ROTHAMSTED RESEARCH

# Rothamsted - the Classical Experiments

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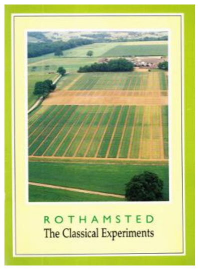


## Rothamsted the Classical Experiments 1991

### Rothamsted Research

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# ROTHAMSTED

## EXPERIMENTAL STATION

# Guide to the Classical Field Experiments

1991

AFRC INSTITUTE OF ARABLE CROPS RESEARCH
HARPENDEN · HERTS · AL5 2JQ · ENGLAND
Telephone (0582) 763133

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*Front cover:* *Broadbalk from the air.*
*Plot 19 is on the left.* *See page 9.*

*Back cover:* *Park Grass from the air.*
*Plot 13 is at top of picture.* *See page 25.*

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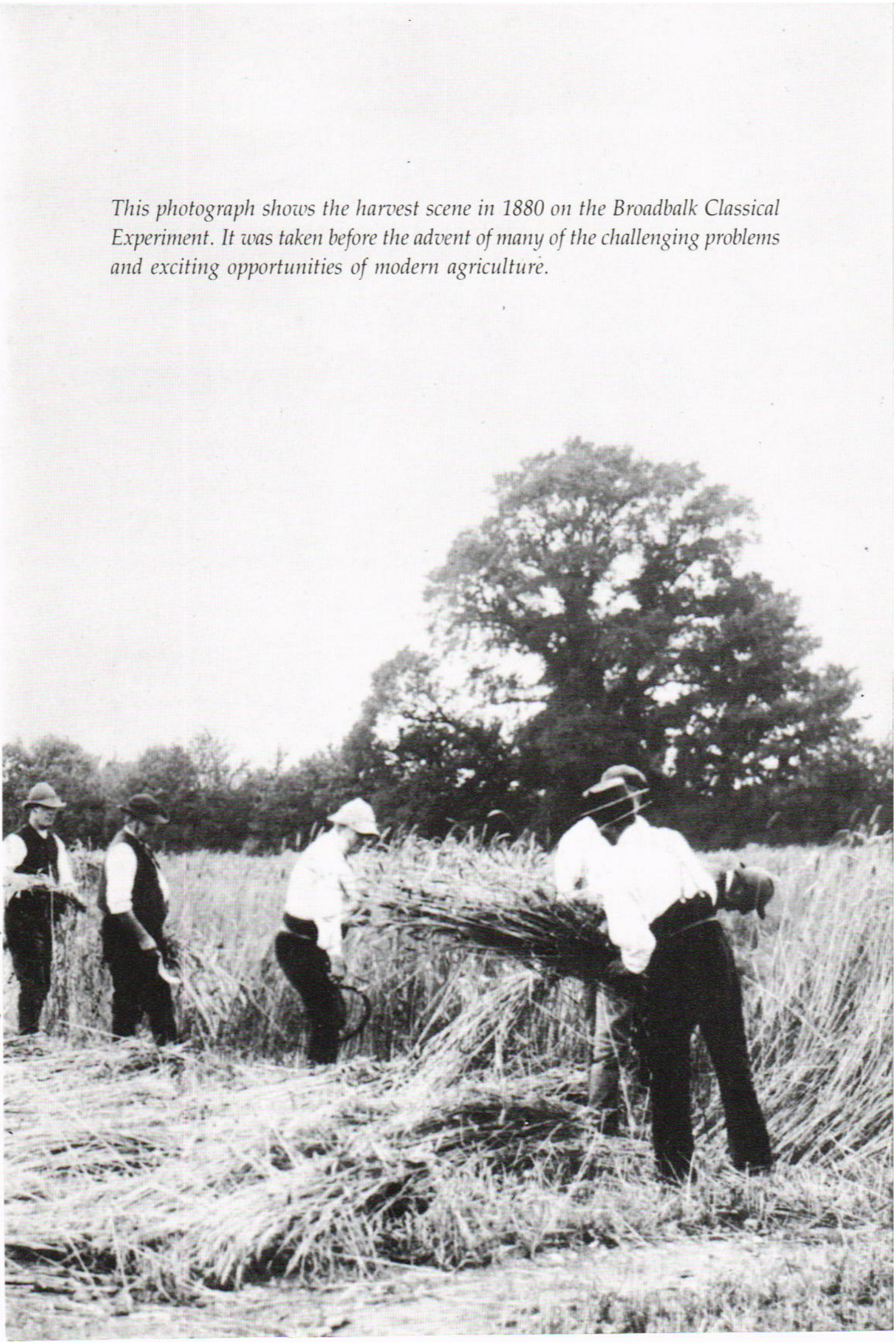
Last century the Rothamsted Classical Experiments were of fundamental importance to the understanding of plant nutrition by organic and inorganic manures. This century, and 148 years after Sir John Lawes and Sir Henry Gilbert commenced their scientific partnership, the unique continuity of the experiments, together with their veritable treasure trove of stored crop and soil samples and data, is allowing them to contribute to current research on many topics ranging from nitrate leaching to pesticide residues.

I am grateful to Jim McEwen and his colleagues for producing this revised account of the history and development of the nine experiments.

Trevor Lewis

Trevor Lewis
Head of Rothamsted
March 1991



*This photograph shows the harvest scene in 1880 on the Broadbalk Classical Experiment. It was taken before the advent of many of the challenging problems and exciting opportunities of modern agriculture.*

# INTRODUCTION

Between 1843 and 1856 Lawes and Gilbert started nine long-term experiments, of which they abandoned only one, in 1878. Some of the plot treatments were changed during the first few years and later further changes were made to a few plots to answer specific questions raised by the results. When Lawes died in 1900 the eight remaining experiments were continuing more or less as originally planned; these are called the 'Rothamsted Classical Experiments'.

Their main object was to measure the effects on crop yields of inorganic compounds containing nitrogen, phosphorus, potassium, sodium and magnesium, elements known to occur in considerable amounts in crops and farmyard manure, but whose separate actions as plant foods had not been studied systematically. The materials used were superphosphate (at first made by mixing bones and sulphuric acid for each experiment) and the sulphates of potash, soda and magnesia (often referred to then, and in this Guide, as minerals) and ammonium salts and nitrate of soda (as alternative sources of nitrogen). The effects of these inorganic fertilizers were compared with those of farmyard manure and rape cake in most of the experiments. The inorganic fertilizers were tested alone and in various combinations. Nitrogen was often applied at two or more rates.

Growing the same crop each year on the same land was a feature of many of the experiments. This practice, considered bad farming in the nineteenth century, is now common in cereal growing and has given added interest to the experiments.

Lawes and Gilbert recorded the weights of all produce harvested from each plot, and samples were kept for chemical analysis. These results, together with details of the quantity and composition of each fertilizer applied, enabled a balance sheet for the major nutrients to be compiled for each plot. Analysis of soil samples showed how nitrogen, phosphate and potash accumulated or diminished in soil depending on fertilizer applications, offtakes in crops and losses from leaching in drainage water.

The results were of immediate importance to farmers, showing which nutrients had the largest effects on different crops. However, their value to farmers diminished as the contrasted processes of depletion and enrichment of nutrients went on, progressively reinforcing the effect of each annual application of the manures. In addition the annual application of FYM caused the soil humus content of fertilizer- and FYM-treated soils to become progressively different. Until about 1939 the best yields obtained on each experiment were roughly equal to the average yields of the same crops grown on English farms. After 1939 with better-yielding varieties and increased use of fertilizers English farm yields exceeded those of the Classicals, until the recent modifications.

The Classical experiments have been modified occasionally since Lawes's death. Sir Daniel Hall, in 1903-06, added a few plots to Broadbalk, Park Grass and Barnfield, mainly to test the combination NKNaMg (that is, all major nutrients except P) which had been omitted from these experiments. Hall also started the first scheme of regular liming on Park Grass, the only Classical experiment not on a neutral or slightly calcareous soil. (The others were on old arable fields and had received the traditional heavy dressings of locally



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dug chalk, a practice not followed on grassland.) A differential liming scheme started on Park Grass in 1965.

From 1957 several of the Classical experiments were modified to evaluate the residual effects of the annually repeated dressings of different combinations of nutrients. This was done for a range of crops (often several crops grown side by side on each of the original plots, as on the Exhaustion Land, Barnfield and Agdell) by subdividing the old plots to test new fertilizer treatments. These modifications, together with detailed analysis of the soil by several methods, gave much information on the value of the accumulated residues of materials applied in the past.

On Broadbalk and Hoosfield Barley crop rotations were introduced in 1968 although substantial areas of each experiment remained in the traditional crops. The rotations were:

Broadbalk: Potatoes, spring beans, winter wheat.
Hoosfield Barley: Potatoes, spring beans, spring barley.

Beans became seriously infested with stem eelworm (*Ditylenchus dipsaci*) and they were not sown after 1978. On Broadbalk the rotation is now:

Fallow, potatoes, winter wheat, winter wheat, winter wheat.

and on Hoosfield Barley the whole area has returned to continuous spring barley. The crop rotations have shown the extent to which the yields of wheat and barley can be increased when soil-borne diseases and pests are lessened by growing non-susceptible crops for two years.

Barnfield, formerly a Classical experiment with mangolds and sugar beet, has been progressively modified since 1960 and is at present in ley.

Another major change introduced in 1968 except on Park Grass was the replacement of sulphate of ammonia and nitrate of soda by ammonium nitrate initially as 'Nitro-Chalk' now as 'Nitram'. Castor meal has been discontinued, but its residual value is assessed. Most of the applications of sodium (as sulphate or chloride) have been discontinued. On Broadbalk, Hoosfield Barley and Barnfield magnesium is now applied as kieserite (replacing Epsom salts), every third year except for certain plots.



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# BROADBALK WINTER WHEAT

The first experimental crop of wheat was sown in autumn 1843 and harvested in 1844. Every year since then wheat has been sown and harvested on all or part of the field. The manurial treatments compared were organic manures (farmyard manure and rape cake, later replaced by castor bean meal) and inorganic fertilizers supplying the elements N, P, K, Na and Mg in various combinations. For the first few seasons these treatments varied somewhat but in 1852 a permanent scheme was established and this has remained largely unaltered. in the early years the field was ploughed in 'lands' by oxen (later by horses) and all the crop from each plot was separately cut with sickles, bound into sheaves and carted into the barns to await threshing. Weights of grain and straw were recorded and samples kept for chemical analysis. (Many of these samples are still available and some have been used in recent investigations as 'pre-pollution' standards.)

