ROTHAMSTED RESEARCH

# The Long Term Experiments

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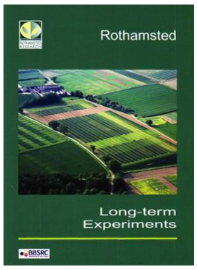


# Park Grass

## Rothamsted Research

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On both sites, much C has been sequestered in trees and soil since they were abandoned in the 1880s. Geescroft has gained, on average, 2.00 t C $ha^{-1}$ $yr^{-1}$ (0.38 t in litter and soil to a depth of 69cm, plus an estimated 1.62 t in trees, including their roots); corresponding gains of N were 22.2 kg N $ha^{-1}$ $yr^{-1}$ (15.2 kg in soil, plus 6.9 kg in trees). Broadbalk has gained 3.39 t C $ha^{-1}$ $yr^{-1}$ (0.54 t in soil, plus an estimated 2.85 t in trees), 49.6 kg N $ha^{-1}$ $yr^{-1}$ (36.8 kg in soil, plus 12.8 kg in trees). Much of the N required for plant growth will have come from inputs in rain and dry deposition. The faster accumulation of C and N in the wooded part of Broadbalk compared to Geescroft is probably because, as it is relatively narrow, there is a large edge effect and greater light interception per unit area, perhaps more scavenging of atmospheric N, and thus more growth. However, additional atmospheric N could have come from the covered yards across the road in which bullocks were housed during the winter.

## PARK GRASS

Park Grass is the oldest experiment on permanent grassland in the world. Started by Lawes and Gilbert in 1856, its original purpose was to investigate ways of improving the yield of hay by the application of inorganic fertilisers and organic manure. Within 2-3 years it became clear that these treatments were having a dramatic effect on the species composition of what had been a uniform sward. The continuing effects on species diversity and on soil function of the original treatments, together with later tests of liming and interactions with atmospheric inputs and climate change, has meant that Park Grass has become increasingly important to ecologists, environmentalists and soil scientists.

Fritillaria meleagris *on Park Grass*

The experiment was established on *c.*2.8 ha of parkland that had been in permanent pasture for at least 100 years. The uniformity of the site was assessed in the five years prior to 1856. Treatments imposed in 1856 included controls (Nil - no fertiliser or manure), and various combinations of P, K, Mg, Na, with N applied as either sodium nitrate or ammonium salts. FYM was applied to two plots but was discontinued after eight years because, when applied annually to the surface in large amounts, it had adverse effects on the sward. FYM, applied every four years, was re-introduced on three plots in 1905.



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The plots are cut in mid-June and made into hay. For 19 years the re-growth was grazed by sheep penned on individual plots but since 1875 a second harvest has been cut and removed immediately. The plots were originally cut by scythe, then by horse-drawn and then tractor-drawn mowers. Yields were originally estimated by weighing the produce from the whole plot, either as hay (1st harvest) or green crop (2nd harvest), and dry matter determined. Since 1960, yields of dry matter have been estimated from strips cut with a forage harvester. However, for the first cut the remainder of each plot is still mown and made into hay, continuing earlier management and ensuring return of seed. For the second cut, the whole of each plot is cut with a forage harvester.

*Hay harvest on Park Grass, 1941*

Park Grass    Fertiliser and organic manure treatments

Treatments (per hectare per year unless indicated)

Nitrogen (applied in spring)

| | |
|---|---|
| N1, N2, N3 | 48, 96, 144 kg N as ammonium sulphate |
| N*1, N*2 | 48, 96 kg N as sodium nitrate |
| (N2) (N*2) | last applied 1989 |

Minerals (applied in winter)

| | |
|---|---|
| P | 35 kg P as triple superphosphate |
| K | 225 kg K as potassium sulphate |
| Na | 15 kg Na as sodium sulphate |
| Mg | 10 kg Mg as magnesium sulphate |
| Si | 450 kg of sodium silicate |
| Plot 20 | 30 kg N*, 15 kg P, 45 kg K in years when FYM is not applied |

Organics (applied every fourth year)

| | |
|---|---|
| FYM | 35 t $ha^{-1}$ farmyard manure supplying c.240 kg N, 45 kg P, 350 kg K, 25 kg Na, 25 kg Mg, 40 kg S, 135 kg Ca |
| PM | Pelleted poultry manure (replaced fishmeal in 2003) supplying c.65 kg N |

On plot 13/2 FYM and PM (previously fishmeal) are applied in a 4-year cycle *i.e.*:
FYM in 2005, 2001, 1997, 1993 etc.
PM in 2003, fishmeal in 1999, 1995 1991 etc.

