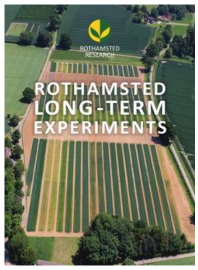
Guide to the Classical and Other Long-term Experiments, Datasets and Sample Archive



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Reserved and Discontinued Experiments

Rothamsted Research

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RESERVED AND DISCONTINUED EXPERIMENTS

Barnfield

This was the first of what became the "Classical" experiments, with treatments applied in spring 1843 for a crop of turnips sown in July. The treatments and cropping, although mainly roots, differed until 1876 when a period of continuous cropping with mangolds was started that lasted until 1959 (sugar beet were also grown, on half-plots, from 1946).

Treatments during the first two years were on long narrow plots, as on Broadbalk. However, the design was modified in 1856 when strips testing minerals and FYM, including FYM + PK, were crossed at right angles by series comparing no N fertiliser with both inorganic and organic forms of N supplying 96 kg ha^{-1} (Warren & Johnston, 1962). Before 1968 this was the only Classical in which N was applied in combination with FYM and FYM + PK fertiliser.

Because yields of continuous roots were declining, perhaps because of increasing amounts of cyst nematodes (*Heterodera schachtii*), the cropping has been progressively modified since 1959 and has included a range of arable crops, with an increased range of N dressings, and grass. From 1977 to 1983 the series that had never received N fertiliser was kept fallow. It was sown to a grass-clover ley in 1984. The remainder has been in grass since 1975.

A feature of the continuous roots and subsequent arable crops was the larger yields on soils given FYM, even where large rates of N were applied in combination with the minerals. This may have been because the extra organic matter had greatly improved soil structure on this field, which is one of the most difficult on the farm to cultivate. Yields of the grass, grown more recently, were also larger on FYM-treated soils, although no FYM was applied after sowing the grass. This was perhaps because more of the N applied to grass on minerals-treated soils was being used to increase soil organic matter. Accordingly, from 1983 to 2000 a range of N dressings (75, 100, 125, 150 kg N ha^{-1} per cut) was tested on the grass. The yields with minerals plus optimum N nearly equalled those from FYM. With neither minerals nor FYM there was no benefit from increasing N above 75 kg ha^{-1}.

No treatments have been applied and no yields measured since 2001, but the soil within the different plots still contain different nutrient concentrations, reflecting their past inputs. Consequently, the site is a useful resource for studies on plant nutrient dynamics and was used recently to investigate the responses of wheat roots to supplies of soil P.

Hoosfield Alternate Wheat and Fallow

From 1856 to 1932, this 0.4 ha area, which has received no applications of fertiliser or manure since 1851, was divided into two strips that alternated between wheat and fallow in successive years. From 1934 to 1982, a modification allowed a yearly comparison of a one-year and a three-year fallow but the effects were small and, in 1983, the experiment reverted to the original design. It does receive chalk, when needed, and pesticides.

The cultivar grown has usually been the same as on Broadbalk and the effects of fallowing may be roughly estimated by comparing yields of wheat on Hoosfield with continuous, unmanured wheat on Broadbalk. In the first 10 years of the experiment the one-year fallow gave an extra 0.6 t ha^{-1}, but, over the next

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60 years the difference was smaller at only 0.14 t ha^{-1}. With modern cultivars, and since its reversion to the original design in 1983, average yields of the wheat after a one-year fallow have been 1.6 t ha^{-1}. When expressed on the basis of the whole area (*i.e.* wheat plus fallow), the yield of 0.8 t ha^{-1} is slightly less than the 1.0 t ha^{-1} for continuous wheat on Broadbalk. Since autumn 2015, the whole experiment (both plots) has been sown to winter wheat. A small amount of N fertiliser (50 kg N ha^{-1}) is applied in spring (mid-April), but, to maintain the low soil P and K status, no other fertilisers are applied. No yields or crop samples have been taken since harvest 2015. It was in this field, in 1935, that symptoms caused by *Gibellina cerealis* were first recorded in the UK (Glynne *et al.*, 1985).

