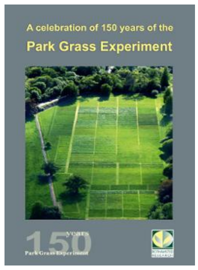
ROTHAMSTED RESEARCH

A Celebration of 150 Years of the Park Grass Experiment



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A celebration of 150 years of the

Park Grass Experiment

150 years

Park Grass Experiment

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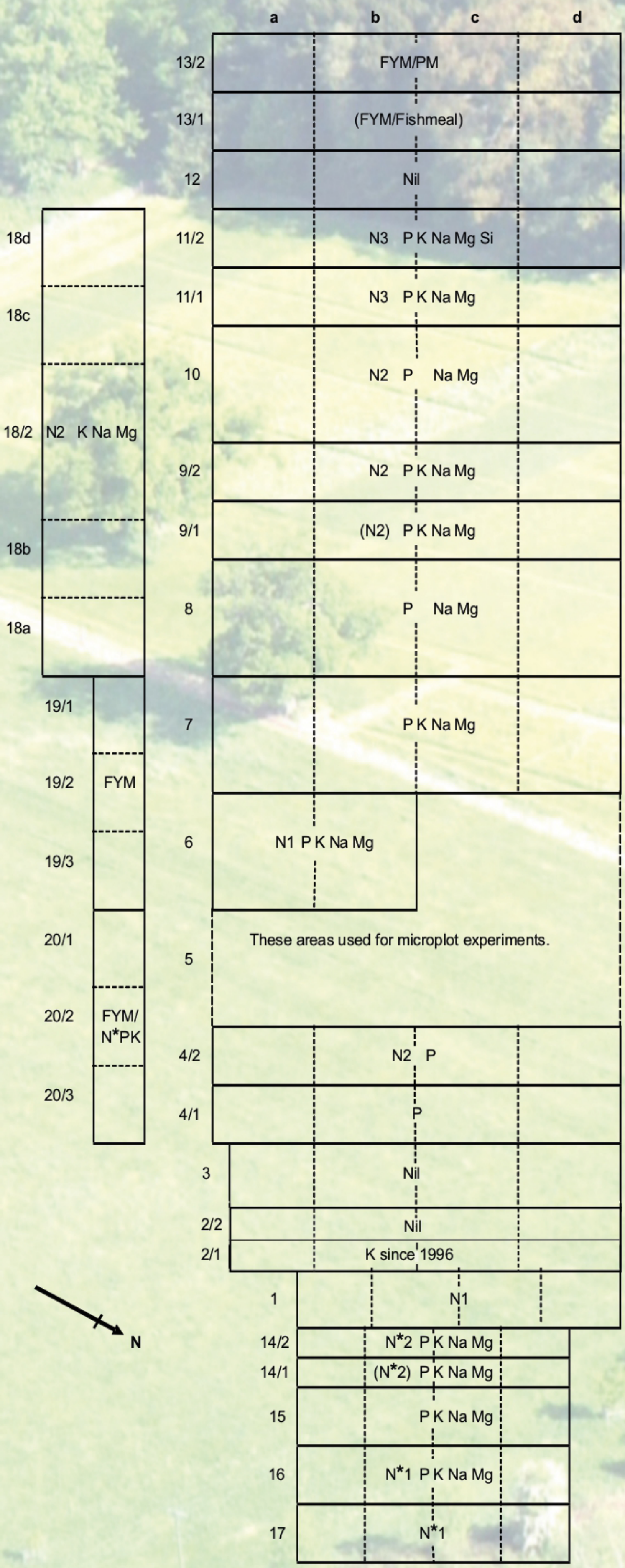


Plot layout and current treatments

Plot treatments
(per hectare per year unless indicated)

Nitrogen (applied in spring)

N1, N2, N3: ammonium sulphate supplying 48, 96, 144 kg N and 55, 110, 165 kg S

N*1, N*2: sodium nitrate supplying 48, 96 kg N and 78, 157 kg Na

(N2), (N*2): last applied 1989

Minerals (applied in winter)

