ENGLISH NATURE

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No. 87 - English Nature Research Reports

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Final Report (Contract F78-12-04)

Nominated Officer: Dr R G Jefferson

Further copies of this report are available from the nominated officer
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ISSN 0967-876X

THE EFFECT OF INORGANIC FERTILIZERS ON BOTANICAL DIVERSITY AND AGRICULTURAL PRODUCTION ON THE SOMERSET LEVELS

Eighth and final Report to the Management Group of the MAFF/NCC/DOE
Tadham Project

- January 1994 -

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SUMMARY

Results are presented for the eight years, 1986 - 1993, of the Tadham Project which was conducted on species-rich hay meadows on the Somerset Levels.

The aims of the Project were to establish:

i) a 'safe' limit to the amount of fertiliser that could be applied to the species-rich hay meadows of the Somerset Levels which would allow their floristic diversity to be maintained,

ii) the agricultural output achievable within any such safe limit,

iii) the agricultural output foregone by adhering to a 'safe' fertiliser input;

and upon the cessation of fertilizer use to establish

iv) the speed and direction of botanical change,

v) impact of disturbance, gap creation and reintroducing seed of lost species on speed and direction of botanical change,

vi) impact of changing the cutting date on botanical recovery.

The Project was sited on 21 hectares of hay meadows on undrained peat soil on Tadham Moor within a Site of Special Scientific Interest and latterly also within the Somerset Levels and Moors Environmentally Sensitive Area. Fieldwork began in April 1986 and continued each year to 1993.

A "large-scale" experiment was established in 1986 involving five nitrogen treatments consisting of a control(N0) and either 25, 50, 100 or 200 kg N applied per ha per year. On plots receiving fertiliser N, the amounts of phosphorus (P) and potassium (K) removed in the hay crop were replaced. In 1990 the plots were split, with one half continuing to receive fertilizer inputs, as previously, until April 1993 (N+), the other half ceased to receive any more fertilizer inputs (N-). All plots were cut for hay on or after 1 July each year and the aftermath growth was grazed with beef cattle into the autumn. Agricultural output was measured in terms of hay yield, animal live weight production per ha and utilised metabolizable energy output (UME).

A "small-scale" experiment was also established in 1986 to investigate the impact on botanical composition of a wider range of fertiliser treatments than those used in the large experiment. Treatments included either nil or high inputs of P, high inputs of K and different timing for fertilizer N input. All fertilizer inputs to this experiment ceased after 1989 in order to investigate the residual effects of the treatments on changes in botanical composition. All plots were cut at the same time as the hay cut in the large-scale experiment and again in the late summer and autumn. Yields of herbage and of N,P and K were measured at each cut each year.

The influence of cutting date and previous fertilizer treatment on the productivity and botanical composition of the meadows was investigated in a small plot experiment in 1991 and 1992. An objective being to establish whether changes in cutting date could provide a way to accelerate recovery of species-richness after the cessation of fertilizer input. Cutting dates were either late May, early-mid July, early August or early September. Each plot was cut once and the regrowth grazed.

The impact of disturbance and gap creation on the recovery of species richness, and the efficacy of re-introducing 'lost' species by sowing their seed, were investigated in a small plot experiment set up on a N200- plot in 1990. The treatments included either autumn rotovation, spring rotovation, or gap creation in the spring using a herbicide and an undisturbed control, all with or without seed introduction. The impact of cessation of grazing disturbance on the recovery of botanical diversity was investigated between 1990 and 1993 using grazing exclosures erected within the N200- plots.

In May each year the botanical composition of the large-scale plots and the grazing exclosures were surveyed by staff from the Institute of Terrestrial Ecology (ITE). Staff from IGER surveyed the small-scale experimental plots at the same time. In each plot estimates of percentage cover for the species present were recorded. In the large-scale experiment the number of species present per plot and in flower per plot were recorded in a sample of 24 quadrats ($1m^2$) during the period 1986 - 1989 and in 16 quadrats ($1m^2$) for the 1990 - 1993 period.

MAFF and DoE provided additional funding from 1987 to 1989 for changes in mineral N to be monitored in the soils following different applications of fertiliser N. Soil nitrate and ammonium concentrations were measured regularly, and between October and March in 1988/89 and 1989/90 rates of microbial degradation of nitrate (denitrification) were also measured and leaching losses calculated.

Throughout the course of the project rainfall and temperature measurements were taken within the experimental area. Changes in the level of the water table in each treatment plot were monitored by staff from the Agricultural Development and Advisory Service (ADAS).

The project has shown that there is no 'safe' amount of fertilizer nitrogen. The species-richness of the hay meadows was significantly reduced by even the lowest fertiliser input, of 25 kg N per ha per annum, within six years. Fertilizer inputs particularly of phosphorus caused increased dominance by grasses and a reduction in the abundance of most of the distinctive hay meadow species. Under high fertilizer input, the species-rich wet hay meadow communities, MG4, MG5 and MG8 of the National Vegetation Classification were replaced by more species-poor types e.g. MG6.

The project has clearly established that the species-rich hay meadows of the Somerset Levels are capable of significant response to inputs of fertiliser, particularly P. The amount of agricultural output from these meadows could readily match that obtained from a wide range of permanent pastures in the UK. The response to fertilizer N was predictable from existing N response models providing that P and K availability were not limiting. Financial margins, calculated either in terms of hay and beef production or as dairy production, could have been improved by £86 per ha or £272 per ha in 1991, respectively, with inputs of 200 kg N per ha plus adequate P and K compared with zero inorganic fertilizer use. Environmentally Sensitive Area (ESA) or Site of Special Scientific Interest (SSSI) compensatory payments for not applying inorganic fertilizers would have been adequate under these circumstances.

The project also established that the peat soils of the Somerset Levels are particularly susceptible to N leaching and in order to avoid this risk annual fertiliser inputs should be kept below 100 kg N per ha.

Upon cessation of fertilizer use there was clearly considerable "inertia" to change in the botanical composition of the meadows; three years after inorganic fertilizer input ceased there had not been a significant recovery of diversity under the traditional late hay cutting and grazing management. This inertia was associated with the persistence of enhanced residues of plant available nutrients, particularly phosphorus.

Changing cutting date caused no significant increase in species diversity over a three year period within previously fertilized meadows. Domination of the vegetation by competitive grasses, such as *Holcus lanatus*, was either maintained or enhanced by early cutting, in May. Grasses contributed the bulk of the seed rain with later cutting. On previously unfertilized species-rich meadows occasional delaying of the cutting date until August or even later allowed more viable seed to be shed by a wider range of species than when the meadows were cut in July. On previously fertilized meadows the nutrient status of the soil would need to be reduced before any benefits of later cutting could be gained.

Disturbance and the creation of gaps in the grass dominated vegetation of a previously fertilized meadow failed to enhance botanical diversity two years after the treatments had been applied. Disturbance enhanced the abundance of competitive grasses and reduced the abundance of forb species. The increase in grass abundance was due to their ready ability to colonise gaps either by seedlings derived from seed rain or from the soil seed bank. Sowing seed of scarce or "lost" species either into gaps or into the undisturbed vegetation failed to increase their abundance. Again it appears that the nutrient status of the soil would need to be reduced before any benefits of sowing desired species would be gained.

Clearly there is a conflict between the interests of agricultural production and the maintenance of the special wet hay meadow communities on the Somerset Levels. These communities lose floristic diversity with inorganic fertilizer inputs and when damaged by fertilizer use they are not readily recovered once inputs cease and the traditional management resumed.

INTRODUCTION

This is the final report of the results from an eight year experiment carried out on Tadham/Tealham Moors in Somerset. The research was undertaken by staff of the Institute of Grassland and Environmental Research - IGER as part of a eight-year research project financed jointly by the Ministry of Agriculture, Fisheries and Food (MAFF), the Nature Conservancy Council for England (English Nature) and the Department of the Environment (DoE).

It is well known that the application of fertilizer increases the abundance of sown grasses at the expense of indigenous species, and reduces floristic diversity of species-rich grassland (Brenchley and Warington, 1958; Tilman,1982; Wells, 1989). Data on specific and/or community effects of fertilizer use on semi-natural grasslands are mainly limited to those from a few long-term experiments in dry mesotrophic plant communities, such as the classic "Park Grass" experiment at Rothamsted (Digby & Kempton, 1987). It is not certain how far this data can be used to predict the response to fertilizers of other species-rich grassland types. It became clear in the early 1980s that a prediction was needed of the degree of damage likely to be caused by agricultural intensification in species-rich meadows on the Somerset Levels and Moors. In 1986 MAFF, English Nature and the DoE commissioned IGER to establish whether there was a 'safe' amount of fertilizer nitrogen that could be applied to these meadows without reducing floristic diversity, also to establish the agricultural output achievable within any such safe fertilizer limit and the output foregone by adhering to this limit. Treatments were imposed within the framework of a large-scale experiment under a traditional management system consisting of a late hay cut (not before 1 July) followed by grazing the aftermath with cattle. A subsidiary small-scale plot experiment investigated the impact of a wider range of fertiliser treatments under cutting management only.

From 1990 to 1993 the objectives of the project were extended to: establish the rate and degree of botanical 'reversion' (increase in species diversity and cover of forb and non-grass species) and establish the impact on agricultural output when fertiliser N is withheld following years of input; also, to establish techniques to accelerate 'reversion' in botanical composition following botanical impoverishment by previous fertilizer use. To accommodate the additional objectives in 1990 all the treatment plots in the large-scale experiment were split so that half of each plot continued to receive fertiliser as previously (N+ plots) and the other half ceased to have further inputs (N- plots). Also in 1990, all fertiliser inputs into the small-scale experiment ceased. This allowed botanical changes to be examined following the cessation of a wider range of fertiliser treatments than those provided by the large-scale experiment.

Staff from the Institute of Terrestrial Ecology (ITE) at Monks Wood were responsible for monitoring changes in botanical composition in the large-scale experimental plots and grazing exclusion areas under a sub-contract; a full description of their results is given in a separate report (Mountford, 1994). Staff from IGER assessed the botanical composition of the small plot experiments during May and June.

EXPERIMENT SITING

The experiments were sited on 21 hectares of undrained hay meadows on Tadham Moor, in the Brue Valley, near Wedmore in Somerset (51°12'N; 2° 49'W). The soil consists of peat to a depth of 125-160 cm over silty clay. The upper soil layers belong mainly to the Altcar series with some Blackland, Adventurers and Turbary Moor series in small amounts (Avery, 1980). The average pH of the surface 0-10cm layer is 5.7. Prior to the experimental period the site management had a long history of late hay cutting followed by aftermath grazing with no inorganic fertilizer use. The area lies within a Site of Special Scientific Interest.

CONDUCT OF EXPERIMENT

1. Large-scale experiment

In a large-scale experiment five levels of fertilizer N namely zero (N0), 25 (N25), 50(N50), 100 (N100) and 200 kg N/ha (N200) were applied to plots laid out in three randomized blocks (Fig. 1). Individual plot size was inversely related to N input and ranged from 0.6 ha in N200 plots to 1.1 ha in N0 plots, the difference in size was designed to support a minimum of two steers throughout the grazing period.

Water table, rainfall and temperature measurements

Staff from the ADAS Farm and Countryside Service (formerly the Land and Water Services Department) at Taunton measured the depth of the water table below ground level at weekly intervals each year in 33 dipwells located across the project site. Details of dipwell positions are given in Kirkham (1990). FCS staff also measured the levels of both the main rhyne and the pumped rhyne to the west of area 3 each week.
Rainfall was measured continuously using a Meteorological Office Mk 2 tilting syphon gauge, whilst weekly accumulated rainfall was also recorded in a simple bucket-type recorder.

Temperature recordings were made at 15-minute intervals in air (inside a Stevenson Screen), at the soil surface and at 10 cm depth in the soil using a Grant 'Squirrel' automatic meter/logger. Data was off-loaded at approximately 3-week intervals onto a hand-held Husky hunter microcomputer and from there onto a MICROVAX 3600 mainframe computer upon which the data was processed.

Fertilizer application

Nitrogen was applied to treatment plots in the form of granular fertilizer containing 34.5% N as ammonium nitrate. A Bamlett tractor-mounted pneumatic distributor was used on the large-scale plots. The fertilizer was applied in two equal dressings, the first in the spring as soon as ground conditions allowed, usually between mid-April and early May, and the second after removal of the hay crop (Table 1).

Phosphorus (P) and potassium (K) were applied individually to all treatment plots except the N0 control after the removal of the hay crop. Phosphorus was applied in the form of triple superphosphate and K as muriate of potash. The amounts of P and K applied were equivalent to their respective yields in the hay crop.

Botanical survey

Staff from ITE assessed the botanical composition of all main plots during May. Techniques used and results gained are described in a separate report (Mountford, 1994).

Harvest of hay

The large-scale plots were cut for hay by local contractors on the dates shown in Table 1. Yield at cutting was measured by weighing 4 m lengths of two adjacent swaths of measured cut width at five randomly-chosen sites per plot. After the plots were split in 1990 the hay yield was measured at three randomly-chosen sites in each of the N+ and N- plots separately. During the period 1986 to 1989 the yield of baled hay was measured by counting the number of bales and weighing a sample of 25 per plot, chosen at random. At each site a sub-sample of approximately 500 g of herbage was removed from the field at the time of cutting (and just prior to baling during the 1986-1989 period), weighed fresh then oven-dried for 12-15 hours at 80°C, weighed again to obtain the herbage dry matter content and ground in a hammer mill. These samples were analyzed for total N, P, K, calcium (Ca), magnesium (Mg) and sodium (Na) content and their *in vitro* digestibility. Details of the analytical procedures are given in Kirkham and Wilkins,(I).

The metabolizable energy (ME) value of the hay was calculated from the *in vitro* digestibility (DOMD) and the N content of the herbage, using the following formula:

ME (MJ per kg DM) = (0.138 x %DOMD) + (0.01 x CP) + 0.23

where CP is the crude protein content in g per kg DM, with crude protein assumed to be 6.25 x N. The rationale for this approach is given in Kirkham and Wilkins (I).

Grazing management

Plots were stocked with 12-month old Hereford x Friesian steers weighing on average 275 kg at the beginning of the grazing period (Table 1). Prior to 1990 each of the large-scale plots was grazed separately. After 1990 each half of the plot was grazed separately with the cattle being moved from the N+ to the N- halves on approximately alternate weeks dependent upon herbage availability. Grazing output was measured using a standard procedure of continuous variable stocking (Tallowin *et al.*, 1990). At the start of grazing two 'core' animals were allocated to each plot, they were selected at random from a group of 30 steers of uniform size. These 'core' animals remained on their respective main plot for the duration of the grazing season. The aim of the grazing management was to maintain a similar amount of herbage on offer across all grazed plots throughout the grazing period. Sward height, measured once a week at 30 random locations per plot with a rising plate meter (Holmes, 1974) was used as a management guide; A height of between 5.5 and 6.5 cm (Equivalent to an uncompressed sward surface height of 8.0 to 9.5 cm) was the target for all plots. 'Spare' cattle of a similar weight to the core animals were used to adjust grazing pressure on the plots by either adding or removing individual animals dependent upon trends in the sward height. All cattle were removed from a plot when the sward height fell below 5.0 cm at the end of the season.

All the cattle were weighed on three consecutive days prior to the start of grazing, then again in September and again at the end of the grazing season when all cattle were removed from the site. Animal output data from each plot were derived from the individual liveweight(LW) gain of the core animals, the number of grazing days per ha and the amount of LW produced per ha (grazing days per ha x LW gain of cores). The utilized metabolizable energy (UME) output of each plot was determined by multiplying the grazing day total by the daily energy requirement for the observed LW gain and maintenance requirement of the cattle (Forbes *et al.*, 1980).

2. Small-scale, reversion, cutting date and grazing exclosure experiments

Small-scale experiment

An experiment involving 19 treatments (Table 2) was established in April 1986 in a randomized block design with three replicate blocks. Plot size was 1.5 x 5m. The experimental area of 25 x 35m, including discard/races for mower access, was fenced to prevent grazing. Granular fertilizer was applied by hand to the plots on up to four occasions each year 1986-1989. Fertilizer application to most treatments was timed to coincide with the applications to the large-scale experiment. All fertilizer inputs ceased after the 1989 season. This allowed an investigation of the residual effects of the previous treatments on changes in botanical composition and dry matter and nutrient yield.

The botanical composition of each plot was assessed once in mid-May on two 0.40 x1.27m quadrats placed randomly within each plot. The presence of every species found within each quadrat was recorded, along with an estimate of the percentage of ground covered by each species. In addition, the remaining area of each plot was searched for further species and any found were given an arbitrary score of 0.1% ground cover; a higher score was sometimes given when it was deemed appropriate, for example for a species occurring in a clump, or clumps, of appreciable size which had by chance escaped inclusion in one of the quadrats.

All plots were cut at least twice during the season: at the time of the hay cut in the large-scale plots and again in October and/or November. An Arun reciprocating blade mower was used to harvest a central 1m wide x 5m long strip from each plot, leaving a stubble height of about 5cm. The fresh weight of the harvested herbage was taken, then a 2-300g sample was removed for dry matter and chemical analysis as in the large-scale plots.

Reversion experiment

Hay meadows on Tadham Moor that have received fertilizer are dominated by competitive perennial plant species. In order for new individuals, genotypes or species, to get into the established community more drastic disturbance and gap creation than that provided by hay making and aftermath grazing may be necessary to create the required niches. A small plot experiment was set up in the autumn of 1990 and spring of 1991 on a N200- plot. The effect of time of gap presence and the potential of the soil seed bank to replenish the impoverished flora was investigated.

The experimental design was a randomised block with 8 treatments in 4 blocks. The treatments were: autumn rotovation, spring rotovation, spring gap creation using herbicide and an undisturbed control; all with + or - seed introduction. Plot size was 4 X 2m. Two 0.5 x 4m long strips either rotovated or treated with herbicide (Glyphosate) were created within a plot. Within a plot these strips were separated by a 0.5m wide undisturbed/unsprayed strip. The species sown into the '+' plots are given in Appendix Table 5.

Botanical assessments carried out between late May - mid-June included a count of species present together with an estimate of percentage cover within two 25 x 25cm quadrats in each treated strip, ie. a total of six quadrats per plot. The control plots were sampled similarly, ie. in three nominal strips. The quadrats were positioned randomly along each strip and in a central position to avoided edge effects. Data from the treated and untreated strips were analyzed both separately and pooled.

Cutting date experiment

In order to increase diversity in species-impoverished meadows it may be desirable to prevent dominant species from setting seed. Where grass abundance in particular has been enhanced by fertilizer inputs then timing of cutting may be critical to reduce both seed rain and cause a hiatus in vegetative spread by tillering; for this an early cutting date timed to remove flowering tillers prior to seed shed would seem appropriate. In species-rich meadows on the Somerset Levels delaying hay cutting to late summer may allow more species to set seed and regenerate than under the existing July cutting recommendation. The agronomic implications, in terms of yield and nutritive value of the hay crop, of varying cutting date need to be established, both for species-rich and poor meadows.

An experiment was set up in March 1991 consisting of six randomized sets of twelve 2 x 4m plots. One set of 12 plots were placed within each of the three replicates of the large-scale N0 and N200 plots. No fertilizer was applied to these small plot areas after mid-summer 1990. Within each set of plots four plots were cut on 22 May in 1991 and 26 May in 1992, two plots were cut on 17 July 1991 and 6 July 1992, two plots were cut on 9 August 1991 and 1 August 1992 and four plots were cut on 4 September 1991 and 1 September 1992. Each plot was surrounded by a 1m guard area cut at the same time as the plot. At each cutting date a 1 x 4m swath was cut with an Arun reciprocating blade mower down the centre of a plot ta a stubble height of 5cm. A sample of 3-500g of cut herbage was removed from random locations along the swath for dry matter and chemical analysis. The total fresh weight of cut herbage was recorded and then the herbage returned to the swath and distributed along 1 x 4m area; then the remainder of the plot area and guard strip were cut. The herbage cut in May was left *in situ* to wilt for 24 hours before being removed. Herbage cut on the later dates was turned and tedded by hand, to simulate the action of mechanized hay-making, until the hay was considered made and ready for baling, the herbage was then removed from the plots. Care was taken not to shed seed onto adjacent plot in this hay-making and removal process. Each plot was cut once in 1991 and then grazed along with the remainder of the large-scale plot from mid-September to mid-October. In 1992 all plots were cut to the same height on 1 September before being grazed, this avoided the rather rank regrowth on the early cut plots being largely rejected by the cattle as they were in 1991.

The botanical composition of each plot in the cutting date experiment was assessed in early May in four 50 x 50cm quadrats placed at random within each plot. The presence of every species found within each quadrat was recorded, along with an estimate of the percentage of ground covered by each species. In addition, the remaining area of each plot was searched for further species and any found were given an arbitrary score of 0.1% ground cover; a higher score was sometimes given when it was deemed appropriate, for example for a species occurring in a clump or clumps of appreciable size which had by chance escaped inclusion in one of the quadrats.

