The Cawthron Institute,
NELSON, NEW ZEALAND.

CAWTHRON LECTURE 1928.

The Work for Agriculture of Two Great Englishmen.

By SIR JOHN RUSSELL, F.R.S.
Director of the Rothamsted Experimental Station.

R. W. Stiles & Co., Printers, Waimea Street, Nelson
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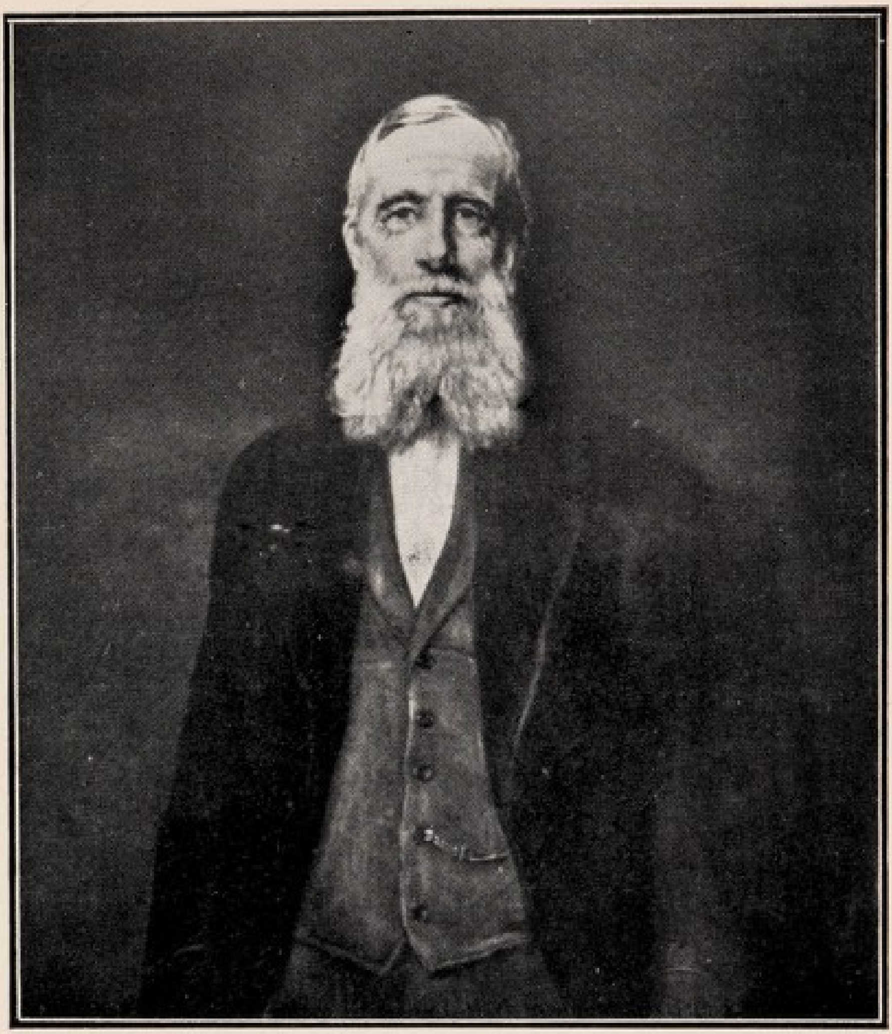
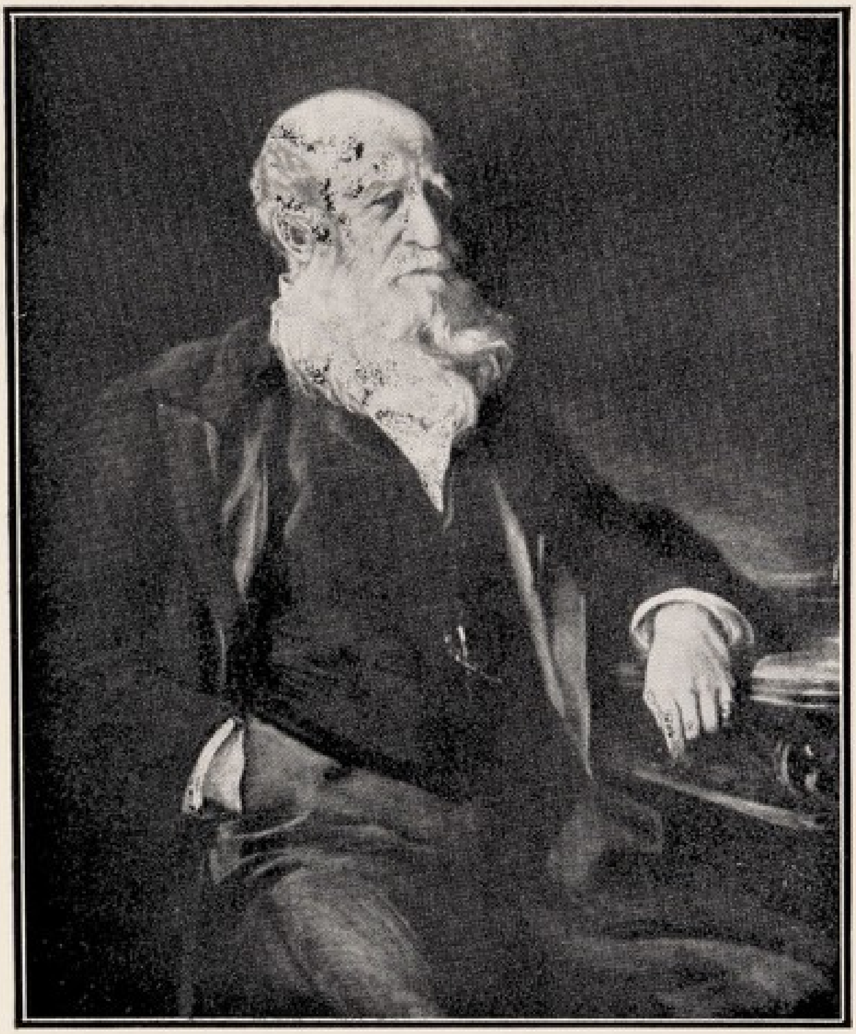