P: triple superphosphate supplying 35 kg P

K: potassium sulphate supplying 225 kg K and 99 kg S

Na: sodium sulphate supplying 15 kg Na and 10 kg S

Mg: magnesium sulphate (Epsom salts) supplying 10 kg Mg and 13 kg S

Si: water soluble sodium silicate supplying 135 kg Si and 63 kg Na

Plot 20: rates of fertilizer in years when FYM is not applied; 30 kg N*, 15 kg P, 45 kg K

Organics (applied every 4th year)

FYM: 35 t 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 *ie:*
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

Sub-plots a, b and c: differential amounts of chalk applied, *if needed,* every three years to maintain soil pH 7, 6 and 5, respectively

Sub-plot d receives no chalk

Plots 1-13 started in 1856, plots 14-17 in 1858, plot 18 in 1865 and plots 19 and 20 in 1872.

Sub-plots range in size from 75 - 634 m^2

Front cover: Aerial view of Park Grass taken 23rd May 2005

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

Percentage of dry matter (Species names are in **Bold** in list opposite).

Treatment	Plot	Soil pH 1995-02	*AC*	*AP*	*AO*	*AE*	*DG*	*FR*	*HP*	*HL*	*LoP*	*LaP*	*TP*	*AS*	*CN*	*HS*	*LH*	*PL*	*RaA*	*RuA*	*SM*	Total number 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
Nil	12a	7.0	15	+	+	+	+	10	+	+	+	+	10	-	+	+	20	+	+	+	+	44
	b	6.3	20	+	+	+	+	20	+	+	+	+	+	-	+	-	15	+	+	+	+	42
	c	5.2	25	+	+	+	+	40	+	+	-	+	+	-	+	+	10	+	+	+	+	37
	d	5.1	30	-	+	+	+	30	+	+	+	+	+	-	+	-	15	+	+	+	+	42
Nil	2/2a	7.1	15	+	+	-	+	15	+	+	+	+	+	-	10	+	20	+	+	+	+	42
	b	6.0	10	+	+	+	+	15	+	+	-	+	+	-	10	-	15	10	+	+	+	37
	c	5.2	30	+	+	+	+	35	+	+	-	+	+	-	10	-	+	+	+	-	+	33
	d	5.1	35	+	+	+	+	30	+	+	-	-	-	-	20	-	+	+	+	+	+	33
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
PNaMg	8a	7.0	10	+	+	+	+	20	+	+	+	-	10	-	10	+	+	+	+	+	+	36
	b	6.1	+	+	+	+	+	20	+	+	+	+	+	-	+	+	15	+	10	+	+	37
	c	5.3	30	+	+	+	+	20	+	+	-	+	+	-	+	+	15	+	+	+	+	32
	d	5.2	30	+	+	+	+	20	+	+	+	+	+	-	+	-	10	+	+	+	+	29
PKNaMg	7a	6.9	+	+	+	15	+	+	+	+	+	15	15	+	+	+	-	10	+	+	-	27
	b	5.9	+	15	+	20	+	+	+	+	+	+	10	+	+	+	-	10	+	+	-	29
	c	5.0	25	+	+	+	+	+	+	+	-	15	10	-	15	+	+	+	+	+	-	28
	d	4.9	40	+	+	+	+	10	+	+	-	+	15	-	10	-	+	+	+	+	-	28
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*1PKNaMg	16a	6.7	+	10	+	25	+	15	+	+	+	10	10	+	-	+	-	+	+	+	-	25
	b	6.2	+	10	+	25	+	15	+	+	+	+	+	+	-	+	-	+	+	+	-	25
	c	5.5	25	10	+	15	+	10	+	+	+	+	+	+	-	+	-	10	+	+	-	23
	d	5.4	35	+	+	15	+	+	+	+	+	+	+	-	+	+	-	+	+	+	-	27
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
N2PNaMg	10a	6.9	10	+	+	+	+	45	+	+	+	-	-	-	-	-	-	10	+	+	-	23
	b	5.9	20	15	10	+	+	40	-	+	-	-	-	-	-	-	-	+	+	10	-	15
	c	4.9	25	+	10	+	+	50	+	+	-	-	+	-	-	-	-	-	-	10	-	16
	d	3.7	+	-	85	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	4
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
N3PKNaMgSi	11/2a	6.7	+	25	+	45	10	+	-	+	+	+	-	+	-	10	-	+	-	+	-	14
	b	5.9	+	35	+	40	10	-	-	10	-	-	-	+	-	+	-	-	-	+	-	10
	c	5.0	10	40	+	35	+	+	+	10	-	-	-	+	-	+	-	-	-	+	-	13
	d	3.7	+	+	-	-	-	-	-	95	-	-	-	-	-	-	-	-	-	-	-	4
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
FYM	19/2	6.1	+	10	+	20	+	+	+	+	+	+	+	+	+	+	-	15	+	+	-	30
	19/3	5.7	25	+	+	15	+	+	+	+	+	+	+	-	+	+	-	10	10	+	-	27
	19/1	5.4	45	+	+	10	+	+	+	+	+	+	+	-	+	+	+	+	+	+	-	31
FYM/N*PK	20/2	6.1	+	15	+	25	+	+	+	10	+	+	+	+	+	+	-	+	+	+	-	29
	20/3	5.9	15	10	+	15	10	+	+	10	+	+	+	+	-	+	-	+	+	+	-	26
	20/1	5.7	35	10	+	15	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	27

