraction C which gave the high moisture level (I_2) a greater total tuber number than the low moisture level (I_0). A greater number of tubers in fractions C and D at N_2 with the high moisture level (I_2) gave a greater total number of tubers than the low moisture level (I_0), despite the latter having a greater number of fraction E tubers. At N_3 the much greater number of tubers in the A and B fractions with the low soil moisture (I_0) gave a greater total number of tubers than the high moisture level (I_2).

The seed/total ratio was not significantly affected by nitrogen at the

Figure 48. Experiment 2. Number of tubers of different size fractions / 8 plants.

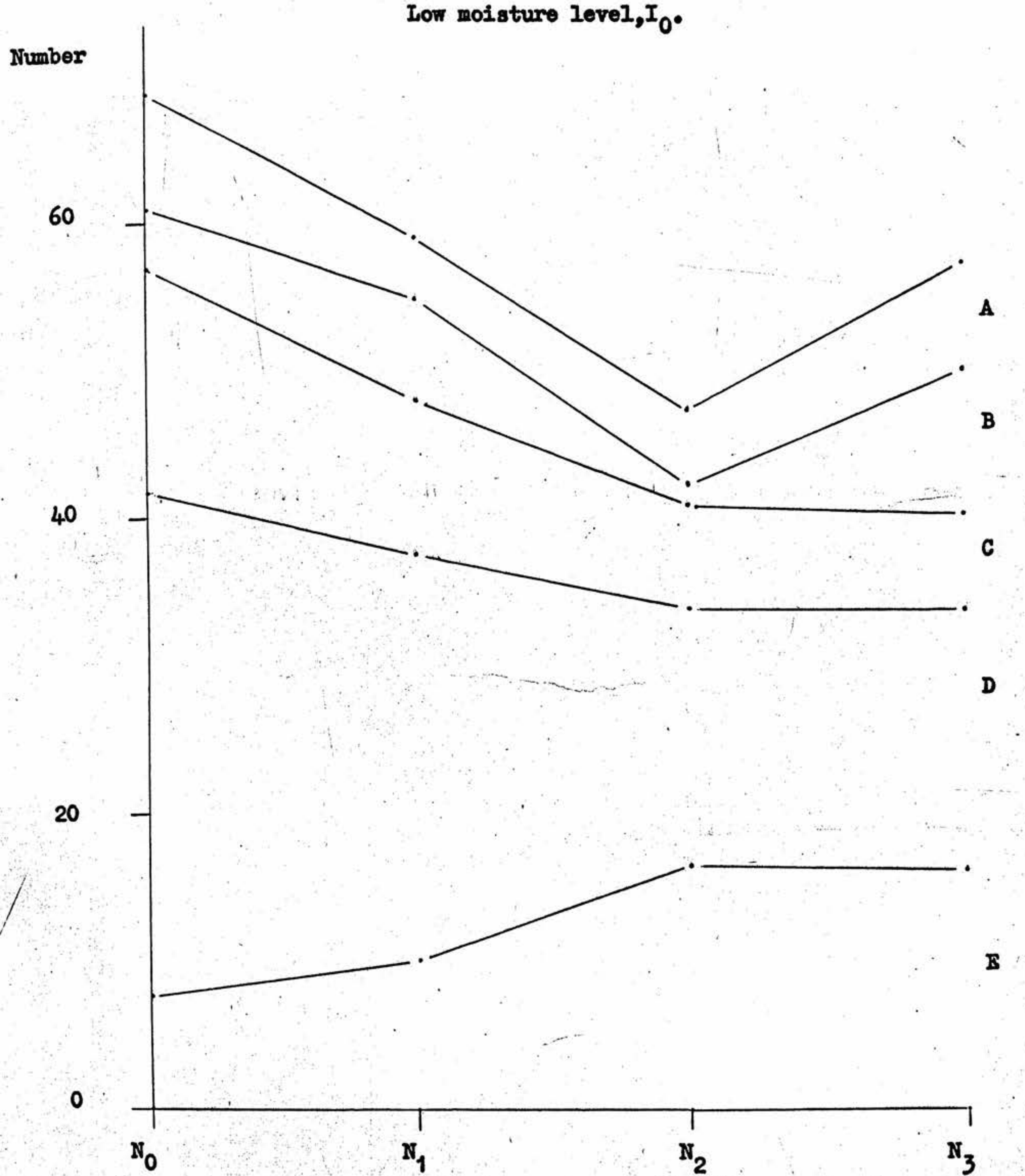


Figure 49. Experiment 2. Number of tubers of different size fractions / 8 plants.

Intermediate moisture level, I_1.

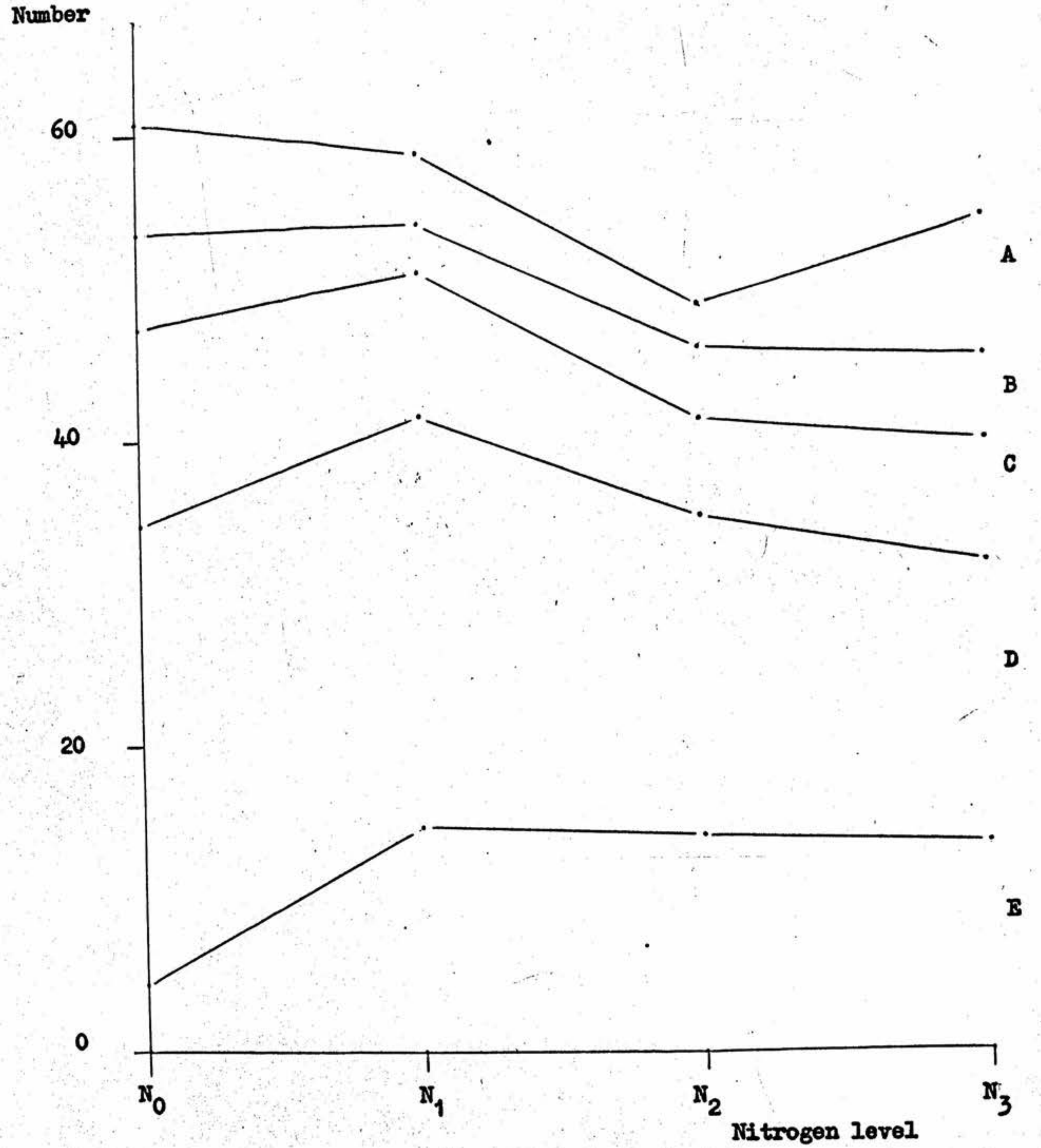


Figure 50. Experiment 2. Number of tubers of different size fractions / 8 plants.

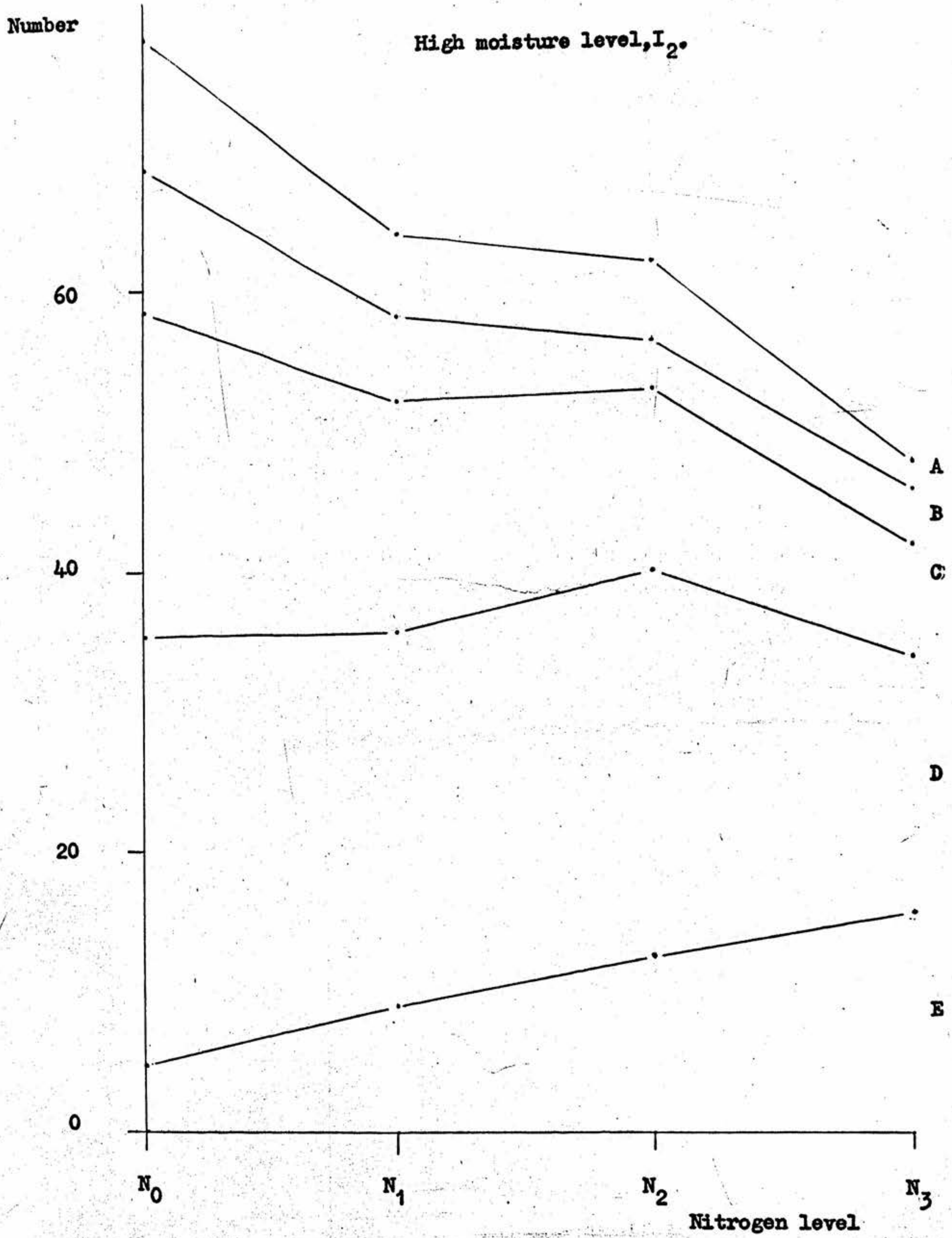
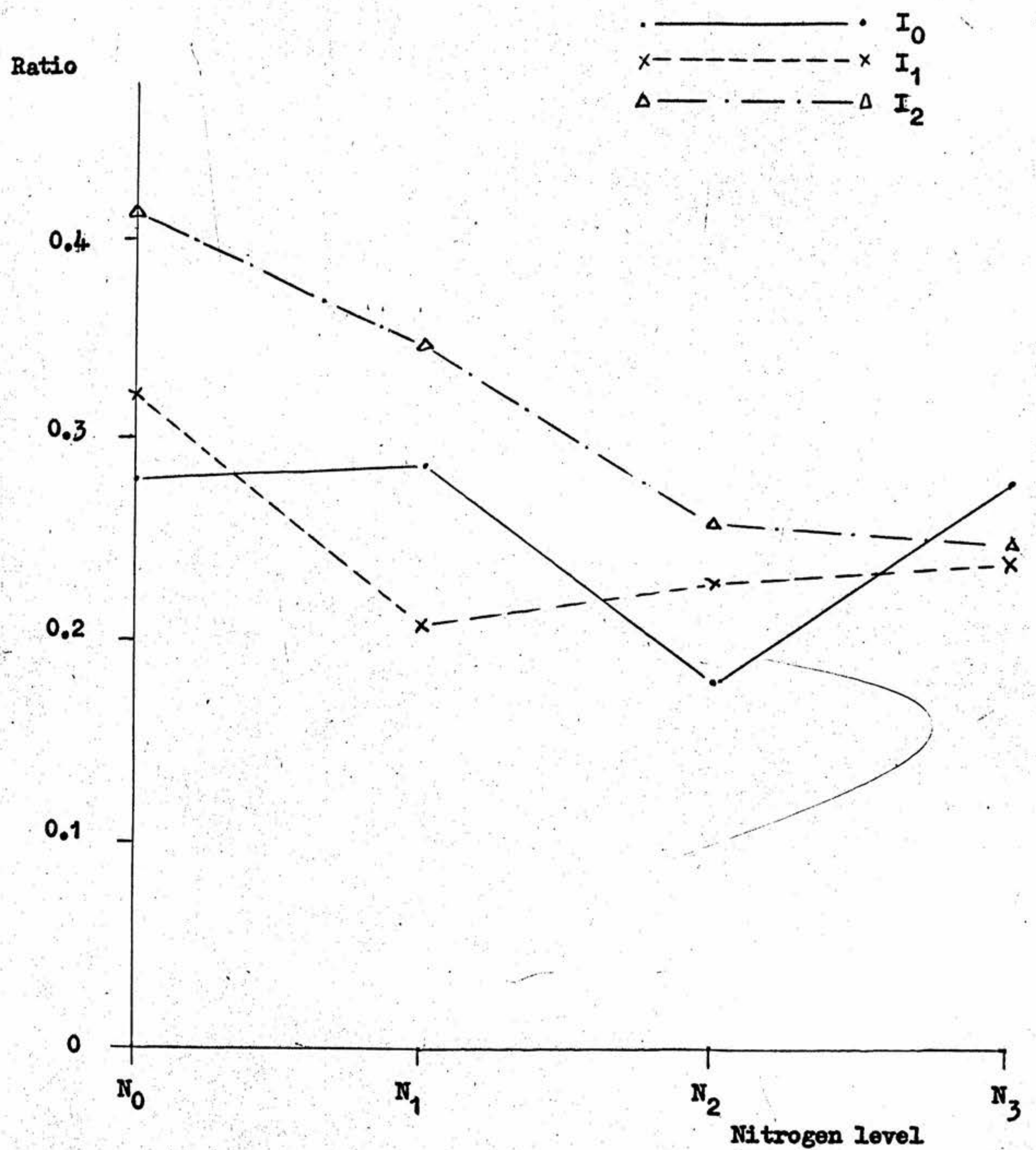


Figure 51. Experiment 2. Seed / Total ratio for tuber number.



low and intermediate moisture levels (I_0 and I_1). There was little effect of moisture level at N_2 and N_3, but at N_0 and N_1 the ratio was higher at the high moisture level (I_2).

Average tuber fresh weight. (Appendix, Table 28)

Nitrogen and soil moisture had no marked effect upon average tuber weight of the A and B fractions except for a high average tuber weight at N_1 with the high moisture level (I_2).

The average weight of tubers in fraction C increased slightly with addition of nitrogen to the N_1 level, but further additions of nitrogen decreased the average tuber weight. There was no significant effect of moisture level. Fraction D showed no significant effect of treatments.

Average tuber weight of fraction E at the high moisture level (I_2) increased almost linearly with additions of nitrogen. At lower moisture levels, average tuber weight was greater than at the high moisture level (I_2) at low nitrogen levels, but lower at N_3.

The combined fractions B+C and D+E showed basically the trends of the larger size fractions of each group.

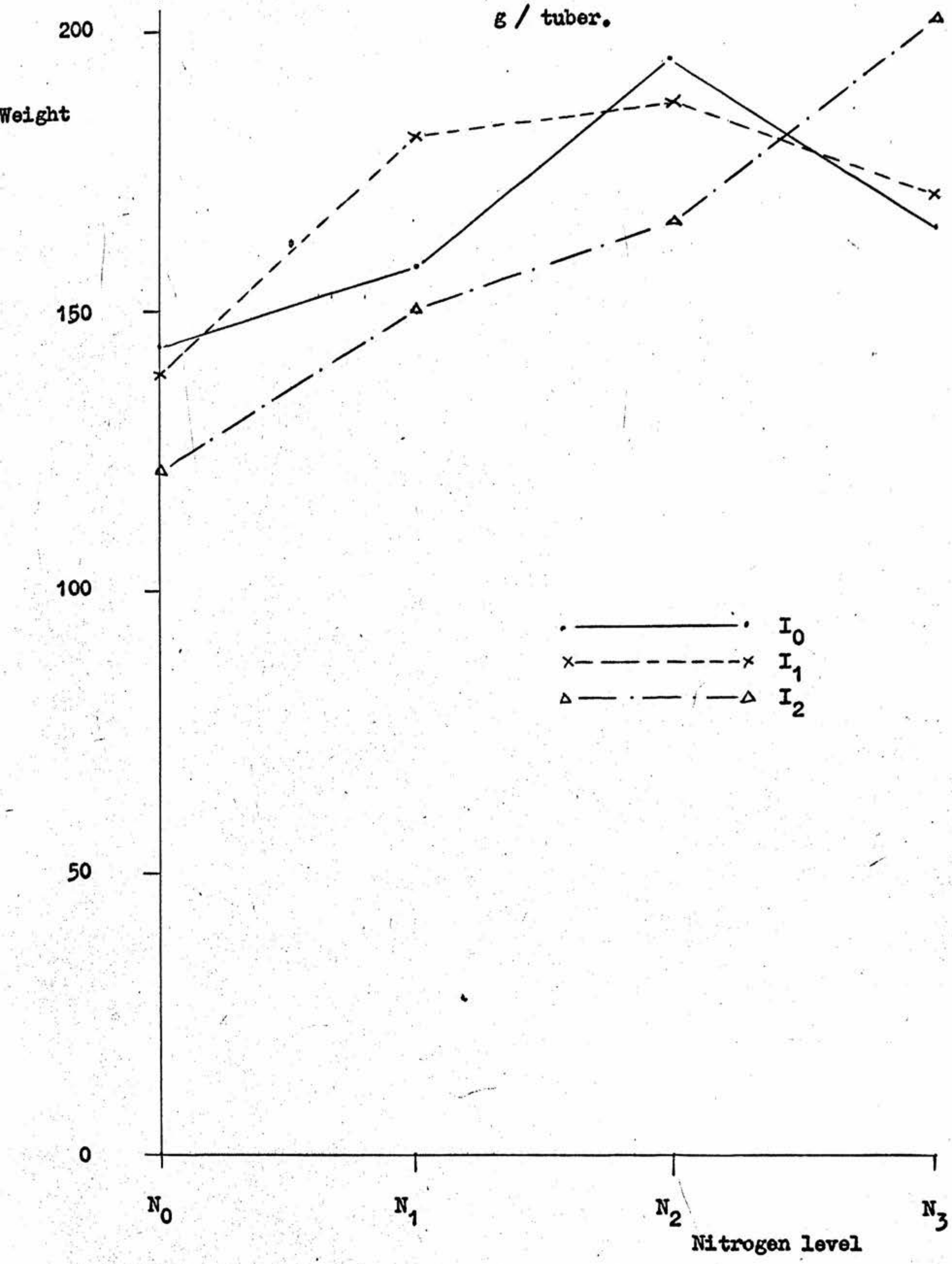
Overall (Figure 52) the effect on average tuber size was dominated by the E fraction. The high moisture level (I_2) showing a linear increase in average tuber weight with increase in nitrogen, but the lower moisture levels showing little difference between N_1, N_2, and N_3.

Dry matter content of tubers. (Appendix, Table 29).

There were no significant effects of treatment on the dry matter content of fractions B+C+D+E and D+E but dry matter content did increase with the low moisture treatment (I_0) when nitrogen was increased from N_1 to N_3.

Fraction B showed a tendency for dry matter content to decrease with an

Figure 52. Experiment 2. Average tuber weight fraction B+C+D+E, g / tuber.



increase in nitrogen level, but the effects of different moisture levels were rather erratic. The same was also true for fraction C. When these two fractions were combined the effect of nitrogen was to decrease the dry matter content from N_0 to N_1, increase it to N_2 and decrease it again at N_3. The low moisture level (I_0) gave higher dry matter contents than the higher moisture levels (I_1 and I_2).

The dry matter content of fraction D increased slightly with addition of nitrogen from N_0 to N_1, regardless of moisture level. Above this level of nitrogen, at the low (I_0) and intermediate (I_1) moisture levels, dry matter content increased. At the high moisture level (I_2) dry matter content at N_2 was slightly lower than at N_1, but increased at N_3 where there was no significant effect of moisture level. Dry matter content of fraction E decreased with addition of nitrogen.

Degree of cracking. (Appendix, Table 30).

There were no marked effects of treatment on the degree of bad and very bad cracking, but very bad cracking at high nitrogen (N_3) was worse when additional water was applied. At N_2 the degree of very bad cracking was high when no additional water (I_0) was added. High nitrogen levels gave a higher proportion of bad + very bad cracking, this being apparent at N_2 and N_3 with no additional water (I_0) and mainly at N_3 when water was applied.

The addition of water at the intermediate level (I_1) reduced moderate cracking at N_0 below that without additional water (I_0) but had no effect at higher nitrogen levels. The high moisture level (I_2) reduced moderate cracking at all but the highest nitrogen level. This was also shown when moderate, bad and very bad cracking were added and also with the inclusion of slightly cracked tubers.

Thus addition of small quantities of water (I_1) reduced cracking at N_0, but to reduce cracking at higher levels of nitrogen more water needed to be added (I_2), but even this did not reduce cracking at N_3. The main effect of added water was a reduction in the moderate category.

N, P and K concentration in tuber dry matter

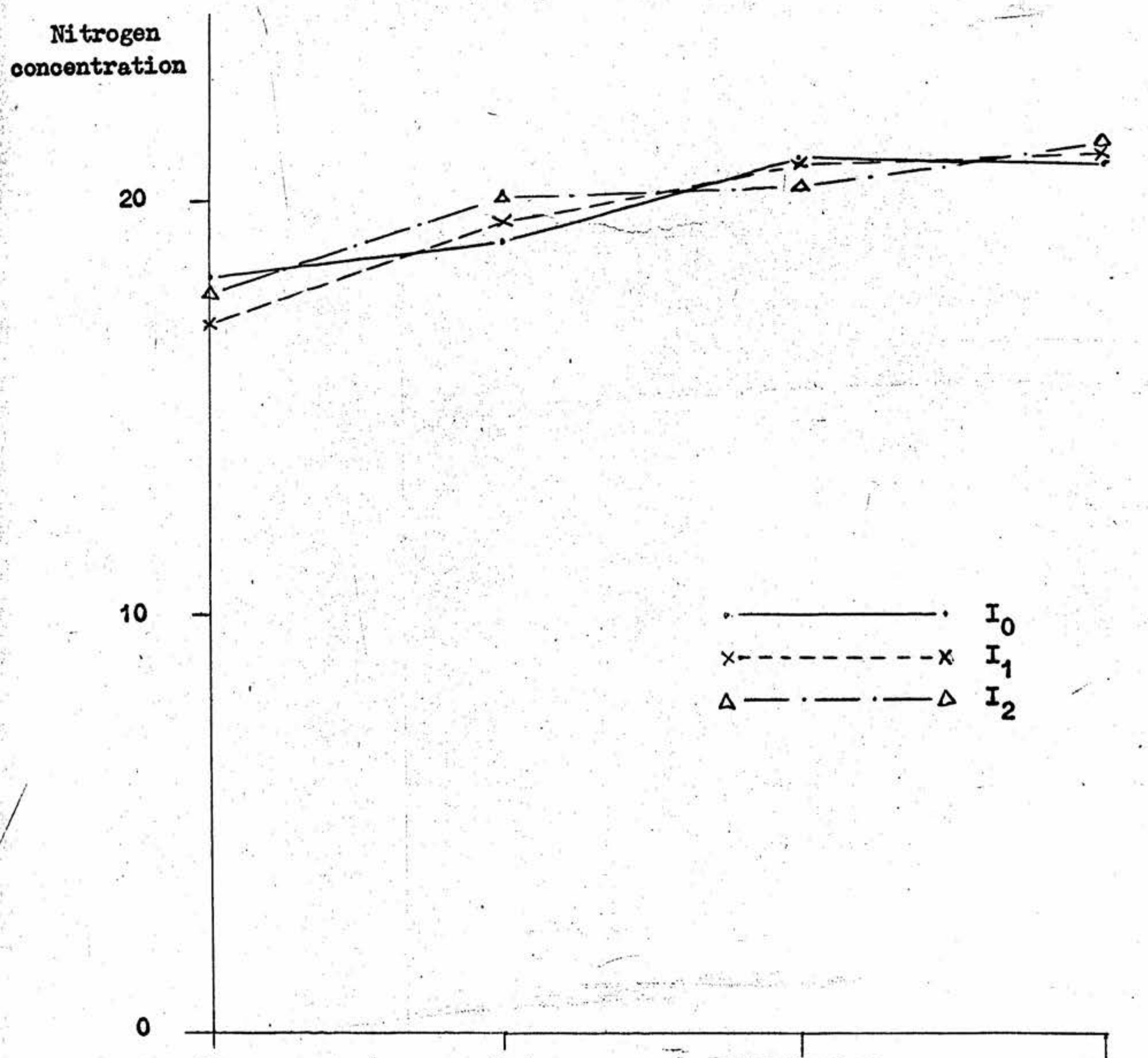
Nitrogen. (Figure 53; Appendix, Table 31). Overall the nitrogen concentration of the tubers increased as the rate of nitrogen application increased. The increase in nitrogen concentration with addition of nitrogen from N_1 to the N_2 level was smaller than the increase with addition of nitrogen from N_0 to N_1. There was little difference between nitrogen concentration at N_2 and N_3 and no significant effect of moisture level at any nitrogen level.

Fractions B, C and E gave prominent linear nitrogen effects but the nitrogen concentration of fraction D increased with addition of nitrogen to the N_2 level but decreased at N_3. It was mainly the latter effect which was responsible for the overall effect of little difference between N_2 and N_3. There was little effect of moisture level.

Phosphorus. (Appendix, Table 32). There was little effect overall on phosphorus concentration, except for a slight tendency at low nitrogen levels for phosphorus concentration to be increased at the higher moisture levels. There was a slight tendency in some fractions for phosphorus concentration to increase slightly with addition of nitrogen, but fraction D had the main influence on the overall effect.

Potassium. (Appendix, Table 33). There was little marked effect of treatment on fractions B, C and E. Fraction D showed a decrease in potassium concentration with increase in nitrogen and it was this fraction which dominated the overall effect on fraction B+C+D+E.

Figure 53. Experiment 2. Tuber nitrogen concentration, fraction B+C+D+E, mg nitrogen / g dry material.



Sugar concentration of tubers.

Reducing sugar. (Appendix, Table 34). Fractions B, C and E showed little effect of treatment but reducing sugar concentration was greater in the small tubers. The reducing sugar concentration offraction D was little affected by nitrogen application when no additional water (I_0) was applied. With additional water however, reducing sugar concentration was higher at N_0 and N_1.

The overall effect was that reducing sugar concentration did not change with addition of nitrogen at the low moisture level (I_0), but at higher moisture levels nitrogen reduced the reducing sugar concentration. Only at N_0 however, was reducing sugar concentration significantly higher with additional water than without it.

Sucrose. (Appendix, Table 35). There was little overall effect of treatment upon sucrose concentration. There was a slight tendency in fractions B and D for sucrose concentration to increase as nitrogen level was increased.

Total sugar. (Appendix, Table 36). Because of the small influence of treatment on the sucrose concentration, total sugar concentration showed the same trends as reducing sugar concentration.

DISCUSSION, EXPERIMENTS 1 AND 2.

Tuber yield and number.

The application of 100 kg N/ha, in experiment 1, increased total yield of tubers, irrespective of moisture level. With low soil moisture levels (I_0 and I_1) however, this was the optimum nitrogen level for tuber yield, which decreased with further additions of nitrogen. With the high soil moisture level (I_2) 200 kg N/ha was the optimum level. The decrease in yield at high nitrogen levels was less marked when water was added.

When the high residual nitrogen level of experiment 2 was taken into account, total tuber yield showed basically the same trends as in experiment 1. The very high residual nitrogen level, as shown by mineralisable nitrogen analysis (Table IV), was no doubt due to the previous cropping of grass. The result was that the yield curves were displaced by approximately one increment of fertiliser nitrogen (100 kg N/ha) in comparison with experiment 1. The no additional nitrogen level of experiment 2 was comparable with the 100 kg N/ha level of experiment 1. Yield at the low moisture level (I_0) decreased with successive additions of nitrogen, but at the high moisture level (I_2) 200 kg N/ha was the optimum nitrogen level. The yield with the intermediate moisture level (I_1) was rather erratic compared with experiment 1. With no additional nitrogen yield was low, but at 100 kg N/ha, the optimum nitrogen level, yield was the highest for any treatment.

Thus, when high levels of fertiliser nitrogen were applied, yield was considerably reduced if the soil moisture was not maintained at an adequate level.

The response to higher levels of nitrogen when soil moisture was maintained at a high level was in agreement with work of Fulton and Finlay (1964) and Ellison and Jacob (1954).

Considerable care must be taken when considering the results for tuber number at harvest, as they may not bear any relationship to the number of tubers produced.

At the low soil moisture level (I_0), in experiment 1, successive additions of nitrogen increased the number of tubers present at harvest. Russell and Garner (1941) and Hanley et al. (1965) both associated increased yield from nitrogen with increased tuber number, but in this case yield only increased up to 100 kg N/ha. At high moisture levels the addition of nitrogen decreased tuber number, an effect also found by Wellings (1969).

In experiment 2 a greater number of tubers were present at harvest than in experiment 1, especially at low nitrogen levels. This greater number of tubers may have been due to the higher residual nitrogen level of experiment 2, but addition of nitrogen tended to decrease tuber number at harvest.

There was an increase in tuber number with addition of nitrogen from 200 to 300 kg N/ha with I_2 in experiment 1 and with I_0 and I_1 in experiment 2. This may have been an effect of maturity. High nitrogen levels can delay tuber formation due to excessive haulm growth (Ivins, 1967) and this may have limited the time for resorption of tubers late in the season i.e. maturity was delayed. The increase in number was due to the small size fraction tubers and had little effect on total yield.

In both experiments with the low soil moisture level (I_0) the addition of 100 kg N/ha increased the number of large tubers (fraction E). In experiment 1 this gave an increased total yield and so was in agreement with work of Birch et al. (1967) who attributed most of the yield response to nitrogen as an increase in yield of large tubers. Experiment 2 was in contrast to this since 100 kg N/ha gave a lower yield than when no nitrogen was added, despite having more large tubers. This may have been due to the higher residual nitrogen level causing excessive haulm growth and delayed tuber initiation, but it does support the view of Russell and Garner (1941) who considered that nitrogen affected yield mainly by its influence on tuber number. In this case tuber number was decreased and so yield decreased, because of a low yield of middle size tubers.

In experiment 2 the yield of large tubers increased with addition of nitrogen up to 200 kg N/ha but then decreased with the low soil moisture level (I_0). Total yield showed a progressive decline with additions of nitrogen. In experiment 1 yield of large tubers with the low soil moisture level decreased above 100 kg N/ha, as did total yield. This decline in yield at high nitrogen levels was no doubt due to excessive haulm growth as described by Ivins (1967). The effect may have been two-fold in delaying tuber formation, thereby shortening the time for tubers to develop to a large size, and preventing bulking, because of the requirement of photosynthate for haulm growth instead of tuber growth. This is also a possible explanation for the displacement of yield curves between the two experiments.

The application of water tended, in most cases, to increase the number of tubers present at harvest, as suggested by Salter and Goode (1967) when water is applied before tuber initiation. There were exceptions however, in experiment 1 at 200 kg N/ha where soil moisture had no effect on tuber number and in experiment 2 at 300 kg N/ha where tuber number was lower with the high moisture level (I_2).

The addition of water (I_2) had little influence on total yield at 0 and 100 kg N/ha because, although there were more tubers, the plant was unable to allow them to grow to a large size. This suggested that at high soil moisture levels 100 kg N/ha was insufficient to allow enough haulm growth for the bulking of the tubers. It is doubtful if the small number of large tubers, with the addition of water, was entirely due to a delay in tuber formation, since at higher nitrogen levels, which would have delayed tuber formation further, more large tubers were produced.

The addition of 200 kg N/ha satisfied the need for more nitrogen at the high moisture level as the number of large tubers increased, as did total yield. In experiment 1 although the increase in soil moisture had no effect on total tuber number at 200 kg N/ha it did allow more tubers to reach a large size, giving the high moisture level a much larger yield than the low moisture level. In experiment 2 the number of large tubers was still greater with the low than the high moisture level at 200 kg N/ha, despite an increase in tuber number with an increase in nitrogen level from 100 to 200 kg N/ha. This was possibly due to insufficient photosynthate for the number of tubers produced. A greater number of middle size tubers however gave, overall, a greater yield with the high moisture level.

In experiment 1 at 300 kg N/ha yield was lower than at 200 kg N/ha because of a lower number of large tubers, possibly because of excessive haulm growth. In experiment 2 there were more large tubers at 300 kg N/ha but this was at the expense of the middle size tubers and total yield was lower than at 200 kg N/ha.

Overall in experiment 1 the main effect of maintaining a high soil moisture level was to give a larger number of small ware tubers (fraction D) at all nitrogen levels, except when no nitrogen was applied when there was a larger number of large seed tubers (fraction C). The reason for different optimum nitrogen levels with different moisture levels was variation in the yield of large ware tubers (fraction E). With the low moisture level 100 kg N/ha gave maximum yield of large tubers and at higher nitrogen levels there was a decline, a similar pattern to that shown by total yield. With the high moisture level (I_2) yield of large ware was at its maximum with 200 kg N/ha, as was total yield.

Thus addition of water (at I_2) had increased the yield of small ware tubers (large seed when no nitrogen was added) but a higher nitrogen level was required for maximum yield of large ware tubers and for maximum total yield than when no water was added.

In experiment 2 successive additions of nitrogen decreased the number of small ware tubers. This decrease was offset by an increase in the number of large ware tubers, but, as with experiment 1, the effect of nitrogen was dependent on the moisture level. With the low moisture level (I_0) the increase in large ware tubers was insufficient to compensate for the decrease in number of smaller tubers and so yield decreased with additions of nitrogen. With the high moisture level the yield of large ware tubers increased linearly with addition of nitrogen. Total yield however, increased to a maximum at 200 kg N/ha before decreasing at the highest nitrogen level. This was because the yield of small ware tubers was maintained at the same level between 100 and 200 kg N/ha but decreased sharply at 300 kg N/ha.

The intermediate moisture level (I_1) in experiment 1 gave the same number of tubers as the high moisture level (I_2) except at 300 kg N/ha where there was an increase in tuber number with the high moisture level. Tuber yield was the same at low nitrogen levels (0 and 100 kg N/ha) with all moisture levels. At 200 kg N/ha yield with the intermediate moisture level was between that with the two moisture extremes but at 300 kg N/ha yield was lowest with the intermediate moisture level, because of a low yield of small ware tubers.

In experiment 2 the intermediate moisture level (I_1) was somewhat similar to the low moisture level (I_0). There were however fewer tubers, especially of ware size, with the intermediate moisture level when no nitrogen was applied. At 100 kg N/ha there was a high proportion of large ware tubers giving a very high yield.

Growth record.

Emergence and vigour of early growth were both reduced by high levels of nitrogen as previously reported by many workers, e.g. Widdowson et al. (1967) and Shotton and Jarvis (1967).

Haulm height during the growing season increased with addition of small quantities of nitrogen but decreased at higher nitrogen levels. This decrease was most marked at low moisture levels. The high moisture level gave the tallest haulms. The deleterious effect of high nitrogen level decreased during the growing season.

Haulm colour early in the season was darker at high nitrogen levels.

Senescence was more advanced in the low nitrogen treatments, with a tendency for the high moisture level to be more advanced than the low moisture level when no nitrogen was added.

Dry matter content.

In contrast to work of Simpson (1962) no significant effect of soil moisture on dry matter content of the tubers was found. This is in agreement with Burton (1966), if one considers that the East of Scotland cannot be described as arid.

The addition of nitrogen tended to decrease the dry matter content of the tubers, as had also been found by many other workers, e.g. Simpson (1962) and Holliday (1963). The decrease was not as great at high nitrogen levels.

It is possible that the decrease in dry matter content with additions of nitrogen may have been an effect of immaturity. All treatments had been harvested at the same time. The haulms had been cut down when only the lower nitrogen treatments had senesced naturally.

Fraction D in experiment 2 was rather peculiar since it gave an increase in dry matter content with addition of nitrogen.

Degree of cracking.

High levels of nitrogen caused an increase in the severity of cracking which was to some extent alleviated by addition of water (at I_2) in experiment 1.