Now Broadbalk is ploughed by a tractor-mounted reversible plough and harvested by a combine harvester; only the central strip of each plot is taken for yield and samples. The wheat seed is treated with insecticide and fungicide and the growing crop is sprayed to control aphids and foliar fungus diseases except on Section 6. (See plan).

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*Broadbalk* (see plan on opposite page)

*Cropping* (each section may be fallowed if necessary to control weeds)
Section 0 — continuous wheat, straw incorporated since autumn 1986.
Sections 1, 9 — continuous wheat.
Section 6 — continuous wheat, no agrochemical sprays except weedkillers.
Section 8 — continuous wheat, no weedkillers.
W40: 40th crop since last fallow.
Sections 2, 3, 4, 5, 7 — five-course rotation: fallow (F), potatoes (P), wheat (W1), wheat (W2), wheat (W3).

*Dressings in autumn*
All manures are applied annually to all sections except:

| | |
|---|---|
| (i) | Fallow receives no 'Nitram' |
| (ii) | Magnesium — see below. |

*Organics* (applied before ploughing)

| | |
|---|---|
| FYM | 35 t ha$^{-1}$ farmyard manure (from bullocks) |
| C | Castor meal (about 5% N) to supply 96 kg N ha$^{-1}$ (about 1.9 t meal ha$^{-1}$), last applied autumn 1987 |

*Minerals* (applied before ploughing)

| | |
|---|---|
| P | 35 kg P ha$^{-1}$ as triple superphosphate (47% $P_2O_5$), single superphosphate (19% $P_2O_5$) until 1987 |
| K | 90 kg K ha$^{-1}$ as sulphate of potash (50% $K_2O$) |
| Na | 35 kg Na ha$^{-1}$ as sulphate of soda (14% Na) to plot 12 only |
| Mg | 30 kg Mg ha$^{-1}$ as kieserite (16.8% Mg) to plot 14 only |
| | 35 kg Mg ha$^{-1}$ as kieserite every third year (1989, 1992) to other plots |

*Residual*

| | |
|---|---|
| Na | 15 kg Na ha$^{-1}$ to plots 5, 6, 7, 8, 9, 15, 16, 20 (and at 7.5 kg Na ha$^{-1}$ to plots 17, 18) discontinued 1974 |

*Nitrogen*

| | |
|---|---|
| N* | 48 kg N ha$^{-1}$ as 'Nitram' in autumn to plots 17 and 18 in alternate seasons (to plot 18 for 1991 wheat; not applied to potatoes) |

*Dressings in spring*
1, 2, 3, 4, 5, 6 'Nitram' supplying 48, 96, 144, 192, 240, 248 kg N ha$^{-1}$ as a single application in April



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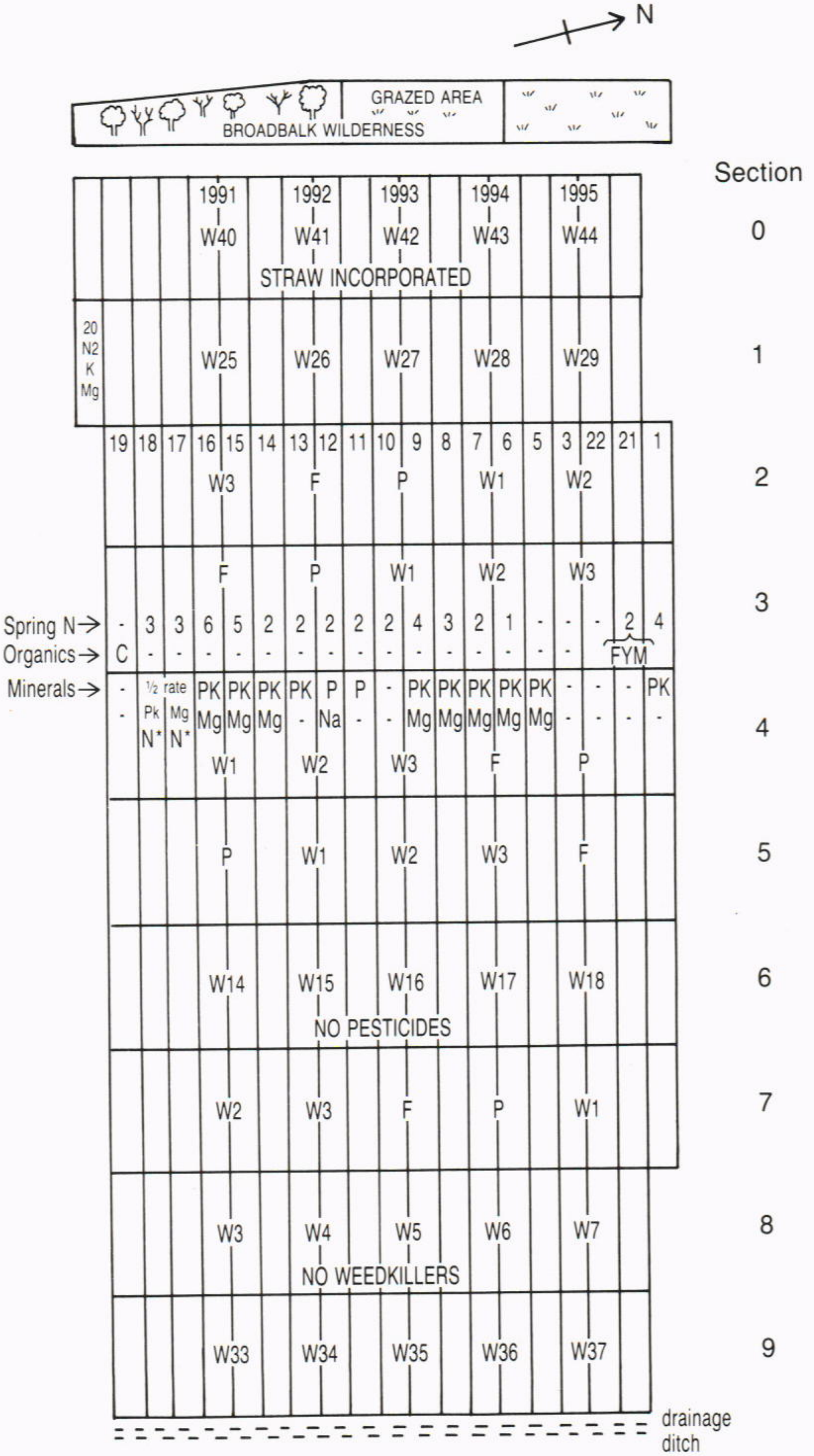
# BROADBALK



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Weeds were controlled by hand-hoeing in the past. When this became impracticable five strips ('Sections', later increased to 10) crossing all the plots at right angles were made and bare fallowed, mainly in a 5-year rotation of fallow with four successive crops of wheat. Now chemical weedkillers are used on all Sections but one (Section 8) which has never received any.

Effective control of weeds by sprays eliminated the need for bare fallowing and the five Sections were halved. Sections 0,1 and 9 were returned to continuous wheat in 1952, 1967 and 1959 respectively. On Section 0 the straw on each plot has been chopped after harvest and incorporated into the soil since autumn 1986. On all other Sections it is baled and removed. On Sections 2, 3, 4, 5 and 7 the crop rotation fallow, potatoes, wheat, wheat, wheat is practised; Section 6 is again in continuous wheat after following the rotation fallow, wheat, wheat from 1968 to 1979, it receives weedkillers but not the other agrochemical sprays used on the other Sections.

In his first Rothamsted paper, published in 1847, J.B. Lawes described the Broadbalk soil as a heavy loam resting upon chalk, capable of producing good wheat when well manured. Similar land in the neighbourhood farmed in rotation would yield about 22 bushels of wheat per acre. In weight this is about 1.5 t $ha^{-1}$. At present the plot that has received neither manure nor fertilizer since 1843 yields about 1.2 t $ha^{-1}$ after continuous wheat, 2.6 t $ha^{-1}$ in rotation (Table 1). Where nutrients are plentifully supplied by farmyard manure (FYM) or fertilizers continuous wheat yields now average 6 to 7 t $ha^{-1}$, almost three times the yield of the same treatments in the early years. These differences reflect the improved varieties, cultivations and control of pests, diseases and weeds that have been introduced on Broadbalk (and on English farms generally) especially in the last 40 years. For most treatments the wheat after a two-year break now yields about 2 t $ha^{-1}$ more than the continuous wheat.

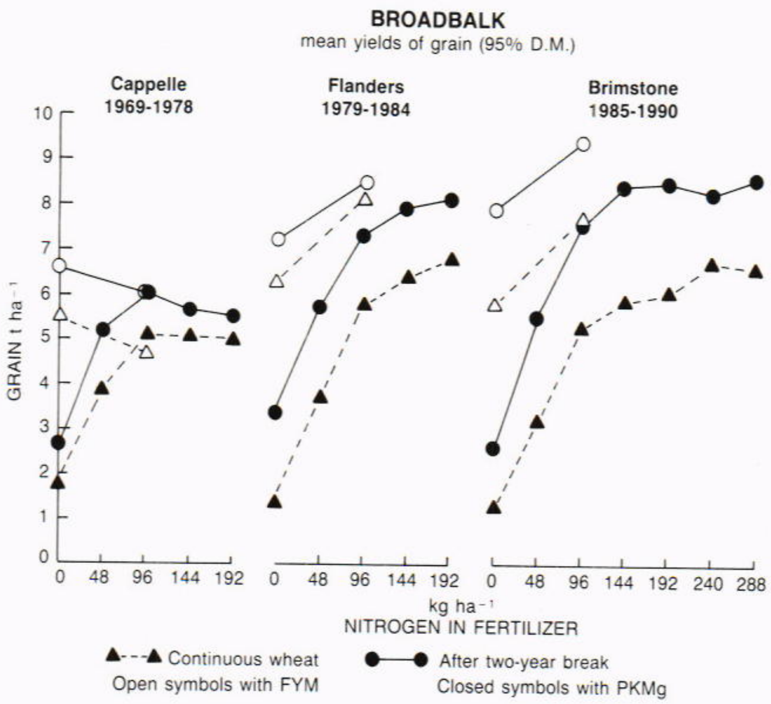


**Figure 1**



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Until 1968 the best yields from fertilizer (given by plots receiving PKNaMg and at least 96 kg N ha$^{-1}$) were equal to those given by FYM. After the change to the shorter-strawed variety Cappelle in 1968, together with the introduction of the rotation, FYM gave about 0.5 t ha$^{-1}$ more grain than fertilizers (Fig. 1). In the period of 10 years in which Cappelle was grown foliar fungicides were not applied and foliar diseases, particularly mildew, were common and most severe on plots given most nitrogen. After the introduction of Flanders in 1979 summer fungicides were used each year. Perhaps as a result the relative yields of FYM and fertilizers again changed (Fig. 1) with best yields from fertilizer exceeding those from FYM alone and with the combination of FYM and 96 kg N ha$^{-1}$ exceeding both. The increased responses to nitrogen fertilizer in this period suggested that yields might be greater if larger rates of nitrogen were tested and since 1985 rates of 240 and 288 kg N ha$^{-1}$ have been included. This change coincided with the introduction of the variety Brimstone which showed a similar pattern of yields to Flanders although with a greater response to the two-year break (Fig. 1 and Table 1). Only the continuous wheat responded