SIR JOHN BENNET LAWES, F.R.S.



SIR JOSEPH HENRY GILBERT, F.R.S.

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THE WORK FOR AGRICULTURE OF TWO GREAT ENGLISHMEN.

By Sir John Russell, F.R.S.,
Director of the Rothamsted Experimental Station.

The Rothamsted experiments were initiated in 1843 by John Bennet Lawes, an English country squire, who lived in the beautiful old manor house of Rothamsted—one of the stately homes of England. The times were bad for farmers, and as Lawes depended on farming, his purpose was to get more out of the land. At that time the yield of wheat on the estate, and probably in England as a whole, was about 20 bushels per acre, but in some seasons it fell much lower.

Lawes had a taste for making agricultural experiments, and great luck in that his experiments nearly always succeeded. He knew a little chemistry and something about the composition of farmyard manure, then the regular manure on all farms and still one of the best. He had found by experiment that one of its constituents, nitrogen, could advantageously be given to crops in the form of sulphate of ammonia, a by-product in the manufacture of coal gas. He further experimented with bones which had worked marvels on some of the English pastures, but had failed at Rothamsted: he found that if they were treated with sulphuric acid they became effective, being converted into the substance then called superphosphate of lime. At that time bones were dear, but rock phosphate, which had only just been discovered, was cheap, and Lawes found that on treatment with sulphuric acid it yielded the same superphosphate of lime as did the more expensive bones. He patented the process, set up a factory near London, and made artificial manures for the first time in history. For many years the whole superphosphate industry was in his hands and he made a considerable fortune. Lawes continued the field experiments on his farm, and brought to Rothamsted a young chemist, Joseph Henry Gilbert. There are at Rothamsted no portraits of either Lawes or Gilbert as young men, though in their old age both were painted: Lawes by Herkomer and Gilbert by Frank Salisbury. The best picture of Gilbert in later life was drawn by an undergraduate sent by his tutor to listen to Gilbert's lectures at Oxford. At the end of the course the tutor, knowing both Gilbert (who was not an interesting lecturer) and the student, asked the latter to produce his note book. The young man hesitated greatly, but the tutor was insistent, and when the note book came it contained only a picture of Gilbert. The tutor recognised the striking likeness and artistic merit of the picture, but having to uphold university discipline, upbraided the young man, and confiscated the picture. Years after when I was lecturing at the University of Oxford, this same tutor, then an old man, offered me the picture for Rothamsted, which, of course, I gladly accepted. Unfortunately, he had forgotten the name of the student, and we do not know to this day who made the portrait.