Moderate cracking was most affected by increasing the soil moisture level. Even small amounts of water (I_1) reduced cracking when no nitrogen was applied. More water (I_2) was needed to reduce moderate cracking at 100 and 200 kg N/ha and water had little effect at 300 kg N/ha. The addition of water tended to decrease the number of tubers developing moderate cracks from slight cracks.

Thus nitrogen tended to increase the severity of cracking, which could be offset to some extent by increasing the soil moisture level. However the more nitrogen that was used the more water was required.

N, P and K concentration in tuber dry matter.

Nitrogen. There were no marked effects of increasing soil moisture level on the nitrogen concentration in the tubers at harvest. There was a slight tendency in experiment 1 for addition of water to lower the nitrogen concentration of the tubers at low nitrogen levels. This was in agreement with Flocker and Timm (1966) who found greater levels of tuber nitrogen in plants grown at high moisture tension.

Previous work on the effects of application of nitrogen on tuber nitrogen concentration at harvest gave variable results. Carpenter (1963) found no effect, neither did Mica (1969). However the results obtained here were in agreement with those of Laughlin (1971), nitrogen concentration of the tubers increased linearly with application of up to 200 kg N/ha. At higher nitrogen levels the nitrogen concentration of the small tubers increased but that of the larger tubers showed little difference and in one instance showed a decrease.

Phosphorus. There were no marked effects of treatment on the phosphorus concentration of tubers in experiment 2 but in experiment 1 there was a linear increase with addition of nitrogen up to 200 kg N/ha. This is in contrast to work of Simpson (1962) who found a decrease in phosphorus concentration with addition of nitrogen. Laughlin (1971) also found the highest phosphorus concentration when no nitrogen was applied but Mica (1969) reported no effect of fertiliser nitrogen on phosphorus concentration of tubers at harvest.

There was a slight tendency, in some fractions, for the higher soil moisture levels to give a higher phosphorus concentration, in agreement with Simpson (1962).

Potassium. Other workers, e.g. Laughlin (1971) and Carpenter (1963), have found no effect of nitrogen fertiliser on the potassium concentration of tubers at harvest. This was also found in experiment 2, except for the D fraction where there was a decrease with increase in nitrogen. This may have been associated with a corresponding increase in dry matter content.

In experiment 1 addition of 100 kg N/ha increased the potassium concentration, but further additions had little effect, except at 300 kg N/ha where there was a slight decrease, especially when water was added. This may have been due to lack of maturity when the haulms were removed, thereby preventing potassium transfer from the haulms to the tubers.

Sugar concentration of the tubers.

The addition of nitrogen had little effect on sucrose concentration of the tubers (Swiniarski and Ladenberger, 1970 and Moll, 1967).

There was a slight tendency for reducing sugar concentration to decrease with addition of nitrogen, as was also found by Swiniarski and Ladenburger (1970), but in some cases this occurred only when sufficient moisture was present. At low nitrogen levels high soil moisture tended to give high reducing sugar concentration.

The small tubers gave higher sugar concentration. This may have been due to lack of maturity or because tubers were being or about to be resorbed.

Summary and conclusions from experiments 1 and 2.

There was a very marked interaction between nitrogen and soil moisture on tuber yield. When soil moisture was maintained at a high level more nitrogen was required for maximum yield of tubers. The interaction appeared to be through an effect on the number of tubers produced and the size that these tubers were able to reach.

In general a high soil moisture level gave a greater number of tubers. The addition of small quantities of nitrogen allowed more tubers to grow to a large size, but there was an optimum nitrogen level above which yields decreased.

In experiment 1 addition of water gave a greater number of small ware tubers (large seed tubers when no nitrogen was added). The effect of nitrogen on total yield was evident through its influence on the yield of large ware tubers, the greater the number the larger the total yield. With the low moisture level 100 kg N/ha was the optimum (of the nitrogen levels tested), but with the addition of water 200 kg N/ha was the optimum for tuber yield.

In experiment 2 nitrogen had a somewhat similar effect on the large ware tubers, but the number of small ware tubers decreased with additions of nitrogen. It was the ratio between these which influenced total yield. With the low moisture level the increase in large ware was insufficient to compensate a big decrease in number of small ware and so yield decreased with increased nitrogen level. With the high moisture level the decrease in yield of small ware was not so marked, except at 300 kg N/ha and so total yield increased with addition of up to 200 kg N/ha, the optimum of the levels tested, and then decreased.

At all moisture levels there was a decrease in yield at very high nitrogen levels (300 kg N/ha). This was no doubt due to excessive haulm growth as described by Ivins (1967), but it could not be concluded from these experiments whether the influence was through delayed tuber initiation or through lack of photosynthate because of the demand for haulm growth.

With the low moisture level early in the season growth was retarded at high levels of nitrogen. This delayed the formation of a satisfactory leaf area and although the plant may have recovered later in the season the late excessive haulm growth coupled with possible delayed tuber initiation and also premature curtailment of growth (by cutting down the haulms) would give a very short and slow tuber bulking period and associated low yield. In experiment 1 yield was reduced by greater than 100 kg N/ha but in experiment 2 yield was reduced even at 100 kg N/ha, no doubt due to the high residual soil nitrogen level.

With the high moisture level early growth was not deleteriously affected by nitrogen except at very high nitrogen levels. This allowed early haulm growth and so gave a long and fast bulking period and this possibly explains the higher yield with the high than with the low moisture level at 200 kg N/ha.

It would appear that the addition of water had alleviated some deleterious factor which retarded growth at high nitrogen levels early in the season.

To investigate the interaction between nitrogen and soil moisture a growth analysis experiment was carried out. It was hoped to substantiate the theories put forward above and to examine possible causes of the deleterious effects of high nitrogen levels at low soil moisture levels. It was hoped to study the following in detail throughout the season:-

a) The development of tubers.

b) The development of the haulm.

c) Changes occurring in the soil with special reference to deleterious conditions.

d) Changes occurring in the plant with special reference to deleterious conditions.

RESULTS, EXPERIMENT 3.

All results are given in Appendix, Tables 39-93 and some are also shown in Figures 54-73.

SAMPLING 1.

Soil Data. The nitrate and ammonium concentrations in the fertiliser band showed highly significant linear increases with additions of nitrogen. Both nitrate and ammonium concentrations were lower at N_1 with the high moisture level (I_1) than with the low moisture level (I_0). At N_3 the position was reversed and the ammonium and nitrate concentrations were significantly higher with the high moisture level (I_1).

As expected soil moisture content was higher with the high moisture level (I_1). However, at both moisture levels, soil moisture content was lower than at N_0 and N_3 when nitrogen was added at the N_1 level, and also at N_2 when no additional water was added.

Conductivity of a saturated soil paste was increased linearly, by additions of nitrogen. There was little marked effect of moisture level except at N_1, where conductivity was higher with the low moisture level (I_0).

Soil pH, in both water and $CaCl_2$, at the high moisture level (I_1) decreased linearly with successive additions of nitrogen. At the low moisture level (I_0) addition of nitrogen at the N_1 level greatly reduced the pH, but with further additions of nitrogen pH increased slightly. Thus, at N_1, the soil at the low moisture level (I_0), had a lower pH than that at the high moisture level (I_1), but at N_3 the low moisture level was higher. Soil pH was lower when measured in $CaCl_2$ than in water, the decrease in pH with addition of fertiliser nitrogen was also less with $CaCl_2$.

At the high moisture level (I_1) the "available P" and "available K" in the soil tended to be higher as nitrogen level was increased. At the low moisture level (I_0) there was an increase at N_1 followed by a decrease at higher nitrogen levels, but there were no significant differences.

Roots. There was no significant effect of treatment on the dry weight of roots. Additions of nitrogen up to the N_2 level increased the nitrogen concentration in the roots, but there was little difference between N_2 and N_3. When no additional nitrogen was added (N_0) nitrogen concentration was significantly greater with the high moisture level (I_1) but with the addition of fertiliser nitrogen the nitrogen concentration in the roots was higher when no additional water was added(I_0).

The nitrate-nitrogen concentration in the roots increased significantly with the addition of nitrogen at the N_1 level and showed a further increase to N_2 but there was little difference between N_2 and N_3. When fertiliser nitrogen was applied the nitrate concentration was lower at the high moisture level (I_1).

The ratio of nitrate-nitrogen to total-nitrogen in the roots increased significantly with addition of nitrogen at N_1. With higher nitrogen levels, at the low moisture level (I_0) the ratio continued to increase but at the high moisture level (I_1) the ratio increased to N_2 and then decreased at N_3. In the presence of applied nitrogen the ratio was higher with the low (I_0) than with the high (I_1) moisture level.

There was little effect of treatment on the phosphorus concentration in the roots, except for a slight decrease at high levels of nitrogen.

The potassium concentration in the roots was not affected by addition of nitrogen at the N_1 level, but with the high moisture level (I_1) further additions of nitrogen caused a decrease. With the low moisture level (I_0) potassium concentration increased to N_2 before decreasing at N_3.

Stolons. With the low moisture level (I_0) additions of nitrogen up to the N_2 level reduced the wet weight and the dry weight of stolons, but there was a slight increase at N_3. The addition of nitrogen at N_1 with the high moisture level (I_1) increased the weight of stolons, but further additions of nitrogen caused a decrease in weight. The high moisturelevel (I_1) gave significantly greater wet weights of stolons at N_1 and N_2 and dry weight at N_1.

Dry matter content of the stolons decreased significantly with addition of nitrogen (at N_1) at the low moisture level (I_0) but further additions of nitrogen had little effect. At N_0 dry matter content was significantly lower with the high (I_1) than the low (I_0) moisture level and additions of nitrogen caused a significant linear decrease in dry matter content.

Tubers. There was little effect of treatment on tuber fresh weight or dry weight, except at N_0 where weight of tubers was significantly greater with the low (I_0) than the high (I_1) moisture level.

The number of tubers with the low moisture level (I_0) decreased significantly with addition of nitrogen at the N_1 level, with little effect from further nitrogen additions. With the high moisture level (I_1) there was no significant effect of nitrogen.

Nitrogen level had little effect on dry matter content of tubers with the high moisture level (I_1), but with the low moisture level (I_0) fertiliser nitrogen reduced dry matter content appreciably but not significantly. Dry matter content was higher, at each nitrogen level, with the high moisture level (I_1).

Average tuber weight with the high moisture level (I_1) tended to increase with additions of nitrogen. With the low moisture level (I_0) average tuber weight was greater at N_0 than with the high moisture level (I_1), but application of nitrogen reduced the average weight of the tubers.

Stems and petioles. There was no significant effect of nitrogen on the fresh weight of stems and petioles with the low moisture level (I_0). With the high moisture level (I_1) however, application of nitrogen at the N_1 level significantly increased the fresh weight.

The dry weight was reduced by addition of nitrogen (at N_1) when no additional water (I_0) was added, but further additions of nitrogen had little effect. With the high moisture level (I_1) the dry weight of stems and petioles was lower than the low moisture level (I_0) at N_0 but addition of nitrogen at N_1 greatly increased the weight. Further additions of nitrogen however, gave a lower weight. Thus when nitrogen fertiliser was applied the weight of stems and petioles was increased by maintaining a high soil moisture level (I_1).

Dry matter content was decreased by additions of nitrogen to the N_2 level, with a slight increase at N_3. At all nitrogen levels dry matter content was lower with the high moisture level (I_1).

The addition of nitrogen (at N_1) significantly increased the concentration of nitrogen in the stems and petioles, but further additions only caused a slight increase. There was little effect of moisture level.

The nitrate-nitrogen concentration in the stems and petioles was increased, significantly, by addition of nitrogen at the N_1 level and was slightly increased at the N_2 level, but there was a decrease at N_3. There was no effect of soil moisture level.

The ratio of nitrate-nitrogen to total-nitrogen increased significantly with addition of nitrogen at N_1, regardless of moisture level. With the high moisture level (I_1) further additions of nitrogen decreased the ratio. With the low moisture level (I_0) the addition of nitrogen at N_2 gave a further increase in the ratio, but there was a decrease at N_3.

There was no significant effect of treatment on phosphorus concentration but there was a tendency, with the low moisture level (I_0), for a decrease at high nitrogen levels.

Although the effects of treatment on potassium concentration were not significant there was a tendency for an increase in concentration at low levels of nitrogen application but a decrease at high levels of nitrogen.

Leaves. When no additional water (I_0) was added the fresh weight and dry weight of the leaves decreased with additions of nitrogen. The addition of nitrogen at N_1 significantly increased the weight of leaves with the high moisture level (I_1), but further additions of nitrogen gave a lower weight of leaves. When nitrogen was added a greater weight of leaves was produced with the high (I_1) than the low (I_0) moisture level, but the difference was significant only at N_1.

The dry matter content of the leaves showed a significant soil moisture effect, being greater with the low moisture level (I_0).

The nitrogen concentration in the leaves increased very significantly with addition of nitrogen at the N_1 level, especially with the low moisture level (I_0). Further additions of nitrogen slightly increased the concentration of nitrogen in the leaves, more particularly with the high moisture level (I_1), giving little difference between moisture levels at N_3. At N_1 the high moisture level (I_1) was significantly lower than the low moisture level (I_0).

Phosphorus concentration increased significantly with addition of nitrogen at N_1 and gave a slight increase with addition of nitrogen at N_2. With the high moisture level (I_1) there was a further increase to N_3 but with the low moisture level (I_0) there was a decrease from N_2 to N_3.

Addition of nitrogen at the N_1 level significantly increased the potassium concentration of the leaves but further additions of nitrogen decreased it. The concentration at each nitrogen level was lower with the high moisture level (I_1).

The leaf area index followed the same pattern as the weight of leaves. Nitrogen decreased the area when no additional water (I_0) was added, but with the high moisture level (I_1) addition of nitrogen at N_1 increased leaf area, further additions of nitrogen decreased it. Leaf area was greater with the high moisture level (I_1) when nitrogen was applied but was smaller than the low moisture level (I_0) when no nitrogen was applied (N_0).

<u>Whole plant</u>. With the low moisture level (I_0) the total dry or fresh weight of the plant decreased with addition of nitrogen at the N_1 level but showed no difference between N_1, N_2 and N_3. When no nitrogen was added the high moisture level (I_1) gave a lower total yield than the low moisture level (I_0). With the addition of nitrogen however, yield increased to N_1 but decreased at higher levels. Thus total yield was greater with I_1 when nitrogen was applied.

At the low moisture level (I_0) total nitrogen uptake was slightly increased by addition of nitrogen at N_1, but further additions of nitrogen had little effect. Nitrogen uptake was lower at N_0 with the high (I_1) than with the low moisture level (I_0), but addition of nitrogen at N_1 with thehigh moisture level (I_1) increased the uptake significantly. The uptake was slightly less at N_2 and N_3. Thus a high soil moisture level (I_1) had increased nitrogen uptake when nitrogen was applied, but decreased it when no nitrogen was applied.

Total phosphorus and potassium uptake with the low moisture level (I_0) decreased with additions of nitrogen. However, with the high moisture level (I_1) the same trend as for nitrogen uptake was followed, uptake being greater with the high moisture level (I_1) when fertiliser nitrogen was applied but lower without it.

SAMPLING 2.

Soil Data. The nitrate-nitrogen concentration of the fertiliser band showed a highly significant linear increase with additions of nitrogen fertiliser. There was a slight tendency, at N_1 and N_2, for the nitrate concentration at the high moisture level (I_1) to be lower than at the low moisture level (I_0).

There was little difference in the ammonium concentrations at N_0 and N_1 but further additions of nitrogen increased the concentration, the difference between N_2 and N_3 being significant. When fertiliser nitrogen was added the ammonium concentration was lower with the high (I_1) than the low (I_0) moisture level.

The soil moisture content was higher with the high (I_1) than the low (I_0) moisture level and at both moisture levels was highest when no nitrogen was applied (N_0).

Conductivity increased with additions of fertiliser nitrogen. At low nitrogen levels the increase was not as great with the high moisture level (I_1) and so conductivity was lower than with the low moisture level (I_0). There was however, a very significant increase between N_2 and N_3 with the high moisture level (I_1) giving no difference between moisture levels at N_3.

The pH, in water and $CaCl_2$, tended to decrease with additions of nitrogen, except with the low moisture level (I_0) at N_3. The pH was generally greater with the high moisture level (I_1).

The "available phosphorus" and "available potassium" decreased with addition of nitrogen at the N_1 level but increased at higher levels of nitrogen. Both were lower when water (I_1) was added than without it (I_0).

Roots. The dry weight of roots increased with additions of nitrogen, except for a slight decrease between N_2 and N_3 at the high moisture level (I_1). The weight of root was greater, at each nitrogen level, with the high moisture level (I_1).

The nitrogen concentration in the roots increased with successive additions of nitrogen but the increase was greater with the low (I_0) than with the high (I_1) moisture level. Thus at N_1, N_2 and N_3 the high moisture level (I_1) had lower nitrogen concentrations in the roots than the low moisture level (I_0).

The nitrate-nitrogen concentration in the roots increased significantly with successive additions of nitrogen. The increases were not so great with the high (I_1) as the low (I_0) moisture level and so in the presence of fertiliser nitrogen the nitrate-nitrogen concentration was lowered by the addition of water (I_1). The ratio of nitrate-nitrogen to total-nitrogen followed the same pattern as the nitrate-nitrogen concentration.

There was no significant effect of treatment on phosphorus concentration of the roots.

Potassium concentration in the roots increased slightly with addition of nitrogen at N_1 but decreased with further additions of nitrogen. The concentration was lower with the high moisture level (I_1) at each nitrogen level.

Stolons. The wet weight of the stolons, with the high moisture level (I_1), increased with additions of nitrogen to the N_2 level, but decreased at N_3. With the low moisture level (I_0) there was an increase to N_1 but a decrease with further additions of nitrogen. The dry weight of the stolons showed basically the same trends as the wet weight. At all nitrogen levels the weight of stolons was greater at the high moisture level (I_1).

The dry matter content showed a highly significant linear decrease with additions of nitrogen. When no nitrogen was added the dry matter content was higher with the high moisture level (I_1) but with higher nitrogen levels (N_2 and N_3) dry matter content was lower with the high (I_1) than the low moisture level (I_0).

Tubers. The weight of tubers (fresh and dry) decreased with additions of nitrogen. The high moisture level (I_1) gave a lower weight of tubers at all nitrogen levels than the low moisture level (I_0).

Dry matter content of the tubers decreased with addition of nitrogen at the N_1 level. With further additions of nitrogen at the high moisture level (I_1) it remained the same but with the low moisture level (I_0) it increased. Dry matter content was always greater with the low moisture level (I_0).

With the high moisture level (I_1) the number of tubers increased with addition of nitrogen at the N_1 level but decreased at higher nitrogen levels. With the low moisture level (I_0) there was an increase to N_2 before a decline at N_3.

The average tuber weight (fresh and dry) decreased linearly with additions of nitrogen at the low moisture level (I_0). With the high moisture level (I_1) the average weight decreased with addition of nitrogen at the N_1 level, with little effect of higher nitrogen levels. Thus at low nitrogen levels (N_0 and N_1) the high moisture level (I_1) had smaller tubers, but there was little difference between moisture levels at high nitrogen levels (N_2 and N_3).

The nitrogen concentration of the tubers was increased significantly by addition of nitrogen at the N_1 level and slightly by further additions of nitrogen. The addition of water (I_1) increased nitrogen concentration at all nitrogen levels.

There was a significant increase in phosphorus concentration of the tubers by addition of water (I_1), but nitrogen had little effect.

Nitrogen, at the N_1 level, increased the potassium concentration of the tubers, but further additions caused a decrease.

Stems and petioles. The weight of stems and petioles (fresh and dry) was increased significantly by addition of nitrogen at N_1 but further additions of nitrogen only gave a slight increase at N_2 and a slight decrease at N_3. At all nitrogen levels there was a greater weight of stems and petioles with the high moisture level (I_1).

The dry matter content decreased significantly with addition of nitrogen at the N_1 level. Further additions of nitrogen gave an increased dry matter content with the low moisture level (I_0) but with the high moisture level (I_1) there was a decrease at the high nitrogen level (N_3). The dry matter content at each nitrogen level was higher with the low (I_0) than the high (I_1) moisture level, the difference being significant at N_0 and N_3.

Addition of nitrogen at the N_1 level increased the nitrogen concentration significantly. Further additions of nitrogen had no significant effect, but there was a tendency for a further increase at higher nitrogen levels. There was little effect of moisture level.

The nitrate-nitrogen concentration was increased significantly by the addition of nitrogen at the N_1 level and further additions of nitrogen caused a slight increase. When nitrogen fertiliser was applied nitrate concentration was slightly lowered by the application of water (I_1).

The ratio of nitrate-nitrogen to total-nitrogen showed similar trends to the nitrate concentration. The difference between moisture levels was greater at N_1 and N_3 than at N_2.

There were no significant effects of treatment on the phosphorus or potassium concentration of the stems and petioles. There was a tendency for the phosphorus concentration to be higher with the high moisture level (I_1) and the potassium concentration to be higher with the low moisture level (I_0).

Leaves. The weight of leaves (fresh and dry) was increased significantly by nitrogen at the N_1 level. With the high moisture level (I_1) there was a slight increase to N_2 but with the low moisture level (I_0) there was little difference between N_1 and N_2. There was a decrease in the weight of leaves at N_3. At all nitrogen levels the high moisture level (I_1) gave a greater weight of leaves.

There was little difference between leaf dry matter content at N_0, N_1 and N_2, but there was an increase at N_3. The low moisture level (I_0) had a higher dry matter content at all nitrogen levels and was significantly greater than the high moisture level (I_1) at N_1 and N_3.

The nitrogen concentration of the leaves increased significantly with additions of nitrogen up to the N_2 level, but there was no significant difference between N_2 and N_3. There was no effect of moisture level.

The phosphorus concentration of the leaves with the low moisture level (I_0) increased with application of nitrogen up to the N_2 level, with no difference between N_2 and N_3. With the high moisture level (I_1) there was a significant increase with addition of nitrogen at the N_1 level, but the phosphorus concentration was lower at higher nitrogen levels. There was a significant difference between the two moisture levels at N_1.

The application of nitrogen at the N_1 level significantly increased the potassium concentration of the leaves, but there was a decrease at higher nitrogen levels.

With the low moisture level (I_0) the leaf area index was significantly increased with the addition of nitrogen at the N_1 level, but further additions of nitrogen decreased the leaf area. There was also a significant increase in the leaf area with addition of nitrogen at N_1 with the high moisture level (I_1) and also a slight increase to N_2 before a slight decrease in leaf area at N_3. Leaf area index was greater with the high (I_1) than the low (I_0) moisture level at each nitrogen level, the difference being significant at N_2.

Whole plant. The total dry weight of the plant increased with addition of nitrogen at the N_1 level, showed little difference between N_1 and N_2 and decreased at N_3. There was no effect of soil moisture level. Total fresh weight showed basically the same pattern as the dry weight, except that at each nitrogen level the high moisture level (I_1) gave a greater wet weight. Thus the moisture level had little effect on dry matter production but affected the dry matter content.

The total nitrogen uptake was increased significantly by addition of nitrogen at N_1 and slightly increased at N_2, but was reduced by N_3. There was no effect of soil moisture level.

The total uptake of phosphorus showed a similar pattern to that of nitrogen uptake. Potassium uptake increased with addition of nitrogen at N_1, showed little difference at N_2 and decreased at N_3. There was no effect of soil moisture level.

SAMPLING 3.

Soil data. The nitrate concentration in the fertiliser band showed a significant linear response to nitrogen. With the low moisture level (I_0) there was a significant increase with each addition of nitrogen, but with the high moisture level (I_1) the increase with addition of nitrogen was significant only between N_2 and N_3. Thus in the presence of nitrogen fertiliser the nitrate concentration was lower at the high moisture level (I_1), the difference being significant at N_2 and N_3.

With the high moisture level (I_1) there were no significant differences between the ammonium concentration at each nitrogen level, but there was a tendency for an increase at high nitrogen levels. With the low moisture level (I_0) the increase at high nitrogen levels was more marked and the difference between N_2 and N_3 was significant, as also was the difference between the two moisture levels at N_3.

With both moisture levels, soil moisture content was lowered when nitrogen was added at the N_1 level, and also at the N_2 level with the high moisture treatment (I_1). At greater nitrogen levels the soil moisture content was higher. The high moisture level (I_1) gave a higher soil moisture content than the low moisture level (I_0) at all nitrogen levels except N_2.

The conductivity increased slightly with addition of nitrogen at N_1, with little difference between moisture levels. With the low moisture level (I_0) a further addition of nitrogen (N_2) increased the conductivity significantly and so gave a significantly higher value than the high moisture level (I_1) at N_2. The high moisture level (I_1) was also lower at the N_3 level, but not significantly.

The pH, in water and $CaCl_2$, decreased with additions of nitrogen. With the high moisture level (I_1) there was little difference between the pH at N_1 and N_2 and with the low moisture level (I_0) little difference between N_2 and N_3. Thus the only significant difference between moisture levels was at N_2, where the high moisture level (I_1) was greater than the low moisture level (I_0).

There was little effect of treatment on "available phosphorus" except for a slight tendency with the low moisture level (I_0) for an increase with additions of nitrogen to the N_2 level, and for the high moisture level to show a decrease.

"Available potassium" decreased with addition of nitrogen at the N_1 level and further to the N_2 level with the high moisture level (I_1). The low moisture level (I_0) increased from N_1 to N_2 giving a significant difference between the moisture levels at N_2. There was an increase from N_2 to N_3 with the high moisture level (I_1).

Roots. The dry weight of roots increased significantly with addition of nitrogen at the N_1 level. With the high moisture level (I_1) this weight of roots was maintained at higher nitrogen levels, but with the low moisture level (I_0) there was an almost significant decrease from N_1 to N_2, with a slight increase at N_3.

The nitrogen concentration in the roots showed a significant linear increase with addition of nitrogen up to the N_2 level, with little difference between N_2 and N_3. There was no significant effect of moisture level.

The nitrate concentration in the roots increased linearly with addition of nitrogen to the N_2 level, with little difference between N_2 and N_3. In the presence of nitrogen fertiliser addition of water (I_1) slightly reduced the nitrate concentration. A similar pattern was shown by the ratio of nitrate-nitrogen to total-nitrogen.

The phosphorus concentration tended to increase with additions of nitrogen, except between N_2 and N_3 with the low moisture level (I_0) where there was a decrease in concentration.

With the low moisture level (I_0) successive applications of nitrogen caused a decrease in the potassium concentration in the roots. Except for a slight increase between N_0 and N_1, the effect was the same with the high moisture level (I_1). At all nitrogen levels the low moisture level (I_0) gave higher potassium concentrations than the high moisture level (I_1).

Stolons. With the high moisture level (I_1) the wet weight of stolons increased with successive additions of nitrogen, although the increase was less at high nitrogen levels. With the low moisture level (I_0) there was an increase with addition of nitrogen at N_1, but a decrease at higher levels of nitrogen. At all nitrogen levels the high moisture level (I_1) gave a greater weight of stolons, being significantly higher than the low moisture level (I_0) at N_3.

The dry weight of stolons showed a similar pattern to the wet weight, except that with the high moisture level (I_1) there was a decrease from N_2 to N_3.

With the low moisture level (I_0) there was no significant effect of nitrogen on the dry matter content of stolons. With the high moisture level (I_1) there was a decrease with addition of nitrogen from N_0 to N_1 and from N_2 to N_3, with little difference between N_1 and N_2. At N_0 the high moisture level (I_1) gave a significantly higher dry matter content than the low moisture level (I_0) but the reverse was the case at higher nitrogen levels, the difference being significant at N_3.

Tubers. The fresh weight of tubers increased with addition of nitrogen from N_0 to N_1. At higher nitrogen levels the weight of tubers declined with the low moisture level (I_0) but was maintained at the same level by addition of water (I_1). At all nitrogen levels the yield of tubers was greater with the high moisture level (I_1), the difference being significant at N_3.

The dry weight of tubers with the low moisture level (I_0) showed little difference between N_0 and N_1, but decreased at higher levels of nitrogen. With the high moisture level (I_1) the dry yield of tubers increased with addition of nitrogen at N_1 but decreased with a further increase to N_2. There was little difference between N_2 and N_3. At N_0 there was little difference between moisture levels, but when nitrogen was added yield was greater with the high (I_1) than the low (I_0) moisture level.

Tuber dry matter content, with the low moisture level (I_0), decreased with additions of nitrogen to N_2, with little difference between N_2 and N_3. With the high moisture level (I_1) there was little difference between dry matter content at N_0 and N_1 or between N_2 and N_3, although there was a decrease between N_1 and N_2.

With the addition of nitrogen at N_1 tuber number increased with the low moisture level (I_0) but decreased with the high moisture level (I_1), giving a significant difference between the two moisture levels at N_1. There was little difference between moisture levels at N_2 and N_3.

Average tuber weight, fresh anddry, with the low moisture level (I_0) tended to decrease with additions of nitrogen. With the high moisture level (I_1) average tuber weight increased with addition of nitrogen at N_1 but decreased at higher levels of nitrogen. Average tuber weight was greater with the high moisture level (I_1) when nitrogen fertiliser was added.

Tuber nitrogen concentration increased with additions of nitrogen to N_2, with a slight decline at N_3. When nitrogen fertiliser was added nitrogen concentration in the tubers was lowered by addition of water (I_1).

Phosphorus content of the tubers was little affected by nitrogen level at the high moisture level (I_1). At the low moisture level (I_0) phosphorus concentration increased with addition of nitrogen to N_2 and decreased at N_3.

The addition of nitrogen at N_1 significantly increased the potassium concentration in the tubers, but there was a decrease at higher levels of nitrogen. At N_1 and N_2 the addition of water (I_1) lowered the potassium concentration.

Stems and petioles. The weight of stems and petioles (fresh and dry) increased significantly with addition of nitrogen at N_1 but there was little difference between N_1 and N_2. With the high moisture level (I_1) there was a further increase to N_3 but with the low moisture level (I_0) the weight decreased at N_3. At each nitrogen level the high moisture level (I_1) gave a greater weight of stems and petioles, being significantly greater than the low moisture level (I_0) at N_1, N_2 and N_3.

Dry matter content of the stems and petioles with the low moisture level (I_0) was little affected by nitrogen level. There were also no significant differences between nitrogen levels at the high moisture level (I_1) but N_1 did give rather a low dry matter content.

The nitrogen concentration increased significantly with additions of nitrogen from N_0 to N_1 and N_1 to N_2, but there was little difference between N_2 and N_3. Soil moisture level had little effect.

Nitrate concentration in the stems and petioles increased with additions of nitrogen, although the increases were not as great at higher nitrogen levels. The nitrate concentration was lowered by addition of water (I_1), significantly so at N_3.

The ratio of nitrate-nitrogen to total-nitrogen was increased significantly with addition of nitrogen at the N_1 level, but further increments of nitrogen only brought about slight rises in the ratio. The ratio was lowered by the addition of water (I_1), particularly at high nitrogen levels.

With the high moisture level (I_1) phosphorus concentration tended to increase with additions of nitrogen but with the low moisture level (I_0) this increase was apparent only to N_2, with a decrease at N_3. The phosphorus concentration at N_2 was significantly greater with the low moisture level (I_0).

Potassium concentration increased significantly with addition of nitrogen at the N_1 level and decreased at higher nitrogen levels, more particularly with the high moisture level (I_1).

<u>Leaves</u>. With the high moisture level (I_1) the fresh weight and dry weight of leaves was significantly increased by the addition of nitrogen at the N_1 level, but there was little difference between N_1 and N_2. There was a further increase to N_3, significantly for the dry weight. The low moisture level (I_0) increased with addition of nitrogen at N_1, but the weight of leaves decreased at higher nitrogen levels. Addition of water (I_1) increased the weight of leaves at all nitrogen levels, wet weight being significantly greater at N_1, N_2 and N_3 and the dry weight at N_3.

The dry matter content of the leaves increased significantly with the addition of nitrogen at N_1, but there were no significant differences at higher nitrogen levels. The dry matter content was significantly greater with the low moisture level (I_0) at all nitrogen levels.

The nitrogen concentration in the leaves increased linearly with additions of nitrogen to N_2, but there was little difference between N_2 and N_3. There was no effect of soil moisture level.

Addition of nitrogen to the N_2 level significantly increased phosphorus concentration in the leaves. There was no difference between N_2 and N_3.

Potassium concentration increased significantly with the addition of nitrogen at N_1, but decreased at higher rates of nitrogen.

The leaf area index was significantly increased by the addition of nitrogen at N_1, but there was little difference between N_1 and N_2. With the high moisture level (I_1) there was a further increase to N_3 but with the low moisture level (I_0) there was a decrease from N_2 to N_3. At all nitrogen levels the leaf area index was increased by the addition of water (I_1), being significantly greater than the low moisture level (I_0) at N_1 and N_3.

Whole plant. The total dry weight and total fresh weight of the plant increased with addition of nitrogen at the N_1 level. With the low moisture level (I_0) further additions of nitrogen decreased plant weight. With the high moisture level (I_1) there was little difference between N_1, N_2 and N_3. Total plant weight was greater with the high moisture level (I_1) when nitrogen fertiliser was applied, the difference between the high (I_1) and the low (I_0) moisture levels being significant for fresh weight at N_2 and N_3 and for dry weight at N_3.

The total uptake of nitrogen increased significantly with the addition of nitrogen at the N_1 level, and with the high moisture level (I_1) increased slightly at the N_2 and N_3 levels. With the low moisture level (I_0) there was little difference between N_1 and N_2 with a decline at N_3, giving a significant difference between moisture levels at N_3.

Uptake of phosphorus was increased by addition of nitrogen at the N_1 level, the increase being significant for the high moisture level (I_1). There was a slight decrease in uptake with addition of nitrogen from N_1 to N_2, and a further decrease with the low moisture level (I_0) at N_3. The high moisture level (I_1) gave an increase in uptake between N_2 and N_3, giving a significant difference between moisture levels at N_3.

There was a significant increase in total potassium uptake with addition of nitrogen at the N_1 level, followed by a decrease at N_2. There was a further decrease at the N_3 level with the low moisture level (I_0) but little difference between N_2 and N_3 with the high moisture level (I_1). When fertiliser nitrogen was added the uptake of potassium was always greater with the high moisture level (I_1), being significantly greater than the low moisture level (I_0) at N_3.

SAMPLING 4.

Soil data. There was little difference between the nitrate concentration in the fertiliser band at N_0 and N_1 with both moisture levels. At higher levels of nitrogen the nitrate concentration increased linearly with addition of nitrogen. At all nitrogen levels the nitrate concentration was lower with the high moisture level (I_1).

The only effect of treatment on the ammonium concentration was at the high nitrogen level (N_3). The addition of nitrogen at N_3 increased the ammonium concentration above that at N_2, the increase being significant with the low moisture level (I_0). The ammonium concentration was significantly greater with the low (I_0) than the high (I_1) moisture level at N_3.

Soil moisture content tended slightly to decrease with addition of nitrogen at N_1 but increased at N_2. There was a slight decrease at N_3 but the differences between nitrogen levels were not significant. At all nitrogen levels the soil moisture content was higher with the high (I_1) than the low (I_0) moisture level, the difference being significant at N_0.

There was a significant linear increase in conductivity with addition of nitrogen, but there was little marked effect of moisture level.

Soil pH, in water and $CaCl_2$, showed a highly significant linear decrease with additions of nitrogen. At all nitrogen levels soil pH was greater with the high (I_1) than the low (I_0) moisture level.

With the high moisture level (I_1) the "available phosphorus" in the soil decreased with additions of nitrogen. With the low moisture level (I_0) there were no significant differences between nitrogen levels.

The "available potassium" in the soil decreased with additions of nitrogen up to N_2, with a slight increase at N_3.

Tubers. With the low moisture level (I_0) tuber fresh weight and dry weight increased slightly with addition of nitrogen at the N_1 level, but decreased at higher levels of nitrogen. With the high moisture level (I_1) tuber fresh weight and dry weight increased with addition of nitrogen at N_1 (the increase being significant for the wet weight) but there were no significant differences at higher nitrogen levels. At all nitrogen levels tuber weight was greater with the high (I_1) than the low (I_0) moisture level, the difference being highly significant at N_3 and nearly significant at N_1 and N_2.

The dry matter content of the tubers was decreased significantly by addition of nitrogen at the N_1 level, but there was little difference with further additions of nitrogen. Dry matter content was higher, at each nitrogen level, with the high (I_1) than the low (I_0) moisture level, the difference being significant at N_0 and N_3.

Although there were no significant differences between tuber number with different treatments there was a tendency for the number of tubers to increase with additions of nitrogen. At all nitrogen levels the high moisture level (I_1) gave more tubers.

The average weight of the tubers (fresh and dry) increased with addition of nitrogen at the N_1 level, but decreased at higher levels of nitrogen (the difference between N_2 and N_3 with the low moisture level (I_0) was significant). At all nitrogen levels average tuber weight was greater with the high moisture level (I_1). The difference was significant at N_3 for both fresh and dry average weight.

Tuber nitrogen concentration increased significantly with successive additions of nitrogen, except with the low moisture level (I_0) where there was little difference between N_2 and N_3. At all nitrogen levels the concentration was significantly higher with the low (I_0) than the high (I_1) moisture level.

There was a significant linear increase in tuber phosphorus concentration with additions of nitrogen. At each nitrogen level the concentration was higher with the low moisture level (I_0).

Potassium concentration increased significantly with addition of nitrogen at the N_1 level, but tended to decrease slightly at higher nitrogen levels. At all nitrogen levels the low moisture level (I_0) gave a higher concentration than the high moisture level (I_1).

<u>Stems and petioles</u>. With the high moisture level (I_1) the fresh weight and dry weight of stems and petioles gave a significant linear increase with additions of nitrogen. With the low moisture level (I_0) there was an increase

with addition of nitrogen to N_2 but little difference between N_2 and N_3. At all nitrogen levels the high moisture level (I_1) gave a greater weight than the low moisture level (I_0), the difference being significant at N_3.

There was little effect of nitrogen level on dry matter content, except for a low dry matter at N_2 with the low moisture level (I_0). The dry matter content tended to be higher with low (I_0) than the high (I_1) moisture level.