**TABLE 1**

*Broadbalk*

*Mean yield (6 years, 1985-90) of wheat grain and potatoes (total tubers) all in t ha$^{-1}$*

| Plot | Treatment | Wheat: After 2-year break | Wheat: Continuous since 1967 | Potatoes |
|---|---|---|---|---|
| 3 | None | 2.6 | 1.2 | 8.2 |
| 5 | PK(Na)Mg | 2.6 | 1.3 | 12.7 |
| 6 | N1PK(Na)Mg | 5.5 | 3.2 | 22.6 |
| 7 | N2PK(Na)Mg | 7.5 | 5.3 | 26.6 |
| 8 | N3PK(Na)Mg | 8.4 | 6.0 | 35.4 |
| 9 | N4PK(Na)Mg | 8.5 | 6.1 | 35.2 |
| 15 | N5PK(Na)Mg | 8.3 | 6.8 | 35.6 |
| 16 | N6PK(Na)Mg | 8.6 | 6.5 | 36.8 |
| 10 | N2 | 4.7 | 2.8 | 8.5 |
| 11 | N2P | 6.0 | 4.1 | 9.4 |
| 13 | N2PK | 6.9 | 5.5 | 20.4 |
| 12 | N2PNa | 6.5 | 4.6 | 11.0 |
| 14 | N2P(K)Mg[1] | 7.4 | 5.7 | 31.3 |
| 17/18* | NO+3PKNaMg½ | 8.5 | 6.2 | 24.6 |
| 18/17** | N1+3PKNaMg½ | 8.9 | 6.4 | |
| 22 | FYM | 7.9 | 5.8 | 32.9 |
| 21 | FYM N2 | 9.4 | 7.7 | 37.8 |
| 1 | FYM N4PK[2] | 9.0 | - | 36.2 |
| 19 | C[3] | 5.0 | 2.7 | 14.6 |

*Yields from the plot not given autumn N; **yields from the plot given autumn N — not applied to potatoes.

[1] K applied since 1968 [2] Since 1968 [3] Last applied 1988.

**TABLE 2**

*Nitrogen % of Broadbalk soils 0-23 cm*

| Plot | Manuring | 1865* | 1944* | 1966* | 1987† |
|---|---|---|---|---|---|
| 3 | None | 0.105 | 0.106 | 0.099 | 0.102 |
| 4 | PKNaMg | 0.107 | 0.105 | 0.107 | 0.104 |
| 7 | N2PKNaMg | 0.117 | 0.121 | 0.115 | 0.124 |
| 22 | FYM | 0.175 | 0.236 | 0.251 | 0.270 |

*Mean of all sections †Mean of sections 1 and 9



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to the greater rates of nitrogen. As with Flanders the largest yields came from FYM + N2 which in 1990 after the two-year break gave the first yield in excess of 10 t $ha^{-1}$ on this experiment. The variety Apollo replaced Brimstone in autumn 1990.

**Organic matter in the Broadbalk soil**

The amounts of soil organic matter can be determined only indirectly from the % carbon or % nitrogen. Percentage carbon may be multiplied by an arbitrary factor of 1.72 to give % organic matter. Most soils have a carbon to nitrogen ratio of about 10:1 so that % N can be converted to % C and hence to % organic matter. Accordingly % N alone can be used to show relative amounts of organic matter. On plots not receiving farmyard manure the nitrogen contents have remained steady for a century since they were first measured in 1865. By that date plots receiving NPK fertilizers had a little more N than the unmanured and minerals-only plots, because the better-fertilized crop gave not only more yield but more stubble, and perhaps roots, to be ploughed in. On the FYM plot nitrogen increased, at first rapidly, then more slowly. After a century, annual dressings of FYM had more than doubled the amounts of nitrogen and hence organic matter (Table 2). The combination of N offtake in the crop and N retained in soil can be calculated for different periods. About 100 kg of N applied in the 225 kg N $ha^{-1}$ present in the FYM cannot be accounted for each year and this has been consistent throughout the course of the experiment. This is because in the early years N offtakes by the crop were small but much was accumulating in the soil, more recently crop offtakes have been larger but N accumulation in the soil has been smaller.

The introduction in 1926 of regular fallowing, with cultivations to kill weeds and no manures applied, decreased the organic matter, especially on the FYM plot. After the reintroduction of continuous wheat on Section 0 (last fallowed in 1951), the organic matter of the soil increased more than on Sections periodically fallowed.

**Microorganisms in the Broadbalk soil**

More actinomycetes and bacteria occur in the FYM plot than in the unmanured plot or that given N2PKMg, both of which contain similar numbers. The FYM plot and the fertilizer plot, although differing greatly in organic matter, contain similar numbers of fungi and amoebae both of which are more than in the unmanured plot.

The nitrogen-fixing bacterium *Azotobacter chroococcum* fluctuates in numbers; the average population is greatest in those plots that receive neither N fertilizer nor organic manure. Anaerobic nitrogen-fixing *Clostridium* spp. are more abundant than *Azotobacter*. Nitrogen-fixing root nodule bacteria for field beans (*Vicia*) and clovers are widely distributed but not abundant in Broadbalk soil and those for the medicks and *Lotus* are sparse; none seems to be much affected by manuring. The continuous wheat crop and the weeds, mainly Equisetum, associated with it, annually remove from the soil on the unmanured and minerals-only plots about 30 kg N $ha^{-1}$ but despite this the amount of N in the soil has remained almost the same since the beginning of the experiment (Table 2). Each year a small amount of N is added in seed (about 3 kg/$ha^{-1}$). Recent research suggests that between 40-45 kg N $ha^{-1}$ may come from a



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combination of wet and dry deposition. A number of free-living heterotrophic nitrogen-fixing bacteria have been found in Broadbalk soils but their contribution to the nitrogen economy of the arable sections is very small.

**Weeds on Broadbalk**

For many years weeds and weed seeds in soil were surveyed regularly until the retirement of Joan Thurston in 1980. The notes below are a modified extract of those written by her in 1976.

About 50 annual and ten perennial weed species occur in the field. Where weedkillers have never been applied each plot has its characteristic 10-20 species, and the ground is covered with weeds after harvest, except on the unmanured plot. Some species, e.g. blackgrass (*Alopecurus myosuroides*) and corn buttercup (*Ranunculus arvensis*) occur on all plots, but others are associated with manurial treatments, e.g. legumes where minerals are applied but not nitrogen. In contrast, in the stubble of the cleanest weedkiller-sprayed plots there may be less than five species, represented by only one or two plants of each.

Wild oats (mainly *Avena ludoviciana* with some *A. fatua*) became very numerous on Broadbalk during the 1940s, the one-year fallow having been ineffective against them. Since 1943 they have been pulled by hand which has decreased the population greatly. On Broadbalk *A. ludoviciana* (winter germinating) is much commoner than *A. fatua* (spring germinating) but in the spring-sown barley on the adjacent Hoosfield the wild oats are mainly *A. fatua*. Most annual weeds germinate mainly at specific times of the year, usually autumn and/or spring, and few species germinate throughout the year. The preparation of seedbeds at different times of the year for winter wheat and spring barley allows different species to survive.

**Weeds in winter wheat.** The use of weedkillers to kill broad-leaved weeds greatly decreased susceptible species, e.g. common vetch (*Vicia sativa*) and corn buttercup, but no species was eliminated. Black medick (*Medicago lupulina*) decreased only slowly because the reserve of seeds in the soil was replenished by plants emerging after spraying and seeding before the stubble was ploughed. Knotgrass (*Polygonum aviculare*) and scentless mayweed (*Tripleurospermum maritimum*) were not controlled by the MCPA initially used but mixtures containing dicamba, bromoxynil or ioxynil have since been effective.

Chlortoluron and isoproturon have been applied just after sowing and have controlled autumn-germinating blackgrass and some broad-leaved autumn-germinating weeds, notably ivy-leaved speedwell (*Veronica hederifolia*) which seeds before the spring spraying and so is not controlled by it.

Field horsetail (*Equisetum arvense*) has not been controlled by the weedkillers used to control grass and broad-leaved weeds and this species has increased, particularly on plots where crop competition has been limited by inadequate nutrition. Since 1990 fluroxypyr has been used specifically to control this weed.

**Weeds in potatoes.** Although spring cultivation destroys weeds from autumn and winter-germinating seeds, the cultivations before planting potatoes bring buried weed seeds to the surface where they germinate, giving a mixture of seedlings of autumn, winter and spring-germinating species. These are controlled by pre-emergence weedkiller (linuron-paraquat mixture) but field



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horsetail (*Equisetum arvense*), which emerges at the same time as the potato shoots and is resistant to these weedkillers, is not controlled. It proliferates more in potatoes than in winter wheat, except where no nitrogen is given, because potatoes offer very little competition at the early stages of its growth, whereas winter wheat, especially with N, overshadows the young horsetail shoots from the start.

**Pests and Diseases on Broadbalk**

The continuity of cropping and manurial treatments has made Broadbalk a valuable field for studying the effects of weather on the incidence of wheat pests and diseases.

**Insect pests.** Before insecticidal seed dressings were used wheat bulb fly (*Delia coarctata* Fall.) often caused severe damage to wheat after fallow on Broadbalk. Bulb fly eggs are laid during the summer on bare soil and damage is caused by larvae burrowing into the young wheat shoots in the early spring. Yield losses on Broadbalk varied greatly with season and were related to the ratio of plants to larvae, to the time of attack and to conditions for plant growth. Plants on plots deficient in potassium usually suffered most because they were less well tillered and damage to the primary shoot often killed the whole plant. The damage was minimized by sowing wheat early.

Other insect pests, cereal aphids, cutworms, wheat-blossom midges and the saddle-gall midge caused damage only sporadically. Since the introduction of potatoes to the rotation, potato aphids occasionally require control.

