HGCA

PROJECT REPORT No. 49

N UPTAKE BY BARLEY RELATED TO MALTING QUALITY

FEBRUARY 1992

PRICE £8.00

HGCA PROJECT REPORT No. 49

N UPTAKE BY BARLEY RELATED TO MALTING QUALITY

by

N. L. CARRECK AND D. G. CHRISTIAN

Final report of a four year project at the AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts., AL5 2JQ. The work commenced in November 1987 and was funded by a grant of £77,924 from the Home-Grown Cereals Authority (Project No. 0025/3/87).

Whilst this report has been prepared from the best available information, neither the authors nor the Home-Grown Cereals Authority can accept any responsibility for any inaccuracy herein or any liability for loss, damage or injury from the application of any concept or procedure discussed in or derived from any part of this report.

Reference herein to trade names and proprietary products without special acknowledgement does not imply that such names, as defined by the relevant protection laws, may be regarded as unprotected and thus free for general use. No endorsement of named products is intended nor is any criticism implied of other alternative, but unamed products.

CONTENTS

ABSTRACT

Between 1987 and 1990, crops of barley at Rothamsted were frequently sampled in order to study the influence of husbandry factors upon malting quality.

Studies during the four years of the project showed that the majority of the nitrogen contained in the grain of both winter and spring barley at harvest is taken up before anthesis, whilst the majority of the carbohydrate is produced after anthesis. The project has demonstrated how husbandry factors such as previous crop, rate and timing of nitrogen fertiliser and disease control, as well as weather conditions, can affect the balance between the processes of nitrogen uptake and translocation and carbohydrate production affecting both yield and malting quality.

In six of the nine field experiments studied, ear nitrogen concentration fell after anthesis and then rose until maturity, in two it rose steadily, and in one it fell steadily during this period. This variability means that prediction of final grain quality from measurements made earlier in the season is unlikely to be feasible.

The final experiment of the project was carried out in 1989-90, when winter barley was grown after winter barley, winter oats, winter beans, oilseed rape or potatoes, with a range of nitrogen fertiliser rates, in order to test whether malting barley could be successfully grown after a break crop, providing that nitrogen rates were suitably reduced.

The highest yields were obtained after potatoes, the lowest after barley. The largest amounts of nitrogen which could be applied without grain nitrogen concentration exceeding 1.8%N were 75, 125, 100, 50 and 50 kg N ha^{-1} after barley, oats, beans, rape and potatoes respectively. The highest margins over nitrogen cost were obtained after oats or beans.

INTRODUCTION

The aims of much agronomic research on cereals have in recent years concentrated on understanding the factors affecting quality. Quality crops such as milling wheat and malting barley are not yet in surplus, and command premiums which can compensate for the slightly lower yields generally associated with quality varieties. In the case of malting barley, these premiums may be as much as £40 t^{-1}, as in 1987/88, but are more generally in the order of £20 t^{-1}.

Malting barley has traditionally been regarded as a low input crop in Britain, being grown mainly on the poorer land with reduced inputs of fertiliser and pesticides. There has been a lack of research into the agronomic factors affecting quality.

Grain nitrogen concentration (% in dry matter) is one of the major factors on which quality is assessed commercially. Because this is related to the amounts of carbohydrate and protein laid down in the developing grain, the relationships between them during grain filling are important.

Carbohydrate production in cereals is well understood, but nitrogen uptake and translocation to the grain have been studied less, and little published work relates to barley (Carreck & Christian, 1989). The aims of this project were therefore to study the nitrogen status of the barley crop, how this is changed by various husbandry factors, and to relate these changes to the malting quality of the grain.

MATERIALS AND METHODS

Sites

The crops sampled were all grown at Rothamsted Experimental Farm, on a well drained flinty clay loam soil overlying clay with flints (Batcombe series), which had P and K indices of 3 and 2 respectively (Johnston *et al*, 1981).

Experimental Design and Husbandry

Experimental details are given in Tables 1-4. Experiments 87-89/R/B/1 were a series of multi-factorial winter barley trials testing the effects on grain yield and quality of six factors, viz; previous crop, winter nitrogen, fungicidal seed dressing, late pathogen control and two rates and times of nitrogen fertiliser. The nitrogen rates were varied in order to take account of available soil nitrogen measured in autumn and spring, and the amount of nitrogen contained in the crop in February. The larger rate was intended to produce maximum grain yield whilst the smaller was intended to produce grain of acceptable quality for malting. Experiments 88/R/B/11 and 89/R/B/6 duplicated the nitrogen treatments from the multi-factorial trials. Data from these experiments also formed part of H-GCA Project 0080/1/87 (HGCA Project Report No. 48).

In order to compare the patterns of nitrogen uptake in winter and spring barley, four plots of the Hoosfield experiment (88/R/HB/2) were sampled. These had received either farmyard manure (FYM) or N, P, K and Mg every year for 137 years. Subsequently, two separate spring barley experiments, 89/R/B/7 and 90/R/B/4 were sampled. These also provided seed dormancy samples for H-GCA Project 0086/1/87.

One factor not studied in the first three years of the project was the effects of previous break crops on the yield and malting quality of barley. Studies on wheat (Vaidyanathan *et al*, 1987) have shown that the crop immediately following a break crop may have an inherently lower grain nitrogen concentration than crops following a cereal, because the residual soil nitrogen is taken up early in the season and contributes more to larger plants than to increased protein content. It was therefore suggested that rather than growing breadmaking wheat as a first cereal after a break crop, malting barley might provide a suitable alternative, providing nitrogen applications are adjusted to take account of the additional residual soil nitrogen. Experiments 89-90/R/CS/337 were therefore a two year trial testing the effects of five previous crops, viz; barley, oats, oilseed rape, winter beans and potatoes, and nitrogen rate on the yield and quality of winter malting barley.

Sampling procedures

Stem sap nitrate concentration

Random samples of eight plants, or when plants became large, eight stems, were removed from each of a subset of plots at fortnightly intervals between November and July. The concentration of nitrate-N (NO_3-N) in the stem sap of six plants was then determined by a rapid colorimetric test (Williams, 1969).

Growth analysis

Between March and anthesis, samples were taken fortnightly, and then weekly until maturity. The fresh samples, divided into ear, leaf and stem components, were dried for 16 h at 80°C, and weighed. Total nitrogen was determined either using a Technicon

"Auto Analyser" after Kjeldahl digestion, or using a Foss Heraeus "Macro-N analyser" calibrated using L-aspartic acid, which produces results in close agreement with those produced by the Kjeldahl method (Wilson, 1990).

Soil samples

Soil samples were taken to a depth of 90 cm in 30 cm horizons, and stored at -20 °C until analysed. 50 g of moist fine soil was then shaken with 125 ml 2 M potassium chloride for 2 h, and then analysed for nitrate and ammonium nitrogen (NO_3-N and NH_4-N) content using a Technicon "Auto Analyser".

Green Area Index

The green area of winter barley samples taken from 88/R/B/11 and 89/R/B/6 was measured using a Delta-T planimeter, and Green Area Index was calculated (Sylvester-Bradley *et al*, 1985).

Weather

Between December 1987 and March 1988, minimum and maximum temperatures were some 1-2 °C higher than the long term average, whilst during grain filling, mean maximum temperatures were 1-2 °C lower than average. Rainfall from September 1987 to August 1988 was 24% greater than the long term figures (861 vs 692 mm), and much of this extra fell in October and January.

In contrast, between September 1988 and July 1989, 21% less rain fell than average. In particular the months from May to September all received significantly less rainfall than average. Only 4.2 mm fell during May, as against the 30 year mean of 51.2 mm. Temperatures in 1988-89 were also unusual. The winter was exceptionally mild, temperatures being consistently more than 2°C above the long term mean between December and March. This was followed by a hot summer, with temperatures 1-3°C greater than average from May to July.

The 1989-90 growing season again showed extremes of rainfall. December, January and February received a total of 264 mm of rain, 97% more than average, whilst during the remaining six months from March to August only 163 mm of rain fell, 51% less than average. Throughout the season, mean temperatures were generally higher than average, being nearly 4°C higher between January and March and approximately 3°C higher in July and August.

RESULTS AND DISCUSSION

Winter barley 1987-89

Dry matter accumulation

Dry weight averaged over all nitrogen treatments (e.g. 88/R/B/11; Fig. 1), increased almost linearly from the onset of stem extension until June, after which the treatments given 125 kg N ha^{-1} (N_{125}) remained constant, whilst those given 200 kg N ha^{-1} (N_{200}) continued to increase until mid July. The growth of the developing ear was supplied by fresh photosynthate since the decline in weight of the remainder of the plant was small. Throughout the season the total dry weight of the crops without nitrogen (N_0) was only approximately, 30% of that of the other treatments.

On a dry matter per shoot basis, plants given nitrogen in March (NE) remained significantly larger than those given nitrogen in April (NL) irrespective of the amount supplied, but this was not reflected in the total dry matter m^{-2}, because the NL plants had more shoots m^{-2}. In March, April and on 2 June, barley given winter nitrogen had a significantly ($P < 0.001$) greater total dry weight than the other crops but this became less obvious later.

In 1989 the pattern of dry matter accumulation (Fig. 2) was generally similar to 1988, but the mild weather allowed the crop to attain roughly three times as much dry weight by mid March as it had by the same time in the previous year. This early advantage was maintained throughout the season and contributed to the resultant good grain yields

(Table 7). The level of yield obtained suggests that the winter barley was not adversely affected by the dry summer.

The crop appeared to translocate a greater proportion of carbohydrate in 1989 than in 1988, as compensation for a lack of fresh assimilate. This was presumably because photosynthesis was limited by the dry soil conditions (Legg *et al*, 1979). The contribution of pre-anthesis assimilation to grain yield is estimated as the loss of dry weight of the leaves and stems of the crop between ear emergence and maturity, expressed as a proportion of the final grain yield. In 1989 this proportion was approximately 36% of yield, as compared with approximately 24% in 1988. This observation is consistent with published work on the effects of drought stress on barley (Lawlor *et al*, 1981).

Green Area Index

Green Area Index (Fig. 3) increased almost linearly during early growth, more quickly with 200 kg N ha^{-1} than with 125 kg N ha^{-1} until a peak was reached at anthesis. Green area then remained roughly constant until senescence at the beginning of July. Crops without nitrogen had about 20% of the green area of the nitrogen treated crops.

The Green Area Index of barley from 89/R/B/6 was more than 3 at the beginning of April, whilst that of the previous comparable experiment 88/R/B/11 had been only 1 in early April (Fig. 4). The lush early growth of 1989 was not maintained throughout the season however, as the maximum Green Area Indices were slightly lower than in 1988. The No crop attained a higher maximum Green Area Index in 1989 than in 1988 (3vs2).

Stem sap nitrate concentration

Fig. 5 shows changes in the stem sap NO_3-N concentration in 1988. On 29 March the concentration was higher where nitrogen had been applied on 14 March. The crop given 200 kg N ha^{-1} reached a higher concentration than that given 125 kg N ha^{-1} and then both declined. The crop given nitrogen in April responded in much the same way, and then following wet weather in early July, NO_3-N concentrations fell rapidly until measurements ceased.

During the winter of 1989, concentrations were significantly higher than during the previous winter (Fig. 6), all treatments remaining higher than 700 ppm between late November and February. Throughout this period there was little difference between the NO_3-N concentration of plants that had been given winter nitrogen and of those relying only on the soil nitrogen supply.

Following the spring 1989 nitrogen applications, the pattern of NO_3-N concentrations was similar to that of 1988, but changes occurred approximately two weeks earlier. As in 1988, the concentration of the March nitrogen treatments declined rapidly during April, whilst the April N_{60} (N_{60}L) treatment remained high until early June, after which measurements ceased. That of the N_0 crop, which was not measured in 1988, remained below 200 ppm from March onwards. This figure of 200 ppm is considered to be the threshold below which the soil nitrogen supply is inadequate to provide the needs of a growing cereal crop (Darby *et al*, 1986).

Nitrogen content of dry matter

The average pattern of nitrogen accumulation in the winter barley in 1988 is shown in Fig. 7. Throughout the season the nitrogen content of the N_0 crop remained about 25% of that of the other treatments. Nitrogen uptake ceased by June. The increase in the nitrogen content of the growing ear was matched by the declining content of the ears and stem, suggesting that nitrogen was being mobilised and translocated to the grain.

By the end of March, the 1989 crop (Fig. 8) had taken up approximately four times as much nitrogen as in the previous year (on average of 12 g N m^{-2} as against 3 g N m^{-2}). The crop subsequently reached a total nitrogen content uptake similar to 1988, showing that the rate of uptake later in the season was reduced, presumably due to the dry conditions.

The total nitrogen uptake of the crops given the larger amount of nitrogen was greater, but the time of application had little significant effect. The N_0 crop, which reflected the soil nitrogen supply, took up approximately twice as much nitrogen in 1989 than in 1988.

One notable feature of the average pattern of nitrogen uptake in 1989 (Fig. 8), is the apparent fall in total nitrogen content in late May, following anthesis. This was observed to a lesser extent in the 1988 experiments, and has been reported to occur in other cereals (Abrol *et al*, 1984). In this case it appears to have been associated with a sudden drop in the nitrogen concentration of the ears and stems of the plant. Its cause remains largely unexplained, but it is usually attributed to the loss of gaseous ammonia from the actively photosynthesising leaves (Hooker *et al*, 1980). Another possibility is that nitrogen becomes stored in the plant roots at this time, and is returned to the above ground parts later (Chatterjee *et al*, 1982).

Nitrogen concentration in ears

The average nitrogen concentrations in the ears for all treatments in 1987 and 1988 are shown in Fig. 9. Compared to 1987, the 1988 figures were approximately 0.15 - 0.2% lower until July, presumably because of the significantly greater rainfall in 1988 which may have decreased available soil nitrogen. The ear nitrogen concentration in 1988 fell from anthesis until leaf senescence at the beginning of July, when it rose again. This pattern contrasts with 1987 when the concentration fell steadily from anthesis to maturity, with only a minor peak occurring at the time of leaf senescence.

The differences between the patterns of ear nitrogen concentration in these two years were presumably due to differences in the weather. In 1987 June was wet, and early July was very dry. In 1988 however, May and the final fortnight of June were dry, prompting senescence, but July was wet, receiving some 95 mm of rain (Fig. 10). This presumably allowed translocation of nitrogen to the grain to continue after photosynthesis had apparently ceased, thus causing the nitrogen concentration to rise.

Throughout much of the 1988 season, the barley given nitrogen in April had significantly ($P < 0.001$) higher ear nitrogen concentrations than that given nitrogen in March, with N_{200} significantly ($P < 0.001$) higher than N_{125}. Although some 0.2% lower than the mean of the nitrogen treatments, the crops without nitrogen followed a similar pattern of changes in ear nitrogen concentration.

The pattern of changes in ear nitrogen concentration in 1988 and 1989 were not dissimilar (Fig.11), except that in 1989, changes occurred about two weeks earlier. Unlike 1988 however, there was little difference between the crops given nitrogen in March or April. Nitrogen uptake in the ear for all treatments was slightly greater in 1989 than in 1988. the N_0 treatment had a final ear nitrogen content roughly twice as much in 1989 as in 1988.

Nitrogen content of leaves

In 1988 the nitrogen concentration of the flag and penultimate leaves fell almost linearly from an average of 3.9% on 2 June, to 1.7% on 30 June. Green area duration was increased by the use of fungicides, and differences were significant ($P < 0.001$) on 16 June and 5 August. Green leaves had a higher nitrogen content (gNm^{-2}) where fungicides had been applied, but this was not reflected in the concentrations (%).

The average concentrations of nitrogen in dead leaves remained roughly constant throughout the grain filling period. Fungicide sprays reduced the concentration (%), the effect becoming more significant ($P < 0.001$) as grain filling proceeded. Similarly, fungicides caused a significant ($P < 0.001$) reduction in the amount of nitrogen (gNm^{-2}) in dead leaves. These results appear to confirm that fungal disease may "lock up" in dying leaves, protein nitrogen which might otherwise be translocated to the developing grain during the senescence of healthy plants. At the final 1988 sampling on 5 August the crop contained a total of 20 and 17 $g\ N\ m^{-2}$ with and without fungicides respectively. Similarly, the ears contained 17 and 14 $g\ N\ m^{-2}$. the concentration of nitrogen in the leaves was also significantly ($P < 0.001$) reduced where fungicides had been applied (1.56% vs 1.83%).