(FYM/Fishmeal) FYM and fishmeal last applied in 1993 and 1995 respectively

Lime (applied every third year)

Ground chalk applied *as necessary* to maintain soil (0-23 cm) at pH 7, 6 and 5 on sub-plots “a”, “b” and “c”.
Sub-plot “d” does not receive any chalk



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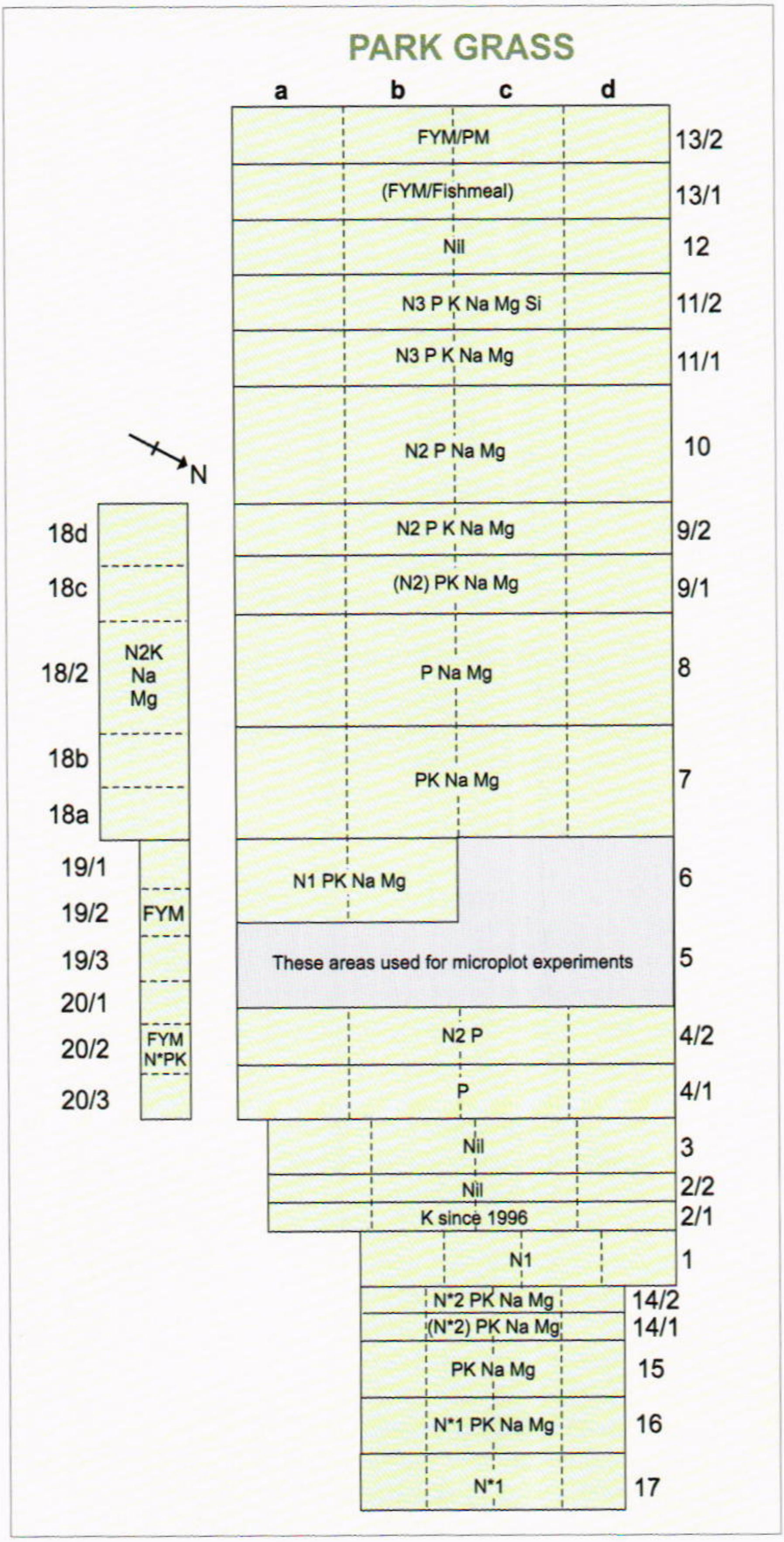




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Park Grass probably never received the large applications of chalk that were often applied to arable fields in this part of England. The soil (0-23cm) on Park Grass probably had a pH (in water) of about 5.5 when the experiment began. A small amount of chalk was applied to all plots during tests in the 1880s and 1890s. A regular test of liming was started in 1903 when most plots were divided in two and 4 t ha$^{-1}$ $CaCO_3$ applied every four years to the southern half. On those plots receiving the largest amounts of ammonium sulphate this was enough to stop the soil becoming progressively more acid. However, it remained difficult to disentangle the effects of N from those of acidity. It was decided to extend the pH range on each treatment and, in 1965, most plots were divided into four: sub-plots "a" and "b" on the previously limed halves and sub-plots "c" and "d" on the unlimed halves. Sub-plots "a", "b" and "c" now receive different amounts of chalk, when necessary, to achieve and/or maintain soil (0-23cm) at pH 7, 6 and 5, respectively. Sub-plot "d" receives no lime and its pH reflects inputs from the various treatments and the atmosphere. Soils on the unlimed sub-plots of the Nil treatments are now at *c.* pH 5.1 whilst soils receiving 96 kg N ha$^{-1}$ as ammonium sulphate or sodium nitrate are at pH 3.6 and 6.1, respectively. For the latter two treatments, between 1965 and 2005, 63 and 14 t ha$^{-1}$ $CaCO_3$, respectively, were required to increase and/or maintain the soil at pH 7.