Lawes and Gilbert were strikingly different. Lawes was a man of great vision, who could lay down the general lines and work out the bold outlines of a scheme, but he had little capacity for detail. His note books are mainly blank spaces, where he meant to enter observations, but did not. Nevertheless as you read through the notes, in spite of their brevity you can see exactly what he was trying to do. And, although the observations are short, you can tell from them pretty well how the investigation was going. Though the record lacks the precision that gives high scientific value, it indicates clearly the solution of a practical problem.

Gilbert was entirely different in character. He lacked imagination and the power of laying down bold outlines, but he had a wonderful aptitude for detail. His note books are a mass of figures so crowded that you cannot tell what the investigation is about or what he was striving to accomplish. The figures, however, were accurate, the observations carefully made and carefully recorded. He had no faith in short cuts, and to the end of his days would never touch logarithms: all calculations were done by long multiplication and division.

The combination of Lawes and Gilbert was almost ideal for scientific purposes. They worked together for 60 years, the longest scientific partnership in history; Lawes' ideas, with Gilbert's painstaking skilful work and close attention to every detail, ensured that the greatest accuracy possible at the time was attained in all the experiments. This fine combination of two distinct sets of qualities gave the Rothamsted experiments the character they have always possessed. For the first 12 years they worked in a barn fitted up as a laboratory; here the first superphosphate was made from imported mineral phosphate and sulphuric acid; it was tested on the field, now well known as Barnfield, which lay just outside.

In that barn much other valuable work was done for agricultural chemistry, illustrating a fact well known in the history of science, that the foundations of a subject have often been laid by men working under adverse conditions in ill-equipped laboratories and with very rough apparatus. While these conditions have sometimes sufficed for the pioneering work, they are entirely unsuitable for the systematic development that comes afterwards. In the history of an important scientific subject there are two stages. First, the discovery or fundamental observation is made: often with simple means. Secondly, it is investigated thoroughly, tested at every point, and studied with scrupulous accuracy. This subsequent work necessitates the best appliances, and that is why modern scientific laboratories are so expensive to equip and to maintain.

Lawes and Gilbert did not confine their attention to the laboratory, but made experiments in the field on wheat, barley, swedes and grass, afterwards adding also oats and potatoes. In each field a comparison was made between farmyard manure and the new artificial fertilisers, Lawes' superphosphate, sulphate of ammonia and sulphate of potash. The artificials gave as good yields as the farmyard manure. We are now accustomed to this fact, but the farmers of that day were not, and some of them were very scathing at the idea that chemicals supplied in a bag could ever benefit a crop. Lawes and Gilbert therefore grew the same crops year after year on the same land applying always the same fertilisers, and allowing visitors to see the experiments at any time.

The farmers had to admit the striking results, but they would not allow that they had any practical value, asserting that the chemicals would sooner or later poison the land.

