ROTHAMSTED RESEARCH

Woburn Experimental Farm

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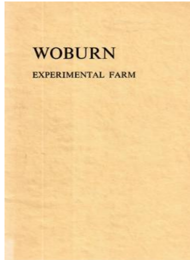

Early Experiments

Rothamsted Research

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Early Experiments

Experiments on the unexhausted manure value of animal feedingstuffs, the Rotation experiments

This experiment benefited from experience gained by Lawes and Gilbert at Rothamsted. In 1848 they started the Agdell Rotation experiment, which tested fertilisers, but only one crop was grown each year and the plots, though large by present standards, could not be easily subdivided to compare carting off the produce with consuming it on the plots by stock, 'feeding-off'.

The treatments and design of the Woburn experiment are given in detail because they illustrate the careful planning given to it. There were four treatments, two manures and two fertilisers. The manures were got by feeding decorticated cotton cake (6·9% N) or maize meal (1·7% N); in 1876 the estimated money value of the manure from one ton of each feed was £6.50 and £1.55, respectively. The fertilisers tested supplied NPKMg equivalent to the amounts estimated to be in the manure from the two feeds. The feedingstuffs were used in two ways. They were given as supplementary feed to sheep grazing the clover swards and they were fed to bullocks being fattened in the feeding boxes at the farm. In four of the boxes the bullocks were given the same amounts of roots, straw-chaff and litter. No extra feed was given to the animals in two boxes; they produced 'ordinary' manure; in the other two boxes the animals got either cotton cake or maize meal and produced enriched manures.

Sixteen acres of Stackyard were divided into four four-acre blocks (this part of the field is still divided in the same way) so that all four crops of the four-course rotation, roots (mangolds or swedes), barley, clover, wheat, were grown every year. Each block was divided into four one-acre plots so that the plots were sufficiently large for sheep to be penned on them. In each block plot 1 always received the decorticated cotton cake treatment, plot 2 the maize meal, plot 3 fertilisers equivalent to cotton cake, plot 4 fertilisers equivalent to maize meal.

The experiment was started on two blocks in 1877 when clover and roots were grown; the other two blocks started with the same two crops the following year. The root crop was manured with FYM, plots 1 and 2 getting the enriched FYMs, plots 3 and 4 ordinary FYM plus the extra fertilisers. Because it was thought that the fertiliser N to be given to plot 3 was too much for the root crop the dressing was split, two-thirds to the roots, one-third to the following barley. The roots on each plot were weighed before they were eaten by sheep. Barley followed the roots and clover was undersown in the barley. Once established the clover was grazed by sheep given equal weights of decorticated cotton cake and maize meal on plots 1 and 2 respectively; no extra feed was given on plots 3 and 4. Ten sheep were penned on each plot and their live weight increase was measured. The clover was ploughed in early autumn and followed by winter wheat. No fertilisers were given where cake or corn had been fed but on plots 3 and 4 NPKMg equal to that in the cake and meal respectively were applied.

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The results for the first eight years were summarised by Voelcker (1897). He showed that when yields on plots 1 and 2 were compared the expensive cotton cake feeding gave only an extra 6 lb liveweight increase in the sheep, 13 cwt/acre more roots and 26 lb/acre more barley whilst wheat yields were less by about 60 lb/acre. Even the smaller amount of fertilisers plus ordinary FYM (plot 4) gave a larger yield of roots than either of the enriched FYMs. The large amount of fertilisers (plot 3) gave 3 tons/acre more roots than the cotton cake FYM and this treatment also gave most barley, probably because it had one-third of the fertiliser N which should have gone to the root crop. However, barley yielded more after roots given enriched FYMs than after roots given ordinary FYM plus the smaller fertiliser dressing. This first year residual effect was probably due to mineralisation of some extra organic N in the enriched FYMs. No manures or fertilisers were applied for the clover. The sheep which were given additional cake (plot 1) or meal (plot 2) had larger liveweight increases than those on plots 3 and 4 where no extra feed was given. Wheat yields on plot 1 and 3 were almost identical and a little less than on plots 2 and 4.