In 1990, plots 9 and 14, which received PKNaMg and N as either ammonium sulphate or sodium nitrate, respectively, were divided so that the effects of withholding N from one half of all the sub-plots could be assessed. Similarly, plot 13, which received FYM and fishmeal (now poultry manure), was divided, and since 1997 FYM and fishmeal has been withheld from one half. In 1996, plot 2, a long-term Nil treatment, was divided, and K has been applied to one half each year to give a "K only" treatment.

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 increase numbers. On limed sub-plots, N fertiliser has neither diminished the numbers nor altered the symbiotic effectiveness of the clover nodule bacteria.

Yields of total dry matter (both harvests) for 2000-4 are shown in Table 2. The largest yields were on limed sub-plots given PKNaMg and 144 kg N ha$^{-1}$ (11/1 and 11/2). Yields with 96 kg N ha$^{-1}$ as either ammonium or nitrate (and PKNaMg) are similar (9/2 and 14/2); where P or K are not applied, yields are less (18, 4/2 and 10). Similarly, yields on plots given N only (1 and 17) are no better than on the Nil plots (3, 12 and 2/2) because lack of P and K limits yield. On soils receiving PKNaMg but no N fertiliser (7 and 15), yields are as good as those on plots receiving PKNaMg plus 96 kg N ha$^{-1}$ because of the large proportion of legumes in the sward (Table 3) except that legumes are less common on the 'd' sub-plot where no lime is applied; here soil pH is about 4.9 and yields are smaller. For all treatments, yields on unlimed sub-plots are less than those on soils maintained at pH 6 or above. However, even on the very acid soils (pH 3.6 - 3.7) dominated by one or two species, mean yields can still be as large as 6-8 t ha$^{-1}$ ("d" sub-plots of 9/2, 11/1 and 11/2).



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Table 2. Park Grass; mean annual yield of dry matter, t ha $^{-1}$ (2000-4)

| Plot | Treatment[1] | a | b | c | d |
|---|---|---|---|---|---|
| | | Sub-plot | | | |
| No nitrogen group | | | | | |
| 3 | Nil | 3.3 | 3.6 | 2.2 | 2.9 |
| 12 | Nil | 3.5 | 3.8 | 3.5 | 2.8 |
| 2/2 | Nil | 3.5 | 4.0 | 2.4 | 3.0 |
| 2/1 | K | 3.8 | 4.1 | 2.4 | 2.7 |
| 4/1 | P | 4.5 | 4.9 | 3.9 | 3.6 |
| 8 | P Na Mg | 4.4 | 5.2 | 4.1 | 4.3 |
| 7 | P K Na Mg | 7.4 | 7.4 | 6.5 | 4.4 |
| 15 | P K Na Mg | 6.2 | 6.1 | 5.0 | 3.6 |
| Ammonium N group | | | | | |
| 1 | N1 | 4.2 | 3.8 | 2.9 | 1.3 |
| 18 | N2 K Na Mg | 3.9 | 4.4 | 6.2 | 2.0 |
| 4/2 | N2 P | 5.5 | 5.0 | 6.0 | 3.0 |
| 10 | N2 P Na Mg | 6.1 | 6.1 | 7.1 | 4.0 |
| 6 | N1 P K Na Mg | 7.0 | 6.9 | - | - |
| 9/1 | (N2) P K Na Mg | 6.1 | 6.4 | 6.5 | 2.1 |
| 9/2 | N2 P K Na Mg | 7.8 | 8.3 | 7.8 | 6.4 |
| 11/1 | N3 P K Na Mg | 10.2 | 9.4 | 8.5 | 7.3 |
| 11/2 | N3 P K Na Mg Si | 9.7 | 9.6 | 8.4 | 8.3 |
| Nitrate N group | | | | | |
| 17 | N*1 | 3.9 | 4.2 | 3.6 | 3.5 |
| 16 | N*1P K Na Mg | 7.4 | 7.5 | 6.1 | 5.3 |
| 14/1 | (N*2) P K Na Mg | 6.1 | 6.8 | 6.0 | 5.9 |
| 14/2 | N*2 P K Na Mg | 7.5 | 7.3 | 7.0 | 6.7 |
| FYM group | | | | | |
| 13/1 | (FYM/fishmeal) | 5.8 | 6.7 | 5.7 | 5.5 |
| 13/2 | FYM/PM | 5.4 | 7.9 | 7.9 | 7.7 |
| | | /1 | /2 | /3 | |
| 19[2] | FYM | 6.5 | 7.8 | 6.5 | |
| 20[2] | FYM/N*PK | 7.6 | 9.0 | 7.5 | |