Lawes and Gilbert boldly continued the field experiments and showed that all these fears were groundless. They went on for 20 years before they published much, and then they wrote up a full account of the experiments. Now-a-days it would be impossible for any experimenter to continue so long without publication, but Lawes and Gilbert were quite independent of any Government or other organisation, everything being done at Lawes' expense: hence they were able to please themeslves. They then continued the experiments for another 20 years, and at the end of 50 years they wrote an elaborate account of their results. Having done the field work for 50 years, they continued it to the end of their lives. In 1902 Sir Daniel Hall was appointed Director, and he continued the experiments till he left. I followed him in 1912 and have continued them ever since, and as a result we are now growing the 86th crop of wheat, the 76th crop of barley, the 72nd crop of hay and the 50th crop of mangolds, the treatment of each plot being the same year after year. It is this long continuance of the experiments on the same ground that gives the Rothamsted field plots their distinctive character. Nowhere else in the world is there a set anything like as extensive or as old, the nearest being American experiments commenced years later at Wooster, Ohio; at State College, Pennsylvania; at Illinois; also a second set begun under Lawes' and Gilbert's supervision at Woburn in England and now brought back under Rothamsted management.

Of all these fields the one attracting most visitors is the Broadbalk wheat field, which has been in wheat every year without break since 1843. There have been a few partial fallows, one half of the plot being fallowed one year and the other half the next, but no year has passed without a crop.

The records have yielded a mass of data about the growing of wheat which is unequalled in the whole world. This is now being examined in the Statistical Department, and correlations made with the numerous weather and other data.

Several important results have emerged. It is shown that wheat will grow quite well on the same land year after year provided it is properly cultivated and supplied with the necessary fertiliser. The yields vary from season to season and they fall off on the unmanured or improperly manured land. There is no evidence of "wheat sickness" or other deterioration resulting from continued cropping.

The experiments further show that wheat cannot be killed by starvation. Part of the land has received no manure since 1839, yet the individual grains of wheat are quite normal. The miller detects no unusual features in the grain, nor the baker in the flour. The only visible difference between these plants and those properly fertilised is that they produce only one stem and one head per plant instead of the usual four or five, but the head is normal. However much the plant is starved the seed, its next generation, is apparently safe.

But although the wheat plant is not killed or even greatly altered by starvation, it is speedily killed by weeds. In another experiment made in 1882, some of the wheat was left standing and was fenced off unharvested. The seed was allowed to shed itself and germinate, and the next crop grew up untouched, but along with the self-sown wheat there came up many weeds. The second crop was again left to shed its seed, and the self-sown wheat of the second generation grew up, this time with more weeds. In the fourth year no wheat could be seen, but search amongst the mass of weeds revealed a few stunted plants utterly unlike the ordinary wheat, the heads having only three or four grains in each. Weeds therefore will do in a very short time what years of starvation completely fail to accomplish: the lesson to cultivators is that the surest way of reducing the output from the land is to let the weeds grow.

The experiment thus proves that wheat can be grown continuously year after year, and its yield maintained, provided it be adequately cultivated and fertilised. But a further experiment shows that it is far easier and more economical to grow wheat in a rotation. Farming experience fully confirms this: the rotation allows a better distribution of labour, control of pests and diseases and maintenance of supplies of organic matter in the soil.

The experiments have demonstrated the great importance of nitrogenous fertilisers for wheat and indeed for all other crops: 1 cwt. of sulphate of ammonia per acre commonly gives an additional 4 bushels of wheat, 5 of barley, 6 of oats; 20 cwt. of potatoes or of mangolds. The effect of nitrogenous fertilisers is more uniform than that of any others. Superphosphate has a marked effect on root development, early growth and tillering of cereals; this is commonly of great advantage to the plant, and further, it improves the feeding value of pastures.

Potassic fertilisers have a special influence on the production of sugar by the leaf: they are therefore very effective for crops like potatoes, mangolds and sugar beet, especially in sunless seasons. They also greatly benefit the leguminous plants.