Grazing exclusion study

Where high fertiliser inputs have resulted in increased grass abundance it is possible that aftermath grazing could exacerbate this effect both directly and indirectly. Morphological and growth responses by grasses to grazing could allow grass cover to increase at the expense of non-graminae. Gaps created in the sward by, for example, dung deposition, urine scorch or physical damage by hooves or pulling up of plants, could be more readily colonised by grass species whose seed are ripe to germinate immediately on falling compared to many of the forb and non-graminae species whose seed germination is controlled by dormancy mechanisms. In order to test whether protection from grazing has an effect on 'reversion' of botanical composition following cessation of high fertiliser inputs, small exclosures were erected in the N200- plots in 1990 following the hay cut.

Three 5 x 5m areas, selected at random within each of replicates II and III of the N200- plots were fenced with electrified wire, after the hay crop had been removed. These areas were again cut in November with a reciprocating blade mower, when three 1m wide x 4m long samples were taken for DM determination and chemical analysis as for the hay cut on the main plots. Changes in the botanical composition of the exclosures are presented by Mountford (1994).

RESULTS AND DISCUSSION

Temperature, rainfall and water-table depth

Daily maximum, minimum, and mean temperature in air (inside a Stevenson screen), at the soil surface and at 10cm depth were recorded continuously between April 1987 and January 1992. A series of faults developed with the automatic logger during 1992 and 1993 and these resulted in losses of data for January 1992 and for the period from August 1992 to the end of the project in June 1993.

Details of within year variations in temperature (Table 3) and rainfall (Figs 1a and 1b) have been presented in each of the annual reports (Kirkham, 1987;1988;1989;1990; Tallowin & Thomas,1991; Tallowin, Thomas & Smith, 1992; Tallowin, Smith & Thomas,1993). In terms of an overview, the weather conditions in some years did have a notable impact on site management and agricultural output. Wet conditions in April 1986, 1989 and 1990 delayed the first application of fertilizer (Table 1). Wet mid-summer conditions in 1988, 1991 and 1992 delayed hay cutting and protracted hay-making, this in turn delayed the onset of grazing. The warm dry conditions during the autumn of 1991 allowed grazing to continue into November.

Changes in the water table depth followed a consistent pattern between 1987 and 1993 (Figs 2), the winter high levels were maintained between November to March then there was a rapid downdraw in April and May to a level of about 60cm. Summer water table depths varied considerably between years; 1988, 1991 and to a lesser extent 1989 had raised water tables in mid-summer, this followed periods of heavy and/or prolonged rain. 1987 and 1990 were notable for the length of time that the water table remained very low over the summer months; in both years the water depth remained below 60cm from June to September. 1986 was an exceptional year in that the spring downdraw was delayed by about a month. The water table was consistently lower in block 3 during the summer months throughout the course of the project.

A detailed analysis of the effects of water table depth on agricultural production and losses of soil nitrogen were made by Kirkham (1991). Hay yields were lowest when the mean water table depth in April - July was below 50cm. High water table depth during this period had little effect on hay yield. Wet conditions and high water table in late summer reduced production from aftermath grazing. High water table in the autumn increased the risk of high N loss via denitrification.

LARGE-SCALE EXPERIMENT

Hay yields and annual dry matter production

Hay yield and total annual herbage production both showed a significant positive response to fertilizer N inputs in all years except 1986 and 1988. In 1986 this was probably due to the fact that no P or K fertilizer had been applied prior to the hay cut, in 1988 it appeared that the lateness of the hay cut was a causal factor. In the years when hay cutting date was delayed due to wet weather conditions, increased hay yields were obtained up to the first week in August, after this time yields declined in the fertilized meadows (Fig. 4). This would suggest that losses of dry matter through senescence had increased above the rate of daily dry matter increment.

The pattern of the dry matter response to fertilizer N in the hay crop in the large-scale experiment is shown in Figure 5. The attenuation in the response above an input of 50 kg N per ha contrasts with the general response pattern for permanent pastures in the UK, where significant increments in dry matter output are widely found with inputs up to 300 kg N per ha (Hopkins *et al*, 1990; Kirkham and Wilkins, I). This marked reduction in dry matter response as N inputs increased in the Tadham hay meadows was largely due to deficiencies in P and K supply from the peat soils (Kirkham and Wilkins, II). It is noteworthy that when no N fertilizer was applied but only P and K in small amounts sufficient to replace that which had been removed in the hay crop herbage, yield was increased by about 2 tonnes DM /ha over the yields from the unfertilized control (Fig. 5). When P and K were provided in unrestricting amounts in the 'small scale' experiment, herbage output (Fig. 5) was similar to that obtained from a wide range of permanent pastures in the UK (Hopkins *et al*, 1990).A detailed analysis of the hay yield data is provided in Kirkham and Wilkins (I and II).

Losses in dry matter during the hay making process averaged about 20% overall, ranging from 10.4% in the N200 treatment in 1988 to 36.2% in the N100 treatment in 1989. During the 1986-1989 period the production of baled hay was significantly increased in the N50,N100 and N200 treatments compared with the control (Kirkham and Wilkins, I).

Hay quality

Herbage *in vitro* digestibility (DOMD) was significantly affected by applied fertilizer only in 1986 and only in baled hay from the N100 treatment which was higher than from any other treatment (Kirkham and Wilkins I). Hay quality in terms of the metabolizable energy value of the crop showed no significant differences between treatments and showed little change with lateness of cut up to the beginning of August (Fig. 6). Consequently no penalties in terms of ME production were incurred by delaying hay making from the beginning of July to the beginning of August (Fig. 7).

N, P and K content and yield in the hay crop

The N content of the herbage when cut for hay showed a significant influence of the fertilizer treatments each year except 1990 and 1991 (Kirkham and Wilkins, I; Tallowin, Smith & Thomas,1993). The N content of the hay was lower in the N25 and N50 treatments compared with the N200 treatment in each year except 1990 and 1991, it was also lower in these two treatments than in the control in 1988 and 1989. These differences, illustrated in Fig. 8, are due to a dilution effect of the relatively large dry matter increment, in response to fertilizer input, in the N25 and N50 treatments compared with the N200 treatment and the control.

The yield of N in the hay crop showed a significant response to fertilizer input in each year except 1986 and 1988 (Fig. 9). N yield was significantly enhanced relative to the control in all treatments in at least one year. The recovery of N from the treatment plots (the yield of N - N yield from the control, as a percent of N amount applied as fertilizer) fell markedly when annual inputs exceeded 50 kg N per ha, as a result of deficiencies in P and K availability (Kirkham and Wilkins, II).

The P content of the hay showed no significant effect of fertilizer treatment in any year.The P content of the herbage was low compared with improved grass crops (Spedding and Diekmahns, 1972), this was partly due to the maturity of the crop but also to deficiency in P supply from the soil. The low P content of the hay together with the relatively high calcium content, of between 0.4 and 0.7 percent in the dry matter (Tallowin, Smith & Thomas,1993), gave a Ca : P ratio well in excess of 2. Such a high Ca : P ratio would have reduced P availability to livestock and impaired fertility in breeding animals (Holmes, 1989). The yield of P in the hay crop showed no response to fertilizer input during the 1986 - 1989 period. There was, however, a significant response in 1990, 1991 and 1992, with the N50 and N200 showing higher P yields in each of the three years, the N100 treatment showed enhanced P yields in 1990 and 1992 and the N25 treatment in 1992 only (Fig. 10). These results would suggest that although P availability and uptake was increased with increased fertilizer input it was still a limiting factor in dry matter production with high N inputs.

The K content of the hay showed a significant response to fertilizer treatment in each year from 1988 to 1992. Over this period all treatments had enhanced K contents compared with the control (Fig. 11). The hay from the N50 treatment had a higher K content than the N200 treatment in 1988, 1989 and 1991. K supply from the peat soil clearly became increasingly limiting in the high N treatments under the K replacement strategy adopted in the large-scale experiment. The K content of the hay from the control showed a downward trend during the course of the project. However, because of the variation in cutting date between years it is not possible to assess whether there was in fact a depletion in K availability in the control plots. The yield of K in the hay crop showed a significant response to fertilizer input each year from 1988 onwards (Fig. 12). All treatment plots yielded a greater amount of K than the control. The N50 treatment tended to yield the greatest amount of K each year and the difference between this treatment and the N200 reached significance in 1988 and 1991. This result suggests that soil

K availability continued to increase through the summer, certainly up to the beginning of August, in the fertilized plots, but clearly in insufficient amounts to sustain high dry matter yields.

Animal production

The cattle grazing the hay aftermaths consistently achieved growth rates of about 1 kg per day (Table 4) across all treatments (Kirkham and Wilkins, I; Tallowin, Smith & Thomas,1993). This level of performance compares very favourably with that achieved by cattle grazing intensively managed permanent pastures in the mid-summer to autumn period (Tallowin *et al*, 1990).

The number of steer grazing days per hectare was strongly influenced by hay cutting date (Fig. 13). A delay of one month in the hay cut reduced grazing day totals by about 55 percent in the N treatments and by about 35 percent in the control, when comparing the 'early' harvest years, 1986, 1987 and 1989 with the 'late' years, 1988, 1991 and 1992. There was a significant response of grazing day total to fertilizer treatment in each of the 'late' years but significance was reached only in 1986 in the 'early' years (Kirkham and Wilkins, I; Tallowin, Smith & Thomas,1993). The increment in grazing day total between the control and the N50 treatment in each of these years and between the N50 and the N200 treatment in 1988 and 1992 was significant. The difference in response between 'early' and 'late' cutting was largely due to a greater contrast between the control and the treatments in the late years. There was poor aftermath growth in the control when cut late, in early August, whereas the promotion of growth in treatment plots by the mid-season fertilizer input compensated, to some extent, for the delay in hay harvest. A detailed discussion on the impact of cutting date on agricultural output is provided by Kirkham and Tallowin (in prep).

Liveweight production per hectare showed a similar pattern of response to fertilizer input as grazing day totals (Fig. 14), due to the fact that individual animal growth rate differed little between treatments. There was a significant response of liveweight production to fertilizer input in each year except 1987 and 1990. Production was enhanced by about 115 kg per ha in the N50 treatment and 150 kg per ha in the N200 treatment compared with the control, these figures are the averages for the years when significant differences were found (Kirkham and Wilkins, I; Tallowin, Smith & Thomas,1993).

The utilized metabolizable energy (UME) output from grazing (Fig. 15) showed significant responses to N input in each year except 1987 and 1990 (Kirkham and Wilkins, I; Tallowin, Smith & Thomas,1993). Overall aftermath grazing contributed about a third of the total annual UME output (Fig. 16), which corresponds with the seasonal distribution of production obtained from permanent pastures elsewhere.

Total UME output (baled hay + aftermath grazing)

The total UME output per year (Fig. 16) showed a significant response to fertilizer treatment in each year (Kirkham and Wilkins, I; Tallowin, Smith & Thomas,1993). The average annual output ranged from 40.6 ± 1.73 GJ per ha in the N0 to 63.9 ± 3.15 GJ per ha in the N200 treatment. These values compare favourably with an overall mean of 40.3 GJ per ha recorded for non-suckler beef farms in a National Farm Study, where the average annual fertilizer N input was 66.2 kg per ha (Forbes *et al.*, 1980). Peel *et al* (1988) using data published by the Milk Marketing Board (Poole *et al*, 1984) estimated a UME output of 64 GJ per ha from dairy farms on which the annual fertilizer input was 263 kg per ha, this value corresponds well with the UME output from the N200 treatment in this experiment.

The results from this project demonstrate that agricultural output from these botanically diverse hay meadows can be predicted with reasonable precision, using a general fertilizer N response model derived from agricultural grasslands, provided that adequate P and K are supplied (Kirkham and Wilkins, I; Kirkham and Wilkins, II). However, the project took no account of losses in UME during storage and feeding of hay and the variable continuous stocking ("put and take") management probably resulted in higher levels of herbage utilization than would be achieved in practical farming situations.

Residual effects of previous fertilizer inputs on agricultural production

Where fertilizer applications were discontinued in the large-scale experiment, there were no significant residual effects of previous fertilizer treatment, compared with the unfertilized control, on either hay dry matter (Table 5) or ME yield (Table 6), grazing output (Table 7) or total UME output (Table 8) in any of the subsequent years (Tallowin, Smith & Thomas,1993; Mountford *et al*, in press). Significant residual effects of previous fertilizer treatment were, however, found in both herbage nutrient contents and yields. All treatment plots had a reduced N content in the hay compared with the control in the year after treatments had ceased (Table 9a). The yield of N was unaffected by previous treatment. The P content of the hay (Table 10a) was unaffected by previous treatment but the yield of P (Table 10b) was enhanced in the former N50 plots compared with the control and N25 treatment two years after treatments had ceased, the N200 plots also had enhanced P yields compared with the N25 treatment in this second year. Potassium content of the hay was significantly enhanced in all former treatments compared with the control one year after fertilizer inputs ceased(Table 11a). The yield of potassium remained enhanced in all treatments relative to the control for two years after the cessation of inputs(Table 11b).

These results demonstrate that at the gross production level of dry matter and livestock output there was no legacy from previous fertilizer applications even though macro-nutrient availability, in particular P and K availabilities, continued to differ from the unfertilized control plots.

In the small-scale experiment there was a highly significant residual effect of previous fertilizer treatment on total dry matter yield two years after the cessation of inputs (Table 12). One year after inputs had ceased total yields were enhanced on all former treatment plots compared with the control. After two years total yields were still enhanced on all treatments except those that had received no P fertilizer; even the treatment that only received small replacement amounts of P and K, but no N fertilizer, gave greater total yields than the control. Three years after the cessation of fertilizer applications herbage dry matter yields at the second harvest were still significantly enhanced on all treatments, except those that had received zero P fertilizer input, compared with the control; however, total yields were enhanced only in the N200, P and K replaced, N200, P75, K200 and the N0, P75, K replaced treatments (Fig. 17). In 1993, four years after fertilizer applications had ceased, no significant residual treatment effects on herbage dry matter yields were found.

It is worth noting the wide variation in total yield of 2.6 tonnes DM per ha from the unfertilized control during the course of the project. Unfortunately because of climatic and water table variations between years affecting both hay cutting date and herbage growth during the summer, it would not be valid to test for trends in dry matter production with either time or water table depth because the two were confounded in this study. Clearly there were factors other than fertilizer input that had important influences on the productivity of the meadows.

Significant residual effects of previous fertilizer treatment on the N content and yield were found in the small-scale experiment three years after the cessation of inputs (Tables 13a and 14a). Herbage N content was most significantly affected in the second harvest with the former high P treatments having a higher N content than the control for three years following cessation of inputs. The yield of N in the first harvest was significantly greater in all treatments than the control, except those that had received no fertilizer P, in the year following cessation of inputs. The yield of N in the second harvest was highly significantly affected by previous fertilizer treatment for three years, only the former treatments that received no fertilizer P did not have enhanced N yields compared with the control in any year. Four years after all fertilizer inputs had ceased N yields still remained significantly enhanced compared with the control in all the former high P treatments (Table 15a). The fact that N yield was enhanced in treatments that had received no additions of fertilizer N indicate the importance of P and K in influencing N availability and/or uptake by the meadow vegetation on the peat soils of Tadham Moor.

The herbage P content and the yield of P in both harvests remained highly significantly affected by previous fertilizer treatment four years after fertilizer inputs had ceased (Tables 13b and 14b). All plots that had received high P inputs had enhanced concentrations of P in the dry matter and enhanced yields of P in each of the four years. Over the four years following the cessation of fertilizer P inputs the difference in P yield between previously treated plots and the unfertilized control showed considerable consistency, it is noteworthy that all former treatments except those which had received no P tending to give enhanced P yields (Table 15b). Assuming continued linearity in P yield, and taking account of P removed in the herbage over the period since inputs ceased, it is estimated that it will take at least a further 13 years under the current cutting management to deplete the "excess" P applied during the period of fertilizer treatments.

Herbage K content and yield showed significant residual effects of fertilizer treatment up to three years after treatments had ceased (Tables 13c and 14c). Herbage K yields were still highly significantly enhanced at the second harvest in all the plots that had received high P inputs three years after fertilizer inputs had stopped. However, by the fourth year there were no significant residual effects of the former treatments on either K content or yield, many treatments tended to show reduced K yields relative to the control (Table 15c).

The availability/uptake of nutrients other than those applied as fertilizers was also affected by the previous fertilizer treatments in the small-scale experiment (Tables 16 and 17). Herbage magnesium yields were enhanced in the second harvest in each of the four years after fertilizer inputs had ceased in those plots that had received 75 kg P/ha. Residual effects of previous fertilizer treatment on calcium and sodium yield were not so consistent, nevertheless in 1993 calcium content of the herbage at cut two was reduced compared with the control. A significant effect of treatment on sodium content was found in the herbage at the first cut in 1993 but there was no consistent pattern to the differences between treatments. High yields of Ca, Mg and Na between 1990 and 1993 were not associated with any significant reduction in their concentration in the harvested herbage. This indicates that these elements continued to have a high relative availability for plant uptake despite repeated large offtakes over the previous years.

There were no consistent significant residual effects of previous fertilizer treatment on either calcium, magnesium or sodium content or yields in the large-scale experiment. The concentrations of Ca and Mg in the harvested herbage from the small-scale experiment were generally higher than the concentrations of these elements in the hay from the N- main plots. The values of these element concentrations in the herbage in the main N- treatments were in line with grassland values generally in the UK (Whitehead,1966). Clearly the difference in the status of these nutrients between the small-scale experimental site and the main N- plots needs to be borne in mind when comparing changes in botanical composition. The difference in the duration and extent of residual fertilizer effects between the small-scale and large-scale experiment indicates that grazing had an important role in influencing nutrient cycling and losses in these meadows.

SMALL PLOT EXPERIMENTS

Small-scale experiment

The botanical changes that occurred in the small-scale experiment (Table 18 and Fig. 18) during the period, 1986 to 1989, when fertilizer treatments were applied were broadly similar to those that occurred in the main plots (Mountford, Lakhani and Kirkham, 1993; Mountford *et al*, in press; Kirkham, Mountford and Wilkins, in prep). Grasses, and in particular *H.lanatus*, became dominant in fertilized plots (Fig.18). Phosphorus was the most influential of the three elements in causing botanical change and in determining herbage production (Kirkham & Wilkins, in press II; Kirkham, Mountford and Wilkins, in prep). This key role of P as a determinant of both productivity and botanical composition of these meadows is in line with findings in other late successional plant communities on peat soil (Verhoeven and Smitz, 1991).

Changes in botanical composition that were independent of the influence of fertilizer input occurred across all treatments in the small-scale experiment, including the control. These changes indicated that the lack of disturbance by grazing in this experiment may have had an important impact on the botanical composition of the plots. At the individual species level, there were marked differences in response to fertilizer input between the large and small-scale experiments, which again probably reflected the influence of grazing disturbance on creating regeneration niches (Kirkham, Mountford and Wilkins, in prep).

During the period from 1990 to 1993 the total number of species per plot and per m^2 in the control tended to decline (Table 18a and 18b). Associated with this decline was a trend towards increased total dry matter yields between 1990 and 1993 (Table 12). This apparent decline was due to reductions in both grass and forb species (Tallowin, Thomas and Smith, 1992; Tallowin, Smith and Thomas, 1993).

In 1993 there were no significant effects of treatment on either total number of species per plot or per m^2 or percent ground cover of the different species groups (Tables 19a, 19b and 20). Although this might suggest that residual effects of previous fertilizer treatment had disappeared by the fourth year after the cessation of inputs in fact species richness was still reduced across all treatments compared with the pre-treatment values observed in 1986 (Fig. 19). Only those plots that had received either P and K in replacement amounts with no fertilizer N or N100, P0 with K replaced had values for species richness in 1993 that approached those found in 1986. In addition, in 1993, the number of dicot species per plot was still significantly reduced in those plots that had received 75 kg P/ha (Table 19a).

At the individual species level, there were significant residual effects of previous fertilizer treatment still present four years after inputs had stopped. Amongst the grasses, *Anthoxanthum odoratum* had a reduced abundance in the former N200, P75 treatments compared with the control in 1993 (Table 20b). The abundance of this species was enhanced in plots that had received K inputs with either replacement or high inputs of P but with no N compared with plots that had received high inputs of both N and P, it also had enhanced abundance in the N50 P and K replaced treatment compared with former high N and high P treatments. *Agrostis capillaris* abundance showed a significant residual effect of treatment in 1993 but influence of particular nutrient inputs either individually or in combination was less clear than in the previous species; its abundance was reduced in former high N high P plots compared with either the N25 or N200 with P and K replaced or the N100 with P0 and K replaced treatments (Table 20b). The abundance of *Festuca rubra* was significantly enhanced in 1993 in the former N200, P75 with K replaced treatment plots compared with the control and most of the other treatments. The abundance of *Holcus lanatus* was still highly significantly affected by previous fertilizer treatment four years after all inputs had stopped (Table 20b). In all plots where high inputs of P had been used the abundance of this species was enhanced compared with the control and all the other treatments. The fact that *H. lanatus* had an enhanced abundance in plots that had not received N fertilizer but only high inputs of P with replacement amounts of K indicates, again, how important this one macro nutrient was in influencing the botanical composition of the meadows.

