Rothamsted Long-Term Experiments
National Bioscience Research Infrastructure

The Broadbalk Wheat Experiment

– first sown to wheat in autumn 1843 and still growing wheat more than 180 years later, is a remarkable demonstration of our ability to grow food sustainably. Experiments like Broadbalk are essential in helping us understand how soil type, cropping, management and climate affect the sustainability of agricultural systems; an important consideration given current concerns about food production and security in an ever changing world.

History

Broadbalk was first sown to winter wheat in autumn 1843 and harvested in summer 1844. The experiment compares farmyard manure (FYM) with fertilizers supplying N, P, K, Na and Mg for their effects on the yield of winter wheat. The soil is a silty clay loam containing 19-39% clay (Batcombe Series), with clay-with-flints below and chalk at 2 m or more.

The experiment consists mainly of single treatment strips 320 m long by 6 m wide. It was first ploughed by oxen, hand-hoed to remove weeds and cut with sickles. Following the First World War, when

shortage of labour limited hand hoeing, the experiment was divided into 5 sections and fallowing was introduced 1 year in 5 to control weeds. In 1968 the experiment was further divided into 10 sections, modern short-straw cultivars were introduced and rotations grown on some sections. From 1982, a 5-year rotation of fallow, potatoes followed by 3 wheat crops was grown; in 1996 this changed to winter oats (without N), forage maize and 3 wheat crops. In autumn 2017 winter beans replaced maize and a new rotation of beans (without N), wheat, wheat, oats (with a half rate of N), wheat began. The other five sections have grown nothing but wheat since the experiment started.

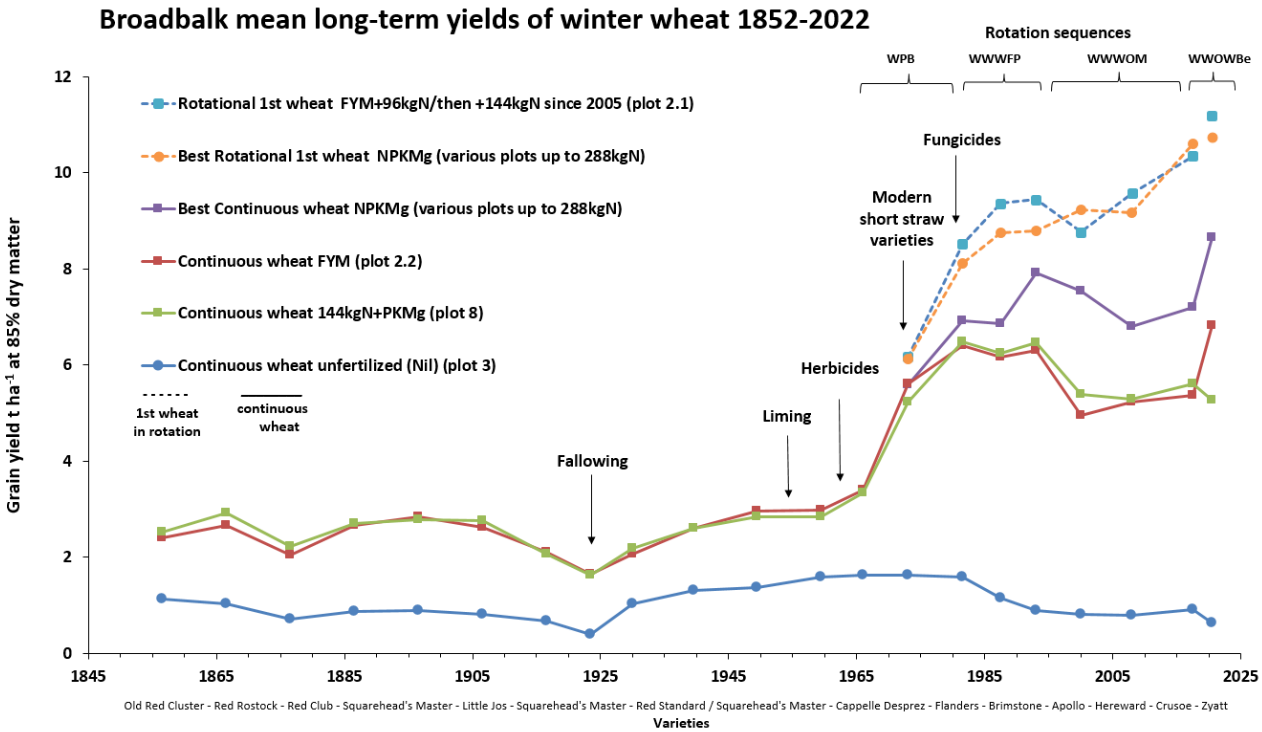
Current practices

The cultivar of wheat is changed regularly to ensure that a recommended cultivar is always grown; the current cultivar is Zyatt. Broadbalk is now ploughed with a reversible plough and harvested with a special plot combine. Herbicides are used to control weeds except on Section 8 and no fungicides are applied to Section 6. Straw has been incorporated on Section 0 since autumn 1986. Chalk has been applied, as needed, to maintain soil at about pH 7 since 1954.