**Soil-borne diseases**

Both eyespot (*Pseudocercosporella herpotrichoides*) and take-all (*Gaeummanomyces graminis* var. *tritici*) are common. It was on this field that, in 1935, eyespot was first identified in this country. Comparisons of yields and of differences in amounts of take-all between continuous wheat on Broadbalk and other fields in shorter sequences of cereals over a period of years culminated in the development of the hypothesis of 'take-all decline'. Severe symptoms of take-all are often seen in short sequences but seldom in the continuous wheat. This decline of take-all, although still inadequately understood, has since been shown to be common when cereals are grown continuously.

**Broadbalk drains**

In 1849 a tile drain was laid down the centre of each of the plots. The tiles, of the 'horsehoe and sole' type, 5 cm internal diameter, were laid 60 cm below the surface, and led to a 10 cm cross main, which took the water to a ditch. The drains were not intended for experimental use, but in 1866 they were opened at their junctions with the main to catch the runnings from each plot. The classical analyses by Dr. A. Voelcker were on samples drawn in this way in 1866-68; the data provided important information on the losses of plant nutrients by leaching. Although ammonium, potassium, magnesium and sodium salts were all added to the soil the biggest loss was of calcium and its loss increased with increasing amounts of ammonium salts given. The loss of nitrate was considerable, and this also increased with the amount of ammonium salts added. Subsequent analyses in 1879-83 showed concentrations



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of $NO_3$-N in autumn flow in excess of current EEC limits where the amount of N applied exceeded that required for the yield potential of the cultivar then grown. A salutary lesson relevant to today's environmental concern. Phosphate, although applied in water-soluble form, was almost completely retained.

Some of the free-living nematodes of the Broadbalk soils are carried down in the water reaching the drains and can be caught on fine-mesh sieves at the outfalls. This has added to the knowledge gained more laboriously by taking soil samples and extracting the nematodes.

### Other uses of Broadbalk

Broadbalk has for many years attracted the interest of scientists working in subjects that were unthought of by Lawes and Gilbert when they planned the experiment. Because the soil of each plot is now in a virtually stable condition and cultivations and husbandry are changed as little as practicable Broadbalk offers particularly good facilities for studying trends in yield and nutrients and fluctuations of pests, and diseases, etc., in relation to seasonal differences. The fluctuations in numbers of wheat blossom midges (*Contarinia tritici* and *Sitodiplosis mosellana*) were studied for nearly 40 years. The statistical analysis of the relation between rainfall and yields of the Broadbalk plots was one of the first tasks of R. A. (later Sir Ronald) Fisher.

Recent projects using Broadbalk have included:

(1) Growth analysis in relation to yield of wheat from season to season in standard soil conditions.

(2) Investigation of the uptake and losses of N fertilizer using $^{15}N$ as a tracer.

(3) Comparison of yields and nutrient responses of a modern short-strawed and older long-strawed variety.

(4) The residual benefit of nitrogen fertilizer used for many years.

(5) The effects of man's industrial activities on the accumulation of heavy metals, especially cadmium, polynuclear aromatic hydrocarbons and dioxins in soils and the effects of these pollutants on their concentration in the grain harvested from the field.

Material from the field can be provided for workers outside Rothamsted subject to acceptance of our regulations.

## BROADBALK WILDERNESS

In 1882 about 0.2 ha of the wheat crop on land unmanured for many years was enclosed by a fence at the end of the Broadbalk Field nearest the present farm buildings, left unharvested and the land not cultivated. The wheat was left to compete with the weeds, and after only four years the few plants surviving were stunted and barely recognizable as cultivated wheat.

One half of the area has remained untouched; it is now woodland of mature trees over 20 m high, and leading species are ash, sycamore and oak. Hawthorn, now the understorey, is dying out. The ground is covered with ivy in the



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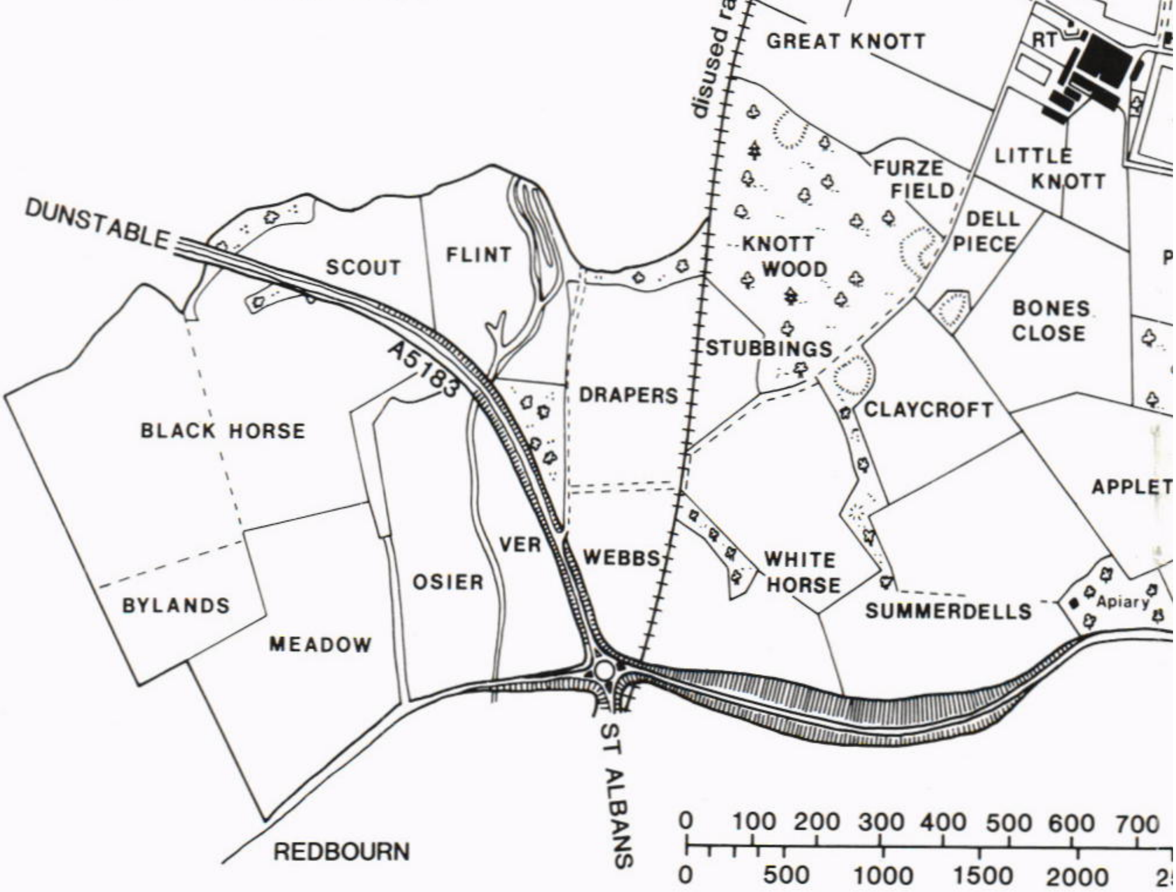
# ROTHAMSTED EXPE

CLASSICAL FIELD EXPERIMENTS

| | |
|---|---|
| Broadbalk | Wheat since 1843 |
| Hoosfield | Barley since 1852 |
| Park Grass | Hay since 1856 |
| Barnfield | Mangolds 1876–1959 |
| Agdell | 4 course rotation 1848–1951 |
| x | Garden Clover, started 1854 |
| y | Wheat and Fallow since 1851 |
| z | Exhaustion land |
| RT | Roman Temple |



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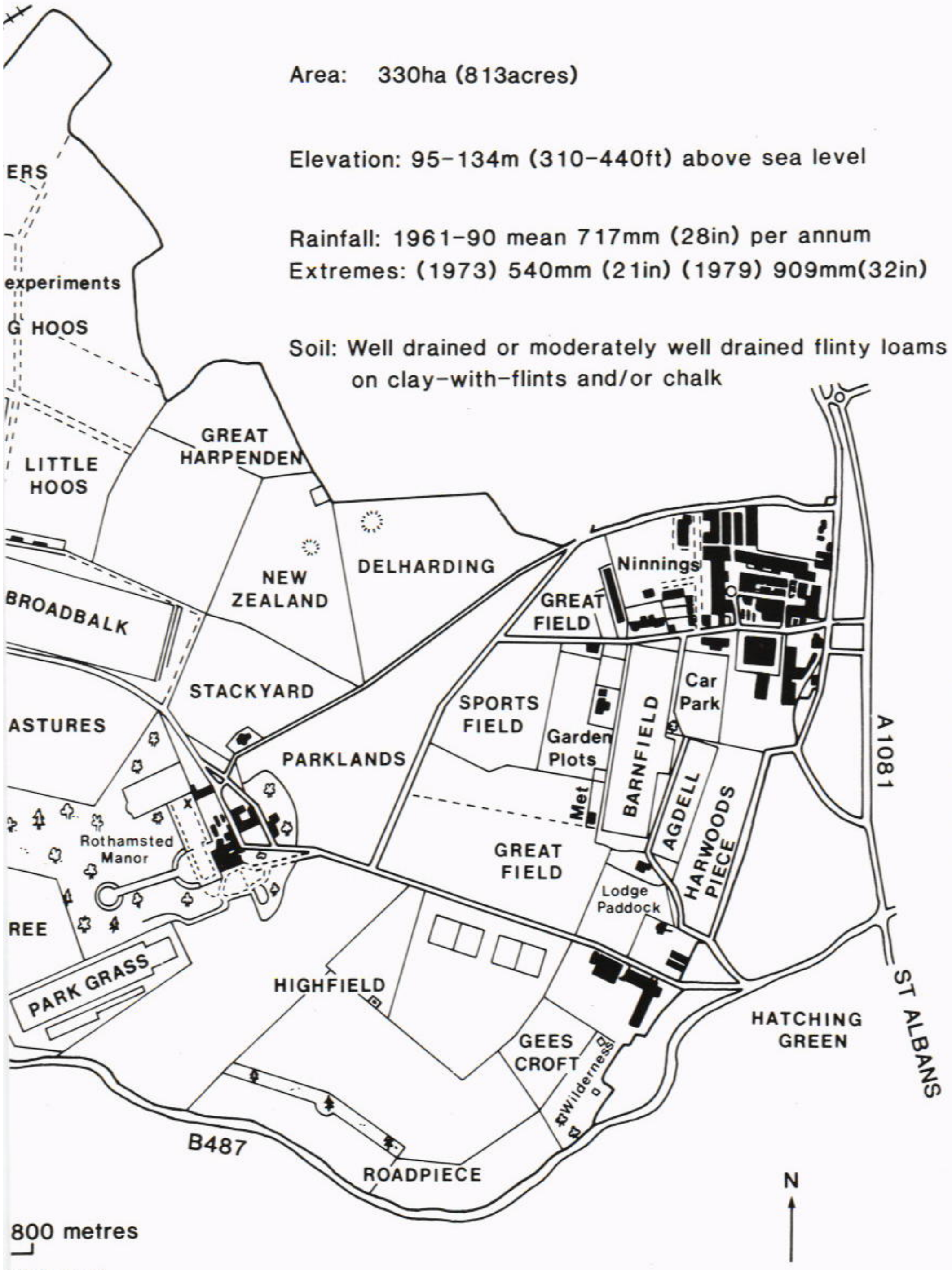
# RIMENTAL STATION

