

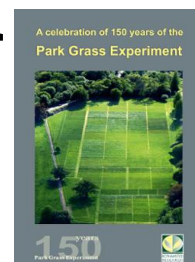
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A Celebration of 150 Years of the Park Grass Experiment

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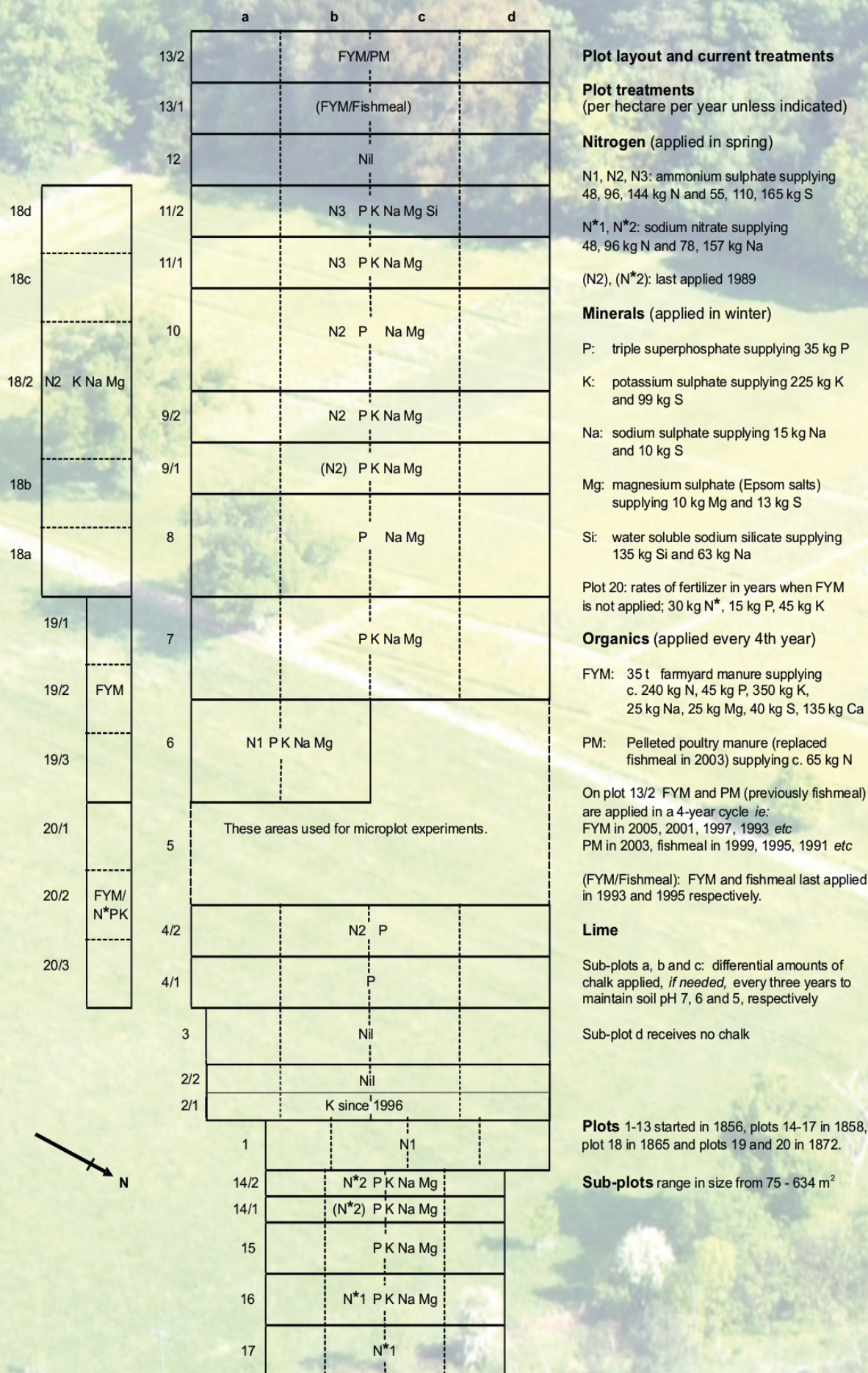
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A celebration of 150 years of the Park Grass Experiment



