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Yields of the Field Experiments 1901

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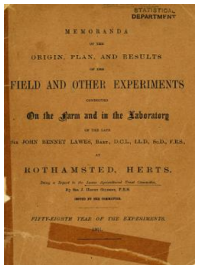

Leguminous Crops

Rothamsted Research

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS.

I.—Beans, Peas, and Tares—Geescroft Field.

Experiments on the growth of Leguminous corn-crops (beans, peas, and tares), with different descriptions of manure, were commenced in 1847, about nine acres being devoted to the purpose.

Experiments with Beans were continued without a break, for thirteen consecutive seasons, to 1859 inclusive; but, during the later years, the crop fell off very much, and the land became very foul.

In 1860 the land was fallowed.

In 1861 a crop of wheat, without manure, was taken.

In 1862 beans were again sown, but with some variation in the manuring.

In 1863 the land was fallowed.

In 1864, 5, 6, 7, 8, and 9, beans were grown, with much the same manures on the same plots, each year, as in 1862.

In the winter of 1869-70, 5000 lbs. of fresh burnt lime were applied per acre, over all the plots.

In 1870 beans were grown with the same manures on the respective plots as in 1864-69.

In October 1870 winter beans were sown (without manure), but the plants were to so great an extent destroyed by the severe weather which followed, that, in April 1871, the crop was ploughed up, and the land left fallow.

During the winter and early spring of 1871-2, the land was so wet that it could not be prepared in time for sowing. It was therefore left fallow for 1872; at the end of May it was subsoiled to a depth of about 12 inches, and re-ploughed in July.

The winter and early spring of 1872–3 were also so extremely wet, that it was again impossible to prepare the land in time for sowing; it was, however, ploughed up towards the end of March, again left fallow, and re-ploughed in July and October (1873).

On February 2, 1874, the land was again set with Beans, but without manure.

In 1875 Beans were re-sown, with the same manures on the respective plots as in 1864-1870; but owing to the wetness of the land in the first instance, and the subsequent hindrance by other spring sowing, they were not put in until April 1 and 2.

The wetness of the winter 1875-6, again prevented the preparation of the land in due time; and, though the manures were sown, and the land ploughed, it was left fallow during the summer of 1876.

Early in October 1876, winter Beans were put in (drilled), without further manuring.

In 1878 the usual manures were sown, and beans were drilled on February 26.

Owing to the wetness of the winter, and the foul condition of the land, it was left fallow in 1879.

Owing to the continued wetness in the autumn, the severe winter, and foulness of the land, it could not be got into order for sowing, and remained fallow in 1880.

During 1880 the land was ploughed, scarified, and partially cleaned, but owing to the wetness of the autumn, and the wetness and severity of the winter, it was again impossible to work it in time for sowing.

In the months of May and June 1881, the land was ploughed, scuffled, and harrowed, and again on July 9–12; since this time, however, the experiments with beans have been finally abandoned.

On February 1–4, 1882, the land was ploughed and cleaned, and on September 6–7 was harrowed, rolled, and sown with grass-seeds. These germinated satisfactorily, but owing probably to the extreme wetness of the succeeding winter months, the plant almost entirely died off.

In April 1883, samples of soil were taken from many of the plots, generally to a depth of 27 inches, but in selected cases to a depth of 72 inches from the surface, and at that time very few grass plants could be seen. After the soil sampling, the whole field was scuffle-harrowed, and sown with Barley and Clover. In order to test the condition of the soil of the different plots of the continuous Bean and the alternate Wheat and Bean land, they were left unmanured; the remaining portion of the field, not recently under exact experiment, receiving 2 cwts. Nitrate Soda, and 2 cwts. Superphosphate per acre.

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS—*continued.*

Notwithstanding the repeated failure of the Beans, though on the other hand the land had practically been fallow since 1878, the Clover came up very well, grew very rapidly, and on many of the plots to a great extent smothered the Barley; so that at harvest (1883) there was a very unusual proportion of Clover in the crop. The Clover plant remained strong through the mild winter, and gave heavy crops in June, and in August 1884; the two crops in many cases approaching, and in some exceeding, 4 tons of hay per acre. In 1885, a good plant remained on most of the plots, yielding a cutting on June 23, which in several cases approached, and in one exceeded, 2 tons of hay per acre. In fact, from several of the plots of this bean-exhausted land, the nitrogen in the surface soil of which had been much reduced, and was very low, more than 6 tons of clover-hay per acre, containing more than 300 lbs. of nitrogen, have been taken. It may be added, that the total yield has been greater on some of the previously continuous bean-plots than on those which had grown beans and wheat alternately. (See below.) After the cutting in 1885, the greater part of the land was thrown into the park for permanent grass; only the previously continuous bean-plots being still reserved for future experiment.

The general result of the experiments with BEANS has been that mineral constituents used as manure (more particularly potash), increased the produce very much during the early years; and, to a certain extent, afterwards, whenever the season was favourable for the crop. Ammonium-salts, on the other hand, produced very little effect; notwithstanding that a Leguminous crop contains two, three, or more times as much nitrogen as a Cereal one grown under similar conditions as to soil, &c. Nitrate of soda has, however, produced more marked effects. But when the same description of Leguminous crop is grown too frequently on the same land it seems to be peculiarly subject to disease, which no conditions of manuring that we have hitherto tried seem to obviate.

Experiments with PEAS were soon abandoned, owing to the difficulty of keeping the land free from weeds, and an alternation of BEANS and WHEAT was substituted; the Beans being manured much as in the experiments with the same crop grown continuously as above described. But the wetness of the winter of 1871–72 prevented the sowing of the Beans for the season of 1872; and again the wetness of the autumn and winter of 1872-3 prevented the sowing of the wheat until April 4, 1873, when Nursery wheat was put in, which, however, did not come to maturity, but was cut in the middle of September, yielding about 27 cwts. of gross produce per acre, containing too little corn to be worth thrashing. The land was ploughed in October 1873, and sown with beans February 3, 1874. On October 23, 1874, wheat was sown without manure. Beans should have been sown in 1876; indeed, the manures were sown, but, for the reason stated above, the land was left fallow; and wheat was put in October 24 (1876). In 1878 Beans were drilled, on February 26, with the usual manures. Owing to the wetness of the winter, and the condition of the land, it was left fallow in 1879; and it continued so up to September, 1882 when it was sown with grass-seeds; since which time it has been treated exactly as the continuous Bean Land. (See the bottom of the preceding page, and the top of this.)

In alternating WHEAT with BEANS, the remarkable result was obtained, that nearly as much wheat, and nearly as much nitrogen, were yielded in eight crops of wheat in alternation with the highly nitrogenous beans, as in sixteen crops of wheat grown consecutively without manure in another field, and also nearly as much as were obtained in a third field in eight crops alternated with bare fallow.

Experiments with TARES, like those with Peas, were soon abandoned, and for the same reasons. Beans were at first substituted, with some variation in the description of the manures employed; but this experiment also had to be abandoned.

II.—RED CLOVER (*Trifolium pratense*).

1. *Experiments on ordinary arable land.*—HOOS FIELD.

EXPERIMENTS on the growth of Clover, on ordinary arable land, with many different descriptions of manure, were commenced in 1848–9, and, with the occasional interposition of a corn-crop, or fallow, were continued up to 1877, inclusive.

As with other *Leguminous* crops, the result was, that mineral constituents applied as manure (particularly potash) considerably increased the crops in the early years. Ammonium-salts had little or no beneficial effect, and were sometimes injurious. It may be added, that the beneficial effects of long previous applications of potash have been apparent whenever there was any growth at all. To go a little more into detail:—

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS—*continued.*

In the first year, 1849, the crops were throughout very heavy; especially with mineral, and without nitrogenous manure.

In autumn 1849, wheat was sown, and in spring 1850, Red Clover. In 1851 small cuttings were taken; and in 1852, though the crops were not heavy, there was by no means a failure.

Since that time, however, all attempts to grow clover year after year on this ordinary arable land have failed to give anything like a full crop, or even a plant which would stand the usual time on the ground.

Small cuttings were obtained in the autumns of 1855 and 1859, from seed sown in the spring of those years; and small but rather heavier cuttings in June and August 1865, from seed sown in 1864.

In April 1868, a portion only of the land was sown with Clover, and the plant for the most part died off in the winter.

In April 1869, the same portion was re-sown, and gave a small cutting in September of that year; but the plant again died off in the winter.

In April 1870, Clover was sown over the whole of the experimental land, this time in conjunction with Barley; but on those portions which had also been sown in 1868 and 1869 the plant again died off during the winter and early spring; whilst from those which had not been sown in 1868 and 1869 two small cuttings were taken in 1871.

In the spring of 1872, the plant being then almost entirely gone, the land was ploughed up. It was again ploughed in July 1872, and in March 1873; the intention being to sow some other Leguminous crop; but owing to the wetness and lateness of the season this was not done, the land was again left fallow, and re-ploughed in the beginning of June and the end of July (1873).