Data are from surveys immediately before hay harvest; rounded to the nearest 5% of dry matter, mean 1991-2000.
+, species present at less than 10%; -, species not identified on that plot.

Species identified 1991-2000. (After Crawley *et al., 2005, American Naturalist*, **165**, 179-192)

Species highlighted in **bold** are those comprising 10%, or more, of dry matter on at least one plot.

Grasses and sedges

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**
Briza media	Quaking Grass
Bromus hordeaceus	Soft Brome
Carex caryophyllea	Spring Sedge
Carex flacca	Glaucous Sedge
Cynosorus cristatus	Crested Dog's-tail
Deschampsia cespitosa	Tufted Hair-grass
Elytrigia repens	Common Couch
Festuca pratensis	Meadow Fescue
Luzula campestris	Field Wood-rush
Phleum pratense	Timothy
Poa annua	Annual Meadow-grass
Poa pratensis	Smooth Meadow-grass
Poa trivialis	Rough Meadow-grass
Trisetum flavescens	Yellow Oat-grass

Legumes

Lathyrus pratensis	**Meadow Vetchling**
Trifolium pratense	**Red Clover**
Lotus corniculatus	Common Bird's-foot-trefoil
Ononis repens	Common Restharrow
Trifolium repens	White Clover
Vicia cracca	Tufted Vetch
Vicia sepium	Bush Vetch

Shrubs and trees

Quercus robur	Pedunculate Oak
Rosa sp.	-
Rubus fruticosus	Bramble

Forbs

Anthriscus sylvestris	**Cow Parsley**
Centaurea nigra	**Common Knapweed**
Heracleum sphondylium	**Hogweed**
Leontodon hispidus	**Rough Hawkbit**
Plantago lanceolata	**Ribwort Plantain**
Ranunculus acris	**Meadow Buttercup**
Rumex acetosa	**Common Sorrel**
Sanguisorba minor	**Salad Burnet**
Achillea millefolium	Yarrow
Agrimonia eupatoria	Agrimony
Ajuga reptans	Bugle
Anenome nemorosa	Wood Anenome
Bellis perennis	Daisy
Capsella bursa-pastoris	Shepherd's-purse
Cardamine pratensis	Cuckooflower
Cerastium fontanum	Common Mouse-ear
Conopodium majus	Pignut
Crepis capillaris	Smooth Hawk's-beard
Filipendula ulmaria	Meadowsweet
Fritillaria meleagris	Fritillary
Galium verum	Lady's Bedstraw
Hieracium pilosella	Mouse-ear Hawkweed
Hypochaeris radicata	Cat's-ear
Knautia arvensis	Field Scabious
Leontodon autumnalis	Autumn Hawkbit
Ophioglossum vulgatum	Adder's-tongue
Ornithogalum angustifolium	Star-of-Bethlehem
Pimpinella saxifraga	Burnet-saxifrage
Potentilla reptans	Creeping Cinquefoil
Potentilla sterilis	Barren Strawberry
Primula veris	Cowslip
Prunella vulgaris	Selfheal
Ranunculus auricomus	Goldilocks Buttercup
Ranunculus bulbosus	Bulbous Buttercup
Ranunculus ficaria	Lesser Celandine
Rumex obtusifolius	Broad-leaved Dock
Senecio jacobea	Common Ragwort
Senecio vulgaris	Groundsel
Stachys officinalis	Betony
Stellaria graminea	Lesser Stichwort
Stellaria media	Common Chickweed
Taraxacum officinale	Dandelion
Tragopogon pratensis	Goat's-beard
Veronica chamaedrys	Germander Speedwell