Grain yields and nitrogen concentration

Yield components in 1988 and 1989 are shown in Tables 5 to 8. Grain yields were increased by winter nitrogen; fungicides, probably by extending leaf duration; and the larger rate of nitrogen, but in contrast with 1987 (Jenkyn *et al*, 1988), there was no significant effect of timing of nitrogen application. Thousand grain weight (TGW) was increased by March nitrogen and fungicides, but not by nitrogen rate.

Despite the lower rates of nitrogen fertiliser used, the winter barley yields were consistently higher in 1989 than in 1988. Particularly notable were the yields produced by the N_0 crops, which represented the soil nitrogen supply. In the case of 89/R/B/1, these were approximately 2.5 times as much as in 88/R/B/1. The yields of the other treatments of 89/R/B/1 were on average, 25% more than in the previous season. These increased yields can be mainly attributed to a greater number of ears per m^{-2}, as the number of grains per ear and thousand grain weights were slightly lower than in 1988.

Final grain nitrogen concentrations were generally higher in 1989 than in 1988, reflecting greater total nitrogen uptake. In both years, grain nitrogen concentration was significantly ($P < 0.001$) increased by the larger amount of nitrogen, and by application in April rather than in March. Previous crop and the use of fungicide seed dressing had no effect on grain nitrogen concentration. The use of late fungicide sprays significantly

($P < 0.001$) increased yields by 0.82 t ha^{-1} in 1989, but unlike 1988, slightly increased the grain nitrogen concentration.

It is clear therefore that the mild weather early in 1989 allowed the crop to take up more nitrogen than usual, producing many tillers, and achieving maximum green area much earlier in the season. This higher number of shoots per m^2 was then retained until harvest, but the number of grains per ear and thousand grain weight, the last components of yield to be determined, were slightly affected by the dry conditions.

Few of the treatments in either year produced grain with nitrogen concentration lower than 1.75%, the usual threshold for sale for malting. This is partly because some of the treatments were designed to examine the effects of higher rates of nitrogen on factors other than malting quality, but also due to the choice of variety. The variety Magie appeared very promising as a malting barley at the time when this series of trials was planned, being given a provisional malting grade of 8 (NIAB, 1986), but subsequently, whilst it became popular because of high yields and good grain size, it performed relatively poorly in malting tests, and was downgraded to 7 (NIAB, 1989).

Spring Barley 1988-90

Crop growth

In both 1989 and 1990 the spring barley was effected by drought. That sown in 1990 was less affected than that sown in 1989, possibly because it was drilled slightly earlier. The 1990 crop achieved a maximum total dry weight of approximately 9 t ha^{-1}, compared to only 6 t ha^{-1} in the previous year. In 1989, dry matter production ceased soon after anthesis (Fig. 12), whilst in 1990 accumulation of dry matter in the leaves and stems continued until early July, and in the ears until maturity. Shortly after anthesis, Klaxon had a larger dry weight than Triumph, but there was no significant difference at harvest between the two varieties or the two rates of nitrogen. The pattern of dry matter accumulation in the ears was similar in both years, but reached a maximum of approximately 6 t ha^{-1} in 1990, compared to only approximately 3.5 t g ha^{-1} in 1989. The barley in 1990 had on average approximately 680 shoots m^{-2}, whilst the 1989 crop had only 520 m^{-2}. There was no significant effects of variety or nitrogen, although Klaxon generally had slightly more shoots than Triumph.

Nitrogen Uptake

The pattern of changes in the nitrogen concentration in ears and grain was very similar in 1988 and 1989, except that it remained approximately 0.2 %N lower throughout in 1989 (Fig. 13). The concentration gradually increased during the grain filling period, and by maturity had reached 2.33 %N after an application of 100 kg N ha^{-1}. The amount of nitrogen contained in the grain was approximately 50% more in 1990 than in 1989 (105 kg N ha^{-1} vs 75 kg N ha^{-1}).

Grain Yields

Table 10 shows the 1990 grain yields, which at an average of 5.5 t ha^{-1} were considerably higher than those of 1989 (Table 9). The higher yields were produced by approximately 50% more ears at harvest than in the previous year (averages of 716 and 489 ears m^{-2} in 1990 and 1989 respectively), as the number of grains per ear was similar, and thousand grain weights were only slightly higher in 1990 than in the previous year (35.6 vs 31.8g).

Discussion

In both 1989 and 1990 the spring barley study was affected by dry weather, most seriously in the former. The poor yields obtained reflected the experiences of many growers, and help to explain why the area sown to spring malting barley has been steadily declining as improved winter varieties become available.

The work has shown that the patterns of dry matter production and nitrogen uptake are generally similar in spring and winter varieties. The shorter growing season of spring barley means however that the crop has less stored material which can be mobilised and translocated to compensate for reduced assimilation during drought. Hence in both 1989 and 1990 grain nitrogen concentrations were unacceptably high because insufficient carbohydrate was available to dilute nitrogen which had been taken up before anthesis.

Winter barley and previous cropping 1989-1990

Experimental details and yields of the first year of this experiment (89/R/CS/337) are given in Tables 3 and 11. The crops grown were winter barley, winter oats, winter beans, winter oilseed rape and potatoes, and husbandry was conventional, according to the standard practice of Rothamsted Experimental Farm. The winter rape was seriously damaged by rabbits and cabbage stem flea beetles, and was replaced by spring rape, which established poorly in the dry spring. In order to prevent delay to the second part of the experiment, the spring rape was not taken to maturity and was removed with a forage harvester. At maturity, the barley, oats and beans were combined and the straw removed. The potato haulms were desiccated and pulverised and the tubers lifted and removed. The entire site was then ploughed prior to drilling the winter barley. Details of the second year (90/R/CS/337) are given in Table 4. The experiment had a randomised block design of three blocks of five main plots, each divided into six subplots. Apart from the nitrogen treatments, the barley was again grown conventionally.

Crop Growth

The pattern of dry matter accumulation in the barley after barley is shown in Fig. 14 and shows a similar pattern to those seen in the two previous years, except that changes occurred slightly later than in 1989, which was an untypically early season. The variety used in 1990 was the malting variety Halcyon, whilst Magie had been used in the three previous years' experiments. It is thus possible that the varieties differ in their patterns of dry matter production and nitrogen utilisation so direct comparison with previous years is unwise, but experience with the spring barley varieties suggests that such differences are small.

Throughout the season, and at all nitrogen rates, the barley grown after potatoes had on average the largest dry weight, whilst the barley after barley had the lowest. These differences were initially small, but became more pronounced later, although they were rarely statistically significant. Crops grown after oats, beans or rape differed little from each other. Fig 15 shows the pattern of total dry matter accumulation in the N_0 crops. The patterns for the other nitrogen rates were similar although totals were in all cases significantly ($P < 0.001$) greater.

Changes in shoot numbers reflected the same patterns. On average, crops grown after potatoes had the largest numbers of shoots, crops after barley the smallest, and the remainder were intermediate. Again, these differences were rarely statistically significant. In the N_0 crops, shoot numbers rose to a maximum of approximately 1300 m^{-2} in April, falling to approximately 500 m^{-2} by May and then remaining relatively constant until harvest. In the N_{100} and N_{150} crops, shoot numbers remained at approximately 700 m^{-2} during this period, and there was no consistent or significant difference between the two treatments.

Available soil nitrogen

Table 12 shows the total mineral (NO_3-N) and NH_4-N) nitrogen to a depth of 90 cm in November and March. There was a considerable loss of available nitrogen between these two measurements, and the amount of nitrogen taken up in the crop before March does not account for all of the loss. Much of the nitrogen available in November was however located in the 30 - 60 cm horizon, below the rooting depth of the crop at this early stage of growth. Much soil nitrogen must have been lost by leaching, as the warm winter would have allowed considerable mineralisation to take place, and the exceptional rainfall between December and February would have eluted soluble nitrogen down the soil profile beyond the rooting zone. Some of the nitrogen may also be accounted for by its immobilisation by soil microbes and incorporation in the soil organic matter, and may have again become available later in the growing season.

Stem nitrate concentration

The concentration of NO_3-N in the stem sap over the winter was only slightly less than in 1989, and considerably larger than in 1988. This presumably reflected mineralisation of soil nitrogen in the mild winter. The concentration remained at approximately 700 ppm between mid November and early February, falling below 250 ppm at the beginning of March (Fig. 16). As with the shoot numbers, the after potatoes plants had the largest concentrations, the after barley plants the smallest, and the remaining crops were intermediate.

Nitrogen content of dry matter

Fig. 17 shows changes in the nitrogen content of the barley after barley. As with dry matter accumulation, this pattern was similar to previous years. The barley after potatoes consistently had a higher nitrogen content than the other crops, and barley after barley had the lowest (Fig. 18). Changes in the ear nitrogen concentration of the N_0 crops are shown in Fig. 19. As in 1989, the concentration decreased gradually for the first few weeks after anthesis, and then increased. The barley after potatoes consistently had the highest concentrations, and the barley after oats the lowest.

Grain yields and quality

Table 13 shows the mean grain yields (t ha^{-1} at 85% DM). The heaviest yields were achieved after potatoes, the lightest after barley, whilst the yields achieved after oats, beans and rape were not significantly different from each other. Each increment of nitrogen significantly increased yield, except for the largest applications made to the crop grown after potatoes. On average, an additional 25 kg N ha^{-1} increased yield by 0.45 t ha^{-1}. The effects on yield of the interaction between previous cropping and nitrogen rate is shown in Fig. 20. The after potatoes crops consistently produced a significantly greater yield for a given amount of added nitrogen, whilst the after barley crops produced the smallest yields. The smallest grain nitrogen concentrations were achieved after oats or beans, and the largest after rape or potatoes (Table 5). As with yield, each increment of added nitrogen increased it, although this was not always statistically significant. On average, an addition of 25 kg N ha^{-1} increased the nitrogen concentration by 0.12 %N.

Discussion

Fig. 21 shows the effects of previous cropping and amount of applied nitrogen on %N in harvested grain. If one assumes that a financial premium would only be paid on grain with less than 1.8 %N, after potatoes or rape, 50 kg N ha^{-1} was the maximum amount of nitrogen which could be added and acceptable quality produced, whilst after oats, this was 125 kg N ha^{-1}. Similarly, after oats, beans, or barley, an application of up to 75 kg N ha^{-1} produced grain of 1.65 %N or less, which would qualify for a larger premium.

Apart from the barley after potatoes, maximum yields had not been achieved at 150 kg N ha^{-1}, the largest rate of nitrogen used (Fig. 20). When the margins over nitrogen costs are considered however, it is evident that the economic optimum applications were much lower than this, and also lower than the recommended applications (ADAS, 1984) of 125 kg N ha^{-1} after cereals, or 100 kg N ha^{-1} after a break crop.

Margins over nitrogen cost, assuming that ammonium nitrate fertiliser cost 30p kg N $^{-1}$, and that grain prices for Halcyon winter barley were 100, 117, 125, 140 and 150 £ t^{-1} for grain with a concentration of > 1.85, 1.76 - 1.85, 1.71 - 1.75, 1.60 - 1.70, and <1.60 %N, respectively, are shown in Fig. 23. The highest margins were achieved after beans or oats, at a nitrogen rate of 75 - 100 kg N ga^{-1}. The maximum margins for the other crops were produced at a rate of just 50 kg N ha^{-1}, and were some £150 less. This demonstrates that the maximum returns from the production of malting barley can only be obtained if acceptable grain quality can be achieved. If excess nitrogen is applied for greater yield, profitability will suffer.

Barley after oats had a yield 0.89 t ha^{-1} greater than barley after barley (Table 13). Similarly, barley after oats had a grain nitrogen concentration 0.15% less than after barley. This is consistent with the results of the Rothamsted experiments over the previous three years. Averaged over the years 1987-9, growing barley after oats produced a yield benefit of 0.84 t ha^{-1}, and reduced grain nitrogen concentration by 0.06%. This yield benefit is not due to nitrogen, but results from the adverse effects of take-all when barley is grown sequentially. In the present experiment the soil in November contained 102 and 69 kg N ha^{-1} after barley and oats, respectively. Although there were no obvious signs of take-all and detailed disease assessments were not made, the after barley crop did not apparently derive any benefit from this additional 33 kg N ha^{-1}, as there was no significant difference between the nitrogen uptake of the two crops at any time.

The results reported here are from one year only, and should therefore be viewed with caution. In particular, it was unfortunate that the original winter rape failed, and had to be replaced with spring rape, which was then harvested before it was mature. This could have had several effects. Firstly, the rape plots had bare soil exposed for a longer period of time than the other crops, and this may have resulted in greater leaching of nitrate during the winter and early spring. Secondly, the winter rape, although very patchy, contained approximately 65 kg N ha^{-1} before it was incorporated prior to the drilling of the spring rape. It is difficult to estimate how long would elapse before nitrogen contained in the crop residue would become available to the following barley crop, so it is uncertain whether it received any benefit.

Finally, the autumn of 1989 was very dry, and it was observed that the winter barley on the after rape plots did not emerge until approximately a fortnight later than that of the other plots. This appeared to be because the other crops were mature by July, and would therefore have been using little water, whilst the spring rape was still green and actively transpiring, resulting in a drier seed bed on the after rape plots. It is not certain what, if any, effect this later emergence may have had on the subsequent growth of the barley.

The above average rainfall which occurred between December and February presumably led to more leaching of soil mineral nitrogen than might be expected in many years. For this reason, the differences found between the previous crops are probably not as great as might have been expected. Had less leaching occurred, it is likely that the optimum rates of nitrogen needed to combine maximum yields with acceptable grain quality would have been lower than those found in this experiment. It is therefore desirable that this work should be repeated, preferably over several years on different sites, as the effects of season and soil type will have a large effect upon the availability of nitrogen left by different break crops, and hence effects on malting quality will vary.

OVERALL CONCLUSIONS

In four years, this study has shown that malting quality is significantly influenced by a number of husbandry factors. This is because grain nitrogen concentration is a product of the amounts of nitrogen and carbohydrate laid down in the developing grain, whilst the processes controlling nitrogen uptake and carbohydrate production are not directly related.

Grain protein is derived mainly from nitrogen taken up before anthesis and later translocated to the grain. A small amount of nitrogen may or may not be taken up after anthesis, depending on the soil nitrogen supply and weather conditions. In contrast, the majority of the grain carbohydrate is the product of post-anthesis assimilation, very little being translocated assimilates produced before anthesis.

The nitrogen concentration in the ears and grain changes during the grain filling period in response to weather conditions, especially rainfall, which may promote uptake or translocation of nitrogen to the grain late in the season, when the senescing crop is unable to dilute it with fresh carbohydrate assimilation.

In six of the nine experiments sampled during the project, the ear nitrogen concentration fell for the first few weeks after anthesis, and then rose until maturity. In two experiments it rose steadily from anthesis until maturity, and in the remaining experiment it fell steadily from anthesis until maturity.

This variability, especially during the final critical period just before harvest, means that predicting the final nitrogen concentration from measurements made earlier in the season is unlikely to be feasible until accurate long-term meteorological predictions become available.

The proportion of grain carbohydrate and nitrogen derived from stored pre-anthesis material is also affected by seasonal differences. In the exceptionally dry 1989 grain filling period for example, a greater proportion of the grain carbohydrate was derived from pre-anthesis assimilates than in the more "normal" 1988 season.

Foliar fungal diseases can affect the cycling of nitrogen within the plant as well as restricting carbohydrate production, adversely affecting both yield and malting quality. This highlights the need to keep crops of barley intended for malting free of foliar disease by the use of an appropriate fungicide.