On May 4, 1874, the land was again ploughed, and sown with Red Clover seed, May 5, without manure. The plant came up well, and was very forward in September, when the flowering stems were cut down, but left on the land. During the winter and early spring the plant on those portions from which cuttings had been taken in 1871 almost entirely failed, and the land was ploughed up in May, and again in August (1875); whilst on those from which none had been taken since 1869 a fair plant remained, and two small cuttings were obtained, namely on June 23, and on August 9 and 12 (1875). On September 22, this portion of the land was ploughed up.

In May (1876), the whole was re-ploughed, and again in July and September, and left fallow.

In May 1877, Barley and Clover were sown over the whole of the experimental land, without further manuring, but the clover plant completely died off during the winter.

On two occasions (1851 and 1854), heavy dressings of Farmyard dung were applied to some of the plots; and in 1854 some received a dressing of 20 tons of dung, and 5000 lbs. of lime, per acre.

On some portions of the land Clover was sown 12 times during the 30 years, 1848–1877, and more frequently alone than with a corn-crop. In 8 out of the last 10 trials the plant died off in the winter and spring succeeding the sowing of the seed; in 4 of these without giving any crop at all, and in the other 4, only very small cuttings.

In reference to these field experiments on clover, it may be added that, in 1864, a portion of the land was trenched 2 feet deep, and one-third of the manure was mixed with the layer of soil from 24 to 16 inches, one-third from 16 to 8 inches, and the remainder from 8 inches upwards. Owing to the characters of the season, the mechanical condition of the land was at first very unfavourable after this treatment; but, although many years have now elapsed, and the excess of constituents supplied was in some cases considerable, the plant has died off as completely on these plots as elsewhere.

In 1878, the land was devoted to experiments with *various Leguminous plants*, differently manured. For further particulars see pp. 46–7, and letterpress at pp. 44–5 and 48–52.

In the winter of 1867-8, a number of small beds, each 3 yards × 2, were arranged on the previously unmanured plot of the experimental land. These were dug, some to the depth of 9 inches, some to the depth of 18, some to the depth of 27, and some to the depth of 36 inches, and sown to the respective depths with different mixtures; supplying in some cases very large amounts of potash, soda, lime, magnesia, phosphoric acid, sulphuric acid, nitrate of soda, &c.

From three similar sized beds, the soil was removed to the depths of 9, 18, and 27 inches respectively, and replaced by soil taken at the same depths from a garden border, on an adjoining portion of which Clover had been grown successfully since 1854 (see pp. 42–4).

In April 1868, clover was sown on the whole of these small beds (as well as on some other portions of the experimental land); but the plant for the most part died off during the following winter.

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS—*continued.*

In April 1869, the small beds (and the other portions as in 1868) were re-sown, small quantities of clover were cut in September of that year, but the plant again died off in the winter.

In April 1870, Clover was again sown on the small beds in conjunction with barley (as on all the rest of the experimental land), but the plant again died in the winter.

In the spring of 1871, the small beds were again re-sown, and the three with garden-soil were entirely enclosed, both around and above, by galvanised wire netting. Small cuttings were taken from these small beds in July 1872; and (excepting from the beds of garden-soil, which had yielded considerably more than the others in 1872), larger cuttings were taken in July 1873. The produce was the largest where potash and nitrate of soda were employed, and where they were applied in the largest quantity, and to the greatest depths.

In April 1874, there was still some healthy plant on all the beds, but it was considered to be too irregular to preserve. It was, therefore, dug in. The artificially-manured beds were re-manured as before, but only to the depth of 9 inches, and seed was sown on May 4th, July 6th, and October 22nd; each time the plant coming up well, but subsequently dying off. On the three beds of garden-soil, the plant from the first sowing (May 4), for the most part stood; requiring only to be made good here and there on July 6; and in September small cuttings were taken.

More small beds were arranged in the spring of 1874; on these the manures were dug in, at the various depths, on May 11th to 14th, and the seed sown on May 16th. At this time, the wire netting was removed from above the three beds of garden-soil, but the whole series of small beds was now surrounded with netting, to keep out ground game. One series of the new plots received sulphate of potash only, another nitrate of soda only, and a third the two together. The plants came up fairly well, but there were some blanks in the rows, which were re-sown on October 22 (1874). A cutting was taken on June 22 and 23 (1875) from these new beds; the blanks in the rows were re-sown on July 24; a second cutting was taken on August 17; and the blanks were again re-sown on September 22 (1875). The plant was the most even on the beds with sulphate of potash, less so on those with nitrate of soda, and less still on those with both together. The amount of produce was also greater with each of the manures used separately, than with the mixture of the two.

In May 1875, the plant was entirely gone on the old artificially-manured beds, which were then dug up, and prepared for re-sowing. On the three beds of garden-soil, though the rows were imperfect, some healthy plants still remained, and gave a small cutting on June 22. On July 24 these beds were dug up; and they, as well as the artificially manured ones just referred to, were re-sown with seed. All came up well, but in May (1876), the plants on the beds of garden-soil were entirely gone, and those on the artificially manured ones nearly so, but they yielded small cuttings on July 17 (1876).

The plants on the new artificially manured beds, like those on the older ones, showed failure in the spring of 1876; but also, like them, gave small cuttings in July. All the small beds were dug up in August (1876); the artificially manured ones re-manured as in 1874, the manures dug in to a depth of 9 inches, and seed was sown on September 1, which came up, but the plants died off on all the plots in the winter of 1876–7.

In May 1877, all the small beds were dug up, and sown with Barley and Clover. To try the effects of shelter, the Barley stubble was left unusually high, but the young clover plants completely died off during the winter (1877–8).

In the spring of 1878, the beds were dug up, and cleaned; and they were re-sown with Clover, without further manuring, on June 12 and 13. All came up well, but the plant was almost entirely destroyed by "Fly."

In May 1879, there remained about a quarter of a plant on the plot with the largest amount of mineral manure, including potash, and sown to the greatest depth, and perhaps a third of a plant where the same mineral manures, with nitrate of soda in addition, had been applied; but there was scarcely a single plant on any of the other plots. On June 9 and 10, 1879, all the beds were cleaned, and re-sown with seed, which came up well; but a very wet and cold season following, most of the plants died off during the summer and autumn.

Early in June 1880, all the small beds were cleaned, and forked up; and on June 10, they were re-sown with seed without further manure. All came up well, but the plants were for the most part destroyed by the severe winter which followed. In May 1881, there was perhaps half a plant on two or three only out of the forty small beds; namely, where the mixed mineral manure, including potash, was used without nitrogenous manure; and the greatest vigour was where the manure was applied in the largest quantity, and to the greatest depths. On no other beds, not even on the three made up of garden-soil, was there nearly as much plant; and on May 12 (1881), all the small beds were cleaned, the clover plants forked

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in, manures also forked in, as in 1876, to a depth of 8 or 9 inches, and clover seed sown, which came up well, but in most cases became very thin during the winter and spring of 1881–82. A small cutting was, however, taken on June 20, and another on August 18, 1882.

In May 1883, the beds were dug up, and sown with *Lucerne* without further manuring, but it gave no crop in that year. On April 3, 1884, the usual Nitrate Plots received Nitrate of Soda at the rate of 1000 lbs. per acre as a top-dressing. From all the plots, three cuttings were taken, viz. on June 27, August 16, and October 7. On March 9, 1885, the Nitrate plots received Nitrate of Soda at the rate of 500 lbs. per acre as a top-dressing; and three cuttings were taken, viz. on June 3, July 22, and October 10. In 1886 three cuttings were taken from all the plots, viz. on June 28, August 11, and December 3; and after the first cutting the usual Nitrate Plots received, on July 13, Nitrate Soda at the rate of 1000 lbs. per acre as a top-dressing. In 1887, three cuttings were taken, viz. on July 2, Aug. 15, and Oct. 12; and in 1888 two cuttings, viz. on July 6 and Sept. 26. In 1889 the usual Nitrate Plots received a solution of Nitrate of Lime, at the rate of 1490 lbs. per acre (= 86 lbs. of Nitrogen per acre); and two cuttings were taken from all the plots, one on July 5, and the other on August 31. In 1890, the plants on the garden-soil plots had almost entirely died off, and these beds were therefore dug up and re-sown with Lucerne on May 2; two cuttings were taken from each of the other plots, on July 5 and Sept. 2; and one cutting from the garden-soil plots on Sept. 2. In 1891, two cuttings were taken, viz. on July 8 and Sept. 15; in 1892, two cuttings, on June 27 and Aug. 30. In 1893, three cuttings, viz. on June 23, Aug. 3, and Oct. 5; in 1894, two cuttings, on July 9 and Oct. 28; in 1895, two cuttings, on May 30 and Aug. 2; in 1896, three cuttings, viz. on May 26, July 11, and Sept. 29; and in 1897, one cutting on June 8. After the cutting in June, there was a thin plant on most of the beds. In recent years they have required a great deal of hand-hoeing to keep down the weeds. The growth has usually been the more luxuriant where either Potash or Nitrate of Soda has been applied, but especially where the two were used together.

It will be observed that, although in the earlier years, the three small beds in the field which had been artificially made up of surface-soil and subsoil brought from a highly manured kitchen garden, maintained a plant of clover, and yielded better crops than the artificially manured beds, yet they finally failed quite as much as the rest.