This demonstration that a 'rich' feedingstuff had so little benefit compared to a poorer one was so unexpected that the experiment was modified on a number of occasions between 1885 and 1937 to try to get the results which had been so confidently expected. All failed. E. J. Russell (1966, p. 172) stated that, 'Scientists and farmers alike knew perfectly well that the result was wrong'. However, this is too sweeping a generalisation. How many farmers had made experiments comparing FYMs made with different feedingstuffs? Probably farmers would not be happy with a result which, if taken to its logical conclusion, would give no more compensation for feeding a 'rich' cake than a 'poor' one. Certainly the result has not been explained. Neither Voelcker nor Lawes, the original sponsors of the experiment, left any record of their views. J. A. Voelcker (1923) considered that Woburn was not atypical of much light land used for sheep feeding in the 1870s and the results would be applicable to many similar soils. He thought that the *preconceived* ideas about the extra value of cake feeding over corn feeding on this soil were exaggerated. He suggested that the extra N from cake feeding had been lost in some way. Much of the extra N was probably in the urine as ammonia or readily mineralised organic N so that N could have been lost by volatilisation or leaching. An experiment testing cake-fed and ordinary FYM and also different forms of N and P fertilisers was started in 1904 by Hall at Rothamsted. There was no feeding on the plots and all the produce was removed. Crowther (1946) showed that between 1907 and 1922 the direct effect of cake-fed FYM at Rothamsted was larger than it had been at Woburn but the result did not support the view that cake-fed FYM was much superior to FYM made by feeding corn.

The Rotation experiment at Woburn continued with various modifications on all four blocks until 1910. In 1911 major changes were made and the experiment was continued on only two blocks, only two crops of the four-course rotation were grown each year. The experiment ended after the wheat crops grown in 1936 (Rotation III) and 1937 (Rotation IV). Details of experiments made on each block (now called Series A, B, C and D) after they ceased to be used for the Rotation experiment were given by Johnston (1975a).

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Experiments on wheat and barley grown continuously

Lawes in particular must have been pleased to have the opportunity to test the continuous growing of wheat and barley on light land and to compare the results with those on Broadbalk and Hoosfield at Rothamsted. After allocating land for the Rotation experiment the remainder of Stackyard which was suitable for experiments was about 5.5 acres (2·2 ha). This was halved; one half was used for the wheat experiment, one for the barley. Originally each experiment had 11 quarter-acre plots, nine tested fertilisers, the other two received single and double dressings of FYM. Two amounts of N were tested and ammonium sulphate and sodium nitrate were compared; PKNaMg were always applied together, only one amount of each nutrient was used. The amounts of NPKNaMg tested were the same as those used for cereals at Rothamsted, the dressings of FYM were smaller.

Lawes (1888) summarised the yields for the first ten years. The responses to N, P and K applied together, and to FYM were much the same as at Rothamsted. At Woburn wheat grown continuously yielded almost as much as barley did. Adequately manured, continuous barley yielded only a little less than barley grown in the Rotation experiment but yields of wheat grown continuously were only about three quarters of those where wheat was grown in rotation. The results showed that wheat and barley could be grown continuously on the light land provided sufficient fertiliser was given but Lawes was careful to point out that much hand labour was required to control weeds.

After about 15 years yields, especially of barley, began to decline where ammonium sulphate was given. This fertiliser had been used for longer at Rothamsted without any deleterious effect but this was on a soil containing as much as 5% calcium carbonate. It was not until the 1940s–50s that yields of cereals at Rothamsted began to decline where ammonium sulphate had been used for 100 years. No evidence now exists to show how the decline in yield was explained in 1890 when the acidifying effect of ammonium sulphate was not known. However in autumn 1897 a number of plots were halved and one half of each plot was dressed with 2 tons/acre of lime (equivalent to 5 t ha^{-1} CaO). There was an immediate improvement in the crop. Between 1898 and 1921 various plots were halved or quartered to test new or additional dressings of lime. The effect of each new dressing was always to increase the yield of both wheat and barley. Recently Johnston and Chater (1975) have determined the pH of most of the soil samples taken from this experiment and discussed the changes in pH with different manurial treatments and liming.

Voelcker (1923) pointed out that this experimental evidence for the beneficial effect of liming was the first to be obtained in this country, although Wheeler at Rhode Island, USA was working on the same problem in the early 1890s. The benefit of liming acid soils is now generally recognised and Voelcker considered that if this had been Woburn's only contribution to British Agriculture then its existence would have been justified. Voelcker and Hall used the results to make their proposals for compensation for the unexhausted value of lime dressings. They used the difference in yield between limed and unlimed plots to assess the period during which lime dressings were effective. Because very small amounts of lime have a beneficial effect at the pH to which these soils had declined the residual effect lasted many years. In 1913 they suggested that compensation should be paid on an eight-year principle,

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i.e. one-eighth is subtracted for each year after application. This was not altered in 1946 when new tables were published (Crowther, 1946).