(1) See plan for details
(2) Plots 19 and 20 are not part of the liming scheme



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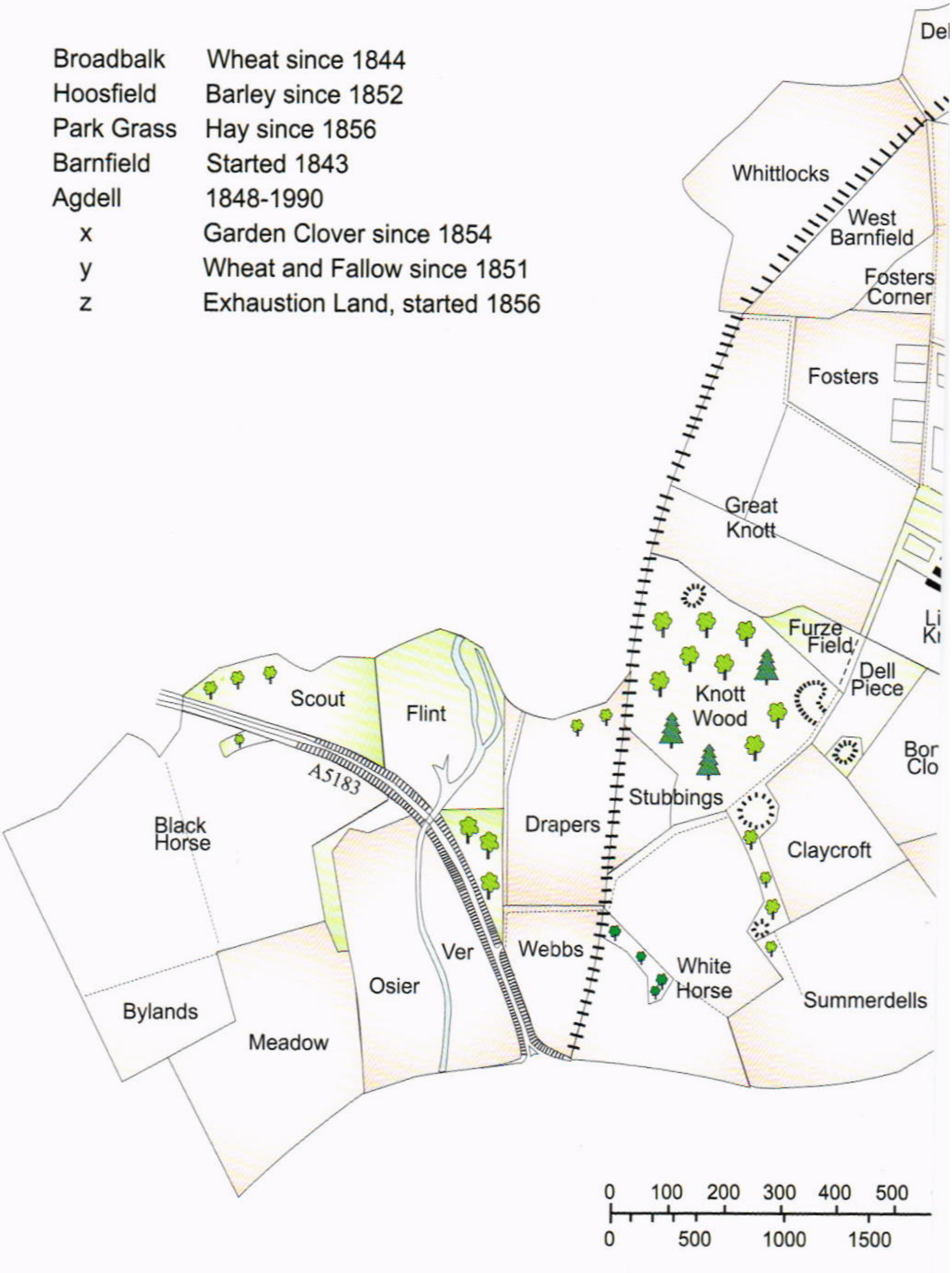
## CLASSICAL FIELD EXPERIMENTS

| | |
|---|---|
| Broadbalk | Wheat since 1844 |
| Hoosfield | Barley since 1852 |
| Park Grass | Hay since 1856 |
| Barnfield | Started 1843 |
| Agdell | 1848-1990 |
| x | Garden Clover since 1854 |
| y | Wheat and Fallow since 1851 |
| z | Exhaustion Land, started 1856 |