Other selected references (and references therein)

Crowther E M (1925) *Journal of Agricultural Science* **15**, 222-231 & 232-236
Dodd M *et al.* (1995) *Journal of Ecology* **83**, 277-285
Jenkinson D S *et al.* (1994) *Journal of Agricultural Science* **122**, 365-374
Lawes J B & Gilbert J H (1900) *Philosophical Transactions of the Royal Society (B)* **192**, 139-210
Silvertown J *et al.* (2006) *Journal of Ecology* (in press)
Snaydon R W & Davis M S (1976) *Heredity* **37**, 9-25
Thurston J M *et al.* (1976) *Annales Agronomiques* **27**, 1043-1082

A comprehensive list of publications relating Park Grass can be found within the Electronic Rothamsted Archive (eRA) on the Rothamsted web-site; see http:www.era.rothamsted.ac.uk

The history and design of Park Grass

150 years
Park Grass Experiment

Park Grass is the oldest experiment on ungrazed 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 fertilizers 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.

The experiment was established on c. 2.8 ha of uniform pasture for at least 100 years old. Treatments included controls (Nil - no fertilizer or manure), and various combinations of P, K, Mg, Na and N as either sodium nitrate or ammonium salts. Farmyard manure (FYM) was applied to two plots but was discontinued after eight years because of adverse effects on the sward. FYM, applied every four years, was re-introduced on three plots in 1905.

Harvesting

The plots are cut in mid-June and made into hay. For the first 19 years the re-growth was often grazed by sheep penned on individual plots but since 1875 a second cut, usually carted green, has been taken. The plots were originally cut by scythe, then by horse-drawn, and now tractor-drawn, mowers. Yields were originally estimated by weighing the produce, either of hay or green crop, from the whole plot but since 1960 yields have been estimated from strips cut with a forage harvester. However, for the first cut the remainder of the plot is still mown and made into hay; thus continuing earlier management and ensuring the return of seed. For the second cut the whole plot is cut, with a forage harvester.

Liming

Park Grass probably never received the large amounts of chalk that were often applied to arable fields in this part of England. The pH of the soil (0-23cm) on Park Grass was therefore about 5.5 (in water) when the experiment began. A small amount of chalk was applied to all plots during tests in the1880s 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.