Nitrogen fertiliser causes a directly linear increase in the grain nitrogen concentration, approximately 25 kg N ha^{-1} causing an increase of 0.1%. At Rothamsted, applications of more than 100 - 125 kg N ha^{-1} on sites at ADAS Nitrogen Index 0 produced grain with unacceptably high grain nitrogen concentrations.

Residual soil nitrogen, whether remaining from previous break crops or derived from mineralisation of soil organic matter is mainly available to the crop early in the season, and thus acts similarly to March applied nitrogen, promoting early growth rather than a large grain nitrogen concentration.

Malting barley may therefore have a role to play as the first cereal in a sequence, taking advantage of a pest and disease break, providing that the rate of applied fertiliser nitrogen is adjusted to take account of the increased soil fertility. The optimum rate which the individual grower needs to apply will vary from site to site, and the computer model recently developed at Rothamsted with H-GCA funding (Bradbury *et al* 1991) which predicts nitrogen release from soils, taking into account local soil characteristics and field history will aid growers in determining this.

REFERENCES

ABROL, Y.P., KUMAR, P.A. & NAIR, T.V.R. (1984). Nitrate uptake and assimilation and grain nitrogen accumulation. *Advances in Cereal Science and Technology* **6**, 1-48.

ADAS (1984). *Malting Barley Booklet 2399* London: MAFF.

BRADBURY, N.J. WHITMORE, A.P. & JENKINSON, D.S. (1991). To construct and test computer models for predicting how much nitrogen is released from soil, and when this release occurs. *Final report of H-GCA Project 0020/1/87.*

CARRECK, N.L. & CHRISTIAN, D.G. (1989). *Growing barley for malting - a review. H-GCA Project Report* **20**. London:H-GCA.

CHATTERJEE, S.R., POKHRIYAL, T.C. & ABROL, Y.P. (1982). Nitrogen economy of the main shoot of field grown barley (*Hordeum vulgare* L.). *J. Exp. Bot.* **33**, 876-885.

DARBY, R.J., WIDDOWSON, F.V., BIRD, E. & HEWITT, M.V. (1986). The relationship of soil mineral NO_3-N with stem NO_3-N concentration, and of fertiliser-N with the amount of nitrogen taken up by winter wheat in experiments testing nitrogen fertiliser in combination with aphicide and fungicides, from 1980 to 1982. *J. Agric. Sci., Camb.* **106**, 497-507.

HOOKER, M.L., SANDER, D.H., PETERSON, E.A. & DAIGGER, L.A. (1980). Gaseous N losses from winter wheat. *Agron. J.* **72**, 789-792.

JENKYN, J.F., CHRISTIAN, D.G., DARBY, R.J. & MULLEN, L.A. (1988). Factors limiting yield and quality of winter barley. *Report of Rothamsted Experimental Station for 1987* 17-20.

JOHNSTON, A.E., POULTON, P.R. & McEWEN, J. (1981). The soils of Rothamsted Farm. *Report of Rothamsted Experimental Station for 1980, Part 2*, 5-20.

LAWLOR, D.W., DAY, W., JOHNSTON, A.E., LEGG, B.J. & PARKINSON, K.J. (1981). Growth of spring barley under drought: crop development, photosynthesis, dry matter accumulation and nutrient content. *J. Agric. Sci., Camb.* **96**, 167-186.

LEGG, B.J., DAY, W., LAWLOR, D.W. & PARKINSON, K.J. (1979). The effect of drought on barley growth: models and measurements showing the relative importance of leaf area and photosynthetic rate. *J. Agric. Sci, Camb.* **92**, 703-716.

NIAB (1986, 1989). *Recommended varieties of cereals. Farmers leaflet No. 8.* Cambridge: NIAB.

SYLVESTER-BRADLEY, R., GRYLLS, J.P. & ROEBUCK, J.F. (1985). Methods for measuring cereal crops. In: *Aspects of Applied Biology* **10**, *Field trials methods and data handling.*

VAIDYANATHAN, L.V., SYLVESTER-BRADLEY, R. BLOOM, T.M., & MURRAY, A.W.A. (1987). Effects of previous cropping and applied nitrogen on grain nitrogen content in winter wheat. *Aspects of Applied Biology* **15**, *Cereal Quality.*

WILLIAMS, R.J.B. (1969). The rapid determination of nitrate in crops, soils, drainage and rainwater by a simple field method using diphenylamine with glass fibre paper. *Chemistry and Industry* 1735-1736.

WILSON, P.R. (1990). A new instrument concept for nitrogen/protein analysis. A challenge to the Kjeldahl methods. *Aspects of Applied Biology* **25**, *Cereal Quality II.*

Table 1
Experimental and Sampling details, winter barley 1988-89

Experiment:	**88/R/B/1**	**88/R/B/11**	**89/R/B/1**	**89/R/B/6**
Variety:	Magie	Magie	Magie	Magie
Sowing date:	25/9/87	25/9/87	20/9/88	20/9/88
Previous crop:	barley/oats	barley	barley/oats	barley
N rates (kg N ha^{-1})	125,200	0,125,200	85,160	0,85,160
N timings	14/3, 13/4	14/3, 13/4	14/3, 10/4	14/3, 10/4
Other factors	winter N[1] early fung.[3] late fung.[4]		winter N[2] early fung[3] late fung[4]	
Plot size	3m x 15.3m	3m x 7.3m	3m x 18.3m	3m x 14.6m
Number of plots sampled	32	20	32	20
Sample size:	1m x 1 row[5]	0.5m x 5 rows[5]	0.5m x 5 rows[5]	0.5m x 5 rows[5]
Date of harvest:	5/8/88	5/8/88	13/7/89	13/7/89

[1] 33 kg N ha^{-1} after barley, 54 kg N ha^{-1} after oats on 17 November; 25 kg N ha^{-1} on 18 February.

[2] 20 kg N ha^{-1} after barley, 49 kg N ha^{-1} after oats on 16 November; 25 kg N ha^{-1} on 20 February.

[3] Triadamenol and fuberidazole as "Baytan".

[4] Prochloraz and Carbendazim as "Sportak Alpha", tridemorph as "calixin" and propaconazole as "Tilt".

[5] 12 cm rows.

Table 2
Experimental and sampling details; spring barley

Experiment:	**88/R/HB/2**	**89/R/B/7**	**90/R/B/4**
Variety:	Triumph	Natasha/Klaxon	Triumph/Klaxon
Sowing date:	13/3/88	28/3/89	8/3/90
Previous crop:	barley	barley	sunflowers
N rates (kg N ha^{-1})	96, 144, FYM, FYM + 96	100, 140	100, 140
N timings	Seedbed	Seedbed	Seedbed
Plot size	10.5m x 12.2m	3m x 15m	3m x 15m
No. of plots sampled	4	12	12
Sample size	1m x 1 row	0.5m x 5 rows	0.5m x 5 rows
Date of harvest	23/8/88	15/8/89	4/8/90

Table 3
Experimental details: 89/R/CS/337

Design: 3 randomised blocks of 5 plots

Plot size: 32m x 20m

Previous crop: winter wheat

Crop:	Barley	Oats	Beans	Rape	Potatoes
Variety:	Halcyon	Image	Bourdon	Ariana, Topaz[1]	Desiree
Sowing date:	18/10/88	18/10/88	18/10/88	9/9/88, 21/4/89[1]	3/5/90
N rates: (kg N ha^{-1})	125	125	-	150	220
N timing:	30/3/89	18/4/89	-	23/2/89, 20/4/89	20/4/89
Date of harvest:	21/7/89	25/7/89	14/8/89	29/8/89	8/9/89

[1] Winter oilseed rape failed - replaced with spring oilseed rape

Table 4
Experimental details: 90/R/CS/337

No. of plots:	90
Plot size:	20m x 3m
Previous crop:	barley, oats, beans, rape, potatoes
Variety:	Halcyon
Sowing date:	21/9/89
N rates (kg N ha^{-1}):	0, 50, 75, 100, 125, 150
N timing:	14/3/90
Date of harvest:	24/7/90

Table 5
Yield Components: 88/R/B/1

	Ears m^{-2}	Yield t ha^{-1}	T.G.W. g	Grain %N
No nitrogen	273	1.68	34.8	1.74
Previous crop:				
Barley	617	5.56	38.4	1.95
Oats	577	6.32	39.4	1.91
Seed treatment:				
Without	595	5.89	38.9	1.92
With	598	5.98	38.9	1.94
Fungicide treatment:				
Without	589	5.56	37.6	1.90
With	605	6.31	40.3	1.96
Winter nitrogen:				
Without	590	5.73	39.3	1.89
With	604	6.15	38.5	1.97
Spring nitrogen:				
125 kg N ha^{-1}	568	5.72	39.2	1.85
200 kg N ha^{-1}	626	6.15	38.7	2.02
Nitrogen time:				
14 March	580	5.96	39.8	1.84
13 April	594	5.91	38.0	2.02
LSD (P = 0.05)	46	0.36	1.02	0.11

Table 6
Yield Components: 88/R/B/11

	Ears m^{-2}	Yield t ha^{-1}	T.G.W. g	Grain %N
No nitrogen	343	2.53	36.7	1.37
Spring nitrogen:				
125 kg N ha^{-1}	633	6.03	40.3	1.67
200 kg N ha^{-1}	718	6.26	39.1	1.85
Nitrogen time:				
14 March	646	6.06	40.7	1.61
13 April	704	6.23	38.7	1.91
LSD (P = 0.05)	155	1.72	3.84	0.19

Table 7
Yield Components: 89/R/B/1

	Ears m^{-2}	Yield $t\ ha^{-1}$	T.G.W. g	Grain %N
No nitrogen	636	4.19	34.6	1.48
Previous crop:				
Barley	1037	7.36	32.4	1.97
Oats	992	7.65	34.7	1.98
Seed treatment:				
Without	1034	7.43	33.4	1.97
With	995	7.59	33.8	1.98
Fungicide sprays:				
Without	987	7.10	32.7	1.93
With	1042	7.92	34.4	2.02
Winter nitrogen:				
Without	1014	7.17	33.9	1.93
With	1015	7.85	33.2	2.02
Spring nitrogen:				
85 kg N ha^{-1}	983	7.30	34.1	1.75
160 kg N ha^{-1}	1045	7.72	33.0	2.20
Nitrogen time:				
14 March	942	7.58	34.1	1.91
10 April	1087	7.44	33.0	2.04
LSD (P = 0.05)	65	0.11	0.52	0.05

Table 8
Yield Components: 89/R/B/6

	Ears m^{-2}	**Yield** $t\ ha^{-1}$	**T.G.W.** g	**Grain** %N
No nitrogen	642	3.45	33.0	1.52
Spring nitrogen:				
85 kg N ha^{-1}	855	6.47	35.4	1.75
160 kg N ha^{-1}	936	7.19	35.1	2.10
Nitrogen time:				
14 March	872	7.05	35.9	1.88
13 April	919	6.61	34.6	1.97
LSD (P = 0.05)	66	0.23	0.65	0.14

Table 9
Yield Components: 89/R/B/7

	Ears m^{-2}	Yield t ha^{-1}	T.G.W. g	Grain %N
Variety:				
Klaxon	476	3.20	32.8	2.48
Natasha	502	3.10	30.8	2.58
Nitrogen rate:				
100 kg N ha^{-1}	515	3.15	31.8	2.51
140 kg N ha^{-1}	463	3.15	31.9	2.55
LSD (P = 0.05)	78	0.48	1.32	0.12

Table 10
Yield Components: 90/R/B/4

	Ears m^{-2}	Yield t ha^{-1}	T.G.W. g	Grain %N
Variety:				
Klaxon	719	5.55	41.3	2.33
Triumph	713	5.38	35.2	2.27
Nitrogen rates:				
100 kg N ha^{-1}	706	5.30	37.1	2.23
140 kg N ha^{-1}	726	5.62	34.0	2.38
LSD P = 0.05	210	0.17	2.59	0.12

Table 11
Yields: 89/R/CS/337

	N fertiliser applied kg N ha^{-1}	Harvested yield t ha^{-1}	Total dry matter t ha^{-1}	N removed in crop kg N ha^{-1}
Crop:				
Barley	125	6.85[1]	12.74[2]	145[2]
Oats	125	6.73[1]	15.90[2]	175[2]
Beans	-	5.38[1]	18.36[2]	397[2]
Rape	150	-[3]	3.36[2]	101[2]
Potatoes	220	26.4[4]	5.09[5]	87[5]

[1] at 85% DM

[2] Grain and Straw

[3] Grain yield not taken

[4] Tuber yield (fresh weight)

[5] Tubers only removed

Table 12
Soil and Crop nitrogen (kg N ha^{-1}): 89-90/R/CS/337

	N applied in 1989	N removed in 1989	Soil N[1] on 22/11	Soil N[1] on 13/3	Crop N[2] on 15/3
Crop:					
Barley	125	145	102	48	16.8
Oats	125	175	69	39	14.4
Beans	-	397	129	42	17.7
Rape	150	101	161	44	14.7
Potatoes	220	87	282	41	19.8
LSD P = 0.05	-	81.1	42.7	14.1	10.6

[1] Total NO_3-N and NH_4-N to 0.9m depth.

[2] Total N content of crop

Table 13
Yield Components: 90/R/CS/337

	Ears m^{-2}	Yield $t\ ha^{-1}$	Thousand Grain Weight g	Grain %N
Previous Crop:				
Barley	645	5.04	41.3	1.81
Oats	682	5.93	40.9	1.66
Beans	706	6.11	41.4	1.72
Rape	694	5.86	42.4	1.90
Potatoes	778	6.75	41.6	1.98
LSD P = 0.05	69.1	0.65	1.68	0.18
Nitrogen Rate:				
0 kg N ha^{-1}	481	3.65	39.2	1.58
50 kg N ha^{-1}	693	5.40	40.8	1.65
75 kg N ha^{-1}	720	5.85	41.4	1.69
100 kg N ha^{-1}	754	6.63	42.0	1.87
125 kg N ha^{-1}	778	6.88	42.8	2.00
150 kg N ha^{-1}	780	7.21	42.9	2.11
LSD P = 0.05	70.9	0.24	0.87	0.10

Fig. 1. The pattern of dry matter accumulation (88/R/B/11). Average of all nitrogen treatments.

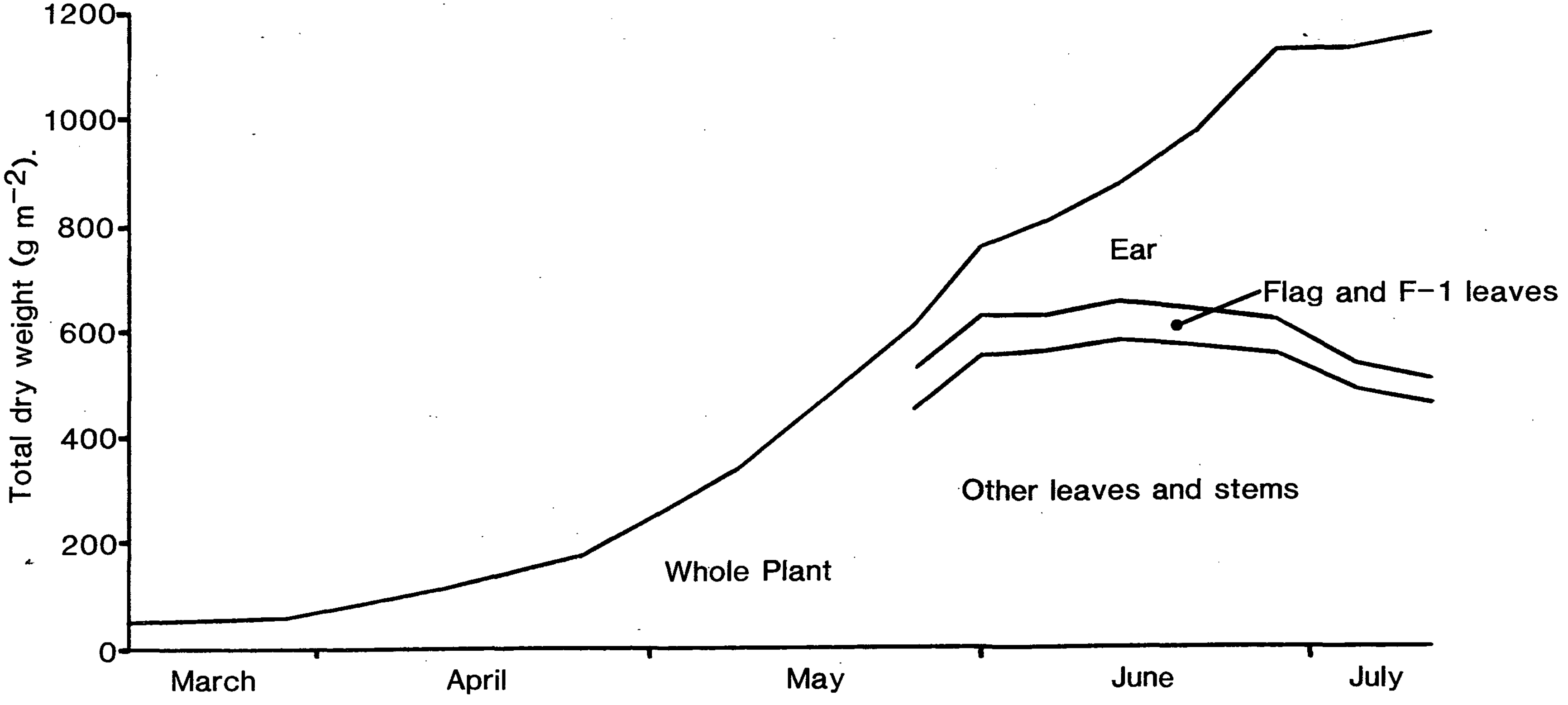


Fig. 2. The pattern of dry matter accumulation (89/R/B/6. Average of all nitrogen treatments.