Woburn Market Garden

The Market Garden experiment started in 1942, originally to look at the effects on crop yield and SOM of various organic inputs; namely FYM, compost and sewage sludge (Johnston & Wedderburn, 1975; Johnston, 1975). The experiment was in grass from 1974 to 1982. When concerns were expressed in the late 1970s about the heavy metal content of sewage sludges being applied to agricultural land, the experiment was “re-activated” to examine the fate of metals that had been applied in the sewage sludge between 1942 and 1961. Archived samples of soils and sewage sludges from the earlier phase of the experiment made it possible to compile, for various metals, a budget of the amount applied and the amount remaining in the soil (McGrath, 1984). Total zinc (Zn) and cadmium (Cd) concentrations in the topsoil were much higher in sludge-amended plots than in those testing other treatments. Calculations suggest that about 80% of the metal load applied between 1942 and 1961 remained in the soil, predominantly in the top 27cm. From 1983, crops potentially sensitive to heavy metals were grown and analysed, as was the soil. Uptakes of Zn and Cd by these crops were minimal, although concentrations of *e.g.* Cd in barley grain could exceed current guidelines when grown on soils with high Cd content. The heavy metals applied in the sludge also affected the soil microbial biomass; more than 20 years after the last application, the total amount of biomass in sludge-amended soils was half that in low-metal soils. It was also found that a strain of *Rhizobium* (*R. leguminosarum* biovar *trifolii*) involved in symbiotic N_2 fixation in clover (*Trifolium repens*) was ineffective in sludge-amended soils, but remained effective in FYM and control soils. Clover grown on the metal-contaminated plots yielded 60% less dry matter than clover grown on uncontaminated plots. Permitted levels of metals in sludges are now much lower than those used in the Market Garden experiment, but results from the experiment were used to help formulate EU legislation to prevent heavy metal contamination of soil.

Agdell

This was the only Classical in which crops were grown in rotation. From 1848 to 1951, three different manurial combinations (none, PKNaMg and NPKNaMg plus rape cake, castor meal) were applied to the root crops of two four-course rotations. The rotations differed only in their third course – roots, barley, fallow or legume, wheat. There were only six large plots and only one course of the rotation was present each year. The root crop was turnips or swedes, the legume clover or beans. From 1920, club-root (*Plasmodiophora brassicae*) became progressively more damaging to the

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root crop, especially on the NPKNaMg plots as a result of increasing soil acidity. By 1948 the produce was too small to weigh, and the four-course rotation ceased in 1951. Soil acidity was corrected and the plots were then used to evaluate the P and K reserves accumulated up to 1951. During this period the original six plots were halved and two levels of soil organic matter were established by growing leys on one half (Johnston & Penny, 1972). Subsequently, the plots were further sub-divided to build up different amounts of P and K in the soil. Crop yields were then related to the reserves of P and K in the soil and the effect of adding fresh P and K. The experiment ended in 1990 but data relating yield to plant-available P is still useful and has been used recently in several papers (Johnston *et al*., 2013).

The Woburn Intensive Cereals Experiments

The Intensive Cereals experiments (winter wheat and spring barley grown continuously to mirror those at Rothamsted) started in 1876. Unlike most of the arable soils at Rothamsted, those at Woburn contain little or no free calcium carbonate and the soil pH at the start of the experiment was probably *c*.6. Consequently, within 20 years, the experiments ran into problems with soil acidification where ammonium sulphate was applied, and yields declined markedly. Tests of liming on these experiments, started in 1897, were the first in the UK, but yields did not recover to their former level. Conceivably, yields were also affected by cereal cyst nematodes which can be a problem with continuous cereals on these lighter textured soils. For many years the yields remained poor and the site was used for a number of other experiments. One tested the effects of growing grass-clover leys for one to six years on the yield of subsequent arable crops. Yields of up to 9.0 t ha^{-1} of wheat grain and 75 t ha^{-1} of potato tubers were achieved following the longer leys (Johnston *et al*., 1994).