Area: 330ha (813acres)

Elevation: 95–134m (310–440ft) above sea level

Rainfall: 1961–90 mean 717mm (28in) per annum
Extremes: (1973) 540mm (21in) (1979) 909mm(32in)

Soil: Well drained or moderately well drained flinty loams
on clay-with-flints and/or chalk



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densest shade, and with dog's mercury, violet and blackberry in the lighter places. On the other half bushes have been hoed out (grubbed) annually to allow the open-ground vegetation to develop. This consists mainly of coarse grasses, hogweed, agrimony, willow-herb, nettles, knapweed and cow parsley, with many other species in smaller numbers. The bushes that appear are mostly hawthorn, dog-rose, wild plum, blackberry, with a few maple and oak.

In 1957 this grubbed section was divided into two parts, that farther from the woodland area has continued to be grubbed each year. The other part was mown several times during each of the next three growing seasons and the produce removed to encourage grasses as a preparation for grazing. Although the hogweed and cow parsley gave place to ground ivy, the grasses did not increase substantially until sheep were put in to graze. By 1962 perennial ryegrass and white clover had appeared, and they are now widely distributed. The ground ivy has almost gone, and the growth of the miscellaneous plants is much restricted. The unwelcome appearance of nettles in this area in 1986 has necessitated occasional applications of weedkillers.

The soil has gained much organic matter since the Wilderness was fenced off in 1882. Over the period 1883-1964, the net gain of nitrogen by the top 69 cm of soil from the grubbed part was 4.5 t $ha^{-1}$, and the corresponding gain of organic carbon 51 t $ha^{-1}$. The wooded and grubbed parts of the Wilderness accumulated carbon and nitrogen at almost exactly the same rates. By 1964, the Wilderness had gained more organic matter than the plot on Broadbalk receiving 35 t $ha^{-1}$ of farmyard manure annually since 1843.

Legumes were absent from the grubbed section of the Wilderness until recently and the nitrogen gains (equivalent to 49 kg N $ha^{-1}$ $year^{-1}$) appear to have come from rain, bird droppings, dry sorption of ammonia (13 kg N $ha^{-1}$ $year^{-1}$) and from nitrogen fixation by bacteria in the rhizosphere of the perennial weeds. Acetylene reduction assays show that hogweed, hedge woundwort, ivy and ground ivy all support a nitrogen-fixing flora which can, under wet conditions, fix as much as 0.5 kg N $ha^{-1}$ $day^{-1}$.

Nitrogen gains in the wooded section are as yet unexplained.

## HOOSFIELD ALTERNATE WINTER WHEAT AND FALLOW

From 1856 to 1932 this area, which has been completely without manures since 1851, was divided into two strips which alternated wheat and fallow in successive years. From 1932 to 1982 a modification allowed a yearly comparison of a one-year and a three-year fallow but the effects were quite small (Table 3) and since 1983 the experiment has reverted to the original design.

The variety of wheat has always been the same as on Broadbalk and the effects of fallowing may be roughly estimated by comparing yields of wheat on Hoosfield with continuous unmanured wheat on Broadbalk (Table 3). In the first 10 years of the experiment the one-year fallow gave an extra 0.6 t $ha^{-1}$. Unlike Broadbalk the yield on Hoosfield has declined steadily during the experiment and in recent years the yield after one-year fallow has been similar to that of the continuous wheat.



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**TABLE 3**

*Hoosfield Wheat after fallow (mean yields of grain, t $ha^{-1}$)*

| | Hoosfield wheat Years of fallow | | Broadbalk wheat Unmanured continuous |
|---|---|---|---|
| | 1 | 3 | |
| 1856-65 | 1.8 | - | 1.2 |
| 1973-82 | 1.5 | 2.0 | 1.6 |
| 1984-90 | 1.2 | - | 1.3 |

## HOOSFIELD SPRING BARLEY

Spring barley has been grown continuously here since 1852. The experiment offers interesting contrasts to that on Broadbalk, being spring-sown, having been fallowed only four times to control weeds and testing not only nitrogen, minerals and FYM but also silicate of soda.

In 1968 a crop rotation of potatoes, beans and barley on small areas of some plots and a four-level N test on all plots were introduced. The effects of the two-year break on the yield of barley were small and the whole experiment has again grown continuous barley since 1979.

The design of the experiment is of a factorial nature with east-west strips (see plan) having the four combinations of:

(1) 0 *vs* P with

(2) 0 *vs* KMg

and north-south strips, which cross these, originally testing forms of nitrogen, all applied at the same rate of N:

(3) 0 *vs* sulphate of ammonia *vs* nitrate of soda *vs* rape cake (later castor meal)

The nitrate of soda strip was divided for a test of 0 *vs* silicate of soda.

Additional plots at the south side test FYM, since the experiment started, and residues of FYM applied only during 1852-71.

**TABLE 4**

*Hoosfield Spring Barley*

*Mean yield (7 years 1984-90) of Triumph spring barley grain t $ha^{-1}$*

| | N0 | N1 | N2 | N3 |
|---|---|---|---|---|
| - | 0.8 | 1.3 | 1.6 | 1.7 |
| P | 1.8 | 3.1 | 3.1 | 2.9 |
| KMg | 1.4 | 2.4 | 2.8 | 2.9 |
| PKMg | 1.9 | 3.9 | 4.9 | 5.0 |
| FYM | 6.0 | 6.5 | 6.6 | 6.5 |
| | (-)- | (S)- | (-)S | (S)S |
| N3- | 2.0 | 2.8 | 2.5 | 2.4 |
| N3P | 2.9 | 3.8 | 4.1 | 4.2 |
| N3KMg | 2.6 | 3.8 | 2.9 | 3.3 |
| N3PKMg | 5.5 | 5.5 | 5.5 | 5.4 |



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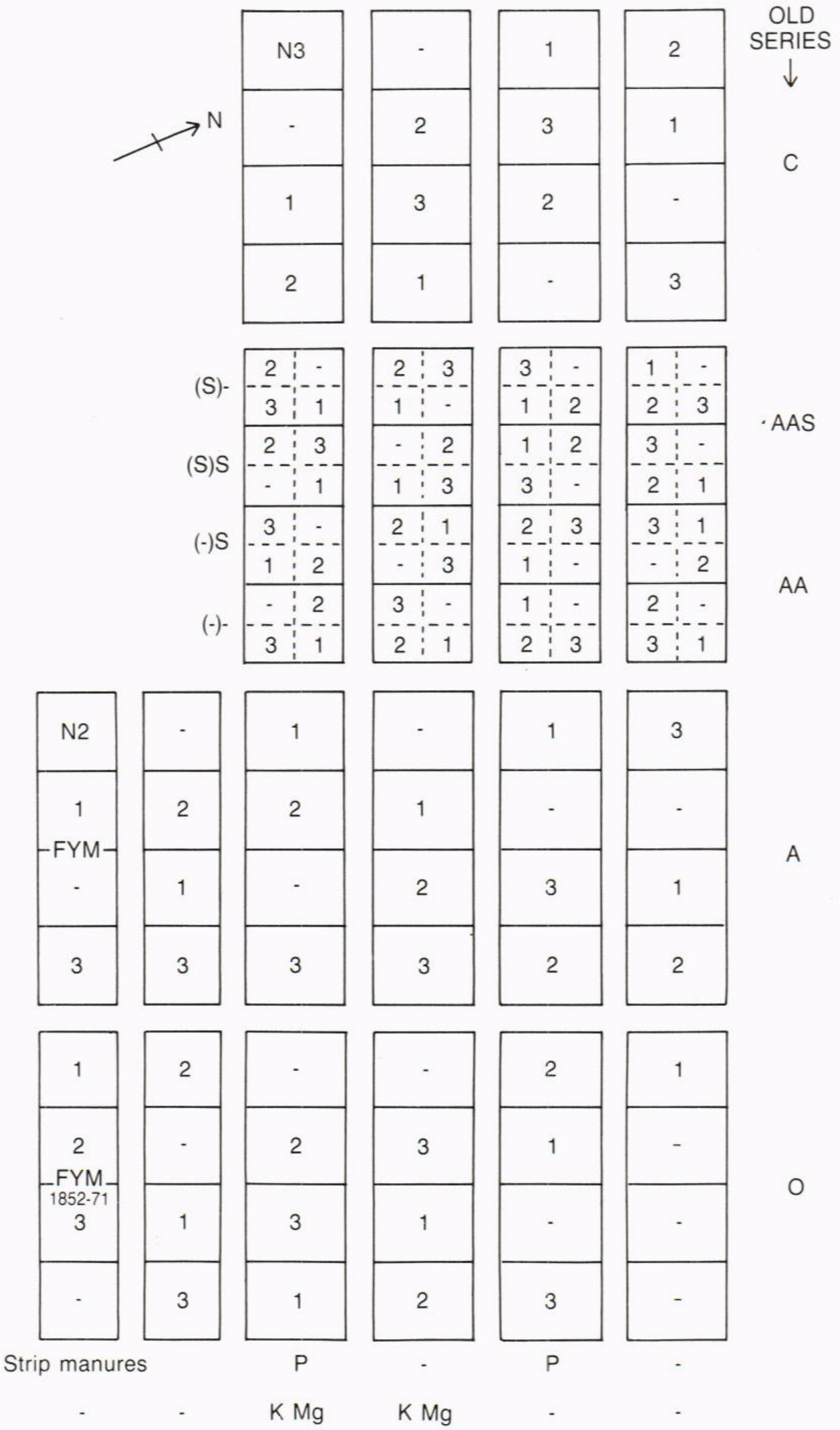
## HOOSFIELD

**Continuous Spring Barley**



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Forms of nitrogen have not been tested since 1967 when a four level sub-plot N test started. PKMg applications on the old rape cake series were discontinued after 1979 and the silicate of soda test was modified in 1980 to include the four combinations of:

(1) 0 *vs* silicate from 1980 with

(2) 0 *vs* silicate 1862-1979

Recent yields (Table 4) continue to show the great importance of P to spring-sown barley as well as large positive interactions between N, P and K Mg. Until 1983 complete fertilizers gave yields as large as those from FYM. Since the introduction of the variety Georgie in 1980 and more especially Triumph in 1984, yields have increased on both treatments but more with FYM and, as on Broadbalk, greatest yields now come from the combination of FYM and nitrogen fertilizer. Silicate of soda continued to give substantial yield increases in the period 1984-90 on plots lacking P or K Mg but, unusually, had no effect on plots with these nutrients.