150 years
Park Grass Experiment





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	+	+	+	+	+	20	10	+	+	+	-	+	+	+	-	28
	b	5.9	+	+	+	15	+	+	+	+	+	+	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	+	35	10	+	+	15	+	+	+	+	-	10	-	+	+	+	-	22
	b	6.3	+	25	+	25	+	+	+	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		Forbs	
<i>Agrostis capillaris</i>	Common Bent	<i>Anthriscus sylvestris</i>	Cow Parsley
<i>Alopecurus pratensis</i>	Meadow Foxtail	<i>Centaurea nigra</i>	Common Knapweed
<i>Anthoxanthum odoratum</i>	Sweet Vernal Grass	<i>Heracleum sphondylium</i>	Hogweed
<i>Arrhenatherum elatius</i>	False Oat Grass	<i>Leontodon hispidus</i>	Rough Hawkbit
<i>Dactylis glomerata</i>	Cock's-foot	<i>Plantago lanceolata</i>	Ribwort Plantain
<i>Festuca rubra</i>	Red Fescue	<i>Ranunculus acris</i>	Meadow Buttercup
<i>Helictotrichon pubescens</i>	Downy Oat-grass	<i>Rumex acetosa</i>	Common Sorrel
<i>Holcus lanatus</i>	Yorkshire Fog	<i>Sanguisorba minor</i>	Salad Burnet
<i>Lolium perenne</i>	Perennial Ryegrass		
<i>Briza media</i>	Quaking Grass	<i>Achillea millefolium</i>	Yarrow
<i>Bromus hordeaceus</i>	Soft Brome	<i>Agrimonia eupatoria</i>	Agrimony
<i>Carex caryophylla</i>	Spring Sedge	<i>Ajuga reptans</i>	Bugle
<i>Carex flacca</i>	Glaucous Sedge	<i>Anemone nemorosa</i>	Wood Anemone
<i>Cynosorus cristatus</i>	Crested Dog's-tail	<i>Bellis perennis</i>	Daisy
<i>Deschampsia cespitosa</i>	Tufted Hair-grass	<i>Capsella bursa-pastoris</i>	Shepherd's-purse
<i>Elytrigia repens</i>	Common Couch	<i>Cardamine pratensis</i>	Cuckooflower
<i>Festuca pratensis</i>	Meadow Fescue	<i>Cerastium fontanum</i>	Common Mouse-ear
<i>Luzula campestris</i>	Field Wood-rush	<i>Conopodium majus</i>	Pignut
<i>Pheum pratense</i>	Timothy	<i>Crepis capillaris</i>	Smooth Hawk's-beard
<i>Poa annua</i>	Annual Meadow-grass	<i>Filipendula ulmaria</i>	Meadowsweet
<i>Poa pratensis</i>	Smooth Meadow-grass	<i>Fritillaria meleagris</i>	Fritillary
<i>Poa trivialis</i>	Rough Meadow-grass	<i>Galium verum</i>	Lady's Bedstraw
<i>Trisetum flavescens</i>	Yellow Oat-grass	<i>Hieracium pilosella</i>	Mouse-ear Hawkweed
		<i>Hypochaeris radicata</i>	Cat's-ear
		<i>Knautia arvensis</i>	Field Scabious
		<i>Leontodon autumnalis</i>	Autumn Hawkbit
		<i>Ophioglossum vulgatum</i>	Adder's-tongue
		<i>Ornithogalum angustifolium</i>	Star-of-Bethlehem
		<i>Pimpinella saxifraga</i>	Burnet-saxifrage
		<i>Potentilla reptans</i>	Creeping Cinquefoil
		<i>Potentilla sterilis</i>	Barren Strawberry
		<i>Primula veris</i>	Cowslip
		<i>Prunella vulgaris</i>	Selfheal
		<i>Ranunculus auricomus</i>	Goldilocks Buttercup
		<i>Ranunculus bulbosus</i>	Bulbous Buttercup
		<i>Ranunculus ficaria</i>	Lesser Celandine
		<i>Rumex obtusifolius</i>	Broad-leaved Dock
		<i>Senecio jacobea</i>	Common Ragwort
		<i>Senecio vulgaris</i>	Groundsel
		<i>Stachys officinalis</i>	Betony
		<i>Stellaria graminea</i>	Lesser Stichwort
		<i>Stellaria media</i>	Common Chickweed
		<i>Taraxacum officinale</i>	Dandelion
		<i>Tragopogon pratensis</i>	Goat's-beard
		<i>Veronica chamaedrys</i>	Germander Speedwell
Legumes			
<i>Lathyrus pratensis</i>	Meadow Vetchling		
<i>Trifolium pratense</i>	Red Clover		
<i>Lotus corniculatus</i>	Common Bird's-foot-trefoil		
<i>Ononis repens</i>	Common Restharrow		
<i>Trifolium repens</i>	White Clover		
<i>Vicia cracca</i>	Tufted Vetch		
<i>Vicia sepium</i>	Bush Vetch		
Shrubs and trees			
<i>Quercus robur</i>	Pedunculate Oak		
<i>Rosa</i> sp.	-		
<i>Rubus fruticosus</i>	Bramble		