Saxmundham Rotations I & II

The soil at Saxmundham is a heavy sandy clay loam, which can be difficult to cultivate; it provides a further contrast to the soils at Rothamsted and Woburn. Two long-term experiments were started at Saxmundham in 1899 by the East Suffolk County Council. Each consisted of four blocks so that a typical Norfolk four-course rotation could be grown, with each crop present in each year. On the Rotation I experiment, there was a factorial test of N, P and K plus bone-meal and FYM treatments (Williams & Cooke, 1971). Rotation II sought to determine how limited amounts of FYM, sodium nitrate and superphosphate could best be used over the four-course rotation. When Rothamsted assumed responsibility for the site in 1965 the experiments were reviewed and modified. Data from the Rotation II experiment have been used extensively to look at the responses by various crops to fresh and residual P (Johnston *et al*., 2013), and the decline in plant-available P when fertiliser P is withheld (Johnston *et al*., 2016). The critical level, above which there is no further response to fresh P, is higher and more variable on this heavier soil than on the better soil at Rothamsted (see Exhaustion Land above). The Rotation I experiment has been used to look at crop responses to both P and K and their interactions with N, particularly where much fertiliser N was applied in recent years to high yielding cultivars of wheat with the aim of achieving bread-making quality. Rothamsted relinquished the site in 2010.

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Amounts of Straw and Continuous Maize Experiments (Rothamsted & Woburn)

Other more recent long-term trials were established to examine the effects of repeatedly incorporating the straw of continuous wheat or continuous maize on the contrasting soils at Rothamsted and Woburn (silty clay loam v sandy loam). The former, were established on the contrasting soils at Rothamsted (Great Knott III; silty-clay loam), and Woburn (Far Field I; sandy loam) in 1987; both were sown to continuous winter wheat. At Rothamsted sixteen plots were established in four replicate blocks with different rates of straw incorporation (0, 1, 2 & 4 times normal straw yield). The same treatments were tested at Woburn in three blocks of four plots. Yields of grain and straw were taken each year, and soil was sampled from all treatments after 7, 11 and 22 years of contrasting straw treatments. Incorporating just the amount of straw produced per unit area had only a small and not significant effect on soil organic C (SOC) even after 22 years. SOC was increased by incorporating greater amounts of straw, but only at the largest rate was the effect significant. (Powlson *et al*, 2011). The experiments were discontinued in 2016.

The Continuous Maize Experiments began in 1997, one was on silty clay loam at Rothamsted (Hoosfield) and the other on the sandy loam at Woburn (Stackyard). The experiments included six cropping treatments: 1. Continuous maize with stubble incorporated; 2. Continuous maize with stubble plus 10t maize tops incorporated; 3. Maize after three years of spring barley with straw removed; 4. Spring barley after five years of maize with stubble incorporated; 5. Continuous spring barley with straw removed plus 10 t maize tops

