ROTHAMSTED RESEARCH

Rothamsted - the Classical Experiments

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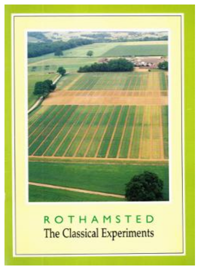

Broadbalk Winter Wheat

Rothamsted Research

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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).

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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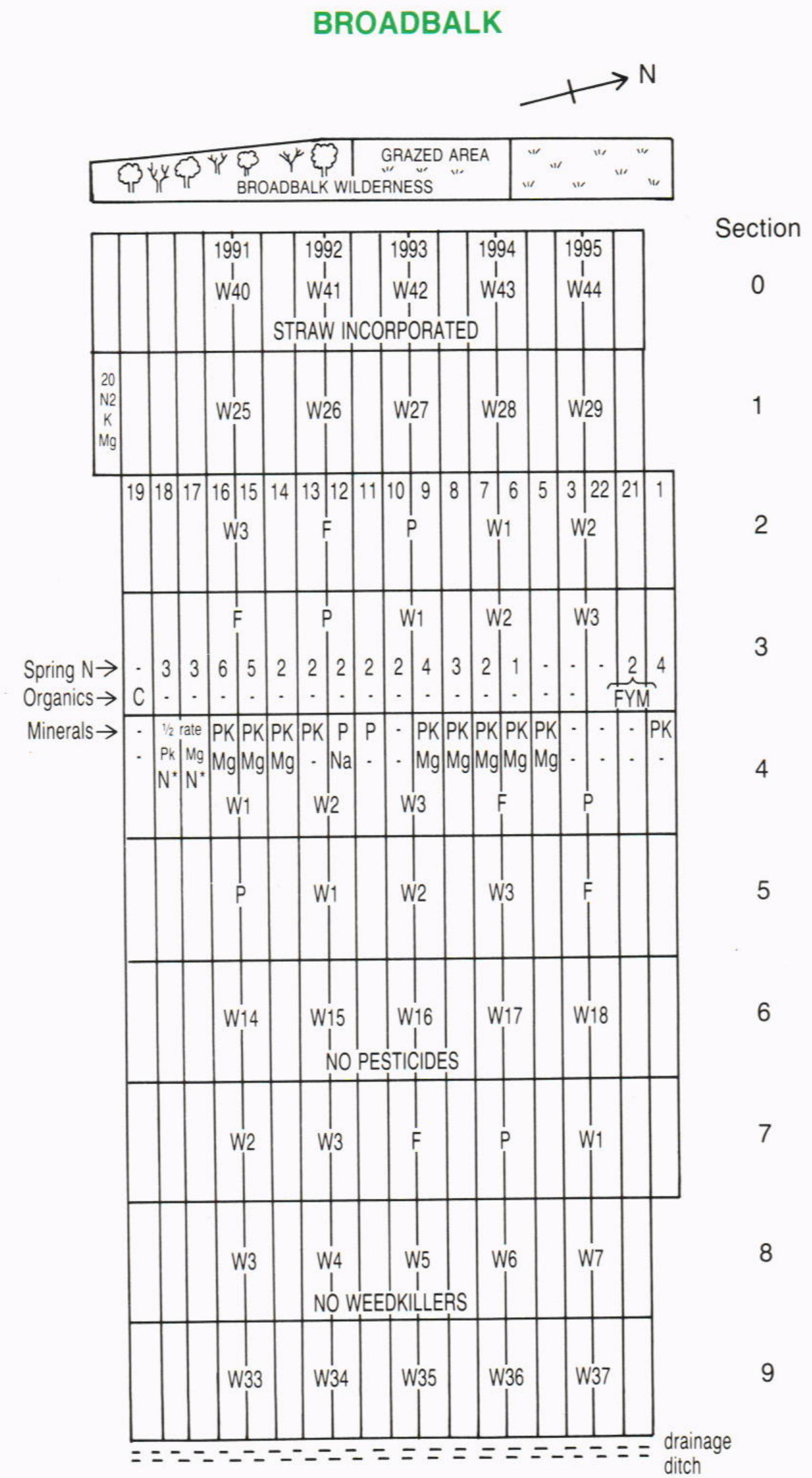

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Weeds were controlled by hand-hoeing in the past. When this became impracticable five strips ('Sections', later increased to 10) crossing all the plots at right angles were made and bare fallowed, mainly in a 5-year rotation of fallow with four successive 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.

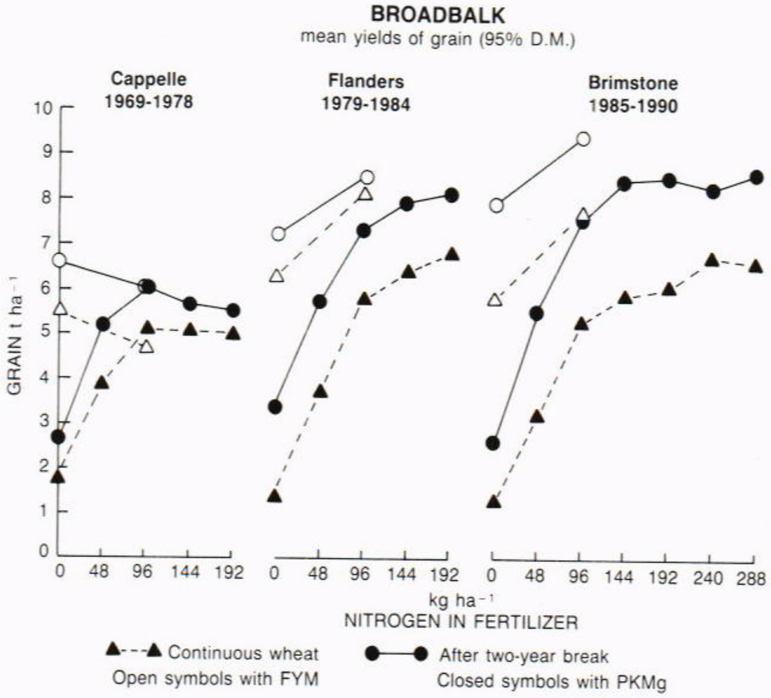

Figure 1

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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}

		Wheat		
Plot	Treatment	After 2-year break	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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