The current main treatments are: No fertilizers or manures (Unmanured), 35 t farmyard manure (FYM) ha^{-1} yr^{-1} in autumn, FYM + 144 kg N ha^{-1} yr^{-1} in spring as ammonium nitrate, 'Minerals' (P, K, Mg) + 0, 48, 96, 144, 192, 240, 288 kg N ha^{-1} yr^{-1} in spring. To maintain the relevance of the experiment, fertilizer N, corresponding to the top 4 rates, has been applied as split dressings on a further 4 plots since 2001. Sulphur has been withheld from Plot 14 since 1999.

Yields

Yields of grain and straw are recorded annually and samples kept and analysed for N and other elements. Best early grain yields were about 3 t ha^{-1}. Now, the largest yields exceed 13 t ha^{-1} with either, fertilizers only or FYM plus extra N in spring. The biggest benefits are from nitrogen, new cultivars, rotational cropping, herbicides and fungicides. Results from Broadbalk show that, on this soil type, with good management, it is possible to maintain or increase yield with manure or fertilizers alone or a combination of both.



Nitrate leaching

Drains were installed in 1849 (1884 on plot 21) and the first samples of drainage water collected in the 1870s. The drains were replaced in Section 9 in 1993.

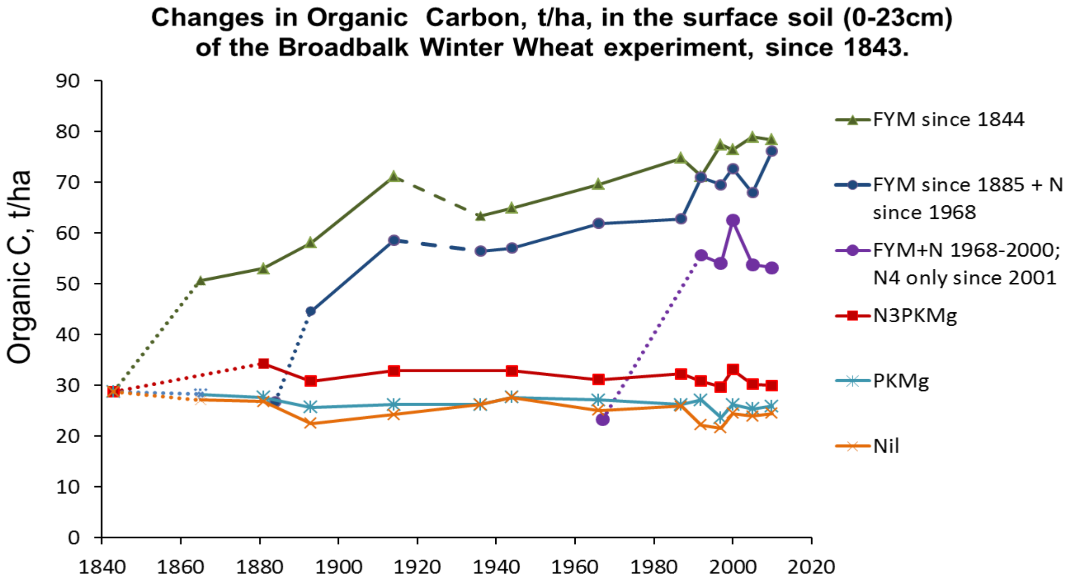
Measurements of leaching show that some N is lost even where no fertilizer N or FYM is applied; this N comes from atmospheric deposition (see below) and soil organic matter. Losses are greatest when much N fertilizer (>200 kg ha^{-1}) is applied or when FYM is used annually. The large loss of N from FYM occurs because (1) the very long-term applications have built up soil organic matter and increased mineralisation rates, and (2) the manure is applied in autumn and releases N through the winter when the crop cannot use it.