Previous high inputs of P were still significantly affecting the abundance of a number of dicot species four years after fertilizer applications had ceased. In 1993 the abundance of *Centaurea nigra, Leontodon autumnalis* and *L. hispidus, Plantago lanceolata, Taraxacum officinale* agg. and *Trifolium pratense* were all reduced compared with the control in the former high N high P treatment plots (Tables 20c and 20d). All of these species except *Taraxacum officinale* agg were also significantly reduced in plots that had received 75 kg P per ha with K replaced but with no fertilizer N input. This continued sensitivity of so many of the attractive dicot species to P availability clearly has important implications where the restoration of species diversity is desired on de-intensified agricultural land on the Somerset Levels.

Only one dicot species, *Rumex acetosa*, had significantly enhanced abundance in former high P treatment plots in 1993, in the case of this species it appeared to be a combination of previous N and P inputs that was important, where no P fertilizer had been applied its abundance remained similar to that found in the control. *Ranunculus acris* was found to be significantly reduced in high N plots that had received no P fertilizer input in 1993.

Cutting date experiment

Botanical changes

Changing cutting date caused no significant increase in species richness or diversity (Table 21) over a three year period within previously fertilized meadows (Kirkham and Tallowin, in prep). Dominance of the vegetation by competitive species (such as *Holcus lanatus*), which display versatility in their regenerative strategy (Grime *et al*, 1988) was either maintained or enhanced by early cutting, in May, presumably through increased lateral vegetative spread. Seedling regeneration was promoted by later cutting (Fig. 20). Grasses contributed the bulk of the seed rain with later cutting, particularly in the previously fertilized plots. Grasses were therefore able to readily exploit gaps in the vegetation created during aftermath grazing. Delaying the cutting date until August or even later allowed more viable seed to be shed by a wider range of species compared with cutting in July (Kirkham, 1993). However, in order to limit the ability of competitive species to dominate previously fertilized meadows, the nutrient status of the community would need to be reduced before any benefits of later cutting could be gained. In unfertilized, species-rich meadows, occasional hay cutting in August or even later could be important for maintaining the populations of some late flowering species. However, if very late cutting were to be repeated over successive years then populations of some species such as *Cynosurus cristatus*, *Bromus hordeaceus* and *B. racemosus* would be severely depleted (Kirkham and Tallowin, in prep).

Dry matter yield and chemical composition of primary growth.

Dry matter (DM) production, averaged over two years, increased between May and July and again between July and August, but not between August and September (Table 22). In neither year was there any significant effect of previous fertilizer treatment (N_0 v N_{200}) on DM yield of primary growth nor any significant cutting date x fertilizer interaction.

The overall effect of previous fertilizer treatment on herbage DOMD was not significant but there was a highly significant cutting date x fertilizer interaction(Table 22). The DOMD of N_{200} herbage was higher than N_0 when cut in May, but the opposite was true for all other cutting dates. Herbage harvested in August on the former N_{200} plots was of significantly lower digestibility than that harvested a month later from N_0 plots (Table 22). Herbage digestibility declined significantly between each cutting date until August with no change between August and September.

The Metabolizable energy (ME) output per hectare increased very significantly between May and July, but showed no further overall change between cutting dates (Table 22). There was no significant overall effect of previous fertilizer treatment on ME output but there was a significant cutting date x fertilizer interaction. When cut in May, previously fertilized plots produced 10.7 GJ ha^{-1} more ME than N_0 plots. ME output tended to be greater from N_{200} plots than N_0 plots at each cutting date (Table 22).

The concentrations of all the minerals tested were significantly affected by cutting date when averaged over 1991 and 1992, but not by previous fertilizer treatment (Table23). Concentrations of N, P and K were all significantly higher in herbage cut in May than on all other occasions. Herbage Ca content was higher in July than at any other cutting date (Table 23), particularly in 1992. Magnesium content declined significantly between July and September (Table 23).

The yields of N and P were higher from the N_{200} plots than N_0, (Table 24). Yield of herbage N per ha, averaged over previous fertilizer treatments, increased significantly between May and July and between August and September but not between July and August (Table 24). N yield showed a highly significant cutting date x fertilizer interaction, with an increase between May and September much greater for N_0 plots (36.2 kg N ha^{-1}) than for N_{200} (14.9 kg N ha^{-1}). Cutting in May gave significantly lower P yields than at all other dates. There was no difference in P yield between cutting in July compared with either August or September cutting. Yields of herbage K were greatest in August, both on N_0 and N_{200} plots, so that August K yield was significantly greater than for any other month averaged over fertilizer treatments (Table 24). K yield declined very significantly between August and September on N_0 plots but negligibly on N_{200} plots, due to differences in herbage K concentration (Table 23). Yields of Na and Mg increased between May and July and declined between August and September (Table 24). Yields of both elements showed peaks in July on N_{200} plots and in August on N_0 plots (Table 24). Yield of Ca in July was significantly higher than at any other date (Table 24).

When regrowth following May cutting was harvested in September dry matter yields were higher in the regrowth than in the primary growth harvested in May, particularly on N_0 plots, so that, whilst digestibility was lower, ME yields were higher (Table 25). When DM yields from 1992 regrowth were added to those of primary growth in the same year, the resulting totals exceeded those from single cuts in September 1992, both on N_0 and N_{200} plots (6.5 t ha^{-1} compared with 5.4 t and 6.9 t ha^{-1} compared with 5.4 t respectively). Total ME output was also greater, by 39% and 53% on N_0 and N_{200} plots respectively. Percentage increases in total yield of N, P, K, Na Ca and Mg were even greater, as follows: 40, 37, 93, 74, 26, 55 respectively on N_0 plots, and 66, 43, 106, 139 55 and 76 respectively on N_{200} plots.

This experiment demonstrated that in unfertilized meadows or where fertilizer use has been discontinued, there was little or no advantage in terms of ME output of cutting in late May as opposed to early July, unless added weight was given to quality of herbage rather than quantity. Delaying hay cutting from July to August incurred penalties both in terms of reduced hay quality and reduced total annual production. These particular penalties were not increased significantly by delaying cutting further until early September, although the practical limitations imposed by the reduced grazing period were not addressed.

Reversion experiment

All treatments involving the disturbance of the established vegetation caused enhanced species richness relative to control in 1992, the year following these treatments (Tallowin, Smith and Thomas, 1993) . This was due to an increase in the number of dicot species, particularly in the autumn rotovated plots. However, the overall benefit of disturbance on species richness was lost by 1993, the second year (Table 26). In 1993 there was a small increase in the number of sown species in those plots where seed had been sown. The abundance of the sown species tended to be higher in both the autumn and spring rotovated plots and in the undisturbed plots where seed had been sown compared with unsown plots (Table 27) however, this effect failed to reach significance ($p<0.071$). In 1993 very few of the sown species tended to show a positive effect of either treatment or being sown some, in fact, appeared to show a negative effect; *Filipendula ulmaria* showed a significant overall reduction in abundance in response to disturbance, only *Hypochoeris radicata* showed an overall benefit from disturbance *per se*. Of the unsown dicot species *Rumex acetosa* in particular showed a significantly reduced abundance in response to the disturbance treatments.In the first year there was a reduction in total grass cover and an increase in dicot cover in the autumn rotovated and spring herbicide treated plots but, these treatment effects were lost by 1993. In 1993 grass cover was enhanced (Table 28) and dicot cover reduced where disturbance treatments had been applied compared with the undisturbed control. The overall effect of the previous disturbance treatments on the abundance of the sown species was negative.

Conclusions

1. Agricultural output from these floristically diverse hay meadows can be predicted with reasonable precision, using a general fertilizer N response model derived from species-poor agricultural grasslands, provided that adequate P and K are supplied.
2. Where fertilizer applications were discontinued in the large-scale experiment, where P and K had been applied in replacement amounts, there were no residual effects on agricultural output.
3. Inputs of P fertilizer caused long term residual effects on the peat soil of Tadham Moor.Where high inputs of P had been used there were enhanced dry matter yields and mineral nutrient yields for at least three years after all inputs had ceased.
4. The species richness of the wet hay meadows of Tadham Moor was reduced by fertilizer input. A tall grass-dominated sward was created where plots received high N inputs. The number of flowering plants of the most attractive species declined in response to fertilizer input.
5. Grazing and in particular the disturbance caused by grazing the hay aftermath with cattle appeared to have had an important influence on maintaining the species richness of the meadows.
6. Upon cessation of fertilizer inputs there was not a significant recovery in species-richness in three years. The lack of recovery in species-richness was associated with the persistence of enhanced residues of plant available macro nutrients, particularly P.
7. Changing cutting date caused no significant increase in species-richness in the short-term. Domination of the vegetation by competitive grasses in previously fertilized meadows was not affected by either early or later cutting.
8. Disturbance and the creation of gaps in grass-dominated vegetation of previously fertilized meadows failed to enhance species-richness. Sowing seed of scarce or "lost" species either into gaps or into undisturbed vegetation failed to increase their abundance.

This project has demonstrated that hay meadow communities of the Somerset Levels and Moors lose floristic diversity with inorganic fertilizer inputs. Once damaged by fertilizer use, they do not readily recover when inputs cease and the traditional management is resumed.

Acknowledgements

This project was funded jointly by the Ministry of Agriculture, Fisheries and Food, the Department of the Environment and English Nature (formerly the Nature Conservancy Council).

Throughout the course of this project many people have been involved. The project's success, quantified by the wealth and quality of information that has been obtained, is a measure of their considerable contribution. In particular we would like to thank F.W. Kirkham who was responsible for setting up and the running of the project during the first four years, 1986-1989, and subsequently for the conduct of the cutting date experiment. We would also like to thank: R.J. Wilkins for his help and advice throughout the course of the project, C.M. Sargent who was responsible for the botanical research in the first two years of the project, R.M. Fuller who carried out the initial survey of the site, Martin Raven and the farm staff of IGER North Wyke for fencing and preparing the site for the project, Colin Lethbridge, Andrew Guscott and Andrew Luxton for assisting with fertilizer application and livestock transport, Ian and Robert Hael for diligent stock minding and help in numerous ways, and them and Trevor Hole for cutting and making the hay each year, staff from the ADAS Farm and Countryside Service for collecting rainfall and dipwell data each year, the chemistry departments at IGER Hurley and Aberystwyth for carrying out analyses on the hay, Richard Ellerton, Linda Gavin, Stephen Jones, Sarah Newman, Christine Venus, Anna Smyth, Simon Thorpe and Mike Willis for their help with the experimental work and day to day running of the project, Jo Tweweek, Sue Wilson, Sue Warr, Carry Akroyd, John Lowday, Susannah Bolton, Julian Woodman, Jacqui Green, Rory Bolton, Anne Bodley, Sarah Hancock and Anne Kelly and others who so ably assisted with the botanical surveys. Thanks are also due to David Hogan and colleagues from the Wetland Evaluation Research Project in the Department of Geography at Exeter University for conducting a soil survey on the trial site.

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Table 1 Dates for fertilizer application, hay making and grazing in each year.

Year	Fertiliser application date		Hay cutting date	Cattle on	Cattle off
	1st	2nd			
1986	14/5	23/7	1 - 2/7	15/8	15/10
1987	24/4	27/7	1 - 7/7	6/8	13/10
1988	18/4	23/8	1 - 11/8	8/9	10/10
1989	3/5	24/7	2 - 5/7	7/8	21/10
1990	3/5	7/8	9 -14/7	20/8	17/10
1991	25/4	5/9	27/7 - 9/8	11/9	5/10
1992	30/4	10/9	25/7 - 8/8	9/9	21/10
1993	6/4	-	-	-	-

Table 2 Application of nitrogen (N), phosphorus (P) and potassium (K) at four possible application dates each year. Figures represent kg ha^{-1} of N, P, K as indicated.

		Application date											
		N	P	K	N	P	K	N	P	K	N	P	K
	Treatment		1			2			3			4	
No.	N-P-K code												
T1	0 - 0 - 0	0	0	0	0	0	0	0	0	0	0	0	0
T2	0 - R - R	0	R	R	0	0	0	0	R	R	0	0	0
T3	25 - R - R	12.5	R	R	0	0	0	12.5	R	R	0	0	0
T4	50 - R - R	25	R	R	0	0	0	25	R	R	0	0	0
T5	100 - R - R	50	R	R	0	0	0	50	R	R	0	0	0
T6	200 - R -R	100	R	R	0	0	0	100	R	R	0	0	0
T7	400 - R - R	100	R	R	100	0	0	100	R	R	100	0	0
T8	400 - R - R(EC)	100	R	R	100	0	0	100	R	R	100	0	0
T9	0/100 - R - R	0	R	R	0	0	0	100	R	R	0	0	0
T10	0/200 - R - R	0	R	R	0	0	0	100	R	R	100	0	0
T11	50/100 -R -R	50	R	R	0	0	0	100	R	R	0	0	0
T12	50/200 -R - R	50	R	R	0	0	0	100	R	R	100	0	0
T13	100/200/ -R - R	100	R	R	0	0	0	100	R	R	100	0	0
T14	100 - 0 - R	50	0	R	0	0	0	50	R	R	0	0	0
T15	200 - 0- R	100	0	R	0	0	0	100	R	R	0	0	0
T16	0 - 75 - R	0	37.5	R	0	0	0	0	37.5	R	0	0	0
T17	100 - 75 -R	50	37.5	R	0	0	0	50	37.5	R	0	0	0
T18	200 - 75 - R	100	37.5	R	0	0	0	100	37.5	R	0	0	0
T19	200 - 75 -200	100	37.5	100	0	0	0	100	37.5	100	0	0	0

R denotes an element applied at 'replacement' rates. These were flat rates of 14kg P and 42 kg K ha^{-1} at date 3 in 1986 (none at preceding datein 1986), and thereafter amounts equivalent to those removed in herbage

Treatment T8 had an extra cut (EC) immediately prior to the second application date. The remaining treatments recieved their first cut (hay stage) soon before application date 3.

Application date 1 = April-May; date 2 late May-early June; date3 = immediately after hay-stage cut (first week in July all years except 1988, first week in August 1988); and date 4 = after first aftermath cut (see text for exact dates).

Treatments T1-6 = Main Series; T1-8, 14-19 = N,P,K Series; T5-7, 9-13 = Seasonal Series; and T7 & T8 = Early *vs.* Standard Cut Series.

Table 3 Mean Monthly temperatures at Tadham Moor 1987 - 1992

Month	1987 Air	1987 Soil (10cm)	1987 Soil surface	1988 Air	1988 Soil (10cm)	1988 Soil surface	1989 Air	1989 Soil (10cm)	1989 Soil surface	1990 Air	1990 Soil (10cm)	1990 Soil surface	1991 Air	1991 Soil (10cm)	1991 Soil surface	1992 Air	1992 Soil (10cm)	1992 Soil surface
Jan				6.4	6.2	6.1	6.6	6.7	6.3	7.4	6.9	6.7	(3.1)	4.7	3.5			
Feb				5.5	5.5	5.2	6.7	6.6	6.1	8.6	7.6	7.6	1.9	2.5	1.9	(5.8	5.6	5.2)
Mar				7.0	7.4	(6.9	8.0	7.7)	7.7	84	8.3	8.3	8.1	7.7	6.7	7.7	7.4	7.3
Apr	10.4	10.8	*	8.3	10.0	9.5	6.8	8.1	7.7	8.3	9.2	9.4	8.1	8.3	5.2	5.3	8.1	8.1
May	11.1	11.1	12.2	12.0	14.1	13.6	13.8	15.0	15.0	12.8	14.3	14.6	11.5	11.9	12.3	13.0	12.4	12.9
Jun	13.2	13.2	14.6	14.8	15.6	15.9	15.2	16.2	15.9	13.8	15.1	15.4	12.6	13.4	13.4	15.4	15.6	15.5
Jul	15.9	15.9	18.2	14.5	15.5	15.2	18.6	18.8	19.6	17.5	17.7	17.3	16.6	16.8	17.1	(16.7	16.7	16.6)
Aug	15.3	15.3	17.3	14.8	16.0	15.9	(16.7	17.1	18.3)	(17.6	18.3	20.3)	(18.3)	15.1	16.8			
Sep	13.6	13.6	14.5	13.2	14.3	13.4	(15.5	15.6	15.8)	12.7	14.0	12.8	14.5	15.2	14.4			
Oct	9.6	9.6	9.7	11.0	11.5	10.9	(11.6)	12.1	12.4	12.0	12.9	12.0	(14.8	11.7	10.5)			
Nov	7.2	7.2	7.1	5.0	5.9	5.1	(5.9)	8.1	6.5	7.9	8.6	7.1	(6.9	7.6	7.0)			
Dec	6.4	6.4	5.7	8.0	7.6	7.3	5.8	5.9	5.2	4.9	5.6	4.2	8.2	6.1	5.2			

Note: Bracketed figures denote some data missing

Table 4 Individual liveweight gain and grazing days per ha from the aftermath grazing in 1990, 1991 and 1992 compared with the four year mean for 1986 -1989

	Individual Liveweight gain (kg/day)				Grazing days/ha						
	1990	1991	1992	mean 1986-89	1990		1991		1992		mean 1986-89
Treatment					N+	N-	N+	N-	N+	N-	N+
N0	1.08	1.26	1.36	1.02	108	106	68	109	89	107	158
N25	0.58	1.10	1.40	0.96	172	136	151	114	111	97	195
N50	1.05	1.16	1.48	1.08	193	141	180	182	127	139	243
N100	1.22	1.27	1.35	1.01	169	169	193	138	155	127	237
N200	1.12	1.16	1.25	1.12	137	128	168	115	177	149	264
se	0.210	0.069	0.041	0.047	29.3	21.0	16.9	25.3	10.3	17.8	10.8
							**		**		***
Rep 1	1.25	1.17	1.31	0.99	210	164	156	118	114	119	239
2	1.06	1.25	1.23	1.07	174	149	156	115	132	104	213
3	0.27	1.15	1.57	1.05	83	95	144	162	148	148	206

Table 5 Dry matter yields (tonnes/DM/ha) at the hay cut in 1990, 1991 and 1992 compared with the mean yield for the years 1986-1989.