Addition of nitrogen gave a significant linear increase in the nitrogen concentration of the stems and petioles. Addition of water (I_1) lowered the concentration at all nitrogen levels, the difference being significant at N_3 and nearly significant at N_2.

The nitrate-nitrogen concentration gave a highly significant linear increase with additions of nitrogen, with little effect of moisture level.

With the high moisture level (I_1) the ratio of nitrate-nitrogen to total-nitrogen increased linearly, but with the low moisture level (I_0) although there was a linear increase to N_2 there was little difference between N_2 and N_3. Thus at N_3 the ratio was significantly higher with the high (I_1) than the low (I_0) moisture level.

The phosphorus concentration increased with successive additions of nitrogen, except with the high moisture level (I_1) where there was little difference between N_2 and N_3. The concentration was higher at each nitrogen level with the low moisture level (I_0).

There were no significant differences between the potassium concentration of the stems and petioles with different treatments.

Leaves. With the high moisture level (I_1) the fresh weight and dry weight of leaves increased linearly with additions of nitrogen. With the low moisture level (I_0) there was a significant increase with addition of nitrogen at the

N_1 level and a slight increase at the N_2 level, but there was a decrease to N_3. The weight of leaves was greater with the high (I_1) than the low (I_0) moisture level at all nitrogen levels (except the dry weight at N_0), the difference being significant at N_3.

The dry matter content of the leaves tended to increase with additions of nitrogen. At all nitrogen levels dry matter content was significantly lowered by addition of water (I_1).

Nitrogen concentration in the leaves increased linearly with additions of nitrogen. Addition of water (I_1) lowered the nitrogen concentration at N_2 and N_3.

There was a significant linear increase in phosphorus concentration with addition of nitrogen, with little effect of moisture level.

The addition of nitrogen at the N_1 level significantly increased the potassium concentration of the leaves. With the high moisture level (I_1) further additions of nitrogen decreased the concentration, but with the low moisture level (I_0) there was an increase to N_2 and a decrease at N_3.

The potassium concentration was generally lowered by the addition of water (I_1).

The leaf area index follwed the same trends as the weight of leaves.

Whole plant. The total dry weight of the plant increased with addition of nitrogen at the N_1 level (significantly with the high moisture level, I_1). With the low moisture level (I_0) further additions of nitrogen gave a decrease in total dry weight. With the high moisture level (I_1) there was little difference between N_1 and N_2 but a significant increase to N_3. Total dry weight was increased significantly by addition of water (I_1) at N_2 and highly significantly at N_3.

The total fresh weight showed similar trends to the dry weight.

There was a highly significant linear increase of nitrogen uptake with additions of nitrogen at the high moisture level (I_1). This was also the case with the low moisture level (I_0), except for a decrease between N_2 and N_3 which gave a significant difference between moisture levels at N_3.

The effect of treatment on phosphorus uptake was similar to that for nitrogen, and potassium uptake followed a somewhat similar pattern.

SAMPLING 5.

Soil data. With the high moisture level (I_1) there were no significant differences between the nitrate concentrations at different nitrogen levels, but there was a tendency for nitrate concentration to increase at high nitrogen levels. With the low moisture level (I_0), which always gave a higher nitrate concentration than the high moisture level (I_1), the increase with higher nitrogen levels was more marked. The difference between moisture levels at N_3 was significant.

There was little effect of nitrogen level on the ammonium concentration with the high moisture level (I_1). With the low moisture level however, there was an increase from N_1 to N_2 and a significant increase from N_2 to N_3. The ammonium concentration was always higher with the low moisture level (I_0), being significantly greater than the high moisture level (I_1) at N_3.

The soil moisture content tended to decrease with additions of nitrogen. The high moisture level (I_1) had a higher moisture content at all nitrogen levels except N_0.

With the high moisture level (I_1) conductivity was not significantly affected by nitrogen level. The low moisture level (I_0) showed a similar trend, except that there was a significant increase from N_2 to N_3. The conductivity was reduced at all nitrogen levels by the addition of water, significantly so at N_3.

There was little effect of nitrogen level on the soil pH, in water or $CaCl_2$, with the high moisture level (I_1), but with the low moisture level (I_0) soil pH decreased linearly with additions of nitrogen. The soil pH in water was significantly lower at N_2 and N_3 with the low moisture level (I_0) but only at N_3 when measured in $CaCl_2$.

There were no significant effects of treatment on the "available phosphorus" in the soil but the "available potassium" tended to decrease with additions of nitrogen.

<u>Tubers</u>. The fresh weight of tubers tended to increase slightly with additions of nitrogen at the low moisture level (I_0). At the high moisture level (I_1) the fresh weight of tubers increased significantly with the addition of nitrogen at N_1, with a slight decrease at higher nitrogen levels. When nitrogen fertiliser was added the high moisture level (I_1) gave a greater fresh weight of tubers than the low moisture level (I_0), the difference being significant at N_1 and N_2.

The dry weight of tubers showed basically the same trends as the fresh weight, except that there was little difference between nitrogen levels at the low moisture level (I_0).

Tuber dry matter content decreased significantly with addition of nitrogen at N_1 and tended to decrease further at higher levels of nitrogen. The high moisture level (I_1) tended to give a greater dry matter content than the low moisture level (I_0).

There was no significant effect of treatment on tuber number, but there was a tendency for fewer tubers when no additional nitrogen was added and for tuber number to be lower with the low moisture level (I_0).

With the low moisture level (I_0) the average tuber weight (fresh and dry) tended to decrease with addition of nitrogen at N_1, with little effect of further additions of nitrogen. With the high moisture level (I_1) the addition of nitrogen at N_1 increased the average weight, but further additions of nitrogen gave a decrease. At N_0 the low moisture level (I_0) gave larger tubers than the high moisture level (I_1), but when nitrogen was added this was reversed.

The tuber nitrogen concentration showed a significant increase with additions of nitrogen. The concentration was lowered by the addition of water (I_1), significantly so at N_0 and N_1.

There was a significant linear increase in phosphorus concentration with addition of nitrogen, but little effect of moisture level.

Tuber potassium concentration was increased significantly by addition of nitrogen at N_1. With further additions of nitrogen at the low moisture level (I_0) there was a decrease in potassium concentration, but at the high moisture level (I_1) there was an increase to N_2 before a decrease at N_3. The addition of water (I_1) reduced the potassium concentration significantly at N_0 and N_1.

Stems and Petioles. The fresh weight and dry weight of stems and petioles showed a highly significant linear increase with additions of nitrogen. The addition of water (I_1) increased the weight when nitrogen was added.

There was a highly significant linear increase in dry matter content with addition of nitrogen, but little effect of moisture level.

With the low moisture level (I_0) additions of nitrogen increased the nitrogen concentration linearly. With the high moisture level (I_1) there was little difference between N_0 and N_1, but a significant increase at N_2 and a further slight increase at N_3. The addition of water (I_1) lowered the nitrogen concentration at all nitrogen levels.

The nitrate-nitrogen concentration and the ratio of nitrate-nitrogen to total-nitrogen showed the same pattern as the nitrogen concentration, except that there was no significant increase with addition of nitrogen at N_1 with both moisture levels.

The addition of nitrogen from N_0 to N_1 and from N_2 to N_3 had little effect on the phosphorus concentration, but there was a significant increase between N_1 and N_2.

With the high moisture level (I_1) nitrogen decreased the potassium concentration linearly. With the low moisture level (I_0) there was an increase with addition of nitrogen at N_1, but further additions of nitrogen caused a decrease. When nitrogen fertiliser was added potassium concentration was significantly lowered by addition of water (I_1).

<u>Leaves</u>. The fresh weight and dry weight of leaves showed a highly significant linear increase with additions of nitrogen. There was little effect of moisture level.

Dry matter content tended to decrease with additions of nitrogen, being lower with the high moisture level (I_1).

Nitrogen concentration increased linearly with additions of nitrogen, the increase being greater with the low moisture level (I_0). At all nitrogen levels nitrogen concentration was lowered by addition of water (I_1).

Phosphorus concentration tended to increase with additions of nitrogen, with little effect of moisture level.

Potassium concentration was increased significantly by addition of nitrogen at N_1, but there were no significant differences at higher levels of nitrogen.

Leaf area index gave a highly significant linear increase with additions of nitrogen. At each nitrogen level leaf area was greater with the high moisture level (I_1).

Whole Plant. At the low moisture level (I_0) the total fresh weight and dry weight of the plant was increased by successive additions of nitrogen. At the high moisture level (I_1) the total weight was increased significantly by addition of nitrogen at the N_1 level, with little effect of further additions of nitrogen. When nitrogen fertiliser was added the total weight was increased at each nitrogen level by addition of water (I_1), significantly at N_1 and N_2.

There was a significant linear increase in total nitrogen uptake with additions of nitrogen, the increase being greater with the high moisture level (I_1). Addition of water at N_1 and N_2 increased nitrogen uptake.

With the low moisture level (I_0) phosphorus uptake increased linearly with additions of nitrogen. With the high moisture level (I_1) there was a significant increase from N_0 to N_1, with a slight increase at higher nitrogen levels. The addition of water (I_1) significantly increased phosphorus uptake at N_1 and N_2.

The addition of nitrogen at N_1 increased the uptake of potassium, but further additions had little effect. When nitrogen fertiliser was added potassium uptake was increased by addition of water (I_1).

SAMPLING 6.

Tubers. The fresh weight and the dry weight of tubers increased linearly with additions of nitrogen to the N_2 level, but further additions caused a slight decrease. At all nitrogen levels yield of tubers was highest with the high moisture level (I_1), there being a significant effect of irrigation.

Tuber dry matter content decreased significantly with addition of nitrogen at N_1. With the high moisture level (I_1) further additions of nitrogen had little effect, but with the low moisture level (I_0) dry matter content increased at high rates of nitrogen. At N_3 dry matter content was significantly higher with the low (I_0) than the high (I_1) moisture level.

The number of tubers increased with additions of nitrogen to the N_2 level, but further additions (to N_3) slightly decreased the number. The addition of water (I_1) tended to decrease the number of tubers, except at N_0.

With the low moisture level (I_0) there was little effect of nitrogen level on the average weight of the tubers. With the high moisture level (I_1) the addition of nitrogen at the N_1 level increased the average tuber weight (Significantly for the average fresh weight). Further additions of nitrogen tended to lower the average weight. At all nitrogen levels the addition of water (I_1) increased the average tuber weight. The increase was significant for the average fresh weight at N_1, N_2 and N_3 and was significant for the average dry weight at N_1 and N_2.

The nitrogen concentration of the tubers with the high moisture level (I_1) increased linearly with additions of nitrogen. With the low moisture level (I_0) there was an increase with additions of nitrogen to N_2, but little difference between N_2 and N_3. Nitrogen concentration was significantly higher at N_0 and N_2 with the low (I_0) than the high moisture level (I_1).

Tuber phosphorus concentration gave a significant linear increase with additions of nitrogen.

With the low moisture level (I_0) additions of nitrogen decreased the potassium concentration in the tubers. With the high moisture level (I_1) there was an increase with addition of nitrogen at N_1, but a decrease with further additions of nitrogen. The only significant effect of moisture level was at N_0 where the potassium concentration was significantly lowered by addition of water (I_1).

Stems and Petioles. With the low moisture level (I_0) the fresh weight and the dry weight of stems and petioles increased with successive additions of nitrogen. With the high moisture level (I_1) the weight increased with additions of nitrogen to the N_2 level, the increase from N_1 to N_2 being highly significant. There was a slight decrease with addition of nitrogen at N_3. Thus at N_2 the weight of stems and petioles was significantly increased by addition of water (I_1).

The dry matter content with the low moisture level (I_0) decreased with additions of nitrogen. The high moisture level (I_1) was very similar to this, except at N_0 where it gave a significantly higher dry matter content than the low moisture level (I_0).

The nitrogen concentration of the stems and petioles tended to increase with additions of nitrogen, but there were no significant differences between N_0, N_1 and N_2 at either moisture level. There was however, a significant increase with addition of nitrogen at N_3.

There was little difference between the nitrate concentration at N_0 and N_1 with either moisture level, but addition of nitrogen at N_2 and N_3 significantly increased the concentration, in particular with the low moisture level (I_0). Addition of water (I_1) decreased the nitrate concentration at N_3 and significantly decreased it at N_2.

The ratio of nitrate-nitrogen to total-nitrogen showed similar trends to the nitrate concentration.

With the low moisture level (I_0) phosphorus concentration was significantly lower with N_1 than with any other nitrogen level. With the high moisture level (I_1) there was a decrease in phosphorus concentration with addition of nitrogen to N_2, but there were no significant differences between N_0, N_1 and N_3. At N_2

the concentration was significantly lowered by addition of water (I_1).

There was no significant effect of treatment on the potassium concentration, but there was a tendency for an increase with addition of nitrogen at N_1, with a decrease at higher levels of nitrogen, especially when water was added (I_1).

Leaves. The fresh weight and the dry weight of the leaves increased slightly with addition of nitrogen at N_1 and showed a significant increase with addition of nitrogen at N_2. There was a further slight increase to N_3 but no effect of soil moisture level.

There were no significant differences in dry matter content of the leaves between nitrogen levels at either moisture level, but there was a tendency for dry matter content to be lower at N_0 than at the other nitrogen levels with the high moisture level (I_1). Dry matter content was lowered by the addition of water (I_1) at each nitrogen level, but this was significant only at N_0.

The nitrogen concentration in the leaves increased linearly with additions of nitrogen. There was a slight tendency for nitrogen concentration to be lowered by the addition of water (I_1), especially at N_0.

There were no significant effects of treatment on phosphorus concentration, but there was a significant linear increase in potassium concentration with additions of nitrogen.

The leaf area index showed the same trends as the leaf weight, but there was a tendency at high nitrogen levels (N_2 andN_3) for leaf area to be increased by addition of water (I_1).

Whole plant. The total fresh weight and the total dry weight of the plant increased with additions of nitrogen up to the N_2 level, but there was little difference between N_2 and N_3. At all nitrogen levels total weight was increased by the addition of water, but the increase was significant only at N_2.

The total uptakes of nitrogen, phosphorus and potassium increased with addition of nitrogen ~~at N_1 and increased significantly with addition of nitrogen~~ at N_1 and increased significantly with addition of nitrogen at N_2. There was little difference between N_2 and N_3.

SAMPLING 7.

Yield of tubers. (Appendix, Tables 56 and 60).

There were no significant treatment effects on theyield of tubers of fractions A and B. All other fractions showed significant nitrogen effects and apart from fractions C and B+C significant soil moisture effects. There were significant interactions between soil moisture and nitrogen for fractions C, D and B+C.

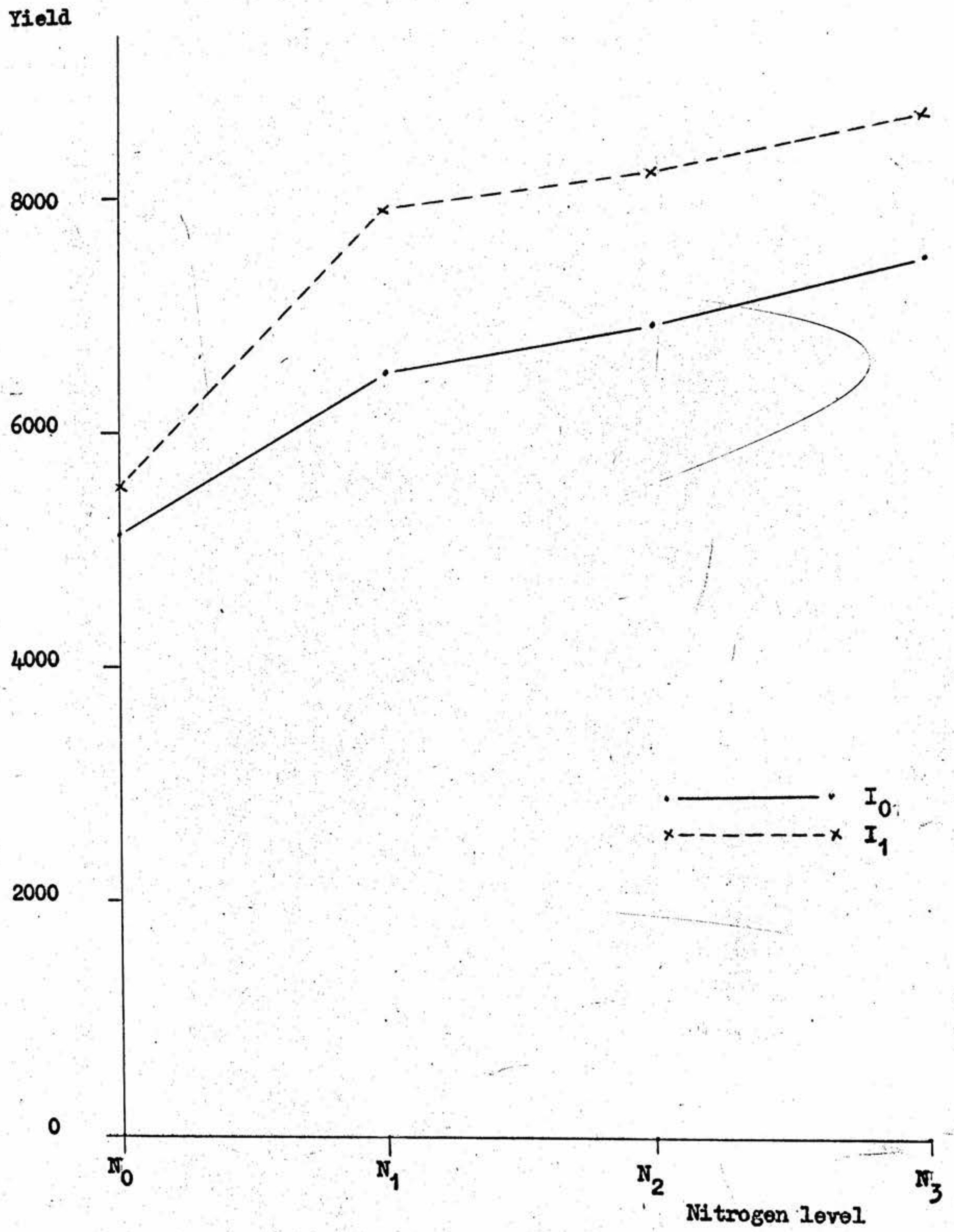
Total yield. (Figure 54). Since fraction A had little effect on total yield, saleable yield (fraction B+C+D) and total yield (fraction A+B+C+D) were considered the same.

With the low moisture level (I_0), total yield increased significantly with addition of nitrogen at the N_1 level, but further additions of nitrogen gave only a slightly increased yield. This was also the pattern for the high moisture level (I_1), but the increase from N_0 to N_1 was highly significant. Thus, although there was little difference between yields at N_0, when nitrogen fertiliser was added yield was increased by addition of water at I_1, the increases being significant at N_1 and N_2.

Yield of different size fractions. Although there were no significant effects of treatment on fractions A and B the yield of fraction B tended to decrease with additions of nitrogen.

Yield of fraction C, with the high moisture level (I_1), decreased with successive additions of nitrogen. With the low moisture level (I_0) there was

Figure 54. Experiment 3. Total tuber yield, g / 8 plants.



little difference between N_0, N_1 and N_2 but a significant decrease from N_2 to N_3. The only significant difference between moisture levels was at N_2 where the low moisture level (I_0) gave a higher yield than the high moisture level (I_1).

Fraction D gave a highly significant linear increase in yield with additions of nitrogen. The increases were greater with the high moisture level (I_1). There was little difference between moisture levels at N_0 but when nitrogen fertiliser was added yield was increased by the addition of water (I_1), the increase being significant at N_2.

The yield of fraction B+C showed the same trends as fraction C and fraction B+C+D showed the same trends as fraction D, the increase from addition of water being significant at N_1 and N_2.

Summary. (Figures 55 - 57). The main effect of addition of water was to increase yield when nitrogen fertiliser was added. There was little difference in yield of tubers of fractions A, B and C with the two moisture levels, except with the low moisture level (I_0) at N_2 where a high yield of fraction C was accompanied by a low yield of fraction D. Thus the main difference between moisture levels was due to the D fraction.

The seed/total ratio (B+C/A+B+C+D) decreased with successive additions of nitrogen with the high moisture level (I_1) due to a large decrease in yield of fraction B+C and an increase in yield of large tubers (fraction D). With the low moisture level (I_0) there was a decrease in the ratio with addition of nitrogen from N_0 to N_1 and from N_2 to N_3, but little difference between N_1 and N_2. This was because there was little difference between yields of fractions B+C and D at N_1 and N_2. When nitrogen fertiliser was added the ratio was lowered by the addition of water (I_1), significantly at N_2.

Figure 55. Experiment 3. Yield of tubers of different fractions, g / 8 plants.

Low moisture level, I_0.

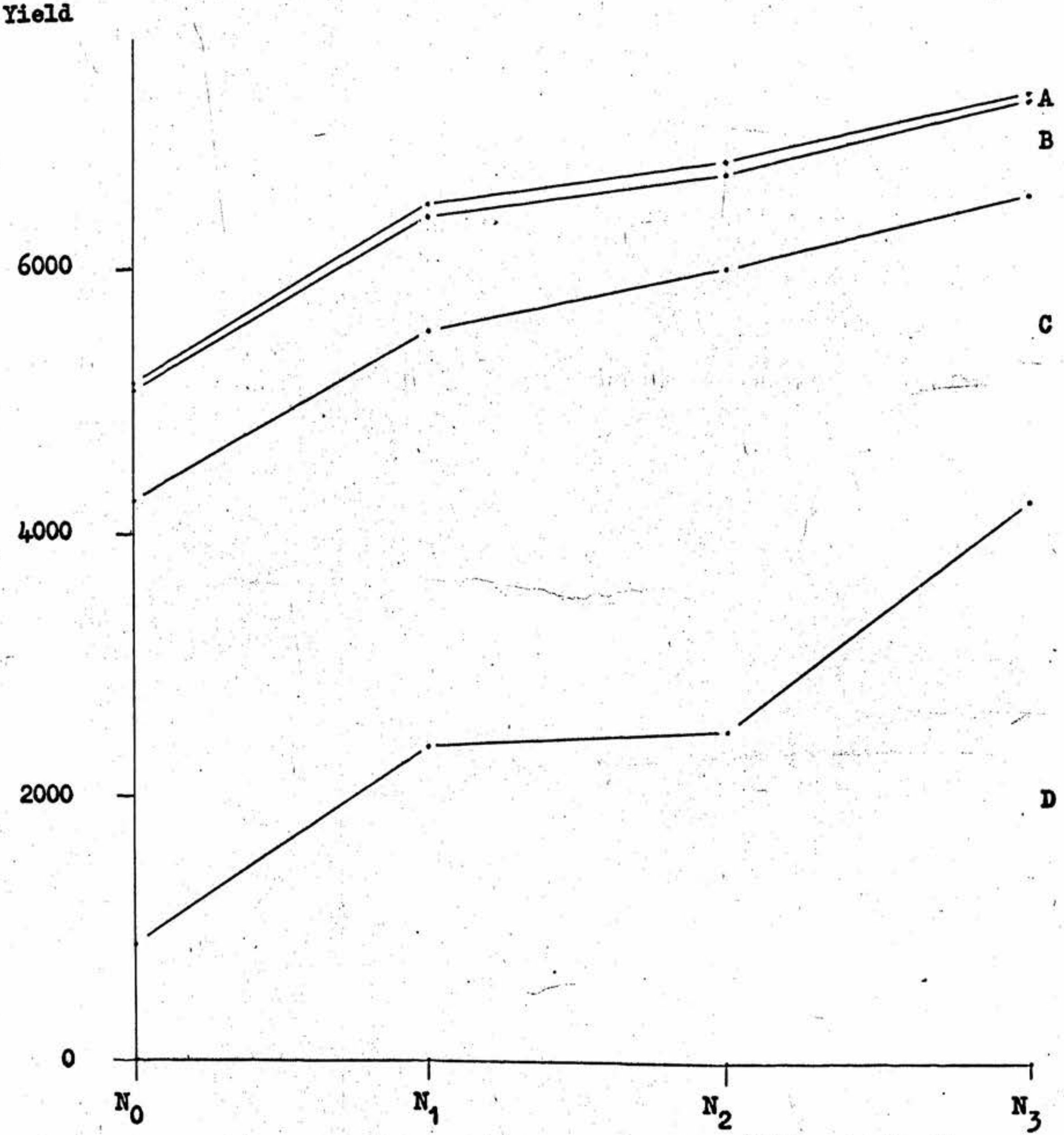


Figure 56. Experiment 3. Yield of tubers of different fractions, g / 8 plants.

High moisture level, I_1.

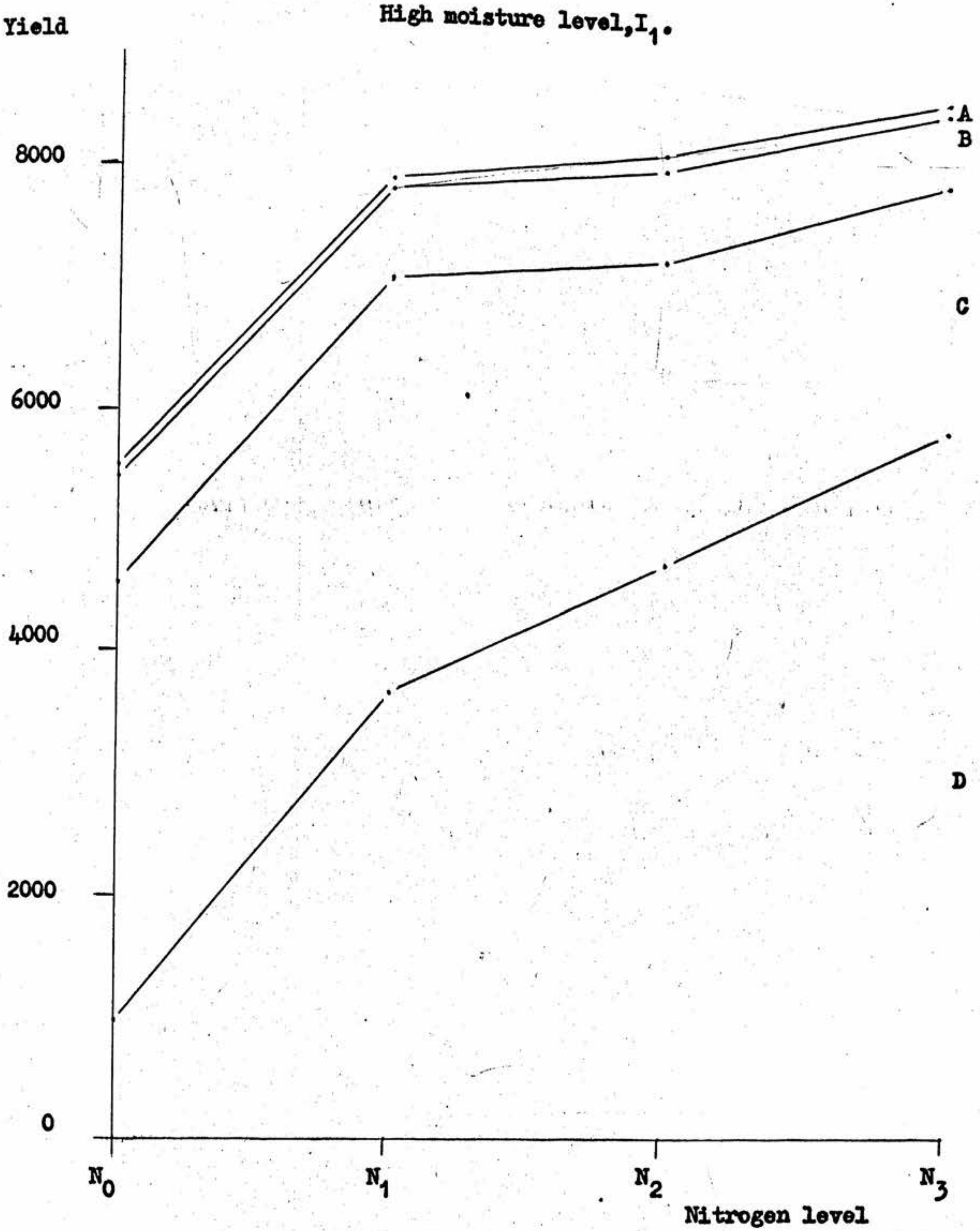


Figure 57. Experiment 3. Seed / Total ratio for weight of tubers.

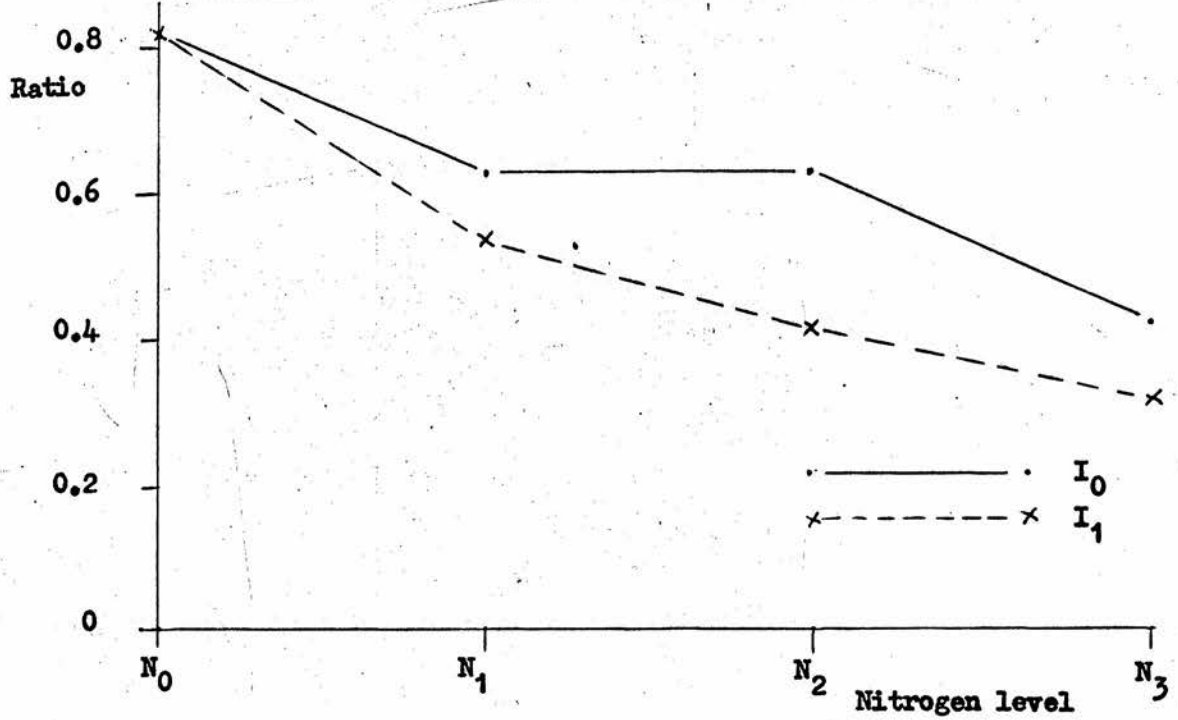
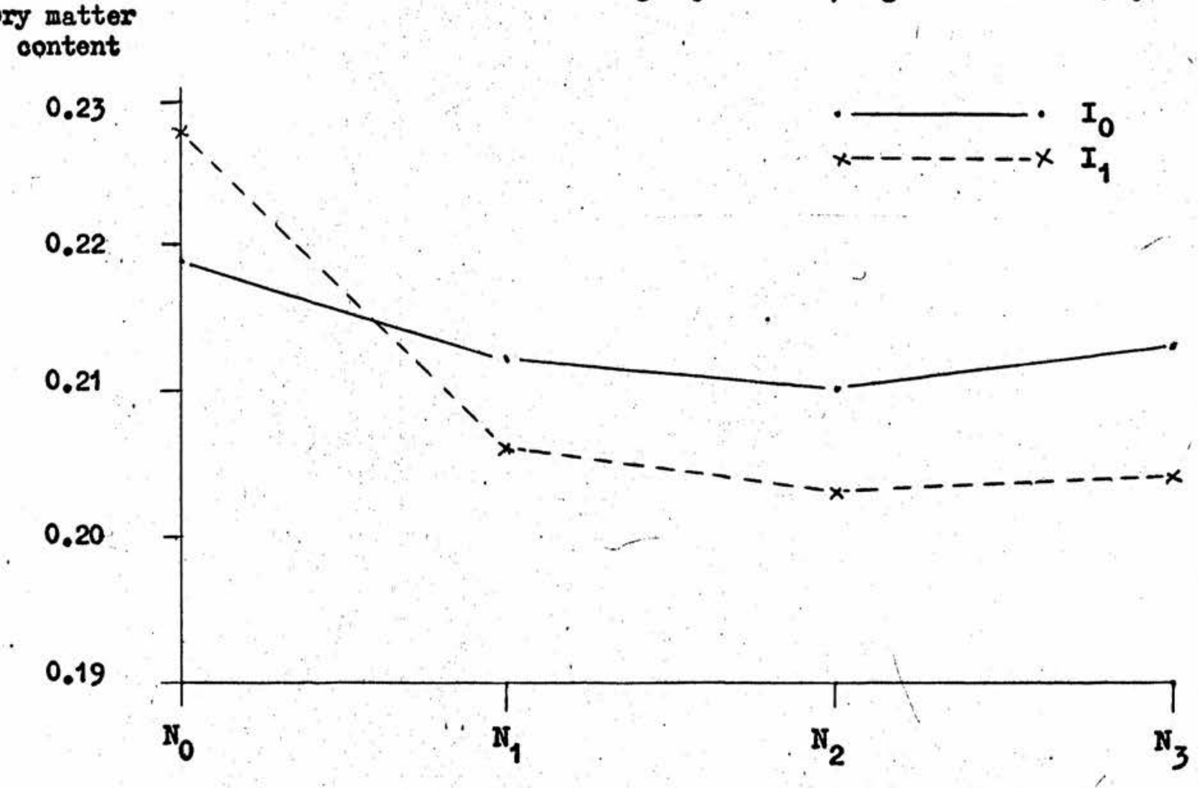


Figure 58. Experiment 3. Tuber dry matter content fraction B+C+D, kg dry matter / kg fresh material.



The dry weight of tubers (Appendix, Table 57) followed similar trends to the tuber yield (fresh weight).

Dry matter content. (Appendix, Table 58).

Overall (Figure 58) the dry matter content of the tubers decreased with addition of nitrogen at N_1 (significantly for the high moisture level, I_1), with little difference at higher nitrogen levels. At N_0 dry matter content was higher with the high moisture level (I_1) but at higher nitrogen levels this was reversed. Similar patterns were shown for fractions C and B+C.

Fraction D showed a somewhat similar trend but at all nitrogen levels dry matter content was lowered by addition of water (I_1).

The dry matter content of fraction B with the high moisture level (I_1) tended to decrease with additions of nitrogen, but with the low moisture level (I_0) there was a decrease to N_1 with little difference between the higher nitrogen levels.

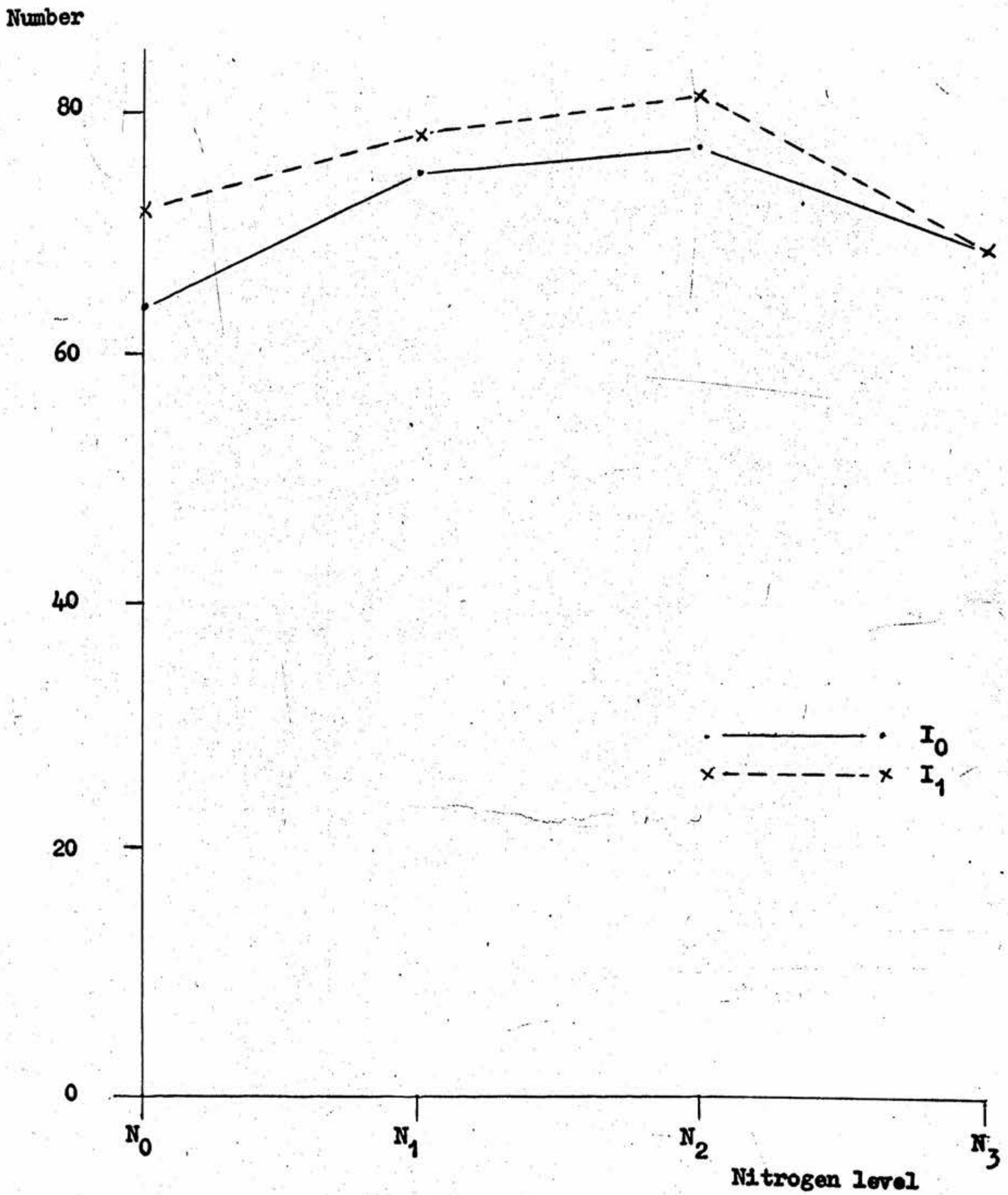
Tuber number. (Appendix, Tables 59 and 61).