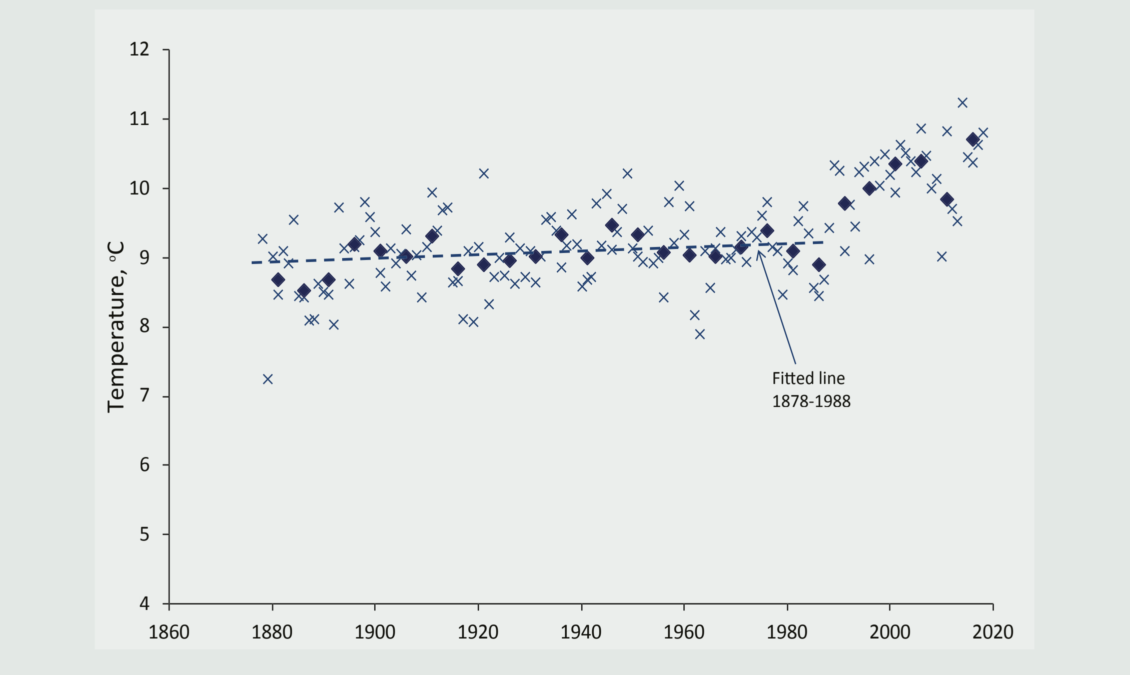

Fig. 14 Rothamsted; average temperature (°C), 1878-2018. Annual mean (x); 5-year mean (♦).

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incorporated; 6. Continuous spring barley with straw removed. In treatments with rotations only one phase was present each year. Crop yields were taken each year and soils were collected in 1997, 2008 and 2015. Maize and spring barley were chosen as crops with contrasting $\delta^{13}C$ enrichment in their residues to provide an opportunity to follow the fate of the C incorporated in the maize crop residues. The experiments were discontinued in 2015.

METEOROLOGICAL DATA

Because of climate change it is important when interpreting data from long-term experiments that changes in temperature, rainfall (amount and distribution), chemical inputs (in rainfall and as dry deposition) *etc*., are all taken into account. Total rainfall has been measured at Rothamsted since 1853 and temperatures since 1873; other meteorological data have been collected subsequently. Annual rainfall averages 704mm (mean 1971-2000) but ranges widely from 380mm in 1921 to 973mm in 2000. Increases in temperature in many parts of the world are well documented (Hansen & Sato, 2016) and Rothamsted data (Figure 14) show that the average (1989-2018) annual mean air temperature was approximately 1.1°C warmer than the long-term mean of 9.04°C (1878 to 1988). There has been a similar rise in average annual temperature at Woburn. Much of that rise is accounted for by increases during the autumn and winter months. Average soil temperatures have also risen.

Rothamsted Meteorological Station, 2017

Since the 1850s, chemical inputs in rain have changed considerably. Inputs of acidity (H^+ ions) are small; less than 0.1 kg $ha^{-1}yr^{-1}$ up to the 1950s. They reached a maximum of 0.4 kg $ha^{-1}yr^{-1}$ in the 1970s and are now about 0.2 kg $ha^{-1}yr^{-1}$. Inputs of sulphate-S were about 5 kg $ha^{-1}yr^{-1}$ in the 1850s and reached a maximum of 65 kg $ha^{-1}yr^{-1}$ by 1980. After a dramatic decline, associated with decreasing emissions from power stations and a decline in heavy industry they are now about 5 kg $ha^{-1}yr^{-1}$. Inputs of nitrate- and ammonium-N in rainfall were 1 and 3 kg $ha^{-1}yr^{-1}$, respectively, in 1855, and increased to 8 and 10 kg $ha^{-1}yr^{-1}$ in 1980. In 1996, N in dry deposition amounted to 34 kg N $ha^{-1}yr^{-1}$; about three times that in rainfall. The total N input for wet and dry deposition at that time was about of 43 kg $ha^{-1}yr^{-1}$. Since then, atmospheric inputs have declined to about 21 kg N ha^{-1} yr^{-1} (Storkey *et al*., 2015) compared with about 10 kg N $ha^{-1}yr^{-1}$in the mid-1850s.

LONG-TERM EXPERIMENTS AS A RESOURCE

Changes in agricultural practices or other factors influencing soil quality and soil processes can take decades to have any measurable effects. Effects of agriculture on

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