Treatment	1990 N+	1990 N-	1991 N+	1991 N-	1992 N+	1992 N-	1986-89 N+ mean
N0	3.99	4.95	5.91	5.39	5.44	5.49	5.06
N25	5.38	4.60	6.30	5.16	6.99	5.17	5.92
N50	6.53	5.26	8.45	6.60	8.59	6.92	6.44
N100	6.42	4.86	7.71	5.69	6.67	6.29	6.36
N200	6.99	5.05	8.51	5.91	8.81	5.72	6.62
se	0.49	0.458	0.355	0.436	0.495	0.488	0.264
	*		**		**		*

Table 6 Metabolizable energy (ME) produced[†] in hay in 1990, 1991, 1992 compared with the mean value for 1986 - 1989

(GJ/ha)

Treatment	1990		1991		1992		Mean 1986-89
	N+	N-	N+	N-	N+	N-	N+
N0	28.0	35.5	38.9	35.5	35.7	35.5	28.8
N25	37.5	31.7	39.0	32.6	44.9	33.6	29.9
N50	45.4	35.9	53.6	43.5	54.7	45.1	37.6
N100	45.7	35.2	48.3	36.3	42.3	41.6	36.4
N200	49.2	35.5	54.2	38.3	57.1	37.2	39.8
se	3.36	3.02	2.57	2.51	3.10	3.14	1.03
	*		**		**		***
Replicate 1	39.9	36.8	60.6	47.2	52.4	46.7	32.4
2	45.5	40.6	59.6	47.0	60.5	42.8	35.4
3	33.3	26.8	57.5	47.2	65.2	57.1	34.7

† Corrected for losses between cutting and baling

Table 7 Liveweight production (kg/ha) from aftermath grazing in 1990,1991 and 1992 compared with the four year mean for 1986/89

	1990		1992		1992		Mean 1986-89
Treatment	N+	N-	N+	N-	N+	N-	N+
NO	121	118	87	137	135	155	158
N25	138	111	166	126	170	148	187
N50	194	143	209	210	197	217	265
N100	223	203	244	177	230	194	244
N200	161	144	193	133	270	227	295
se	44.3	21.8	20.4	34.9	25.5	28.5	15.0
			**		*		***

Table 8 Total utilized metabolizable energy (UME) output (GJ/ha) from hay[†] and aftermath grazing in 1990, 1991 and 1992 compared with the four year mean for 1986-89

	1990		1991		1992		Mean 1986-90
Treatment	N+	N-	N+	N-	N+	N-	N+
N0	35.1	41.9	42.9	43.2	43.7	44.8	40.6
N25	46.9	39.1	49.1	40.1	54.6	42.9	44.5
N50	57.4	44.6	65.8	56.4	66.0	59.6	57.8
N100	60.6	49.1	63.0	47.0	57.1	53.8	53.3
N200	59.0	45.0	65.0	45.7	76.0	53.8	61.7
se	4.78	2.95	3.30	3.81	4.20	4.88	
	*		**		**		

[†] Corrected for losses between cutting and baling

TABLE 9a Concentration of Nitrogen (%N) in herbage cut for hay

Treatment	1990 N+	1990 N-	1991 N+	1991 N-	1992 N+	1992 N-
NO	1.41	1.46	1.45	1.44	1.15	1.43
N25	1.32	1.28	1.29	1.33	1.31	1.44
N50	1.30	1.18	1.31	1.36	1.59	1.36
N100	1.39	1.22	1.34	1.27	1.46	1.45
N200	1.54	1.17	1.50	1.44	1.92	1.28
se	0.080	0.062	0.075	0.043	0.079	0.095
		*			**	

Table 9b Yield (kg/ha) of Nitrogen (N) in herbage cut for hay

Treatment	1990 N+	1990 N-	1991 N+	1991 N-	1992 N+	1992 N-
N0	56.4	71.7	86.1	77.6	81.7	78.7
N25	71.4	59.3	81.7	68.8	91.5	74.5
N50	84.9	61.8	111.0	89.4	136.4	94.8
N100	89.1	59.5	103.4	72.6	97.5	91.8
N200	107.0	58.0	128.7	84.4	169.9	73.6
se	8.72	6.57	9.84	6.10	9.42	9.11
	*		*		***	

Table 10a Concentration of Phosphorus (%P) in herbage cut for hay

	1990		1991		1992	
Treatment	N+	N-	N+	N-	N+	N-
N0	0.11	0.1	0.11	0.11	0.13	0.11
N25	0.10	0.11	0.11	0.10	0.12	0.12
N50	0.11	0.10	0.11	0.12	0.14	0.12
N100	0.10	0.10	0.11	0.11	0.11	0.12
N200	0.09	0.10	0.10	0.12	0.13	0.12
se	0.007	0.005	0.006	0.004	0.009	0.003

Table 10b Yield (kg/ha) of Phosphorus (P) in herbage cut for hay

	1990		1991		1992	
Treatment	N+	N-	N+	N-	N+	N-
N0	4.24	5.24	6.79	6.14	6.83	6.05
N25	5.55	5.05	7.18	5.24	8.14	6.03
N50	7.44	5.42	9.57	7.80	12.05	6.08
N100	6.66	4.88	8.22	6.20	7.56	7.77
N200	6.50	4.93	8.81	7.17	11.46	6.93
se	0.617	0.558	0.553	0.488	0.098	0.549
	*		*	*	***	

Table 11a Concentration of Potassium (%k) in herbage cut for hay

	1990		1991		1992	
Treatment	N+	N-	N+	N-	N+	N-
N0	0.69	0.77	0.68	0.69	0.57	0.54
N25	1.27	1.21	1.17	0.98	1.04	0.72
N50	1.19	1.26	1.28	1.07	1.08	0.82
N100	1.12	1.25	1.09	0.87	0.99	0.59
N200	1.06	1.07	0.92	0.93	0.89	0.72
se	0.093	0.073	0.086	0.079	0.082	0.081
	*	**	**		*	

Table 11b Yield (kg/ha) of Potassium (K) in herbage cut for hay

	1990		1991		1992	
Treatment	N+	N-	N+	N-	N+	N-
N0	28.4	37.0	40.1	36.7	30.7	29.6
N25	67.6	54.8	73.3	50.3	73.3	38.8
N50	75.2	63.5	108.6	70.2	95.5	58.8
N100	70.9	60.9	84.5	50.5	66.8	37.0
N200	73.3	52.7	77.7	54.3	78.1	40.6
se	6.80	4.52	8.32	5.29	9.27	7.42
		*	**	*	*	

Table 12 Dry matter yield (tonnes DM/ha) from the small-scale experiment in 1990, 1991,1992 and 1993.

	1990			1991			1992			1993		
	Cut 1	Cut 2	Total	Cut 1	Cut 2	Total	Cut 1	Cut 2	Total	Cut 1	Cut 2	Total
Treatment Date	17/7	29/10		31/7	5/11		30/7	3/11		19/7	12/10	
N0,P0,K0	2.63	0.30	2.93	3.60	0.12	3.72	4.69	0.22	4.91	4.16	0.95	5.11
N0,P & K replaced	4.74	0.53	5.27	4.35	0.45	4.80	4.98	0.57	5.55	4.52	1.50	6.02
N25,P & K repaced	4.34	0.50	4.84	4.40	0.44	4.84	5.14	0.79	5.92	3.75	1.33	5.08
N50, P& K replaced	4.03	0.27	4.30	4.59	0.39	4.98	5.19	0.81	6.00	4.50	1.34	5.81
N100,P & K replaced	4.45	0.49	4.94	4.31	0.48	4.79	4.57	0.59	5.16	4.69	1.21	5.99
N200,P & K replaced	4.60	0.68	5.28	4.39	0.63	5.02	5.60	0.53	6.13	5.18	1.29	6.50
N100,P0,&K replaced	3.80	0.41	4.21	4.11	0.34	4.45	4.72	0.41	5.13	4.22	1.42	5.64
N200,P0,&K replaced	3.75	0.63	4.38	3.96	0.37	4.33	4.53	0.36	4.88	4.10	1.26	5.36
N0,P75, &K replaced	4.36	0.71	5.07	4.59	0.92	5.51	5.85	0.98	6.83	4.23	2.05	6.27
N100,P75,&Kreplaced	4.81	0.79	5.60	5.37	0.72	6.09	4.66	1.01	5.67	4.18	1.78	5.97
N200,P75,&Kreplaced	5.05	1.08	6.13	4.58	0.62	5.19	4.57	1.13	5.70	4.25	1.94	5.99
N200,P75, K200	5.39	0.91	6.30	5.49	0.78	6.27	5.33	1.14	6.46	5.61	1.76	7.07
se	0.255	0.120	0.302	0.295	0.101	0.302	0.386	0.113	0.399	0.379	0.257	0.478
	***	**	***	**	***	***		***	*			

Table 13a Concentration (%) and yield (kg/ha) of Nitrogen in the herbage from cut 1 on the small scale experiment in 1990, 1991,1992 and 1993

	1990		1991		1992		1993	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0,P0,K0	1.67	43.7	1.71	60.9	1.68	78.9	1.74	72.1
N0, P & K replaced	1.49	70.8	1.62	70.7	1.72	86.1	1.67	75.8
N25, P & K repl.	1.46	63.6	1.64	71.6	1.63	83.3	1.70	64.0
N50, P & K repl.	1.38	55.8	1.49	68.7	1.60	82.9	1.71	76.8
N100, P & K repl.	1.26	56.1	1.52	65.5	1.72	78.8	1.71	79.8
N200, P & K repl.	1.22	56.3	1.41	62.2	1.50	84.4	1.52	78.7
N100, P0 & K repl.	1.39	52.1	1.52	62.0	1.48	69.7	1.70	71.4
N200, P0, K repl.	1.37	51.2	1.53	60.5	1.67	75.4	1.69	69.0
N0, P75, K repl.	1.47	61.3	1.43	65.4	1.70	96.7	1.78	73.6
N100, P75, K repl.	1.19	57.4	1.44	77.1	1.64	76.9	1.99	83.1
N200, P75, K repl.	1.13	57.0	1.49	68.0	1.91	86.9	1.76	74.8
N200, P75, K200	1.10	59.3	1.25	68.7	1.58	85.0	1.55	87.5
se	0.103	4.14	0.075	5.36	0.089	6.15	0.087	5.35
	*	*	*					

Table 13b Concentration (%) and yield (kg/ha) of Phosphorus (P) in the herbage from cut 1 on the small-scale experiment in 1990, 1991, 1992 and 1993

	1990		1991		1992		1993	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0,P0,K0	0.15	3.9	0.16	5.8	0.14	6.6	0.14	5.6
N0, P & K replaced	0.12	5.5	0.15	6.5	0.15	7.3	0.14	6.5
N25, P & K repl.	0.12	5.3	0.15	6.4	0.14	7.2	0.14	5.3
N50, P & K repl.	0.11	4.4	0.14	6.4	0.13	6.7	0.14	6.6
N100, P & K repl.	0.11	4.9	0.15	6.3	0.14	6.6	0.14	6.3
N200, P & K repl.	0.10	4.7	0.14	6.0	0.13	7.1	0.12	6.2
N100, P0 & K repl.	0.12	4.4	0.14	5.9	0.13	6.4	0.12	5.3
N200, P0, K repl.	0.12	4.4	0.15	5.9	0.13	6.0	0.14	5.8
N0, P75, K repl.	0.28	12.1	0.34	15.4	0.27	15.4	0.32	12.7
N100, P75, K repl.	0.29	13.7	0.36	19.3	0.23	10.9	0.28	11.8
N200, P75, K repl.	0.27	13.7	0.35	16.1	0.27	12.1	0.27	11.4
N200, P75, K200	0.25	13.5	0.28	15.5	0.32	16.5	0.20	11.3
se	0.013	0.73	0.011	0.67	0.013	0.889	0.020	0.59
	***	***	***	***	***	***	***	***

Table 13c Concentration (%) and yield (kg/ha) of Potassium (K) in the herbage from cut 1 on the small scale experiment in 1990, 1991,1992 and 1993

	1990		1991		1992		1993	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0,P0,K0	0.61	16.5	0.74	26.6	0.47	22.0	0.56	24.2
N0, P & K replaced	0.82	38.8	0.78	33.9	0.62	30.6	0.49	22.3
N25, P & K repl.	0.86	37.3	0.77	33.8	0.52	26.4	0.47	17.7
N50, P & K repl.	0.85	34.7	0.76	35.3	0.52	27.0	0.44	20.0
N100, P & K repl.	0.86	38.1	0.76	32.6	0.52	23.5	0.44	20.6
N200, P & K repl.	0.97	44.5	0.79	34.5	0.52	29.1	0.49	25.5
N100, P0 & K repl.	0.84	31.7	0.80	32.9	0.66	30.6	0.52	21.9
N200, P0, K repl.	0.75	28.2	0.80	31.8	0.52	23.5	0.44	18.1
N0, P75, K repl.	0.84	36.2	0.68	31.0	0.52	30.4	0.48	19.8
N100, P75, K repl.	0.82	39.5	0.63	33.8	0.42	19.7	0.39	16.5
N200, P75, K repl.	0.72	36.3	0.58	26.5	0.42	19.1	0.51	21.6
N200, P75, K200	1.00	54.1	0.69	38.7	0.60	32.6	0.57	31.8
se	0.037	2.08	0.044	2.87	0.038	2.75	0.042	3.13
	***	***	*		**	*		

Table 14a Concentration (%) and yield (kg/ha) of Nitrogen (N),in the herbage from cut 2 on the small scale experiment in 1990, 1991, 1992 and 1993

	1990		1991		1992		1993	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0, P0, K0	1.99	5.9	2.34	2.8	2.4	5.2	2.70	25.6
NO, P & K replaced	2.16	11.3	2.44	11.0	2.5	14.6	2.53	38.0
N25, P & K repl.	2.23	11.1	2.47	10.9	2.3	18.1	2.63	35.2
N50, P & K repl.	2.19	5.7	2.53	9.9	2.3	19.0	2.75	37.9
N100, P & K repl.	2.30	11.0	2.55	12.1	2.5	15.0	2.69	31.8
N200, P & K repl.	2.00	13.4	2.34	15.0	2.2	11.6	2.42	31.7
N100, P0, K repl.	1.96	8.1	2.27	7.8	2.1	8.8	2.19	30.9
N200, P0, K repl.	2.12	13.0	2.56	9.8	2.5	8.5	2.67	33.7
N0, P75, K repl.	2.27	15.5	2.68	24.6	2.9	28.2	2.84	55.9
N100, P75, K repl.	2.41	19.3	2.84	20.3	3.1	31.1	2.95	52.6
N200, P75, K repl.	2.44	26.3	2.77	16.5	2.6	29.8	2.87	56.4
N200, P75, K200	2.33	21.2	2.53	19.5	2.9	32.9	3.02	52.3
se	0.086	2.79	0.089	2.60	0.099	3.04	0.164	6.86
	**	***	**	***	***	***		*

Table 14b Concentration (%) and yield (kg/ha) of Phosphorus (P) in the herbage from cut 2 on the small scale experiment in 1990,1991, 1992. and 1993

	1990		1991		1992		1993	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0, P0, K0	0.14	0.4	0.16	0.2	0.39	0.8	0.17	1.59
NO, P & K replaced	0.16	0.8	0.18	0.8	0.44	2.6	0.17	2.50
N25, P & K repl.	0.15	0.8	0.17	0.8	0.42	3.6	0.18	2.42
N50, P & K repl.	0.15	0.4	0.17	0.7	0.47	3.9	0.18	2.48
N100, P & K repl.	0.16	0.8	0.18	0.9	0.44	2.6	0.18	2.16
N200, P & K repl.	0.13	0.9	0.16	1.0	0.49	2.7	0.16	2.11
N100, P0, K repl.	0.14	0.6	0.15	0.5	0.39	1.6	0.14	1.99
N200, P0, K repl.	0.15	0.9	0.17	0.6	0.42	1.5	0.17	2.13
N0, P75, K repl.	0.31	2.2	0.36	3.4	0.49	4.8	0.37	7.68
N100, P75, K repl.	0.32	2.5	0.36	2.6	0.42	4.3	0.34	6.14
N200, P75, K repl.	0.34	3.6	0.36	2.2	0.42	4.8	0.36	6.98
N200, P75, K200	0.30	2.8	0.31	2.5	0.59	7.1	0.31	5.47
se	0.009	0.314	0.111	0.34	0.048	0.88	0.015	0.921
	***	***	***	***		**	***	***

Table 14c Concentration (%) and yield (kg/ha) of Potassium (K) in the herbage from cut 2 on the small scale experiment in 1990, 1991 ,1992. and 1993

	1990		1991		1992		1993	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0, P0, K0	0.47	1.4	0.52	0.6	0.95	2.1	0.49	4.66
NO, P & K replaced	0.61	3.2	0.57	2.6	0.76	4.2	0.47	7.01
N25, P & K repl.	0.59	3.0	0.55	2.5	0.75	5.5	0.45	5.94
N50, P & K repl.	0.57	1.5	0.60	2.4	0.83	6.4	0.43	5.76
N100, P & K repl.	0.59	2.8	0.60	2.8	0.81	4.7	0.39	4.72
N200, P & K repl.	0.64	4.4	0.61	3.9	0.93	4.9	0.51	6.64
N100, P0, K repl.	0.52	2.2	0.56	1.9	1.00	4.3	0.44	6.27
N200, P0, K repl.	0.59	3.7	0.59	2.2	0.69	2.5	0.44	5.49
N0, P75, K repl.	0.65	4.7	0.64	5.9	0.80	7.9	0.42	8.34
N100, P75, K repl.	0.62	4.8	0.58	4.1	0.80	8.0	0.37	6.60
N200, P75, K repl.	0.65	7.0	0.58	3.7	0.73	8.2	0.39	7.50
N200, P75, K200	0.88	7.9	0.70	5.4	0.82	9.4	0.52	8.72
se	0.037	0.90	0.025	0.67	0.071	0.98	0.030	0.94
	***	***	**	***		***		

Table 15a Difference in total N yield (kg/ha) between the treatment and the control in the small-scale experiment in 1990, 1991 , 1992. and 1993

	1990	1991	1992	1993
N0,P & K replaced	32.5	18.0	16.6	16.1
N25,P & K repl.	25.1	18.8	17.3	1.6
N50,P & K repl.	11.9	14.9	17.8	15.7
N100,P & K repl.	17.5	13.9	9.7	13.9
N200,P & K repl.	20.1	13.5	11.9	9.6
N100,P0 & K repl.	10.6	6.1	-5.6	4.6
N200,P0 & K repl.	14.6	6.6	-0.2	5.0
N0,P75 & K repl.	27.2	26.3	40.8	31.9
N100,P75 & K repl.	27.1	33.7	23.9	38.0
N200,P75 & K repl.	33.7	20.8	32.6	22.9
N200,P75,K200	30.9	24.5	33.8	35.0

Table 15b Difference in total P yield (kg/ha) between the treatment and the control in the small-scale experiment in 1990, 1991, 1992.and 1993

	1990	1991	1992	1993
N0,P & K replaced	2.0	1.3	1.4	1.7
N25,P & K repl.	1.8	1.2	2.2	0.5
N50,P & K repl.	0.5	1.1	1.2	1.8
N100,P & K repl.	1.4	1.2	1.0	1.2
N200,P & K repl.	1.3	1.0	1.0	0.8
N100,P0 & K repl.	0.7	0.4	0.1	0.1
N200,P0 & K repl.	1.0	0.5	0.2	0.6
N0,P75 & K repl.	10.0	12.8	10.9	13.2
N100,P75 & K repl.	11.9	15.9	6.6	10.8
N200,P75 & K repl.	13.0	12.3	8.3	9.9
N200,P75,K200	12.0	12.0	8.6	8.6

Table 15c Difference in total K yield (kg/ha) between the treatment and the control in the small-scale experiment in 1990, 1991 ,1992. and 1993

	1990	1991	1992	1993
N0,P & K replaced	24.1	9.3	10.7	0.5
N25,P & K repl.	22.4	9.1	7.8	-5.2
N50,P & K repl.	18.3	10.5	9.3	-3.2
N100,P & K repl.	23.0	8.2	4.1	-3.5
N200,P & K repl.	31.0	11.2	9.9	4.6
N100,P0 & K repl.	16.0	7.6	10.8	-0.6
N200,P0 & K repl.	14.0	6.8	1.9	-5.2
N0,P75 & K repl.	23.0	9.7	14.2	-0.7
N100,P75 & K repl.	26.4	10.7	3.6	-5.7
N200,P75 & K repl.	25.1	3.0	3.2	-0.3
N200,P75,K200	44.1	16.9	17.9	10.7

Table 16 Concentration (%) and yield (kg/ha) of Calcium (Ca), Magnesium and Sodium (Na) in the herbage from cut 1 on the small scale experiment in 1991,1992.and 1993

	1991						1992						1993					
	Ca		Mg		Na		Ca		Mg		Na		Ca		Mg		Na	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0, P0, K0	1.24	44.9	0.30	10.7	0.79	28.2	1.59	75.9	0.37	17.2	0.53	24.9	0.82	33.6	0.23	9.57	0.48	19.87
N0, P & K replaced	1.15	50.0	0.26	11.5	0.63	27.3	0.99	48.7	0.36	17.9	0.59	29.2	0.73	33.1	0.23	10.59	0.46	20.78
N25, P & K replaced	1.13	49.9	0.24	10.5	0.63	27.5	1.02	51.8	0.32	16.2	0.51	25.9	0.62	24.1	0.20	7.56	0.49	18.33
N50, P & K replaced	0.88	41.0	0.23	10.9	0.60	27.6	0.77	40.1	0.31	15.9	0.49	25.3	0.71	32.2	0.20	9.00	0.47	21.17
N100, P & K replaced	0.77	32.9	0.23	9.8	0.56	24.1	0.82	37.8	0.33	15.3	0.59	27.0	0.60	27.7	0.20	9.05	0.48	22.45
N200, P & K replaced	0.92	40.9	0.22	9.9	0.54	23.6	0.94	54.1	0.29	16.1	0.42	23.9	0.74	38.6	0.20	10.20	0.39	20.28
N100, PO, K replaced	1.13	46.5	0.23	9.5	0.63	25.9	0.82	39.3	0.24	11.8	0.46	22.4	0.73	30.9	0.20	8.39	0.50	21.11
N200, P0, K replaced	0.92	36.4	0.23	9.2	0.62	24.6	0.82	37.1	0.34	15.3	0.56	25.1	0.79	32.2	0.22	8.83	0.48	19.88
N0, P75, K replaced	0.91	41.3	0.27	12.1	0.67	30.6	0.90	55.1	0.39	22.6	0.53	30.2	0.61	25.3	0.23	9.63	0.41	17.22
N100, P75, K replaced	1.04	54.7	0.31	16.5	0.63	34.3	1.60	76.8	0.43	20.3	0.50	23.3	0.63	26.2	0.26	10.87	0.38	16.17
N200, P75, K replaced	1.34	60.1	0.40	18.1	0.73	33.1	1.29	58.5	0.43	19.6	0.47	21.5	0.63	26.8	0.27	11.75	0.46	19.71
N200, P75, K200	0.85	46.7	0.26	14.0	0.57	31.4	0.73	39.3	0.33	18.3	0.45	24.6	0.53	29.9	0.22	12.41	0.41	22.82
	0.092	4.71	0.012	0.95	0.044	2.25	0.232	13.15	0.026	2.05	0.038	2.54	0.074	4.35	0.020	0.986	0.026	1.941
	**	*	***	***	*	*			***								*	

Table 17 Concentration (%) and yield (kg/ha) of Calcium (Ca), Magnesium and Sodium (Na) in the herbage from cut 2 on the small scale experiment in 1991,1992.and 1993