Statistical analysis was carried out by logarithmic transformation. There were significant effects of nitrogen on all fractions and groupings of fractions except B. There was a significant soil moisture effect for fraction D and a significant soil moisture - nitrogen interaction for fraction A.

Total number of tubers. (Figure 59). Additions of nitrogen to the N_2 level increased the total number of tubers, but there was a decrease at N_3. There was a tendency at low nitrogen levels for a greater number of tubers with the high moisture level (I_1).

Number of tubers in different size fractions. There was a tendency for the number of tubers in fraction A to increase with addition of nitrogen to N_2, but decrease at N_3.

Figure 59. Experiment 3. Total tuber number / 8 plants.



Fraction B showed a tendency for tuber number to decrease with additions of nitrogen. This was also apparent for fraction C with the high moisture level (I_1), but with the low moisture level (I_0) there was little difference between N_0, N_1 and N_2 and a significant decrease at N_3.

The number of fraction D tubers increased with successive additions of nitrogen, the increases being greater with the high moisture level (I_1). There was no difference between moisture levels at N_0, but with the addition of fertiliser nitrogen the number of tubers was increased by the addition of water (I_1).

Fraction B+C was similar in pattern to fraction C and fraction B+C+D similar to the total number of tubers, except with the high moisture level (I_1) which had a greater number of tubers at N_1 than at N_2.

Summary. (Figures 60-62). At N_0 the increase in number of tubers with the high moisture level (I_1) was due to an increase in number of tubers in the A and B fractions. The total number of tubers increased with addition of nitrogen at N_1, mainly because of an increase in D fraction tubers. The increase in fraction D was greater with the high moisture level (I_1) and so gave a slightly greater total number of tubers than the low moisture level. At N_2 the low moisture level (I_0) had a large number of fraction C tubers, but this was to some extent compensated by a low number of fraction B and D tubers. Again there was an increase in the number of D fraction tubers with addition of nitrogen from N_1 to N_2. At N_3 the number of tubers of fraction D increased, but the other fractions tended to decrease in number. With the low moisture level (I_0) there were fewer tubers in the D fraction but a greater number of tubers of the small size fractions gave the same total number as the high moisture level (I_1).

Figure 60. Experiment 3. Number of tubers of different size fractions / 8 plants.

Low moisture level, I_0.

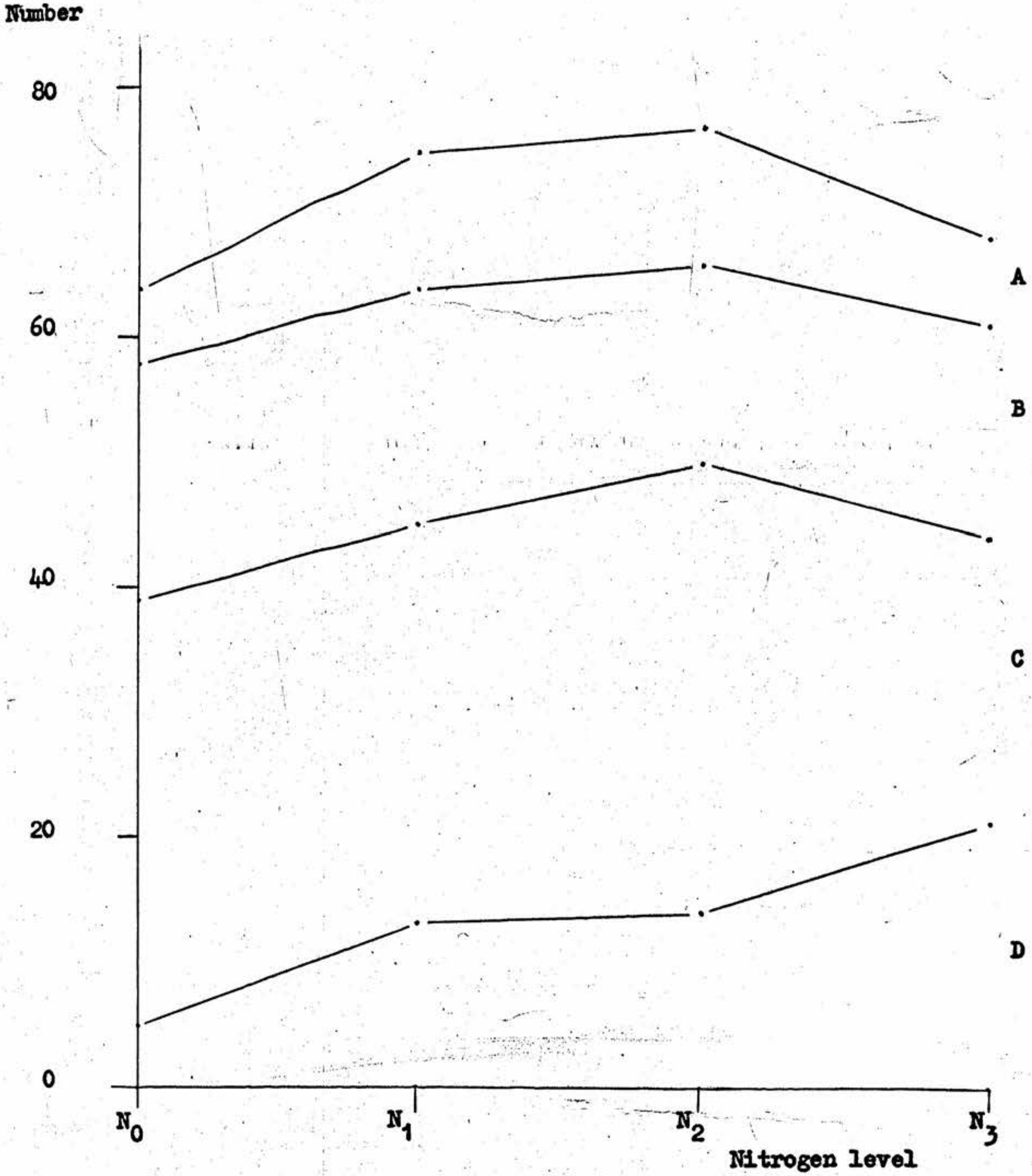


Figure 61. Experiment 3. Number of tubers of different size fractions / 8 plants.

High moisture level, I_1.

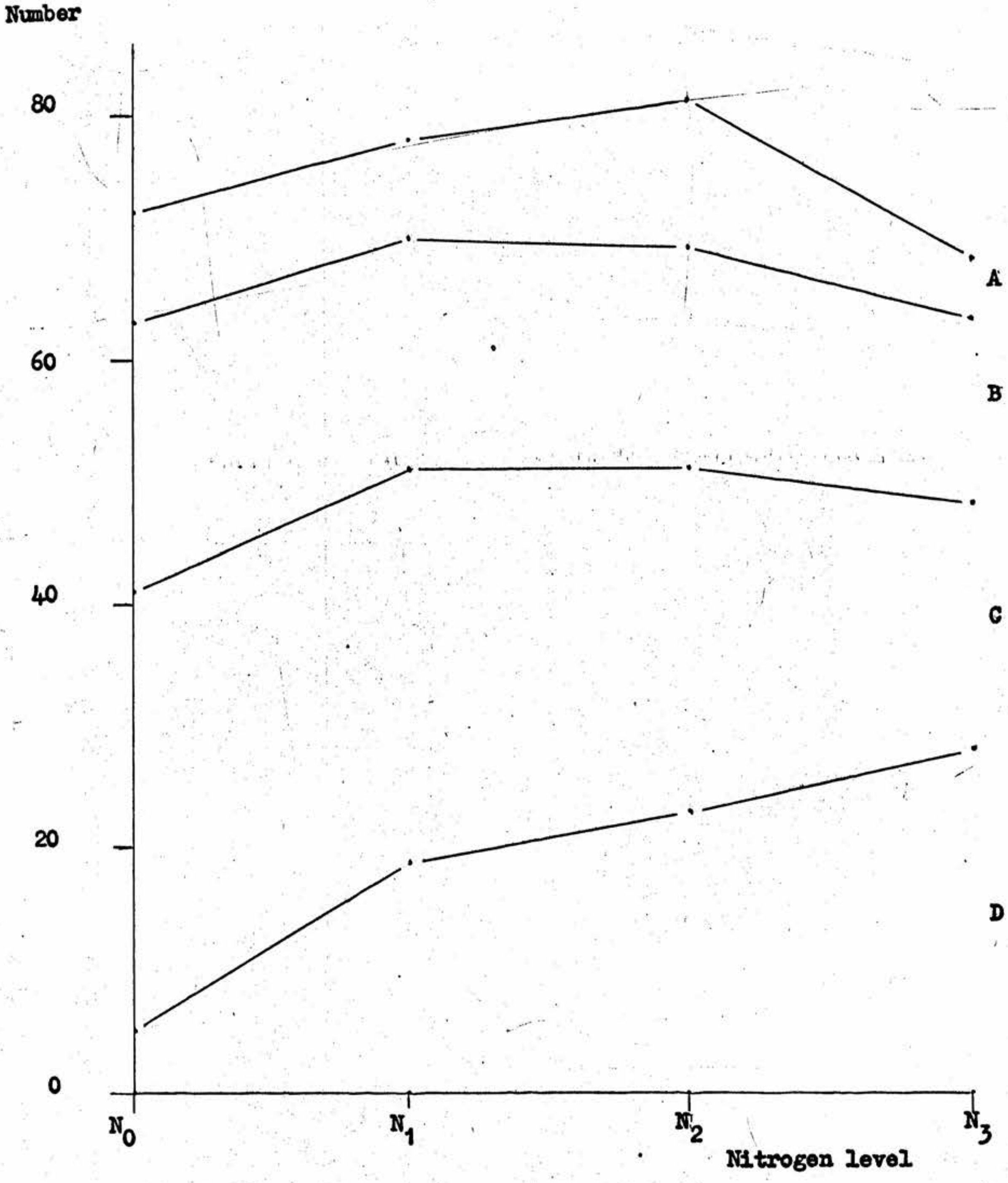
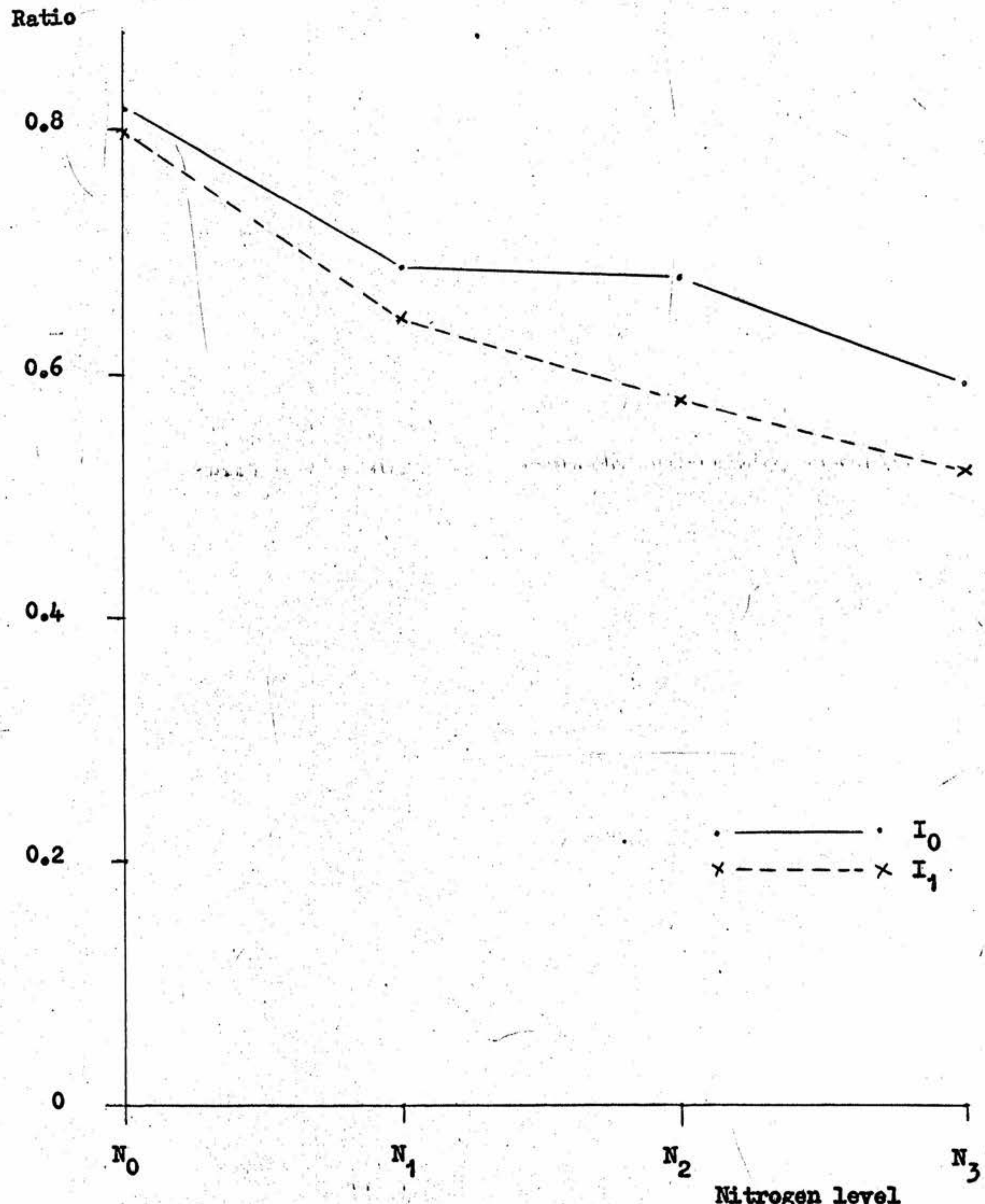


Figure 62. Experiment 3. Seed / Total ratio for tuber number.



There was a significant linear decrease in the ratio of seed/total with addition of nitrogen, the decrease being greater with the high moisture level (I_1) because of a more marked increase in the number of fraction D tubers and a greater decrease in fraction C tubers. The ratio was lowered at all nitrogen levels by addition of water (I_1).

Average tuber fresh weight. (Appendix, Table 63).

With the high moisture level (I_1) the average weight of fraction A decreased with addition of nitrogen at N_1, but there was little effect of higher nitrogen levels. With the low moisture level (I_0) there was little effect of nitrogen at low levels, but a significant increase with addition of nitrogen from N_2 to N_3.

With the high moisture level (I_1) there was no effect of nitrogen on fraction B. However, at N_0, N_1 and N_2 average tuber weight was greater with the low moisture level (I_0), but at N_3 there was a decrease in average tuber weight with the low moisture level (I_0) giving little difference between moisture levels.

There was little effect of treatment on fractions C or B+C.

The average fresh weight of tubers in fractions D, B+C+D and A+B+C+D increased linearly with additions of nitrogen. At all nitrogen levels, except N_0, average weight was increased by addition of water.

The only difference between average fresh weight and average dry weight (Appendix, Table 64) was shown by fraction B where average dry weight decreased linearly with additions of nitrogen and average dry weight was lowered by the addition of water (I_1).

N, P and K concentration of tuber dry matter.

Nitrogen. (Appendix, Table 65). The nitrogen concentration of all size fractions increased linearly with additions of nitrogen to the N_2 level. The concentration was generally significantly greater with the low (I_0) than the high (I_1) moisture level. With fraction B there was no difference between nitrogen concentration at N_2 and N_3. With the other fractions there was a further increase to N_3, the increase being less with the low moisture level (I_0) and so there was no difference between moisture levels at N_3.

Phosphorus. (Appendix, Table 66). With all size fractions, phosphorus concentration tended to increase linearly with additions of nitrogen, except with the low moisture level (I_0) where there was a tendency for phosphorus concentration to decrease from N_2 to N_3.

Potassium. (Appendix, Table 67). With the low moisture level (I_0) the potassium concentration of all size fractions tended to increase with additions of nitrogen to N_2, but decreased at N_3. With the high moisture level (I_1) there was an increase in potassium concentration with addition of nitrogen at N_1, but a decrease with further additions of nitrogen. At N_2 and N_3 the potassium concentration of fractions C, D, B+C and B+C+D was lowered by addition of water.

Sugar concentration of tubers. (Appendix, Table 62).

Reducing sugar. The reducing sugar concentration of fraction C+D tended to decrease with successive additions of nitrogen. At all levels, except N_2, the concentration was increased significantly by addition of water (I_1).

Sucrose. Sucrose concentration increased with additions of nitrogen to N_2, but there was little difference between N_2 and N_3. At all nitrogen levels the concentration was lowered by addition of water (I_1), significantly at N_1, N_2 and N_3.

Total sugar. The total sugar concentration was lowered significantly by addition of nitrogen at N_1, but there were no significant differences at higher nitrogen levels. The concentration was higher with the high moisture level (I_1) at all nitrogen levels, except N_2.

CHANGES DURING THE SEASON.

Growth record. (Figures 63 to 65).

Emergence at 37 days after planting tended to decrease with additions of nitrogen.

Haulm height at 82 days increased with additions of nitrogen, except at N_3 with the high moisture level (I_1). At N_1 and N_2 the haulm height was greater with the high moisture level (I_1).

Haulm colour at 82 days was darker with the addition of nitrogen, except at N_3 with the high moisture level (I_1). At N_0 the haulm was lighter with the high (I_1) than the low (I_0) moisture level.

Soil data.

Nitrate concentration. (Figure 66). Early in the season nitrate-nitrogen concentration, in the fertiliser band, increased linearly with addition of nitrogen, but by sampling 4 there was little difference between N_0 and N_1. The concentration decreased with time, especially with the high moisture level (I_1), and by sampling 5 there was little difference between nitrogen levels with the high moisture level (I_1), although there was still a marked increase in concentration at high nitrogen levels with the low moisture level (I_0). At N_2 and N_3 with the low moisture level (I_0) there was little change from sampling 1 to sampling 3, but with the high moisture level (I_1) there was a marked decrease.

Figure 63. Experiment 3. Emergence at 37 days,%.

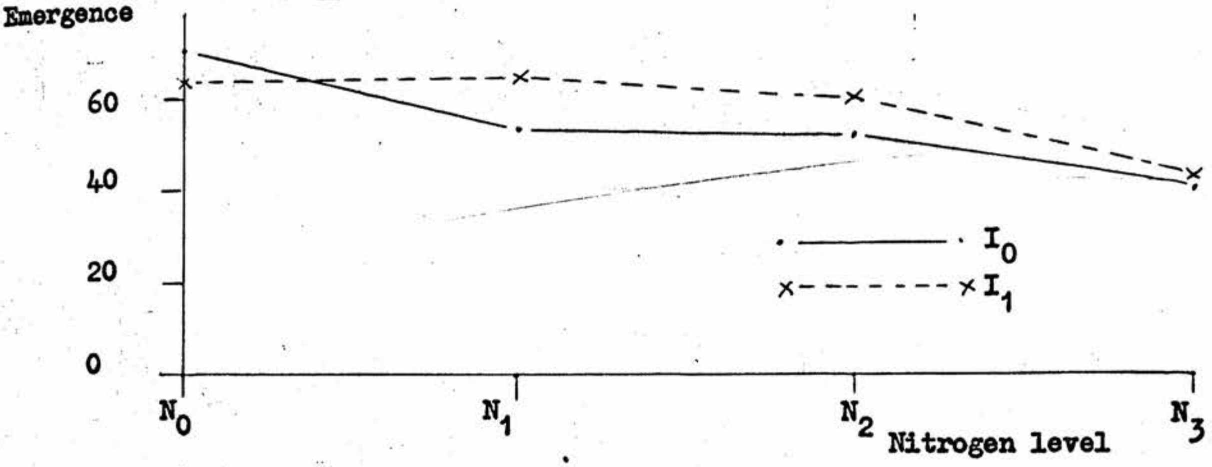


Figure 64. Experiment 3. Haulm height estimate at 82 days.

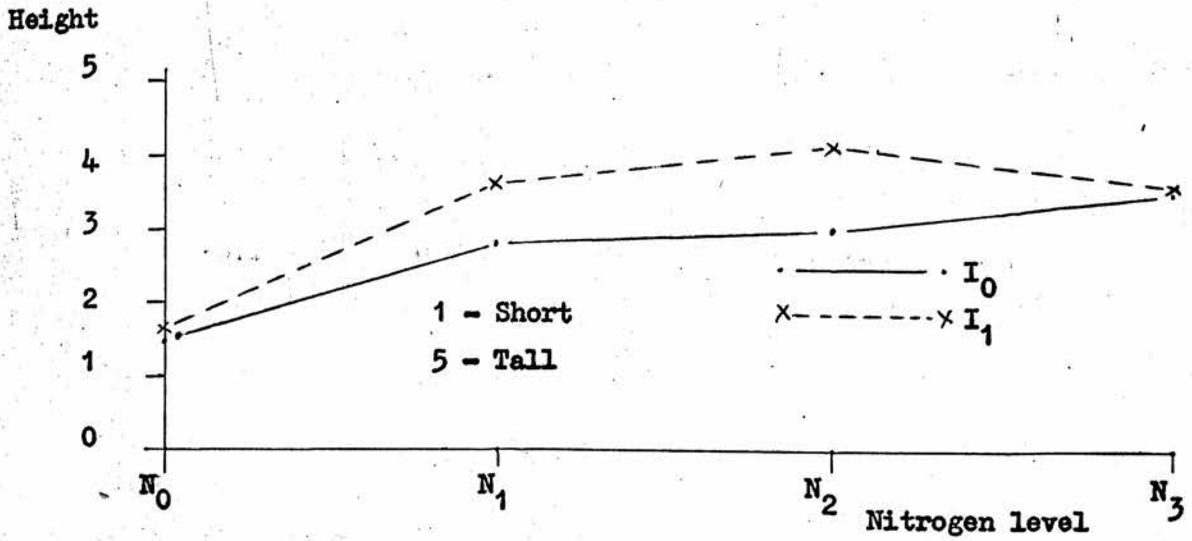


Figure 65. Experiment 3. Haulm colour estimate at 82 days.

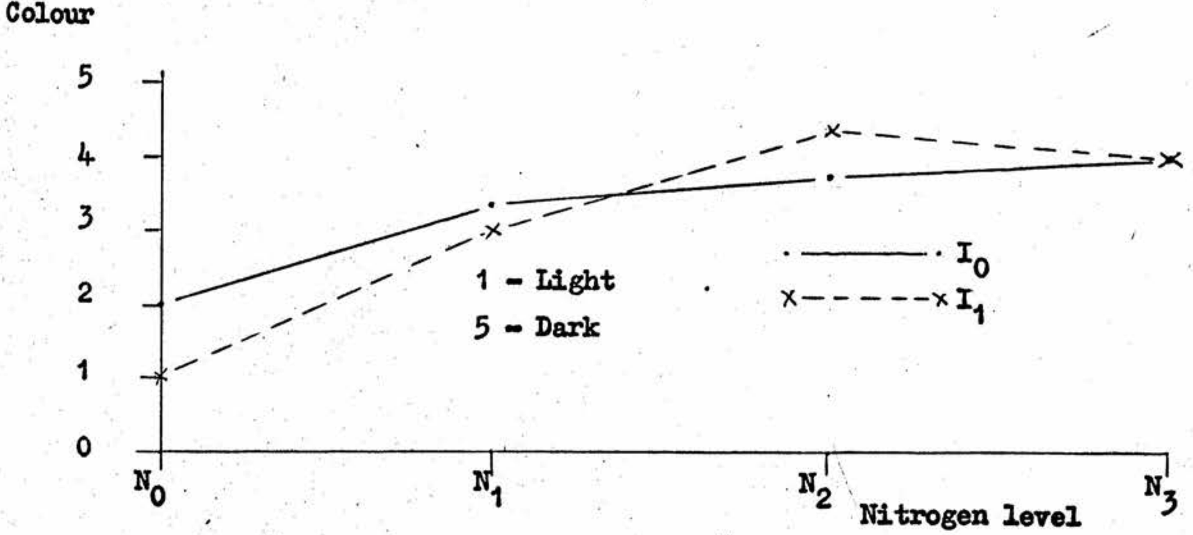


Figure 66. Experiment 3. Soil nitrate concentration, µg nitrate-nitrogen / g soil.

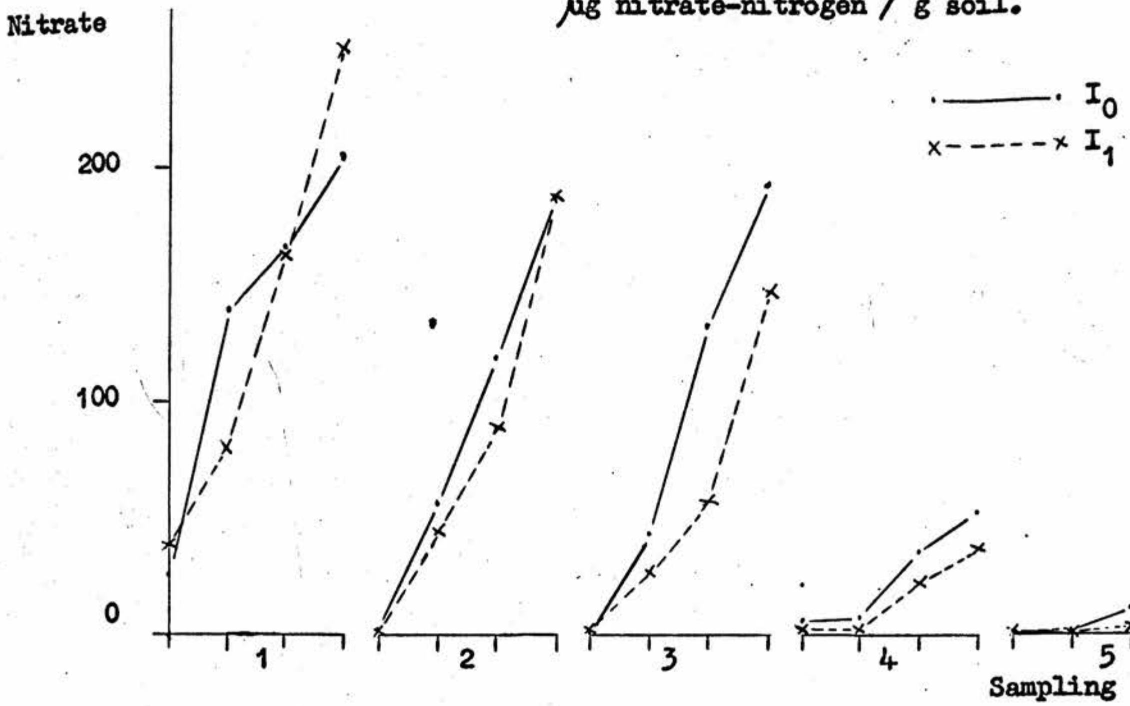
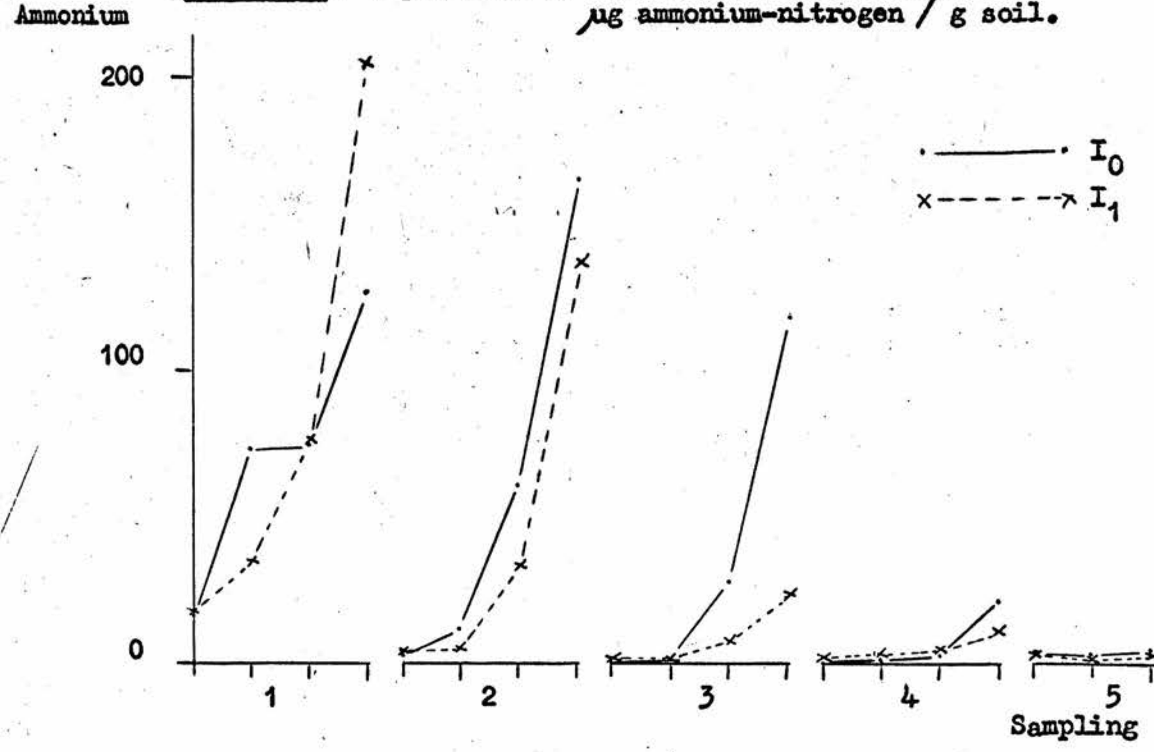


Figure 67. Experiment 3. Soil ammonium concentration, µg ammonium-nitrogen / g soil.



The abscissa at each sampling represents rate of nitrogen.

Ammonium concentration. (Figure 67). In a similar manner to nitrate concentration ammonium concentration at sampling 1 increased linearly with addition of nitrogen. There was however, a more rapid decrease in ammonium concentration with time, especially with the high moisture level (I_1). By sampling 3 there was little difference between nitrogen levels with the high moisture level (I_1), although the concentration was still higher at high nitrogen levels with the low moisture level (I_0). At sampling 5 there was little difference between treatments, except for a significantly higher concentration at N_3 with the low moisture level (I_0).

Soil moisture. The largest changes in soil moisture were with time. At sampling 3, when the soil moisture content was very low, there was little difference between moisture levels, especially at N_2 and N_3. Early in the season there was a tendency for a lower moisture content at N_1, but by sampling 5 moisture content tended to decrease with additions of nitrogen.

Conductivity. (Figure 68). There was a decrease in conductivity with time, especially with the high moisture level (I_1). At sampling 2 there was little difference between conductivity at N_0, N_1 and N_2 with the high moisture level (I_1). There was little major difference between treatments at samplings 4 and 5, except for a high conductivity at N_3 with the low moisture level (I_0). Early in the season soil moisture had little effect on conductivity at N_3. There was little effect of moisture level at N_0.

pH. Soil pH (in water) tended to increase with time, the effect being slightly more marked with the high moisture level (I_1). Addition of fertiliser nitrogen gave a linear decrease in pH, but by sampling 5 there was little effect of nitrogen at the high moisture level (I_1). There was little effect of moisture level early in the season.

Figure 68. Experiment 3. Conductivity of saturated soil paste, μ mhos cm^{-1}

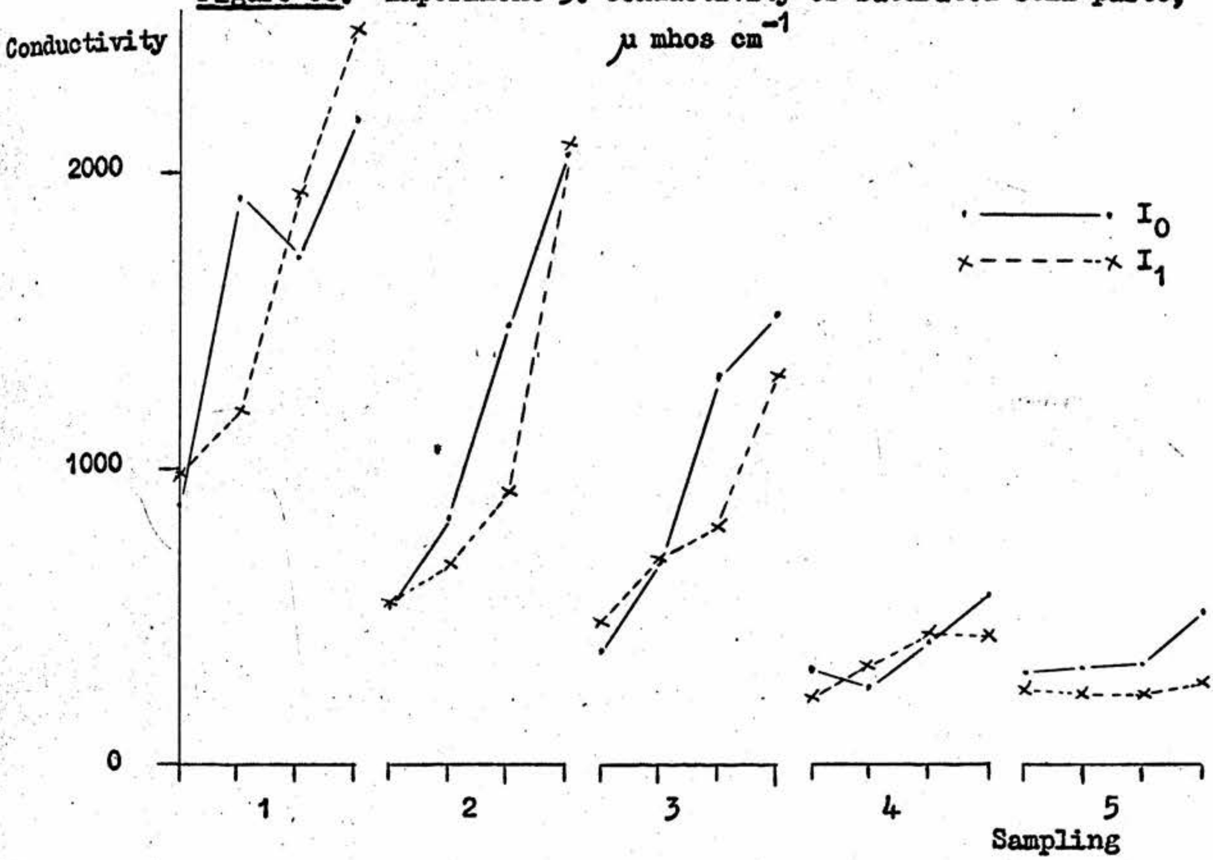
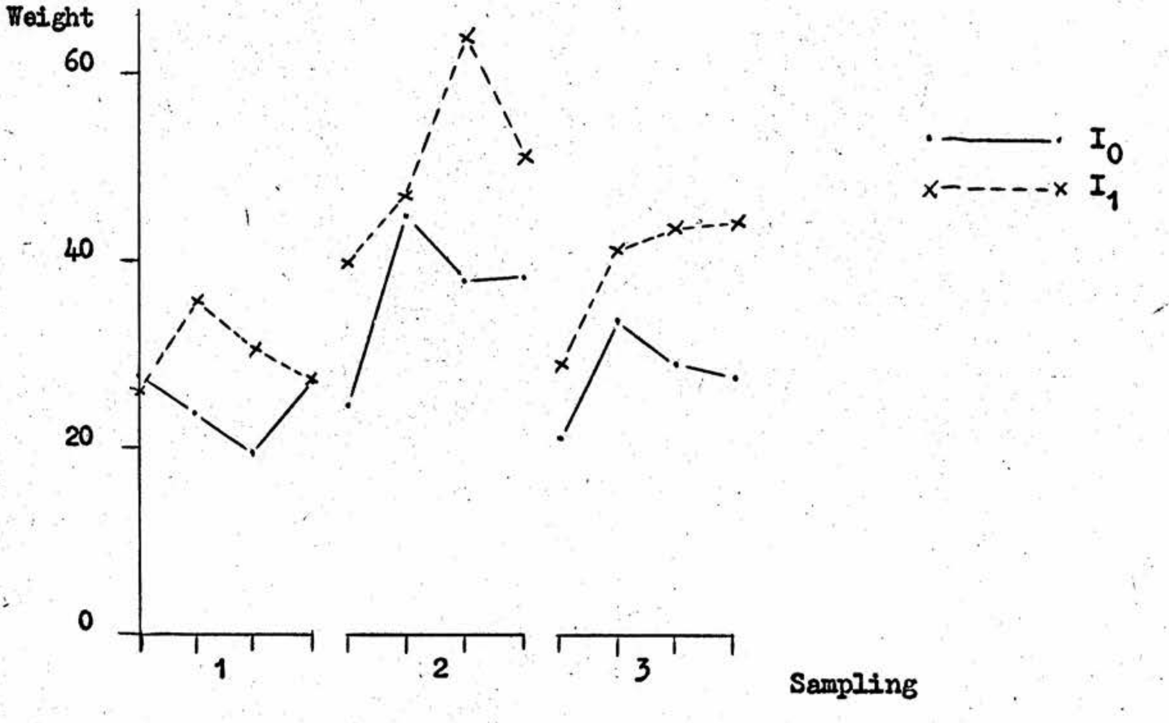


Figure 69. Experiment 3. Stolon fresh weight, g / 4 plants.



The abscissa at each sampling represents rate of nitrogen.

"Available phosphorus". There was a marked decrease in the "available phosphorus" with time up to sampling 3, but little change later in the season.

"Available potassium". The "available potassium" decreased with time. Early in the season there was a tendency for a linear increase with addition of nitrogen, mid-season there was little difference, but later in the season there was a decrease with additions of nitrogen.

Roots.

Dry weight. At N_0 with the low moisture level (I_0) there was little difference in root weight with time. With the high moisture level (I_1) at N_0 there was an increase to sampling 2 with a slight decrease at sampling 3. The addition of nitrogen fertiliser gave a marked increase in the weight of roots from samplings 1 to 2 with little difference between samplings 2 and 3.