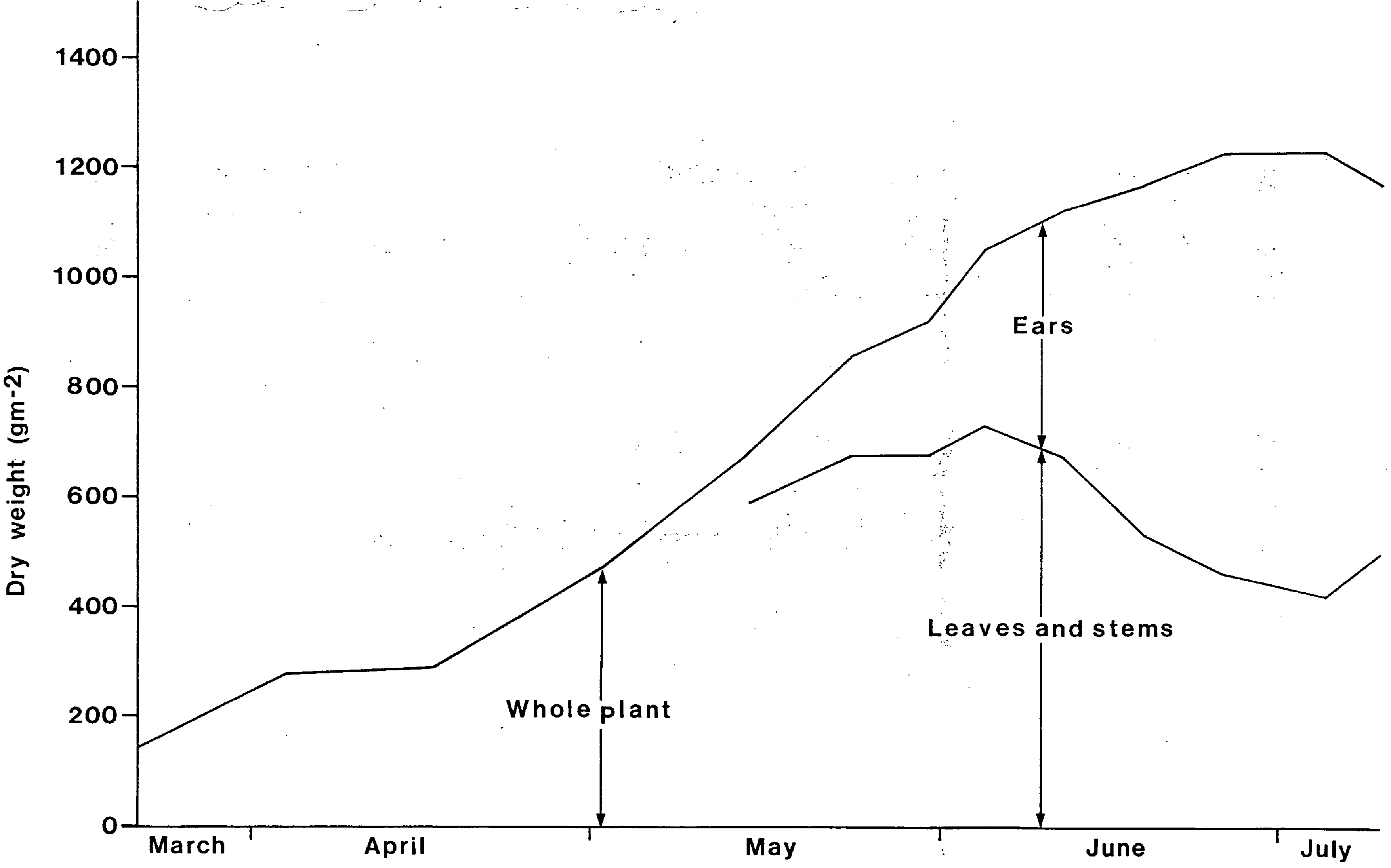


Fig. 3. The pattern of growth and decline of the Green Area Index (88/R/B/11).

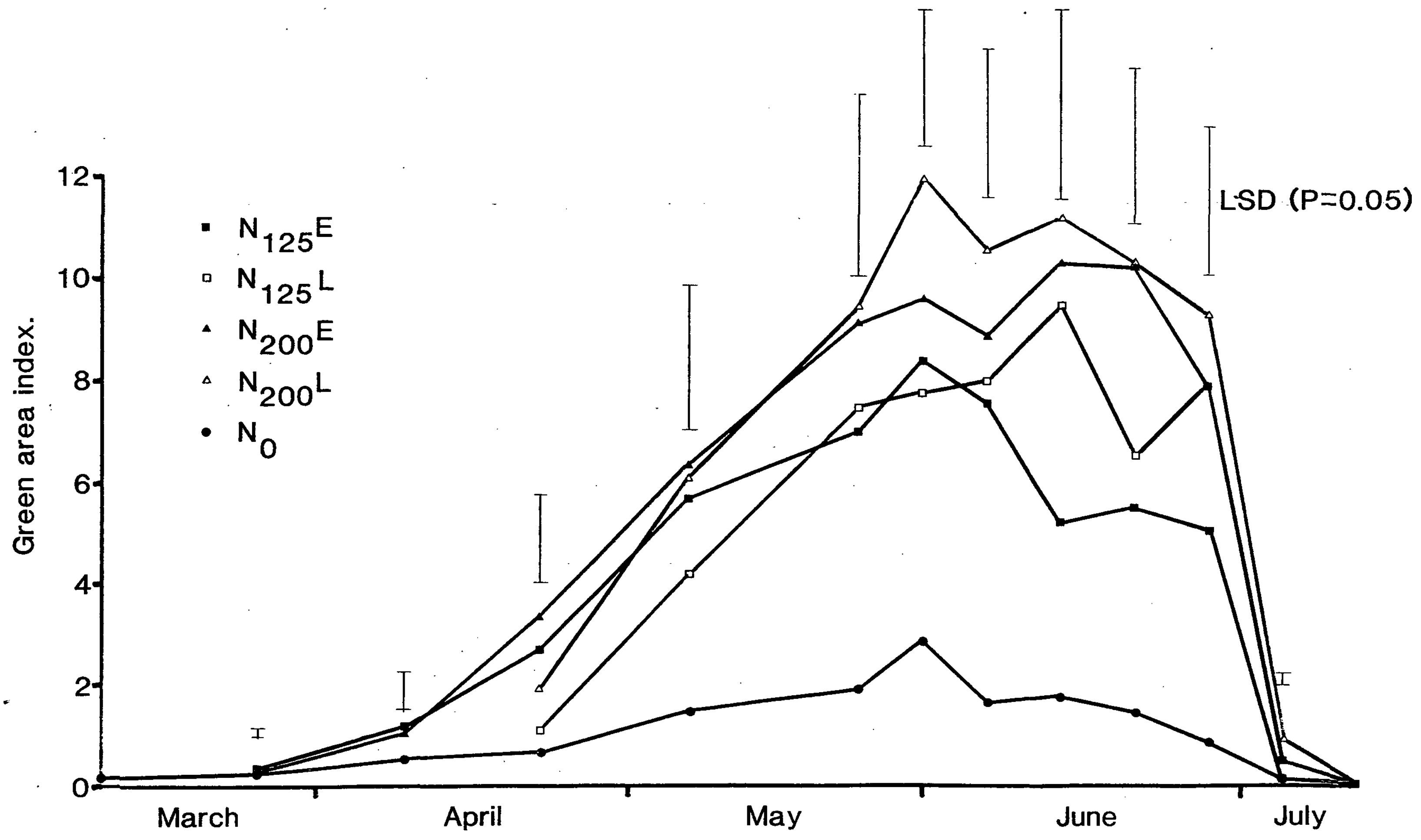


Fig. 4. The pattern of Green Area Index in 1988 and 1989.

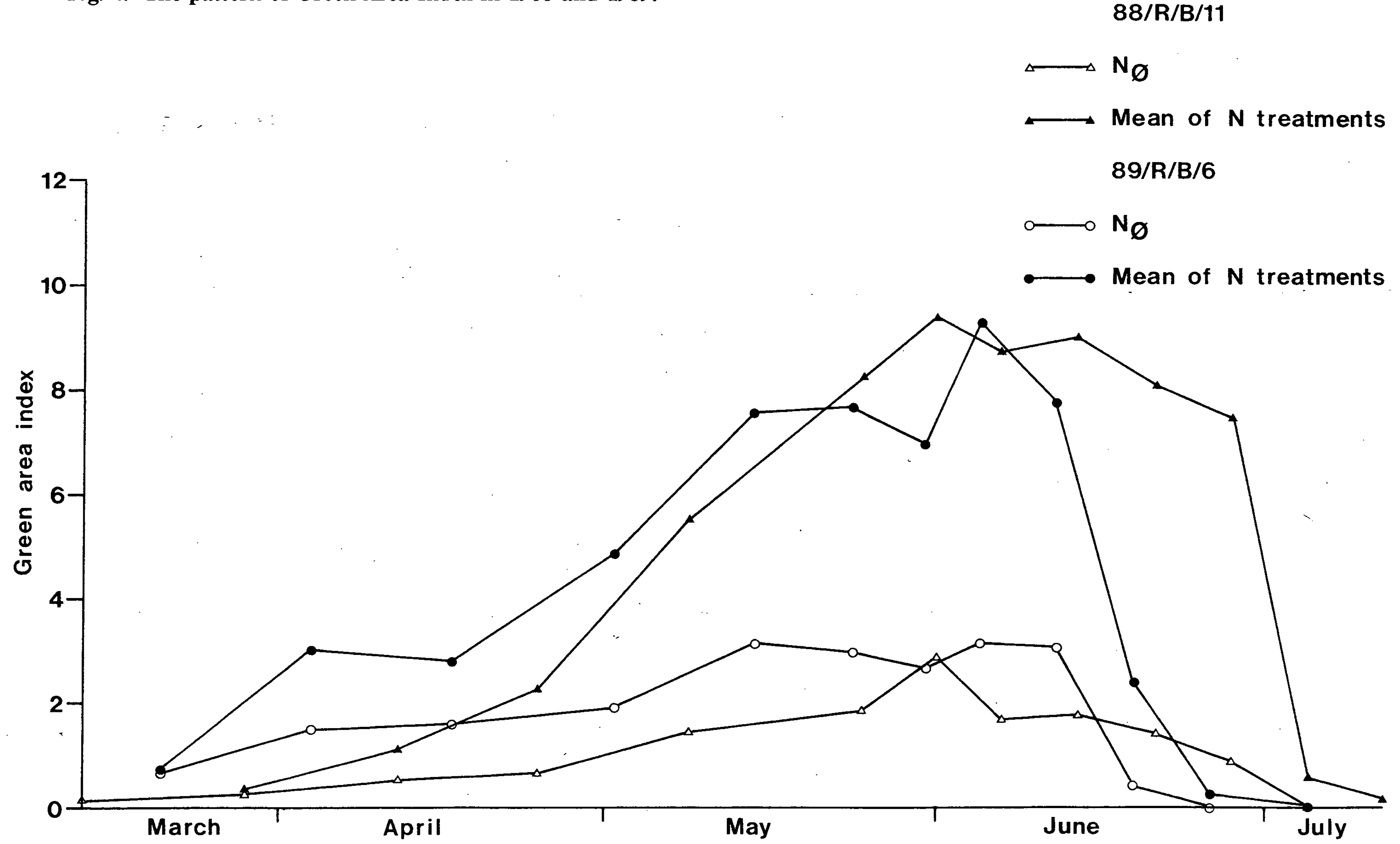


Fig. 5. The pattern of changes in the stem sap nitrate-N concentration (88/R/B/1).

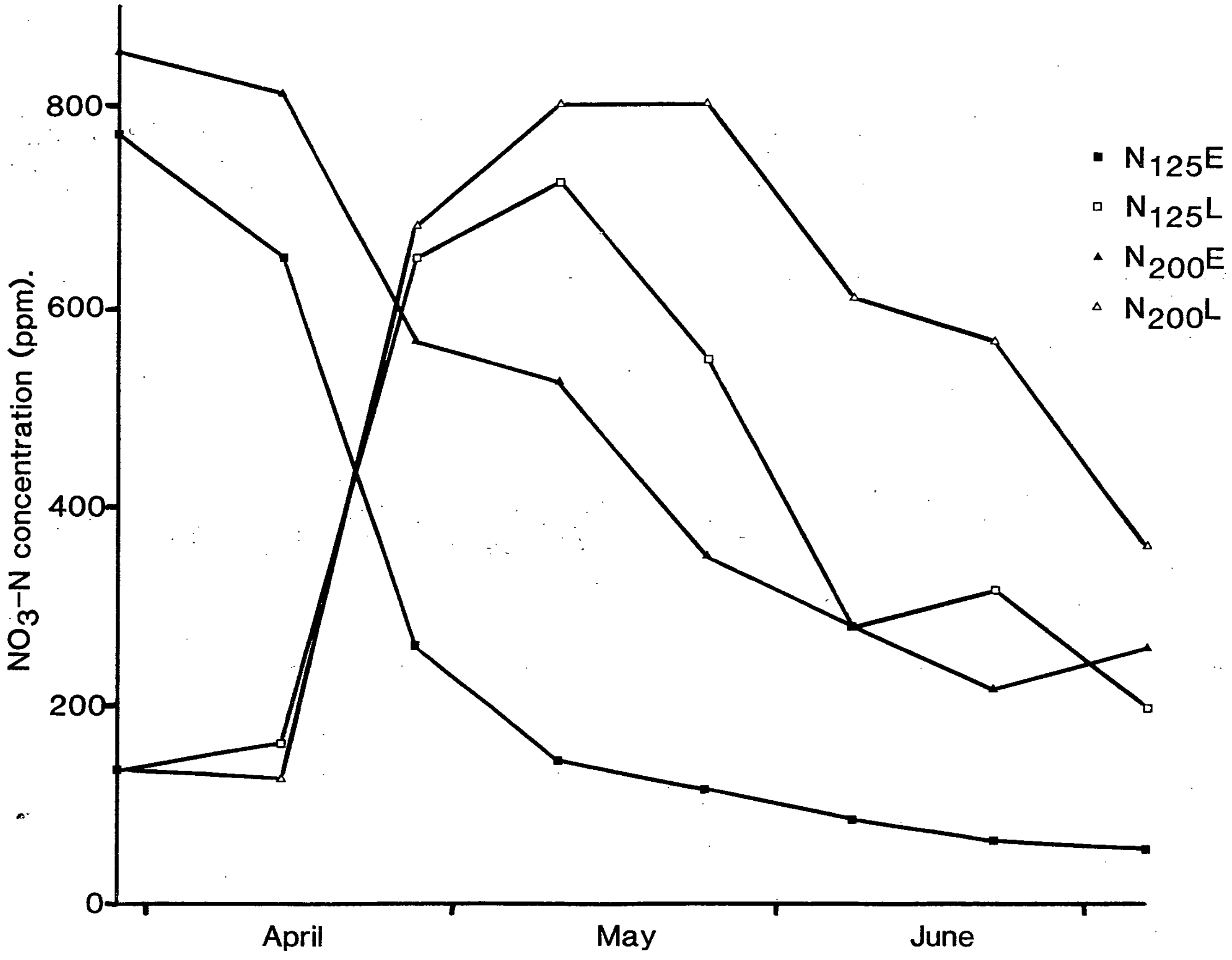


Fig. 6. The pattern of stem sap nitrate-N concentration in 1988 and 1989.