In 1898, owing to the thinness of the plant, and the great prevalence of weeds, the whole of the small beds were ploughed up, and the experiment was abandoned. (See plan and footnote, p. 36.)

2.—*Experiments on rich garden-soil.*

In view of the failures in the attempt to grow Clover continuously on ordinary arable land it is a fact of much interest, that in 1854 Red Clover was sown in a garden, scarcely half-a-mile distant from the experimental field, on soil which had been under ordinary kitchen garden cultivation for probably two or three centuries, and it has shown very luxuriant growth almost every year since.

From the produce of the seed sown in 1854 (March 29), two cuttings were taken in 1854, three in 1855, two in 1856, three in 1857, two in 1858, and two in 1859.

In 1856, the plot was divided into three equal portions, one being left without manure, another receiving gypsum, and the third a mixed mineral manure containing potash. In 1857 the surface-soil was sampled to a depth of 9 inches.

Seed was re-sown in 1860 (end of May); and yielded one cutting in October of that year, two in 1861, two in 1862, two in 1863, and two in 1864.

Seed was again sown in 1865 (April 22); and this sowing yielded one cutting in September of that year, two in 1866, two in 1867, and one very small cutting in April 1868.

Gypsum and the mixed mineral manure were again applied, and seed was re-sown, April 29, 1868; and from this sowing there were obtained two cuttings in 1869, and one in 1870.

The same manures were again applied March 30, and fresh seed was sown April 10, 1871; yielding one cutting in August of that year, two cuttings in 1872, and two in 1873.

Notwithstanding some injury from Dodder in 1873, there still remained too much plant to break up in the spring of 1874; and accordingly fresh seed was sown *between the rows* on May 4, and this failing, again on July 7, 1874. The manures had been applied between the rows on April 16. Three very small cuttings were taken in 1874 (in June, July, and September); and a small cutting again in June, 1875.

In 1875 (July 13), the old plants were dug in, and seed again sown, and this failing, seed

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS—*continued.*

was re-sown September 22. In spring 1876 there was luxuriant growth, but deficient plant, which yielded two small cuttings, on June 26, and August 7.

In 1876 (September 1), the beds were dug up, and re-sown with seed, which came up fairly, but the plant suffered during the winter, and in May 1877 it was dug up and re-sown. From this sowing a small cutting was taken on September 5, 1877; and three cuttings in 1878 (on June 10, July 26, and November 1).

In May 1879, there remained some fairly vigorous plants, but not nearly enough for a crop, so the ground was dug up (the soil sampled to a depth of 18 inches), the plants then dug in, and fresh seed was sown, on May 21. From this sowing a cutting was taken on September 13.

Owing to injury from Dodder in the autumn (1879), and the subsequent severity of the winter, the plant again died off, and seed was sown afresh on April 17, 1880. From this sowing two cuttings were taken in that year (August 5 and September 24).

In April 1881, there being too much plant to break up, but not enough to cover the ground, the blanks in the rows were re-sown with seed (April 29), and two small cuttings were afterwards taken, on June 23 and August 16.

On April 6, 1882, there being again many blanks in the rows, these were re-sown with seed. Three cuttings were afterwards taken—on June 14, August 8, and October 20, of the same year.

On April 18, 1883, the same manures were sown on the same portions as in 1874, and the ground was dug, the old plants being dug in. Fresh seed was sown on May 17, which gave one cutting on August 13, 1883; three cuttings in 1884, viz. on June 17, August 11, and October 6; and three cuttings in 1885, viz. on June 2, July 16, and August 31.

Owing probably in great part to the severe winter of 1885–6, the plants nearly all died, and on April 14, 1886, the few that remained were dug in, and fresh seed sown, without further manure, from which one cutting was taken on August 11. In 1887, owing to some destruction of the plant by a mole, a portion of the Unmanured Plot was re-sown with seed on April 21. Two cuttings were taken, viz. on July 8 and August 29.

The plant died during the winter, fresh seed was sown on April 13, 1888, the rows were mended on June 12, and a small cutting was taken on September 6. In April 1889, the rows were again mended, after which two cuttings were taken, viz. on June 21 and October 25.

In April 1890, the plants had almost entirely died off; and the beds were therefore dug up and re-sown with seed, which gave one crop, on August 12. Later in the autumn, however, many plants were destroyed by a dog after mice, so that the rows had to be mended with fresh seed, in May 1891, and cuttings were taken on July 15 and September 25.

During the winter of 1891–2 most of the plants died, the ground was therefore dug up and re-sown with seed on May 7, 1892. The seed germinated well, but some of the young plants were destroyed by "Fly," and the rows were mended on May 27, and one cutting was taken on August 26.

During the winter of 1892–3 some of the plants died, and the rows were accordingly mended on April 20, 1893, and cuttings were obtained on June 24, and on August 22.

In 1894 the rows were again mended on April 19 and gave two cuttings on July 9 and September 4. The plants had now become exceedingly thin and the soil covered with seed-weeds; the beds were therefore dug up later in the autumn, left fallow during the winter, and re-sown with seed on April 19, 1895. The seed germinated well, but was afterwards destroyed by "Fly," and was again sown on May 20; but owing to drought and heat the seed did not germinate, and a third sowing was made on July 2; no crop was, however, obtained in1895.

During the winter of 1895, and early spring of 1896, most of the plants died, the plots were therefore cleaned from weeds, and prepared for re-sowing. On April 23, 1896, the soil was sampled at two places on each of the three portions. Each sample taken was $4 \times 4 \times 9$ inches deep; and a similar sample was taken of the second 9 inches of depth. The top 9 inches of soil of each of the three portions was then taken out, a mixed mineral manure was then dug into the second 9 inches, and a similar quantity of the same mineral manure was mixed with the surface soil, which was then returned to its position. Seed was sown on July 1, which, however, gave no crop.

Most of the plants died during the winter of 1896–7. The beds were accordingly dug up in April 1897, and seed was resown on April 29, and gave two cuttings, viz., Aug. 7, and Oct. 27.

At the beginning of the winter of 1897, there was a strong and even plant; but it gradually declined, and in January, 1898, failure was very marked. On January 27 the plots were microbe-seeded, with the watery extract of the rich kitchen garden soil at Rothamsted. This did not, however, arrest the failure. Many of the plants were covered with a white fungus;

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the foliage was destroyed, and the crowns blackened and rotted away, very few plants remaining healthy. Early in March specimens of the plants were forwarded to Mr. Carruthers, who decided that they had suffered from the attack of the fungus "*Sclerotinia Trifoliorum.*" Eventually, all the diseased plants were taken up, removed, and burnt, and the ashes returned to the soil. The surface soil was also, little by little, removed, very carefully examined, the Sclerotia carefully picked out, and then the soil was returned. About 6 ozs. of the Sclerotia were thus picked out from the surface-soil of an area of not quite 10 square yards. It was thought desirable, however, to apply a fungicide to the soil before resowing with clover-seed, and bisulphide of carbon was selected for the purpose, as leaving less permanent residue than others. Accordingly, a small dressing of this was applied on May 7, and it was immediately raked in. It was hoped that by the application any remaining Sclerotia would be killed, and that the Leguminous nodule-microbes might not be injuriously affected. On June 2, that is nearly 4 weeks after the application of the bisulphide, clover-seed was again sown, and gave two small cuttings, viz., July 19 and Sept. 5.

The plant continued even and strong, and apparently healthy, throughout the autumn and winter; but in April, 1899, indications of failure were observed. On examination on April 26, it was found that about one-third of the plants were dying off. These were carefully dug up and examined, and it was found that most of them had been attacked by the fungus "*Sclerotinia Trifoliorum*"; but some by the "*Tylenchus Devastatrix*," and some by wireworm. On May 9, about twelve more plants were found to have failed, and on being dug up Sclerotia were found on each. By May 18, three more plants had failed, each being affected by the Sclerotia. On June 1, a few more plants were seen to be failing, but the remainder, perhaps nearly one-half of the whole, showed vigorous growth, and gave a cutting on June 30. On July 25 it was found that the Clover plants were still dying off. Accordingly the whole of the plants, both living and dead, were taken up and removed. The underground growth was picked from the soil as far as practicable, burnt, and the ashes returned to the soil. The soil was also carefully looked over for Sclerotia. Several were found, some adhering to the roots, but the most were loose in the soil. Numerous wire-worms, and three large grubs, were found and removed. On March 15, 1900, a dressing of 1 lb. of bisulphide of carbon was applied to the whole area, and was immediately raked into the soil. Seed was sown August 24, but gave no crop. At the present time (June 1901) a fairly healthy but thin plant is growing.

This (1901) is the 48th season of Clover, year after year, on this plot of rich garden ground. From the foregoing statements, it will be seen that seed was sown in 1854, 1860, 1865, 1868, 1871, 1874 (twice—between the rows), 1875 (twice), 1876, 1877, 1879, 1880, 1883, 1886, 1888, 1890, 1892, 1895 (3 times), 1896, 1897, 1898, and 1900; and in addition, the blanks in the rows were filled up in 1881, 1882, 1887, 1888, 1889, 1891, 1892, 1893, and 1894. Including the partial sowings to mend the rows, seed has been sown thirty-four times in the 48 years; only five times in the first 20 years, but 29 times in the last 28. It is obvious, therefore, that the plants stood very much longer in the earlier, than in the later years. It may be added that the produce of the first five sowings (1854, 1860, 1865, 1868, and 1871) was rather more than one and a-half time as much as has been obtained since. Lastly, the reduced persistence of the plant, and the reduced produce, have been coincident with a considerable reduction in the stock of nitrogen in the soil. Still, there has frequently been very luxuriant growth, even in the later years; and the produce over 40 years, to 1893 inclusive, was equivalent to an average of nearly 3 tons of clover hay per acre per annum.