	1991						1992						1993					
	Ca		Mg		Na		Ca		Mg		Na		Ca		Mg		Na	
Treatment	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
N0, P0, K0	1.60	2.0	0.35	0.4	0.62	0.8	0.75	1.6	0.17	0.4	0.43	0.9	1.09	10.35	0.35	3.34	0.62	5.86
N0, P & K replaced	1.97	9.0	0.39	1.7	0.63	2.8	0.63	3.5	0.18	1.0	0.42	2.4	0.84	12.57	0.31	4.70	0.52	7.76
N25, P & K replaced	1.66	7.4	0.36	1.6	0.57	2.5	0.69	5.7	0.26	1.9	0.50	3.3	0.89	11.15	0.34	4.49	0.54	7.33
N50, P & K replaced	1.55	6.0	0.35	1.4	0.58	2.3	0.59	4.8	0.18	1.4	0.38	3.1	0.83	10.89	0.30	4.17	0.58	7.92
N100, P & K replaced	1.30	6.2	0.35	1.7	0.55	2.6	0.67	4.0	0.23	1.3	0.53	3.1	0.81	9.04	0.38	4.25	0.50	5.84
N200, P & K replaced	1.48	9.3	0.33	2.1	0.51	3.3	0.56	2.9	0.17	0.9	0.36	1.9	1.01	12.90	0.34	4.42	0.54	7.02
N100, PO, K replaced	1.88	6.5	0.36	1.2	0.53	1.8	0.67	2.9	0.17	0.7	0.37	1.5	1.10	15.50	0.37	5.11	0.58	7.93
N200, P0, K replaced	1.50	5.6	0.35	1.3	0.54	2.1	0.65	2.3	0.17	0.6	0.42	1.5	0.91	11.33	0.36	4.45	0.62	7.89
N0, P75, K replaced	1.62	14.9	0.39	3.5	0.68	6.2	0.75	7.3	0.29	2.6	0.46	4.3	0.74	15.35	0.36	7.35	0.56	11.31
N100, P75, K replaced	1.61	11.6	0.42	3.0	0.66	4.8	0.68	6.8	0.28	2.8	0.57	5.7	0.79	14.06	0.41	7.46	0.51	9.05
N200, P75, K replaced	1.79	11.4	0.42	2.7	0.69	4.4	0.69	7.8	0.29	3.2	0.48	5.5	0.76	14.46	0.37	7.16	0.59	11.72
N200, P75, K200	1.62	12.4	0.41	3.3	0.62	4.9	0.69	7.9	0.32	3.6	0.55	6.3	0.76	13.37	0.38	6.64	0.68	11.61
se	0.101	1.81	0.021	0.42	0.045	0.71	0.063	0.93	0.034	0.30	0.052	0.52	0.075	2.106	0.027	0.93	0.038	1.19
	**	**		***		**		***	*	***		***	*			*		

Table 18 Species richness and diversity (number of species per plot and Simpson's Diversity Index) in May each year 1986-90

Treatment No.	N-P-K code	Mean number of species per 7.5 m^2 plot 1986	1987	1988	1989	1990	Simpson's Diversity Index 1986	1987	1988	1989	1990
T1	0-0-0	33.3	37.3	35.3	33.0	31.7	0.913	0.932	0.872	0.824	0.846
T2	0-R-R	32.0	36.7	34.7	32.7	30.3	0.930	0.938	0.884	0.899	0.900
T3	25-R-R	29.7	37.0	34.0	29.7	29.7	0.931	0.884	0.861	0.890	0.909
T4	50-R-R	30.7	37.0	32.0	29.7	30.7	0.915	0.872	0.874	0.878	0.913
T5	100-R-R	29.3	33.7	28.3	27.3	27.3	0.904	0.885	0.847	0.794	0.887
T6	200-R-R	30.0	36.0	29.7	28.7	28.3	0.899	0.879	0.864	0.872	0.875
T7	400-R-R	30.3	35.7	29.3	27.7	25.0	0.916	0.884	0.861	0.776	0.819
T8	400-R-R (EC)	32.7	31.3	28.0	26.0	24.5	0.922	0.859	0.844	0.842	0.828
T9	0/100-R-R	31.3	33.7	31.3	30.7	29.0	0.918	0.910	0.868	0.830	0.912
T10	0/200-R-R	33.0	35.7	29.0	28.0	26.0	0.922	0.880	0.879	0.883	0.866
T11	50/100-R-R	30.7	33.0	28.7	29.0	26.3	0.913	0.879	0.865	0.835	0.889
T12	50/200-R-R	30.7	32.7	27.7	27.0	26.0	0.921	0.853	0.868	0.866	0.846
T13	100/200-R-R	30.7	34.7	31.3	28.3	26.7	0.911	0.894	0.843	0.871	0.886
T14	100-0-R	28.3	36.0	33.7	32.3	27.0	0.922	0.924	0.799	0.872	0.853
T15	200-0-R	31.3	35.0	30.0	31.3	26.3	0.917	0.910	0.862	0.892	0.893
T16	0-75-R	31.3	37.0	34.7	32.0	32.7	0.917	0.921	0.889	0.807	0.873
T17	100-75-R	28.7	34.3	27.0	23.3	26.0	0.921	0.901	0.672	0.472	0.708
T18	200-75-R	29.0	31.0	27.0	19.0	18.3	0.924	0.887	0.611	0.542	0.512
T19	200-75-200	29.7	30.0	26.3	22.0	19.7	0.912	0.856	0.685	0.527	0.656
s.e. T1-6	(10)	2.15	1.91	1.36^{*}	1.39	1.87	0.0132	0.0143^{*}	0.0178	0.0138^{**}	0.0183
T1-6, 14-19	(22)	1.73	1.94	1.42^{**}	1.74^{***}	1.56^{***}	0.0102	0.0151^{*}	0.0437^{***}	0.0522^{***}	0.0463^{***}
T5-7, 9-13	(14)	1.46	2.04	1.92	1.04	1.76	0.0118	0.0134	0.0147	0.0336	0.0225
T7,8	(2)	1.03	3.52	2.32	0.47	1.93	0.0066	0.0197	0.0225	0.0383	0.0153

Asterisks denote significant treatment effects in ANOVA: * = P<0.05; ** = P<0.01; *** = P<0.001 (degrees of freedom in brackets)
See Table 1 for description of treatments.

Table 19a Species diversity (Nos. of species/plot) on the small-scale experiment in May 1993

Previous treatment	Grasses	Dicots	Carex spp.	Rush spp.†	Bryophytes	Total nos. of species/plot			
						1993	1992	1991	1990
N0, P0, K0	7.0	15.0	0.67	0.67	1.33	24.7	26.7	31.3	31.7
N0, P & K replaced	9.3	15.7	1.33	0.33	1.33	28.0	29.7	31.3	30.3
N25 P & K replaced	9.0	14.6	1.33	0.00	2.00	27.0	27.7	25.3	29.7
N50 P & K replaced	8.0	15.0	0.33	0.33	1.00	24.7	27.0	27.3	30.7
N100, P & K replaced	9.6	13.7	0.00	0.33	1.67	25.3	26.7	26.7	27.3
N200, P & K replaced	7.7	14.3	0.00	0.00	1.67	23.7	25.7	22.7	28.3
N100, P0, K replaced	9.3	16.0	1.00	0.67	2.00	29.0	28.7	28.3	27.0
N200, P0, K replaced	7.0	15.3	0.33	0.33	2.00	25.0	27.0	28.3	26.3
N0, P75, K replaced	10.0	11.7	1.00	0.67	1.00	24.3	26.3	27.7	32.7
N100, P75, K replaced	11.0	12.3	0.00	0.67	2.00	26.0	19.7	23.7	26.0
N200, P75, K replaced	8.3	9.7	0.33	0.33	1.33	20.0	16.3	19.0	18.3
N200, P75, K200	11.0	11.0	0.00	0.00	2.00	24.0	24.3	19.7	19.7
se	1.01	0.96	0.382	0.301	0.647	1.99	1.92	2.92	1.56
		**					**	p<0.088	***

† Includes *Juncus* spp., *Eleocharis palustris* and *Luzula campestris*

Table 19b Number of species per m^2 on the small-scale experiment in May 1991,1992,1993

Previous treatment	1991 No/m^2	1992 No/m^2	1993 No/m^2
N0, P0, K0	23.3	25.3	22.7
N0, P & K replaced	27.3	28.7	26.7
N25, P & K replaced	21.7	25.7	25.7
N50, P & K replaced	20.0	24.7	24.3
N100, P & K replaced	21.3	22.7	21.7
N200, P & K replaced	18.0	22.0	23.7
N100, PO, K replaced	23.7	27.0	27.7
N200, P0, K replaced	22.3	23.0	24.3
N0, P75, K replaced	23.0	24.7	22.3
N100, P75, K replaced	20.3	19.0	23.0
N200, P75, K replaced	13.3	13.7	17.7
N200, P75, K200	13.7	19.7	23.3
se	1.73	1.41	1.90
	***	***	

Table 20a Percent ground cover of different species groups on the small-scale experiment in May 1993

Previous treatment	Grasses		Dicots		Carex spp		Rush spp.[†]		Bryophytes	
N0, P0, K0	33.8	(35.4)	65.3	(54.0)	0.2	(1.4)	0.6	(3.5)	0.2	(2.1)
P & K replaced	47.8	(43.8)	51.1	(45.6)	0.1	(1.5)	0.7	(2.8)	0.3	(2.5)
N25, P & K replaced	46.0	(42.7)	53.5	(47.0)	<0.1	(0.8)	0.0	(0.0)	0.5	(3.5)
N50, P & K replaced	45.0	(42.1)	54.6	(47.7)	<0.1	(0.3)	0.3	(1.9)	<0.1	(0.7)
N100, P & K replaced	39.3	(38.4)	59.9	(51.1)	0.0	(0.0)	0.1	(1.2)	0.7	(3.8)
N200, P & K replaced	42.7	(40.6)	56.7	(49.0)	0.0	(0.0)	0.0	(0.0)	0.7	(3.2)
N100, PO, K replaced	41.8	(40.2)	54.0	(474)	0.2	(1.6)	2.1	(5.1)	2.0	(6.6)
N200, P0, K replaced	40.5	(39.5)	57.1	(49.1)	1.2	(3.6)	0.3	(1.8)	0.9	(4.8)
N0, P75, K replaced	62.0	(52.4)	37.4	(37.2)	0.4	(2.9)	<0.1	(0.4)	0.2	(1.3)
N100, P75, K replaced	65.2	(53.8)	34.0	(35.7)	0.0	(0.0)	0.1	(0.9)	0.7	(4.7)
N200, P75, K replaced	58.2	(49.8)	41.5	(40.0)	<0.1	(0.1)	<0.1	(0.1)	0.3	(2.3)
N200, P75, K200	52.4	(46.4)	47.0	(43.3)	0.0	(0.0)	0.0	(0.0)	0.5	(3.4)
se		(4.29)		(4.25)		@		@		(1.79)

[†] Includes *Juncus* spp., *Eleocharis palustris* and *Luzula campestris.*
@ Presentation of a standard error value not meaningful due to the number of zero values in the data.
() = angular transformed values

Table 20b Percent ground cover of selected grass species on the small-scale experiment in May 1993

Previous treatment	*Agrostis capillaris*		*Alopecurus pratensis*		*Anthoxanthum odoratum*		*Festuca rubra*		*Holcus lanatus*		*Poa trivialis*	
N0, P0, K0	6.4	(14.0)	0.0	(0.0)	14.7	(22.5)	7.2	(15.5)	2.3	(8.4)	0.0	(0.0)
N0, P & K replaced	4.4	(11.8)	0.2	(1.3)	29.9	(32.7)	7.8	(15.9)	1.9	(7.9)	0.0	(0.0)
N25, P & K replaced	10.2	(17.8)	0.8	(3.0)	15.6	(23.0)	13.6	(21.2)	1.7	(7.6)	0.2	(0.4)
N50, P & K replaced	7.0	(15.3)	<0.1	(0.3)	22.8	(28.5)	7.3	(15.7)	2.8	(8.7)	0.0	(0.0)
N100, P & K replaced	3.3	(9.8)	<0.1	(0.1)	12.4	(20.5)	15.9	(22.5)	1.8	(7.1)	<0.1	(0.3)
N200, P & K replaced	17.4	(23.9)	0.0	(0.0)	14.0	(21.2)	5.7	(13.2)	1.7	(6.7)	0.0	(0.0)
N100, P0, K replaced	15.1	(21.8)	0.0	(0.0)	13.9	(20.8)	4.8	(12.5)	1.4	(5.6)	0.0	(0.0)
N200, P0, K replaced	5.4	(12.7)	0.0	(0.0)	21.2	(27.1)	6.8	(14.1)	1.8	(7.6)	0.0	(0.0)
N0, P75, K replaced	7.2	(13.6)	0.6	(3.7)	22.4	(28.0)	14.3	(21.7)	10.5	(18.5)	0.9	(4.5)
N100, P75, K replaced	4.2	(11.3)	7.3	(12.8)	11.3	(19.6)	15.4	(22.1)	15.4	(22.7)	3.9	(9.5)
N200, P75, K replaced	2.6	(6.9)	1.6	(6.1)	4.9	(11.4)	30.4	(32.4)	11.3	(19.4)	1.7	(6.1)
N200, P75, K200	2.0	(7.5)	14.1	(18.2)	2.0	(7.9)	2.7	(9.5)	16.3	(22.4)	5.1	(10.1)
se		(3.41)		@		(3.47)		(3.84)		(2.8)		@
		*				**		*		***		

( ) = angular transformed values

@ Presentation of a standard error value not meaningful due to the number of zero values in the data.

Table 20c Percent ground cover of selected dicots on the small-scale experiment in May 1993

Previous treatment	*Centaurea nigra*		*Leontodon hispidus*		*Plantago lanceolata*		*Ranunculus acris*		*Rumex acetosa*	
N0, P0, K0	13.7	(20.0)	8.6	(15.9)	18.3	(25.3)	4.8	(12.4)	2.1	(7.6)
N0, P & K replaced	5.9	(13.3)	1.7	(6.7)	14.8	(21.1)	4.9	(12.5)	5.5	(13.5)
N25, P & K replaced	2.0	(8.0)	0.5	(3.2)	10.0	(18.1)	6.8	(15.1)	11.6	(18.1)
N50, P & K replaced	1.2	(6.2)	0.8	(4.1)	21.6	(27.5)	2.9	(9.8)	6.0	(14.2)
N100, P & K replaced	0.6	(2.5)	0.1	(1.3)	24.5	(29.2)	2.8	(9.1)	8.7	(17.1)
N200, P & K replaced	5.6	(13.5)	1.9	(7.3)	15.9	(23.4)	2.4	(8.6)	6.5	(14.7)
N100, PO, K replaced	14.7	(21.2)	5.7	(12.4)	13.1	(21.1)	3.2	(10.2)	2.1	(8.2)
N200, P0, K replaced	5.7	(12.0)	8.6	(14.8)	14.6	(22.0)	0.5	(3.2)	3.6	(10.9)
N0, P75, K replaced	2.7	(7.2)	0.0	(0.0)	1.9	(6.1)	6.4	(14.5)	12.3	(20.3)
N100, P75, K replaced	0.9	(4.2)	<0.1	(0.3)	1.6	(4.5)	2.6	(9.2)	15.0	(22.4)
N200, P75, K replaced	<0.1	(0.1)	0.0	(0.0)	1.0	(5.0)	2.5	(8.9)	15.3	(22.9)
N200, P75, K200	<0.1	(0.1)	0.0	(0.0)	4.8	(10.5)	3.0	(9.3)	17.5	(24.2)
se		(3.57)		@		(3.28)		(1.64)		(2.56)
		**				***		**		***

( ) = Angular transformed values

@ Presentation of a standard error value not meaningful due to the number of zero values in the data.

Table 20d Percent ground cover of selected dicots and *Carex* species on the small-scale experiment in May 1993

Previous treatment	*Taraxacum officinale*		*Leontodon autumnalis*		*Trifolium pratense*		*Carex disticha*	
N0, P0, K0	2.5	(8.9)	4.8	(10.1)	3.2	(10.2)	0.0	(0.0)
N0, P & K replaced	1.3	(6.4)	1.2	(4.9)	3.6	(10.7)	0.1	(1.0)
N25, P & K replaced	1.5	(6.1)	1.0	(4.1)	2.9	(9.5)	<0.1	(0.6)
N50, P & K replaced	1.4	(5.8)	1.2	(5.0)	4.3	(11.8)	<0.1	(0.3)
N100, P & K replaced	1.4	(5.7)	0.7	(2.9)	1.4	(6.4)	0.0	(0.0)
N200, P & K replaced	2.4	(8.4)	0.8	(4.5)	3.3	(10.4)	0.0	(0.0)
N100, PO, K replaced	5.4	(13.4)	2.6	(9.1)	2.9	(9.7)	0.0	(0.0)
N200, P0, K replaced	3.7	(10.7)	1.6	(7.4)	2.8	(9.5)	0.0	(0.0)
N0, P75, K replaced	1.8	(6.1)	0.3	(1.8)	0.1	(1.0)	0.3	(2.5)
N100, P75, K replaced	0.5	(2.5)	0.0	(0.0)	<0.1	(0.3)	0.0	(0.0)
N200, P75, K replaced	0.3	(2.6)	0.0	(0.0)	<0.1	(0.4)	<0.1	(0.1)
N200, P75, K200	0.7	(4.1)	0.2	(1.3)	<0.1	(0.1)	0.0	(0.0)
se		(1.56)		(2.14)		(0.89)		@
		**		*		***		

( ) = Angular transformed values

@ Presentation of a standard error value not meaningful due to the number of zero values in the data.

Table 21 The influence of previous fertilizer treatment 1986-90 (N_0 and N_{200}) and different cutting dates in 1991 and 1992 on species richness and diversity in May 1991,1992 and 1993.

Fertilizer	Cutting date	Species richness (no. of species per plot)			Species diversity (Shannon-Wiener Index)		
		1991	1992	1993	1991	1992	1993
N_0	May	32.3	29.8	31.4	3.93	3.68	3.49
	Jul	28.3	34.2	34.7	3.68	3.75	3.54
	Aug	33.7	33.8	37.2	4.10	3.97	3.94
	Sep	31.7	32.1	32.9	3.89	3.80	3.62
N_0 mean		31.6	31.9	33.4	3.90	3.78	3.67
N_{200}	May	24.5	22.8	23.8	3.54	3.37	2.99
	Jul	23.7	25.0	27.5	3.65	3.54	3.47
	Aug	25.2	25.0	25.8	3.62	3.53	3.71
	Sep	24.8	25.9	26.9	3.63	3.63	3.23
N_{200} mean		24.6	24.6	25.8	3.60	3.51	3.27
Mean N_0/N_{200}	May	28.4	26.3	27.6	3.73	3.53	3.24
"	Jul	26.0	29.6	31.1	3.67	3.65	3.65
"	Aug	29.4	29.4	31.5	3.86	3.75	3.83
"	Sep	28.2	29.0	29.9	3.76	3.72	3.43
SED N means		2.55	3.08	3.06	0.278	0.240	0.157
SEDs C-date means:							
May v Sep		1.15	1.01	0.93	0.084	0.066	0.091
Jul v Aug		1.62	1.42	1.32	0.119	0.094	0.128
May/Sep v Jul/Aug		1.40	1.23	1.14	0.103	0.081	0.111
			*	**		*	***

Asterisks denote significant treatment effects in ANOVA: * = P<0.05; ** = P<0.01; *** = P<0.001
(SEDs for Cutting date x fertilizer interaction not shown since interaction was not significant)
See text for formulae for calculation of Shannon Wiener Index

Table 22. The effect of previous fertilizer treatment 1986-90 (N_0 and N_{200} - see text) and different cutting dates on DM production, digestibility (*in vitro* DOMD), ME value and ME output of herbage harvested, averaged over two years 1991 and 1992.

Fertilizer	Cutting date	DM yield (t ha^{-1})	DOMD	ME value (MJ kg^{-1})	ME output (GJ ha^{-1})
N_0	May	1.68	61.7	10.2	16.7
	Jul	4.72	55.4	8.9	41.8
	Aug	5.48	50.9	8.2	44.7
	Sep	5.73	50.2	8.1	46.6
N_0 mean		4.17	55.0	9.0	35.5
N_{200}	May	2.64	63.7	10.5	27.4
	Jul	5.71	52.8	8.3	47.7
	Aug	6.12	47.6	7.7	46.9
	Sep	6.17	48.6	7.9	48.8
N_{200} mean		4.91	54.2	8.8	41.1
Mean N_0/N_{200}	May	2.16	62.7	10.3	22.0
"	Jul	5.22	54.1	8.6	44.8
"	Aug	5.80	49.2	7.9	45.8
"	Sep	5.95	49.4	8.0	47.7
SED fertilizer means:		0.191	0.23	0.06	1.38
SEDs C-date means:					
May v Sep		0.172	0.50	0.08	1.50
Jul v Aug		0.243	0.71	0.12	2.12
May/Sep v Jul/Aug		0.210	0.61	0.10	1.84
		***	***	***	***
SEDs C-date x fertilizer:					
(1) Same level N					
May v Sep		0.243	0.71	0.12	2.12
Jul v Aug		0.343	1.00	0.17	3.00
May/Sep v Jul/Aug		0.298	0.86	0.14	2.60
(2) Others:					
May v Sep		0.276	0.62	0.11	2.22
Jul v Aug		0.367	0.94	0.16	3.00
May/Sep v Jul/Aug		0.325	0.80	0.14	2.60
			***	***	*

Asterisks denote significance of treatment effects in ANOVA:
* = $P<0.05$; *** = $P<0.001$

Table 23. The effect of previous fertilizer treatment 1986-90 (N_0 and N_{200} - see text) and different cutting dates on the concentration of six minerals in herbage DM, averaged over two years 1991 and 1992.