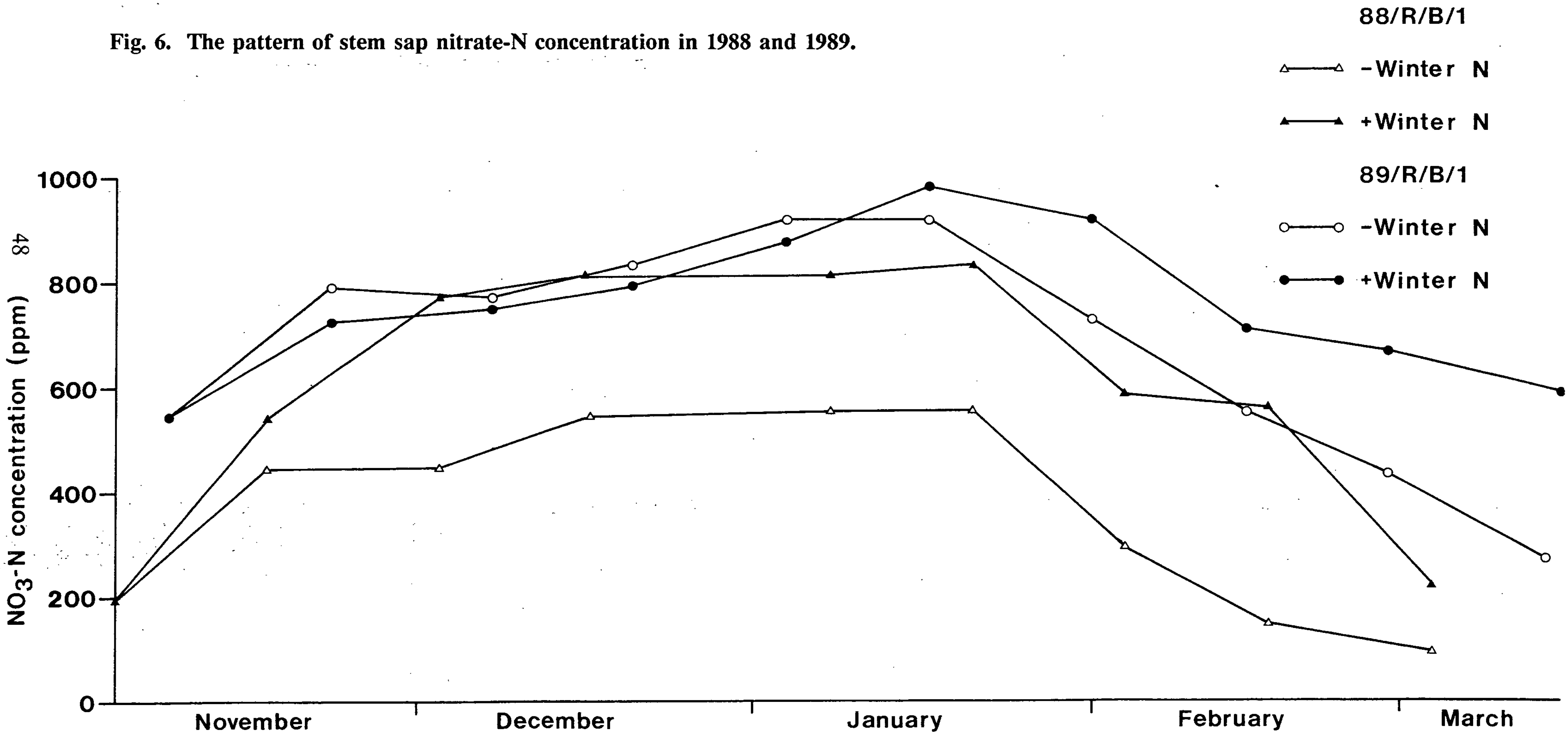


Fig. 7. The pattern of nitrogen accumulation (88/R/B/11). Average of all nitrogen treatments.

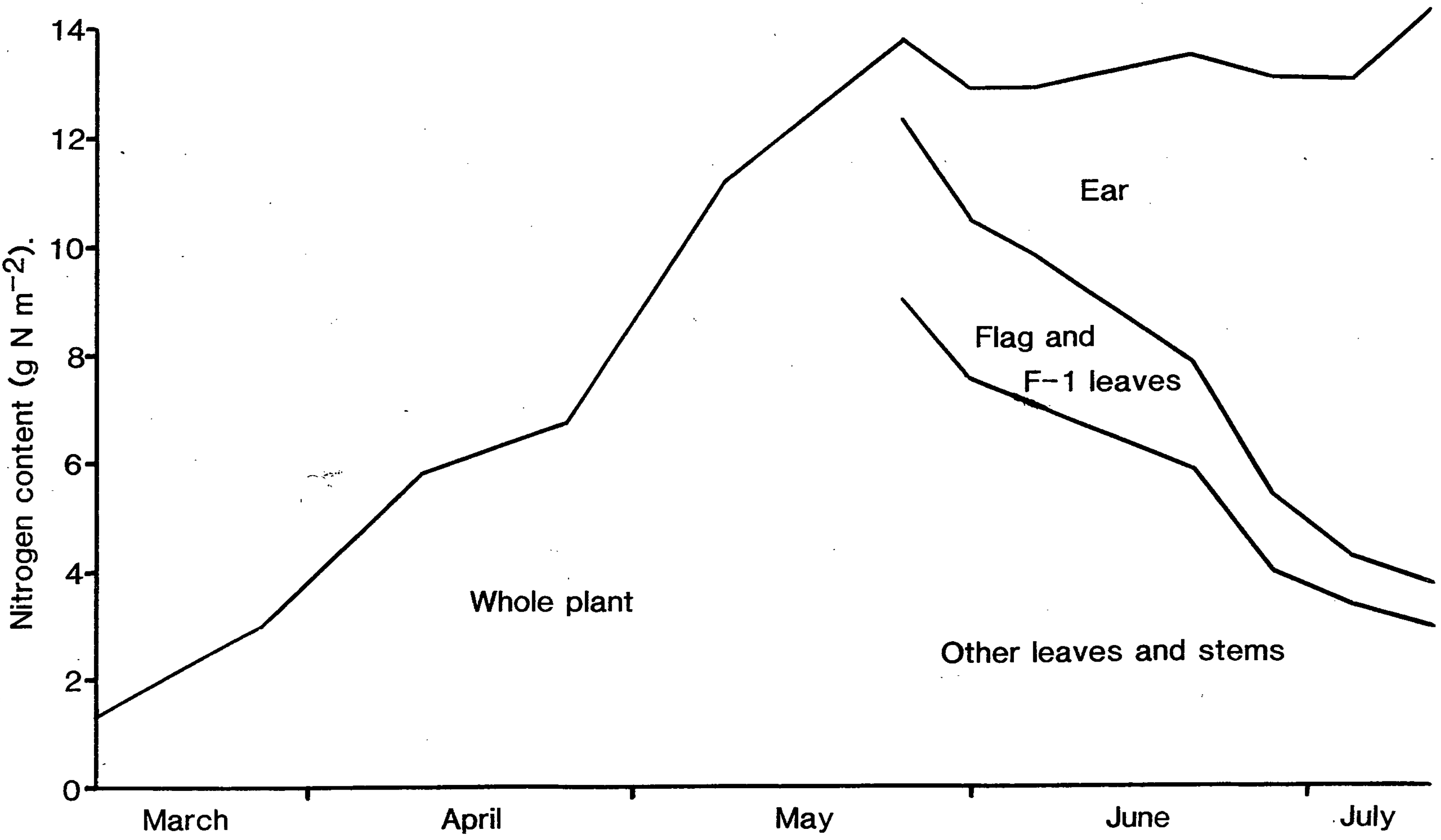


Fig. 8. The pattern of nitrogen accumulation (89/R/B/6). Average of all nitrogen treatments.

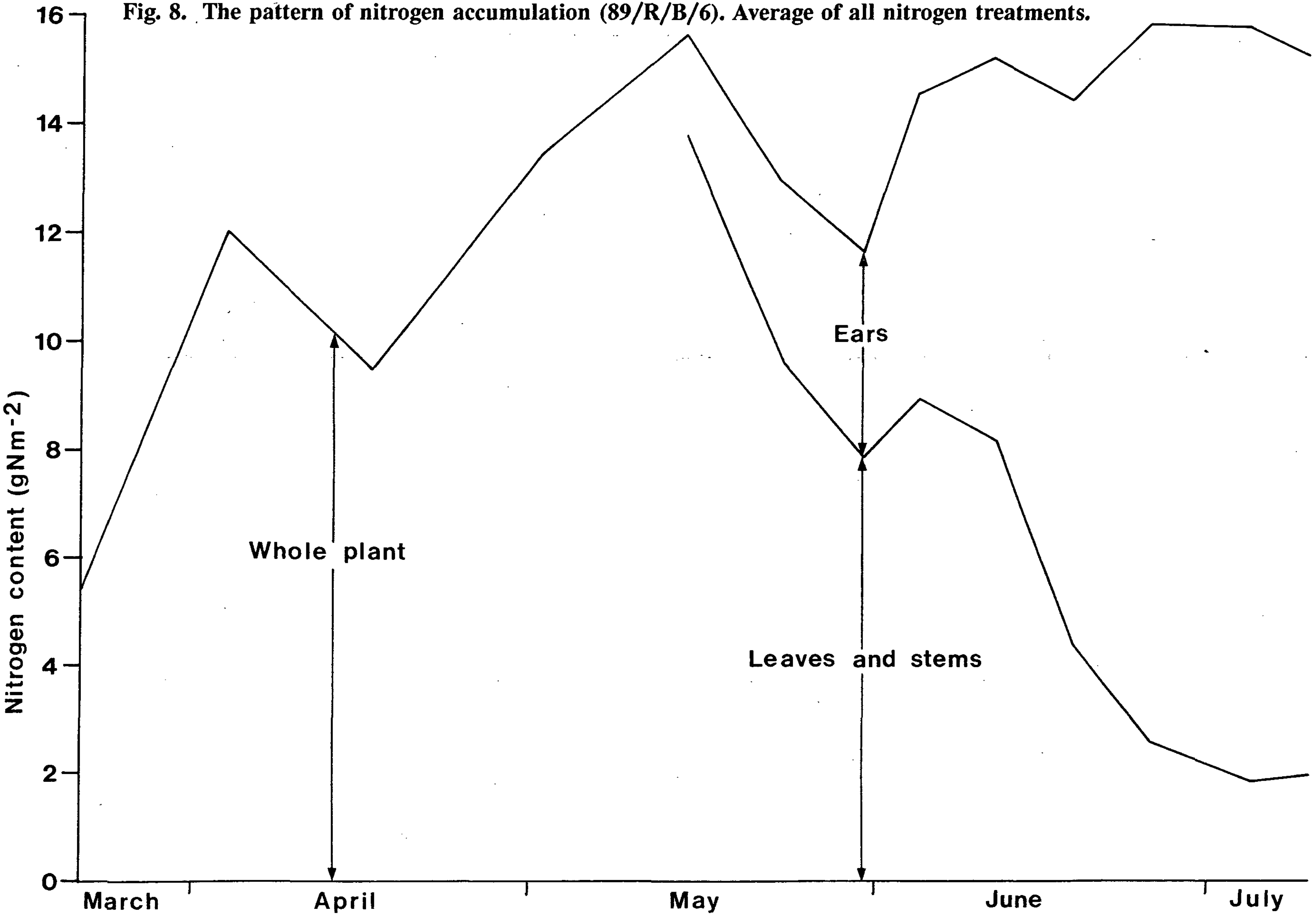


Fig. 9. The pattern of changes in ear %N of winter and spring barley

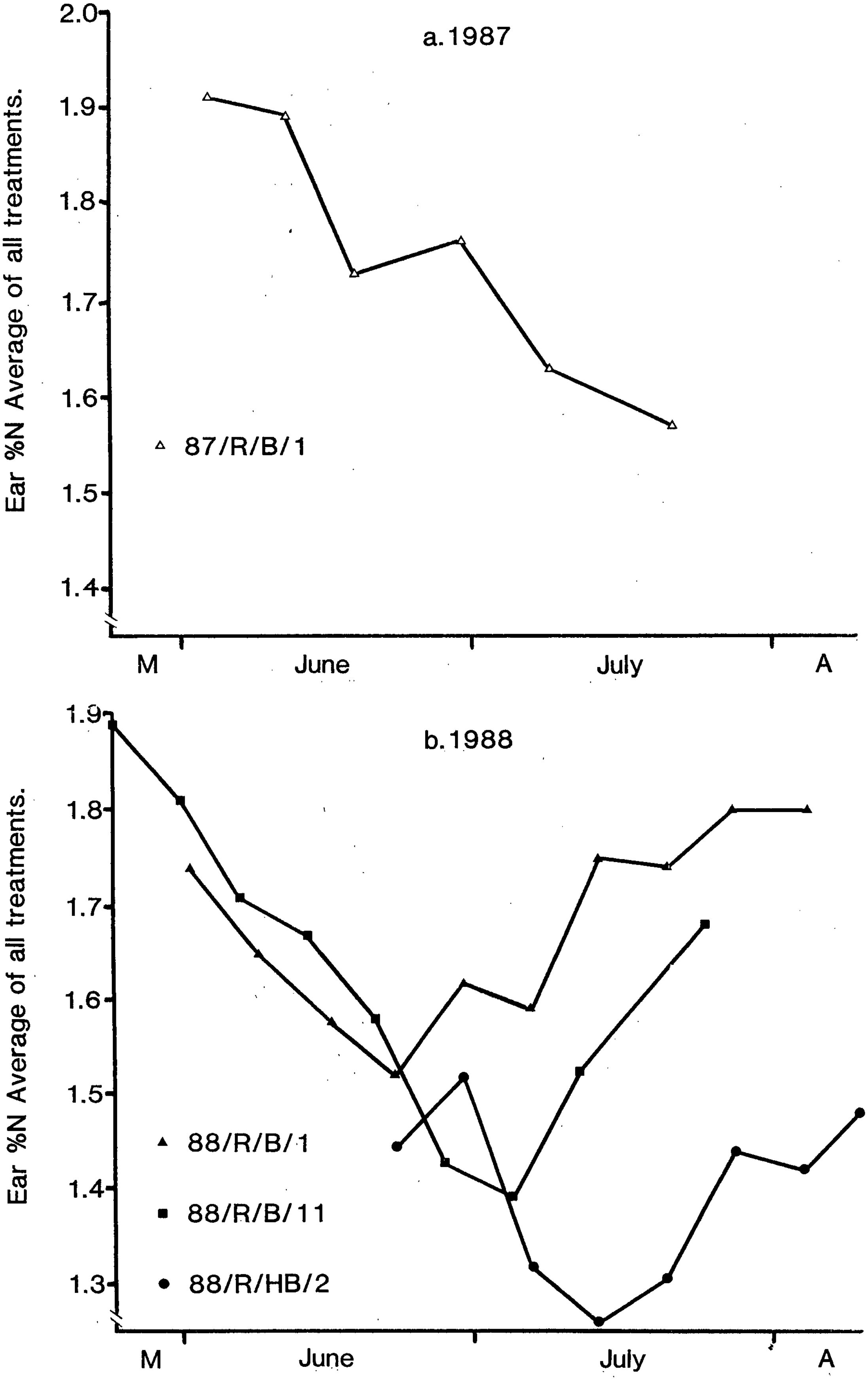
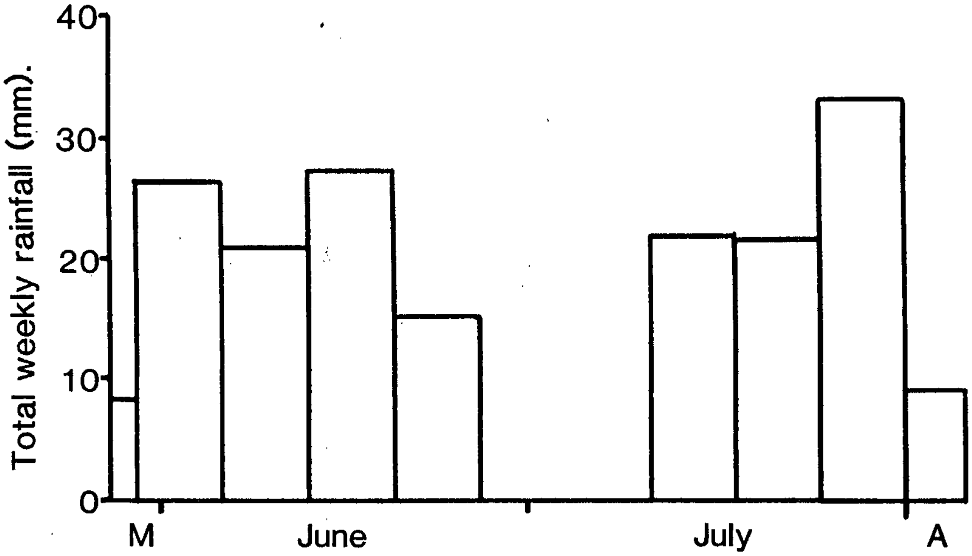