The Continuous Wheat and Barley experiments well illustrate the dilemma which must often be resolved by those who have responsibility for long-term experiments. Such experiments, especially if they have well chosen and contrasted treatments, are necessary to monitor changes in biological, chemical and physical properties of soils. They provide results which help to explain what happens in soils which have been similarly treated in agricultural practice and if there are problems remedial treatments can be tried on soils with contrasted histories.

The original aim of the Continuous Wheat and Barley experiments was to see which manurial treatments would best maintain yield when these cereals were grown continuously. Increasing soil acidity caused yield to decline and lime was shown to have a beneficial effect. However a comprehensive test of fresh lime and its residual effects could not be included. So neither the original aims, nor the factors which it became necessary to investigate were tested effectively. In the late 1950s it was realised that the liming test should be taken out of the experiments. Ground chalk was used to raise the pH of all soils first to pH 6 and later to pH 7. The history of the experiment, the yields and the effect of treatment on soil pH and soil N, C, P and K have been described recently (Johnston, 1975a; Johnston and Chater, 1975; Mattingly, Chater and Johnston, 1975). A new long-term liming experiment was started on Stackyard (Series C) in 1962 (p. 24).

Experiments on green manuring

The value of green manures has been tested almost continuously since 1892. Green manuring may be described as the practice of growing one crop to prepare the ground for a second and more important one. Hellriegel's discovery that bacteria in root nodules of legumes fixed atmospheric nitrogen to the benefit of the host plant partly explained why wheat yielded well when it followed clover in the traditional four-course rotation. Voelcker decided to test whether other legumes had the same effect, and to compare the effect of legumes and non-leguminous crops used as green manures. In his first experiment on Lansome barley followed tares (vetches), rape and mustard grown for one year with and without PK. Barley was used as test crop again in 1895, but from 1897 winter wheat was grown. Rape rarely grew well on the light soil and was not often tested in later experiments. A much larger experiment was started on Stackyard in 1911 using one of the four-acre blocks previously used for the Rotation experiment. In this second experiment the green crops were fed off by sheep usually given some supplementary feed. In both the Lansome and Stackyard experiments wheat following tares invariably gave the smallest yield. On Stackyard yields were often smaller than those given by NPK fertilisers in the Continuous Wheat experiment and much smaller than those in the Rotation experiment where wheat followed clover. This result, which was consistent throughout 1897–1925, has never been explained. It was observed that wheat following tares always grew more and looked greener in winter and early spring than did wheat following mustard or rape. This led to the suggestion that the larger crop outgrew the amount of water available on this light soil so that at harvest grain yield was less. Pot experiments provided some confirmation for this suggestion. Wheat

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grown in pots of soil taken from the tares and mustard plots yielded equally well when sufficient water was supplied. Irrigation was not available at that time to confirm this result on a field scale. Green crop samples showed that tares provided more organic matter and more N than mustard did and soil samples showed that this extra N increased total soil N. Like the extra N in manure from decorticated cotton cake, the extra N in the tares failed to increase significantly the yields of following arable crops and, even now, this result is not fully explained.

Experiments on grass and fodder crops

These were all short term experiments. One tested seed mixtures suitable for laying down arable fields to pasture. It started on Great Hill Bottom in 1889 at a time of controversy about whether the best pastures in England owed much of their character to the presence of ryegrass. The experiment was sponsored by Mr Carruthers, the RASE's Consulting Botanist, who was opposed to the inclusion of ryegrass in seed mixtures. During the experiment ryegrass became not only an important constituent of the swards where it had been sown but it also spread to most of the other plots. Another experiment tested Elliot's seed mixtures for pasture. These mixtures included deep rooting plants, e.g. chicory, burnet and kidney vetch; the roots were thought to open up hard stony soils, improving both aeration and drainage.