Nitrogen concentration. The nitrogen concentration in the roots decreased with time. At all samplings there was a large increase with addition of nitrogen at N_1 and a smaller increase to N_2. Between N_2 and N_3 the effect was more variable, but there was usually little difference. When nitrogen fertiliser was applied nitrogen concentration early in the season was lowered by addition of water (I_1), most noticeably at sampling 2, but there was little effect at sampling 3.

Nitrate-nitrogen concentration. The pattern was very similar to that of total-nitrogen concentration, except at N_0 where there was a decrease between samplings 1 and 2 and little difference between samplings 2 and 3. At higher nitrogen levels the concentration was lowered by addition of water (I_1).

Ratio of nitrate-nitrogen to total-nitrogen. At N_0 the ratio decreased between samplings 1 and 2 but showed little difference between samplings 2 and 3. There was a decrease from sampling 1 to 3 with N_1. At N_2 and N_3 there was little difference with time, except an increase at sampling 2 with N_3. There was a tendency for the addition of water (I_1) to lower the ratio when nitrogen was applied.

Phosphorus concentration. There was a decrease in phosphorus concentration with time, but little effect of treatment.

Potassium concentration. The potassium concentration decreased from sampling 1 to sampling 2, with little effect from sampling 2 to sampling 3, except for a decrease at N_3 with the high moisture level (I_1). There was little difference between the concentrations at low nitrogen levels but a decrease at high nitrogen levels. The addition of water decreased potassium concentration.

Stolons.

Fresh weight. (Figure 69). The fresh weight of stolons increased from sampling 1 to sampling 2, but decreased between samplings 2 and 3, except at N_0 with the low moisture level (I_0) where there was a decline from sampling 1 to 3. There was a significant soil moisture effect at all samplings, the addition of water increasing the fresh weight of stolons. With the high moisture level (I_1) the maximum weight of stolons at sampling 1 was given with N_1, at sampling 2 with N_2 and at sampling 3 with N_3. With the low moisture level (I_0) the maximum weight at samplings 2 and 3 was with N_1.

Dry weight was very similar to fresh weight, except at sampling 3 where there was a decrease from N_2 to N_3 with the high moisture level (I_1).

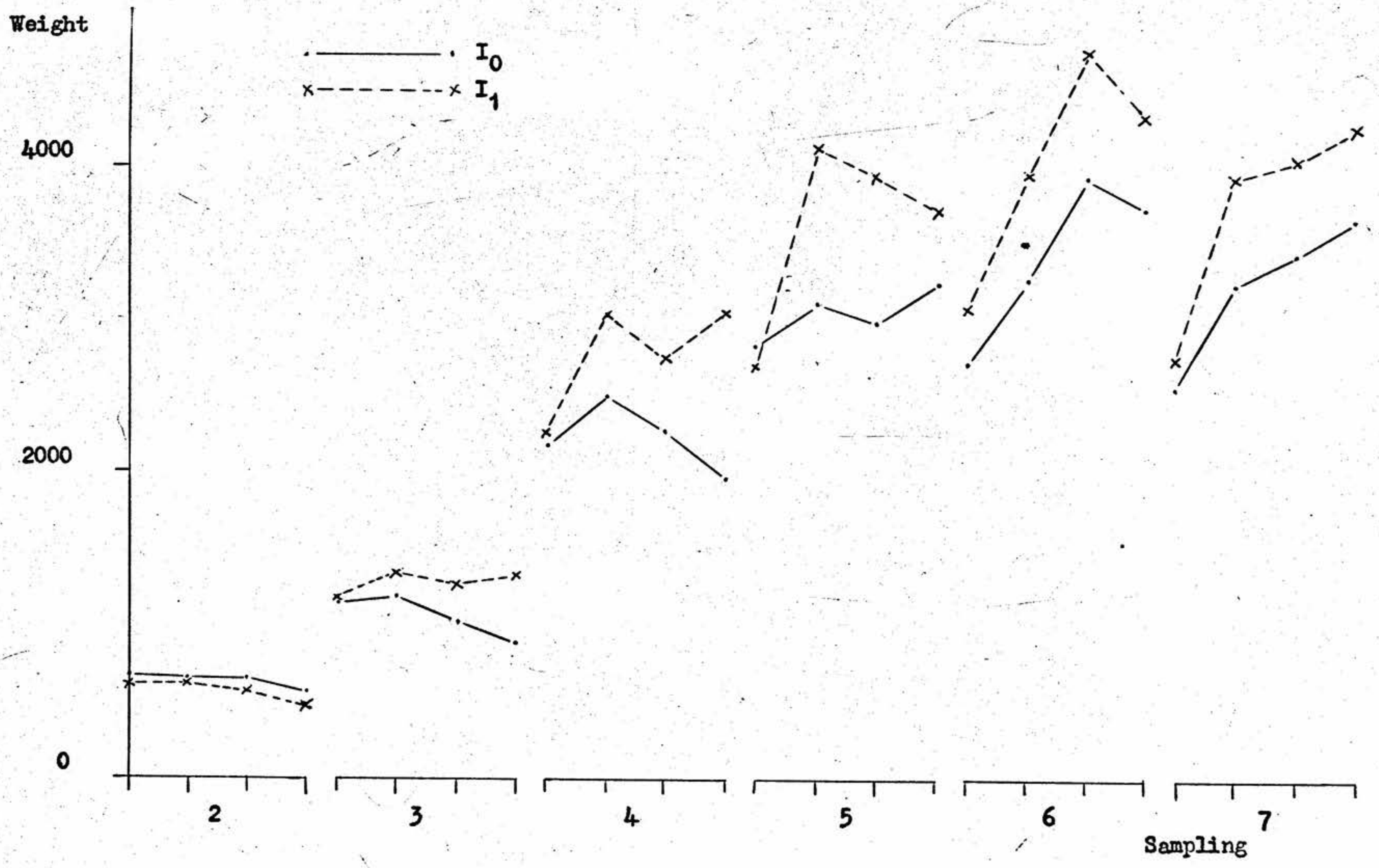
Dry matter content. There was an increase from sampling 1 to 2, but a decrease at sampling 3. Additions of nitrogen decreased the dry matter content linearly, the effect being less marked with the low moisture level (I_0).

Tubers.

Fresh weight. (Figure 70). The fresh weight of tubers increased with time, except for a slight decrease between samplings 6 and 7. At sampling 1 there was little effect of treatment, except for a high weight with the low moisture level (I_0) at N_0. The weight of tubers at sampling 2 decreased with addition of nitrogen and was also decreased by addition of water (I_1). However, at later samplings this was reversed. At samplings 3 and 4 with the low moisture level (I_0) there was a slight increase with addition of nitrogen at N_1, but a decrease at higher levels of nitrogen. With the high moisture level (I_1) there was an even greater increase with addition of nitrogen at the N_1 level, but little difference at higher nitrogen levels. There was a similar pattern at sampling 5, but there were no detrimental effects of high nitrogen at the low moisture level (I_0). At sampling 6 yield increased with additions of nitrogen to N_2, but decreased at N_3. Yield was increased by addition of water (I_1). At the final harvest (sampling 7) there was a marked increase with addition of nitrogen at N_1, with further slight increases at N_2 and N_3. The addition of water (I_1) increased the yield markedly when nitrogen fertiliser was applied, but only slightly without it.

With the high moisture level (I_1) it was evident from sampling 3 onwards that N_0 would give a low yield. However, with the low moisture level (I_0) N_0 gave the lowest yield only from sampling 5, before this, lowest yield was given by the highest nitrogen level (N_3). Between samplings 2 and 3 with the high moisture level (I_1) there was a somewhat similar increase in yield with all nitrogen levels, but with the low moisture level (I_0) the increase was not as great and decreased with higher levels of nitrogen.

Figure 70. Experiment 3. Fresh weight of tubers, g / 4 plants.



The abscissa at each sampling represents rate of nitrogen.

The dry weight of tubers followed similar trends as the fresh weight.

Dry matter content. The dry matter content of the tubers tended to increase with time. There was a sharp increase at sampling 3 followed by a slight decrease. The effect of moisture level was inconsistent, addition of water (I_1) gave higher dry matter contents at samplings 1, 4 and 5 but not at the other samplings.

Tuber number. The number of tubers increased early in the season but then declined to harvest. The high moisture level (I_1) tended to maintain a large number of tubers for a longer period than the low moisture level (I_0). With the high moisture level (I_1) the maximum number of tubers was produced at sampling 4 at N_3. With the low moisture level (I_0) at N_3 the maximum number of tubers was produced at sampling 2. The maximum number of tubers with the low moisture level (I_0) was with N_1. There were no marked consistent effects of treatment upon tuber number.

Average fresh tuber weight. Average tuber weight increased with time, except between samplings 6 and 7 at N_0 with the high moisture level (I_1), when there was a decrease. Early in the season (samplings 1 and 2) the largest tubers were produced with the low moisture level (I_0) at low nitrogen levels. At sampling 3 average weight with the low moisture level (I_0) still decreased with additions of nitrogen, but with the high moisture level (I_1) there was an increase to N_1 before a decrease at higher nitrogen levels. When nitrogen was added tubers were larger with the high moisture level (I_1). The pattern at sampling 3 with the high moisture level (I_1) was followed by both moisture levels at sampling 4. At sampling 5 although tubers were larger at N_0 with the low (I_0) than the high (I_1) moisture level, when nitrogen fertiliser was added the effect of moisture level was reversed. This was also the case at sampling 7.

Sampling 6 showed a significant increase in average tuber weight at all nitrogen levels by addition of water (I_1).

Nitrogen concentration. The nitrogen concentration in the tubers decreased with time, particularly with the high moisture level (I_1) early in the season. The trend was for a sharp increase in concentration with addition of nitrogen at N_1, a slight increase at N_2 and little difference at N_3. Addition of water (I_1) increased the nitrogen concentration at sampling 2 and also at sampling 3 with N_0. At later samplings nitrogen concentration was lowered by addition of water.

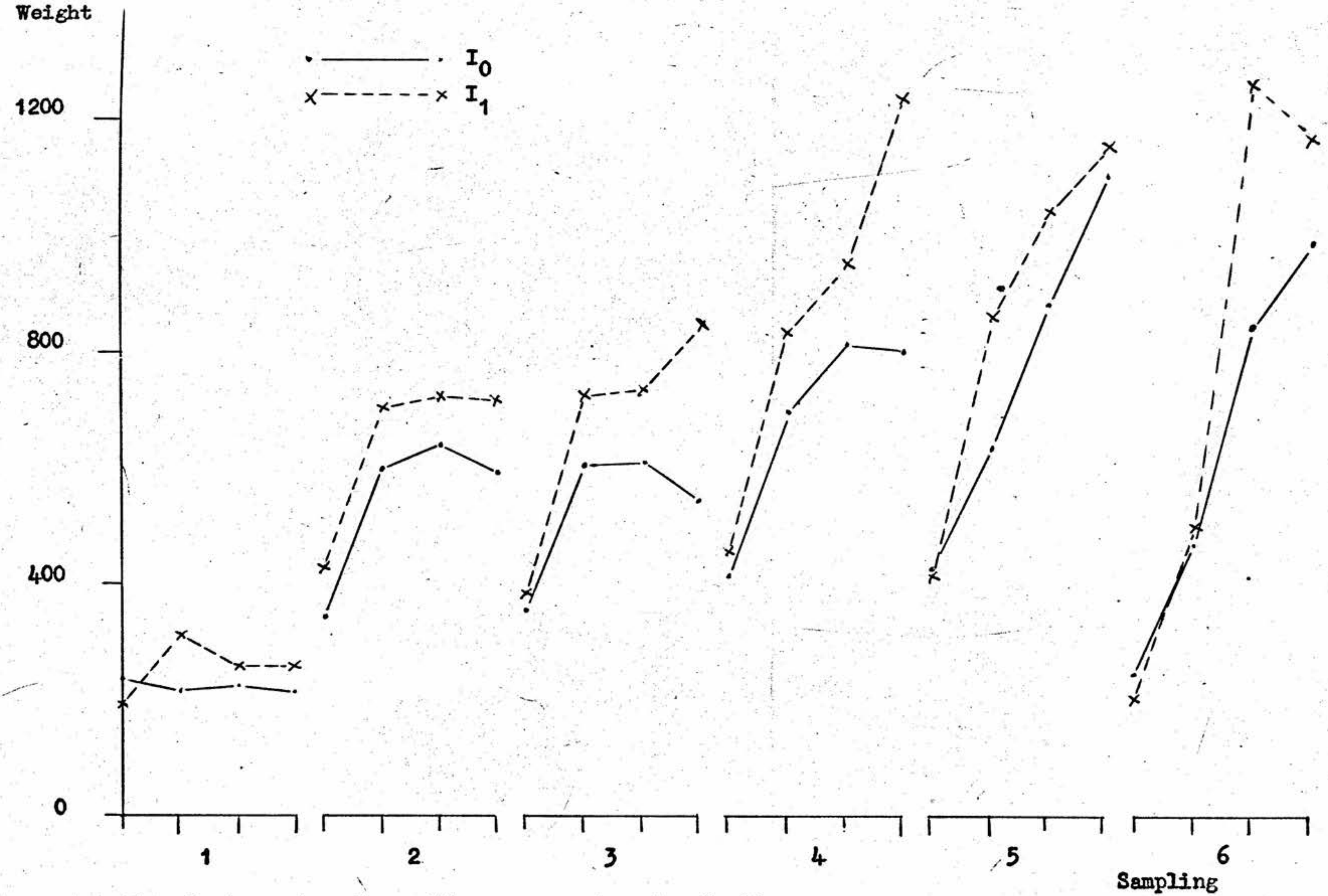
Phosphorus concentration. There was a sharp decrease in phosphorus concentration with time early in the season (especially at the high moisture level, I_1), with little difference later. There was a tendency for a linear increase in phosphorus concentration with addition of nitrogen from sampling 4 onwards. The effects of soil moisture were inconsistent.

Potassium concentration. There was a decrease in potassium concentration with time up to sampling 5, which was more marked with the high moisture level (I_1). The concentration then increased until final harvest. Potassium concentration increased with small additions of nitrogen but decreased at higher levels. At sampling 2 there was little difference between moisture levels, but later in the season addition of water lowered the concentration.

Stems and petioles.

Fresh weight. (Figure 71). The fresh weight increased with time to a maximum and then decreased. At N_0 with the high moisture level (I_1) there was a large increase from sampling 1 to 2, but little difference from sampling 2 to 5 and a decrease at 6. With the low moisture level (I_0) at N_0 there was a

Figure 71. Experiment 3. Fresh weight of stems and petioles, g / 4 plants.



The abscissa at each sampling represents rate of nitrogen.

gradual increase from sampling 1 to 5 and a decrease at 6. There was little difference between moisture levels at N_0 at sampling 5. When nitrogen fertiliser was added there was a marked increase in weight of stems and petioles between samplings 1 and 2, with little difference between nitrogen levels, but a greater increase with the high (I_1) than the low (I_0) moisture level. At N_1 there was a continued increase to sampling 5 and a decrease to 6 with the high moisture level (I_1), but with the low moisture level (I_0) there was a slight increase to sampling 4 followed by a decrease to sampling 6. The weight of stems and petioles increased with time to sampling 6 with the high moisture level at N_2, but with the low moisture level (I_0) there was a slight decrease between samplings 2 and 3, an increase to 4 but little difference between later samplings. With the high moisture level (I_1) at N_3 there was a marked increase up to sampling 4, but little difference later in the season. With the low moisture level (I_0) the increase at N_3 was much slower, with a decrease between samplings 2 and 3 and a maximum at sampling 5.

At sampling 1 addition of nitrogen with the low moisture level (I_0) decreased the weight of stems and petioles, but there was an increase with N_1 at the high moisture level (I_1). Later in the season additions of nitrogen increased the weight, although with the low moisture level (I_0) there was a decrease at very high levels of nitrogen. At sampling 5 both moisture levels gave a linear increase with additions of nitrogen, but the high moisture level (I_1) still gave the greater weight. At sampling 6 the low moisture level (I_0) still gave a linear increase with addition of nitrogen, but there was a slight decrease at N_3 with the high moisture level (I_1), although the weight was still greater than the low moisture level (I_0).

Dry weight. The dry weight showed similar trends to the wet weight. There were however, no decreases between samplings 2 and 3 and few decreases between samplings 5 and 6, indicating that changes in the fresh weight were due to loss of water.

Dry matter content. The most noticeable effects were an increase in dry matter content between samplings 2 and 3 and a most marked increase between samplings 5 and 6. The increase just before harvest was less marked the more nitrogen was applied. Early in the season dry matter content was lowered by additions of water, but there was little effect later.

Nitrogen concentration. The nitrogen concentration decreased with time, except for some slight increases between samplings 5 and 6. Early in the season addition of nitrogen at N_1 gave a large increase in concentration, with little increase from further additions of nitrogen. As the season progressed there was a linear increase with additions of nitrogen. At sampling 6 there was little difference between nitrogen levels except for a high concentration at N_3. Mid-season the addition of water (I_1) tended to decrease nitrogen concentration.

Nitrate-nitrogen concentration. There was a decrease in nitrate concentration with time, except with N_3 between samplings 1 and 2 when there was an increase. Early in the season addition of nitrogen at N_1 gave a large increase in concentration, with little difference at higher nitrogen levels. Mid-season there was a linear nitrogen effect, but later there was little difference between N_0 and N_1, although there was an increase at higher nitrogen levels. There was a tendency for nitrate concentration to be lowered by the addition of water, especially when nitrogen fertiliser was added.

Ratio of nitrate-nitrogen to total-nitrogen. When no additional nitrogen was added the ratio decreased with time, but when fertiliser nitrogen was added the ratio increased then decreased, the decrease being more marked with N_1 than the higher nitrogen levels.

Phosphorus concentration. There was a decrease in the phosphorus concentration of the stems and petioles during the season. Mid-season there was a tendency for a linear increase in the concentration with additions of nitrogen and a lower concentration with the high moisture level (I_1).

Potassium concentration. There was a tendency for a decrease with time except between samplings 1 to 2 and 4 to 5. There was a tendency throughout the season for an increase at N_1, but a decrease at higher levels of nitrogen.

Leaves.

Fresh weight. The effect of treatments was very similar to that on the weight of stems and petioles. However, the decrease in weight between samplings 2 and 3 was much more marked with the leaves, as also was the decrease between samplings 5 and 6. The weight of leaves decreased from sampling 4 onwards. The dry weight of leaves followed a similar pattern but the decrease at sampling 3 was not as marked.

Dry matter content. The main effect was a large increase in dry matter content at sampling 3 followed by a decrease and a further increase with senescence at sampling 6. At all samplings dry matter content was higher with the low moisture level (I_0).

Nitrogen concentration. The nitrogen concentration of the leaves decreased with time. Early in the season there was a marked increase with addition of nitrogen at N_1, with little effect of higher nitrogen levels. Later in the season there was a tendency for a linear increase with additions of nitrogen. The nitrogen concentration tended to be lowered by addition of water (I_1).

Phosphorus concentration. There was a decrease in the concentration with time and a linear increase with additions of nitrogen, except at the last sampling.

Potassium concentration. The potassium concentration decreased between samplings 1 and 3, showed little difference between samplings 3 and 5; but decreased at sampling 6, the decrease being greater at the lower nitrogen levels. Early in the season the concentration increased with addition of nitrogen at N_1 and decreased at higher nitrogen levels. Later in the season there was little effect of nitrogen level above N_1.

Leaf area. (Figures 72 and 73). The leaf area index was closely related to leaf weight, but because of the importance of leaf area the results are given in detail.

Figure 72. Experiment 3. Leaf area development.

Low moisture level, I_0

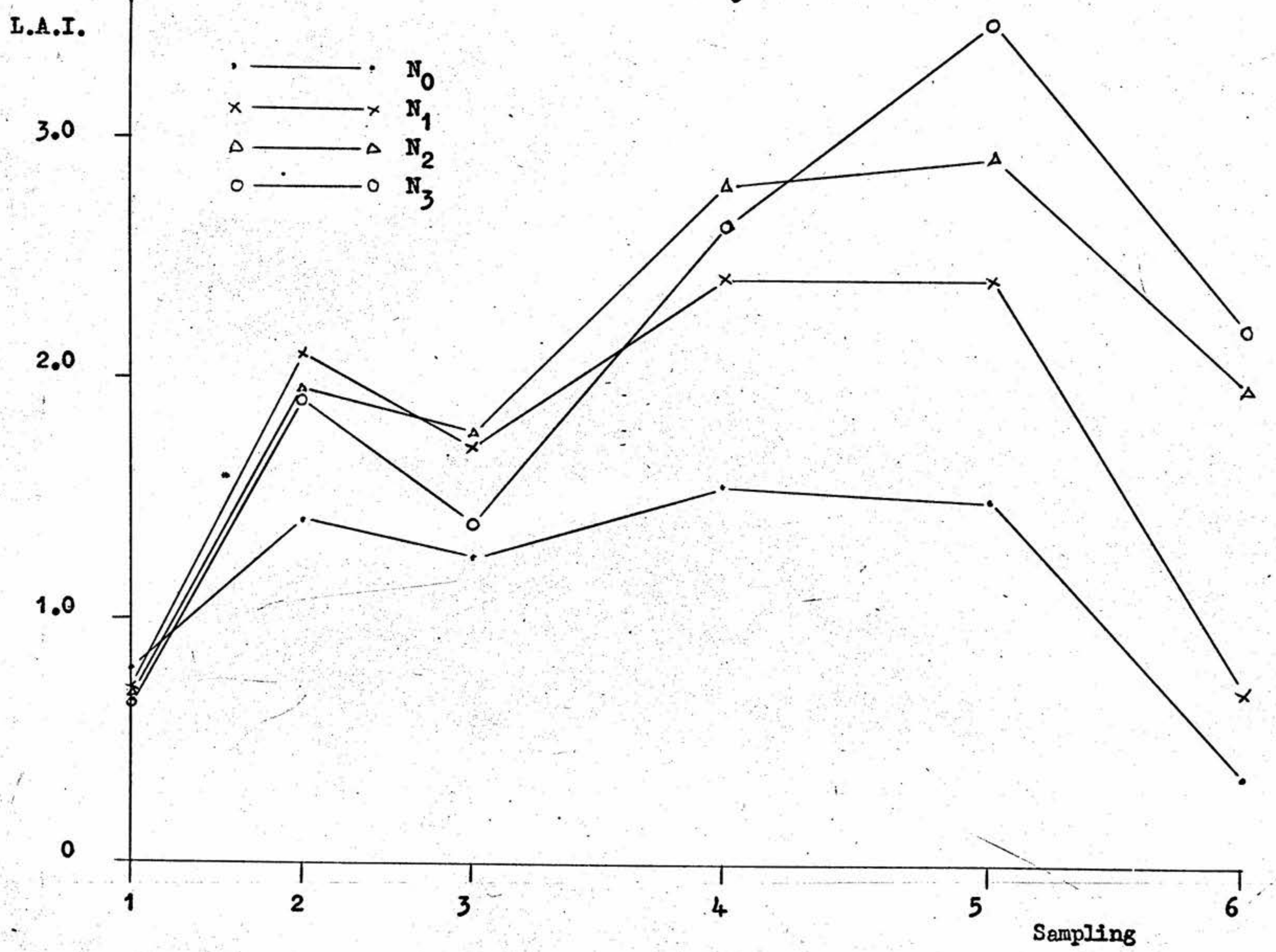
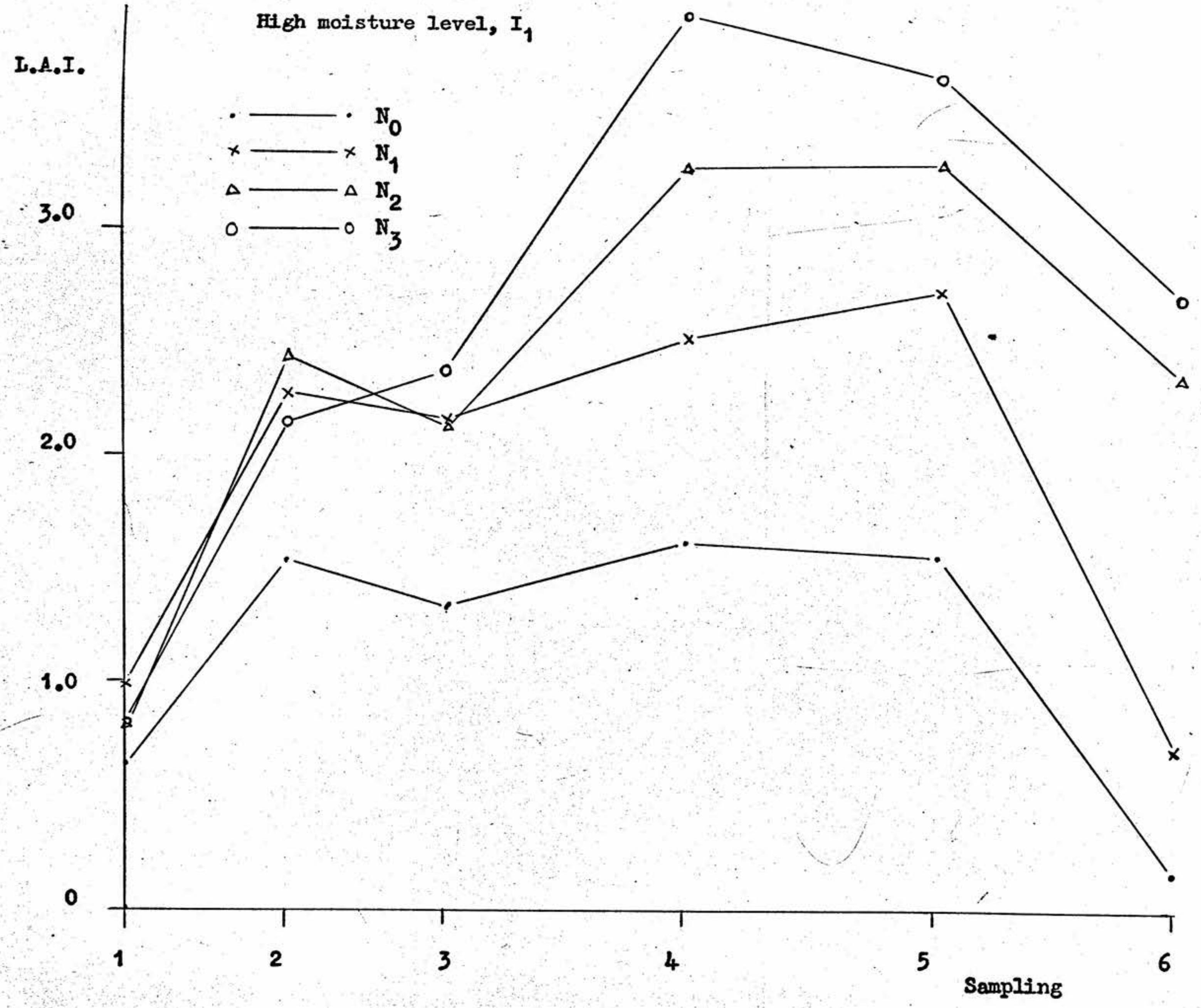


Figure 73. Experiment 3. Leaf area development.



High moisture level, I_1

The general pattern was for an increase in leaf area to a maximum and then a decrease later in the season. There was a slight decrease in leaf area index between samplings 2 and 3 with all treatments, except N_3 with the high moisture level (I_1). There was little difference between moisture levels at N_0. The L.A.I. increased from sampling 1 to 2, but showed little difference to sampling 5 and a decrease at sampling 6. The increase between samplings 1 and 2 was more marked when nitrogen was added, especially with the high moisture level (I_1). The high moisture level (I_1) also showed a smaller decrease between samplings 2 and 3. There was a marked increase in L.A.I. with the high moisture level (I_1) between samplings 3 and 4 when nitrogen was added. The increase was greater the higher the nitrogen level, N_3 reaching a L.A.I. of 4, but thereafter declining. The N_1 and N_2 levels showed little difference between samplings 4 and 5, but decreased at sampling 6. With the low moisture level (I_0) the increases from sampling 3 to 4 were not as great as when water (I_1) was added and the highest L.A.I. (2.8) at sampling 4 with the low moisture level (I_0) was given by N_2. With N_1 and N_2 there was little difference between samplings 4 and 5, with a decrease at sampling 6. At N_3 with the low moisture level (I_0) there was an increase to sampling 5 (L.A.I. 3.5), but then a decrease.

Leaf area duration was calculated from the area beneath the leaf area index-time curves and is shown in Table IX.

Table IX. Experiment 3. Leaf area duration, weeks.

	N_0	N_1	N_2	N_3
I_0	16.6	25.2	29.4	30.2
I_1	16.9	28.2	34.6	38.6

Leaf area duration increased with addition of nitrogen. At N_0 there was no difference between moisture levels, but with the addition of nitrogen the high moisture level (I_1) showed a greater increase than the low moisture level (I_0). The difference between moisture levels increased with additions of nitrogen.

Whole plant.

Fresh weight. There was an increase in total weight of the plant with time until sampling 5, but between samplings 5 and 6 there was a decrease with N_0 and N_1. There was little effect of moisture level at N_0, there being a gradual increase to sampling 5 with the main growth periods between samplings 1 to 2 and 3 to 4. With the addition of nitrogen fertiliser there was a greater increase between samplings 1 and 2, more so with the high moisture level (I_1), but little affected by level of applied nitrogen. There was little increase in weight between samplings 2 and 3 with the low moisture level (I_0), but an increase with the high moisture level (I_1). There was a very marked increase in growth between samplings 3 and 4, especially with the high moisture level (I_1), where N_3 was higher than N_1 or N_2. With the low moisture level (I_0) at sampling 4, N_1 and N_2 were the same and higher than N_3. Between samplings 4 and 5 there was a very marked increase in total weight with the low moisture level (I_0) at N_3, but little difference between the increases with the other treatments.

Dry weight. With the low moisture level (I_0) there was a general increase in dry weight with time up to sampling 5. There was little difference between samplings 5 and 6 with N_0 and N_1, but an increase with N_2 and N_3. At samplings 3 and 4, N_3 gave the lowest dry weight, but at samplings 5 and 6 was the highest. The N_0 level with the high moisture level (I_1) was similar to that with the low moisture level (I_0). However, with addition of nitrogen at the high moisture level (I_1) there was a greater increase in dry weight.

Total nitrogen uptake. The total nitrogen uptake increased with time, except between samplings 5 and 6 with N_0 and N_1. Nitrogen uptake was lower with N_0 than when nitrogen fertiliser was applied. Late in the season nitrogen uptake at N_0 was greater at the low moisture level (I_0). With the low moisture level (I_0) the increase in uptake from increase in applied nitrogen was apparent only late in the season. With the high moisture level (I_1) the increase from applied nitrogen was apparent from sampling 3.

Total phosphorus uptake. Total uptake of phosphorus increased during the season. Uptake was enhanced by addition of water (I_1) and by addition of nitrogen, except early in the season when high nitrogen levels, especially with the low moisture level (I_0) reduced phosphorus uptake.

Total potassium uptake. There was an increase in uptake with time which was enhanced by addition of nitrogen, especially with the high moisture level (I_1).

Growth characteristics.

Unfortunately the growth characteristics had rather large standard errors, arising no doubt from the small sampling size. There were no consistent significant effects of treatment and the results are discussed only in general terms.

Relative growth rate. The R.G.R. decreased with time. There was a large decrease from between samplings 1 and 2 to between samplings 2 and 3, which was greater with the low (I_0) than the high (I_1) moisture level. The decrease was more gradual later in the season.

Net assimilation rate. There was a decrease in N.A.R. with time, but no consistent effect of treatment.

Economic assimilation rate. There was an increase in E.A.R. from between samplings 1 and 2 to between samplings 2 and 3 with all treatments, except the low moisture level (I_0) at N_2 and N_3. Thereafter the E.A.R. tended to decline. Early in the season there was a deterimental effect of high nitrogen level and the greatest E.A.R. was given by the N_0 level. Between samplings 1 and 2 E.A.R. was greater with the low (I_0) than the high (I_1) moisture level.

Crop Growth rate. With the low moisture level (I_0) there was little difference in C.G.R. with time, except for a decrease at the end of the season. With the high moisture level (I_1) the situation was somewhat similar except at N_3, where there was a large increase mid-season.

Relative leaf growth rate. There was a large decrease in R.L.G.R. from between samplings 1 and 2 to between samplings 2 and 3. This was followed by a slight increase. There was a further decrease at the end of the season which was greater the lower the nitrogen level.

Relative tuber growth rate. The R.T.G.R. decreased with time, the greatest decrease being early in the season.

DISCUSSION, EXPERIMENT 3

The total yield of tubers increased with additions of nitrogen up to the highest level tested (300 kg N/ha). There were slight increases from 100 to 200 kg N/ha and from 200 to 300 kg N/ha with little effect of moisture level on the magnitude of the increases. The main yield increase was however with addition of nitrogen from 0 to 100 kg N/ha. There was a significant increase with the low moisture level (I_0) and a highly significant increase with the high moisture level (I_1). Thus, although there was little difference in yield when no nitrogen was added, in the presence of nitrogen fertiliser, yield was increased considerably by the addition of water (I_1).

This continued increase in yield, at very high levels of nitrogen, is not normally found, but in certain circumstances does occur. In this case it may have been related to the length of the growing season. Normally, very large haulm growth delays development of a large tuber yield at high nitrogen levels (Ivins, 1967) as the plant is unable to fully utilise the large haulm in a curtailed season. In experiment 3 the time from planting to the cutting down of the haulm was 154 days. This compared with 126 days and 139 days for experiments 1 and 2 respectively, which were similar to a normal growing season in the South East of Scotland. It was probably the much longer growing season which allowed full utilisation of the large haulm developed at high nitrogen levels, so giving a large tuber yield. This view is supported by tuber yield data from samplings taken during the season, when yield was reduced by high levels of nitrogen fertiliser.

Tuber initiation was delayed by both the addition of nitrogen and addition of water (Ivins, 1967). This was shown at sampling 1 by the weight, the number and the average weight of tubers, which was highest when no nitrogen or water was added. The effect of nitrogen and water may have been through two different mechanisms. When no water (I_0) was added the effect of the addition of nitrogen on both stem and leaf weight was a decrease, because of some detrimental effect delaying haulm development. When water was added however, addition of nitrogen increased the haulm weight and it was possibly this early haulm development which delayed tuber initiation and development.

The detrimental effects of nitrogen and water on tuber yield were also evident at sampling 2. Addition of nitrogen decreased yield and at each nitrogen level yield was decreased by addition of water (I_1). The average tuber weight showed a somewhat similar pattern, again indicating delayed tuber development by addition of nitrogen and water. Haulm weight (stems and petioles plus leaves) however, showed the opposite effect with a large increase in weight with addition of 100 kg N/ha and a slight increase to 200 kg N/ha. There was however, a slight decrease at 300 kg N/ha which was more marked with the leaves than the stems and petioles. At all nitrogen levels haulm weight was increased by the addition of water. There was a highly significant soil moisture effect on the dry matter content, indicating that the addition of water maintained a greater turgidity in the haulms, thereby increasing the capacity for growth.

By sampling 3 the benefit of a larger haulm was beginning to be shown in the fresh tuber weight, with an increase in tuber yield from addition of 100 kg N/ha. However, when no water (I_0) was applied there was a marked decrease in the weight of tubers at higher nitrogen levels, but with the addition of water (I_1) there was little effect of high nitrogen levels. At this time the soil moisture level was very low and this had an adverse effect on plant growth. There was very little increase in the weight of stems between samplings 2 and 3 and the fresh weight tended to show a decrease at high nitrogen levels when no water (I_0) was applied. This effect was even more marked with the fresh weight of leaves, there being a decrease between samplings 2 and 3 with both moisture levels, but the decrease was greater with the low moisture level (I_0). Although there had been a retardation in growth between samplings 2 and 3, which was associated with a low soil moisture content, the detrimental effects were not as great when water was added (I_1). There was still a detrimental effect on haulm growth at greater than 100 kg N/ha when no water (I_0) was added. When water was applied however, leaf weight increased with addition of nitrogen above 100 kg N/ha. Although this increased haulm growth did not give an immediate increase in tuber yield, it did maintain yield with high nitrogen levels at the same level as with 100 kg N/ha. Average tuber weight was greater with the high (I_1) than the low (I_0) moisture level and with I_0 there was a decrease with successive additions of nitrogen. Stolon weight showed a very similar pattern to tuber weight.

The tuber yield pattern at sampling 4 was very similar to sampling 3, yield was however greater and there was a large increase with addition of 100 kg N/ha. Average tuber weight increased with addition of nitrogen at 100 kg N/ha but decreased at higher nitrogen levels, the decrease being greater at the low moisture level (I_0), which gave lower average tuber weights at all nitrogen levels. At this sampling there was less detrimental effect of high nitrogen levels at the low moisture level (I_0) on haulm growth than there was earlier in the season.

At sampling 5 with the low moisture level (I_0) the high nitrogen levels (200 and 300 kg N/ha) gave similar yields to 100 kg N/ha. Yield was much higher with the high moisture level (I_1) when nitrogen was applied, although at high nitrogen levels there was a tendency for a decrease. The largest increase in yield from addition of water was at 100 kg N/ha. The addition of nitrogen gave a linear increase in the weight of the stems and petioles and the leaves. The addition of water slightly increased the weight of the stems and petioles, but had little effect on leaf weight. The detrimental effect of high nitrogen levels at the low moisture level (I_0) had now been overcome and the addition of nitrogen gave similar effects at both moisture levels.

Tuber weight at sampling 6 increased with addition of nitrogen up to 200 kg N/ha, but decreased at 300 kg N/ha. At this time leaf area was decreasing rapidly, the decrease being greater the higher the nitrogen level. Leaf area was increased by additions of nitrogen and at 200 and 300 kg N/ha was higher when water (I_1) was added. The high moisture level (I_1) combined with high nitrogen showed a greater leaf persistence.