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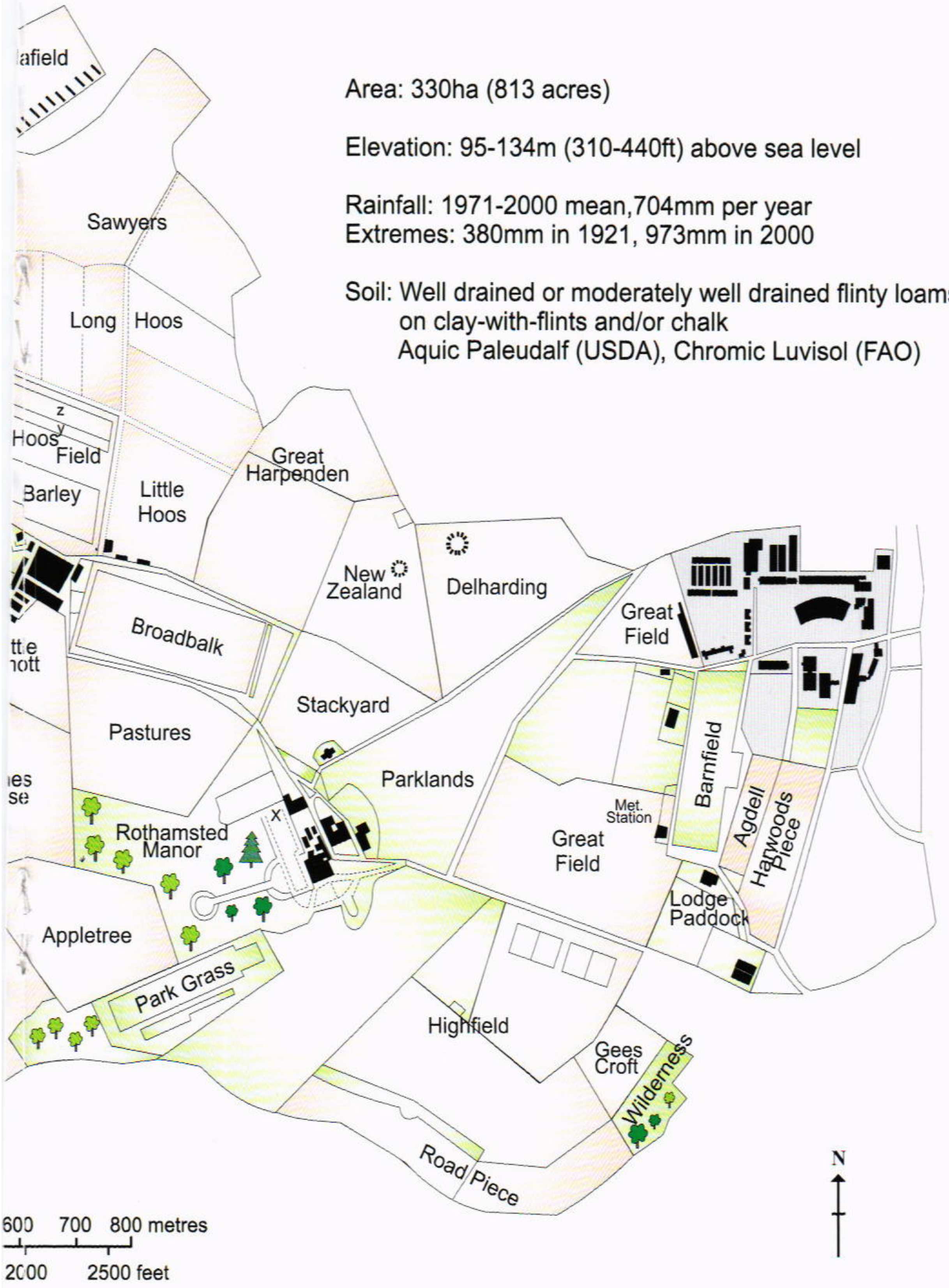
Area: 330ha (813 acres)

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

Rainfall: 1971-2000 mean,704mm per year
Extremes: 380mm in 1921, 973mm in 2000

Soil: Well drained or moderately well drained flinty loams on clay-with-flints and/or chalk
Aquic Paleudalf (USDA), Chromic Luvisol (FAO)



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## Botanical composition

The most recent, comprehensive surveys of botanical composition, made just before the first cut, were done annually between 1991 and 2000. Table 3 shows soil pH and those species comprising 10% or more of the above-ground biomass, and the total number of species identified on each sub-plot (selected treatments, mean 1991-2000). There are many interactions, some clear, some not, between fertiliser and manure treatments and pH. Without exception all the original treatments imposed in 1856 have caused a decline in species number compared to the original sward. In most cases this was due to changes in soil fertility and annual nutrient inputs and, perhaps, also the way the sward was managed.

*Sorting herbage samples from Park Grass, 1930s*

The most diverse flora, including many broad-leaved species, is on the Nil plots (plots 2/2, 3 and 12), with about 35-45 species in total. These swards are probably the nearest approximations to the species composition of the whole field in 1856, although gradual impoverishment of the plant nutrients soon caused decreases in perennial ryegrass (*Lolium perenne*) and Yorkshire fog (*Holcus lanatus*) and later increases in common bent (*Agrostis capillaris*), red fescue (*Festuca rubra*), rough hawkbit (*Leontodon hispidus*) and common knapweed (*Centaurea nigra*). Species characteristic of poor land e.g. quaking grass (*Briza media*) and cowslip (*Primula veris*) are also present in small amounts, on these plots. Lime alone does not greatly alter the absence/presence of individual species but it decreases the contribution of common bent and red fescue, and increases that of some broad-leaved species.