The Rothamsted plots demonstrate better than any others the properties of fertilisers, and much of the information they have yielded has now passed into current knowledge and practise. For many years the standard recognised fertilisers, the nitrogenous, the phosphatic and the potassic, were regarded as sufficient for all crop needs. In recent years, however, both at Rothamsted and elsewhere, a good deal of scientific work has been done on the influence of other elements on the growth of the crop.

The effect of using ammonium chloride instead of ammonium sulphate on the barley crop is to give a larger yield of grain, the chloride apparently stimulating the tillering: the increase has varied from 3 to 8 bushels per acre and has been obtained with wheat, barley and oats. It was shown some years ago at Rothamsted that minute quantities of iron are indispensible for broadbeans: without it they make only partial growth. Manganese is known to be essential to plants: in its absence the plants show certain disease symptoms and may even die. Samuel and Pepper have proved at the Waite Institute that the grey fleck disease of oats is the result of manganese deficiency; pineapple growers in Hawaii have also noticed ill-effects. Iron deficiency studied by Mr. B. C. Aston is equally serious. These observations are helping with some of the rather obscure diseases of plants.

Considerable attention is being paid now to the relationship between season and fertiliser efficiency. The subject is approached in two ways. Observations in the field show that some of the changes in growth induced by fertilisers enable the plant better to stand up against certain seasonal conditions such as spring drought; lack of sunshine, etc. Statistical examination of the field data brings out many relationships: this method, however, requires considerable masses of data which are fortunately now available. During the 86 years of the Broadbalk experiments on wheat there have been many kinds of season: the results therefore are of special value for showing the influence of season on growth. The yields vary from year to year, but the amount of variation is less with some fertiliser scheme than with others. It is least with farmyard manure and low with complete dressings of artificial fertilisers; it is greatest with incomplete fertilisers, but it is also large on the unmanured plot. This accords with general experience that proper manuring increases not only the yield but the certainty of a yield, and it emphasises the need of proper field experiments to guide farmers in their choice of fertilisers and to save them from errors which might be costly.

Dr. R. A. Fisher has studied in detail the effect of one inch of rain above the normal in the separate months. Usually winter rain is harmful and spring rain beneficial, but the magnitude of the effect varies with the fertiliser scheme. If the rainfall could be predicted it would be possible to suggest the most suitable type of fertilisers. Accurate prediction is improbable: the results can, however, be utilised in another way; they are of the same character as the Tables for the Expectancy of human life that forms the basis of the Life Insurance business, and with further developments it may be possible to work out tables for Expectancy of crop yield that could form the basis of a satisfactory Crop Insurance business.

These investigations into the relationship between the weather and fertiliser efficiency have necessitated a change in the way of making field experiments so as to increase their accuracy, and what is more important, to show the probable degree to which the result is accurate. This has necessitated control of the work by the staff of mathematicians in the Statistical Department, who advise as to the best lay out of the plots, and of the number of repetitions of each treatment: further they examine the results in detail. In arranging the experiment there must be no personal bias: the order of the plots is therefore determined by chance: the drawing of cards, casting of dice, etc. The advantage of statistical control is so great that it should be available for all agricultural experimental work.

Lawes and Gilbert confined their field work entirely to artificial fertilisers. In those days labour was cheap and cultivation was an art, well understood and practised. But now things are different: labour is no longer cheap nor is it always efficient; reliance has to be placed more and more on the machine, and therefore the art of cultivation is more and more having to be changed to a science: for you cannot expect a machine to do its work well unless you know precisely what you want the machine to do and design it accordingly. The Rothamsted experiments have therefore been widened so as to include cultivation: to find out what is meant by good tilth, what cultivation does, and why it needs to be done. This work is done under Dr. Keen. Of all the soil constituents the clay appears to be the one most affected by cultivation, it can exist in two states, one is very sticky, the other is less so; and cultivation brings the clay into a good workable condition. The problem is studied in two ways. The operations of cultivation are examined in detail,—a dynamometer being inserted between the tractor and the plough so as to measure the drawbar pull while various soil conditions such as its moisture content are simultaneously measured; this provides material for precise expression of the facts of cultivation. These facts are then examined in the laboratory: the properties of the clay and the other soil constituents are also studied; and the information thus obtained is assembled to see what light it throws on the cultivation processes. The usual history is that the first laboratory observations seem to explain everything, and to enable one to set up a complete theory on the subject; then further work shows that the subject is more complex than it appeared and finally the investigator begins once more at the beginning in chastened mood, improves his methods, avoids the old pitfalls and does some really useful work.