Broad Mead, a field on the heavier soil, was used between 1890 and 1926 for experiments related to the current farming practices of manuring of grassland. Fertilisers and lime were not applied each year and the plots were usually mown for hay and grazed in alternate years. One interesting feature was that nitrogen fertilisers were not tested, probably because little N was then used on permanent pasture. However yields were always largest when FYM was given, presumably because it supplied N, but the herbage was described as 'coarse'. Always mowing for hay was compared with continuous grazing and alternate mowing and grazing. The grazed plots appeared best and liming improved the grazed swards most. The results indicate a shortcoming in the experimental technique used at that time when grazing animals were involved. No attempt was made to assess the amount of herbage available to stock when they were first put on the plots. Cutting and weighing sample areas was introduced much later.

Much work was done on two other forage crops, clover and lucerne. Testing clover varieties suitable for the light soil began in 1883 and work with NPK fertilisers showed beneficial effects of K. However, clover would not grow continuously on the same plots and tended to die off in patches, a phenomenon known as 'clover sickness' (p. 33). In 1885 Miss Ormerod, Consulting Entomologist to the RASE found an eelworm (*Tylenchus devastatrix*) in many of the dying plants. Carruthers, the Botanist to the Society, attributed the dying off to a fungus. Lucerne, however, was a success. It was thought that it would not grow on the lime-deficient soil on Stackyard but some was drilled in 1889. It grew well without being reseeded for eight years and did not completely die off during the next five. NPK fertilisers were tested alone and in combination and at first they had little effect except that yield diminished where N alone was given. As the experiment continued the beneficial effect of K increased.

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Experiments on other crops including maize and potatoes

Maize was first grown at Woburn in 1894 and 1897. Harvested green for fodder it yielded 50 and 30 t ha^{-1} (20 and 17 tons/acre) respectively in the two years. Sugar beet grown in 1910–12 yielded well, 30–40 t ha^{-1} (12–16 tons/acre) of roots, with a sugar content of 14·5–17·5%. Linseed was grown successfully but soya bean in 1912–14 failed because the variety did not mature before it was killed by frost. Another failure was the attempt to grow gorse for stock feed. The plants grew well but it was necessary to buy a 'Gorse Masticator', a machine used to bruise the stems. However, bullocks and sheep would eat only a little even when it was fed with chaffed hay.

Even before 1914 there had been many experiments on potatoes. Some tested various types of FYM, others compared forms of N and K fertilisers. Magnesium was also tested, as it was for wheat and mangolds. Other experiments included a series during 1892–1911 on preventing 'potato disease' (blight). These showed the effectiveness of copper sulphate/lime treatments applied to the foliage and subsequently all potato crops on the farm were treated each year. Many substances claimed to prevent 'finger and toe' in swedes were tested between 1896 and 1904. The only effective materials were those containing lime (no specific fungicides were tested). The fact that the fungus (*Plasmodiophora brassicae*) responsible for the disease only flourished in acid soils was not appreciated and the need to maintain soils at a high pH was not obvious.

Recent work on seed rates and N top dressings for wheat was preceded by similar work at Woburn before the First World War. A test of thick versus thin sowing for wheat showed that the thin sowing was best. Sewage sludge, a treatment in the Market Garden experiment, 1942–67, was first used in 1907–14 in experiments done for the Royal Commission on Sewage Disposal.

Experiments on ensilage

Some of the first experiments done on silage making were at Woburn. Not only were different crops used but a detailed analysis of each silage was made, losses in the ensilage process were calculated and the feeding value of the silage was assessed by feeding trials. The Duke of Bedford gave extra facilities for these experiments, which were started by A. Voelcker about the time he published a paper on the 'Chemistry of Ensilage'. In 1884 four silos capable of holding from 20 to 30 tons of green herbage were constructed in a barn in Woburn Park. One detailed account of the first experiment described the 'opening day' when the Duke of Bedford, Voelcker, Carruthers, Lawes, Gilbert and most of the Chemical Committee gathered to inspect the silages. Apparently the silage in one silo was rotten, the smell was terrible and neither cattle, sheep nor pigs would touch it. However, most of the work was much more successful. It showed that good quality silage could only be made from good crops, that care in packing the silos was essential and that good silage would keep. As techniques improved grass silages were produced which gave live weight increases of bullocks almost equal to those given by feeding roots and hay. Later, oat silage did better than roots fed with chaffed straw and an even later experiment showed that silage and hay gave the same live weight increases. In the last experiment fresh grass from a 5·5 acre meadow was halved, one half was made into hay, the other into silage. The hay and

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silage each provided 84 days feeding for six bullocks and both groups of animals made the same liveweight gains.