THE EXPERIMENTS WITH VARIOUS LEGUMINOUS PLANTS AFTER RED CLOVER.

The general result of the experiments described at pp. 46–7 has been that very much more nitrogen has been removed in some of the other Leguminous plants than in the Red Clover. The average annual yield in Red Clover over the 5 years of the 8 (1878–85), when there was any crop, was only about 22 lbs. per acre, giving over the 8 years an average of only 14 lbs. of nitrogen. Against this, *Melilotus leucantha* (Bokhara Clover) yielded, in 1879 about 130 lbs., in 1882 about 145 lbs., and over the 8 years (1878–85) an average of about 70 lbs. per acre; *Vicia sativa* (Common Vetch) gave over 3 years (1882–84) an average of 120 lbs., and over the 8 years (1878–85) an average of about 84 lbs.; and, lastly, *Medicago sativa* (Lucerne) yielded, in 1884 nearly 340 lbs., in 1885 about 270 lbs., and over the 6 years (1880–85), an average of about 153 lbs., of nitrogen; and over the 12 years ending 1891, it gave an average of 160 lbs. of nitrogen per acre per annum. Further, as late as 1895 even *Red Clover* yielded very fair produce under some conditions of manuring, and Sainfoin and Bokhara Clover much more; whilst in 1897, and in 1899, Bokhara Clover yielded very large crops.

Notwithstanding these remarkable results, there has, in recent years, been a tendency to failure, especially of the weaker plants; due largely to the difficulty of keeping the land clean.

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS—*continued.*

It was, therefore, decided early in 1898 to reduce the area from 3 acres to less than one acre, in the hope that with so much less land it may be possible to keep it properly cultivated and cleaned, and so obviate one serious source of failure—foulness. The five plots of Series I., each with mineral manure only, have yielded the most important results, and they are retained, so that the manure, the crop, and the soil history is substantially continued. (See Plan and footnotes thereto, at p. 36.)

THE PLOTS STILL RETAINED UNDER EXPERIMENT WITH LEGUMINOUS PLANTS.

Plot 2 was previously manured with superphosphate of lime, but under the new arrangement receives basic slag; Plot 3 receives sulphate of potash; Plot 4 sulphate of potash and basic slag (formerly superphosphate); Plot 5 salts of potash, soda, lime, and magnesia; and Plot 6, the same as Plot 5, and basic slag (formerly superphosphate). For details see p. 47.

Each of the five differently manured plots is sown with the seven descriptions of leguminous plant:—namely (1) Lucerne, (2) Beans (or Peas), (3) Melilotus leucantha (Bokhara Clover), (4) Sainfoin, (5) White Clover, (6) Red Clover, (7) Vetches.

Lucerne (Nos. 1 and 2).—The seed was sown on a portion of each of the five differently manured plots on June 8 and 9, 1898; and small cuttings were obtained in September. In 1899, fair first crop cuttings were obtained in July, and smaller second crops in August. In 1900 moderate crops were obtained in July. At each of the periods there was more produce by potash and phosphate together (Plot 4), than by either alone. There was also more on Plot 6, with the mixed alkali-salts and phosphate than on Plot 5 with the mixed alkali-salts alone in the first two years, while in 1900 Plot 5 gave rather more than Plot 6. At the present time (June 1901) there is a fairly even and a fairly luxuriant plant on each of the five plots.

Peas or Beans (Nos. 3 and 4).—Beans were sown in April 1898, yielding only small crops; but more on Plot 4 with the potash and phosphate together than with either alone, and again more with the mixed alkali-salts and phosphate than with the mixed alkali-salts alone. In March 1899, Peas were sown, and yielded small crops, but considerably more with the potash and phosphate together than with either separately; and, as in other cases, considerably more with the mixed alkali-salts and phosphate than with the mixed alkali-salts alone. In March 1900, Beans were sown and yielded fair crops. The potash and phosphate together (Plot 4) gave nearly double the produce of either alone, and the mixed alkali-salts and phosphate yielded rather more than the alkali-salts alone. In April 1901, Peas were again sown, and at the present time (June 1901) there is a somewhat thin plant owing to destruction by pigeons.

Melilotus leucantha—Bokhara Clover (Nos. 5 and 6).—Seed was sown in June 1898, but no produce was removed. In 1899 there were heavy crops, which were cut in July; and as with other plants there was more produce with the potash and phosphate together than with either separately, and more with the mixed alkali-salts and phosphate than with the mixed alkali-salts alone. After the removal of the crops it was found that most of the plant was dead, and as the land was becoming rather foul it was ploughed up in March 1900, and resown with seed in September, which germinated well, but the plant died during the winter. The land was ploughed up and resown with seed in May, 1901.

Sainfoin (Nos. 7 and 8).—Seed was sown in June 1898, but the growth was not sufficient for any cutting that year. In 1899 the plant was somewhat irregular, and owing to the drought the growth was not luxuriant. Cuttings were obtained in July, yielding, however, much less weights of produce than the lucerne. In July 1900, fair crops were obtained, the phosphate and potash together (Plot 4) yielding more than either alone, and the mixed alkali-salts and phosphate considerably more than the alkali-salts alone. At the present time (June 1901) there is still an irregular plant, though quite enough to preserve.

Trifolium repens—White or Dutch Clover (Nos. 9 and 10).—Seed was sown in June 1898, but there was not sufficient growth to yield a cutting in that year; nor was there in 1899, owing to the drought. In July 1900, small cuttings were obtained, the mixed alkali-salts and phosphate (Plot 6) yielding considerably more than any of the other plots. At the present time (June 1901) there is a somewhat irregular plant, but considered enough to leave for a crop.

Trifolium pratense—Red Clover (Nos. 11 and 12).—Seed was sown in June 1898, and again in May 1899, but as in the case of the White Clover there was not sufficient growth to yield a cutting in either 1898 or 1899. In July 1900, very small cuttings were obtained either with potash alone, phosphate alone, or with potash and phosphate together; while with mixed alkali-salts alone, and mixed alkali-salts and phosphate together, there were fair crops. During the winter so large a proportion of the plants died, that it was ploughed up. New seed was sown May 1901.

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EXPERIMENTS WITH VARIOUS **LEGUMINOUS PLANTS.**—HOOS FIELD.

The arable land (in Hoos Field) upon which attempts had been made to grow Red Clover in frequent succession since 1849, was devoted to experiments with *various* Leguminous Plants in 1878; so that the present season, 1901, is the twenty-fourth year of these experiments.

The object was to ascertain whether, among a selection of plants all belonging to the Leguminous family, but of different habits of growth, and especially of different character and range of roots, some could be grown successfully for a longer time, and would yield more produce, containing more nitrogen as well as other constituents, than others; all being supplied with the same descriptions and quantities of manuring substances, applied to the surface soil. Further, whether the success in some cases, and the failure in others, would afford additional evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of the failure of Red Clover in particular, when it is grown too frequently on the same land.

Below are given, in a Tabular form, lists of the Plants grown in previous years, and now growing (June 1901); and below the Table, the dates of sowing seed are given.

As the details show, there were at first 14 descriptions of Leguminous Plant grown, but that some of these, which more or less failed, have been given up; whilst others have been transferred from one plot to another. Indeed, the object during the last few years has been to reduce the number from 14 to 7, taking two plots instead of one for each description. The land had, however, notwithstanding much hand-hoeing, become very foul, and after cutting the crops of 1892, all but the Medicago sativa plots were ploughed up, thoroughly cleaned, and re-arranged; with one exception (9 and 10), two of the original plots being ploughed into one, and permanent paths of separation left, between the now larger plots; and in 1896, the Medicago sativa on No. 10 having failed, the two lands (9 and 10) were then thrown together, and devoted to Trifolium repens.

As the tabular statement shows, the arrangement at the present time (1901), is as follows:—

Nos. 1 and 2, Medicago sativa (Lucerne).
Nos. 3 and 4, Pisum arvense (Field Peas), or Faba vulgaris arvensis (Field Beans), alternately.
Nos. 5 and 6, Melilotus leucantha (Bokhara Clover).
Nos. 7 and 8, Onobrychis sativa (Sainfoin).
Nos. 9 and 10, Trifolium repens (White or Dutch Clover).
Nos. 11 and 12, Trifolium pratense (Red Clover).
Nos. 13 and 14, Vicia sativa (Common Tare or Vetch).