Fertilizer	Cutting date	Mineral concentration %N	%P	%K	%Na	%Ca	%Mg
N_0	May	2.34	0.13	0.75	0.60	0.69	0.23
	Jul	1.60	0.11	0.68	0.58	0.81	0.23
	Aug	1.46	0.12	0.73	0.60	0.65	0.22
	Sep	1.55	0.12	0.52	0.55	0.69	0.20
N_0 mean		1.81	0.12	0.66	0.58	0.70	0.22
N_{200}	May	2.33	0.14	1.18	0.51	0.59	0.22
	Jul	1.32	0.12	0.70	0.54	0.72	0.21
	Aug	1.38	0.12	0.84	0.46	0.56	0.18
	Sep	1.53	0.13	0.83	0.37	0.56	0.18
N_{200} mean		1.74	0.13	0.93	0.46	0.56	0.20
Mean N_0/N_{200}	May	2.34	0.14	0.96	0.56	0.64	0.22
"	Jul	1.46	0.12	0.69	0.56	0.76	0.22
"	Aug	1.42	0.12	0.79	0.53	0.61	0.20
"	Sep	1.54	0.12	0.67	0.46	0.62	0.19
SED fertilizer means:		0.038	0.004	0.097	0.030	0.031	0.011
SEDs C-date means:							
May v Sep		0.051	0.003	0.038	0.017	0.025	0.006
Jul v Aug		0.072	0.004	0.053	0.024	0.035	0.009
May/Sep v Jul/Aug		0.063	0.003	0.046	0.020	0.031	0.008
		***	***	***	***	***	***
SEDs C-date x fertilizer means:							
(1) Same level N							
May v Sep		0.072	0.004	0.053	0.024	0.035	0.009
Jul v Aug		0.103	0.005	0.075	0.033	0.050	0.013
May/Sep v Jul/Aug		0.089	0.005	0.065	0.029	0.043	0.011
(2) Others:							
May v Sep		0.070	0.005	0.107	0.036	0.043	0.013
Jul v Aug		0.101	0.006	0.119	0.043	0.055	0.016
May/Sep v Jul/Aug		0.087	0.006	0.113	0.040	0.049	0.015
			*	***	**		

Asterisks denote significance of treatment effects in ANOVA:
* = $P<0.05$; ** = $P<0.01$; *** = $P<0.001$

Table 24. The effect of previous fertilizer treatment 1986-90 (N_0 and N_{200} - see text) and different cutting dates on the herbage yield of six minerals N, P and K (kg ha^{-1}) in 1991 and 1992

		Mineral yield (kg ha^{-1})					
Fertilizer	Cutting date	N	P	K	Na	Ca	Mg
N_0	May	38.5	5.0	28.6	27.9	32.4	9.1
	Jul	74.7	6.5	38.7	33.4	45.8	12.7
	Aug	79.9	7.3	46.2	36.4	40.0	13.2
	Sep	88.9	6.9	30.0	32.1	39.9	11.5
N_0 mean		68.2	6.3	33.7	31.7	38.4	11.2
N_{200}	May	60.6	6.5	54.2	24.7	31.1	9.9
	Jul	75.5	7.3	44.7	34.6	44.8	13.0
	Aug	84.0	7.3	53.6	28.4	35.1	11.3
	Sep	93.7	7.8	51.8	23.1	35.3	10.9
N_{200} mean		78.0	7.2	51.7	26.5	35.4	11.0
Mean N_0/N_{200}	May	49.5	5.8	41.4	26.3	31.8	9.5
"	Jul	75.1	6.9	41.7	34.0	45.3	12.9
"	Aug	82.0	7.3	49.9	32.4	37.5	12.3
"	Sep	91.3	7.4	40.9	27.7	37.6	11.2
SED fertilizer means:		1.19	0.21	6.08	2.13	2.51	0.10
		*	*				
SEDs C-date means:							
May v Sep		3.65	0.27	2.41	1.31	1.55	0.39
Jul v Aug		5.16	0.38	3.40	1.85	2.19	0.56
May/Sep v Jul/Aug		4.47	0.33	4.17	1.60	1.89	0.48
		***	***	*	***	***	***
SEDs C-date x fertilizer means:							
(1) Same level N							
May v Sep		5.16	0.38	3.40	1.85	2.19	0.56
Jul v Aug		7.30	0.54	4.80	2.62	3.09	0.79
May/Sep v Jul/Aug		6.32	0.47	4.17	2.27	2.68	0.68
(2) Others:							
May v Sep		4.38	0.38	6.69	2.61	3.08	0.47
Jul v Aug		6.77	0.54	7.50	3.20	3.78	0.72
May/Sep v Jul/Aug		5.71	0.47	7.11	2.92	3.45	0.61
		*		**	**		*

Asterisks denote significance of treatment effects in ANOVA:
* = P<0.05; ** = P<0.01; *** = P<0.001

Table 25. Dry matter yield, *in vitro* digestibility (%DOMD), ME production and yield of herbage N, P, K, Na, Ca and Mg in regrowth between 26 May and 1 September in 1992.

Previous fertilizer treatment	t DM ha^{-1}	DOMD	ME (GJ ha^{-1})	Yield of minerals (kg ha^{-1})					
				N	P	K	Na	Ca	Mg
N_0	4.09	54.3	36.3	76.0	6.4	25.3	23.1	21.9	10.8
N_{200}	3.83	54.4	34.0	72.8	6.4	33.6	17.0	21.8	9.9
SED	0.445	0.52	3.92	7.61	0.68	4.62	2.40 *	2.71	0.97

* = significant treatment effect in ANOVA, P<0.05

Table 26. The effect of either autumn rotovation (RA), spring rotovation (RS) or spring herbicide treatment (H) with (+) or without (-) seed of different dicotyledinous and carex species, on number of species per 25 x 25cm quadrat in June 1993. Undisturbed = undisturbed area of each plot.

		RA	RS	H	Control	Significance
Total diversity	+	15.4	14.9	15.2	15.6	NS effect of time and type of disturbance or seed introduction. NS effect of disturbance versus no disturbance
	-	14.4	14.7	15.5	14.5	
	Undisturbed	14.3	15.0	15.0		
Sown species	+	3.4	3.5	3.1	3.7	* effect of seed introduction NS effect of time and type of disterbance
	-	2.8	3.0	2.9	2.9	
Grass		6.9	7.6	7.1		NS effect of time and type of disturbance or seed introduction. NS effect of disturbance versus no disturbance
	Undisturbed	6.3	7.3	7.0	6.9	
Dicotyledons	+	7.8	7.8	7.8	8.7	NS effect of time and type of disturbance or seed introduction. or of disturbance versus no disturbance
	-	7.7	7.3	7.9	7.1	
	Undisturbed	7.8	7.6	7.7		
Carex	+	<0.1	0.0	0.0	0.1	Because of the number of zero values it was not valid to test for significant differences between treatments
	-	<0.1	0.0	<0.1	<0.1	
	Undisturbed	0.1	<0.1	0.00		
Juncus	+	0.1	<0.1	<0.1		NS effect of time and type of disturbance NS effect of disturbance xno disturbance
	Undisturbed	<0.1	<0.1	<0.1	<0.1	
Bryophytes	+	0.2	0.2	0.3		NS effect of time and type of disturbance NS effect of disturbance versus no disturbance
	Undisturbed	<0.1	0.1	0.2	<0.1	

Table 27. The effect of either autumn rotovation (RA), spring rotovation (RS) or spring herbicide treatment(H) on % cover of dicotyledonous species with (+), or without (-) added seed, (per 25 x25cm quadrat) in June 1993. Undisturbed = untreated area of each plot.

		RA	RS	H	Control	Significance
Dicotyledons	+	42.16	44.6	38.0	56.0	NS effect of time & type of disturbance * effect of disturbance versus no disturbance
	-	43.5	38.0	48.1	53.0	NS effect of seed introduction
	Undisturbed	45.9	52.5	48.7		
Sown species	+	26.0	26.1	19.2	23.6	p<0.071 effect of disturbance versus no disturbance
	-	22.6	25.2	27.4	20.6	
	Undisturbed	25.2	31.5	29		
Filipendula ulmaria	+	4.9	8.9	5.3	8.7	* effect of time & type of disturbance x no disturbance interaction
	-	4.9	13.3	8.1	9.1	* effect of disturbance versus no disturbance
	Undisturbed	7.7	12.7	14.4		
Hypochoeris radicata	+	0.1	0.6	1.2	0.0	* effect of disturbance versus no disturbance
	-	0.2	0.0	0.0	0.0	
	Undisturbed	<0.1	0.0	<0.1		
Leontodon autumnalis	+	<0.1	0.8	0.0	0.9	* seed introduction x disturbance/no disturbance
	-	0.8	0.0	0.4	0.2	
	Undisturbed	0.0	0.9	0.0		
Ranunculus acris		2.5	0.7	3.6		** effect of disturbance versus no disturbance
	Undisturbed	2.6	1.3	2.5	2.3	
Rumex acetosa		6.5	5.2	6.0		* effect of time & type of disturbance * effect of disturbance versus no disturbance
	Undisturbed	9.8	6.1	6.6	10.2	
Taraxacum agg.		3.4	2.8	4.9		* time/type of disturbance x disturbance/no disturbance
	Undisturbed	3.3	5.0	2.9	3.5	
Trifolium repens		0.2	0.4	0.3		NS effect of time & type of disturbance
	Undisturbed	0.6	0.5	0.4	0.4	

Analysis of variance carried out on angular transformations of the data. True means are presented in the table

Table 28 The effect of either autumn rotovation (RA), spring rotovation (RS) or spring herbicide treatment (H) on % grass cover (per 25 X 25cm quadrat) in June 1993. Undisturbed = untreated area of each plot

		RA	RS	H	Control	Significance
Grass total		55.5	58.2	56.7		NS effect of time and type of disturbance
	Undisturbed	53.7	47.5	51.1	54.5	* effect of disturbance versus no disturbance
Agrostis capillaris		11.8	11.0	10.0		NS effect of time and type of disturbance
	Undisturbed	14.6	10.0	7.9	15.2	NS effect of disturbance versus no disturbance
Anthoxanthum odoratum		18.2	20.0	17.6		NS effect of time and type of disturbance
	Undisturbed	19.1	15.7	16.2	19.0	NS effect of disturbance versus no disturbance
Bromus mollis		0.8	0.9	1.7		NS effect of time and type of disturbance
	Undisturbed	0.3	1.0	1.0	0.6	NS effect of disturbance versus no disturbance
Cynosurus cristatus		3.4	3.6	2.9		NS effect of time and type of disturbance
	Undisturbed	3.6	2.6	4.0	2.6	NS effect of disturbance versus no disturbance
Festuca rubra		0.1	0.4	0.1		NS effect of time and type of disturbance
	Undisturbed	0.4	0.1	0.1	0.2	NS effect of disturbance versus no disturbance
Holcus lanatus		8.6	8.9	11.5		NS effect of time and type of disturbance
	Undisturbed	7.0	8.9	9.1	7.2	NS effect of disturbance versus no disturbance
Poa trivialis		0.7	0.9	1.2		* effect of disturbance versus no disturbance
	Undisturbed	0.0	0.1	0.5	0.2	NS efect of time and type of disturbance
Lolium perenne		5.1	7.3	8.0		NS effect of time and type of disturbance
	Undisturbed	3.5	6.0	6.8	5.5	NS effect of disturbance versus no disturbance
Phleum pratense		2.6	3.1	1.6		* time and type of disturbance x disturbance
	Undisturbed	2.2	1.9	3.4	2.8	versus no disturbance interaction

Analysis of variance carried out on angular transformations of the data. True means are presented in the table

Figure 1. Plan of Tadham Moor site.