The change in the clay from the sticky to the workable state can be brought about by adding calcium carbonate (limestone or chalk) or lime, and this is an ancient way of improving soil. The reduction in drawbar pull is sometimes considerable: on one of our tests it took 1300 to 1500lb. drawbar pull to get a two furrow plough through the untreated soil, but only 1100 to 1250 to get it through the chalked soil. Organic matter as supplied by farmyard manure or green manure has the same kind of effect. We may, then, hope for considerable improvement in cultivation in the future. Suitable soil treatment reduces the work to be done, and better knowledge of the purpose of the work should enable the engineer to improve the implements. Rotary cultivation seems promising: the principle appears to be sound.

Among the most recent devolopments at Rothamsted are the laboratories for studying plant diseases and pests. No good estimate can be formed of the losses these agents cause to farmers, but it may easily exceed 10 per cent. of the gross income from the crops: the aggregate loss to the country is considerable. Trouble may arise from insects, fungi, from an unknown agent called a "virus," or from an unhealthy condition of the plant resulting from malnutrition, unsuitable air supply to the roots, acidity and other causes. At the Cawthron Institute you are familiar with Dr. Imm's work through his associations with Dr. Tillyard in supplying insects needed for the biological control of weeds and of insects. The work on insecticides is likely to expand considerably, as is also that on mosaic and virus diseases generally, while the study of fungi in their relation to plants has been much facilitated by the recent extension of the glass houses made possible by a grant from the Rockfeller foundation. It is impossible in this lecture to refer in any detail to this work.

I must, however, give some account of the recent work on soil microbiology because of its intimate connection with the field work of Lawes and Gilbert. In their experiments on nitrogenous fertilisers they used chiefly sulphate of ammonia, it being currently believed that ammonia was the form in which plants assimilated nitrogen. About 1860, the French chemists showed that the ammonia rapidly changed to nitrate in the soil, and they set up the hypothesis, which gradually became accepted, that nitrate, and not ammonia, was the true plant food. The question then arose, however: how was the nitrate formed? After many years of discussion the answer came, again from France, that it was formed by micro-organisms which oxidised the ammonia. Warington, one of the Rothamsted staff, spent ten years in trying to isolate the organisms, but without success: the problem was solved by a young Russian bacteriologist, Winogradsky. Warington had, however, demonstrated the presence of many kinds of organisms in the soil, and Berthelot, a distinguished French chemist, put forward the view that some of them were responsible for the nitrogen in the soil. Slowly it became recognised that the micro-organisms bring about many of the changes that determine soil fertility. It was shown that farm-yard manure and green manure are not themselves plant foods: indeed, in themselves they are harmful to plants. But once in the soil, they go through a remarkable series of changes and end up by being of great value to soil fertility; and these changes are caused by soil organisms. The organisms are present in great numbers: they are, indeed, so numerous that a salt-spoon of soil may contain many millions of them, and they are so small that even with the microscope they can be seen only imperfectly. Gradually they are being picked out from the soil and their life histories studied: methods have also been devised for estimating their numbers. Every month, however, new soil organisms are discovered and no one would venture to say what this great soil population is really like. Some of them change the useless residues of dead plants into humus and valuable food for the next generation of plants. Others fix nitrogen from the air and build it up into complex proteins by a process that no chemist can imitate or even understand. Others supply nitrogen to the clovers and other valuable leguminous plants. Some are like plants in that they simply take up plant foods without themselves making any: yet these also are useful because they protect the nitrate from being washed out by the rain, assimilating it, converting it into protein, which however is reconverted into nitrate as soon as they die. All these are being studied. As yet, the knowledge gained has not found much practical application, but beginnings have been made in (i.) making artificial farm-yard manure, (ii.) inoculation for the growth of leguminous crops, (iii.) the treatment of sick soils, (iv.) making manure from sewage. A full account of this work would require many lectures.