## EXHAUSTION LAND SPRING BARLEY

This area has had four phases since experiments started here in 1856 (ten plots from 1876):-

(1) From 1856 to 1901 annual dressings of N, P, K or FYM (from 1876 only) were applied (Table 5), initially to wheat then to continuous potatoes from 1876.

---

*Hoosfield* (see plan on opposite page)

*Nitrogen dressing in spring*
N–, 1, 2, 3 'Nitro-Chalk' supplying 48, 96, 144 kg N ha$^{-1}$
The rates of N shown on the diagram are those applied to barley in 1991; they change cyclically, every year in order N3 following N– following N1 following N2.

*Organic* (applied before ploughing in autumn)

| | |
|---|---|
| FYM | 35 t ha$^{-1}$ farmyard manure |

*Minerals* (applied before ploughing in autumn)

| | |
|---|---|
| P | 35 kg P ha$^{-1}$ as triple superphosphate (47% $P_2O_5$) discontinued to Series C since 1980 |
| K | 90 kg K ha$^{-1}$ as sulphate of potash (50% $K_2O$) discontinued to Series C since 1980 |
| S | 450 kg ha$^{-1}$ silicate of soda since 1980, (S) each year until 1979 |

*Applied every 3rd year* (1989, 1992 etc.)

| | |
|---|---|
| Mg | 35 kg Mg ha$^{-1}$ as kieserite (15% Mg) |

*Residual*

| | |
|---|---|
| Na | 15 kg Na ha$^{-1}$ as sodium sulphate discontinued in 1974 (applied with K and Mg) |

*Series treatments* (discontinued 1968)

| | |
|---|---|
| O | None |
| A | 48 kg N ha$^{-1}$ as sulphate of ammonia |
| AA & AAS | 48 kg N ha$^{-1}$ as nitrate of soda |
| C | 48 kg N ha$^{-1}$ as castor bean meal |



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**TABLE 5**

*Exhaustion Land Spring Barley*

*Number of annual dressings applied 1856-1901 and estimated amounts of P and K applied in FYM and fertilizer*

| | Plot number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | Number of dressings | | | | | | | | | |
| FYM | - | 6 | 26 | 26 | - | - | - | - | - | - |
| PK | - | - | - | - | - | - | 42 | 42 | 17 | 42 |
| P | - | - | 7 | 7 | - | - | - | - | 25 | - |
| N | - | - | - | 6 | 43 | 43 | 43 | 43 | - | - |
| | Nutrients applied (kg ha$^{-1}$) | | | | | | | | | |
| P | 0 | 235 | 1260 | 1260 | 0 | 0 | 1410 | 1410 | 1410 | 1410 |
| K | 0 | 900 | 3920 | 3920 | 0 | 0 | 5040 | 5040 | 1570 | 5040 |

**TABLE 6**

*Exhaustion Land Spring Barley*

*Mean yields of barley 1949-90 and recent soil analyses*

| Period | N kg ha$^{-1}$ | Variety | Plots 1,2,5,6* no P, no K | Plots 7,8* residues of PK fertilizers 1856-1901 | Plots 3,4* residues of FYM 1876-1901 |
|---|---|---|---|---|---|
| | | | Mean yields of grain, t ha$^{-1}$ | | |
| 1949-63 | 63 | Plumage Archer | 1.8 | 2.9 | 3.2 |
| 1964-69 | 88 | Maris Badger | 1.7 | 3.6 | 4.3 |
| 1970-75 | 88 | Julia | 1.8 | 4.2 | 4.8 |
| 1976-79 | 0 | Julia | 0.9 | 1.6 | 2.1 |
| | 48 | | 1.3 | 2.9 | 3.5 |
| | 96 | | 1.4 | 3.0 | 4.0 |
| | 144 | | 1.6 | 3.1 | 3.8 |
| 1980-83 | 0 | Georgie | 0.7 | 1.5 | 2.3 |
| | 48 | | 1.1 | 2.2 | 3.2 |
| | 96 | | 1.1 | 2.7 | 3.8 |
| | 144 | | 1.2 | 2.8 | 3.8 |
| 1984-85 | 0 | Triumph | 1.2 | 2.1 | 2.3 |
| | 48 | | 1.5 | 2.5 | 3.0 |
| | 96 | | 1.6 | 2.8 | 3.4 |
| | 144 | | 1.7 | 3.0 | 3.4 |
| 1986-90 | 0 | Triumph | 1.1 | 1.5 | 1.9 |
| | 48 | | 1.4 | 2.4 | 3.1 |
| | 96 | | 1.5 | 2.7 | 3.0 |
| | 144 | | 1.4 | 2.7 | 3.2 |

| | Year | Nutrients in air-dry soil and year of sampling | | |
|---|---|---|---|---|
| N% | 1974 | 0.102 | 0.100 | 0.124 |
| P soluble in 0.5M-$NaHCO_3$ mg kg$^{-1}$ | 1951 | 7 | 21 | 27 |
| | 1965 | 6 | 12 | 18 |
| | 1974 | 2 | 8 | 12 |
| | 1981 | 2 | 6 | 10 |
| | 1987 | 1 | 4 | 6 |
| K soluble in M-ammonium acetate, mg kg$^{-1}$ | 1951 | 74 | 121 | 106 |
| | 1965 | 88 | 122 | 114 |
| | 1974 | 69 | 89 | 87 |
| | 1981 | 66 | 85 | 81 |
| | 1987 | 74 | 92 | 83 |

*Odd numbered plots not included after 1985



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(2) From 1902 to 1939 no manures were applied and with few exceptions cereals were grown. Yields were recorded in some of the earlier years, residual effects of the previous treatments were very small in the absence of fresh nitrogen fertilizer.

(3) From 1940 to 1985 spring barley was grown and nitrogen fertilizer applied to all plots every year, initially at a single rate, from 1976 testing four rates. Nitrogen not only increased yields, which have been recorded since 1949, but also allowed the crop to take advantage of P and K residues remaining in the soil from the first period of the experiment. The effects of these were initially large but declined as amounts of phosphate in the soil declined (Table 6).

(4) Since 1986 spring barley has continued to be grown each year. Plots 2, 4, 6, 8 and 10 have continued unchanged from the third period and yields have continued to decline on these plots without fresh P or K (Table 6). Plots 1, 3, 5, 7 and 9 have all been given 144 kg N ha$^{-1}$ and 83 kg K ha$^{-1}$ annually and divided for an annual, cumulative test of 0 v 44 v 87 v 131 kg P ha$^{-1}$. Responses to fresh phosphate have been large (Table 7), even on plots with residues. Best yields now equal those from the earlier years despite including yields of the two exceptionally dry summers of 1989 and 1990.

**TABLE 7**

*Exhaustion Land Spring Barley — Fresh P test*

*Mean yields of Triumph barley grain, t ha$^{-1}$, 1986-90*

| Annual P*kg ha$^{-1}$ 1986-90 | Plots 1, 5, no P, no K | Plot 7, residues of PK fertilizers 1856-1901 | Plot 3, residues of FYM 1876-1901 |
|---|---|---|---|
| 0 | 2.0 | 3.4 | 3.7 |
| 44 | 4.0 | 4.4 | 4.6 |
| 87 | 4.4 | 4.7 | 4.8 |
| 131 | 4.4 | 4.4 | 4.5 |

*All plots received N at 144 kg and K at 83 kg ha$^{-1}$ annually in this period

## PARK GRASS

The Park Grass experiment, laid down in 1856, is the oldest on grassland in Great Britain. The field had been pasture for at least a century when the experiment began. It demonstrates in a unique way how continued manuring with different fertilizers affects both the botanical composition and the yield of a mixed population of grasses, clovers and other herbs. After more than 130 years, the boundaries of the plots are still clearly defined; the transition between adjacent treatments occupies 30 cm or less, showing that there is little sideways movement of nutrients in flat undisturbed soil.

The plots have been cut each year for hay, all at the same time, although no single date can be suitable for all plots. For a few years the aftermath was grazed by sheep, but from 1876 a second cut has been weighed and carted



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green. Since 1960 yields, corrected to dry matter, have been calculated from the weights of produce from sample strips cut with a forage harvester (two per plot). Yields of dry matter are now larger than previously because dry matter loss during haymaking in the field no longer occurs on the samples taken for yield. At the first cutting the produce of the remainder of each plot is made into hay; this allows the return of seeds to the soil as in the past. At the second cutting the whole produce is carted green. The position of the sample strips differs from year to year.

The soil of Park Grass, in contrast to that of the nearby arable fields, probably never received large dressings of calcium carbonate and the pH was probably about 5.7 when the experiment began. On plots treated with sulphate of ammonia increasing acidity caused a gradual change in the species composition, although not the yield, of the sward. Lawes made two tests of lime in 1883 and 1887, but these were without immediate effect. Regular liming was not begun until 1903. Then, and every fourth year until 1964, lime (originally burnt lime, more recently calcium carbonate) was applied to the southern halves of most of the plots (see plan). Except for plots 18, 19 and 20, a fixed amount was applied on each occasion. From 1965 each half-plot on plots 1 to 18 was further subdivided. (At this stage the old plots 5/1, 5/2 and part of 6, whose treatments had not been constant throughout were used for new experiments.) From 1965 only sub-plots 'd' remain unlimed; on some of these soil pH has changed little over many years, the values now range from 5.7 to 3.5 depending on treatment. Sub-plots 'c' (previously unlimed) now receive chalk calculated to give pH 5, sub plots 'b' to give pH 6 and (from 1976) sub-plots 'a' to give pH 7.

Since 1990 nitrogen fertilizer and lime have been withheld from half of all the sub-plots of plots 9 and 14 to study processes controlling soil acidification and heavy-metal mobilization and changes in botanical composition.