Below, is also given a Table showing the description and quantities of the manures applied to the different plots. Up to 1897 inclusive there were 3 "*Series*": Series 1, comprising 5 plots, and Series 2 and 3 each 6 plots. The same mineral manure (if any) has been applied to the same plot of each of the 3 *Series*:—*Series* 1, mineral manures only; *Series* 2, the same mineral manures, and nitrate of soda or lime; *Series* 3, the same mineral manures, with ammonium-salts, or rape-cake, or cows' urine, in addition. The manures have been applied in the quantities per acre stated in the Table, and the foot-notes thereto.

For general result, and further particulars of the experiments, see pp. 44–5, and pp. 48–53.

(Original area under Experiment, about 3 acres; each plot about $\frac{1}{6}$th acre. In 1898, plots 1–6 of Series 3, and Series 2, and plot 1 of Series 1, ploughed up for cleaning and sown with wheat, leaving plots 2–6 of Series 1 under leguminous experiment.)

PLANTS GROWN ON EACH PLOT. There were originally 14 Plants on each Plot; but the number is now reduced to 7.

Years.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	Years.
1878									1878
1879								Trifolium procumbens (*Yellow Trefoil or Hop Clover*).	1879
1880			Trif. prat. hybridum (*Suttons' Hybrid—Cow Clover*).		Trif. rep. perenne (*Giant perennial White Clover*).		Trifolium incarnatum (*Early Red or Crimson Clover*).	Trif. tardiflora incarnatum (*Late Red Clover*).	1880
1881	Trifolium pratense (*Common Red or Broad Clover*).	Trif. prat. perenne (*Perennial Clover or Cow-grass*).						Trif. tardiflora album (*Late White Clover*).	1881
1882								Trifolium minus (*Yellow Suckling Clover*).	1882
1883				Trifolium repens (*Common White or Dutch Clover*).		Trifolium hybridum (*Alsike Clover*).			1883
1884							Lupinus hirsutus (*Blue Lupin*).	Lupinus luteus (*Yellow Lupin*).	1884
1885									1885
1886	Lupinus hirsutus (*Blue Lupin*).	Lupinus luteus (*Yellow Lupin*).							1886
1887	Medicago sativa (*Lucerne or Purple Medick*).		Pisum arvense (*Field Grey Peas*).		Faba vulg. arvensis (*Field Beans*).		Trifolium pratense (*Common Red or Broad Clover*).	Trifolium pratense perenne (*Perennial Clover or Cow-grass*).	1887
1888	,, ,,	,,							1888
1889	,, ,,	,,							1889
1890	,, ,,	,,		Fallow.		Melilotus leucantha.	Onobrychis sativa (*Sainfoin*).		1890
1891	,, ,,	,,		Faba vulg. arvensis (*Field Beans*).	Melilotus leucantha (*Bokhara Clover*).		,,		1891
1892	,, ,,	,,			,,		,,		1892
1893	,, ,,	,,	Pisum arvense (*Field Grey Peas*).		,,		,,		1893
1894	,, ,,	,,	Faba vulg. arvensis (*Field Beans*).		,,		,,		1894
1895	,, ,,	,,	Pisum arvense (*Field Grey Peas*).		,,		,,		1895
1896	,, ,,	,,	Faba vulg. arvensis (*Field Beans*).		,,		,,		1896
1897	,, ,,	,,	Pisum arvense (*Field Grey Peas*).		,,		,,		1897
1898	,, ,,	,,	Faba vulg. arvensis (*Field Beans*).		,,		,,		1898
1899	,, ,,	,,	Pisum arvense (*Field Grey Peas*).		,,		,,		1899
1900	,, ,,	,,	Faba vulg. arvensis (*Field Beans*).		,,		,,		1900
1901	,, ,,	,,	Pisum arvense (*Field Grey Peas*).		,,		,,		1901

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EXPERIMENTS WITH VARIOUS LEGUMINOUS PLANTS.—HOOS FIELD—*continued.*

Years.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	Years.
1878		(Not sown).				Lathyrus pratensis (*Meadow Vetchling*).	1878
1879	Medicago lupulina (*Black Medick or Non-such*).			Lotus corniculatus (*Bird's-foot Trefoil*).			1879
1880							1880
1881							1881
1882							1882
1883			Melilotus leucantha (*Bokhara Clover*).		Vicia sativa (*Common Tare or Vetch*).	Onobrychis sativa (*Sainfoin*).	1883
1884							1884
1885							1885
1886				Melilotus leucantha (*Bokhara Clover*).			1886
1887	Vicia sativa (*Common Tare or Vetch*).	Medicago sativa (*Lucerne or Purple Medick*).					1887
1888							1888
1889							1889
1890			Trifolium pratense (*Common Red or Broad-leaved Clover*).			Fallow.	1890
1891	Trifolium repens (*Common White or Dutch Clover*).		,,		Vicia sativa (*Common Tare or Vetch*).		1891
1892			,,		,,		1892
1893			,,		,,		1893
1894			,,		,,		1894
1895			,,		Fallow (Plant failed).		1895
1896	Trifolium repens (*Common White or Dutch Clover*).		,,		Vicia sativa (*Common Tare or Vetch*).		1896
1897	,,		,,		,,		1897
1898	,,		,,		,,		1898
1899	,,		,,		,,		1899
1900	,,		,,		,,		1900
1901	,,		,,		,,		1901

DATES OF SOWING SEED, &C.

No. 1. Trifolium pratense—May '78; May '80; April '81; March '82; April '83; April '84; Lupinus hirsutus—May '86. **No. 2.** Trifolium pratense perenne—May '78; May '80; April '81; March '82; April '83; April '84; Lupinus luteus—May '86.

Nos. 1 and 2 together. Medicago sativa—April '87; May '96; June '98.

No. 3. Trifolium pratense hybridum—May '78; May '80; April '81; March '82; April '83; Pisum arvense—Feb. '84; March '85; March '86; Feb. '87; April '88; Feb. '89; Feb. '90; March '91; Feb. '92. **No. 4.** Trifolium repens—May '78; May '80; April '81; April '83; April and June '88; April '89; Faba vulgaris arvensis—March '91; Feb. '92.

Nos. 3 and 4 together. Pisum arvense—Mar. '93; Faba vulg. arvensis—Mar. '94; Pisum arvense—March '95; Faba vulg. arvensis—Feb. '96; Pisum arvense—March '97; Faba vulg. arvensis—April '98; Pisum arvense—March '99; Faba vulgaris avensis—March 1900; Pisum arvense—April 1901.

No. 5. Trifolium repens perenne—May '78; May '80; April '81; April '83; Faba vulgaris arvensis—Feb. '84; March '85; March '86; March '87; April '88; Feb. '89; Feb. '90. **No. 6.** Trifolium hybridum—May '78; May '79; May '80; April '81; March '82; April '83; April '84; May '86; April '87 (mended); April and June '88; April '89; Melilotus leucan.—May '90.

Nos. 5 and 6 together. Melilotus leucantha—(No. 6, April '90, and No. 5, April '91);—April '93; April '94; June '96; June '98; May 1901.

No. 7. Trifolium incarnatum—May '78; May '79; May '80; April '81; Jan. and Sept. '82; Lupinus hirsutus—April '83; April '84; April '85; Trifolium pratense—May '86; April '89. **No. 8.** Trifolium procumbens—May '78; May '79; Trif. tardiflora incarn.—May '80; April '81; Trif. tard. album—May '81; Trif. minus—Oct. '81; Trif. incarn.—Sept. '82; Lupinus luteus—April '83; April '84; April '85; Trif. prat.—May '86; April '89.

Nos. 7 and 8 together. Onobrychis sativa.—May '90; April '93; April '94; June '98.

No. 9. Medicago lupulina—May '78; May '79; May '80; April '81; Vicia sativa—Sept. '82; Oct. '83; Sept. '84; Sept. '85; Oct. '86; Sept. '87; Oct. '88; Oct. '89; Trifolium repens—April '91; April '93; April '94. **No. 10.** Medicago sativa—May '79; May '80; April '81; April '83 (mended).

Nos. 9 and 10 together. Trifolium repens—May '96; May '97; June '98; May '99.

No. 11. Melilotus leucantha—May '78; May '80; April '81; April '83; April '84 (mended); March '85 (mended); May '86; May and June '88 (mended); April '89. **No. 12.** Lotus corniculatus—May '78; May '79; May '80; April '81; Melilotus leucantha—Sept. '82; April '83; April '84 (mended); March '85 (mended); May '86; May and June '88 (mended); April '89. [May 1901.

Nos. 11 and 12 together. Trifolium prat.—May '90; April '93; April '94; May '97; June '98; May '99;

No. 13. Vicia sativa—May '78; May '79; May '80; April '81; Sept. '82; April '83 (mended); Oct. '83; Sept. '84; Sept. '85; Oct. '86; Sept. '87; Oct. '88; Oct. '89. **No. 14.** Lathyrus pratensis—May '78; Onobrychis sativa—May '79; May '80; April '81; April '83 (mended); April '84 (mended); April '85 (mended); May '86 (mended); April '89.

Nos. 13 and 14 together. Vicia sativa—Sept. '90; Sept. '91; Sept. '92; Sept. '93; Oct. '94; Sept. '95; Oct. '96, April '98; March '99; Oct. '99; April 1901.

MANURES; QUANTITIES PER ACRE.