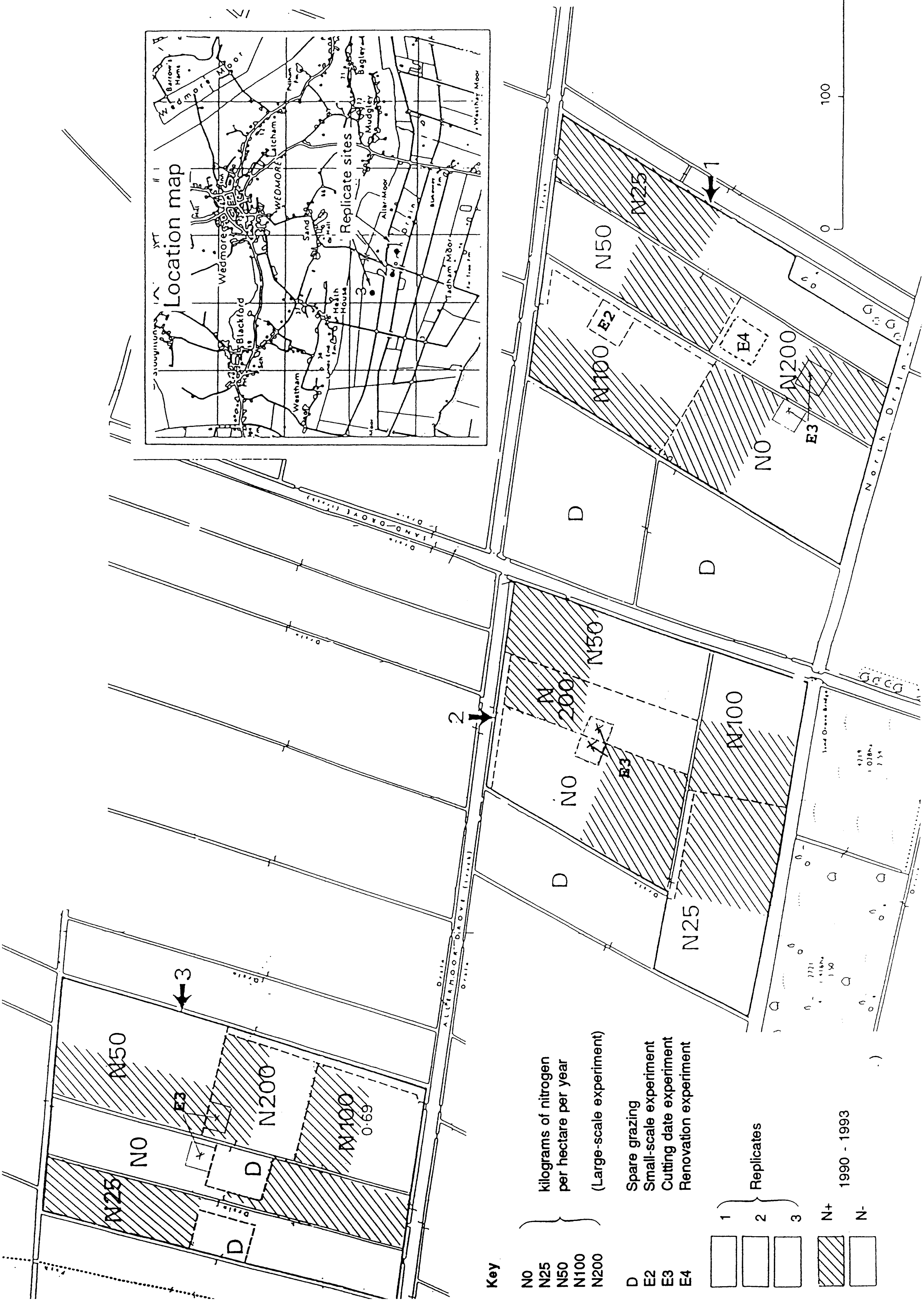

Fig. 2a Rainfall 1986-1992

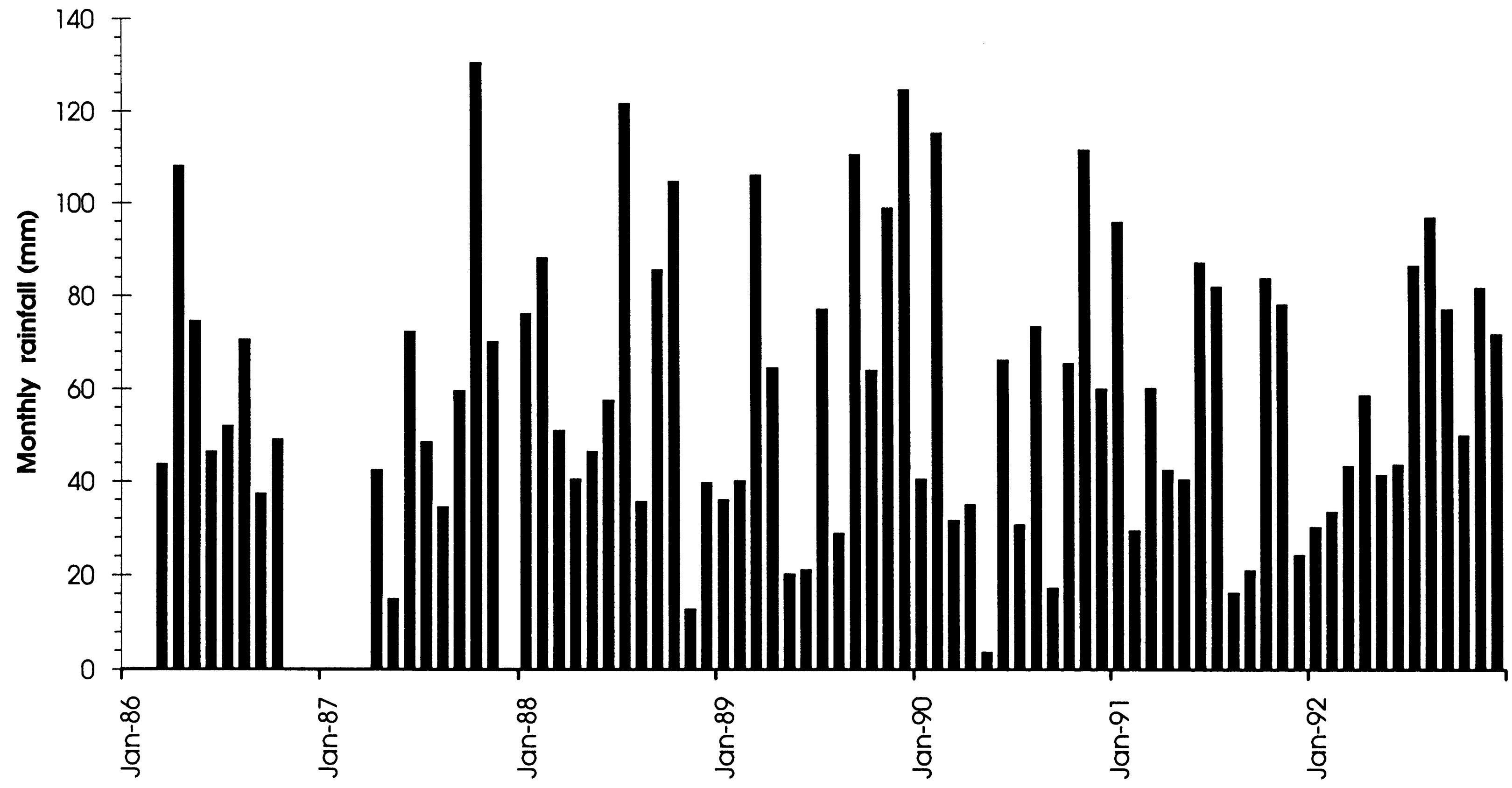

Fig. 2b Mean monthly temperatures at Tadham Moor April 1986 - July 1992

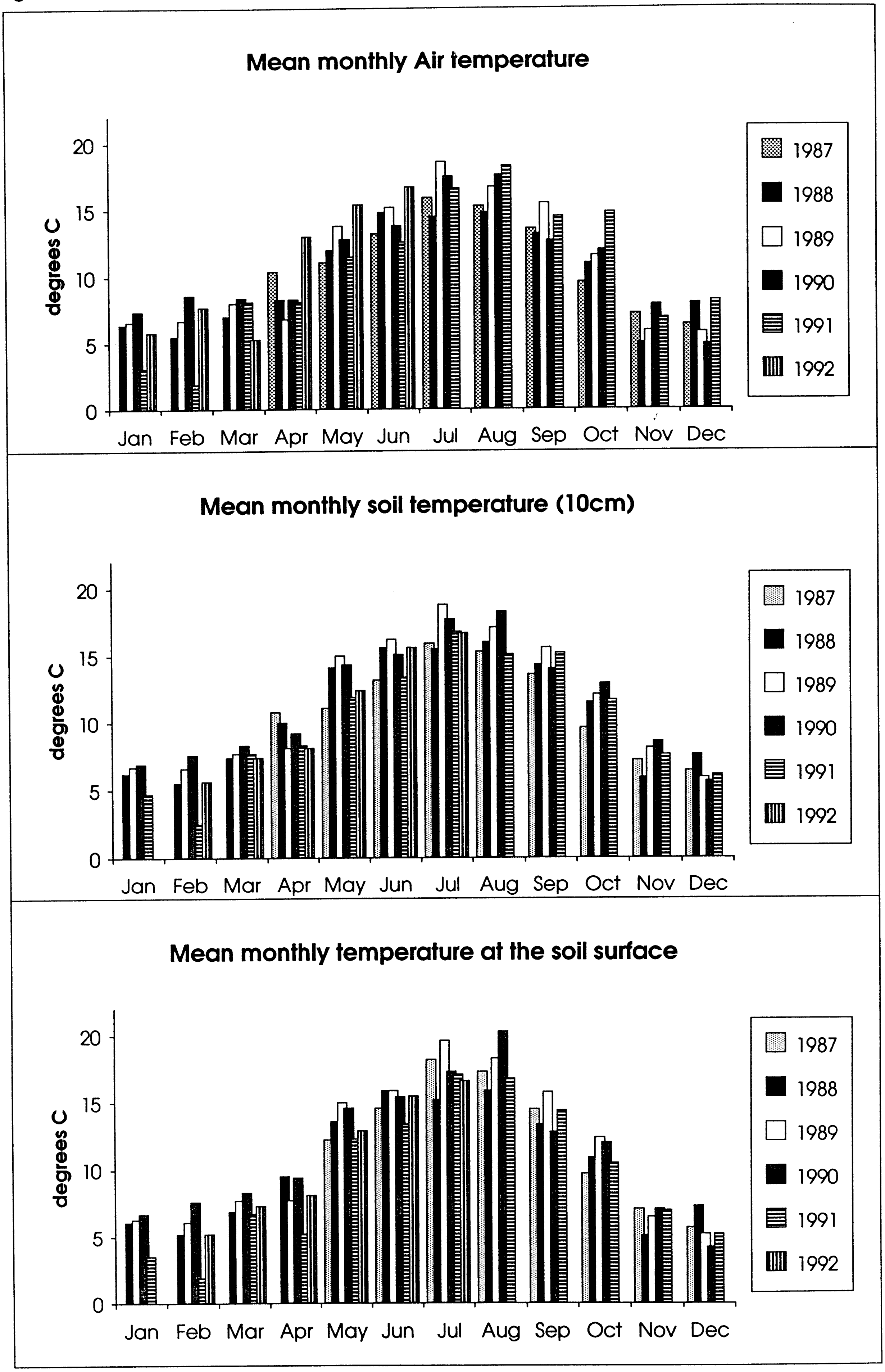

Fig. 3 Water table depth (weekly mean of all plots) 1986 - 1992

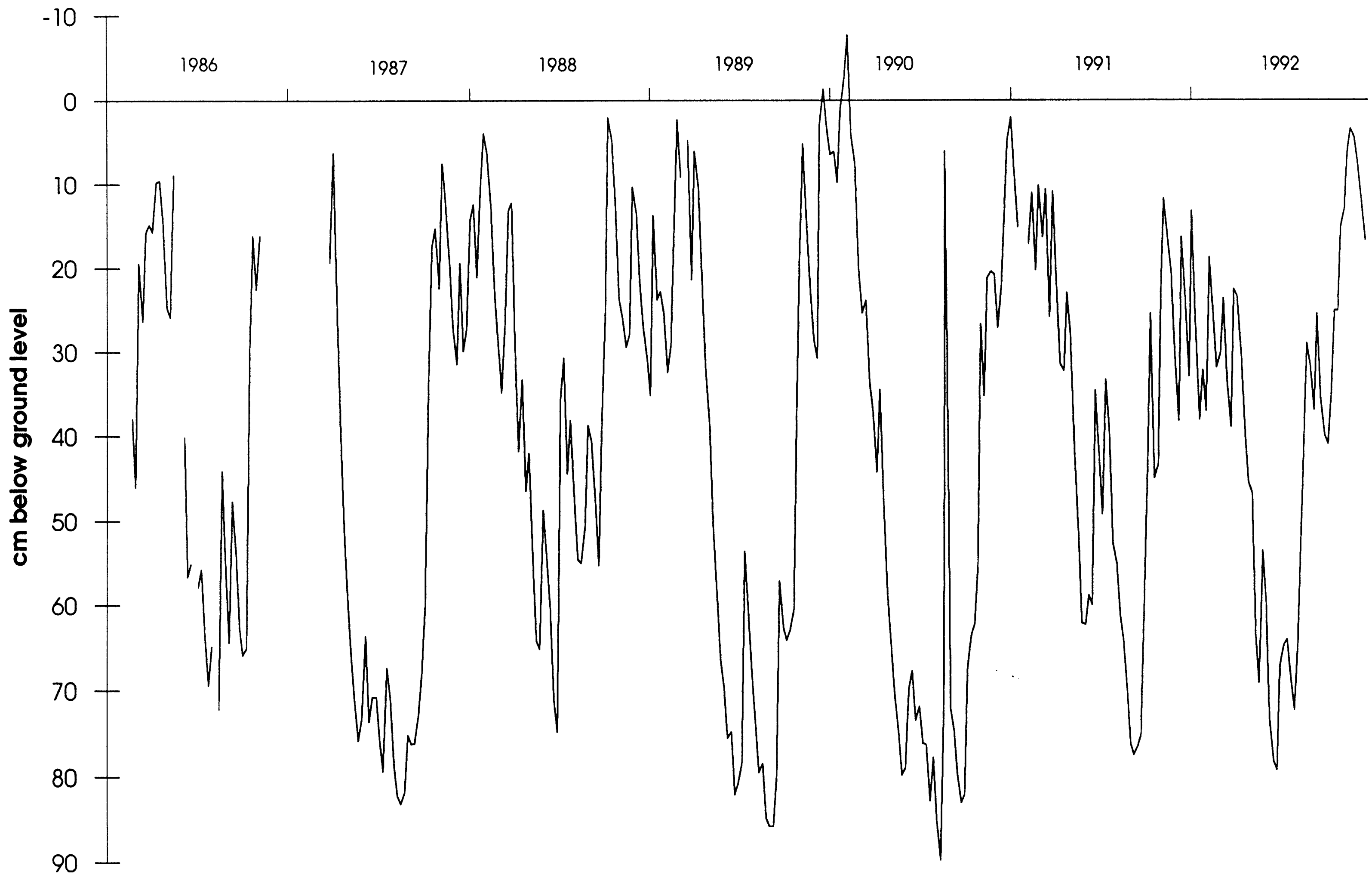

Fig. 4 Hay dry matter yields

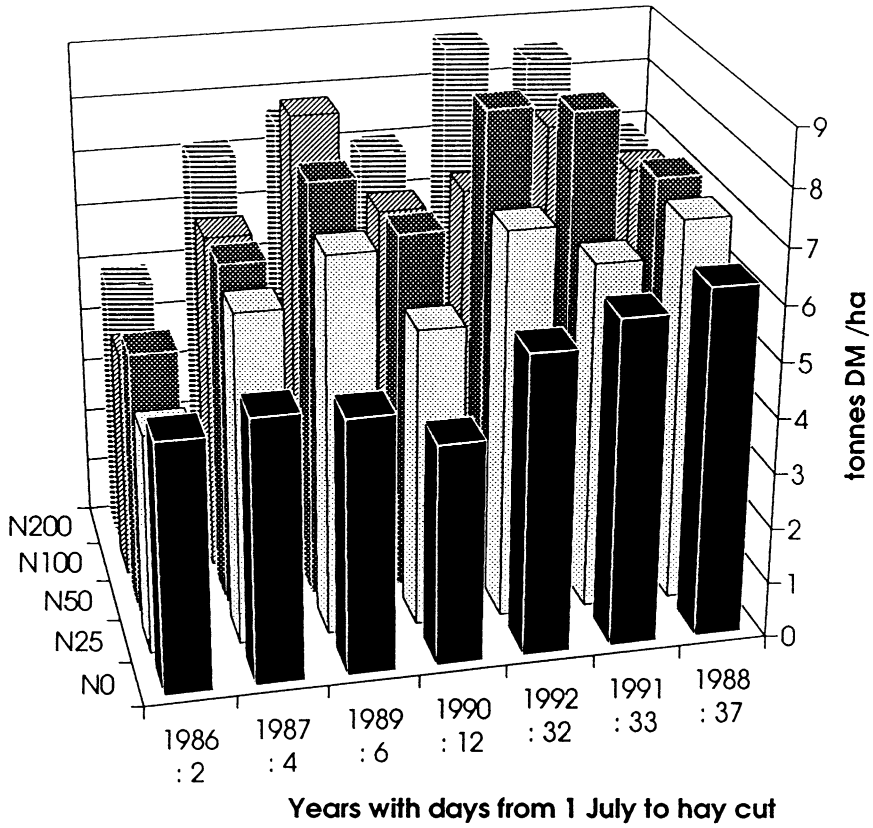

Fig. 5 Hay yield and total dry matter production

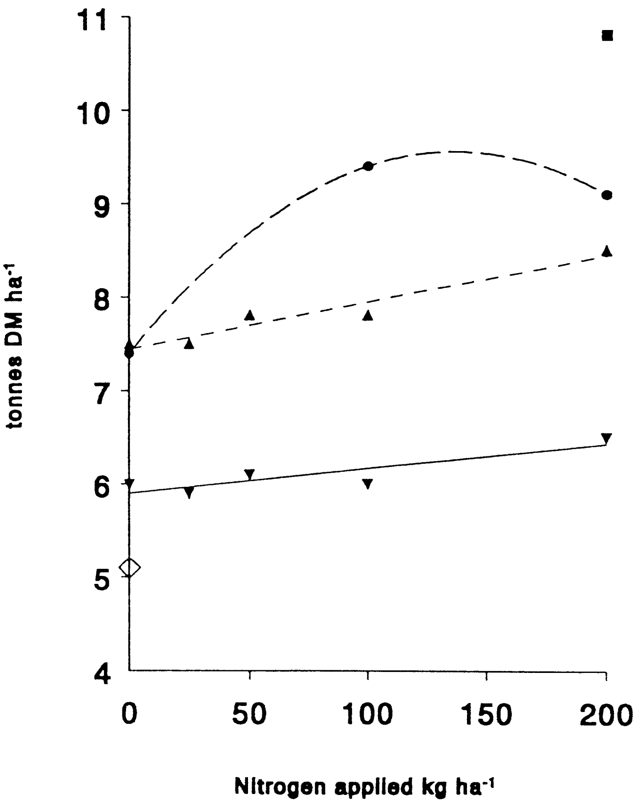

Fig. 6 Metabolizable energy value of hay

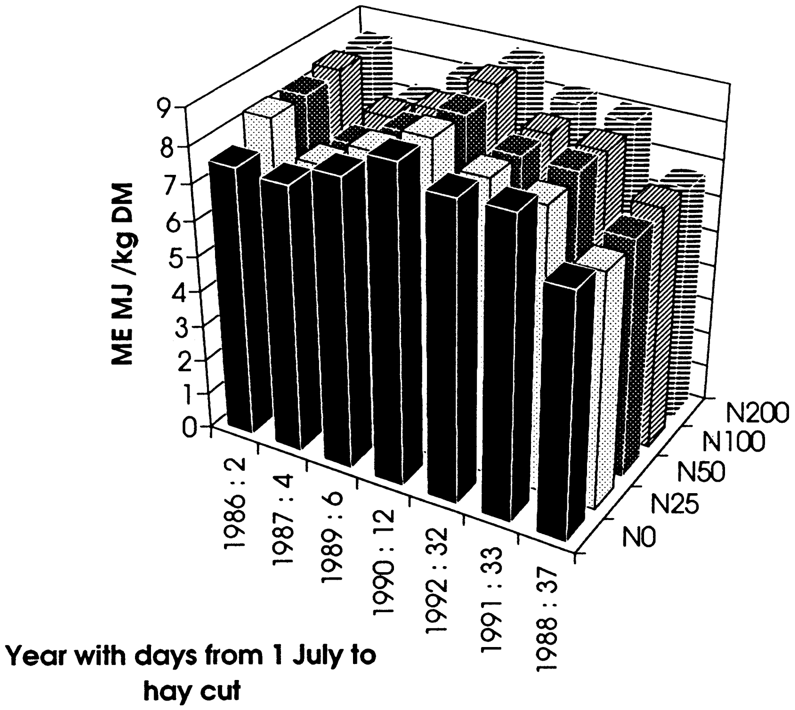

Fig. 7 Metabolizable energy produced at hay cut

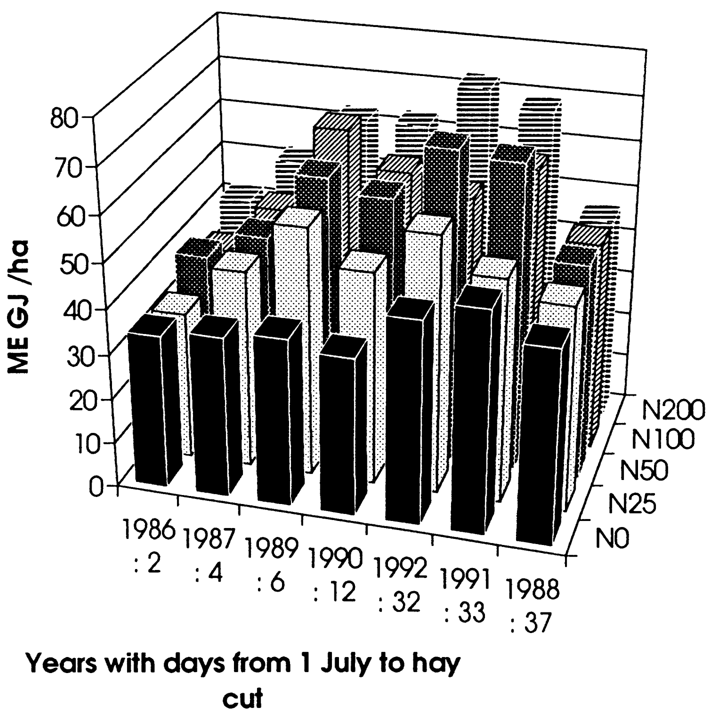

Fig. 8 Percent N content in hay

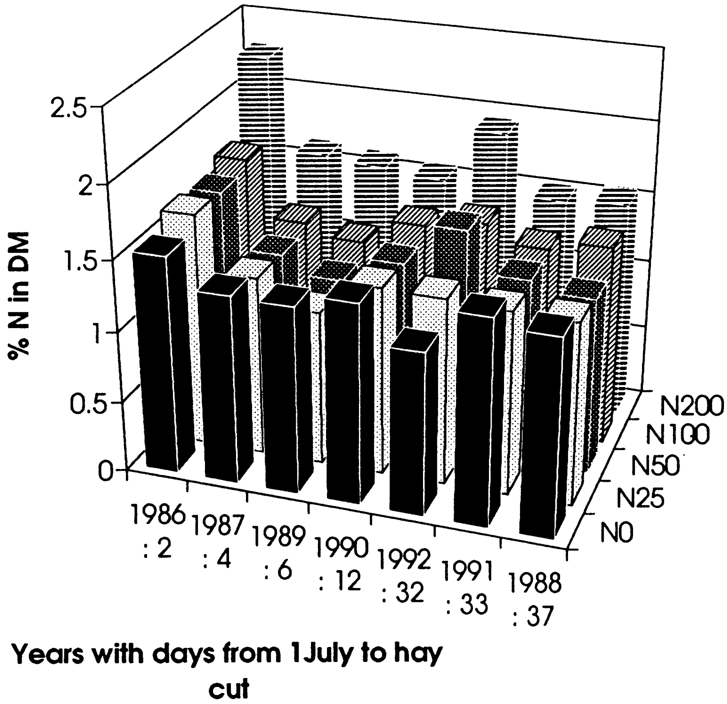

Fig. 9 Yield of N in the hay crop

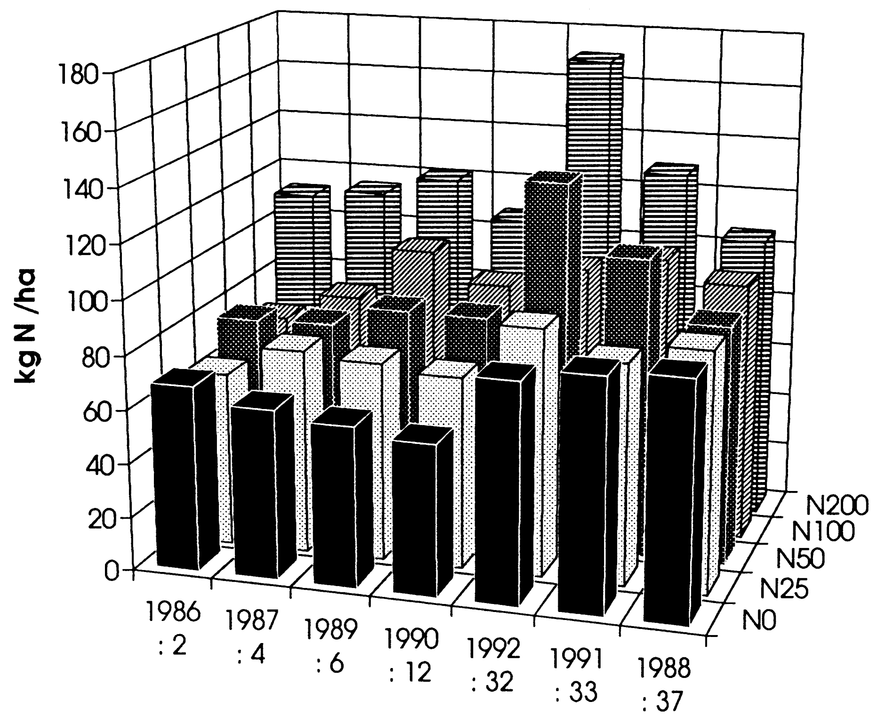

Fig. 10 Yield of P in hay crop

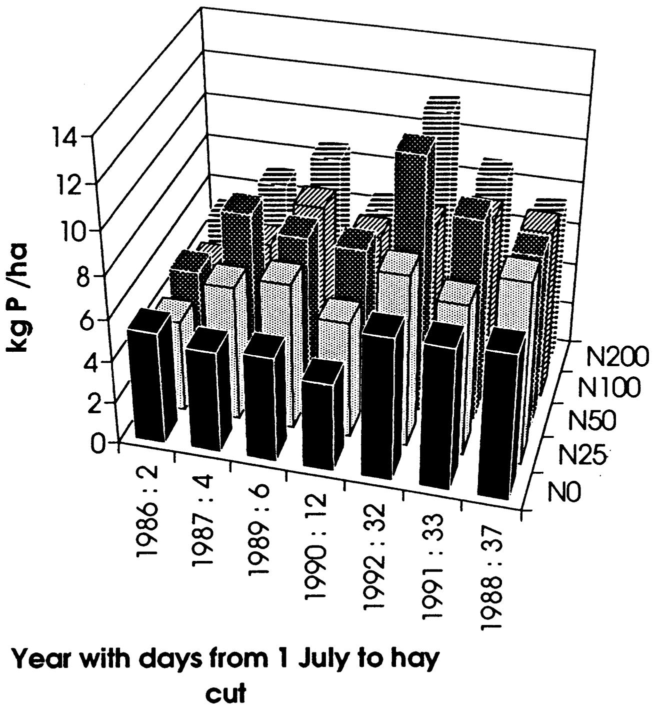

Fig. 11 Percent K content in the hay crop

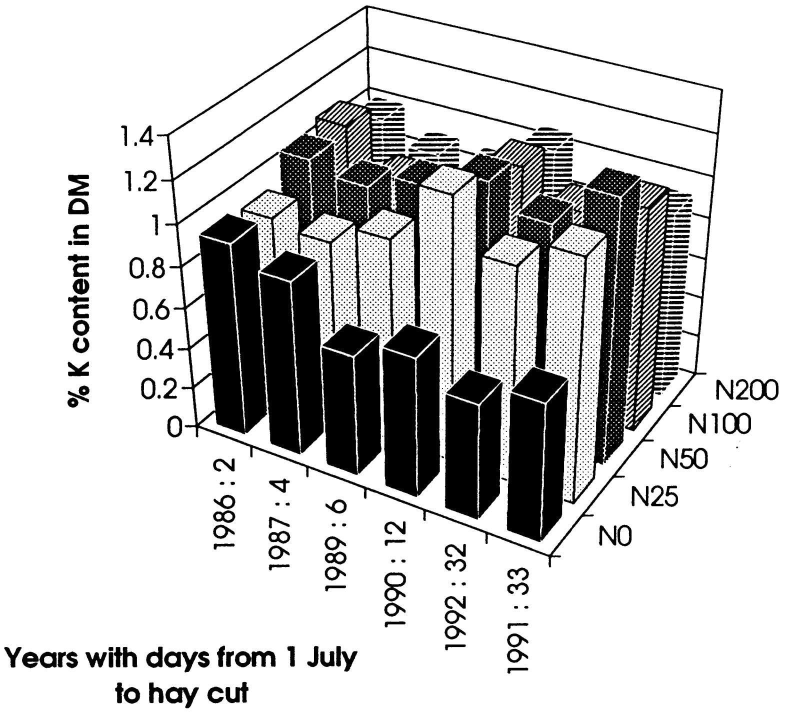

Fig. 12 Yield of K in hay crop

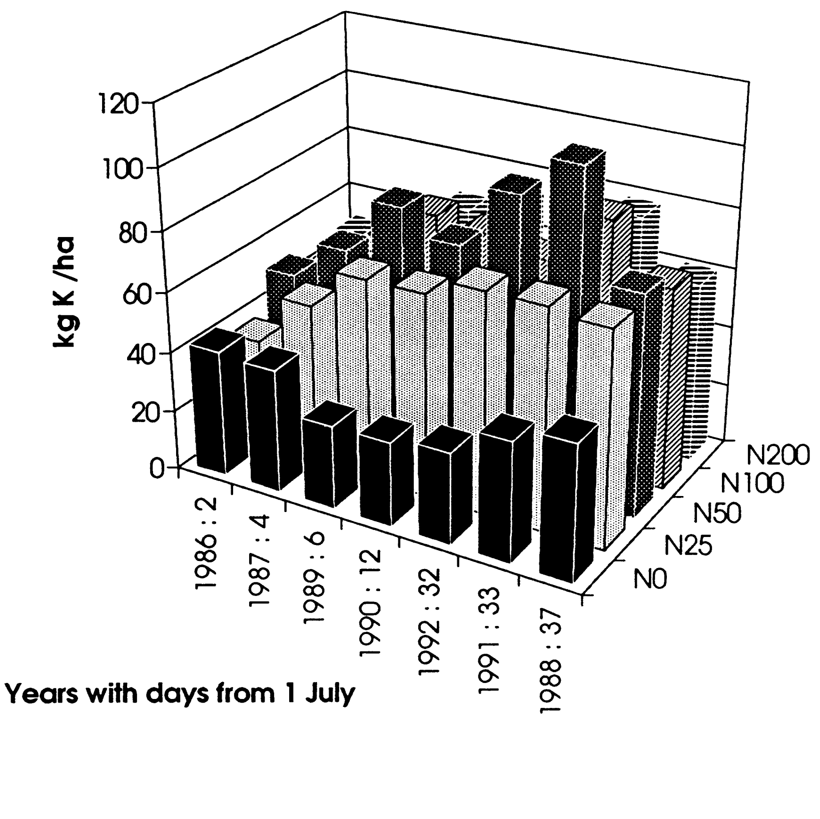

Fig. 13 Grazing days per hectare

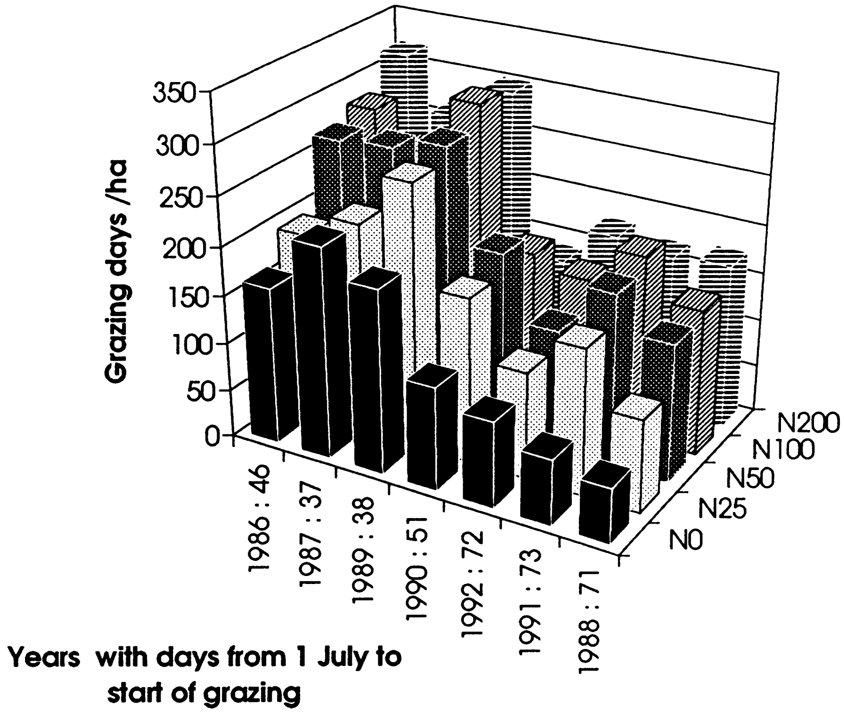

Fig. 14 Liveweight produced per hectare