Applying P alone (plot 4/1) and PNaMg (plot 8) has decreased the total number of species a little, but no more than any other treatment when soils are maintained at pH 5 and above. Compared to the Nil plots, the dominant species of grasses and forbs are similar, except that at pH 6 and above, common bent is no longer present in large amounts and is replaced by ribwort plantain (*Plantago lanceolata*) and meadow buttercup (*Ranunculus acris*). Applying N with P (N2P, plot 4/2 and N2PNaMg, plot 10) has greatly decreased the total number of species, especially at pH 6 and below. There are fewer forbs and larger proportions of red fescue or sweet vernal grass (*Anthoxanthum odoratum*).

Applying P alone (plot 4/1) had relatively minor effects on species composition, compared to the Nil plots. But giving K with P (plots 7 and 15), increased the amount of legumes, especially red clover (*Trifolium pratense*) and meadow vetchling (*Lathyrus pratensis*), thus greatly increasing yield.



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Table 3. Species comprising at least 10% of herbage, and total number of species; mean 1991-2000.

| Treatment | Plot | Soil pH 1995-02 | Percentage of dry matter (Species names are listed below) AC | AP | AO | AE | DG | FR | HP | HL | LoP | LaP | TP | AS | CN | HS | LH | PL | RaA | RuA | SM | Total no. of species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nil | 3a | 7.2 | 10 | + | + | + | + | 20 | + | + | + | + | + | - | 10 | + | 15 | + | + | + | 10 | 39 |
| | b | 6.4 | 10 | + | + | + | + | 20 | + | + | - | + | + | - | 10 | - | 15 | 10 | + | + | + | 36 |
| | c | 5.3 | 30 | - | + | - | + | 30 | + | + | - | + | + | - | + | + | 15 | + | + | + | + | 37 |
| | d | 5.2 | 45 | + | + | + | + | 30 | + | + | - | + | + | - | 10 | - | + | + | + | + | + | 36 |
| P | 4/1a | 6.9 | + | + | + | + | + | 20 | + | + | + | + | 10 | - | + | + | 15 | 10 | + | + | + | 34 |
| | b | 6.1 | + | + | + | + | + | 20 | + | + | + | + | + | - | + | - | 10 | 15 | 10 | + | + | 34 |
| | c | 5.2 | 30 | + | + | + | + | 25 | + | + | + | + | + | - | + | - | 10 | + | + | + | + | 29 |
| | d | 5.3 | 25 | + | + | + | + | 25 | + | + | + | + | + | - | + | - | 15 | + | + | + | + | 32 |
| PKNaMg | 15a | 6.7 | + | + | + | 10 | + | 10 | + | + | + | 20 | 10 | + | + | + | - | + | + | + | - | 28 |
| | b | 5.9 | + | + | + | 15 | + | 10 | + | + | + | + | 20 | + | + | + | + | 10 | + | + | - | 27 |
| | c | 5.0 | 20 | + | + | + | + | 10 | + | + | + | + | 20 | - | 15 | + | - | + | + | + | - | 26 |
| | d | 4.9 | 40 | + | + | + | + | 10 | + | + | + | + | 10 | - | + | + | + | + | + | + | - | 27 |
| N*1 | 17a | 7.1 | 10 | + | + | + | + | 15 | + | + | + | - | + | - | + | + | 25 | 10 | + | + | + | 32 |
| | b | 6.4 | 15 | + | + | + | + | + | + | + | + | + | - | - | + | + | 30 | 15 | + | + | + | 34 |
| | c | 5.8 | 25 | + | + | + | + | 10 | + | + | + | - | - | - | + | + | 25 | 10 | + | + | + | 34 |
| | d | 5.8 | 25 | + | + | + | + | 10 | + | + | + | - | + | + | 10 | + | 10 | + | + | + | - | 34 |
| N*2PKNaMg | 14/2a | 6.9 | + | 20 | - | 50 | + | + | + | - | + | + | - | 10 | - | + | - | + | + | + | - | 24 |
| | b | 6.4 | + | 20 | + | 40 | + | + | - | + | + | - | + | 10 | - | + | - | - | + | + | - | 24 |
| | c | 6.1 | + | 20 | + | 40 | + | + | - | + | + | + | - | + | - | + | - | + | + | + | - | 21 |
| | d | 5.9 | + | 25 | - | 30 | 10 | + | + | + | + | + | - | + | - | 10 | - | + | + | + | - | 22 |
| N1 | 1a | 7.1 | + | + | + | + | 10 | 25 | 10 | + | - | + | + | - | + | - | 10 | + | + | + | + | 33 |
| | b | 6.2 | 20 | + | + | + | 10 | 25 | + | + | + | + | + | - | 10 | - | + | + | + | + | + | 31 |
| | c | 5.3 | 35 | - | + | + | + | 45 | + | + | + | + | + | - | + | - | - | - | + | + | - | 33 |
| | d | 4.1 | 65 | - | 30 | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | 10 |
| N2KNaMg | 18a | 7.1 | 15 | + | + | + | 10 | 15 | + | + | + | - | + | - | 10 | + | 10 | + | - | + | - | 30 |
| | b | 6.3 | 30 | + | + | + | + | 15 | + | + | + | - | - | - | 25 | + | + | + | - | + | - | 29 |
| | c | 5.4 | 35 | + | + | + | 15 | 20 | + | + | 10 | - | - | - | + | + | - | - | - | + | - | 21 |
| | d | 3.8 | 80 | - | 20 | + | - | - | - | + | - | - | - | - | - | - | - | - | - | + | - | 6 |
| N2P | 4/2a | 6.9 | 10 | + | + | + | + | 55 | + | 10 | + | - | - | - | + | - | - | + | + | + | - | 22 |
| | b | 6.2 | 15 | 10 | + | + | + | 55 | + | 10 | + | - | - | - | - | - | + | - | - | + | - | 14 |
| | c | 5.2 | 30 | + | + | + | + | 55 | + | + | + | - | - | - | - | - | - | + | - | 10 | - | 18 |
| | d | 3.7 | 30 | - | 70 | + | - | + | - | + | - | - | - | - | - | - | - | - | - | + | - | 10 |
| N2PKNaMg | 9/2a | 6.9 | + | 15 | + | 25 | 10 | + | - | 15 | + | + | + | + | - | 10 | - | + | + | + | - | 22 |
| | b | 6.3 | + | 25 | + | 35 | + | + | + | 15 | - | + | + | + | - | + | - | - | - | + | - | 17 |
| | c | 5.0 | 30 | 10 | 10 | + | + | 15 | - | + | - | + | + | + | - | + | - | - | - | + | - | 18 |
| | d | 3.7 | 15 | - | 65 | - | - | - | - | 20 | - | - | - | - | - | - | - | - | - | - | - | 4 |
| N3PKNaMg | 11/1a | 6.5 | + | 20 | - | 40 | 10 | + | + | 10 | + | - | - | + | - | + | - | - | + | + | - | 14 |
| | b | 6.2 | + | 20 | + | 35 | 20 | + | + | 10 | + | - | - | + | - | + | - | - | - | + | - | 15 |
| | c | 4.9 | + | 30 | + | 20 | + | - | - | 30 | - | - | - | + | - | + | - | - | - | + | - | 13 |
| | d | 3.6 | - | - | + | - | - | - | - | 100 | - | - | - | - | - | - | - | - | - | - | - | 3 |
| FYM/PM | 13/2a | 6.8 | 30 | + | + | + | 10 | 15 | + | + | 10 | - | - | - | + | + | - | - | - | + | - | 28 |
| | b | 6.1 | + | 15 | + | 20 | 10 | + | - | + | + | + | - | + | + | 10 | - | + | + | + | - | 30 |
| | c | 5.3 | 20 | + | + | + | + | + | + | 10 | - | + | + | + | + | + | + | 10 | + | + | - | 32 |
| | d | 5.1 | 35 | 10 | + | + | + | 10 | + | 10 | + | + | + | - | + | + | + | + | + | + | - | 34 |