Plots.	Series 1; 5 Lands.(1) Without Manure, or with Mineral Manure only. The Mineral Manures were applied in the quantities stated below, or in half the quantities in the years given in parentheses, in 1878, 1880, (1882), (1883), (1884), (1885), 1887, (1889), 1893, and 1898. In October 1883, 2000 lbs. of fresh-burnt Lime (slacked) were applied per Acre over all the Plots of Series 1.(5) [In 1898, 400 lb. Basic Slag throughout used instead of Superphosphate.]	Series 2. 5 Lands (1); Each Plot as Series 1, and—	Series 3; 5 Lands. 2 lands (2); Each Plot as Series 1, and—	Series 3; 5 Lands. 3 Lands (3); Each Plot as Series 1, and—
1	Without Mineral Manure. (Series 1, portion devoted to the experiments on "Small Beds," 1867–8, and since. See pp. 40–2)	Nitrate of Soda, 550 lbs. in 1878, '82, and '84; 275 lbs. in 1879, '80, '81, '85, '86, and 1887. 1889. (6)	Ammonium-salts. 400 lbs. in 1878, '82, and '84; 200 lbs. in 1879, '80, and '81; 225 lbs. Sulph. Amm., 1887.	Rape Cake, 2000 lbs. in 1878, 1880, 1882, and 1884; 500 lbs. in 1885; 1000 lbs. in 1887.
2	5 cwts. Superphosphate of Lime(4)			
3	1000 lbs. Sulphate Potash			
4	1000 lbs. Sulphate Potash, 5 cwts. Superphosphate			
5	1000 lbs. Sulph. Potash, 250 lbs. Chloride Sodium (in 1884–5 and '87 Sulph. Soda instead), 250 lbs. Sulph. Lime, 250 lbs. Sulph. Magnesia			
6	1000 lbs. Sulph. Potash, 250 lbs. Chlor. Sod. (in 1884–5 and '87 Sulph. Soda instead), 250 lbs. Sulph. Lime, 250 lbs. Sulph. Mag., 5 cwts. Superph.			

(1) In November 1879, Lime was applied to the fifth land of Series 1. and to the adjoining land of Series 2, in addition to the other manures. (2) One of the two lands had received Cows' Urine, 6120 lbs. per acre in 1879; and in 1885 both lands received Cows' Urine, at the rate of 21,500 lbs. per acre.

(3) In 1880, the Rape-cake was applied on only two lands (2nd and 3rd of the 3), Cows' Urine, at the rate of 6120 lbs. per acre, having been applied to the 1st of the 3 lands in 1879.

(4) "Superphosphate of Lime," 1878 to 1887 inclusive, made from 300 lbs. Bone-ash, 225 lbs. Sulphuric acid sp. gr. 1·7 (and water); 1889, made from high percentage mineral phosphates, and containing 37 per cent., or more, of soluble phosphate.

(5) In November 1887, fresh-burnt Lime (slacked), at the rate of 1000 lbs. per acre, was applied over the whole of the three Series. In November 1893, 2 tons of Chalk (crushed) per acre was applied over the whole of the three Series.

(6) On September 13, 1889, instead of Nitrate of Soda, a solution of Nitrate of Lime (1490 lbs. per acre), corresponding to 550 lbs. Nitrate of Soda, and to 86 lbs. Nitrogen per acre.

NOTE.—In addition to the manures above described, a top-dressing of 550 lbs. Nitrate of Soda, 400 lbs. Ammonium-salts, or 2000 lbs. Rape-cake, per acre, was applied to the respective portions of **No. 10** (Medicago sativa), **No. 11** (Melilotus leucantha), and **No. 14** (Onobrychis sativa), on September 20, 1882. In 1898, and since, all sown in rows; Beans 20 inches apart; Vetches 12 inches; Lucerne, Melilotus, Sainfoin, White Clover, and Red Clover, each 11 inches apart.

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS—*continued.*

Vicia sativa, Common Vetch (Nos. 13 and 14).—Seed was sown in April 1898, which yielded small crops in September. Seed was again sown in March 1899, and yielded small crops in July. Seed was also sown in October 1899, yielding small crops in July 1900. Seed was again sown in April 1901, and at the present time (June 1901) there is a thin but fairly even plant.

Still confining attention to the plots retained under experiments with leguminous plants, it may be further explained, that in 1898, before the mineral manures were applied and seed sown, samples of the surface soils were taken where each of the seven different leguminous plants had been grown, on each of the five differently manured plots. The samples were taken primarily for the purpose of obtaining watery extracts for the inoculation of artificial soils, composed of sand and the properly prepared ashes of the plant, in which, in pots in a glass-house, the seven different descriptions of leguminous plant were to be grown; the object being to gain some information as to how far the absence, or the weakly condition, of the microbes involved in the fixation of free nitrogen had probably been one cause of the failure, or of the less favourable growth on the different plots in the field in some cases than in others.

THE POT PLANT EXPERIMENTS IN THE GLASS-HOUSE.

As each of the seven descriptions of leguminous plant had been grown in the field under five different conditions as to manuring, five pots of washed and heated sand, with the ash of the plant, were sown with each description of plant; to be microbe-seeded, respectively, by the watery extract of the surface-soil of the five differently manured plots in the field on which the plant had been grown. There was also, for each description of plant, a pot with similarly prepared sand and ash, but to be microbe-seeded by a watery extract from rich garden soil. Thus, the only supply of nitrogen to the plants was that contained in the seed sown, a very small amount in the sand, and the practically-negligible amounts in the soil extract used for microbe-seeding.

For each description of plant there were, therefore, six pots, respectively microbe-seeded as under:—

Pot 1.—From rich garden soil.

Pot 2.—From Plot 2 in the field, which had been manured with superphosphate only.

Pot 3.—From Plot 3 in the field, which had been manured with sulphate of potash only.

Pot 4.—From Plot 4 in the field, which had been manured with sulphate of potash and superphosphate together.

Pot 5.—From Plot 5 in the field, which had been manured with salts of potash, soda, and magnesia.

Pot 6.—From Plot 6 in the field, which had been manured with both superphosphate, and salts of potash, soda, and magnesia.

The two annuals, beans and vetches, were cut, and the roots taken up, in September 1898.

Beans (No. 2).—Three seeds were sown in each of the six pots on April 16 (1898). The seed of the bean being very large, it would supply much nitrogen to the growing plants. Examination of the roots showed that there had been a considerable development of nodules, which was evidence that the soil-extracts had effectively seeded the growing roots, and was also clear indication that there had been fixation of free nitrogen. It is of interest to observe, too, that in several cases the development of the nodules was greater in the pots microbe-seeded by the extract from the soil of the leguminous plots in the field, than by that from the garden-soil. Nitrogen determinations have not yet been made in the separated nodules; but they have been in the corn, in the stems and leaves, and in the roots; and the results so far show from nearly seven to more than eight times as much nitrogen in the products of growth as in the seed sown. It is remarkable, too, that in the case of this ripened seed-bearing annual, a much larger proportion of the total nitrogen of the products was accumulated in the corn than in the stem and leaves where the microbe-seeding was from a plot in the field where phosphate had been used, than where a salt of potash, or salts of potash, soda, and magnesia without phosphate, had been employed.

Vicia sativa—Common Vetch (No. 7).—The seed was sown on April 19 (1898). The seed of the Vetch is also comparatively large, but very much smaller than that of the Bean, and the three seeds sown in each pot contained only about one-twelfth as much nitrogen as was supplied in the seed in the case of the Beans. Examination of the roots showed that there had been considerable development of nodules on them; but many appeared to be in an exhausted

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condition, which is what would be expected with a fairly ripened crop. Excluding any nitrogen in the nodules, the amount in the products of growth was in no case so low as twenty, and in most over thirty times, as much as was supplied in the seed sown.

Melilotus leucantha—Bokhara Clover (No. 3).—In the first instance six seeds were sown in each of the six pots, on April 27, 1898. The Melilotus seed, which is very small, did not germinate well, and some of the pots had to be resown several times. The growth was in fact very irregular, there being one or two plants two or three feet high, and others only as many inches, in the same pot. In pot 2 there was scarcely any growth; and in pot 6 it was very defective. The above-ground growth of all the pots was cut on November 8, 1898, and as there was not sufficient development of shoots from the crown to promise a second growth, the roots were taken up on December 29. There were, however, numerous nodules on the roots of many of the plants, showing that the microbe-infection had been effective, and indicating that there had been fixation of free nitrogen. The nitrogen determinations (excluding any in the nodules) show, in fact, some gain even in the two pots of comparative failure (2 and 6), and in the others there was a variable amount of gain from over 100 to nearly 400 times, as much as was in the seed sown.

The remaining plants, those of longer life, were—White Clover, Red Clover, Sainfoin, and Lucerne.