Something has already been said about artificial farm-yard manure. The inoculation of leguminous crops has been practised mainly on lucerne; the process consists in adding with a seed a culture of the organisms associated with the lucerne plant to ensure that they may be in the soil and ready to act as soon as the young plant has begun to grow. It is proving successful in helping to establish lucerne in certain districts where it would not previously grow. The method of treating sick soils is to heat the soil, or partially sterilise it in some other way; it has proved successful in dealing with a serious trouble in commercial nurseries. The making of manure from sewage is one of the great needs of to-day: at present little or nothing is done, the ordinary sewage being very poor material. In one process, however, air is blown through the sewage and the microbiological activities produce a sludge of considerable fertiliser value. These various investigations are still being continued both on the practical and on the scientific sides.

The true purpose of scientific work is to gain fresh knowledge; to reveal to mankind a few more of the unexhaustable secrets of Nature. The work of Lawes and Gilbert has done that. In their own generation it taught men something about the food of plants and showed how to use this knowledge for the solution of the everyday problems of the practical farmer. The field experiments they began have in our own time continued to help in the solution of the farmers' problems, and are furnishing material for scientific study rich in promise for the future. A further interesting fact stands out clearly. An Institute for the study of scientific agriculture is one of the best investments a patriotic donor can make. Its work continues all through the years, gathering strength as it goes. So long as the results are trustworthy and all the work honestly and conscientiously done it cannot fail to bear fruit sooner or later. The Rothamsted experiments at first were written down as "unpractical," but before long even the most practical of men turned to them for guidance. Perhaps the best lesson taught by the Rothamsted experiments is the absolute necessity for leaving the agricultural investigator to get on with his work in peace, putting no pressure on him for immediate results; requiring only that he shall honestly, conscientiously and diligently seek the truth.

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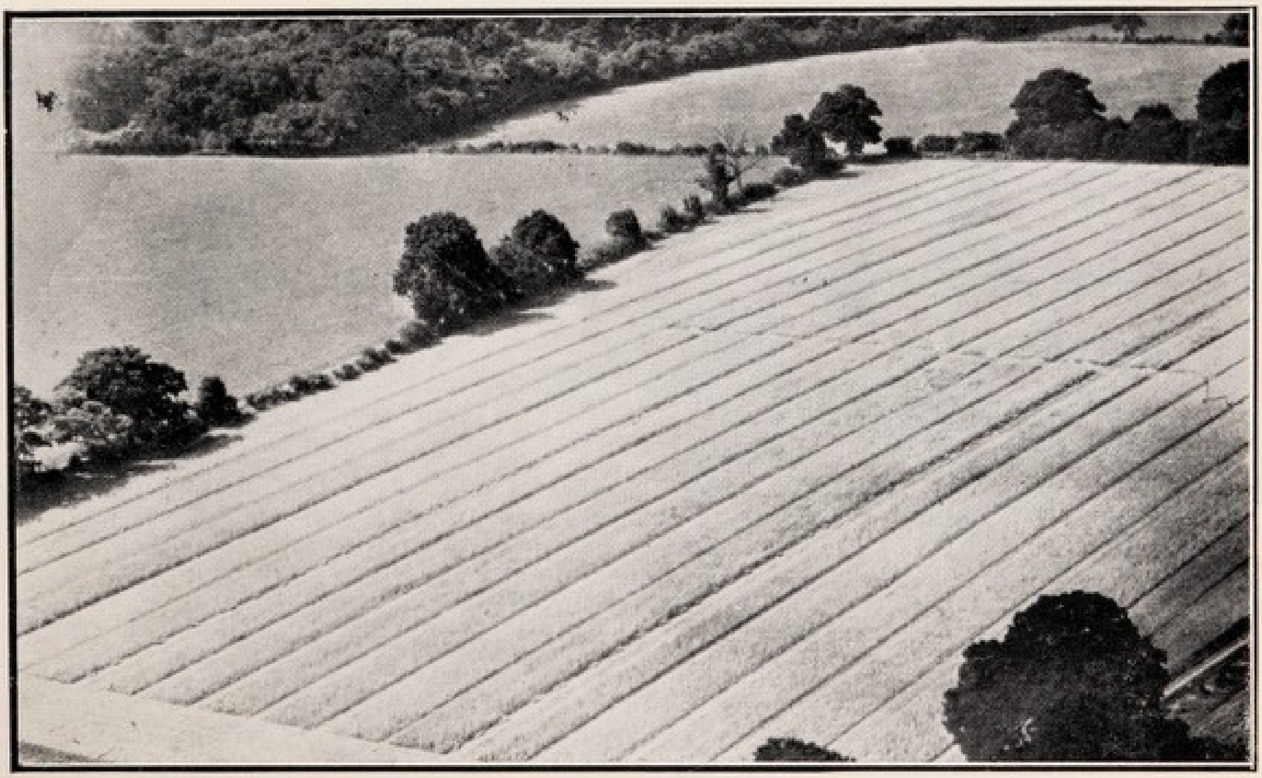
ROTHAMSTED HOUSE FRONT VIEW, 1925.