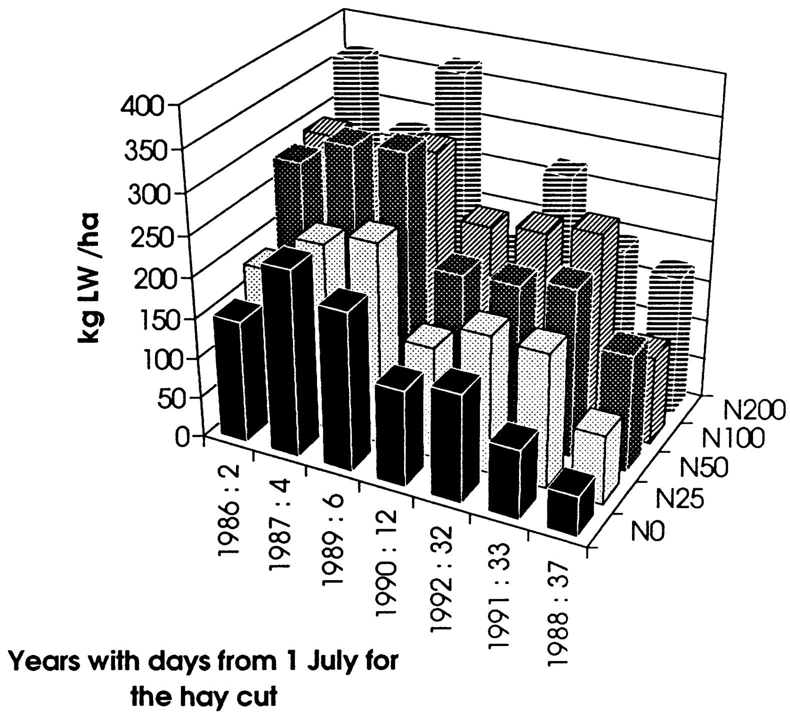

Fig. 15 Utilized metabolizable output from grazing

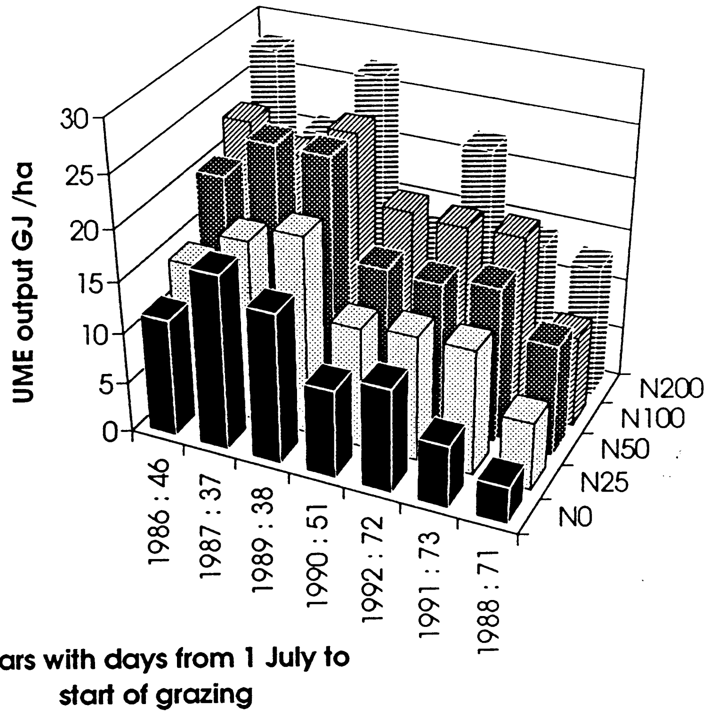

Fig. 16 UME output from hay and aftermath grazing

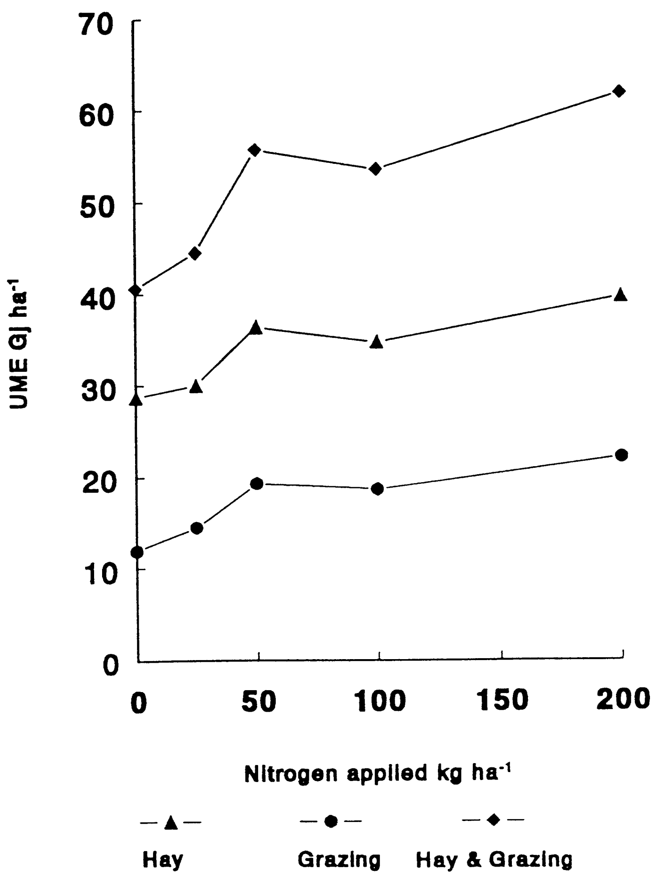

Fig. 17 Total dry matter yield in small-scale experiment

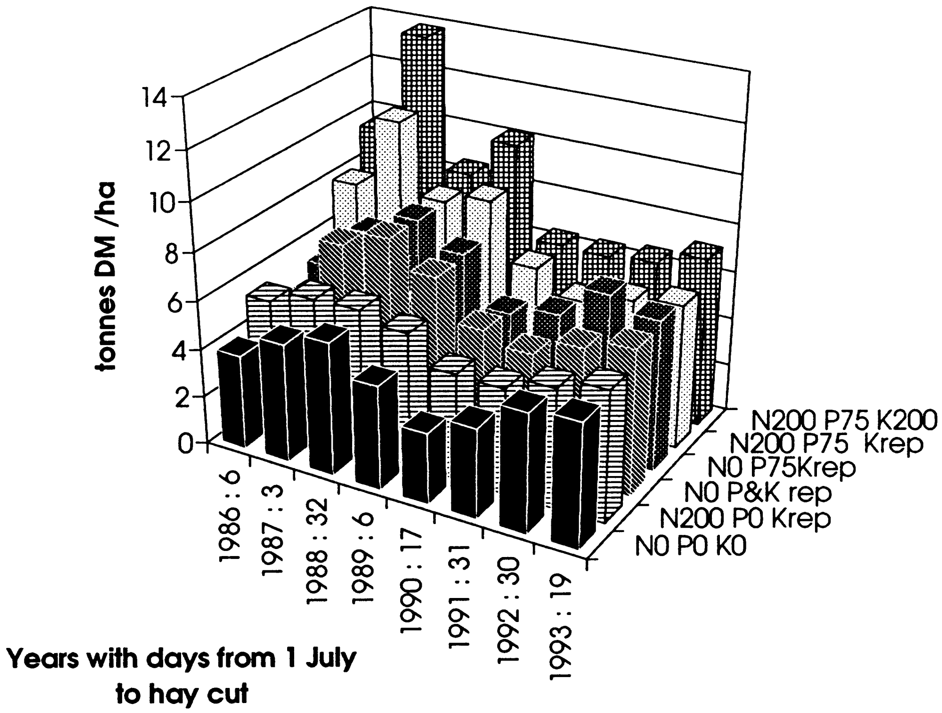

Fig. 18 Species abundance in May 1990 in the small-scale experiment.

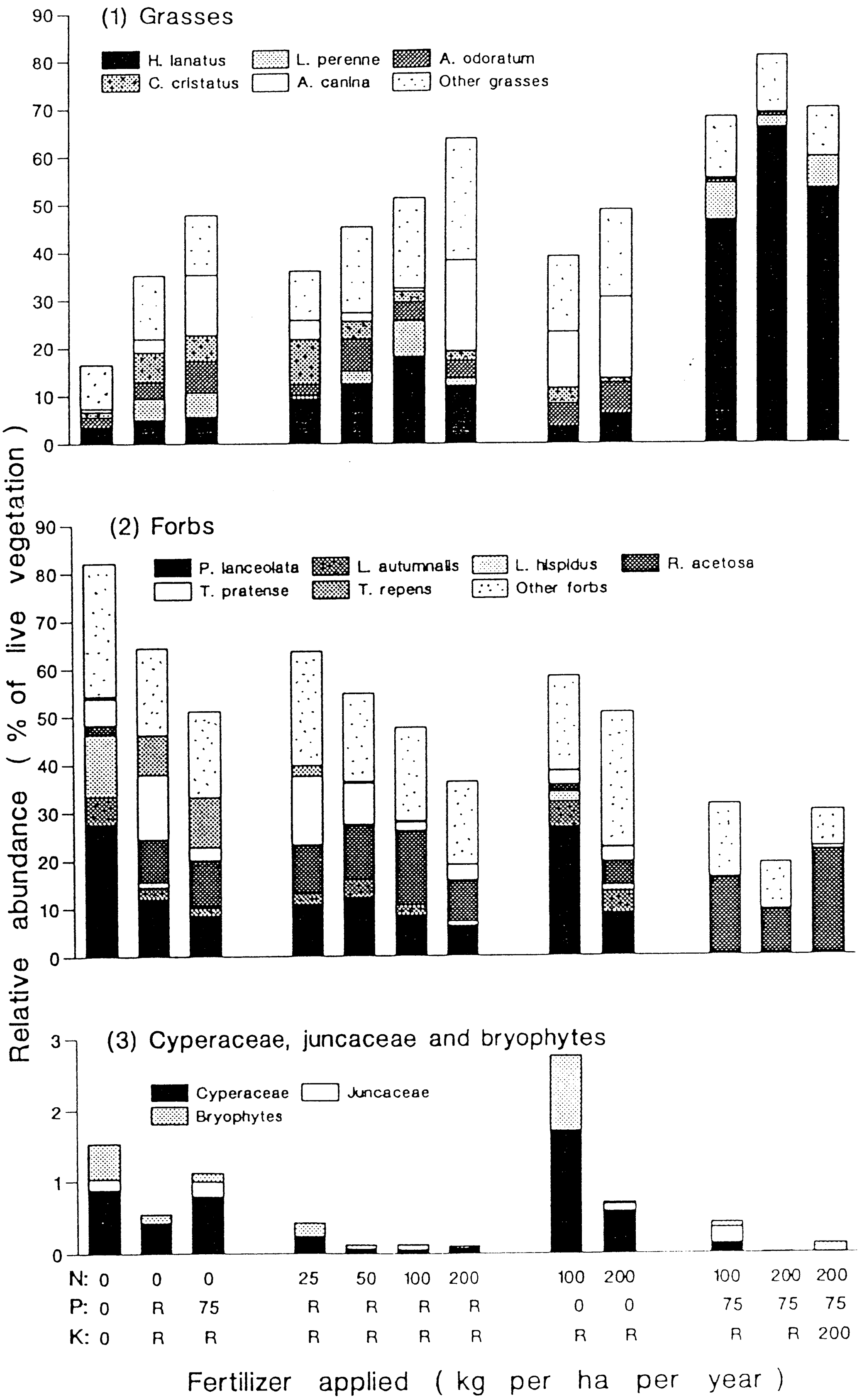

Fig 19 Species richness in the small-scale experiment

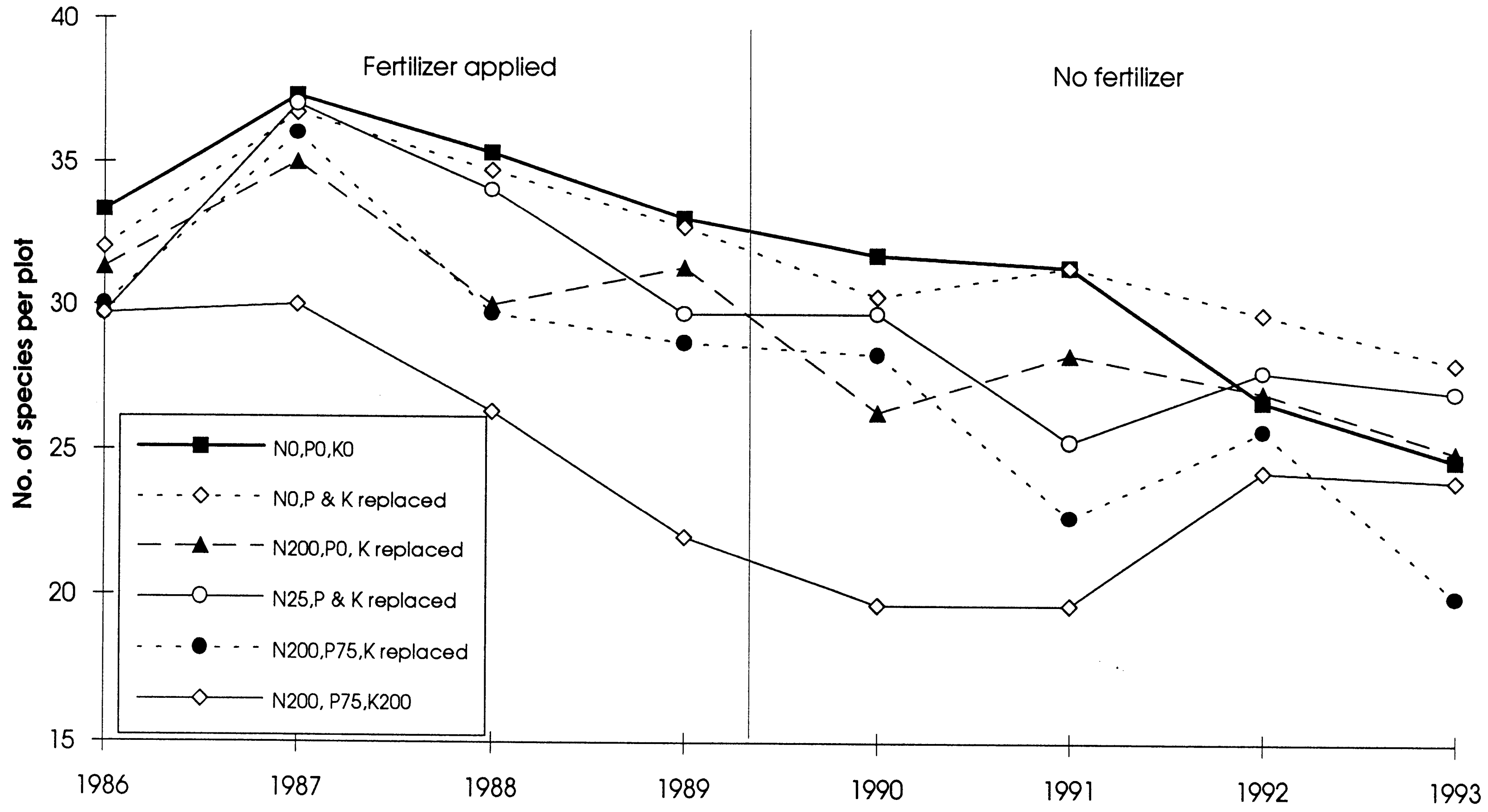

Fig 20 *The effect of previous fertilizer treatment 1986-1990 (N_0 and N_{200} - see text) and of cutting dates in 1991 and 1992 on species abundance in May 1993. Species grouped by regenerative strategy (Grime et al., 1988)*: (a) species relying on seasonal seedling regeneration: *L. perenne* ( ), *Ph. pratense* ( ), *C. cristatus* ( ), *B. hordaceus* ( ), *B. racemosus* ( ); (b) species showing lateral vegetative spread; *F. ulmaria* ( ), *A. capillaris* ( ), *P. lanceolata* ( ), *P. trivialis* ( ), *R. repens* ( ); (c) those that show both strategies: *H. lanatus* ( ), *F. rubra* ( ), *R. acetosa* ( ), *Cen. nigra* ( ). Other species within each group = ( ).