Trifolium repens—White Clover (No. 5).—Six seeds were sown in each pot on May 2, 1898; and later four more were put into pot 3, five more into pot 4, and four more into pot 6, to fill up gaps. Microbe-seeding by soil-extract was first applied on June 15, and the application was repeated at intervals of a few days until the effect was obvious. In this way each of the pots 2, 3, 4, 5, and 6, received five applications, in all equal to about 114 cc. of the soil-extract; but No. 1, with garden soil-extract, required three more applications than the others, equal in total to about 180 cc. of the extract. In fact, the infection seemed to be more successful under the influence of the extract from the field-soil where white clover had grown, than of that from the garden-soil. Towards the end of August the plants in pots 2, 3, 5, and 6, were well in flower, and the produce was cut from pots 2, 5, and 6, on August 22, and from pot 3 on August 30. The first cuttings from pots 1 and 4 were, however, not taken until October 7; but at that time the plants of pot 4 had developed so much growth that the stems fell over the sides of the pot on to the bench, whilst those of pot 1 fell over considerably, but in a less degree. At the same date, October 7, the plants in pots 2, 3, 5, and 6, again showed much growth, but no flowers, and were then cut a second time. Further cuttings were taken from all the pots on May 25, July 3, and August 16, 1899; also on June 8, July 20, September 7, and December 5, 1900; in all eight cuttings from pots Nos. 1 and 4, and nine from Nos. 2, 3, 5, and 6. Excluding any nitrogen in the roots or in the nodules, there are so far, from nearly 2000 to nearly 4500 times as much nitrogen in the products as in the seed sown; indicating, therefore, an enormous gain of nitrogen due to the microbe-seeding. At the present time (June 1901) the plants in each pot are in flower, and will soon be cut again.

Trifolium pratense—Red Clover (No. 6).—Six seeds were sown in each pot on May 2, 1898; and later four more in pot 3, and one each in pots 4, 5, and 6, to fill up gaps. In due time after the microbe-seeding, there was fair growth in all the pots, but less than in the case of the white clover. Cuttings were taken from each pot towards the end of August; and again on October 7, 1898; on June 24, and August 15, 1899; also on July 20, September 7, and December 5, 1900—in all, therefore, seven cuttings. There has been less total growth, and less free-flowering, in the case of the red than of the white clover. Red Clover seed is very small, though still much larger than that of the white; and each seed would supply more than 3 times as much combined nitrogen as the white clover seed. The first five cuttings in no case show less than 300, and in some more than 600 times as much nitrogen in the products as was supplied in the seed sown. The nitrogen in the two last cuttings has not yet been determined. At the present time (June 1901), there is fair growth in all the pots, but little tendency to flowering; another cutting will soon be taken, and probably one or more afterwards; and eventually the nitrogen in the roots and in the nodules will have to be brought into account.

Onobrychis sativa—Sainfoin (No. 4).—The Sainfoin seed is small, but considerably larger than that of either White Clover, Red Clover, Lucerne, or Bokhara Clover. Three seeds were sown in each of the six pots on April 29; and later two more in pots 1 and 2; three more in pots 3, 4, and 6; and five more in pot 5, to fill up gaps. There were eventually two plants in pots 1 and 6, and three in each of the others. All the pots were microbe-seeded on June 25, July 7, and July 9; but pot 1, with garden soil-extract, had to be seeded three times more, namely, on July 15, 19, and 28; and the other pots were each seeded once more on July 19. The growth in all the pots was more limited than in the case of any of the other plants, but the foliage had the characteristic dark green colour. Cuttings have been taken at seven periods,

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namely, on November 8, 1898; May 24, and August 17, 1899; May 14, July 20, and December 5, 1900; and May 31, 1901. The plants in most of the pots flowered in May 1899, and in May 1900. In July 1899, one dead plant was taken out of pot 1, one out of pot 3, and one out of pot 5; there being then no plant left in pot 3. Nitrogen determinations have been made in each of the first three cuttings, from pots Nos. 1, 2, 4, 5, and 6; and in the two cuttings from pot 3. The results, so far, show some gain of nitrogen compared with that in the seed sown, even in pots 3 and 5, microbe-seeded from the plots in the field which had not been manured with phosphate, and where the growth in the pots was the most restricted; more in pot 1 with garden soil microbe-seeding, and considerably more in pots 2, 4, and 6 microbe-seeded from the plots in the field which had been manured with phosphate;—indeed in these three cases there was from 30 to 40 times as much nitrogen in the products of the three cuttings as in the seed sown. It may be added that the cuttings taken on May 14, 1900, the nitrogen in which has not yet been determined, were in each case more than at either of the preceding cuttings. There was the most from pot 6, less from pots 2 and 4, less from pot 1, and much less still from pot 5.

Medicago sativa—Lucerne (No. 1).—The seed of Lucerne is very small, about the size of that of Red Clover. Six seeds were sown in each of the six pots on April 25, 1898; and in each of the pots 2, 3, 4, 5, and 6, more were put in from time to time to fill up gaps. The application of soil-extract for microbe-seeding commenced on June 16, and was repeated in the case of all the pots on June 20 and July 9; and the result was satisfactory in the case of each of the five pots where the soil-extract was taken from the Lucerne plots in the field. In pot 1, however, treated with extract from rich garden soil, the plants did not recover from the "nitrogen-hunger" stage indicated by pale colour and restricted growth, although the extract was applied five more times up to August 1. On August 10, four of the diminutive pale green plants were therefore removed, and their roots examined, when on a root-fibril of one plant, which had for a few days shown slight increase of colour, some small nodules were found; and two very small nodules were observed on the root-fibrils of the smallest plant, but there were none on either of the other two. The three plants left in the pot were then microbe-seeded by the extract of the surface-soil from the lucerne plot 4 in the field, the manure of which had been superphosphate and sulphate of potash. The effect was soon observable, the plants acquiring a bright green colour, and developing activity of growth. The produce has been cut seven times from each pot, namely, on November 1, 1898; on June 24, August 19, and December 9, 1899; and on July 20, September 7, and December 5, 1900. There was comparatively little tendency to flowering in the plants of the first cutting (November 1, 1898), but there was more in pots 2 and 4 than in the rest. In the second cuttings (June 24, 1899), there were some flowering heads in those of pot 2, but not in the others. In the cuttings of August 19, 1899, the only indication of flowering was again in pot 2; and in those of December 9, 1899, there were no flowering heads. In the cuttings of July 1900, the plants in each pot produced flowers, except No. 4. The largest quantity was yielded in that of pot 2. In the cutting of September 7, 1900, the plants in all the pots produced flowers, the most matured were in pots 1 and 5, which yielded some seeding heads. In the cuttings of December 5 none of the plants showed a tendency to flowering. The nitrogen has been determined in each of the first four cuttings. The largest amounts were in the cuttings of June 24, 1899, and next in those of August 19, 1899, whilst the least was in those of December 9, 1899. The largest yield of total nitrogen was in the produce of pot No. 2, next in that of pot 3, then in that of pot 5; pots 4 and 6 coming next, and pot 1, originally seeded with garden soil-extract, giving the least. Calculating the yield of nitrogen determined in the produce in relation to that in the seed sown, it ranged from over 100 to nearly 300 times as much as was supplied in the seed. The produce of the next three cuttings is considerably more than that of the first four, and at the present time (June 1901) there is again a considerable amount of growth in each of the six pots; so that there will be much more nitrogen to credit to the produce in all the pots, besides that in the roots and nodules. It may be stated generally, that there is more tendency to lower and leafy vegetation in the pots microbe-seeded from the plots in the field manured with plenty of potash but without phosphate, and more tendency to the production of stems and flowering when the extract was taken from the soil where phosphate had been applied.

In conclusion, a careful study of the results of these experiments, so far as they have yet been obtained, will show how enormous, under certain conditions, may be the fixation of nitrogen in proportion to the amounts otherwise available to the plants.

THE PLOTS PLOUGHED UP FOR CLEANING, &c.—WHEAT AFTER VARIOUS LEGUMINOUS PLANTS.

As explained in the footnote at the bottom of the plan of the plots on which experiments have been made on Leguminous Plants for so many years (see p. 36), owing to the growing

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EXPERIMENTS ON THE GROWTH OF LEGUMINOUS CROPS—*continued.*

foulness of the land in recent years, it was decided early in 1898 to plough up for thorough cleaning Plot 1 of Series I. (Small Beds), also the whole of the plots of Series II. and Series III. Accordingly, the portions named, comprising more than two acres, and rather more than two-thirds of the original area, were ploughed up in March of that year. The land was ploughed a second time in May, and then scuffled twice and harrowed twice. In July the land was ploughed for the third time. During these various processes a good deal of rubbish was brought to the surface, and with the drought and hot sun most of it was killed, and it was finally ploughed in. The land was re-ploughed early in October, and as it was now considered to be sufficiently clean, wheat was drilled over the whole on November 2; the description being Club Wheat (Red); the land having been harrowed three times before the drill, and once after it.

The land was thus sown with wheat without manure, as a means of gauging the effects of the different treatment of the plots under Leguminous growth. It may be further explained that there had been 3-feet paths separating from one another each of the Plots 1 to 6 of the different Series, and also between each description of leguminous plant, as indicated by the lines shown on Plot 2 of Series I. in the plan. As it was impossible to plough each of the differently manured plots, and each of the different plants separately, Series II. and Series III. were each ploughed, and otherwise mechanically worked, from one end to the other, that is through the six plots and through all the separating paths.