It can thus be seen that the final yield of tubers was closely related to the leaf area; its size, time of development and persistence, as suggested by Radley (1963). In this experiment the correlation coefficient for yield and leaf area duration (for all treatments) was 0.955. For the low moisture level (I_0) alone the correlation coefficient was 0.984, but for the high moisture level (I_1) 0.960. Thus the relationship between tuber yield and leaf area duration was not as marked at the high moisture level (I_1), where leaf area was greater than at the low moisture level (I_0). Radley (1963) considered a L.A.I. of greater than 3 to be superfluous and he suggested that there was a better relationship between tuber yield and leaf area persistence (the leaf area duration calculated assuming L.A.I. in excess of 3 to be 3). When this correction was applied to this experiment the correlation coefficients were:- for all treatments 0.952, for the low moisture level (I_0) 0.975 and for the high moisture level (I_1) 0.979. With the high moisture level (I_1) there was a better relationship between yield and leaf area duration when excess haulm growth was disregarded.

It can be seen from this that it is not necessarily the highest leaf area which gives the greatest yield but the greatest leaf area persistence. When no nitrogen was added there was little difference in leaf area persistence with addition of water (I_1). When nitrogen was added however, addition of water (I_1) allowed a greater leaf area to develop earlier. It also gave a greater leaf area late in the season. This was due to the large leaf area reached, which gave a slower rate of senescence. Thus addition of water had alleviated deleterious factors which prevented haulm growth at high nitrogen levels early in the season.

The timing of leaf area development is especially important when related to incoming solar radiation. Alcock (1967) suggested that radiation levels were highest in June, when the potential rate of maximum dry matter production would be at its highest. Thus early development of a large leaf area would allow a greater utilisation of the incoming energy.

The detrimental factors which limited haulm growth occurred early in the season as by sampling 5 there was little effect of soil moisture level on haulm growth and even by sampling 4 the detrimental effects of high nitrogen levels at the low moisture level (I_0) were not as great as they had been at earlier samplings.

It is doubtful if increased nitrogen uptake was responsible for the greater haulm growth at high nitrogen levels when water was added (I_1) as there was no significant effect of moisture level on total nitrogen uptake until sampling 3.

The nitrate concentration in the plant gives an indication of the rate of protein synthesis. If there is an accumulation of nitrate it indicates that the system is not working at its maximum (Wright and Davison, 1964). Early in the season (samplings 1-3) the addition of water (I_1) when nitrogen fertiliser was applied lowered the nitrate-nitrogen concentration and the ratio of nitrate-nitrogen to total-nitrogen in the roots and in the stems and petioles. This would suggest that addition of water (I_1) in the presence of fertiliser nitrogen allowed more rapid protein synthesis during the early part of the season.

It is unlikely that the detrimental effect of high nitrogen at the low moisture level (I_0) was due to lack of water in the soil per se as it was not apparent in the absence of nitrogen. It may however have been due to the total (i.e. physical + osmotic) stress on the soil water. A measure of the osmotic effect is given by the conductivity of the fertiliser band. The conductivity decreased with time, the decrease being greater with the high (I_1) than the low (I_0) moisture level. There was also an increase in conductivity with additions of nitrogen. Although there was a tendency for a decrease in conductivity at each nitrogen level by the addition of water (I_1), this was not very marked at 300 kg N/ha and so it is unlikely that the detrimental effects of high nitrogen levels at the low moisture level (I_0) can be totally explained in terms of the high osmotic pressure of the soil solution.

Soil pH was decreased by additions of nitrogen, with an increase in pH with time; the increase being greater with the high moisture level (I_1). It is doubtful if this had any detrimental effect on growth as the pH was high on this site.

The addition of water had a considerable effect on the nitrate and ammonium concentrations in the fertiliser band. Nitrate concentration with the low moisture level (I_0) was little changed between samplings 1 and 3 at high nitrogen levels, but with the high moisture level (I_1) there was a marked decrease. There was a similar pattern for ammonium concentration and by sampling 4, except for a slight increase at 300 kg N/ha, there was little effect of treatment. However, at earlier samplings nitrogen increased ammonium concentration, the increase being less at the high moisture level (I_1).

There were two possible mechanisms for this decrease with time:- uptake by theplant and movement away from the fertiliser band. It is doubtful if plant uptake would account for all the decrease and it would not explain the effect of moisture level, as there was little effect of moisture level on total-nitrogen uptake until sampling 3. Thus it seems probable that a high soil moisture level early in the season allowed greater movement of nitrate and ammonium away from the fertiliser band.

Summary.

Thus it can be seen that addition of water when nitrogen was added overcame deleterious factors which were present early in the season. It is doubtful if the effect was to increase nitrogen uptake as total uptake of nitrogen was not increased by addition of water until later in the season. Nitrogen uptake was increased by additions of nitrogen and this gave large concentrations of nitrate in the plants. This would stimulate the plant to draw upon its supply of available carbohydrates for reductive energy and carbon skeletons for protein synthesis. At the low moisture level (I_0) it is probable that the plant was unable to give a continued plentiful supply of available carbohydrates but at the high moisture level (I_1) the supply would be greater because of the larger photosynthetic capacity of a more turgid plant. Thus with the low moisture level (I_0) in the presence of nitrogen fertiliser, nitrate would accumulate and protein synthesis would be retarded, giving rise to a slower growth rate than with the high moisture level (I_1).

As well as this beneficial effect on photosynthesis and protein synthesis there may have also been other beneficial effects of the high moisture level(I_1).

The addition of water (I_1) reduced the concentrations of nitrate and ammonium in the fertiliser band, when nitrogen fertiliser was added, more quickly than when no water (I_0) was added. This may have been beneficial as some workers e.g. Devine and Holmes (1963), Widdowson et al. (1960), have suggested injurious effects from high concentrations of nitrate around the "seed". Ammonium would be in equilibrium with ammonia in the soil and ammonia can be toxic even in small amounts when the pH is high (Warren, 1962). Thus a faster decrease in these harmful substances would give rise to faster growth. Root weight did show a slight beneficial effect of the high moisture level (I_1) at sampling 2, but this was at all nitrogen levels.

There may have been a beneficial effect of addition of water in reducing the osmotic stress, but the only data to support this were conductivity measurements and these only showed a decrease early in the season at 100 and 200 kg N/ha (but not at 300 kg N/ha) from the addition of water.

GENERAL DISCUSSION

The variation between replicate plots was rather large, especially when results for individual tuber size fractions were considered. The reason was primarily the small size of the plots. The size of the plots was limited by the irrigation equipment, which was only capable of covering a plot 2.84m wide. In the second year the length of travel of the irrigation trolley was increased, but this necessitated a different system for supporting the equipment. Considerable time was involved in applying water, especially as all plots in one experiment had to be watered the same day. The rate of water application could not be increased because of erosion and because water tended to run down the sides of the ridges and collect in the bottom of the drills.

Because of the time taken to apply the water, often, in periods of very dry weather insufficient water could be applied to bring the soil to the required moisture level. This happened several times in the experiments, most noticeably in Experiment 3, where, at one time, the soil in the fertiliser band was at wilting point. There was also a considerable problem with the wind, since, on very windy days, it was impossible to irrigate because of the detrimental effect on water distribution. The sites for Experiments 1 and 3 were purposely chosen in the dry East Coast region, but this unfortunately exposed them to the wind, which as well as affecting water distribution also caused considerable damage to the haulms. Travelling to these sites also occupied considerable time.

To overcome these problems different irrigation equipment would have been needed. Trickle irrigation would have been of little use because of its uneven distribution and so overhead spray lines would be the only other alternative. Unfortunately, these have very poor distribution patterns and this would have meant very large plots and thus, in the growth analysis experiment, a very large amount of material to handle at each sampling. The increased plot size could also have increased soil variability across the experiment. The use of spray lines would have necessitated a change in experimental design to a split-plot design with irrigation as main-plots and nitrogen as sub-plots. The information gained about the effects of irrigation would then have been less precise.

In the 1970 experiments the sites had to be visited the day before irrigation to take moisture samples and moisture contents had to be determined the following morning before travelling to the site. In 1971, to overcome this, moisture blocks were used so that moisture content could be determined more rapidly and for a greater number of positions. Unfortunately, these were never used to their full potential since, whenever irrigation was to be carried out, the major problem was that there was insufficient time to get the required amount of water on to the plots and so a "blanket" application was applied to all plots.

The performance of the resistance blocks was not as good as expected. One reason for this was that the blocks were not calibrated individually, because of the large number involved. One possible way to overcome this would be to use the ethanol calibration method (Kosonen, 1970) and group all blocks of similar characteristics together and to have separate calibrations for each group. Further difficulties in the calibration occurred because of variation in the soil both with depth and across the experiment. Because of this it was decided to use a single calibration for all blocks, hoping that sufficient replication would give representative results. The blocks were installed in a slurry of soil and water, but unfortunately when this dried out contact between the dried-out slurry containing the block and the surrounding soil was not always maintained, thereby giving false readings.

For the first three samplings in Experiment 3 roots were recovered from the soil. Early in the season it is possible to obtain quite good recovery of the roots of potatoes in the field, but as the season progresses it is impossible to assess the proportion recovered. Results for root weight should therefore be discussed with caution.

Material taken from each sampling was dealt with as soon as possible on the day of sampling, but soil samples had to be stored over night in a cold room. Plant material was quickly dried and then stored for analysis. It would have been desirable to analyse for nitrate-nitrogen on fresh plant material, but insufficient time was available so analysis was carried out later on material which had been rapidly dried at 90°C.

Soil samples were only taken from the fertiliser band. To obtain a complete picture of spread of fertiliser it would have been desirable to study the distribution of nitrogen fertiliser in the ridge with time. Conductivity measurements gave a rather imprecise estimate of osmotic effects in the soil especially as water was added in the determination, so dissolving any undissolved soluble fertilisers.

The growing season in Experiment 3 was longer than normal and this allowed full utilisation of the large haulm developed at high nitrogen levels and there was a response in tuber yield even at 300 kg N/ha. The total tuber yield was related to the leaf area persistence. When no nitrogen was added there was little effect of addition of water on tuber yield or leaf area persistence. However, when nitrogen fertiliser was applied addition of water allowed a larger leaf area to develop earlier, so increasing the leaf area persitence and total yield of tubers.

The growing season for Experiments 1 and 2 was much shorter and the yield of tubers did not respond to such high levels of nitrogen, because there was insufficient time to utilise the large haulm growth. The optimum nitrogen level was greater with the high than the low moisture level. From the results of the growth analysis experiment this would appear to be because the addition of water allowed earlier haulm development at high nitrogen levels and greater utilisation of this large leaf area. Thus in a shortened season the early development of the haulm is very important.

In a long growing season the level of nitrogen applied is not as critical as in a short growing season as there is a response even at 300 kg N/ha. In a short growing season high levels of nitrogen reduce yield. Also in a long growing season addition of water gives a "bonus yield" when nitrogen is applied. In a short growing season the interaction between nitrogen and soil moisture can be critical, as addition of water allows a response to higher levels of nitrogen than when no water is added.

It is thus very important to maintain a long growing season and this shows the necessity for blight spraying to delay the onset of haulm destruction. Growth early in the season is also very important and can be improved by the use of sprouted seed. Soil moisture must be maintained at an adequate level to permit early haulm growth. Thus it is advisable to irrigate early in the season to maintain an adequate soil moisture level to offset the deleterious effects of high nitrogen levels. This is in contrast to recommended practice (e.g. M.A.F.F., 1962 and North, 1964) which is to irrigate during the period of tuber swelling. Early irrigation as shown in these experiments, will permit early haulm growth and increase tuber yield. Irrigation later in the season may also be necessary to maintain a fully turgid haulm.

The addition of nitrogen and water delayed tuber initiation. At the low moisture level there was a detrimental factor which also delayed haulm growth. When water was added, the addition of nitrogen increased haulm growth and it was possibly this early haulm development which delayed tuber initiation. The delayed tuber initiation was of little consequence as it was soon offset by the more rapid growth rate.

The addition of water tended to increase tuber number at harvest. This may be of importance in processingas, for canning, a large number of small tubers are required, rather than a small number of a large size. The addition of nitrogen increased yield through the effect on large tubers.

The dry matter content of the tubers decreased with additions of nitrogen. This may have been related to maturity as all treatments were harvested at the same time. To overcome this all treatments would need to be allowed to senesce naturally before harvest. This would be very difficult to achieve when carrying out experiments on commercial farms.

The degree of cracking of the tubers was increased by additions of nitrogen. It was to some extent alleviated by addition of water, but the more nitrogen that was applied the more water was needed.

It was evident that there was a detrimental effect on growth early in the season at high nitrogen levels, which could be overcome by addition of water. Some suggestions have been made as to what these deleterious factors were (see Discussion, Experiment 3), but further experiments would be required to elucidate these effects. In these experiments special attention would need to be paid early in the season to root development and changes occurring in the soil, with a measure of the osmotic pressure of the soil solution and of the ammonia concentration.

SUMMARY AND CONCLUSIONS.

Two similar experiments were carried out in 1970, using potatoes as a test crop, to investigate the effect of soil moisture on response to nitrogen fertiliser. The treatments were four levels of nitrogen (0, 100, 200 and 300 kg N/ha) and three moisture levels (no additional water, soil moisture maintained between pF 3.0 and 3.5, soil moisture maintained between pF 2.0 and 2.5). At harvest, tuber yield and number were determined for different size fractions, as well as chemical composition.

To investigate the effects found in these experiments a further experiment was carried out in 1971. This was of similar design, testing the same four levels of nitrogen with the two moisture extremes of the previous experiments. Growth analysis techniques were used to study changes occurring in the plant and soil during the season.

The conclusions reached were:-

1. In a "long" growing season (154 days) yield of tubers increased with additions of nitrogen even at 300 kg N/ha. Although there was little beneficial effect of addition of water when no nitrogen was added, in the presence of fertiliser nitrogen yield was increased by addition of water.
2. In a "normal" growing season (126-139 days) yield was reduced at very high levels of nitrogen. The optimum nitrogen level was greater when water was added than when no water was added.
3. Final yield of tubers was closely related to leaf area persistence. In a "long" growing season leaf area persistence was increased by additions of nitrogen and was further increased by addition of water. The addition of water allowed the leaf area to develop earlier, to grow larger and to last longer.

4. There were deleterious factors which delayed haulm growth at high nitrogen levels when no water was added.
5. The deleterious effect may have been through the retardation of protein synthesis when high levels of nitrogen fertiliser were applied at low soil moisture levels.
6. Addition of water may have reduced the injurious effects of high nitrate and ammonium concentrations around the "seed".
7. There may have been some alleviation of osmotic effects at high nitrogen levels by the addition of water.
8. Addition of nitrogen and water delayed tuber initiation.
9. The increases in yield from additions of nitrogen and water were mainly due to increases in the yield of large tubers.
10. Addition of water tended to increase the number of tubers at harvest.

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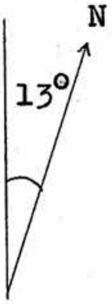
Table 1 Experiment 1. Layout

$I_0\ N_2$	$I_2\ N_3$	$I_2\ N_2$
$I_1\ N_0$	$I_1\ N_2$	$I_2\ N_0$
$I_0\ N_0$	$I_1\ N_3$	$I_2\ N_1$
$I_0\ N_3$	$I_1\ N_1$	$I_0\ N_1$



$I_0\ N_2$	$I_1\ N_1$	$I_1\ N_2$
$I_1\ N_3$	$I_2\ N_1$	$I_2\ N_2$
$I_0\ N_0$	$I_2\ N_0$	$I_2\ N_3$
$I_0\ N_1$	$I_1\ N_0$	$I_0\ N_3$

$I_0\ N_0$	$I_2\ N_3$	$I_2\ N_1$
$I_2\ N_0$	$I_1\ N_0$	$I_0\ N_2$
$I_0\ N_3$	$I_2\ N_2$	$I_0\ N_1$
$I_1\ N_2$	$I_1\ N_3$	$I_1\ N_1$

Table 2. Example of statistical analysis.
Experiment 1, fraction C, weight of tubers, g/8 plants.

	DF	SS	MS	
R	2	52237	26118	
NL	1	2576902	2576902	***
NQ	1	2830806	2830806	***
NC	1	122148	122148	n.s.
I. NL	2	45130	22565	n.s.
I. NQ	2	953260	476630	*
I. NC	2	81049	40524	n.s.
I	2	1097759	548879	*
ERROR	22	2441485	110977	
TOTAL	35	10200776		

C.V. = 34.1%

I. N TABLE

	NO	N1	N2	N3	MEAN
I 0	1131.7	824.3	623.7	540.3	780.0
I 1	1759.7	583.0	617.3	834.7	948.7
I 2	2038.3	809.3	726.7	1244.7	1204.8
MEAN	1643.2	738.9	655.9	873.2	977.8
SE	192.33	96.17			
	111.04				

Statistical significance (determined by analysis of variance) is indicated by means of asterisks.

*** significant, P = 0.001
** significant, P = 0.01
* significant, P = 0.05
n.s. not significant.

Table 3. Experiment 1. Soil moisture levels, g/100g oven dry soil.

U = Upper horizon L = Lower horizon

Treatment		9.6.70	16.6.70	23.6.70	1.7.70	7.7.70	16.7.70	30.7.70	5.8.70	12.8.70	18.8.70
I_0N_0	U	12.7	10.6	10.3	15.0	12.9	13.9	16.3	16.5	13.1	17.0
	L	17.1	15.3	13.5	15.1	13.8	14.3	17.3	16.1	14.9	17.5
I_0N_1	U	12.2	11.9	9.5	13.1	12.2	12.5	16.7	14.2	12.8	15.5
	L	16.7	16.4	13.0	13.8	13.3	13.4	16.8	15.1	14.1	14.6
I_0N_2	U	12.6	12.2	11.1	13.9	12.1	12.9	16.4	14.5	12.1	16.1
	L	16.6	16.2	14.4	15.4	13.9	14.3	16.0	15.4	13.0	14.5
I_0N_3	U	12.9	11.7	11.0	14.0	12.1	14.0	15.9	12.6	12.0	15.8
	L	17.3	15.8	14.3	14.1	13.2	14.2	16.5	14.9	13.5	14.8
I_1N_0	U	12.9	11.4	10.6	15.5	12.0	13.6	17.1	17.2	13.3	17.8
	L	17.0	16.2	14.1	15.5	13.8	14.8	18.2	17.4	15.6	18.0
I_1N_1	U	12.5	13.4	11.4	13.1	12.2	12.3	16.8	16.0	13.6	15.0
	L	17.3	16.5	14.9	14.3	13.3	13.8	15.8	15.1	13.5	15.0
I_1N_2	U	12.8	12.7	11.5	14.2	12.2	13.6	16.2	13.0	12.2	16.9
	L	17.1	15.8	14.6	14.8	13.8	14.8	16.3	15.8	13.0	15.1
I_1N_3	U	12.6	11.9	10.9	14.3	12.2	13.2	17.2	15.1	14.1	15.3
	L	18.1	16.5	15.1	15.9	13.8	14.0	17.0	16.0	14.3	15.6
I_2N_0	U	12.1	12.7	13.7	17.4	14.2	15.0	18.6	15.9	15.3	18.8
	L	17.4	16.1	16.3	17.2	16.0	15.9	19.1	17.6	16.8	18.5
I_2N_1	U	12.7	13.9	12.7	15.8	12.7	14.9	17.2	13.1	15.7	17.8
	L	17.2	16.8	15.1	16.5	14.7	15.8	19.2	14.9	16.3	18.3
I_2N_2	U	13.5	13.3	13.3	16.4	13.7	14.3	18.8	13.8	14.5	18.0
	L	17.9	16.6	16.2	17.1	15.4	15.5	18.3	15.1	15.0	16.4
I_2N_3	U	13.2	14.1	14.0	15.8	13.9	14.2	17.2	14.9	15.6	16.8
	L	17.4	16.7	16.9	16.6	15.9	16.8	17.5	16.0	15.2	17.3

Table 4. Experiment 1. Irrigation applied, mm. Cumulative

Irrigation level	I_2				I_1			
Nitrogen level	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3
5.6.70	9.6	9.6	9.6	9.6				
10.6.70	28.8	27.6	23.4	25.2				
18.6.70	50.4	43.2	41.4	40.2	2.4			1.2
26.6.70	57.6	57.0	48.6	45.6	2.4			1.2
3.7.70	61.2	66.6	54.0	54.6	2.4			1.2
8.7.70	69.6	79.8	64.8	63.6	3.6	1.2	0.6	1.8
20.7.70	84.0	94.8	82.8	77.4	3.6	1.2	0.6	1.8
7.8.70	90.6	117.6	101.4	92.4	3.6	1.2	0.6	1.8

Table 5. Experiment 1. Irrigation water analysis, μg/ml

Date	Potassium	Sodium	Calcium	Magnesium
26.6.70	18	68	18	6
3.7.70	18	68	18	6
8.7.70	19	68	19	7
7.8.70	17	68	19	7

Table 6. Experiment 1. Soil, temperature, °C at 30cm

Date	Temperature	Date	Temperature
16.6.70	17.2	30.7.70	14.2
17.6.70	15.6	5.8.70	16.9
23.6.70	16.1	10.8.70	15.3
25.6.70	14.2	18.8.70	12.2
1.7.70	13.3	25.8.70	13.3
3.7.70	12.8	1.9.70	13.6
16.7.70	14.4	12.9.70	12.5
20.7.70	13.6		

<u>Table 7</u>. Experiment 1. Tubers, yield, g/8 plants

Fraction		Nitrogen level				S.E.	Significant effects	
		N_o	N_1	N_2	N_3			
A	I_0	9.0	15.3	36.3	29.7	9.49		I. N ***
	I_1	42.0	26.7	36.3	21.7			
	I_2	34.0	27.7	14.7	51.7			
B	I_0	124	92	237	186	63.0	N *	I.N **
	I_1	284	194	164	138			
	I_2	275	76	82	158			
C	I_0	1132	824	624	540	192.3	N_ℓ ***	I. N_q *
	I_1	1760	583	617	835		N_q ***	
	I_2	2038	809	727	1245		I *	
D	I_0	3263	2660	2328	2690	528.5	I *	
	I_1	3172	2748	3283	2477			
	I_2	3642	4312	3802	3743			
E	I_0	1660	4563	4058	3917	565.0	N_ℓ ***	
	I_1	912	4615	3867	3113		N_q ***	
	I_2	506	2788	3931	3082			
B + C	I_0	1256	916	860	726	216.3	N_ℓ ***	I. N_q *
	I_1	2044	777	781	973		N_q ***	
	I_2	2313	885	808	1403		I *	
D + E	I_0	4923	7222	6386	6607	322.0	N_ℓ ***	I. N_q *
	I_1	4084	7363	7150	5590		N_q ***	
	I_2	4149	7101	7733	6825		N_c **	
B+C+D+E	I_0	6179	8138	7246	7333	208.9	N_ℓ ***	I. N_ℓ **
	I_1	6128	8140	7932	6562		N_q ***	I. N_q *
	I_2	6462	7986	8541	8228		N_c **	I. N_c *
							I ***	
A+B+C+ D+E	I_0	6188	8154	7282	7363	208.8	N_ℓ ***	I. N_ℓ **
	I_1	6170	8166	7968	6584		N_q ***	I. N_q *
	I_2	6496	8014	8556	8280		N_c **	I. N_c *
							I ***	

Table 8. Experiment 1. Number of tubers/8 plants.

Fraction		Nitrogen level				Significant effects	
		N_0	N_1	N_2	N_3		
A	I_0	1.0	2.3	6.3	5.0	N_ℓ *	I. N ***
	I_1	4.0	4.7	5.0	5.3		
	I_2	3.3	4.0	2.0	6.0		
B	I_0	3.7	2.3	6.0	5.7	N *	I. N **
	I_1	7.7	5.0	4.3	3.7		
	I_2	7.0	2.0	3.0	4.7		
C	I_0	11.0	8.0	6.7	6.0	N_ℓ ***	I. N *
	I_1	19.0	6.7	5.7	8.3	N_q ***	
	I_2	20.7	8.7	8.0	12.3	I *	
D	I_0	17.7	13.7	12.3	15.0	I *	
	I_1	17.3	14.7	17.7	13.7		
	I_2	21.3	22.3	20.3	19.3		
E	I_0	5.0	14.3	12.0	12.0	N_ℓ ***	I *
	I_1	2.7	14.3	11.3	10.7	N_q ***	
	I_2	1.7	8.0	11.0	9.7	N_c **	
B + C	I_0	14.7	10.3	12.7	11.7	N_ℓ **	I. N **
	I_1	26.7	11.7	10.0	12.0	N_q ***	
	I_2	27.7	10.7	11.0	17.0		
D + E	I_0	22.7	28.0	24.3	27.0	N_ℓ **	I. N *
	I_1	20.0	29.0	29.0	24.3	N_q ***	
	I_2	23.0	30.3	31.3	29.0		
B+C+D+E	I_0	37.3	38.3	37.0	38.7	N *	I. N **
	I_1	46.7	40.7	39.0	36.3	I **	
	I_2	50.7	41.0	42.3	46.0		
A+B+C+ D+E	I_0	38.3	40.7	43.3	43.7	I **	I. N_ℓ *
	I_1	50.7	45.3	44.0	41.7		
	I_2	54.0	45.0	44.3	52.0		

Statistical analysis was carried out by log. transformation, thus no standard errors are presented.

Table 9. Experiment 1. Seed/Total ratio for weight of tubers

Moisture level	Nitrogen level				S.E.	Significant effects
	N_0	N_1	N_2	N_3		
I_0	.20	.11	.12	.10	.032	N_ℓ *** I. N_q *
I_1	.33	.10	.10	.15		N_q ***
I_2	.36	.11	.10	.17		

Table 10. Experiment 1. Seed/Total ratio for number of tubers

Moisture level	Nitrogen level				S.E.	Significant effects
	N_0	N_1	N_2	N_3		
I_0	.38	.25	.29	.26	.049	N_ℓ *** I. N *
I_1	.51	.26	.23	.28		N_q ***
I_2	.51	.23	.25	.32		

Table 11. Experiment 1. Average tuber fresh weight, g/tuber

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
A	I_0	8.8	7.1	5.4	5.8	1.16	N_ℓ **	I. N *
	I_1	10.3	6.0	7.1	3.8		N_q *	
	I_2	10.1	6.8	7.3	8.6			
B	I_0	36.4	40.8	41.0	32.2	3.12	N *	I. N ***
	I_1	35.5	38.3	39.3	36.3			
	I_2	39.8	38.8	26.5	32.6			
C	I_0	102	104	93	93	5.7		I. N ***
	I_1	93	86	108	99			
	I_2	98	91	88	103			
D	I_0	185	193	189	179	6.4	N **	I. N *
	I_1	184	185	185	181			
	I_2	171	195	189	195			
E	I_0	318	319	340	329	26.5		
	I_1	324	322	341	294			
	I_2	293	348	327	319			
B + C	I_0	87	88	71	63	6.8		I. N_ℓ *
	I_1	78	65	78	84			
	I_2	83	83	71	85			
D + E	I_0	217	258	263	246	14.0	N_ℓ **	
	I_1	204	256	247	231		N_q ***	
	I_2	181	235	253	237			
B+C+D+E	I_0	167	212	196	192	11.9	N_ℓ ***	
	I_1	134	200	203	181		N_q ***	
	I_2	128	197	206	180			
A+B+C +D+E	I_0	164	201	168	170	11.8	N_ℓ *	I. N **
	I_1	124	180	181	160		N_q ***	
	I_2	120	179	199	160			

<u>Table 12</u>. Experiment 1. Tubers, dry matter content, kg dry matter/kg fresh material.

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	.198	.179	.171	.155	.0198	N_ℓ **	
	I_1	.215	.185	.175	.177			
	I_2	.212	.169	.160	.137			
C	I_0	.236	.213	.182	.192	.0070	N_ℓ ***	I. N **
	I_1	.226	.216	.206	.191			
	I_2	.230	.223	.205	.205			
D	I_0	.194	.195	.185	.192	.0059	N_ℓ **	I. N **
	I_1	.207	.215	.185	.191		N_c *	
	I_2	.205	.191	.185	.191			
E	I_0	.220	.185	.176	.185	.0080	N_ℓ ***	
	I_1	.224	.192	.178	.185		N_q ***	
	I_2	.228	.193	.186	.180			
B + C	I_0	.231	.206	.180	.184	.0059	N_ℓ ***	I. N **
	I_1	.225	.205	.199	.188		N_q *	
	I_2	.228	.221	.199	.198		I *	
D + E	I_0	.199	.189	.180	.188	.0051	N_ℓ ***	
	I_1	.211	.201	.181	.187		N_q **	
	I_2	.208	.192	.177	.186			
B+C+D+E	I_0	.206	.191	.180	.187	.0045	N_ℓ ***	
	I_1	.215	.201	.183	.187		N_q ***	
	I_2	.214	.195	.179	.188			

Table 13. Experiment 1. Tubers, degree of cracking, number of tubers as a ratio of total number of tubers.

Category		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
Slight	I_0	.64	.55	.46	.48	.055	N_ℓ **	
	I_1	.77	.61	.59	.58		I **	
	I_2	.76	.63	.66	.59			
Moderate	I_0	.29	.35	.21	.23	.049	N_q *	I. N *
	I_1	.11	.23	.20	.10		I **	
	I_2	.08	.22	.18	.18			
Bad	I_0	.026	.025	.023	.075	.0136	N_ℓ **	I. N_q *
	I_1	.008	.015	.083	.036			I. N_c *
	I_2	.025	.022	.055	.045			
Very bad	I_0	.000	.016	.008	.062	.0123	N_ℓ *	I. N_ℓ *
	I_1	.007	.029	.023	.044			
	I_2	.025	.035	.017	.018			
Very bad + bad	I_0	.026	.041	.031	.137	.0166	N_ℓ ***	I. N_ℓ *
	I_1	.014	.044	.105	.080			I. N_q *
	I_2	.049	.057	.072	.063			
Very bad + bad + moderate	I_0	.32	.39	.24	.37	.051	N ***	I. N **
	I_1	.13	.28	.30	.18		I *	
	I_2	.13	.28	.26	.25			
Very bad + bad + moderate + slight	I_0	.96	.93	.70	.85	.025	N_ℓ ***	I. N_ℓ *
	I_1	.90	.88	.89	.77			I. N_q ***
	I_2	.89	.91	.92	.84			I. N_c ***

Table 14. Experiment 1. Tubers, nitrogen concentration, mg nitrogen/g dry material

Fraction		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
B	I_0	10.0	14.9	16.8	19.1	1.34	N_ℓ ***
	I_1	8.5	11.5	15.5	17.3		
	I_2	7.3	11.5	15.6	18.9		
C	I_0	7.3	11.7	15.0	15.3	0.56	N_ℓ ***
	I_1	7.7	11.0	15.8	16.2		N_q ***
	I_2	6.9	10.5	14.3	15.4		N_c *
D	I_0	10.5	14.1	16.8	17.2	0.68	N_ℓ *** I.N **
	I_1	9.3	11.6	17.4	18.3		N_q *
	I_2	8.9	12.8	15.9	17.7		
E	I_0	8.7	14.2	17.1	17.7	0.85	N_ℓ ***
	I_1	8.0	14.1	18.1	17.9		N_q ***
	I_2	7.4	12.5	16.5	18.9		
B + C	I_0	7.5	12.1	15.5	15.9	0.57	N_ℓ ***
	I_1	7.7	11.2	15.7	16.5		N_q ***
	I_2	6.9	10.4	14.4	15.8		N_c *
D + E	I_0	10.0	14.1	17.0	17.5	0.66	N_ℓ *** I.N *
	I_1	8.9	13.2	17.8	18.1		N_q ***
	I_2	8.7	12.7	16.5	18.2		
B+C+D+E	I_0	9.4	13.8	16.8	17.3	0.58	N_ℓ *** I.N *
	I_1	8.5	13.0	17.6	17.9		N_q ***
	I_2	8.1	12.4	16.4	17.8		

Table 15. Experiment 1. Tubers,phosphorus concentration, mg phosphorus/g dry material

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	1.7	2.1	1.9	2.1	0.14	N_ℓ *	
	I_1	1.7	1.8	1.9	2.1			
	I_2	1.8	1.7	2.0	1.8			
C	I_0	1.5	1.7	1.9	1.8	0.10	N_ℓ ***	
	I_1	1.7	1.7	1.9	2.0			
	I_2	1.7	1.8	1.9	1.9			
D	I_0	1.7	1.8	1.8	1.9	0.07	N_ℓ **	
	I_1	1.7	1.8	2.0	1.8			
	I_2	1.7	1.9	2.0	1.9			
E	I_0	1.7	1.9	1.8	1.9	0.09	N_ℓ **	I.N *
	I_1	1.7	1.9	2.1	1.9		N_q *	
	I_2	1.7	2.0	2.1	2.1			
B + C	I_0	1.5	1.8	1.9	1.9	0.09	N_ℓ ***	
	I_1	1.7	1.8	1.9	2.0			
	I_2	1.7	1.8	1.9	1.9			
D + E	I_0	1.7	1.9	1.8	1.9	0.07	N_ℓ **	I.N *
	I_1	1.7	1.9	2.1	1.8		N_q **	
	I_2	1.7	1.9	2.1	2.0			
B+C+D+E	I_0	1.6	1.8	1.8	1.9	0.07	N_ℓ ***	I.N **
	I_1	1.7	1.9	2.1	1.9		N_q ***	
	I_2	1.7	1.9	2.1	2.0		I *	

Table 16. Experiment 1. Tubers, potassium concentration, mg potassium/g dry material

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	18.4	21.0	20.5	20.6	1.49	N **	
	I_1	16.6	19.3	20.2	18.8			
	I_2	17.8	22.0	19.6	19.6			
C	I_0	16.2	19.4	19.8	18.3	0.80	N_ℓ *	I.N *
	I_1	17.4	17.8	19.6	19.1		N_q *	
	I_2	18.7	18.5	19.9	18.5			
D	I_0	20.0	20.7	19.7	19.6	0.89	N_q *	I.N **
	I_1	18.3	19.0	21.2	19.1			
	I_2	20.6	21.3	20.7	17.8			
E	I_0	17.9	21.0	20.8	20.8	1.11	N_ℓ *	
	I_1	17.4	21.4	22.3	19.4		N_q ***	
	I_2	17.8	20.2	21.5	18.9			
B + C	I_0	16.3	19.7	20.0	18.6	0.71	N_ℓ *	I.N *
	I_1	17.3	18.3	19.6	19.1		N_q **	
	I_2	18.6	18.5	19.8	18.6			
D + E	I_0	19.5	20.9	20.3	20.3	0.95	N_q **	I.N *
	I_1	18.0	20.4	21.8	19.2			
	I_2	20.2	20.9	21.3	18.3			
B+C+D+E	I_0	18.7	20.7	20.2	20.1	0.85	N_q **	I.N *
	I_1	17.8	20.2	21.5	19.2			
	I_2	19.6	20.6	21.2	18.3			

Table 17. Experiment 1. Tubers, reducing sugar concentration, mg reducing sugar/g fresh tuber

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
C	I_0	3.8	3.5	4.3	3.8	0.36	N **	$I.N_q$ *
	I_1	3.8	3.4	2.0	3.9			$I.N_c$ *
	I_2	4.1	3.5	3.1	2.6			
D	I_0	2.7	2.0	2.2	1.9	0.17	N_ℓ **	I.N **
	I_1	2.7	2.7	2.2	1.9			
	I_2	3.1	2.3	2.0	2.0			
E	I_0	2.7	1.8	1.8	1.8	0.38	N_ℓ ***	
	I_1	2.6	1.8	1.6	1.9			
	I_2	3.5	2.9	2.1	1.5			
D + E	I_0	2.7	1.9	2.0	1.8	0.21	N_ℓ ***	I.N *
	I_1	2.7	2.3	1.9	1.9			
	I_2	3.3	2.6	2.1	1.8			
C+D+E	I_0	3.1	2.4	2.8	2.5	0.17	N_ℓ ***	$I.N_\ell$ **
	I_1	3.1	2.7	2.0	2.6		N_q *	$I.N_c$ *
	I_2	3.5	2.9	2.4	2.0			

Table 18. Experiment 1. Tubers, sucrose concentration
mg sucrose/g fresh tuber

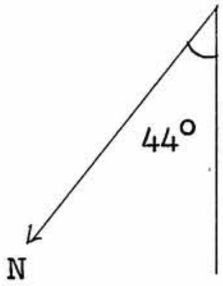
Fraction		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
C	I_0	2.6	2.6	2.7	2.8	0.30	I.N *
	I_1	2.4	2.5	2.9	3.0		
	I_2	2.1	2.9	2.0	2.3		
D	I_0	2.4	2.4	2.5	2.5	0.20	
	I_1	2.4	2.6	2.7	2.7		
	I_2	2.1	2.4	2.3	2.3		
E	I_0	2.7	2.3	2.5	2.4	0.20	N *
	I_1	2.7	2.5	2.5	2.5		I *
	I_2	2.3	1.9	2.2	2.1		
D + E	I_0	2.6	2.4	2.5	2.4	0.16	I *
	I_1	2.5	2.5	2.6	2.6		
	I_2	2.2	2.2	2.3	2.2		
C+D+E	I_0	2.6	2.4	2.6	2.6	0.15	I **
	I_1	2.5	2.5	2.7	2.7		
	I_2	2.2	2.4	2.2	2.3		

Table 19. Experiment 1. Tubers, total sugar concentration, mg sugar/g fresh tuber.

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
C	I_0	6.4	6.1	7.0	6.6	0.48	I *	I.N ***
	I_1	6.2	6.0	5.0	6.9			
	I_2	6.2	6.3	5.1	4.9			
D	I_o	5.1	4.3	4.7	4.4	0.29	N_ℓ **	
	I_1	5.1	5.3	5.0	4.5			
	I_2	5.2	4.7	4.3	4.3			
E	I_0	5.4	4.2	4.3	4.1	0.45	N_ℓ ***	
	I_1	5.3	4.3	4.1	4.3			
	I_2	5.8	4.8	4.4	3.7			
D + E	I_0	5.2	4.2	4.5	4.3	0.30	N_ℓ ***	
	I_1	5.2	4.8	4.5	4.4			
	I_2	5.5	4.7	4.3	4.0			
C+D+E	I_0	5.6	4.8	5.4	5.0	0.26	N_ℓ **	I.N ***
	I_1	5.6	5.2	4.7	5.3			
	I_2	5.7	5.3	4.6	4.3			

<u>Table 20</u>. Experiment 2. Layout.