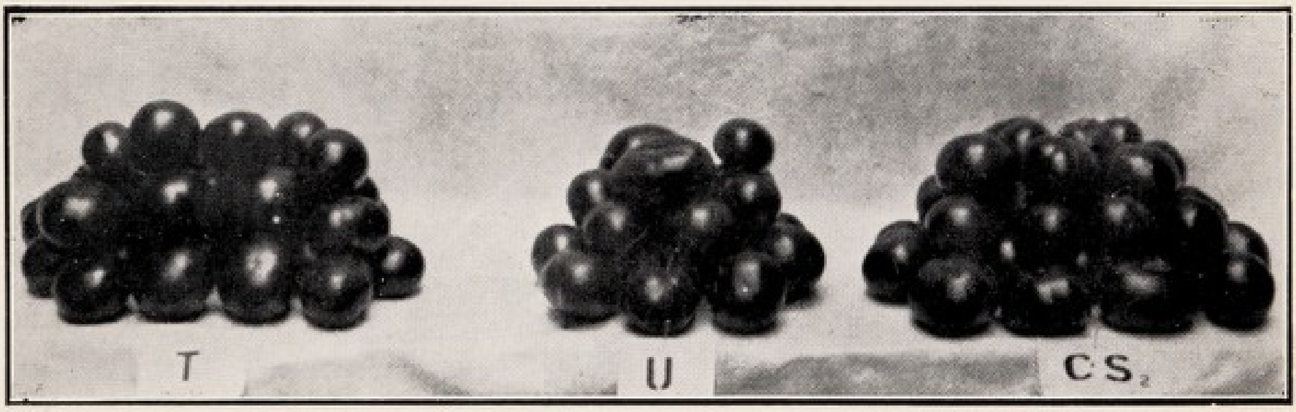
ORIGINAL BARN LABORATORY—INTERIOR.

ROTHAMSTED LABORATORY (PRESENT), 1914.



VIEW OF BROADBALK FROM AIR.

CUTTING OF WHEAT CROPS, BROADBALK.



RESULTS OF PARTIAL STERILIZATION EXPERIMENTS.

T—Soil treated with Toluene.

U—Untreated soil.

CS_2—Soil treated with Carbon-di-sulphide.

Other and more easily handled substances are used in practice.

PENCIL SKETCH OF GILBERT WHEN AT OXFORD.
Drawn by a student.