Fig. 10. Total weekly rainfall during grainfilling period. Rothamsted 1987 and 1988.

a. 1987



b. 1988

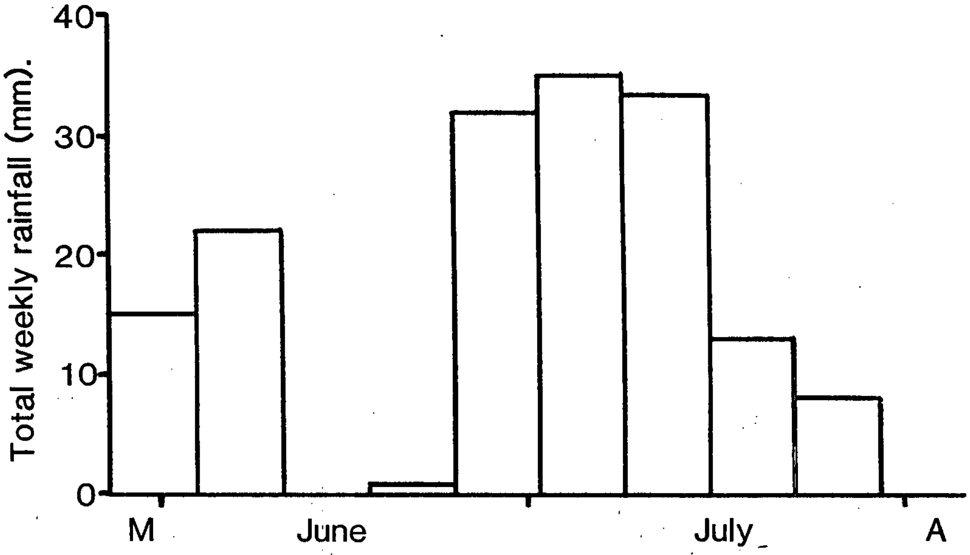


Fig. 11. The pattern of changes in ear %N (87-89/R/B/1.

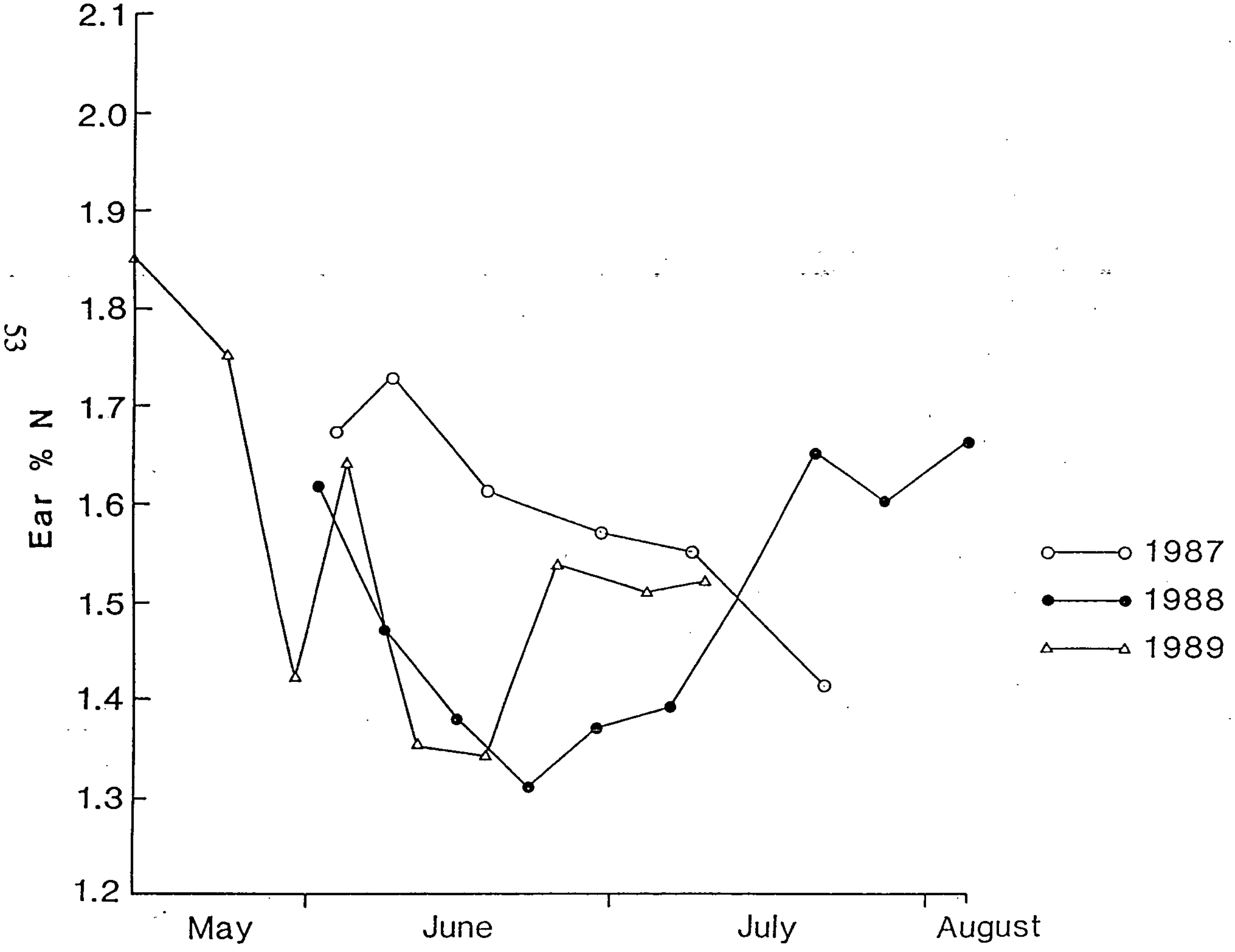


Fig. 12. The pattern of dry matter accumulation (89/R/B/7).

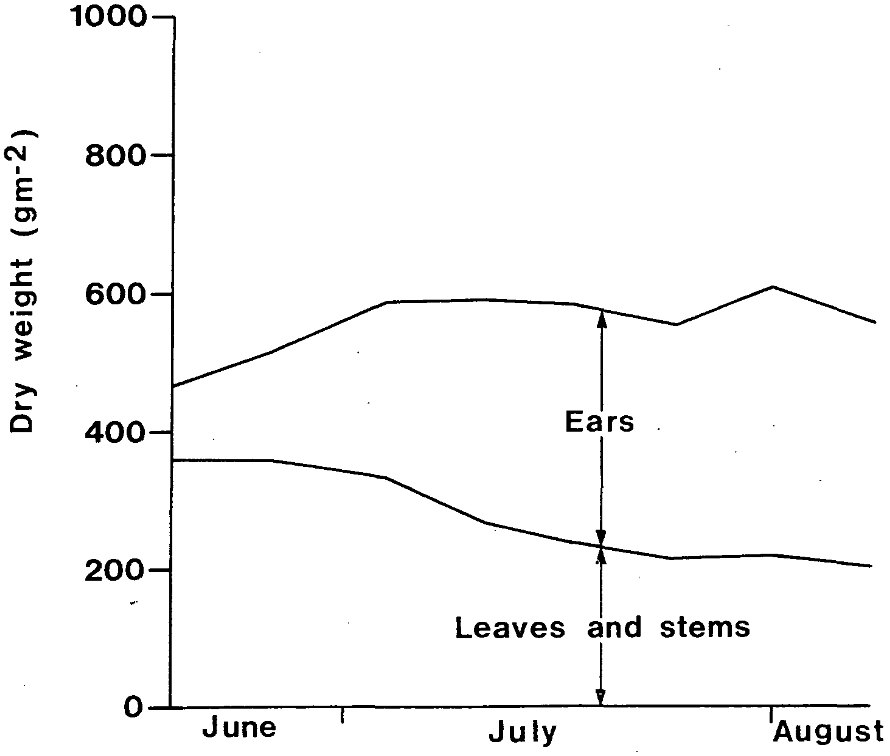


Fig. 13. The pattern of changes in ear and grain %N in spring barley.

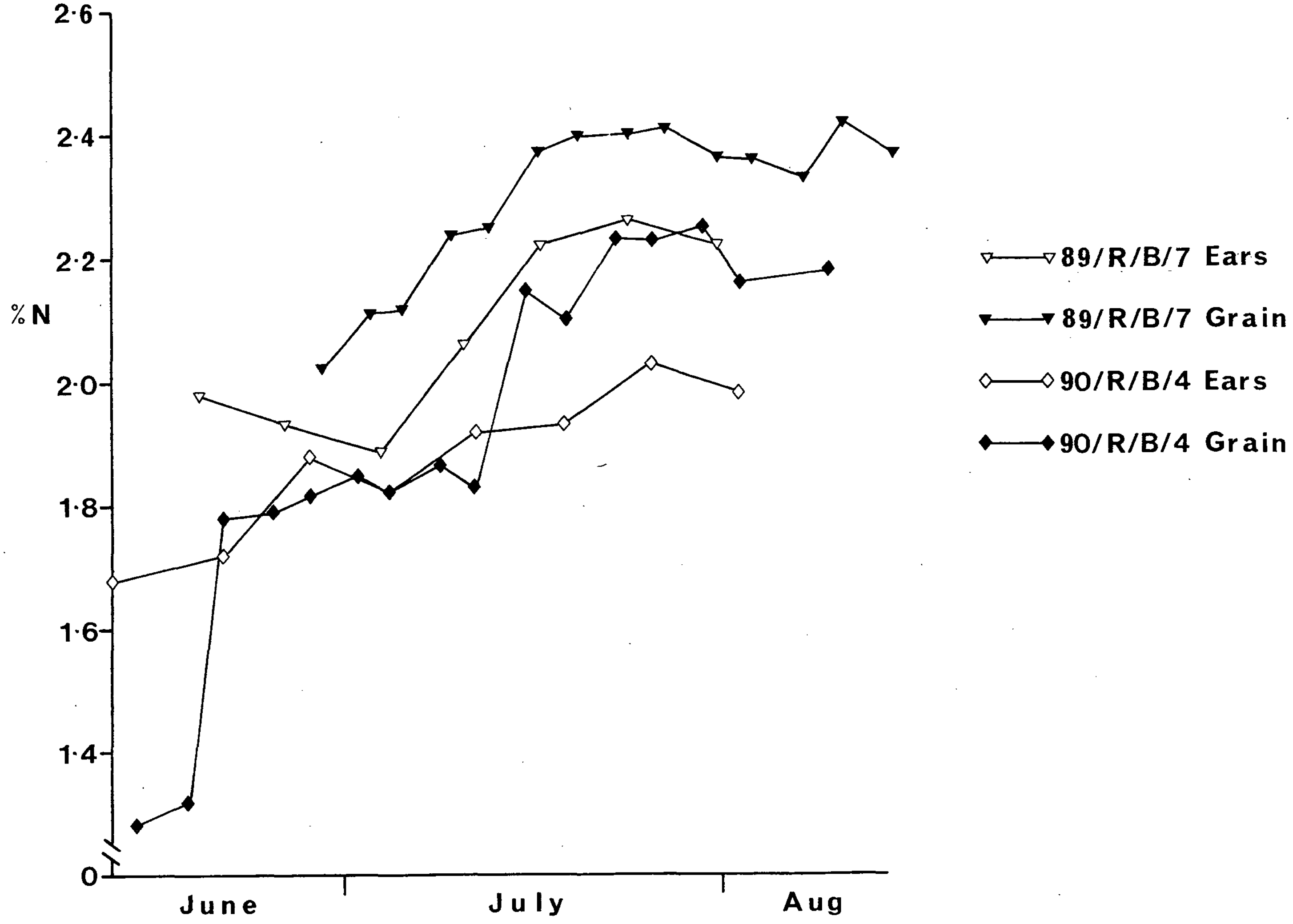


Fig. 14. The pattern of dry matter accumulation (90/R/CS/337).

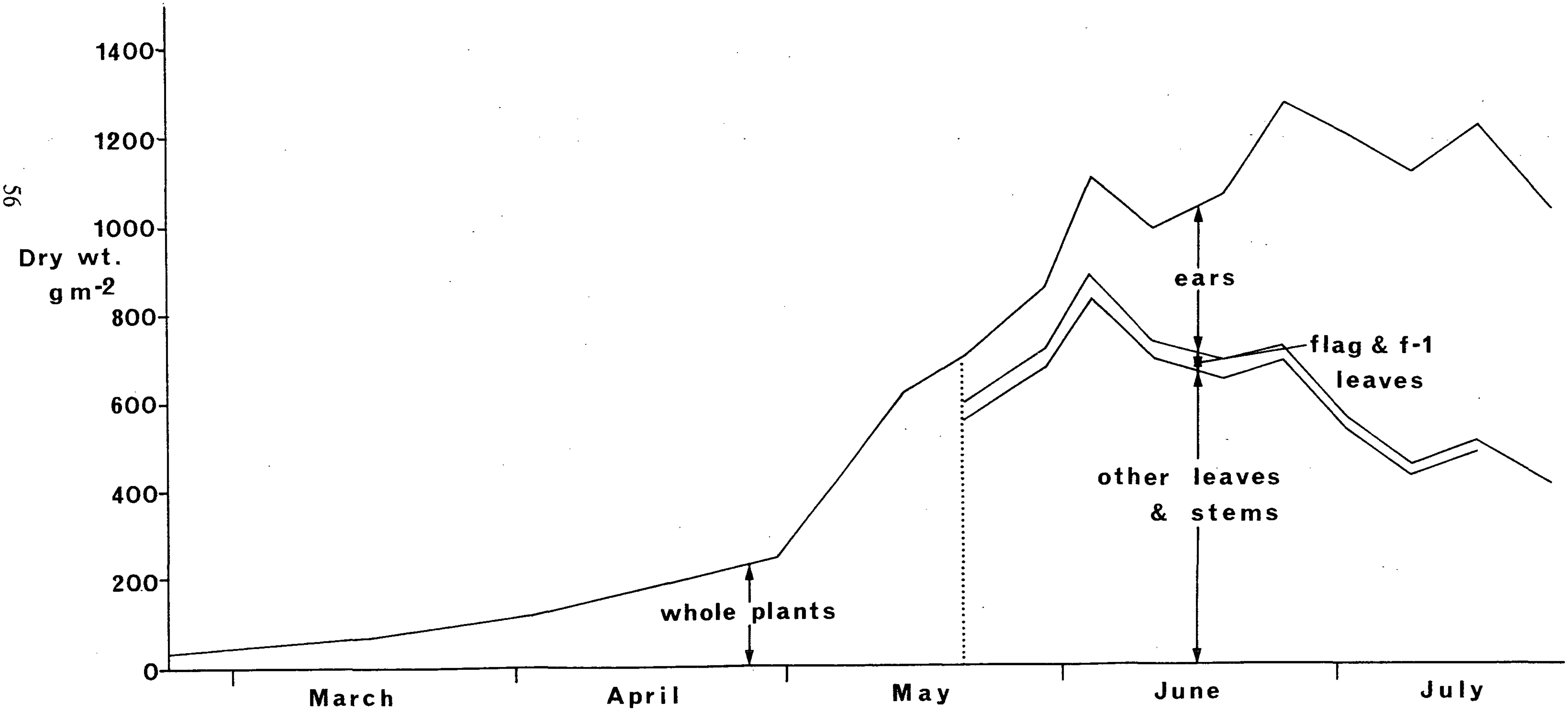


Fig. 15. The effect of previous crop on dry matter accumulation (90/R/CS/337).