After Crawley *et al.*, 2005, *American Naturalist*, **165**, 179-192.

Data are from surveys immediately before hay harvest; rounded to the nearest 5% of dry matter, mean 1991-2000. (Selected plots only)

+, species present at less than 10%; -, species not identified on that plot.

Species that do not occur at 10%, or more, on any one plot are not shown.

| | | |
|---|---|---|
| Grasses: | *Agrostis capillaris* | Common Bent |
| | *Alopecurus pratensis* | Meadow Foxtail |
| | *Anthoxanthum odoratum* | Sweet Vernal Grass |
| | *Arrhenatherum elatius* | False Oat Grass |
| | *Dactylis glomerata* | Cock's-foot |
| | *Festuca rubra* | Red Fescue |
| | *Helictotrichon pubescens* | Downy Oat-grass |
| | *Holcus lanatus* | Yorkshire Fog |
| | *Lolium perenne* | Perennial Ryegrass |

| | | |
|---|---|---|
| Legumes: | *Lathyrus pratensis* | Meadow Vetchling |
| | *Trifolium pratense* | Red Clover |

| | | |
|---|---|---|
| Forbs: | *Anthriscus sylvestris* | Cow Parsley |
| | *Centaurea nigra* | Common Knapweed |
| | *Heracleum sphondylium* | Hogweed |
| | *Leontodon hispidus* | Rough Hawkbit |
| | *Plantago lanceolata* | Ribwort Plaintain |
| | *Ranunculus acris* | Meadow Buttercup |
| | *Rumex acetosa* | Common Sorrel |
| | *Sanguisorba minor* | Salad Burnet |



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Grasses are dominant on the "d" sub-plots, where the soil pH ranges from 4.1 to 3.6. On these very acid soils, adding P, or P plus K, in the presence of N has had very interesting effects on the proportions of the three dominant grass species (Table 4).