Weeds

On Section 8, which has never received herbicides, about 50 arable weed species occur with black-grass and poppy being the commonest weeds on most plots. However, for many other species there are striking differences in frequency between plots due to their ecological adaption to the availability of different nutrients. Section 8 also provides an invaluable reserve for several species that are rare, or declining, nationally. These include corn buttercup, shepherd's needle and fine-leaved sandwort that tend to be found on plots with low to intermediate fertility. Broadbalk is also the only site in the UK where corn cleavers have been recorded in recent years.

Soil Organic Matter (SOM) Dynamics

Measurements of organic carbon (C) and nitrogen (N) in soils from Broadbalk show that long-term additions of FYM (35 t ha^{-1} yr^{-1}) have more than doubled the SOM (organic C x 1.72) content of the plough layer (0-23 cm), but that increases were greater in the early years of the experiment. Much of



Data includes adjustment for changes in bulk density on FYM treatments.
Continuous wheat sections only, since 1968.

the C and N added in FYM more recently has been lost from the soil as SOM approaches equilibrium. Mineral N fertilizer enhanced SOM a little, probably due to increased returns of organic matter in crop roots and above ground residues, but the SOM content of soils receiving no additional inputs have remained relatively constant.

Data from Broadbalk and other long-term experiments have been used to develop and test the Rothamsted Carbon Model, RothC, which has successfully simulated soil C dynamics in many experiments in a wide range of environments worldwide. It is now used by more than 3600 scientists in 125 countries.

Other points of interest

Samples of dried grain and straw have been archived every year since 1844 in the Rothamsted Sample Archive. Soil samples, taken periodically, have also been archived. The experiment has been used for detailed studies on N cycling using the stable isotope, ^{15}N, whilst other work has focussed on the soil's ability to act as a sink for methane. The archived soil and plant samples have allowed retrospective analyses for ^{14}C and pollutants such as dioxins and poly-aromatic hydrocarbons. The DNA of two important wheat pathogens has been extracted from archived straw; changes in the relative abundance of the two species were strongly correlated to SO_2 emissions in the UK which have declined markedly in recent years. Similarly, wet N deposition at Rothamsted has declined since the 1980s; total N deposition is now estimated to be 20-25 kg N ha^{-1} yr^{-1}.

Broadbalk Wilderness, at the top of the field, was part of the experiment that was fenced off and abandoned in 1882. The wheat survived for 4 years, but was barely recognisable by this time. The uncultivated half of the Wilderness is now deciduous woodland, mainly ash, sycamore and hawthorn and has accumulated much C and N. Recent work indicates that the relative abundance of *Candidatus* Nitrososphaera, a member of the ammonia–oxidising archaea, is greater in the cultivated arable areas of Broadbalk compared with the adjacent wilderness and grassland. In contrast, *Bradyrhizobium* was more abundant in the non-agricultural areas, indicating that these genera are signature microorganisms for agricultural land use.

Data from Broadbalk are stored in the Electronic Rothamsted Archive (e-RA) and are available, together with archived samples, to researchers in the UK and abroad; see www.era.rothamsted.ac.uk.

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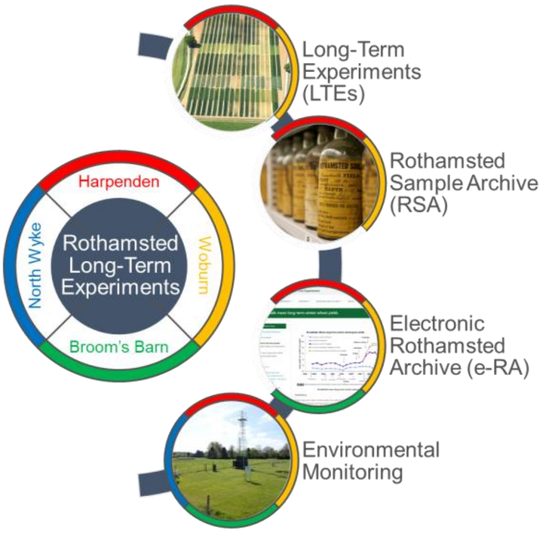
We continue to develop innovations that benefit agriculture and the wider environment.

The Rothamsted Long-Term Experiments - National Bioscience Research Infrastructure (RLTE-NBRI) is funded by the UK Research and Innovation – Biotechnology and Biological Sciences Research Council (UKRI-BBSRC) under award BBS/E/RH/23NB0007 (2023-2028). The RLTE-NBRI is also supported by the Lawes Agricultural Trust.



Biotechnology and Biological Sciences Research Council

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