---

*Park Grass* (see plan on opposite page)

Treatments (every year except as indicated)

*Nitrogen* (applied in spring)

| | |
|---|---|
| N1, N2, N3 | sulphate of ammonia supplying 48, 96, 144 kg N ha$^{-1}$ |
| N1*, N2* | nitrate of soda supplying 48, 96 kg N ha$^{-1}$ |
| (N2), (N2*) | last applied 1989 |

*Minerals* (applied in winter)

| | |
|---|---|
| P | 35 kg P ha$^{-1}$ as granular superphosphate (19% $P_2O_5$) |
| K | 225 kg K ha$^{-1}$ as sulphate of potash (50% $K_2O$) |
| Na | 15 kg Na ha$^{-1}$ as sulphate of soda (14% Na) |
| Mg | 10 kg Mg ha$^{-1}$ as sulphate of magnesia (10% Mg) |
| Si | Silicate of soda at 450 kg ha$^{-1}$ of water soluble powder |

Plot 20. Rates of manuring in years when FYM not applied:
30 kg N, 15 kg P, 45 kg K ha$^{-1}$

*Organics* (each applied every fourth year)

FYM 35 t ha$^{-1}$ farmyard manure (bullocks) (1989, 1993)

Fish meal (about 6.5% N) to supply 63 kg N ha$^{-1}$ (1991, 1995)

*Lime*

| | |
|---|---|
| a, b, c | Lime applied as needed to maintain pH 7, 6 and 5 respectively |
| d | No lime applied (pH range 3.5 to 5.7, Plots 11/1 to 17 respectively) |



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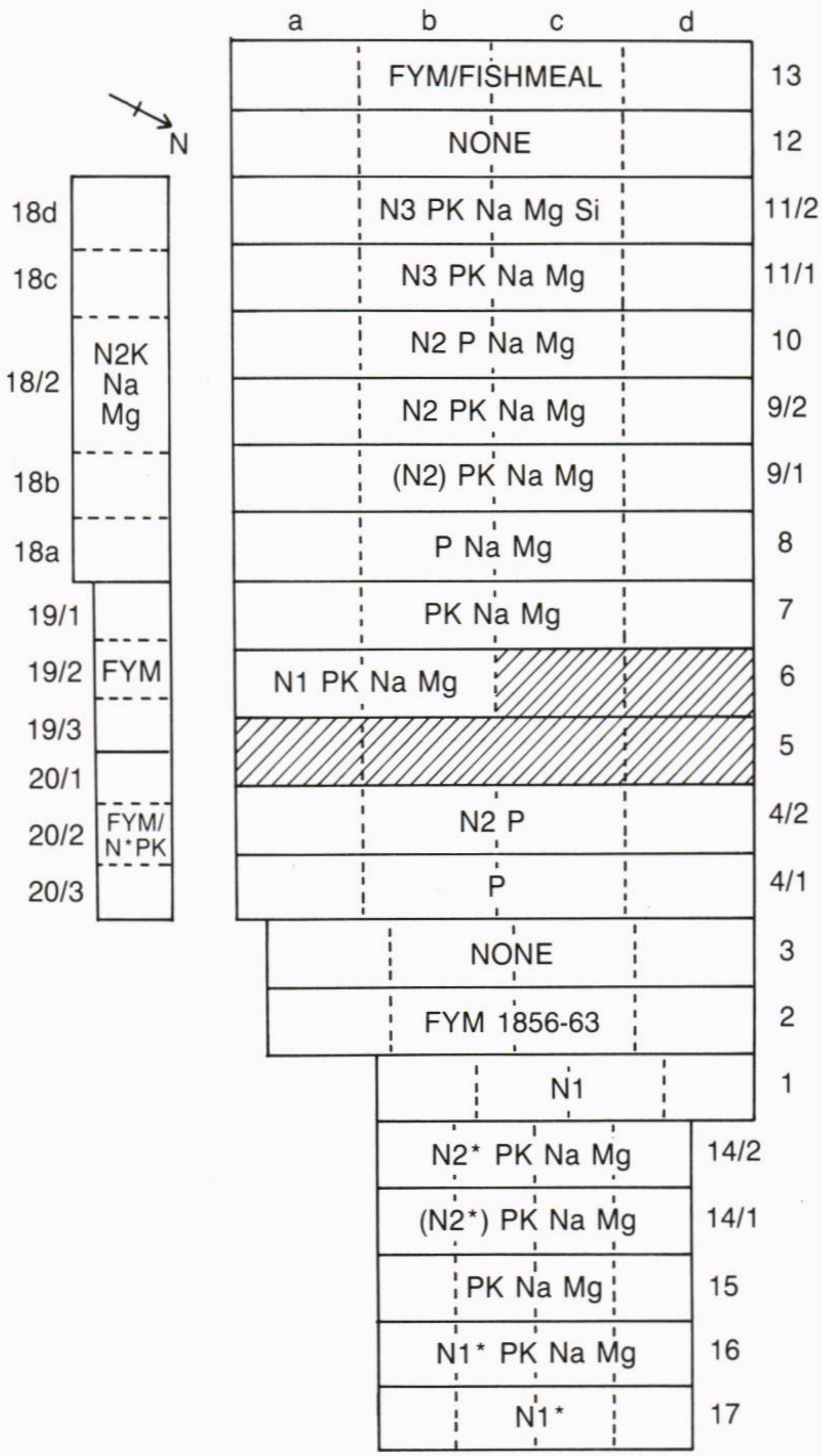
## PARK GRASS
## Hay since 1856



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(The botanical notes below have been supplied by Dr. E.D. Williams, formerly at Rothamsted, currently at the AFRC Institute of Grassland and Environmental Research, Aberystwyth).

The unmanured plots (2, 3 and 12), possibly with about 50-60 species, have the most diverse flora including many red clover (*Trifolium pratense*) plants and other broad-leaved species, but no species is dominant and yields are small. Although these swards are the nearest approximation to the state of the whole field in 1856, cumulative impoverishment of the soil soon caused decreases in rye-grass (*Lolium perenne*) and Yorkshire fog (*Holcus lanatus*) and later increases in common bent-grass (*Agrostis capillaris*), red fescue (*Festuca rubra*), rough hawkbit (*Leontodon hispidus*) and salad burnet (*Sanguisorba minor ssp minor*). Species characteristic of poor land e.g. quaking grass (*Briza media*) and cowslip (*Primula veris*) also occur on these plots. Lime alone does not greatly alter the character of the herbage but it decreases the contribution of bent and fescue and increases that of downy oat-grass (*Avenula pubescens*) and some broad-leaved species. P alone (Plot 4/1) has only minor effects; in particular, it slightly increases common sorrel (*Rumex acetosa*). Giving PK Na Mg (Plot 7) increases the amount of legume, especially meadow vetchling (*Lathyrus pratensis*) and red clover; on this plot lime greatly increases the vigour and yield of these two legumes and the contribution of false oat-grass (*Arrhenatherum elatius*), buttercups (*Ranunculus* spp), dandelion (*Taraxacum* spp) and hogweed (*Heracleum sphondylium*). Omitting K and giving P Na Mg (Plot 8) results in much less meadow vetchling but more ribwort plantain (*Plantago lanceolata*), and on this plot lime depresses yields.

With nitrogen, either as sulphate of ammonia or as nitrate of soda, yields (Table 8) are reasonable except on some of the unlimed sub-plots. Some of the most spectacular treatment effects and some of the largest changes with time have been caused by the acidifying effect of ammonium sulphate. On all the unlimed sub-plots of these plots earthworms are absent and the plots are dominated by acid-tolerant grasses and some have a peaty-layer of partly decomposed plant residues overlying the mineral soil. Applications of ammonium sulphate at 48 kg N $ha^{-1}$ (Plot 1) or at 96 kg N $ha^{-1}$ without P (Plot 18) have resulted in common bent becoming dominant, whereas sweet vernal-grass (*Anthoxanthum odoratum*) is dominant on plots 4/2, 9 and 10, receiving it at 96 kg N $ha^{-1}$ plus P, and Yorkshire fog on plots 11/1 and 11/2 given it at 144 kg N $ha^{-1}$ plus PKNa Mg. The long-limed halves of these plots have a wider range of grasses; the main species on plot 1 are downy oat and quaking grass, on plot 4/2 and 10, red fescue, and false oat and meadow foxtail (*Alopecurus pratensis*) on plots 9, 11/1 and 11/2 which yield as much as some sown grassland. Nitrate of soda (Plots 14, 16 and 17) supplies nitrogen without acidifying the soil; lime has a relatively small effect on these plots. Even without lime about 30 species of plants occur with the smallest amount of N alone (Plot 17). The dominant species on the other two plots (14 and 16) is false oat, together with meadow foxtail on the unlimed ends. The organic manures are applied on a four-year cycle of farmyard manure, none, fish meal, none to Plot 13 which has a well mixed herbage but yield is generally less than from the best fertilizer treatment.

The largest and most rapid recent changes in botanical composition have occurred as a result of applying lime for the first time to the previously unlimed