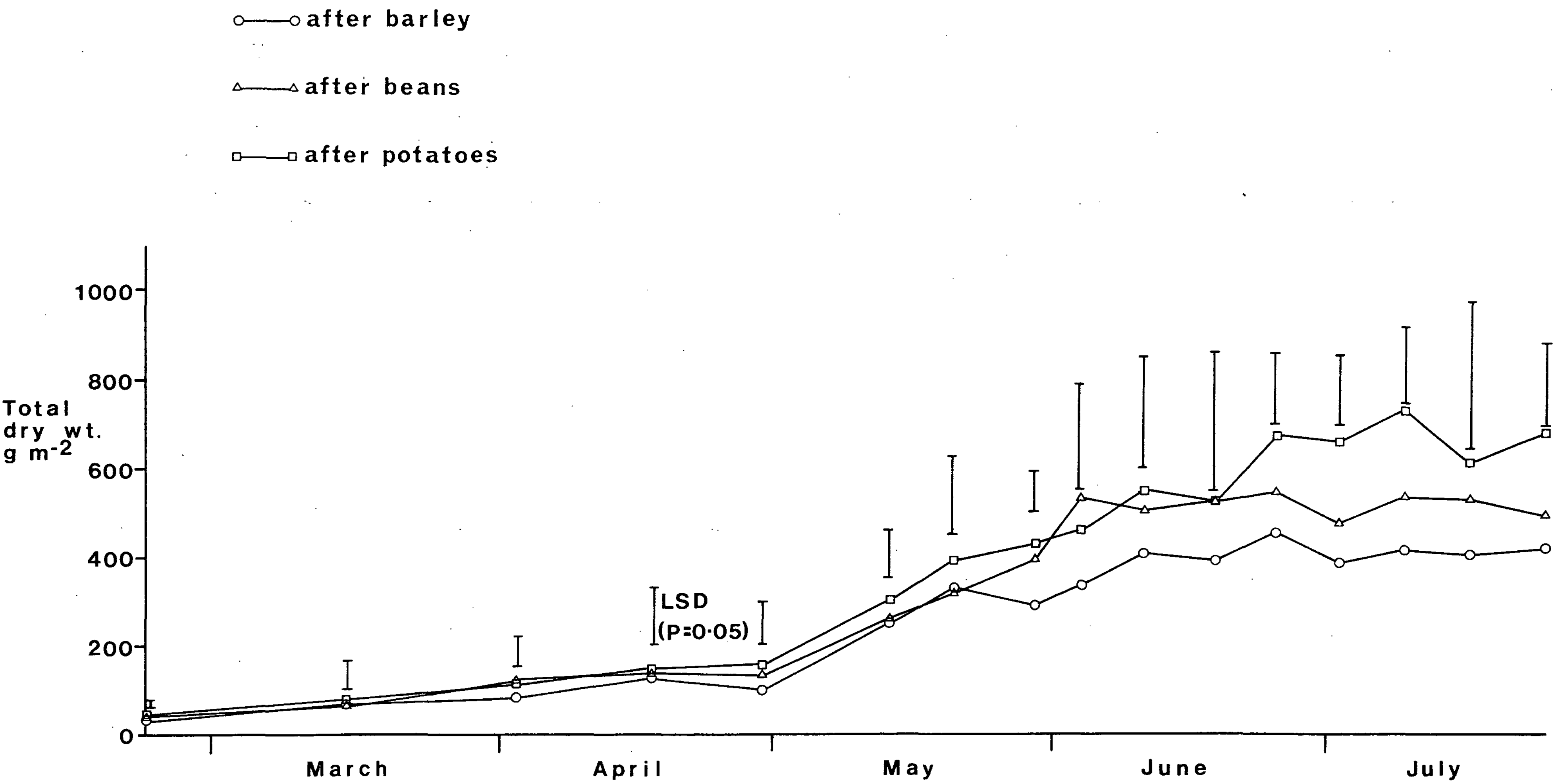


Fig. 16. The pattern of changes in stem sap nitrate-N concentration and soil mineral N content (90/R/CS/337).

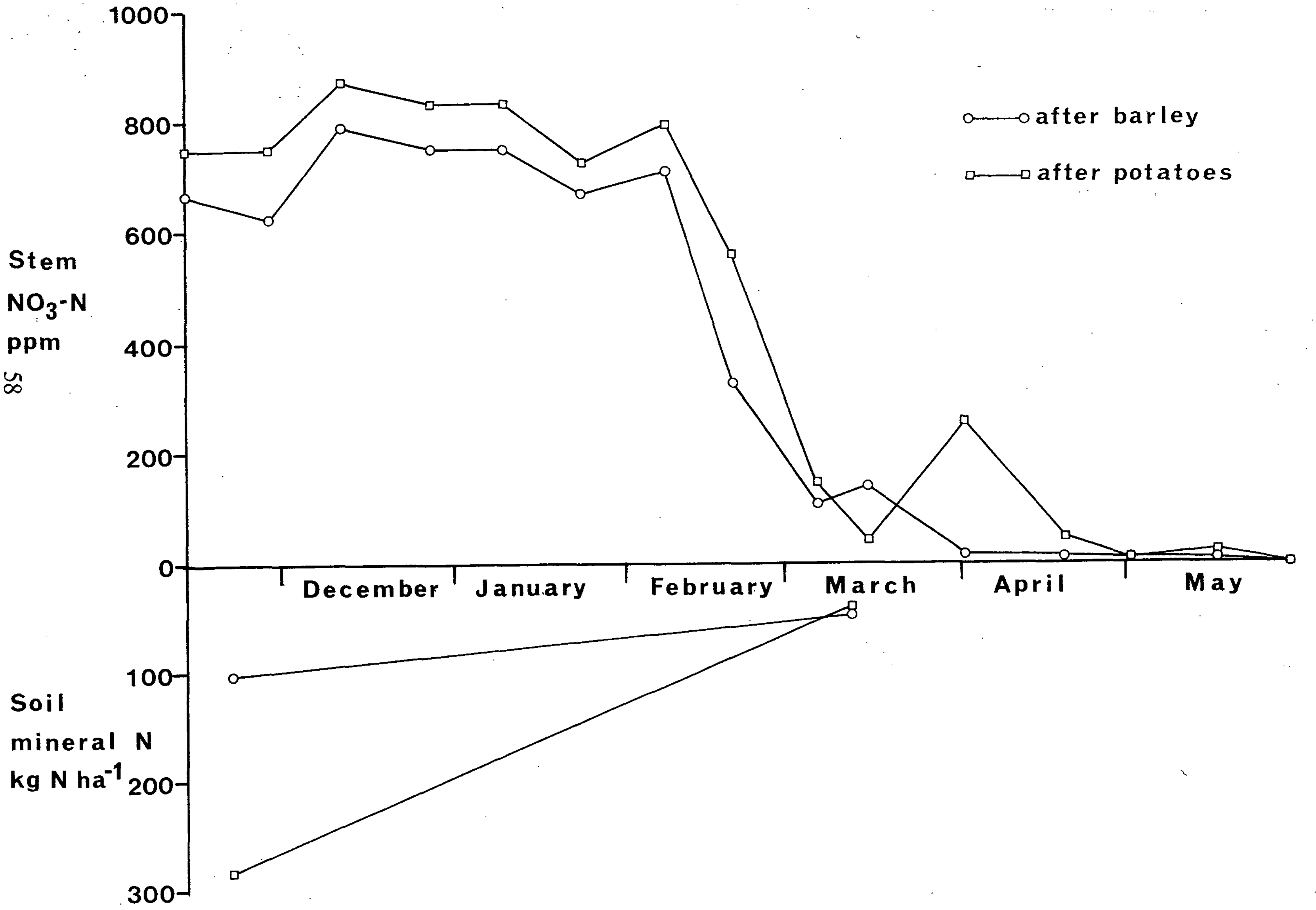


Fig. 17. The pattern of nitrogen accumulation (90/R/CS/337).

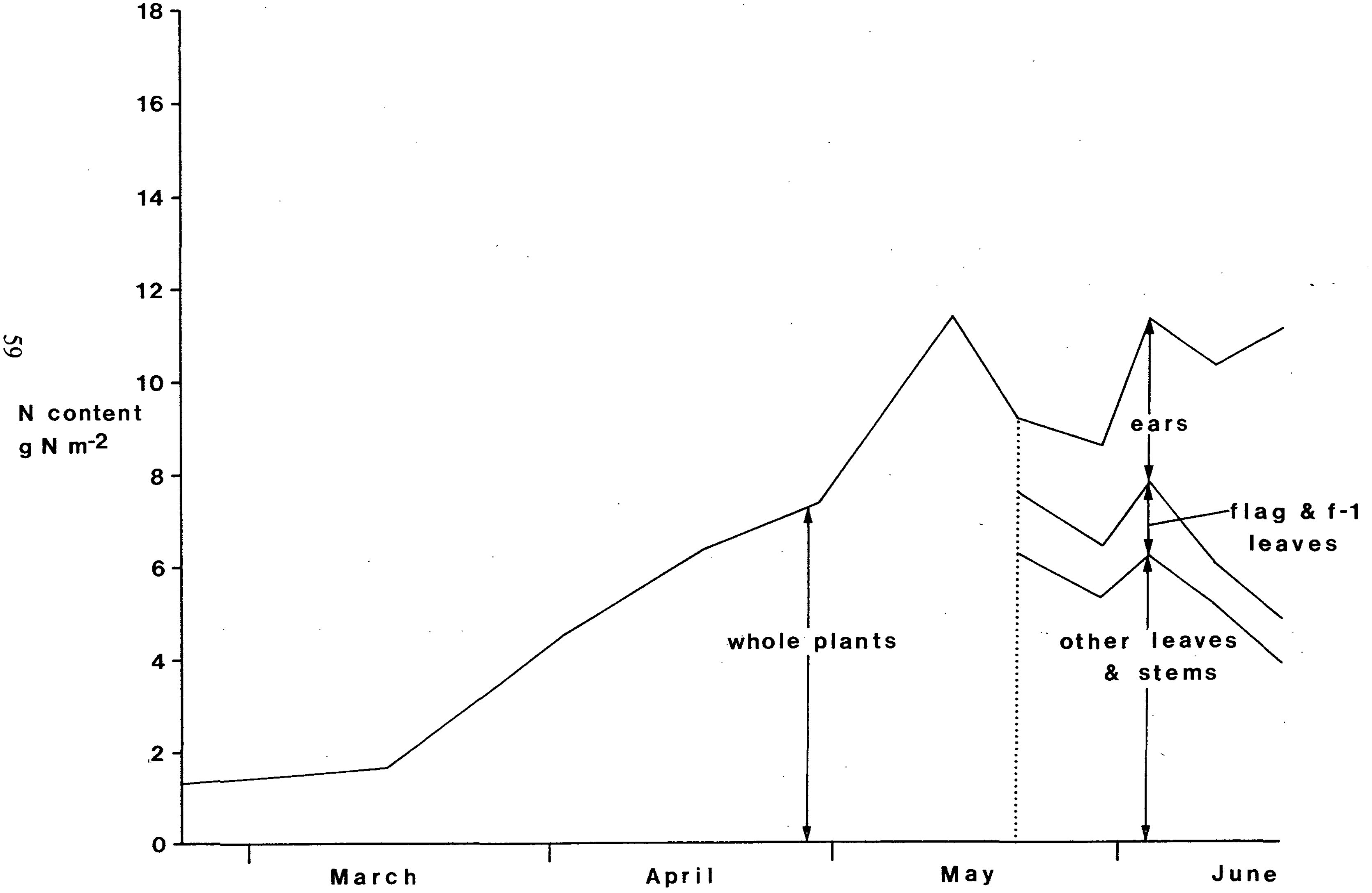


Fig. 18. The effect of previous crop on nitrogen accumulation (90/R/CS/337).

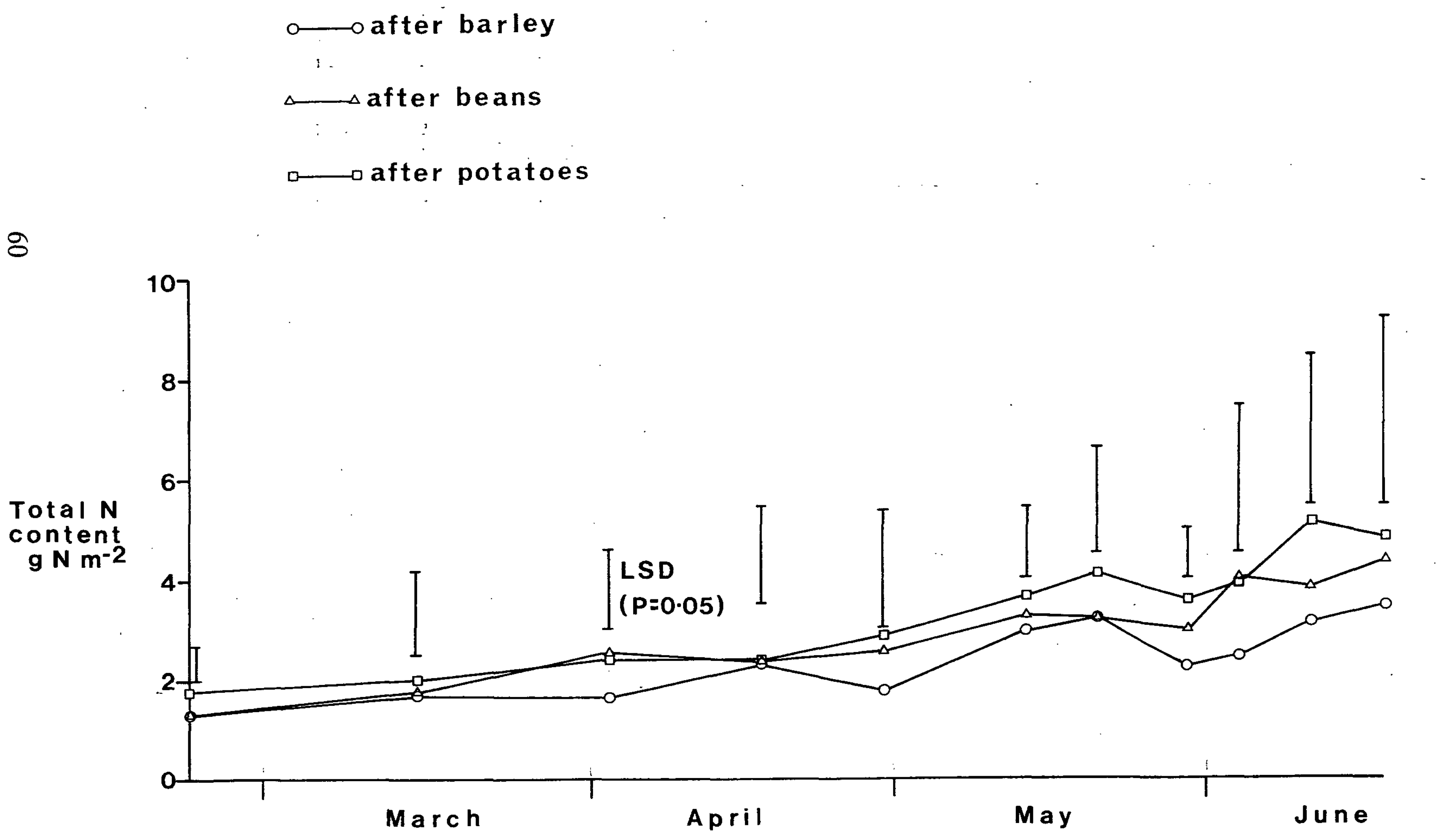


Fig. 19. The effect of previous crop on changes in ear %N (90/R/CS/337).