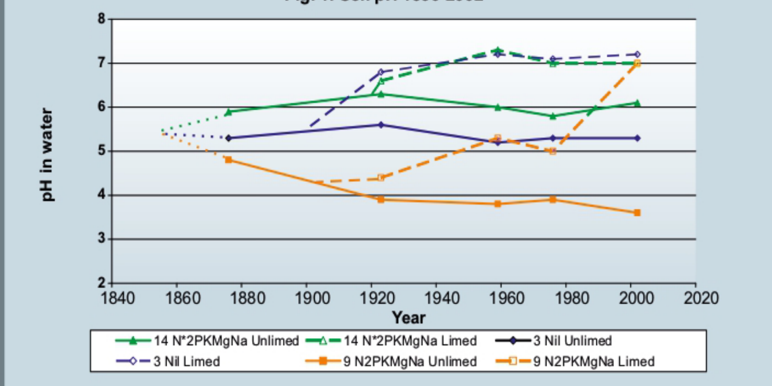


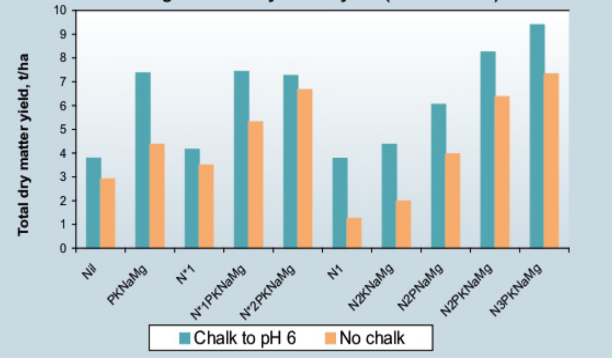
Fig. 1. Soil pH 1856-2002

However, on those plots receiving the largest amounts of ammonium sulphate this was not enough to stop the soil becoming progressively more acid; making it 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 differential amounts of lime, when and where necessary, to achieve and/or maintain soils 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 5.3 (Fig. 1) whilst soils receiving 96 kg N ha^{-1} as ammonium sulphate or sodium nitrate are at pH 3.6 and 6.1 respectively. The latter two treatments required 63 and 14 t ha^{-1} $CaCO_3$, respectively, between 1965 and 2005 to increase and/or maintain the soil at pH 7.

Yields

Yields of total dry matter (not hay) are shown in Fig. 2. Largest yields are on limed sub-plots given PKNaMg and 144 kg N ha^{-1}. Yields with 96 kg N ha^{-1} as either ammonium or nitrate (and PKNaMg) are similar; where P or K has been withheld yields are reduced. Similarly, yields on plots given N only are no better than the Nil plots because lack of P and K limits yield. Interestingly, on soils receiving PKNaMg but no N fertiliser 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 (see main table). However, where no lime is applied soil pH is about 4.9 and legumes are less common; consequently yields are less. On all treatments, yields on unlimed sub-plots are less than those on soils maintained at pH 6, or above. However, even on the acid soils (pH 3.6 - 3.7) dominated by one or two species, yields are c.7 t ha^{-1}.

Fig. 2. Total dry matter yield (mean 2000-4)



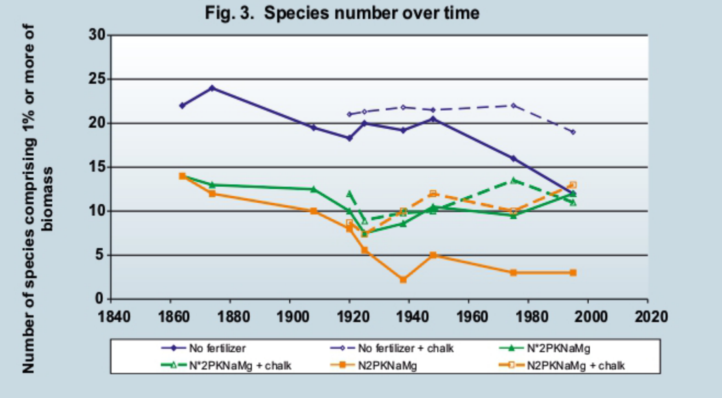
Archiving Samples

Soil samples (most 0-23cm, some deeper) have been taken periodically from the experiment, infrequently at first, more regularly in the last 40 years as we have sought to control soil pH more closely. The soils, together with unground samples of herbage from each plot every year, have been archived Such action was incredibly far-sighted and has allowed us to retrospectively analyse samples for many factors which could not have been anticipated 150 years ago. Such analyses have included ^{14}C, ^{34}S, cadmium and other heavy metals, dioxins, PAH's and DNA. Recent analysis of archived herbage for plutonium and uranium provided the first evidence that fallout from atmospheric bomb tests carried out in the Nevada Desert in 1952/3 reached northwest Europe. (Warneke *et al*, 2002, *EPSL* **203,** 1047-1057)

Botanical composition

The table overleaf shows soil pH and those species comprising 10% or more of the above ground biomass together with the total number of species identified on each sub-plot (mean 1991-2000 data). There are many interactions, some clear, some not, between fertilizer and manure treatments and pH. Figure 3 shows the impact of selected treatments on the number of species comprising 1% or more of the biomass. Numbers of species have decreased, even on the Nil plots, through acid deposition. Applying N as sodium nitrate or ammonium sulphate reduces diversity further, and in the ammonium form also rapidly acidifies the soil, reducing the number of species to one or two, *Holcus lanatus* (Yorkshire Fog) and *Anthoxanthum odoratum* (Sweet Vernal Grass). Lime aids recovery from acidity. Withholding N also causes more species to return (not shown).

Fig. 3. Species number over time



150 years

Park Grass Experiment

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