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**TABLE 8**

*Park Grass*

*Mean annual yield of dry matter, t ha⁻¹ (1986-90)*

| Plot | a | b | c | d | Mean |
|---|---|---|---|---|---|
| | Sub plots | | | | |
| 1 | 4.3 | 3.5 | 2.3 | 1.1 | 2.8 |
| 2 | 3.5 | 4.2 | 2.5 | 2.4 | 3.2 |
| 3 | 3.1 | 4.0 | 2.2 | 2.5 | 3.0 |
| 4/1 | 4.1 | 4.5 | 3.5 | 3.9 | 4.0 |
| 4/2 | 4.0 | 4.0 | 3.8 | 2.7 | 3.6 |
| 6 | 6.1 | 6.2 | - | - | - |
| 7 | 6.6 | 6.4 | 5.7 | 4.8 | 5.9 |
| 8 | 3.7 | 4.3 | 4.6 | 4.4 | 4.2 |
| 9 | 6.3 | 6.8 | 5.3 | 3.9 | 5.6 |
| 10 | 4.4 | 4.6 | 4.2 | 2.6 | 4.0 |
| 11/1 | 7.5 | 6.8 | 6.6 | 6.0 | 6.7 |
| 11/2 | 8.0 | 7.2 | 6.2 | 6.2 | 6.9 |
| 12 | 3.1 | 2.7 | 2.3 | 2.5 | 2.6 |
| 13 | 7.5 | 7.9 | 5.9 | 5.3 | 6.6 |
| 14 | 6.9 | 7.8 | 6.5 | 6.6 | 7.0 |
| 15 | 6.0 | 5.6 | 4.5 | 4.5 | 5.2 |
| 16 | 6.8 | 7.0 | 5.5 | 4.8 | 6.0 |
| 17 | 4.0 | 4.3 | 4.2 | 4.0 | 4.1 |
| 18/1 | - | - | 1.5 | 1.3 | - |
| 18/2 | 4.4 | - | - | - | - |
| 18/3 | 3.8 | 3.6 | - | - | - |
| 19/1 | 5.9 | - | - | - | - |
| 19/2 | 6.6 | - | - | - | - |
| 19/3 | 5.9 | - | - | - | - |
| 20/1 | 7.1 | - | - | - | - |
| 20/2 | 7.4 | - | - | - | - |
| 20/3 | 6.7 | - | - | - | - |

very acid sub-plots. Lime applied during 1965-68, in many instances only raised the pH of the surface litter, but it increased the mean number of species per sub-plot heading in early June from 4 in 1965 to 15 (range 11-21) in 1972. The number then remained fairly constant at about 12 during the rest of the 70s but only 9 were recorded in 1990. Visual surveys, and botanical analyses of hay samples during the mid 70s, indicated that the three acid-tolerant grasses were, to varying extents depending on treatment, replaced by red fescue, smooth-stalked and rough-stalked meadow grass (*Poa pratensis* and *Poa trivialis*), cocksfoot (*Dactylis glomerata*), false oat and meadow foxtail. The survey done in 1990, and for some plots those done in the late 70s, indicate reversion on most of these sub-plots to the botanical composition 3 to 5 years after the start of the new liming, possibly indicating the sensitivity of species balance to small changes in soil pH and resulting availability of other nutrients. Visual surveys have not detected large changes from increasing soil pH on previously-limed sub-plots a and b. Analyses of hay samples in 1974 however indicated that raising the pH on several of the b-sub plots of the acid plots favoured false oat at the expense of meadow foxtail.

The distributions in the soil of nodule bacteria (*Rhizobium spp.*) for clover, *Lathyrus* and *Lotus* correspond closely to the distributions of their hosts in the different plots; neither medicks nor their nodule bacteria occur. Acid sub-plots contain no nodule bacteria; increasing amounts of lime increases numbers. On limed sub-plots, N fertilizer has neither diminished the numbers nor altered the symbiotic effectiveness of the clover nodule bacteria.



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## BARNFIELD

Although less well-known than the other Classicals this was the first, having treatments applied in spring 1843 for a crop of turnips sown in July, several months before the start of Broadbalk. However, the treatments and the cropping, although mainly roots, varied until 1876 when a period of continuous cropping with mangolds was started which lasted until 1959 (sugar beet were also grown from 1946).

As on Broadbalk, the treatments during the first two years were on long narrow plots. However, the design was modified and in 1856 it became the most sophisticated. North-south strips testing minerals and FYM, including a test of FYM + PK, were crossed at right angles by strips comparing no nitrogen fertilizer with both inorganic and organic forms of nitrogen supplying 96 kg N $ha^{-1}$. Before 1968 this was the only Classical in which N was applied with both FYM and FYM + PK fertilizer.

Because yields of the continuous roots were declining, perhaps because of increasing amounts of cyst nematodes (*Heterodera schachtii*), the cropping has been progressively modified since 1959 and has included a range of arable crops, with an increased range of N dressings, and grass. From 1977 to 1983 the strip which had never received nitrogen fertilizer was kept in fallow. It was sown to grass.clover ley in 1984. The remainder has been in grass since 1975.

A feature of the continuous roots and subsequent arable crops was the superiority of yields from plots given FYM even when a wide range of N dressings were tested with the minerals. This may have been because the extra organic matter had improved soil structure with greater effect on this field which

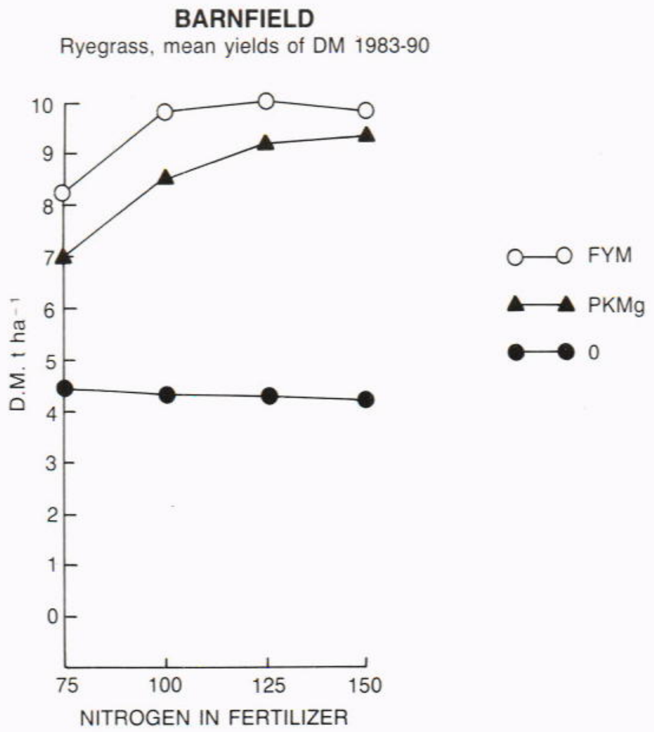


**Figure 2**



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is one of the most difficult to cultivate well. Yields of the grass grown subsequently were also larger on FYM-treated soils, although FYM was not applied again after sowing the grass. This was perhaps because more of the N applied to grass on fertilizer-treated soils was being used to increase soil organic matter. Accordingly since 1983 a range of nitrogen dressings (75, 100, 125, 150 kg N $ha^{-1}$ per cut) has been tested on the grass. Yields in the period 1983 to 1990 showed a large benefit from FYM residues and from PK Mg but with optimum N the yields from the fertilizer nearly equalled those from FYM (Fig. 2). With neither fertilizers nor FYM there was no benefit from increasing N above 75 kg $ha^{-1}$.

## AGDELL

This was the only Classical in which crops were grown in rotation. From 1848 to 1951 three different manurial combinations (none, PKNaMg and NPKNaMg plus rape cake.castor meal) were applied to the root crops of two four-course rotations. The rotations differed only in their third course — roots, barley, fallow or legume, wheat. There were only six plots and only one course of the rotation was present each year. The roots were turnips or swedes, the legume clover or beans. From 1920 club-root (*Plasmodiophora brassicae*) became progressively more damaging to the root crop especially on the NPKNaMg plots as a result of increasing acidity. By 1948 the produce was too small to weigh and the four-course rotation ceased in 1951. The soil acidity was subsequently corrected and the plots were then used to evaluate the P and K residues accumulated up to 1951. During this first period the original six plots were halved and two levels of soil organic matter were established. Subsequently crop responses were related both to fresh P and K and to amounts in the soil. The experiment ended in 1990.

## GARDEN CLOVER

The Garden Clover, pleasantly situated in the formal garden of the Manor House, has some claim to be the first micro-plot experiment. It is the simplest of the Classical Experiments, with (until 1956) only one plot, and that unmanured. Lawes, interested in the repeated growing of the same crop on the same land, found that red clover, however often resown on farmland, soon failed to give a useful yield. In 1854 he laid down this small plot in his garden. Yields were very large for the first 10 years averaging about 10 t dry matter $ha^{-1}$, probably because the soil was very rich in nutrients and because the soil-borne pests and diseases of clover were absent. Average crops were obtained over the next 30 years but thereafter yields showed a marked decline and there were several complete failures.

Between 1956 and 1972 the plot was sub-divided and a sequence of tests made of potassium, molybdenum, formalin, nitrogen and magnesium. N, K and Mg all increased yields, molybdenum and formalin did not. With N, P, K and Mg



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yields of about 6 t dry matter $ha^{-1}$ were obtained in the year of sowing. The crop was usually severely damaged during the winter by clover-rot (*Sclerotinia trifoliorum*) and was resown each spring. From 1973 to 1982 basal N, P, K and Mg were applied (corrective dressings were given to sub-plots which did not receive K and Mg in years of tests) and by 1975 the plot had returned to reasonable uniformity.

Between 1976 and 1978 aldicarb was tested (clover cyst nematode, *Heterodera trifolii*, was known to be present) and the variety Hungaropoly, believed resistant to clover-rot, was compared with the standard susceptible variety S.123. The combination of aldicarb with Hungaropoly gave yields up to 8 t dry matter $ha^{-1}$ but winter survival remained poor.

The plot then grew Hungaropoly only, with basal aldicarb, and tested benomyl applied during autumn and winter. This treatment gave almost complete winter survival and a mean yield in 1980-82 of 16.6 t dry matter $ha^{-1}$, the largest yield in the history of the experiment.

In 1983 basal nitrogen fertilizer was withdrawn to measure N fixation in its absence. In 1989 basal aldicarb was also withdrawn. In that year the crop gave a mean yield of just over 10 t dry matter $ha^{-1}$, despite an exceptionally dry summer, but then died for reasons that are not clear. It was resown to Hungaropoly in 1990. It continues to receive basal P, K and Mg but the test of benomyl has ceased.

Clover nodule bacteria and the bacteriophages are abundant. Nodule bacteria for *Vicia* are sparse and those for *Lotus* and medicks absent.



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# PUBLICATIONS

**The following are available from the Librarian:**

*Report, Rothamsted Experimental Station* From 1909 (annual, some are out of print). Prices upon application.

*Yields of the Field Experiments* Formerly called 'Numerical Results'... or 'Results'...published annually 1948 onwards. Prices upon application.

*Details of the Classical and Long-term Experiments up to 1973* Two books '...up to 1967' and supplementary volume '...up to 1973'. Price £5 each, sold separately.

*Botanical Composition of the Park Grass Plots at Rothamsted 1856-1976.* Price £5.

*The Broadbalk Wheat Experiment* Up to 1968. Price £10.

*The Manor of Rothamsted* Price £2.

# CONVERSION FACTORS

**Weights and areas**

1 metric ton or tonne (t) = 1000 kilograms (kg) = 0.984 ton
1 hectare (ha) = 10000 square metres = 2.47 acres
1 tonne hectare$^{-1}$ (t ha$^{-1}$) = 0.398 tons acre$^{-1}$
= 7.97 cwt acre$^{-1}$
= 892 lb acre$^{-1}$

**Nutrients**

| To convert | Multiply by |
|---|---|
| $P_2O_5$ to P | 0.436 |
| $K_2O$ to K | 0.830 |



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# NOTES

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