I_1 N_2	I_0 N_2	I_2 N_2
I_0 N_1	I_0 N_3	I_1 N_1
I_2 N_1	I_2 N_3	I_2 N_0
I_1 N_3	I_0 N_0	I_1 N_0



I_2 N_2	I_0 N_1	I_1 N_1
I_1 N_3	I_2 N_0	I_0 N_2
I_0 N_0	I_0 N_3	I_1 N_0
I_2 N_3	I_2 N_1	I_1 N_2

I_0 N_0	I_2 N_0	I_2 N_1
I_0 N_3	I_1 N_2	I_0 N_2
I_2 N_2	I_2 N_3	I_1 N_3
I_0 N_1	I_1 N_1	I_1 N_0

Table 21. Experiment 2. Irrigation applied, mm. Cumulative

Irrigation level	I_2				I_1			
Nitrogen level	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3
9.6.70	4.8	4.8	4.8	4.8				
16.6.70	9.6	12.6	14.4	11.4				
22.6.70	28.2	30.0	25.8	22.2	4.2		0.6	
7.7.70	36.6	40.8	29.4	27.6	4.2		1.8	
15.7.70	37.8	44.4	34.8	27.6	4.2		1.8	
13.8.70	40.2	55.8	41.4	37.2	4.2		1.8	

Table 22. Experiment 2. Irrigation water analysis, μg/ml

Date	Potassium	Sodium	Calcium	Magnesium
7.7.70	17	52	12	4
15.7.70	16	52	12	4

Table 23. Experiment 2. Soil moisture levels, g/100g oven dry soil.

U = Upper horizon L = Lower horizon

Treatment		15.6.70	21.6.70	29.6.70	6.7.70	14.7.70	22.7.70	28.7.70	3.8.70	11.8.70	26.8.70
I_0N_0	U	19.2	16.7	18.5	17.6	21.1	22.5	25.3	25.2	20.3	24.9
	L	23.9	17.7	19.5	18.6	19.6	18.6	23.9	25.1	21.1	25.5
I_0N_1	U	19.4	16.3	17.2	18.2	18.5	23.6	26.4	23.8	19.2	25.6
	L	21.8	19.5	19.9	17.2	17.7	17.4	25.8	23.2	19.5	25.4
I_0N_2	U	19.9	17.7	19.0	21.6	21.5	21.0	25.8	25.0	19.7	24.8
	L	24.8	21.5	20.8	18.1	20.7	20.2	25.8	25.6	20.8	25.7
I_0N_3	U	19.4	19.3	20.5	23.4	22.1	21.2	28.1	25.6	19.8	25.2
	L	23.1	20.8	21.6	20.8	21.5	21.0	25.8	25.6	22.9	24.9
I_1N_0	U	19.5	16.1	19.6	19.3	20.0	22.8	26.6	25.3	21.8	26.4
	L	24.2	18.5	20.9	20.6	20.0	19.4	26.0	25.5	22.4	27.8
I_1N_1	U	20.6	18.4	22.5	18.3	21.5	22.5	27.2	24.7	19.9	28.1
	L	24.0	21.6	21.4	19.6	18.2	19.6	26.4	25.4	21.2	26.5
I_1N_2	U	21.6	18.9	22.0	20.4	21.6	21.8	27.3	24.6	22.1	25.9
	L	23.3	21.8	22.3	19.0	21.1	19.1	26.5	24.5	21.4	25.8
I_1N_3	U	18.9	18.6	20.0	19.2	21.3	22.1	26.8	24.3	20.6	26.2
	L	22.9	22.6	24.6	20.1	21.5	21.5	25.0	24.8	21.9	24.5
I_2N_0	U	21.3	17.8	23.9	19.3	23.1	22.0	27.3	25.8	22.2	26.6
	L	22.8	21.1	24.0	22.3	22.2	21.6	26.7	26.6	24.1	27.9
I_2N_1	U	20.1	18.4	23.0	19.6	22.7	23.2	27.8	25.0	21.3	26.3
	L	24.4	21.5	23.9	21.6	22.6	20.8	25.6	25.0	20.5	25.7
I_2N_2	U	19.5	19.5	23.2	21.4	22.2	23.9	27.0	25.1	21.2	25.9
	L	23.2	22.6	24.9	23.9	21.1	20.2	26.1	25.7	22.1	24.8
I_2N_3	U	20.6	19.6	22.8	21.5	23.2	21.3	26.3	25.0	20.1	27.1
	L	23.8	22.4	23.5	21.9	23.0	21.2	26.9	24.9	22.4	25.4

Table 24. Experiment 2. Tubers, yield, g/8 plants

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
A	I_0	56.0	31.7	34.3	55.3	28.11		
	I_1	58.3	38.7	12.0	71.7			
	I_2	75.0	61.7	35.3	10.7			
B	I_0	152	276	79	345	55.2	N_q *	$I.N_\ell$ **
	I_1	265	116	160	204		N_c *	$I.N_c$ *
	I_2	349	307	108	133			
C	I_0	1369	1048	596	571	273.4	N_ℓ ***	
	I_1	1221	917	592	662		I *	
	I_2	2081	1660	1263	722			
D	I_0	6016	5039	3211	3471	602.6	N_ℓ ***	
	I_1	5244	5006	3858	3337			
	I_2	5452	4881	4965	3284			
E	I_0	2258	2955	5311	4660	700.7	N_ℓ ***	I.N *
	I_1	1325	4495	4467	4597			
	I_2	1311	2540	3964	5488			
B + C	I_0	1521	1324	675	916	295.0	N_ℓ ***	
	I_1	1486	1033	753	866		I *	
	I_2	2430	1967	1371	855			
D + E	I_0	8273	7994	8523	8131	527.4	N_ℓ *	I.N ***
	I_1	6569	9502	8325	7934		N_q *	
	I_2	6763	7421	8929	8772			
B+C+D+E	I_0	9794	9318	9198	9047	450.4	N_q *	$I.N_c$ *
	I_1	8055	10535	9077	8800			
	I_2	9193	9388	10300	9627			
A+B+C +D+E	I_0	9850	9350	9232	9102	450.8	N *	$I.N_c$ *
	I_1	8113	10574	9089	8872			
	I_2	9268	9450	10335	9637			

Table 25. Experiment 2. Number of tubers/8 plants.

Fraction		Nitrogen level				Significent effects	
		N_0	N_1	N_2	N_3		
A	I_0	8.0	4.3	5.0	7.3		I.N *
	I_1	6.7	4.3	2.7	9.0		
	I_2	9.7	5.7	5.3	2.0		
B	I_0	4.0	6.7	1.7	9.7	N_q *	$I.N_\ell$ *
	I_1	6.3	3.3	4.7	5.3	N_c *	$I.N_c$ *
	I_2	10.0	6.3	3.3	4.0		
C	I_0	15.0	10.3	6.7	6.3	N_ℓ ***	
	I_1	13.0	9.3	6.3	8.0	I **	
	I_2	23.0	16.3	13.3	8.0		
D	I_0	34.0	27.7	17.7	17.7	N_ℓ ***	
	I_1	30.0	27.0	21.0	18.3		
	I_2	30.7	27.0	27.7	18.3		
E	I_0	7.7	10.0	16.3	16.0	N_ℓ ***	I.N **
	I_1	4.3	14.3	14.0	13.3	N_q **	
	I_2	4.7	9.0	12.7	15.7		
B + C	I_0	19.0	17.0	8.3	16.0	N_ℓ ***	I.N **
	I_1	19.3	12.7	11.0	13.3	N_q *	
	I_2	33.0	22.7	16.7	12.3	I *	
D + E	I_0	41.7	37.7	34.0	33.7	N_ℓ *	I.N **
	I_1	34.3	41.3	35.0	31.7		
	I_2	35.3	36.0	40.3	34.0		
B+C+D+E	I_0	60.7	54.7	42.3	49.7	N_ℓ ***	I.N **
	I_1	53.7	54.0	46.0	45.0	I *	
	I_2	68.3	58.7	57.0	46.0		
A+B+C +D+E	I_0	68.7	59.0	47.3	57.0	N_ℓ ***	I.N **
	I_1	60.7	58.3	48.7	54.0		
	I_2	78.0	64.3	62.3	48.0		

Statistical analysis was carried out by log transformation, thus no standard errors are presented.

Table 26. Experiment 2. Seed/total ratio for weight of tubers

Moisture level	Nitrogen level				Standard error	Significant effects	
	N_0	N_1	N_2	N_3			
I_0	.16	.14	.07	.10	.033	N_ℓ ***	I.N *
I_1	.18	.10	.08	.10		I *	
I_2	.27	.21	.13	.09			

Table 27. Experiment 2. Seed/Total ratio for number of tubers

Moisture level	Nitrogen level				Standard error	Significant effects	
	N_0	N_1	N_2	N_3			
I_0	.28	.29	.18	.28	.040	N_ℓ **	I.N *
I_1	.32	.21	.23	.24		I *	
I_2	.41	.35	.26	.25			

Table 28. Experiment 2. Average tuber fresh weight, g/tuber.

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
A	I_0	7.8	7.4	6.5	7.6	1.55	N_c *	I.N **
	I_1	6.8	8.1	5.4	7.8			
	I_2	7.1	13.2	5.9	4.8			
B	I_0	37.7	41.1	46.1	34.6	5.54		I.N **
	I_1	41.5	35.0	35.7	38.8			
	I_2	36.3	54.4	33.4	34.0			
C	I_0	92	99	89	91	7.3	N **	
	I_1	94	99	92	83			
	I_2	91	105	96	90			
D	I_0	177	182	182	196	7.9		
	I_1	175	186	187	185			
	I_2	177	180	179	180			
E	I_0	293	299	329	298	18.3	N_ℓ *	I. N *
	I_1	306	317	317	332			
	I_2	271	283	319	348			
B + C	I_0	79	76	81	57	8.2	N_q *	
	I_1	78	81	71	65			
	I_2	73	91	84	72			
D + E	I_0	198	212	251	244	16.7	N_ℓ ***	
	I_1	191	232	238	258			
	I_2	189	206	221	262			
B+C+D+E	I_0	161	171	217	184	13.7	N_ℓ ***	I.N **
	I_1	151	195	199	200			
	I_2	137	161	181	211			
A+B+C+ D+E	I_0	144	158	195	165	14.6	N_ℓ ***	I.N **
	I_1	139	181	187	171			
	I_2	122	150	166	202			

Table 29. Experiment 2. Tubers, dry matter content, kg dry matter/kg fresh material

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	.185	.151	.172	.158	.0142	N_ℓ *	I.N *
	I_1	.170	.156	.136	.150			
	I_2	.179	.157	.176	.122			
C	I_0	.199	.200	.195	.192	.0065	N_c *	I.N *
	I_1	.198	.181	.201	.188			
	I_2	.198	.179	.190	.175			
D	I_0	.161	.162	.182	.186	.0060	N_ℓ ***	I.N *
	I_1	.164	.166	.177	.177			
	I_2	.164	.167	.165	.179			
E	I_0	.190	.180	.171	.176	.0088	N_ℓ ***	I.N *
	I_1	.210	.173	.164	.169			
	I_2	.194	.189	.176	.167			
B + C	I_0	.199	.188	.192	.182	.0049	N_ℓ **	
	I_1	.195	.177	.190	.180		N_c ***	
	I_2	.194	.176	.190	.168			
D + E	I_0	.169	.170	.175	.180	.0053		
	I_1	.173	.169	.168	.169			
	I_2	.169	.171	.169	.171			
B+C+D+E	I_0	.173	.172	.176	.180	.0046		
	I_1	.176	.170	.169	.170			
	I_2	.174	.172	.172	.170			

Table 30. Experiment 2. Tubers, degree of cracking, number of tubers as a ratio of total number of tubers.

Category		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
Slight	I_0	.39	.49	.36	.40	.059	N **	I.N *
	I_1	.36	.39	.49	.41			
	I_2	.31	.48	.46	.46			
Moderate	I_0	.26	.23	.33	.24	.054	N *	I.N **
	I_1	.14	.32	.27	.18		I *	
	I_2	.11	.09	.16	.23			
Bad	I_0	.033	.011	.021	.051	.0174	N_ℓ *	
	I_1	.004	.029	.007	.047			
	I_2	.004	.023	.010	.052			
Very bad	I_0	.022	.006	.042	.005	.0143		$I.N_c$ *
	I_1	.017	.022	.014	.039			
	I_2	.025	.036	.006	.035			
Very bad + bad	I_0	.05	.02	.06	.06	.022	N **	$I.N_c$ *
	I_1	.02	.05	.02	.09			
	I_2	.03	.06	.02	.09			
Very bad + bad + moderate	I_0	.32	.24	.40	.29	.063	N *	I.N **
	I_1	.16	.37	.29	.27		I *	
	I_2	.14	.15	.17	.32			
Very bad + moderate + slight	I_0	.71	.73	.75	.69	.048	N_ℓ ***	$I.N_\ell$ **
	I_1	.52	.76	.78	.68		N_q **	
	I_2	.44	.63	.64	.77		I *	

Table 31. Experiment 2. Tubers, nitrogen concentration, mg nitrogen/g dry material

Fraction		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
B	I_0	17.4	19.5	21.8	24.8	2.49	N_ℓ **
	I_1	17.9	19.8	20.3	23.2		
	I_2	15.6	19.7	16.4	22.6		
C	I_0	15.9	14.9	18.8	19.3	0.96	N_ℓ *** $I.N_c$ *
	I_1	15.4	18.4	16.4	19.5		
	I_2	15.8	18.8	18.5	20.8		
D	I_0	19.6	20.6	21.1	20.4	0.99	N_q *
	I_1	18.4	19.9	21.4	19.9		
	I_2	19.0	21.0	22.6	20.4		
E	I_0	16.3	18.0	21.2	21.1	1.10	N_ℓ *** I.N **
	I_1	13.7	19.2	20.9	21.2		
	I_2	17.1	18.9	18.8	21.7		
B + C	I_0	16.0	15.6	19.2	20.9	0.98	N_ℓ *** $I.N_c$ *
	I_1	15.5	18.6	16.6	20.4		
	I_2	15.9	18.8	18.3	21.0		
D + E	I_0	18.6	19.6	21.2	20.8	0.82	N_ℓ ***
	I_1	17.3	19.6	21.4	21.0		
	I_2	18.5	20.5	20.8	21.4		
B+C+D+E	I_0	18.2	19.0	21.1	20.8	0.77	N_ℓ ***
	I_1	17.0	19.5	21.0	21.0		
	I_2	17.8	20.1	20.4	21.3		

Table 32. Experiment 2. Tubers, phosphorus concentration, mg phosphorus/g dry material.

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	2.4	1.9	2.6	2.7	0.21		I.N **
	I_1	2.4	2.2	2.4	2.3			
	I_2	2.3	2.5	1.9	2.4			
C	I_0	1.9	2.0	2.3	2.4	0.12	N **	$I.N_\ell$ *
	I_1	2.3	2.2	2.0	2.1			
	I_2	2.1	2.4	2.1	2.5			
D	I_0	2.2	2.1	2.3	2.1	0.11	N_ℓ *	I.N **
	I_1	2.5	2.1	2.1	2.2		I *	
	I_2	2.4	2.5	2.3	2.2			
E	I_0	2.1	2.2	2.4	2.3	0.12	N_ℓ *	I.N *
	I_1	2.1	2.2	2.6	2.3			
	I_2	2.2	2.4	2.3	2.3			
B + C	I_0	1.9	2.0	2.3	2.5	0.11	N_ℓ *	$I.N_\ell$ **
	I_1	2.3	2.2	2.0	2.2			
	I_2	2.2	2.4	2.1	2.5			
D + E	I_0	2.1	2.1	2.4	2.2	0.09	N *	$I.N_c$ *
	I_1	2.4	2.1	2.4	2.3		I *	
	I_2	2.3	2.5	2.3	2.3			
B+C+D+E	I_0	2.1	2.1	2.4	2.2	0.09		$I.N_c$ *
	I_1	2.4	2.1	2.3	2.3			
	I_2	2.3	2.5	2.3	2.3			

Table 33. Experiment 2. Tubers, potassium concentration, mg potassium/g dry material

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	21.2	20.9	25.9	23.1	2.01	N_ℓ *	$I.N_c$ *
	I_1	22.5	23.0	23.1	24.4			
	I_2	19.0	24.1	19.4	27.5			
C	I_0	19.6	19.3	21.6	20.0	1.05		I.N ***
	I_1	22.3	21.6	18.7	20.0			
	I_2	20.0	20.8	20.3	22.2			
D	I_0	24.8	21.5	20.0	19.0	1.15	N_ℓ ***	
	I_1	23.7	21.6	19.6	20.1			
	I_2	24.1	22.6	22.8	19.7			
E	I_0	21.9	19.3	22.2	20.7	1.26	N *	I.N **
	I_1	18.3	22.4	22.7	20.7			
	I_2	20.4	19.4	21.4	20.3			
B + C	I_0	19.7	19.6	22.1	20.9	0.96		I.N ***
	I_1	22.0	21.7	19.1	20.6			
	I_2	19.9	21.2	20.2	22.7			
D + E	I_0	23.9	20.5	21.4	20.0	1.06	N_ℓ **	
	I_1	22.4	22.2	21.4	20.9			
	I_2	23.4	21.7	22.3	20.2			
B+C+D+E	I_0	23.2	20.4	21.5	20.1	0.96	N_ℓ *	
	I_1	22.3	22.1	21.2	20.9			
	I_2	22.5	21.6	21.9	20.4			

Table 34. Experiment 2. Tubers, reducing sugar concentration, mg reducing sugar/g fresh tuber

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	4.1	6.7	3.8	6.2	1.65		I.N *
	I_1	4.8	6.3	8.5	3.8			
	I_2	6.6	4.7	4.7	7.8			
C	I_0	2.1	3.2	3.2	3.0	0.61	N **	I.N *
	I_1	3.1	4.3	2.3	2.3			
	I_2	2.7	3.6	2.6	3.3			
D	I_0	2.1	1.8	1.7	2.0	0.26	N_ℓ **	
	I_1	2.8	2.4	1.8	2.0			
	I_2	2.9	2.3	2.0	2.1			
E	I_0	1.7	1.7	1.9	1.7	0.26	N_c *	I.N *
	I_1	2.6	1.7	2.2	1.6			
	I_2	2.0	1.5	2.2	1.7			
B + C	I_0	2.3	4.1	3.1	3.8	0.54	N_c *	I.N **
	I_1	3.4	4.3	3.1	2.5			
	I_2	3.5	3.7	2.8	3.8			
D + E	I_0	2.0	1.8	1.8	1.8	0.21	N_ℓ ***	I.N *
	I_1	2.8	2.1	2.0	1.8			
	I_2	2.7	2.1	2.1	1.8			
B+C+D+E	I_0	2.0	2.1	1.9	2.0	0.21		$I.N_\ell$ *
	I_1	2.9	2.3	2.1	1.8			
	I_2	2.9	2.5	2.2	2.0			

Table 35. Experiment 2. Tubers, sucrose concentration, mg sucrose/g fresh tuber.

Fraction		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
B	I_0	2.1	1.9	2.0	2.9	0.40	
	I_1	2.1	1.9	2.4	2.5		
	I_2	1.9	2.0	2.3	1.9		
C	I_0	2.8	2.9	2.9	3.3	0.31	I.N *
	I_1	2.9	3.0	3.1	2.4		
	I_2	2.7	3.0	3.3	2.5		
D	I_0	2.7	2.5	3.1	3.1	0.21	N *
	I_1	2.9	2.9	2.9	3.1		
	I_2	2.7	2.8	2.9	2.8		
E	I_0	3.1	2.8	3.1	3.1	0.23	I.N *
	I_1	3.4	3.4	2.8	3.0		
	I_2	2.9	3.0	2.8	2.8		
B + C	I_0	2.8	2.7	2.7	3.2	0.25	I.N **
	I_1	2.8	2.8	3.1	2.5		
	I_2	2.6	2.8	3.2	2.4		
D + E	I_0	2.8	2.6	3.1	3.1	0.16	I.N **
	I_1	3.0	3.1	2.8	2.9		
	I_2	2.7	2.8	2.9	2.8		
B+C+D+E	I_0	2.8	2.6	3.1	3.1	0.17	I.N **
	I_1	2.9	3.1	2.8	2.8		
	I_2	2.7	2.8	2.9	2.7		

Table 36 Experiment 2. Tubers, total sugar concentration, mg sugar/g fresh tuber.

Fraction		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
B	I_0	6.3	8.6	5.8	9.1	1.69		I.N *
	I_1	6.9	8.2	10.9	6.4			
	I_2	8.5	6.6	7.0	9.7			
C	I_0	4.9	6.2	6.1	6.3	0.71	N **	I.N *
	I_1	6.0	7.3	5.4	4.7			
	I_2	5.4	6.5	5.9	5.8			
D	I_0	4.8	4.3	4.8	5.1	0.34	N **	I.N *
	I_1	5.7	5.2	4.6	5.0			
	I_2	5.5	5.1	4.9	4.9			
E	I_0	4.8	4.5	4.9	4.8	0.34	N *	I.N *
	I_1	6.0	5.1	5.0	4.6			
	I_2	4.8	4.4	5.0	4.5			
B + C	I_0	5.0	6.7	5.9	7.0	0.61	N *	I.N **
	I_1	6.1	7.1	6.1	5.0			
	I_2	6.1	6.5	6.0	6.2			
D + E	I_0	4.8	4.4	4.9	4.9	0.28	N_ℓ *	I.N_ℓ *
	I_1	5.7	5.2	4.8	4.6			
	I_2	5.4	4.9	4.9	4.5			
B+C+D+E	I_0	4.8	4.7	5.0	5.1	0.29	N_ℓ *	I.N_ℓ *
	I_1	5.8	5.4	4.9	4.7			
	I_2	5.6	5.3	5.1	4.7			

Table 37. Experiment 3. Layout

$I_0\ N_2$	$I_1\ N_1$	$I_1\ N_2$	$I_0\ N_1$
$I_1\ N_3$	$I_0\ N_3$	$I_0\ N_0$	$I_1\ N_0$
$I_1\ N_3$	$I_0\ N_0$	$I_0\ N_3$	$I_1\ N_0$
$I_0\ N_2$	$I_1\ N_2$	$I_0\ N_1$	$I_1\ N_1$
$I_0\ N_1$	$I_0\ N_0$	$I_0\ N_3$	$I_1\ N_3$
$I_1\ N_1$	$I_1\ N_0$	$I_1\ N_2$	$I_0\ N_2$
$I_0\ N_3$	$I_0\ N_1$	$I_1\ N_0$	$I_1\ N_2$
$I_1\ N_1$	$I_0\ N_0$	$I_1\ N_3$	$I_0\ N_2$

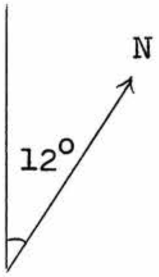


Table 38. Experiment 3. Soil, temperature, °C at 30cm

Date	Temperature	Date	Temperature
3.5.71	11.7	21.6.71	11.6
6.5.71	11.1	28.6.71	11.7
11.5.71	13.9	5.7.71	15.0
18.5.71	11.7	8.7.71	18.9
26.5.71	11.7	12.7.71	17.2
27.5.71	9.7	21.7.71	16.1
28.5.71	11.1	11.8.71	13.6
31.5.71	11.7	18.8.71	12.5
2.6.71	13.6	25.8.71	14.4
3.6.71	12.8	31.8.71	12.2
4.6.71	12.2	3.9.71	12.8
15.6.71	12.2	6.9.71	12.8
16.6.71	12.5	13.9.71	13.3
17.6.71	12.2		

Table 39. Experiment 3. Soil, nitrate concentration, µg nitrate-nitrogen/g soil

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	25.5	139.4	166.3	204.5	23.61	N_ℓ ***	I.N **
	I_1	37.9	79.5	163.0	251.5			
2	I_0	1.0	55.5	118.3	186.0	15.84	N_ℓ ***	
	I_1	1.1	44.3	89.2	188.5			
3	I_0	0.3	43.1	132.1	193.1	13.78	N_ℓ ***	I **
	I_1	3.1	27.6	57.5	147.5		N_q *	$I.N_\ell$ *
4	I_0	6.2	7.8	35.6	53.0	8.66	N_ℓ ***	
	I_1	3.0	3.8	23.2	37.0			
5	I_0	1.9	2.3	11.1	39.3	10.69	N **	
	I_1	1.4	1.1	3.1	6.7			

Table 40. Experiment 3. Soil, ammonium concentration, µg ammonium-nitrogen/g soil

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	15.8	72.8	74.9	127.1	23.71	N_ℓ ***	I.N **
	I_1	16.9	34.4	75.8	206.0			
2	I_0	3.0	12.3	61.4	165.4	27.56	N_ℓ ***	
	I_1	4.1	6.3	33.9	137.3		N_q *	
3	I_0	1.3	2.2	27.8	118.6	18.50	N_ℓ ***	I *
	I_1	1.9	2.2	8.1	23.3			$I.N_\ell$ *
4	I_0	1.3	2.4	3.3	21.6	2.54	N_ℓ ***	I.N ***
	I_1	2.4	3.0	4.2	10.8		N_q **	
5	I_0	2.7	2.2	3.5	5.3	0.48	N_ℓ **	I *
	I_1	2.5	2.0	2.9	2.6			$I.N_\ell$ *

Table 41. Experiment 3. Soil, moisture content, g/100g oven dry soil.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	17.1	16.1	16.4	16.9	0.32	N_q *	I ***
	I_1	17.9	17.3	17.8	17.9			
2	I_0	14.1	12.9	13.1	13.0	0.41	N_ℓ *	I ***
	I_1	15.2	14.4	13.9	14.5		N_q *	
3	I_0	8.6	7.4	8.5	8.6	0.46	N *	
	I_1	9.3	8.6	8.4	8.9			
4	I_0	18.2	18.1	18.8	18.5	0.34	N *	I **
	I_1	19.2	18.9	19.6	19.0			
5	I_0	14.0	13.3	13.2	12.5	0.33	N_ℓ **	
	I_1	13.9	13.5	13.8	13.1			

Table 42. Experiment 3. Soil, conductivity of saturated paste, μ mhos cm^{-1}.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	886	1913	1704	2181	240.4	N_ℓ ***	I.N **
	I_1	981	1198	1934	2481			
2	I_0	532	833	1480	2065	148.2	N_ℓ ***	I.N **
	I_1	542	679	924	2100		N_q **	
3	I_0	388	675	1305	1522	124.8	N_ℓ *	I.N **
	I_1	483	693	801	1326			
4	I_0	317	252	416	565	86.2	N_ℓ **	
	I_1	225	335	437	430			
5	I_0	310	322	336	511	45.8	N_ℓ *	I **
	I_1	257	234	233	285			I.N *

Table 43. Experiment 3. Soil, pH in water.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	6.4	5.9	6.0	6.0	0.07	N_ℓ ***	I.N ***
	I_1	6.4	6.1	6.0	5.8		N_q **	
2	I_0	6.6	6.3	5.9	6.0	0.08	N_ℓ ***	$I.N_q$ *
	I_1	6.6	6.3	6.3	5.9			$I.N_c$ *
3	I_0	6.6	6.2	5.8	5.9	0.11	N_ℓ ***	
	I_1	6.7	6.2	6.2	5.8			
4	I_0	6.7	6.5	6.3	6.1	0.11	N_ℓ ***	
	I_1	7.0	6.6	6.4	6.2			
5	I_0	6.8	6.5	6.3	6.0	0.10	N_ℓ ***	I *
	I_1	6.7	6.6	6.6	6.5			$I.N_\ell$ **

Table 44. Experiment 3. Soil, pH in $CaCl_2$

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	6.0	5.6	5.8	5.8	0.07	N_ℓ ***	I.N **
	I_1	6.0	5.8	5.7	5.6		N_q *	
2	I_0	6.1	5.8	5.5	5.8	0.07	N_ℓ ***	$I.N_q$ **
	I_1	6.2	5.9	5.9	5.6		N_q *	$I.N_c$ *
3	I_0	6.1	5.9	5.6	5.6	0.08	N_ℓ ***	$I.N_c$ *
	I_1	6.2	5.9	5.9	5.6			
4	I_0	6.1	5.9	5.7	5.6	0.10	N_ℓ ***	
	I_1	6.2	5.9	5.8	5.6			
5	I_0	6.2	5.9	5.8	5.6	0.09	N_ℓ **	I **
	I_1	6.1	6.0	6.0	6.0			$I.N_\ell$ *

Table 45. Experiment 3. Soil, "available phosphorus", mg phosphorus/kg air dry soil.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	65	76	61	62	6.9		I.N *
	I_1	62	61	65	71			
2	I_0	65	60	65	67	3.7	N_q *	I *
	I_1	62	52	57	62			
3	I_0	42	42	52	47	3.5		I.N_ℓ *
	I_1	52	45	42	45			
4	I_0	42	40	40	45	2.8	N *	I.N_ℓ *
	I_1	50	45	42	40			
5	I_0	45	40	42	40	3.1		
	I_1	42	45	42	40			

Table 46. Experiment 3. Soil "available potassium", mg potassium/kg air dry soil.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	497	693	524	536	77.3		I.N *
	I_1	456	471	533	622			
2	I_0	364	327	482	529	52.6	N_ℓ *	
	I_1	337	306	307	497			
3	I_0	375	321	484	461	50.8	N *	I.N ***
	I_1	434	359	270	395			
4	I_0	301	221	166	253	27.9	N_ℓ ***	I.N *
	I_1	359	254	189	196		N_q **	
5	I_0	258	215	202	211	23.6	N **	I.N *
	I_1	205	242	171	196			

Table 47. Experiment 3. Roots, dry weight, g/4 plants

Sampling		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
1	I_0	7.2	5.8	5.3	6.4	0.76	
	I_1	6.1	6.6	6.2	6.7		
2	I_0	6.5	8.4	8.6	8.9	0.59	N_ℓ **
	I_1	7.8	8.9	9.5	9.1		
3	I_0	6.7	9.7	8.0	9.0	0.63	N_ℓ ** N_c *
	I_1	6.6	9.4	9.1	9.2		N_q *

Table 48. Experiment 3. Roots, nitrogen concentration, mg nitrogen/g dry material

Sampling		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
1	I_o	25.8	39.6	42.6	41.7	1.09	N_ℓ *** $I.N_q$ *
	I_1	29.7	35.8	41.3	40.0		N_q ***
2	I_0	21.7	31.5	34.6	35.2	1.05	N_ℓ *** I **
	I_1	21.3	29.4	30.6	33.1		N_q ***
3	I_0	17.1	24.5	30.0	29.7	0.86	N_ℓ ***
	I_1	16.1	25.4	28.4	29.4		N_q ***

Table 49. Experiment 3. Roots, nitrate concentration, mg nitrate-nitrogen/g dry material

Sampling		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
1	I_0	3.2	9.8	10.9	11.2	0.56	N_ℓ *** I.N **
	I_1	3.9	7.9	9.9	9.7		N_q ***
2	I_0	0.6	7.0	9.0	10.9	0.48	N_ℓ *** I **
	I_1	0.9	5.9	7.3	9.0		N_q *** $I.N_\ell$ *
							N_c *
3	I_0	0.5	4.4	8.2	8.2	o.58	N_ℓ ***
	I_1	0.5	4.2	7.3	7.3		N_q ***

Table 50. Experiment 3. Roots, ratio of nitrate-nitrogen to total nitrogen

Sampling		Nitrogen level N_0	N_1	N_2	N_3	S.E.	Significant effects
1	I_0	0.121	0.248	0.255	0.269	0.0135	N_ℓ ***
	I_1	0.129	0.221	0.251	0.241		N_q ***
2	I_0	0.029	0.224	0.260	0.311	0.0118	N_ℓ *** N_c ***
	I_1	0.042	0.200	0.239	0.273		N_q *** I.N **
3	I_0	0.029	0.182	0.275	0.276	0.0173	N_ℓ ***
	I_1	0.032	0.163	0.254	0.250		N_q ***

Table 51. Experiment 3. Roots, phosphorus concentration, mg phosphorus/g dry material

Sampling		Nitrogen level N_0	N_1	N_2	N_3	S.E.	Significant effects
1	I_0	3.5	3.3	3.2	3.2	0.12	N_ℓ *
	I_1	3.3	3.5	3.2	3.2		
2	I_0	2.5	2.6	2.5	2.4	0.10	
	I_1	2.6	2.7	2.5	2.6		
3	I_0	1.7	2.0	2.2	2.0	0.07	N_ℓ *** I.N **
	I_1	1.8	2.0	2.0	2.1		N_q **

Table 52. Experiment 3. Roots, potassium concentration, mg potassium/g dry material

Sampling		Nitrogen level N_0	N_1	N_2	N_3	S.E.	Significant effects
1	I_0	28.7	29.8	33.5	26.6	1.47	N_ℓ * I.N **
	I_1	30.1	29.6	27.1	24.7		N_q *
2	I_0	24.6	26.1	24.5	21.6	0.96	N_ℓ **
	I_1	24.3	24.4	23.1	21.4		N_q *
3	I_0	26.4	26.1	25.0	21.1	1.54	N_ℓ ** I *
	I_1	22.6	23.4	22.6	18.4		

Table 53. Experiment 3. Stolons, fresh weight, g/4 plants

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	27.9	23.9	19.3	26.9	3.37	I *	$I.N_q$ *
	I_1	26.0	35.8	30.2	27.0			
2	I_0	24.4	44.3	37.7	37.9	4.12	N_ℓ **	I ***
	I_1	39.9	46.7	63.8	50.6		N_q **	$I.N_c$ *
3	I_0	20.7	33.1	29.0	27.7	5.03	N_ℓ *	I **
	I_1	28.4	40.4	43.5	43.9			

Table 54. Experiment 3. Stolons, dry weight, g/4 plants

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	3.1	2.1	1.7	2.4	0.41	N *	$I.N_q$ *
	I_1	2.6	3.3	2.5	2.1			
2	I_0	2.8	4.6	3.8	3.6	0.44	N_q *	I ***
	I_1	4.9	4.9	6.1	4.7			$I\ N_c$ *
3	I_0	1.9	3.3	2.8	2.6	0.45	N **	I **
	I_1	3.1	3.7	4.1	3.7			

Table 55. Experiment 3. Stolons, dry matter content,
kg dry matter/kg fresh material

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	0.112	0.087	0.086	0.088	0.0044	N_ℓ ***	I.N **
	I_1	0.097	0.092	0.082	0.079		N_q *	
2	I_0	0.113	0.105	0.101	0.096	0.0040	N_ℓ ***	
	I_1	0.121	0.106	0.097	0.094			
3	I_0	0.093	0.099	0.098	0.093	0.0025	N_ℓ ***	$I.N_\ell$ ***
	I_1	0.109	0.093	0.094	0.086			$I.N_q$ **

Table 56. Experiment 3. Tubers, fresh weight, g/4 plants (except sampling 7, g/8 plants)

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	49.0	8.7	14.5	10.2	8.85	N_ℓ *	I.N ***
	I_1	9.7	24.1	10.7	10.5			
2	I_0	672	643	634	541	94.6		
	I_1	600	601	575	482			
3	I_0	1132	1193	1003	873	134.8		I *
	I_1	1179	1322	1278	1308			
4	I_0	2196	2502	2298	1963	199.2	N **	I **
	I_1	2266	3045	2776	3063			$I.N_\ell$ *
5	I_0	2833	3104	2992	3230	225.3	N_ℓ *	I **
	I_1	2718	4139	3960	3715		N_q *	$I.N_q$ *
6	I_0	2707	3294	3936	3721	277.1	N_ℓ ***	I **
	I_1	3095	3979	4761	4323		N_q *	
7 Fraction A	I_0	73	88	101	70	21.1		
	I_1	84	73	103	76			
7 Fraction B	I_o	822	847	695	693	124.0		
	I_1	874	736	761	591			
7 Fraction C	I_0	3356	3158	3520	2319	344.5	N_ℓ ***	I.N *
	I_1	3590	3407	2496	2015			
7 Fraction D	I_0	892	2377	2507	4265	556.2	N_ℓ ***	I **
	I_1	968	3657	4741	5834			I.N *
7 Fraction B + C	I_0	4178	4005	4215	3012	337.9	N_ℓ ***	I.N *
	I_1	4465	4142	3257	2606			
7 Fraction B+C+D	I_0	5070	6382	6722	7277	432.0	N_ℓ ***	I **
	I_1	5433	7799	7999	8440		N_q *	
7 Fraction A+B+C+D	I_0	5143	6470	6824	7347	432.8	N_ℓ ***	I **
	I_1	5517	7873	8102	8517		N_q *	

Table 57. Experiment 3. Tubers, dry weight, g/4 plants (except sampling 7, g/8 plants)

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	6.7	1.1	1.9	1.3	1.19	N_ℓ *	I.N ***
	I_1	1.3	3.2	1.4	1.4			
2	I_0	105	94	94	82	14.8		
	I_1	88	86	80	67			
3	I_0	255	253	196	175	28.3	N *	
	I_1	240	270	242	247			
4	I_0	405	413	376	316	35.2	I ***	$I.N_\ell$ *
	I_1	432	515	470	522			
5	I_0	582	583	555	589	44.0	N **	I ***
	I_1	570	800	735	702			$I.N_q$ *
6	I_0	585	656	801	799	60.7	N_ℓ ***	I *
	I_1	657	790	963	850			
7 Fraction B	I_0	174	165	134	139	24.5	N_ℓ *	
	I_1	183	138	141	105			
7 Fraction C	I_0	741	681	749	491	72.6	N_ℓ ***	I.N **
	I_1	831	712	509	416			
7 Fraction D	I_0	198	504	528	914	114.9	N_ℓ ***	I **
	I_1	212	761	973	1199			I.N *
7 Fraction B + C	I_0	915	845	883	630	74.6	N_ℓ ***	I.N **
	I_1	1014	850	651	521			
7 Fraction B+C+D	I_0	1113	1349	1410	1545	82.4	N_ℓ ***	I *
	I_1	1226	1610	1623	1720			

Table 58. Experiment 3. Tubers, dry matter content, kg dry material/kg fresh material

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	0.136	0.094	0.100	0.103	0.0218		
	I_1	0.148	0.127	0.142	0.138			
2	I_0	0.155	0.145	0.148	0.150	0.0034	N_q *	I **
	I_1	0.146	0.138	0.138	0.138			
3	I_0	0.224	0.214	0.196	0.200	0.0081	N_ℓ **	I *
	I_1	0.204	0.207	0.187	0.188			
4	I_0	0.184	0.165	0.164	0.161	0.0023	N_ℓ ***	N_c *
	I_1	0.191	0.170	0.169	0.170		N_q ***	I ***
5	I_0	0.206	0.187	0.185	0.182	0.0028	N_ℓ ***	I *
	I_1	0.209	0.194	0.185	0.189		N_q ***	
6	I_0	0.215	0.199	0.203	0.215	0.0042	N_q **	I.N. **
	I_1	0.212	0.198	0.202	0.196			
7 Fraction B	I_0	0.210	0.196	0.193	0.198	0.0084	N_ℓ *	
	I_1	0.207	0.188	0.188	0.176			
7 Fraction C	I_0	0.221	0.217	0.212	0.210	0.0062	N_ℓ **	I.N *
	I_1	0.232	0.210	0.204	0.206			
7 Fraction D	I_0	0.222	0.212	0.210	0.216	0.0039	N_ℓ *	I *
	I_1	0.215	0.206	0.205	0.205		N_q *	
7 Fraction B+C	I_0	0.219	0.211	0.209	0.207	0.0060	N_ℓ **	I.N *
	I_1	0.228	0.206	0.199	0.200			
7 Fraction B+C+D	I_0	0.219	0.212	0.210	0.213	0.0047	N_ℓ ***	I.N *
	I_1	0.228	0.206	0.203	0.204		N_q *	

Table 59. Experiment 3. Number of tubers/4 plants.
(except sampling 7, number per 8 plants)

Sampling		Nitrogen level				Significant effects	
		N_0	N_1	N_2	N_3		
1	I_0	22	6	10	9	N *	I.N *
	I_1	12	15	8	8		
2	I_0	49	56	68	61	N **	
	I_1	50	65	58	53		
3	I_0	57	74	61	58		$I.N_q$ **
	I_1	61	53	56	65		
4	I_0	54	57	53	59		
	I_1	57	64	59	71		
5	I_0	41	51	49	51		
	I_1	50	53	53	53		
6	I_0	36	44	52	48	N_ℓ **	
	I_1	38	40	49	45		
7 Fraction A	I_0	6	11	11	7	N_q *	I.N *
	I_1	9	8	12	5		
7 Fraction B	I_0	18	19	16	17		
	I_1	21	18	18	15		
7 Fraction C	I_0	34	32	36	23	N_ℓ ***	
	I_1	36	32	28	20		
7 Fraction D	I_0	5	13	14	21	N_ℓ ***	I *
	I_1	5	19	23	28	N_q *	
7 Fraction B + C	I_0	52	51	52	40	N_ℓ ***	
	I_1	57	50	46	35		
7 Fraction B+C+D	I_0	58	64	66	61	N_q *	
	I_1	63	70	69	63		
7 Fraction A+B+C+D	I_0	64	75	77	68	N_q **	
	I_1	72	78	81	68		

Statistical analysis was carried out by log. transformation, thus no standard errors are presented.