Experiments on feeding bullocks and sheep and on calf-rearing

Feeding experiments were made from 1876 to 1901, those with bullocks were done in the feeding boxes, those with sheep were in the open. Different feedingstuffs were compared and the quantities consumed and increases in live weights were measured. The extent to which imported foods could be replaced by home produced ones was determined and also whether less expensive foods could take the place of expensive ones.

The object of the calf rearing experiments, 1912–18, was to see whether whole milk could be replaced by other feeds during the first 10 to 14 weeks of the calf's life. The effects were measured as increases in live weight at the end of this first period. However, any subsequent benefit from each feed was also assessed. After the first period all calves received the same food until they were ready to go to the butcher when their weights were again measured. It was found that the calves which grew fastest in the first period continued to make most growth later.

The results were given in detail in the Society's Journal and summarised by Voelcker (1923). Much of what was found passed into practice and the experiments which provided the information were forgotten.

Experiments on farmyard manure

These experiments, made in 1899–1901, were amongst the first to measure losses of N during the making and storing of FYM. Many analyses were made and the results largely confirmed assumptions made by Lawes and Gilbert about losses of N in FYM which they used in their tables of Manurial Values published in 1897 and 1898. Later work, both in this country and abroad, confirmed the accuracy of these early experiments.

Although there was no doubt about Lawes and Gilbert's estimates of the amounts of N retained in animal carcasses, the amounts of N which reached the field in FYM had not been investigated. By the mid-1880s it was obvious that the 'rich' cake-fed FYM had done little better than the poorer corn-fed FYM in the Rotation experiment on Stackyard.

Bullocks were weighed before and after fattening in the feeding boxes and the N retained in the increased carcass weight was calculated using Lawes and Gilbert's tables. All the food given was weighed and analysed as was the litter. The amount of N excreted by the animals was calculated and added to that in the litter to find how much should have been in the manure. The manure was weighed and sampled for analysis as it was taken from the boxes. It always contained less N than expected. The loss was about 15% even though the manure was made under cover in boxes from which there was no seepage. Later work done elsewhere showed that these were gaseous losses, partly due to direct volatilisation, partly to microbial activity.

The manure from the boxes was made into heaps and covered with earth to prevent leaching. Although no liquid was lost by seepage there was a further considerable loss of N, about 15% during six months storage. So under these almost ideal conditions about 30% of the N in faeces, urine and litter was lost. Under more average farming conditions the usual estimate of 50% loss of N is not excessive.

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Experiments in the glasshouse

Mr Hills bequest (p. 7) was for experiments to be made on the 'rarer forms of ash' in which he included 'fluorine, manganese, iodine, bromine, titanium and lithia'; at that time little was known about trace elements. The experiments were made on plants grown in pots and much had to be learnt about the techniques for doing this. Large zinc pots, 25 cm (10 in) diameter by 25 cm depth, or glazed earthenware pots, 28 cm (11 in) diameter by 28 cm depth, were used. Soil to fill the pots was taken from the field, about 15 kg (34 lb), dry soil was needed for each pot. Wheat was usually used as the test crop, although various root and legume crops were also tried.

The materials tested in the first year were: calcium fluoride, calcium oxide, manganese oxide, sodium iodide, sodium bromide, sodium chloride, titanium oxide, ferric oxide, lithium chloride and calcium chloride. All were tested at a rate equivalent to a dressing of 630 kg ha^{-1} (5 cwt/acre). In many pots seeds failed to germinate and those that did grew poorly. Very few plants grew well and subsequently much time and effort was spent finding the amounts of these and other elements which could be applied without inhibiting growth. The other elements tested included caesium, cerium, zinc, lead, copper, strontium, boron, barium, iron, arsenic, tin and chromium.

The tragedy of the work done under the Hills Bequest was that, as early as 1899, experiments were made which gave leads for further work but these leads were not effectively followed. Plants grown from seeds soaked for 10 minutes in very dilute solutions of a number of salts were better than untreated controls. The inference that only a minute amount of the element was required was missed. Also in 1899 nutrient culture experiments were tried using tall glass jars. The technique allowed both root and shoot growth to be observed as well as control of nutrients available to the plant. It was not until much later, and then not at Woburn, that nutrient culture techniques were improved and used to investigate the role of trace elements in plant nutrition.

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