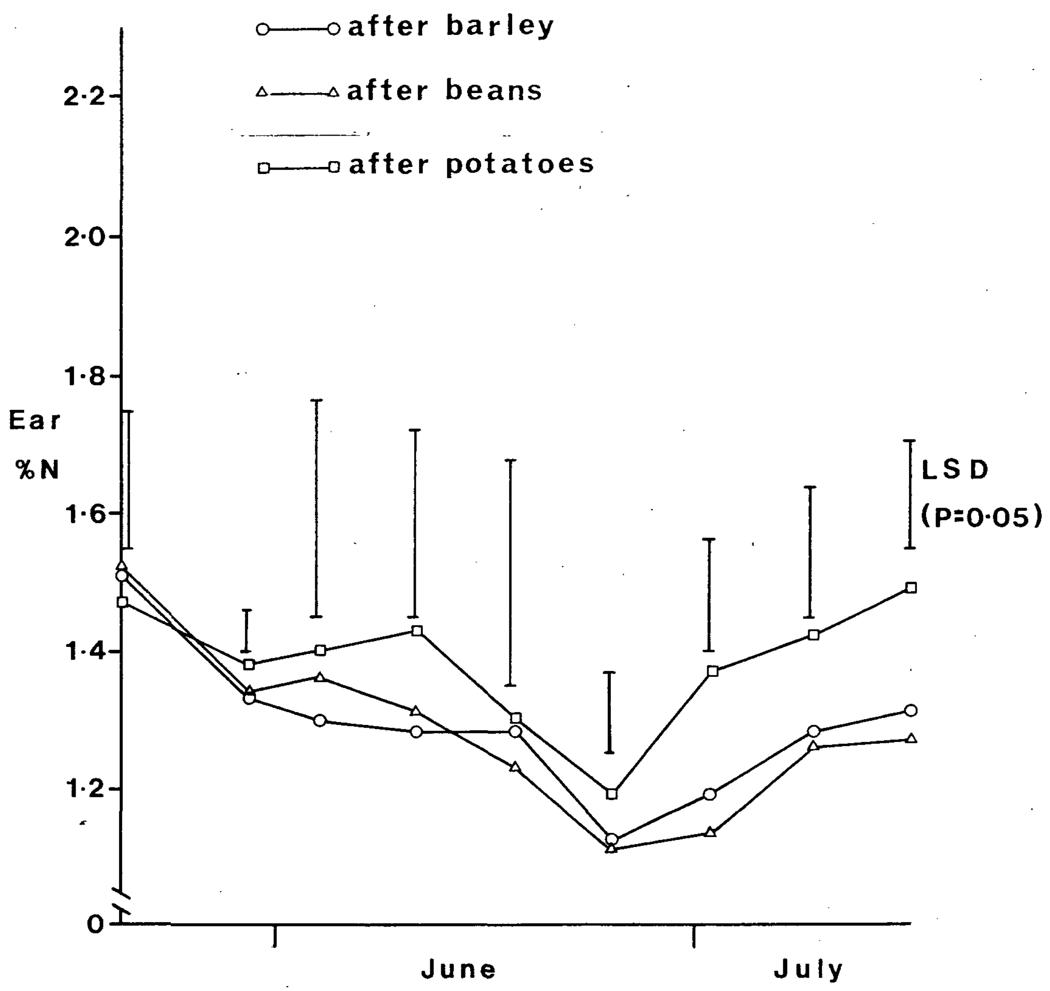


Fig. 20. The effect of previous crop and nitrogen rate on grain yield (90/R/CS/337).

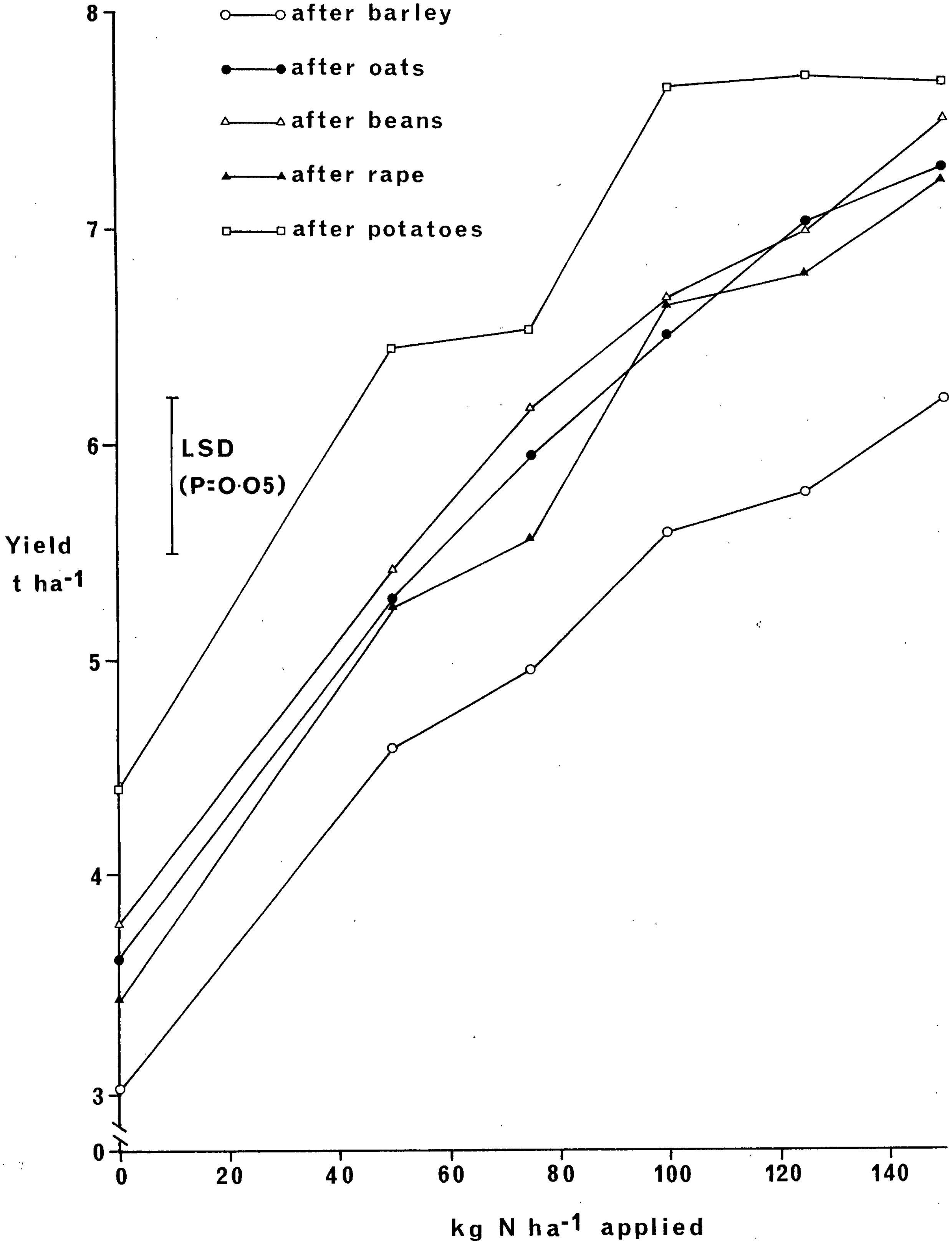


Fig. 21. The effect of previous crop and nitrogen rate on grain %N (90/R/CS/337).

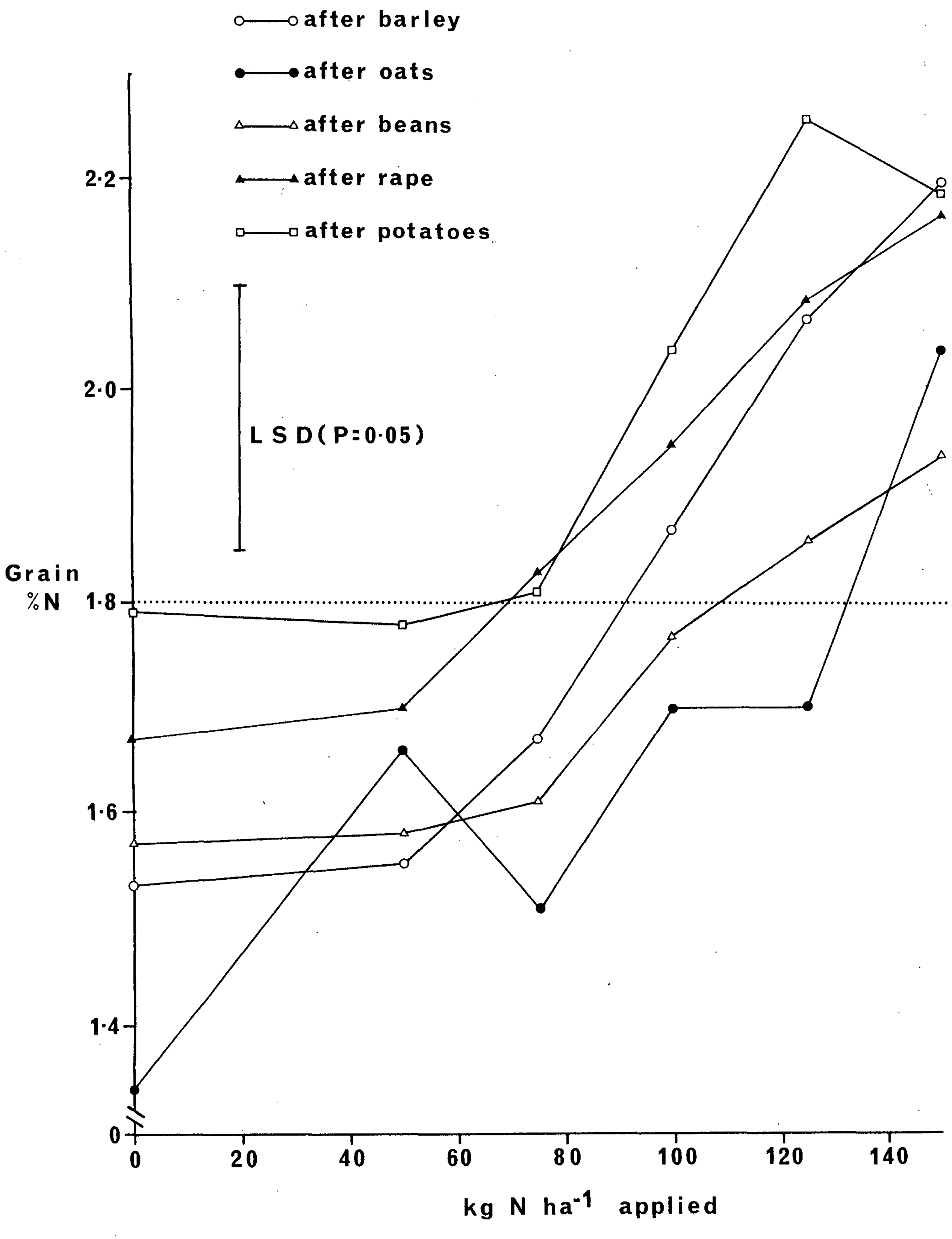


Fig. 22. The effect of previous crop and nitrogen on total N content at harvest (90/R/CS/337).

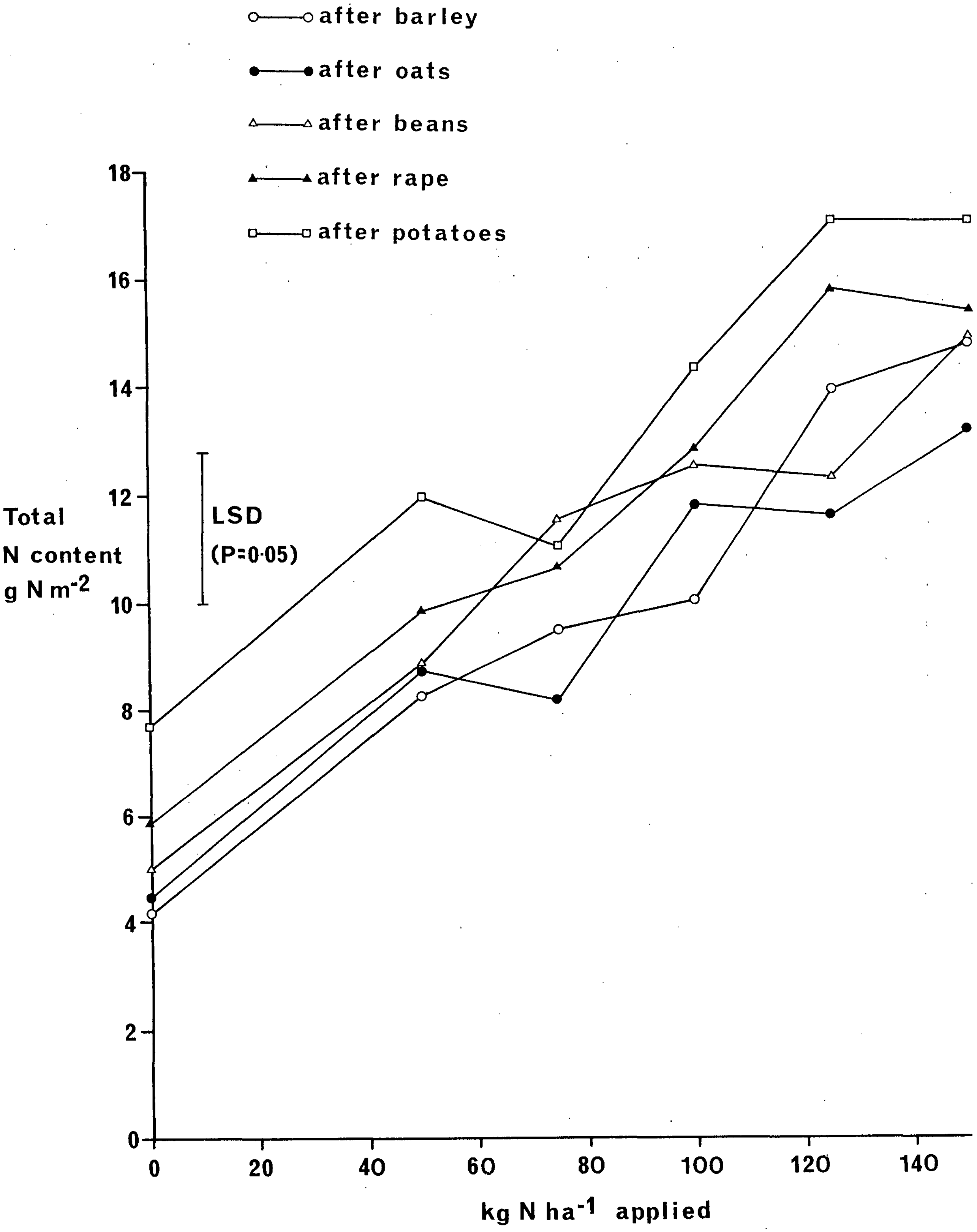


Fig. 23. The effect of previous crop and nitrogen on margin over N cost (90/R/CS/337).