Table 60. Experiment 3. Sampling 7.
Seed/total ratio for weight of tubers.

Moisture level	Nitrogen level				Standard error	Significant effects
	N_0	N_1	N_2	N_3		
I_0	0.817	0.621	0.622	0.420	0.0542	N_ℓ *** I *
I_1	0.817	0.531	0.406	0.311		I.N *

Table 61. Experiment 3. Sampling 7.
Seed/Total ratio for number of tubers.

Moisture level	Nitrogen level				Standard error	Significant effects
	N_0	N_1	N_2	N_3		
I_0	0.816	0.683	0.670	0.583	0.0360	N_ℓ *** I *
I_1	0.799	0.643	0.572	0.511		

Table 62. Experiment 3. Sampling 7 Fraction C + D.

Tubers, sugar concentration,
mg/g fresh tuber

	Moisture level	Nitrogen level				Standard error	Significant effects
		N_0	N_1	N_2	N_3		
Reducing sugar	I_0	1.95	1.15	1.18	0.80	0.158	N_ℓ*** I **
	I_1	2.47	1.69	1.26	1.27		N_q *
Sucrose	I_0	1.70	1.80	2.04	1.97	0.058	N_ℓ*** I ***
	I_1	1.57	1.60	1.76	1.80		
Total sugar	I_0	3.65	2.94	3.23	2.77	0.181	N_ℓ*** I.N *
	I_1	4.05	3.30	3.02	3.07		

Table 63. Experiment 3. Average tuber fresh weight, g/tuber.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	2.07	1.12	1.09	0.98	0.433		$I.N_{\ell}$ *
	I_1	0.69	1.37	1.25	1.59			
2	I_0	13.9	12.0	9.8	8.9	1.72	N_{ℓ} *	
	I_1	12.5	8.8	9.8	9.2			
3	I_0	20.0	16.6	17.2	14.7	2.86		I *
	I_1	19.7	26.3	22.5	20.0			
4	I_0	39.4	45.6	43.7	33.6	3.14	N_q **	
	I_1	40.6	47.6	47.2	43.4			
5	I_0	69.8	60.5	66.0	65.7	6.99		I.N **
	I_1	58.5	79.5	75.9	71.4			
6	I_0	75.0	75.3	75.6	76.8	5.53	N *	I ***
	I_1	82.9	100.6	97.7	95.8			
7 Fraction A	I_0	11.6	8.2	8.7	10.0	1.53	N_q *	I.N **
	I_1	9.3	9.6	8.0	14.3			
7 Fraction B	I_0	44.5	44.4	46.0	41.2	2.12		I *
	I_1	40.6	40.6	40.5	41.1			
7 Fraction C	I_0	100.0	98.6	97.6	100.2	4.99	N *	
	I_1	100.5	106.2	89.5	101.8			
7 Fraction D	I_0	160	182	182	202	8.1	N_{ℓ} ***	
	I_1	171	186	207	207			
7 Fraction B+C	I_0	80.0	79.1	80.8	75.5	4.37		
	I_1	78.1	82.7	70.8	76.6			
7 Fraction B+C+D	I_0	87.6	100.1	102.2	121.0	6.60	N_{ℓ} ***	I *
	I_1	86.4	112.4	116.6	135.1			
7 Fraction A+B+C+D	I_0	80.4	86.8	88.5	109.8	6.95	N_{ℓ} ***	I *
	I_1	76.7	101.7	101.0	127.1			

Table 64. Experiment 3. Average tuber dry weight, g/tuber

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	0.282	0.144	0.146	0.129	0.0574		$I.N_\ell$ *
	I_1	0.100	0.175	0.170	0.219			
2	I_0	2.16	1.74	1.44	1.34	0.270	N_ℓ *	
	I_1	1.84	1.26	1.36	1.29			
3	I_0	4.50	3.52	3.36	2.96	0.572	N *	I.N *
	I_1	4.01	5.36	4.22	3.77			
4	I_0	7.24	7.52	7.15	5.42	0.523	N_ℓ *	I *
	I_1	7.74	8.06	7.95	7.36			
5	I_0	14.3	11.3	12.2	11.9	1.31		I.N **
	I_1	12.2	15.4	14.1	13.5			
6	I_0	16.1	15.0	15.4	16.5	1.13		I ***
	I_1	17.5	20.0	19.8	18.8			I.N *
7 Fraction B	I_0	9.35	8.70	8.91	8.16	0.516	N_ℓ *	I **
	I_1	8.41	7.63	7.58	7.19			
7 Fraction C	I_0	22.1	21.3	20.7	21.0	1.12	N_ℓ *	I.N *
	I_1	23.2	22.2	18.2	21.0			
7 Fraction D	I_0	35.5	38.6	38.3	43.5	1.76	N_ℓ ***	
	I_1	37.0	38.5	42.5	42.4			
7 Fraction B+C	I_0	17.5	16.7	16.9	15.6	0.97	N_ℓ *	I. N *
	I_1	17.8	17.0	14.1	15.3			
7 Fraction B+C+D	I_0	19.2	21.2	21.4	25.7	1.22	N_ℓ ***	
	I_1	19.6	23.2	23.6	27.5			

Table 65. Experiment 3. Tubers, nitrogen concentration, mg nitrogen/g dry material

Sampling		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
2	I_0	13.8	19.5	21.6	21.9	1.28	N_ℓ ***
	I_1	14.6	21.5	22.4	22.4		N_q **
3	I_0	12.1	18.2	20.5	19.9	0.95	N_ℓ *** I.N **
	I_1	13.6	17.2	18.4	17.8		N_q ***
4	I_0	12.3	17.6	20.4	20.2	0.39	N_ℓ *** I ***
	I_1	10.5	15.6	17.4	18.6		N_q *** I.N *
5	I_0	11.4	16.2	17.8	19.2	0.45	N_ℓ *** I ***
	I_1	10.0	13.9	17.3	18.0		N_q *** I.N *
6	I_0	13.4	14.7	19.6	19.2	0.74	N_ℓ *** I **
	I_1	10.2	14.3	17.2	19.2		I.N **
7 Fraction B	I_0	12.4	17.1	20.4	20.3	0.66	N_ℓ *** I *
	I_1	10.7	15.6	19.5	19.6		N_q ***
7 Fraction C	I_0	12.7	15.7	18.7	19.9	0.50	N_ℓ *** I **
	I_1	10.3	14.2	17.6	19.9		N_q * I.N_ℓ *
7 Fraction D	I_0	12.3	16.0	18.6	19.1	0.38	N_ℓ *** I ***
	I_1	10.7	14.1	17.0	19.5		N_q *** I.N_ℓ *
7 Fraction B+C	I_0	12.7	16.0	19.0	20.0	0.39	N_ℓ *** I ***
	I_1	10.3	14.4	18.0	19.9		N_q *** I.N_ℓ **
7 Fraction B+C+D	I_0	12.6	16.0	18.7	19.5	0.34	N_ℓ *** I ***
	I_1	10.4	14.3	17.4	19.6		N_q *** I.N_ℓ **

Table 66. Experiment 3. Tubers, phosphorus concentration, mg phosphorus/g dry material.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
2	I_0	2.7	2.8	2.7	2.7	0.17		I *
	I_1	2.9	3.2	3.0	2.9			
3	I_0	2.0	2.3	2.5	2.2	0.08	N_ℓ *	I.N **
	I_1	2.1	2.3	2.2	2.3		N_q *	
4	I_0	1.9	2.1	2.2	2.3	0.08	N_ℓ ***	I *
	I_1	1.7	2.0	2.0	2.2			
5	I_0	1.8	2.0	2.0	2.1	0.09	N_ℓ ***	
	I_1	1.8	1.9	2.1	2.1			
6	I_0	1.9	1.9	2.0	2.0	0.07	N_ℓ **	
	I_1	1.8	1.9	2.0	2.1			
7 Fraction B	I_0	1.8	2.2	2.2	2.0	0.09	N_ℓ **	I *
	I_1	2.0	2.2	2.2	2.4		N_q *	I.N **
7 Fraction C	I_0	1.8	1.9	2.1	2.0	0.09	N_ℓ *	
	I_1	1.9	2.0	2.0	2.2			
7 Fraction D	I_0	1.9	1.8	2.0	2.0	0.07	N_ℓ *	
	I_1	1.9	1.9	2.0	2.0			
7 Fraction B+C	I_0	1.8	2.0	2.1	2.0	0.08	N_ℓ **	I.N *
	I_1	2.0	2.1	2.1	2.3			
7 Fraction B+C+D	I_0	1.9	1.9	2.1	2.0	0.06	N_ℓ **	
	I_1	2.0	2.0	2.0	2.1			

Table 67. Experiment 3. Tubers, potassium concentration, mg potassium/g dry material

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
2	I_0	27.0	30.5	30.0	27.9	0.94	N_q ***	
	I_1	27.1	32.2	30.0	28.8			
3	I_0	24.7	30.0	28.9	26.1	0.83	N_q ***	
	I_1	24.3	28.6	27.1	26.6		N_c *	
4	I_0	24.0	28.2	27.3	27.4	0.71	N_ℓ ***	N_c **
	I_1	22.4	26.7	25.2	25.6		N_q ***	I **
5	I_0	22.0	25.6	24.0	22.1	0.86	N_q **	I *
	I_1	19.3	21.8	23.5	22.3			$I.N_\ell$ *
6	I_0	25.0	24.8	23.4	22.5	0.92	N *	I.N **
	I_1	21.7	24.2	23.6	22.9			
7 Fraction B	I_0	25.5	27.1	27.6	26.9	0.89	N_ℓ *	
	I_1	23.8	28.0	26.7	26.7		N_q *	
7 Fraction C	I_0	25.0	26.1	26.3	25.4	0.59	N_q **	
	I_1	23.8	26.4	25.1	24.5			
7 Fraction D	I_0	25.5	25.0	26.0	24.6	0.59	N **	I *
	I_1	24.4	25.6	24.0	23.5			$I.N_c$ *
7 Fraction B+C	I_0	25.1	26.2	26.6	25.7	0.58	N_q **	
	I_1	23.8	26.7	25.5	24.9			
7 Fraction B+C+D	I_0	25.2	25.7	26.4	25.1	0.45	N_q **	I **
	I_1	23.9	26.0	24.6	23.9			$I.N_c$ *

Table 68. Experiment 3. Stems and Petioles, Fresh weight, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	236	214	221	211	27.3		I.N **
	I_1	194	310	255	258			
2	I_0	346	597	640	595	33.6	N_ℓ ***	I ***
	I_1	430	703	726	720		N_q ***	
3	I_0	354	609	609	541	23.1	N_ℓ ***	I ***
	I_1	386	722	735	845		N_q ***	$I.N_\ell$ ***
							N_c ***	
4	I_0	410	700	818	801	70.8	N_ℓ ***	I **
	I_1	452	834	955	1232			$I.N_\ell$ *
5	I_0	425	634	883	1106	79.1	N_ℓ ***	
	I_1	414	864	1046	1154			
6	I_0	242	469	846	992	84.8	N_ℓ***	I *
	I_1	201	498	1260	1166		N_c **	I.N ***

Table 69. Experiment 3. Stems and petioles, dry weight, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	18.3	15.6	16.0	15.8	1.91		I.N **
	I_1	14.6	21.6	17.4	17.8			
2	I_0	27.3	41.1	44.6	42.6	2.34	N_ℓ ***	I **
	I_1	31.3	47.5	48.9	47.7		N_q ***	
3	I_0	32.1	53.5	55.0	48.8	2.55	N_ℓ ***	I ***
	I_1	34.7	61.7	64.9	73.9		N_q ***	$I.N_\ell$ ***
							N_c *	
4	I_0	35.9	62.3	68.9	70.3	7.17	N_ℓ ***	I **
	I_1	38.0	71.3	81.4	107.2			I.N *
5	I_0	33.6	50.6	75.1	94.0	7.02	N_ℓ ***	
	I_1	31.3	70.6	86.0	102.0			
6	I_0	33.0	61.8	82.0	91.3	7.91	N_ℓ ***	I *
	I_1	43.9	57.3	120.1	110.0		N_c *	$I.N_c$ *

Table 70. Experiment 3. Stems and petioles, dry matter content, kg dry matter/kg fresh material.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	0.078	0.073	0.073	0.074	0.0014	N_ℓ ***	I **
	I_1	0.076	0.070	0.068	0.069		N_q **	
2	I_0	0.079	0.069	0.070	0.072	0.0009	N_ℓ ***	I ***
	I_1	0.073	0.067	0.067	0.066		N_q ***	$I.N_q$ **
							N_c **	
3	I_0	0.091	0.088	0.090	0.090	0.0016	N *	
	I_1	0.090	0.086	0.088	0.087			
4	I_0	0.087	0.089	0.083	0.091	0.0022		I.N *
	I_1	0.084	0.085	0.085	0.084			
5	I_0	0.079	0.080	0.085	0.085	0.0024	N_ℓ ***	
	I_1	0.076	0.082	0.082	0.089			
6	I_0	0.139	0.133	0.097	0.092	0.0132	N_ℓ ***	$I.N_\ell$ *
	I_1	0.224	0.118	0.096	0.095		N_q *	$I.N_q$ *

Table 71. Experiment 3. Stems and petioles, nitrogen concentration, mg/nitrogen/g dry material.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	29.9	46.9	48.1	48.4	1.08	N_ℓ ***	N_c *
	I_1	32.0	45.2	49.6	49.4		N_q ***	I.N *
2	I_0	18.9	40.3	43.7	42.1	1.54	N_ℓ ***	N_c **
	I_1	20.9	39.7	42.0	43.6		N_q ***	
3	I_0	12.7	27.7	34.0	35.6	1.30	N_ℓ ***	
	I_1	13.0	26.9	33.7	33.9		N_q ***	
4	I_0	12.2	18.5	27.7	30.9	1.35	N_ℓ ***	I **
	I_1	10.5	15.5	23.8	25.4		N_c *	
5	I_0	10.1	13.7	20.9	24.6	1.13	N_ℓ ***	I *
	I_1	9.9	10.5	18.1	20.7		N_c *	
6	I_0	14.6	14.0	17.7	22.3	1.26	N_ℓ ***	I.N *
	I_1	14.2	16.1	15.1	23.8		N_q **	

Table 72. Experiment 3. Stems and petioles, nitrate concentration, mg nitrate-nitrogen/g dry material.

Sampling		Nitrogen level N_0	N_1	N_2	N_3	S.E.	Significant effects	
1	I_0	11.4	22.0	23.3	22.0	0.72	N_ℓ ***	N_c **
	I_1	12.3	22.0	22.6	22.2		N_q ***	
2	I_0	4.6	22.3	23.7	24.9	0.88	N_ℓ ***	N_c ***
	I_1	5.9	20.6	22.4	23.5		N_q ***	I.N *
3	I_0	1.8	15.0	20.5	22.5	1.06	N_ℓ ***	I *
	I_1	1.4	13.6	18.1	19.2		N_q ***	
4	I_0	1.3	6.0	12.2	14.0	1.01	N_ℓ ***	
	I_1	0.6	4.9	11.3	14.8			
5	I_0	0.2	2.1	8.7	12.3	1.25	N_ℓ ***	
	I_1	0.2	1.0	6.5	9.3			
6	I_0	0.1	0.6	6.4	11.0	0.84	N_ℓ ***	
	I_1	0.4	0.2	3.7	9.4		N_q ***	

Table 73. Experiment 3. Stems and petioles, ratio of nitrate-nitrogen to total nitrogen.

Sampling		Nitrogen level N_0	N_1	N_2	N_3	S.E.	Significant effects	
1	I_0	0.381	0.469	0.486	0.454	0.0154	N_ℓ ***	
	I_1	0.383	0.487	0.457	0.450		N_q ***	
2	I_0	0.242	0.555	0.544	0.592	0.0229	N_ℓ ***	N_c ***
	I_1	0.282	0.522	0.535	0.539		N_q ***	I.N *
3	I_0	0.145	0.541	0.602	0.639	0.0356	N_ℓ ***	N_c **
	I_1	0.104	0.501	0.538	0.567		N_q ***	I *
4	I_0	0.110	0.316	0.447	0.455	0.0344	N_ℓ ***	I.N_ℓ *
	I_1	0.054	0.305	0.464	0.587		N_q **	
5	I_0	0.020	0.150	0.395	0.501	0.0474	N_ℓ ***	
	I_1	0.020	0.072	0.329	0.441			
6	I_0	0.007	0.045	0.349	0.496	0.0369	N_ℓ ***	I *
	I_1	0.034	0.012	0.239	0.393		N_q *	I.N. *
							N_c **	

Table 74. Experiment 3. Stems and petioles, phosphorus concentration, mg phosphorus/g dry material.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	3.6	4.0	3.7	3.4	0.17		
	I_1	3.9	3.9	3.9	3.9			
2	I_0	2.9	3.0	3.1	2.9	0.17		
	I_1	3.1	3.2	3.3	3.1			
3	I_0	1.6	2.2	2.5	2.2	0.13	N_{ℓ} ***	I.N **
	I_1	1.7	2.0	2.0	2.2		N_q *	
4	I_0	1.6	1.8	2.1	2.3	0.11	N_{ℓ} ***	I *
	I_1	1.4	1.6	2.0	2.0			
5	I_0	1.3	1.3	1.6	1.7	0.09	N_{ℓ} ***	
	I_1	1.2	1.2	1.7	1.7		N_c *	
6	I_0	1.2	0.8	1.1	1.1	0.09	N_q ***	$I.N_c$ **
	I_1	1.2	1.0	0.7	1.2			

Table 75. Experiment 3. Stems and petioles, potassium concentration, mg potassium/g dry material.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	72.5	80.5	75.3	73.5	4.14		
	I_1	73.1	77.3	78.1	74.8			
2	I_0	71.8	78.1	73.7	74.5	3.85		
	I_1	70.5	69.8	71.3	72.4			
3	I_0	56.3	72.5	67.6	62.7	2.86	N_q ***	I.N *
	I_1	58.0	72.6	64.5	53.8		N_c *	
4	I_0	42.1	49.3	46.8	52.0	4.14	N *	
	I_1	43.7	51.7	50.2	43.4			
5	I_0	41.0	51.3	47.5	44.3	2.90	N_{ℓ} *	I **
	I_1	46.4	39.4	35.5	31.9			$I.N_{\ell}$ **
6	I_0	29.8	37.5	36.0	36.3	4.24		
	I_1	31.2	34.7	29.2	30.8			

Table 76. Experiment 3. Leaves, fresh weight, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	245	214	209	202	26.3		I.N **
	I_1	205	301	237	243			
2	I_0	390	573	577	523	38.8	N_ℓ **	I *
	I_1	448	637	672	614		N_q ***	
3	I_0	312	376	365	322	30.2	N_ℓ **	I ***
	I_1	351	489	489	568			$I.N_\ell$ *
4	I_0	415	605	675	662	54.7	N_ℓ ***	I **
	I_1	432	675	823	957			$I.N_\ell$ *
5	I_0	399	543	708	865	56.7	N_ℓ ***	
	I_1	390	637	739	878			
6	I_0	92	136	395	470	45.6	N_ℓ ***	
	I_1	39	129	439	553		N_c *	

Table 77. Experiment 3. Leaves, dry weight, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_2			
1	I_0	30.4	26.4	26.1	25.4	3.23		I.N **
	I_1	25.2	36.0	29.0	29.3			
2	I_0	45.2	68.0	67.5	65.5	4.82	N_ℓ ***	
	I_1	50.2	70.2	75.2	70.5		N_q **	
3	I_0	47.5	68.0	66.0	58.0	4.38	N_ℓ ***	I ***
	I_1	48.7	76.0	78.2	92.0		N_q *	$I.N_\ell$ **
4	I_0	57.7	86.0	98.0	95.8	7.38	N_ℓ ***	I *
	I_1	54.8	87.8	109.2	131.4			$I.N_\ell$ *
5	I_0	51.3	69.3	87.2	108.1	7.63	N_ℓ ***	
	I_1	49.9	76.9	89.6	105.7			
6	I_0	13.8	20.8	61.8	67.7	6.25	N_ℓ ***	
	I_1	5.6	18.2	61.3	73.4		N_c **	

Table 78. Experiment 3. Leaves, dry matter content, kg dry matter/kg fresh material.

Sampling		Nitrogen level				S.E.	Significant Effects	
		N_0	N_1	N_2	N_3			
1	I_0	0.124	0.124	0.124	0.126	0.0016		I **
	I_1	0.123	0.119	0.122	0.121			
2	I_0	0.116	0.118	0.117	0.125	0.0022	N_ℓ *	I ***
	I_1	0.112	0.110	0.112	0.115			
3	I_0	0.153	0.181	0.181	0.181	0.0034	N_ℓ ***	I ***
	I_1	0.139	0.156	0.160	0.162		N_q ***	
4	I_0	0.139	0.142	0.146	0.145	0.0028	N_ℓ **	I ***
	I_1	0.128	0.130	0.133	0.137			
5	I_0	0.128	0.129	0.124	0.125	0.0028	N_ℓ *	
	I_1	0.128	0.121	0.121	0.121			
6	I_0	0.153	0.156	0.157	0.144	0.0139		I *
	I_1	0.110	0.144	0.141	0.132			

Table 79. Experiment 3. Leaves, nitrogen concentration, mg nitrogen/g dry material.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	51.0	61.1	61.6	61.6	0.77	N_ℓ ***	N_c *
	I_1	50.4	57.9	60.5	62.1		N_q ***	
2	I_0	47.5	56.1	60.0	59.7	0.68	N_ℓ ***	
	I_1	47.4	56.9	59.2	60.5		N_q ***	
3	I_0	42.7	50.7	56.4	57.2	1.11	N_ℓ ***	
	I_1	40.9	49.5	55.9	57.1		N_q ***	
4	I_0	36.4	41.9	45.9	47.7	1.05	N_ℓ ***	
	I_1	36.6	42.1	43.3	46.4		N_q *	
5	I_0	31.7	34.1	40.9	46.4	1.19	N_ℓ ***	I *
	I_1	31.2	34.0	37.6	43.0			I.N *
6	I_0	28.5	31.5	37.0	41.5	2.85	N_ℓ ***	
	I_1	21.1	30.3	34.3	40.9			

Table 80. Experiment 3. Leaves, phosphorus concentration, mg phosphorus/g dry material.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	4.5	5.0	5.1	4.7	0.16	N_ℓ **	I.N **
	I_1	4.3	4.9	5.0	5.2		N_q **	
2	I_0	3.0	3.2	3.3	3.3	0.09	N_ℓ **	I.N *
	I_1	3.1	3.5	3.3	3.4		N_q *	
3	I_0	2.6	2.9	3.1	3.1	0.08	N_ℓ ***	
	I_1	2.7	3.0	3.1	3.1		N_q *	
4	I_0	2.4	2.6	3.0	3.1	0.10	N_ℓ ***	
	I_1	2.5	2.6	2.8	3.1			
5	I_0	1.9	2.0	2.2	2.2	0.09	N_ℓ **	
	I_1	2.0	2.0	2.2	2.3			
6	I_0	1.9	1.7	1.8	1.8	0.21		
	I_1	1.6	1.8	1.8	2.1			

Table 81. Experiment 3. Leaves, potassium concentration, mg potassium/g dry material

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	43.4	48.8	46.2	44.9	0.96	N_q ***	
	I_1	42.1	47.0	45.5	44.4		N_c *	
2	I_0	34.8	41.5	40.8	36.3	0.93	N_q ***	
	I_1	33.9	41.8	38.3	36.5		N_c **	
3	I_0	30.3	36.2	33.7	32.1	1.19	N_q ***	
	I_1	29.5	26.3	32.6	32.0		N_c **	
4	I_0	31.0	35.4	36.9	35.3	1.40	N_ℓ *	I *
	I_1	28.7	35.3	34.2	32.0		N_q **	
5	I_0	27.5	33.9	31.3	35.4	1.59	N_ℓ **	N_c *
	I_1	26.9	34.1	33.5	32.0		N_q *	I.N *
6	I_0	21.9	28.4	29.8	31.3	3.23	N_ℓ ***	
	I_1	13.7	28.6	27.2	31.9			

Table 82. Experiment 3. Leaf area index.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	0.801	0.731	0.721	0.654	0.0889	N *	I.N **
	I_1	0.627	0.991	0.803	0.810			
2	I_0	1.411	2.103	1.958	1.906	0.1647	N_ℓ **	I *
	I_1	1.542	2.293	2.450	2.154		N_q ***	
3	I_0	1.251	1.723	1.785	1.401	0.1432	N_ℓ ***	I ***
	I_1	1.326	2.168	2.129	2.387		N_q **	$I.N_\ell$ **
4	I_0	1.574	2.444	2.814	2.663	0.2342	N_ℓ ***	I **
	I_1	1.626	2.530	3.275	3.964			$I.N_\ell$ *
5	I_0	1.504	2.430	2.948	3.494	0.2642	N_ℓ ***	
	I_1	1.563	2.748	3.293	3.668			
6	I_0	0.374	0.710	1.999	2.231	0.2274	N_ℓ ***	
	I_1	0.167	0.710	2.357	2.722		N_c **	

Table 83. Experiment 3. Whole plant, fresh weight, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	558	460	464	451	62.7		I.N **
	I_1	435	671	533	538			
2	I_0	1433	1859	1889	1697	151.0	N_q **	
	I_1	1518	1988	2037	1867			
3	I_0	1818	2211	2006	1763	172.2	N_q *	I ***
	I_1	1945	2573	2545	2765			$I.N_\ell$ *
4	I_0	3042	3808	3791	3425	299.3	N_ℓ **	I **
	I_1	3150	4554	4555	5253		N_q *	$I.N_\ell$ *
5	I_0	3658	4281	4583	5202	303.0	N_ℓ ***	I **
	I_1	3522	5640	5744	5747		N_q *	$I.N_q$ *
6	I_0	3041	3900	5177	5184	346.2	N_ℓ ***	I **
	I_1	3335	4606	6461	6042		N_q *	

Table 84. Experiment 3. Whole plant, dry weight, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	65.7	51.0	51.0	51.4	7.01		I.N **
	I_1	50.0	70.8	56.5	57.5			
2	I_0	186	216	218	203	20.4	N *	
	I_1	182	218	220	199			
3	I_0	343	388	328	294	33.6	N *	I *
	I_1	334	421	399	426			I.N_ℓ *
4	I_0	497	561	530	473	42.2	N_ℓ **	I ***
	I_1	525	674	660	823			I.N_ℓ *
5	I_0	667	703	717	791	51.9	N_ℓ **	I **
	I_1	651	948	911	910			I.N_q *
6	I_0	632	739	945	958	67.0	N_ℓ ***	I *
	I_1	706	865	1145	1033			

Table 85. Experiment 3. Whole plant, nitrogen uptake, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	2.28	2.58	2.60	2.58	0.286	N ***	I.N *
	I_1	1.92	3.28	2.76	2.97			
2	I_0	4.25	7.50	8.32	7.76	0.478	N_ℓ ***	
	I_1	4.49	7.73	8.55	8.13		N_q ***	
3	I_0	5.60	9.76	9.85	8.79	0.728	N_ℓ ***	I *
	I_1	5.80	10.28	11.25	12.42		N_q ***	I.N_ℓ *
4	I_0	7.44	12.01	14.06	12.79	0.972	N_ℓ ***	I *
	I_1	6.92	12.89	14.80	19.74			I.N_ℓ *
5	I_0	8.66	12.50	15.10	18.63	1.050	N_ℓ ***	I.N *
	I_1	7.54	15.36	17.68	19.29			
6	I_0	8.90	11.27	19.31	20.28	1.317	N_ℓ ***	
	I_1	7.49	12.72	20.52	21.91		N_c *	

Table 86. Experiment 3. Whole plant, phosphorus uptake, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	0.229	0.214	0.209	0.194	0.0246	N *	I.N. **
	I_1	0.187	0.288	0.233	0.243			
2	I_0	0.516	0.618	0.644	0.583	0.0498	N_q *	
	I_1	0.533	0.667	0.672	0.605			
3	I_0	0.703	0.911	0.848	0.695	0.0759	N_q *	I *
	I_1	0.706	0.992	0.915	1.044			I.N_{ℓ} *
4	I_0	0.987	1.219	1.297	1.159	0.1034	N_{ℓ} ***	I *
	I_1	0.947	1.372	1.418	1.957			I.N_{ℓ} **
5	I_0	1.19	1.36	1.44	1.66	0.119	N_{ℓ} ***	I **
	I_1	1.16	1.76	1.85	1.90			I.N_{ℓ} *
6	I_0	1.21	1.34	1.81	1.88	0.148	N_{ℓ} ***	
	I_1	1.23	1.60	2.11	2.07			

Table 87. Experiment 3. Whole plant, potassium uptake, g/4 plants.

Sampling		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1	I_0	2.85	2.73	2.60	2.46	0.323	N *	I.N *
	I_1	2.32	3.59	2.82	2.80			
2	I_0	6.53	9.08	9.06	8.00	0.704	N_q **	
	I_1	6.49	9.10	8.94	8.13			
3	I_0	9.70	14.13	11.86	9.54	1.053	N_q ***	I *
	I_1	9.45	15.15	13.59	13.67		N_c *	I.N_{ℓ} *
4	I_0	13.12	17.80	16.83	15.15	1.524	N_{ℓ} **	I *
	I_1	12.91	20.72	19.69	23.02		N_q *	I.N **
5	I_0	15.69	19.94	19.64	21.05	1.463	N_{ℓ} ***	I.N *
	I_1	13.86	22.75	23.27	22.29		N_q **	
6	I_0	15.88	19.32	23.50	23.65	1.792	N_{ℓ} ***	
	I_1	15.71	21.87	28.06	24.98		N_q *	

Table 88. Experiment 3. Relative growth rate, g/g/day.

Between samplings		Nitrogen level N_0	N_1	N_2	N_3	S.E.	Significant effects	
1-2	I_0	0.0758	0.1018	0.1054	0.1011	0.00912	N*	I.N **
	I_1	0.0924	0.0786	0.0983	0.0890			
2-3	I_0	0.0432	0.0435	0.0287	0.0259	0.00984		
	I_1	0.0431	0.0510	0.0405	0.0539			
3-4	I_0	0.0203	0.0177	0.0213	0.0288	0.00644		
	I_1	0.0214	0.0224	0.0252	0.0308			
4-5	I_0	0.0151	0.0099	0.0120	0.0185	0.00452		I.N *
	I_1	0.0099	0.0154	0.0150	0.0048			
5-6	I_0	-0.0027	0.0024	0.0129	0.0089	0.00461	N_ℓ *	
	I_1	0.0039	-0.0043	0.0112	0.0055		N_c *	

Table 89. Experiment 3. Net assimilation rate, g/m^2/day

Between samplings		Nitrogen level N_0	N_1	N_2	N_3	S.E.	Significant effects	
1-2	I_0	9.56	10.58	11.54	10.97	1.036		I.N **
	I_1	10.92	7.74	9.47	8.68			
2-3	I_0	9.87	8.13	4.84	4.60	1.774	N **	
	I_1	8.84	8.32	6.37	8.28			
3-4	I_0	7.00	4.73	4.52	6.44	1.405		
	I_1	7.15	5.92	5.54	7.00			
4-5	I_0	6.52	2.95	3.09	4.33	1.556		I.N *
	I_1	4.33	5.44	4.43	1.22			
5-6	I_0	-2.60	1.28	5.59	3.20	2.513	N **	I.N *
	I_1	4.45	-1.03	5.00	2.25			

Table 90. Experiment 3. Economic assimilation rate, $g/m^2/day$.

Between samplings		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1-2	I_0	7.70	5.91	6.35	5.70	0.773	N_ℓ **	I *
	I_1	7.14	4.12	4.51	4.02			
2-3	I_0	9.48	7.48	4.53	4.72	1.425	N_ℓ **	
	I_1	8.93	7.48	5.82	6.58			
3-4	I_0	6.76	4.35	3.74	5.18	1.107	N *	
	I_1	7.21	5.78	4.81	5.88			
4-5	I_0	6.68	3.62	3.36	4.20	1.272	N *	I.N *
	I_1	4.68	5.71	4.68	1.65			
5-6	I_0	0.11	2.91	6.01	4.08	2.402		I.N *
	I_1	7.26	1.78	4.84	2.66			

Table 91. Experiment 3. Crop growth rate, $g/m^2/day$.

Between samplings		Nitrogen level				S.E.	Significant effects	
		N_0	N_1	N_2	N_3			
1-2	I_0	10.12	13.81	14.03	12.68	1.540	N *	
	I_1	11.10	12.31	13.66	11.87			
2-3	I_0	13.13	14.42	9.22	7.63	3.350		I.N *
	I_1	12.67	17.09	15.04	19.03			
3-4	I_0	9.45	9.68	10.63	11.65	3.438	N *	
	I_1	10.67	14.13	14.62	21.60			
4-5	I_0	11.05	7.56	8.40	12.70	3.719		$I.N_q$ *
	I_1	6.76	14.60	13.37	4.77			
5-6	I_0	-1.97	2.01	12.73	9.33	4.864	N_ℓ *	
	I_1	3.07	-4.61	13.07	6.91		N_c *	

Table 92. Experiment 3. Relative leaf growth rate, m^2/m^2/day.

Between samplings		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
1-2	I_0	0.0417	0.0740	0.0729	0.0789	0.00862	N_ℓ * I.N **
	I_1	0.0643	0.0614	0.0822	0.0702		
2-3	I_0	-0.0087	-0.0123	-0.0081	-0.0221	0.00734	I.N **
	I_1	-0.0108	-0.0024	-0.0114	0.0069		
3-4	I_0	0.0106	0.0167	0.0217	0.0307	0.00598	N_ℓ **
	I_1	0.0089	0.0071	0.0208	0.0243		
4-5	I_0	-0.0020	-0.0016	0.0025	0.0122	0.00606	I.N.*
	I_1	-0.0012	0.0033	0.0002	-0.0036		
5-6	I_0	-0.0681	-0.0610	-0.0189	-0.0217	0.01113	N_ℓ ***
	I_1	-0.0962	-0.0699	-0.0179	-0.0144		N_c *

Table 93. Experiment 3. Relative tuber growth rate, g/g/day.

Between samplings		Nitrogen level				S.E.	Significant effects
		N_0	N_1	N_2	N_3		
1-2	I_0	0.209	0.366	0.304	0.311	0.0434	I.N **
	I_1	0.328	0.247	0.303	0.293		
2-3	I_0	0.064	0.074	0.052	0.055	0.0172	
	I_1	0.073	0.099	0.077	0.094		
3-4	I_0	0.026	0.024	0.031	0.031	0.0080	
	I_1	0.028	0.031	0.034	0.035		
4-5	I_0	0.018	0.015	0.018	0.028	0.0046	I.N *
	I_1	0.013	0.020	0.021	0.015		
5-6	I_0	-0.000	-0.006	0.017	0.014	0.0048	N_ℓ *
	I_1	0.007	-0.001	0.013	0.009		