Table 4. The effects on three grass species of applying P and K with N where soil pH is 4.1 - 3.6.

| | | Percentage of dry matter | | |
|---|---|---|---|---|
| Plot | Treatment[1] | *Agrostis capillaris* | *Anthoxanthum odoratum* | *Holcus lanatus* |
| 1d | N1 | 67 | 32 | 0 |
| 4/2d | N2P | 28 | 70 | 1 |
| 9/2d | N2PKNaMg | 13 | 67 | 20 |
| 11/1d | N3PKNaMg | 0 | 0 | 100 |

(1) See plan for details

Applying N as ammonium sulphate or as sodium nitrate has resulted in the most spectacular contrasts. In the absence of applied chalk, soil pH on the "d" sub-plots ranges from 4.1 to 3.6 where ammonium sulphate has been applied and from 5.4 to 5.9 with sodium nitrate. The effect of soil acidification on the total number of species in the sward is dramatic, 4-10 with ammonium sulphate, but 22-34 with sodium nitrate. The effect on species number of adding chalk to these soils is shown in Table 3. Figure 5 summarises, for three contrasting treatments, effects over time on the numbers of species comprising 1%, or more, of the above-ground biomass. Even on the Nil plots the number of species has decreased since the start of the experiment, possibly as a consequence of atmospheric inputs and/or changes in the management of the sward. Applying either form of N reduced species number further in the absence of chalk, more so with ammonium sulphate than sodium nitrate. Raising soil pH, by adding chalk, has had more effect on the Nil and ammonium sulphate treatments than on those given sodium nitrate.



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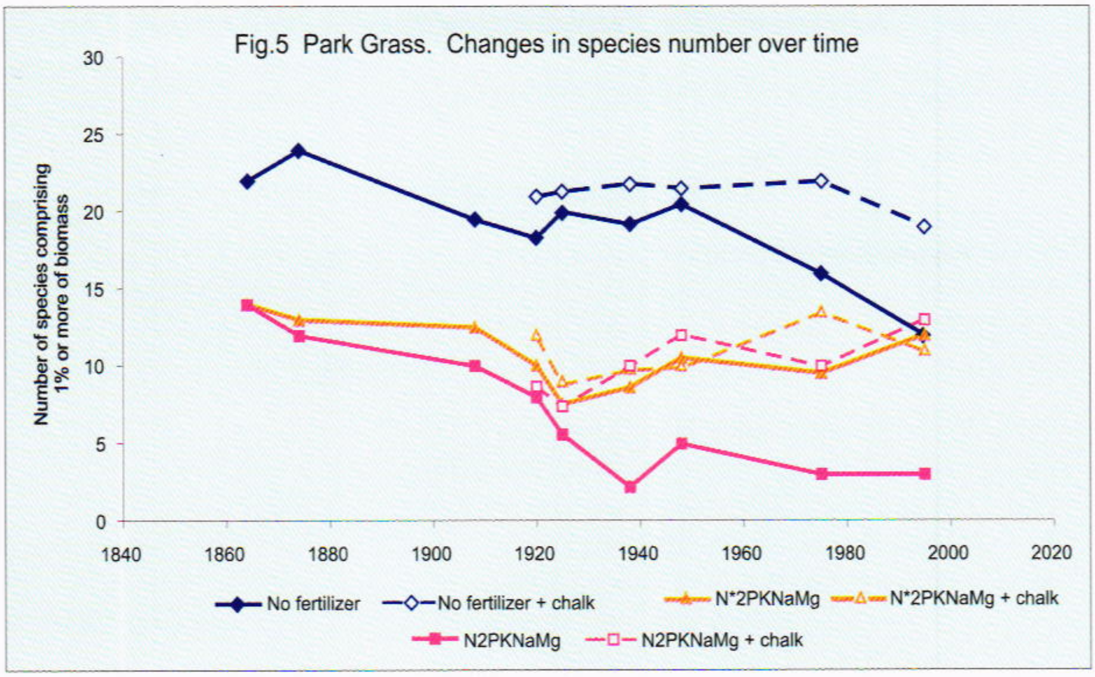


## HOOSFIELD SPRING BARLEY

Spring barley has been grown continuously on this experiment since 1852. It offers interesting contrasts to Broadbalk; being spring-sown it has only needed to be fallowed four times to control weeds, and it tests not only nitrogen, minerals and FYM but also sodium silicate.

The design of the experiment is of a factorial nature with strips 1-4 (see plan), originally testing four combinations of nutrients: 0 v P v KMgNa v PKMgNa, crossed by four Series, originally testing no N or three forms of N, applied (usually) at 48 kg N $ha^{-1}$ (Series 0, no N; Series A, ammonium sulphate; Series AA, sodium nitrate; Series C, rape cake, later castor meal).

The sodium nitrate series was divided in 1862 for a test of 0 v sodium silicate; this was modified in 1980 to test: 0 v silicate 1862-1979 v silicate since 1980 v silicate since 1862. Additional plots, on the south side, test: unmanured (plot 61); ashes, 1852-1932 (plot 62); residues of FYM applied 1852-71 (plot 71); FYM since 1852 (plot 72). Ashes were tested because in the early years of the experiment they were used to bulk up the different fertilisers to the same volume for ease of spreading. Thus, ashes alone were tested to ensure that no additional nutrients were being added. Two new plots, started in 2001, test: P2KMg (plot 63) and FYM (plot 73). Strip 5 tested various other combinations of N, P, K and Mg.



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