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.

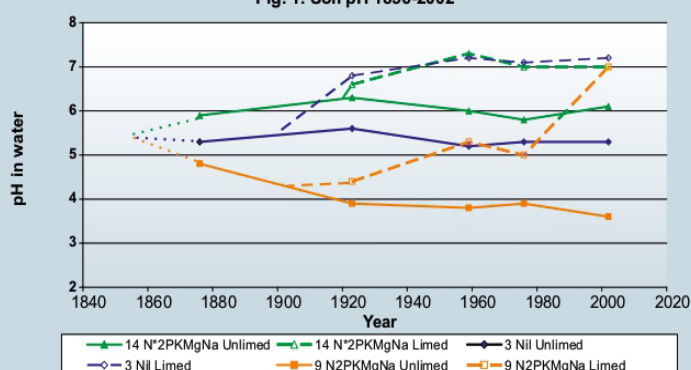
Harvesting

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 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 CaCO₃ applied every four years to the southern half.

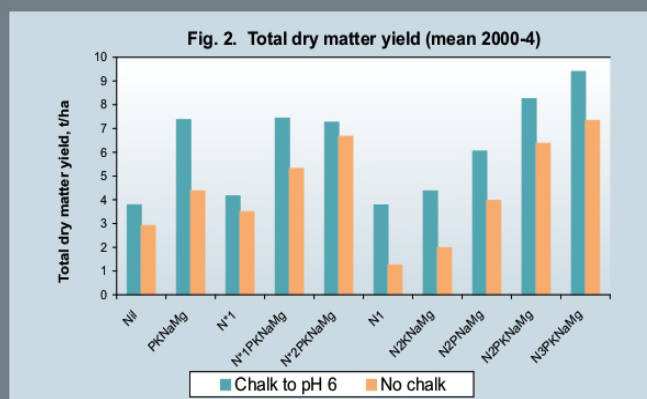
Fig. 1. Soil pH 1856-2002



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 CaCO₃, 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 $c.7 \text{ t ha}^{-1}$.

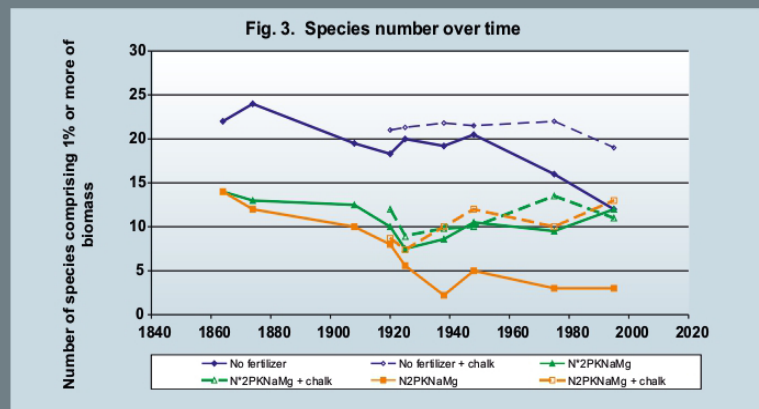


Archiving Samples

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).



150 years
Park Grass Experiment

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