Throughout the period of growth there was a good and even plant of wheat over the whole area, and as the season advanced there was a promise of very heavy crops; showing, however, marked distinctions according to the description of leguminous plant which had previously been grown; the luxuriance being by far the most marked on the lucerne plots, on which the wheat had a very deep green colour, and was early laid quite flat.

As explained in the plan, each of the six plots had been differently manured, and each differently manured plot had had seven different leguminous crops growing upon it. It is obvious that it would have been impracticable to harvest and thresh separately, the produce after each of the seven descriptions of plant, on each of the six differently manured plots, which would have involved the separation, and the threshing and dressing separately, of forty-two different lots. Accordingly, there were mixed together the produce after each description of leguminous plant, each grown under the six conditions as to manuring; thus reducing the number of lots to be dealt with to seven. There is obviously some disadvantage in ignoring the difference of effect of the different manures on the individual leguminous plants; but it was considered to be more important to separate the produce after the different plants, than to take that on each differently manured plot, each of which had grown seven different descriptions of leguminous plant.

As explained in the footnote to the plan, p. 36, wheat was again sown in October 1899, and for a third time in October 1900.

The following Table shows the produce of wheat obtained on the plots of Series II. and Series III., which had been devoted to various leguminous plants from 1878 to 1897 inclusive; with, however, occasional fallow when there was failure of plant, or the land was foul. Results are given for the produce of wheat in 1899, and also in 1900; and columns are left for that of 1901.

WHEAT, 1899, 1900, AND 1901.

Leguminous Plants previously grown.	Dressed Grain.						Total Straw per acre.			Total Produce (Grain and Straw) per acre.		
	Produce per acre.			Weight per bushel.								
	1899.	1900.	1901.	1899.	1900.	1901.	1899.	1900.	1901.	1899.	1900.	1901.
	bush.	bush.	bush.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Lucerne	39¼	26½		63·6	61·7		5,499	2,614		8,108	4,291	
Peas	42½	14¼		63·9	61·0		5,622	1,312		8,430	2,202	
Bokhara Clover	43¾	16½		64·1	61·4		5,592	1,549		8,508	2,582	
Sainfoin	45¼	19		64·3	61·4		5,611	1,788		8,639	2,986	
White Clover ..	43½	19¼		64·1	61·5		5,404	1,707		8,308	2,927	
Red Clover ..	43	19		64·3	61·5		5,580	1,787		8,505	2,992	
Vetches	40	14¼		64·4	61·9		5,051	1,360		7,766	2,262	

Referring first to the produce of 1899, owing to the drought and heat of the summer, the crops ripened well, but rather too quickly, and they were cut on August 10 and 11, and carted on August 12. At a glance it is seen that the produce of both grain and straw was very

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high, as also was the weight per bushel of the grain. Thus, the produce of dressed grain per acre, ranged after the different leguminous crops, from nearly 40 to over 45 bushels; the produce of straw in two cases exceeded 2½ tons, and in the others was not much less; whilst the weight per bushel of the grain was in only two cases under, and in five over, 64 lbs. It has already been stated, that after lucerne, the luxuriance of growth was more marked than after any of the other leguminous plants; but it is seen that the produce of grain was the lowest, and the weight per bushel was also the lowest, owing to the too heavy crop being laid quite early. The growth was also very luxuriant on all the plots, especially after the Sainfoin, the Bokhara Clover, and the Red Clover, and the yield and quality depended much on the condition of the crops when cut.

It may be added, that with the high condition of the land after so many years under leguminous crops, a winter and spring favourable to luxuriance, and great deficiency of rain and considerably over average temperature in the summer, early vegetative activity was followed by favourable ripening and harvest conditions. Under these circumstances, the grains were adjudged by Mr. Hewlins to be upon the whole very well grown, and characterised by great strength; the wheat after Lucerne being the strongest of all, and that after the peas perhaps the weakest. The grains were, in fact, found to contain a high percentage of nitrogen, and there can be little doubt that there was a high condition of the nitrogenous substances.

In the second year the description of wheat sown was "Square Head's Master." There was a good plant on all the plots, though much less growth than in 1899. Nevertheless, the plants again showed more luxuriance after the Lucerne than after any of the other leguminous plants, and the Table shows that the produce of both grain and straw was considerably higher on the Lucerne plots than on any of the others. The produce was, however, on all the plots very much less in 1900 than in 1899. Part of the result would doubtless be due to the great exhaustion of nitrogenous residue in the growth of the large crops of 1899; and part to the season of 1900 being very much less favourable for wheat production than that of 1899. The weight per bushel was also much lower in 1900 than in 1899.

Square Head's Master was again sown for the third crop, that of 1901, and at the present time (June 1901) the wheat shows a good plant on all the plots, though only restricted growth. Still, the Lucerne plots again show more luxuriance than any of the others.

General Conclusions; Fixation of Free Nitrogen, &c.

The general result of the experiments on ordinary arable land in the field has been—that neither organic matter rich in carbon as well as other constituents, nor ammonium-salts, nor nitrate of soda, nor mineral constituents, nor a complex mixture, supplied as manure, availed to restore the clover-yielding capabilities of the land; though, where some of these were applied in large quantity, and at considerable depths, the result was better than when they were used in only moderate quantities, and applied only on the surface.

On the other hand, it is clear that the soil in the garden, which at the commencement contained in its upper layers about four times as much nitrogen as the arable land, and would doubtless be correspondingly rich in other constituents, has supplied the conditions under which clover can be grown year after year on the same land for many years in succession.

The results obtained on the soil in the garden seem to show that what is called "clover-sickness," cannot be due to the injurious influence of excreted matters upon the immediately succeeding crop.

That Clover frequently fails coincidently with injury from parasitic plants, or insects, cannot be disputed; but it may be doubted whether such injury should be reckoned as the cause, or merely the concomitant, and an aggravation, of the failing condition.

The results of the experiments seem, therefore, to exclude the supposition that the *primary* cause of failure is either destruction by parasitic plants or insects, injury from excreted matters, or the shade of a corn-crop, and to indicate that it must be looked for in exhaustion of some kind within the range of the roots.

Still there remain several open questions. Is it exhaustion of certain organic matters rich in carbon, of nitrogenous food, or of mineral constituents? Again: is there an absolute deficiency in the soil of some of the substances in question, or only an unfavourable condition of combination, or, so to speak, of *soil-digestion* of them, for the requirements of Leguminous plants? Or, is there only an unfavourable distribution of them within the soil, considered in relation to the extent and character of the root-range of the crop? Or, lastly, is the failure connected with the condition, the distribution, or the exhaustion, of the organisms, the development of which in symbiosis with leguminous plants, has been shown to be associated with the fixation of free nitrogen? For further reference to this point, see next page, also page 7.

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In reference to these various questions, it is a fact of much significance that from October 1857 to May 1879, the diminution in the amount of nitrogen in the garden-soil to the depth of 9 inches only, represented approximately two-thirds as much as was estimated to have been taken out in the crops of the 21 intermediate seasons; and it was concluded that there had been reduction in the lower depths also.

The subject cannot be further considered within the limits of this brief notice, which may be concluded by the following quotation from Rothamsted papers ('Journal of the Royal Agricultural Society of England,' vol. xxi. Part I. p. 178; and 'Journal of the Royal Horticultural Society of London,' vol. iii. p. 86, 1872):—

"When land is not what is called 'clover-sick,' the crop of clover may frequently be increased by top-dressings of manure containing potash and superphosphate of lime; but the high price of salts of potash, and the uncertainty of the action of manures upon the crop, render the application of artificial manures for clover a practice of doubtful economy.

"When the land is what is called 'clover-sick,' none of the ordinary manures, whether 'artificial' or natural, can be relied upon to secure a crop.

"So far as our present knowledge goes, the only means of insuring a good crop of Red Clover is to allow some years to elapse before repeating the crop upon the same land."

Experiments at Rothamsted have confirmed those of others, in showing that, by adding to a sterilised sandy-soil growing leguminous plants, a small quantity of the watery extract of a soil containing the appropriate organisms, a marked development of the so-called leguminous nodules on the roots is induced, and that there is, coincidently, increased growth, and gain of nitrogen. There is no evidence that the leguminous plant itself assimilates free nitrogen; the supposition is, that the gain is due to the fixation of nitrogen in the course of development of the lower organisms within the root-nodules, the nitrogenous compounds so produced being taken up and utilized by the higher plant.

It would seem, therefore, that in the growth of leguminous crops, such as clover, vetches, peas, beans, sainfoin, lucerne, &c., at any rate some of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, may be due to atmospheric nitrogen brought into combination by the agency of lower organisms. It has yet to be ascertained, however, under what conditions a greater or less proportion of the total nitrogen of the crop will be derived—on the one hand from nitrogen-compounds within the soil, and on the other from such fixation. It might be supposed, that the amount due to fixation would be the less in the richer soils, and the greater in soils that are poor in combined nitrogen, and which are open and porous. On the other hand, recent results obtained at Rothamsted, indicate that, at any rate with some leguminous plants, there may be more nodules produced, and presumably more fixation, with a soil rich in combined nitrogen, than in one poor in that respect.

In conclusion, as referred to above, the question remains—how far the failure of clover, and other leguminous crops, may be due to the exhaustion of available combined nitrogen, or mineral constituents, within the range of the roots, and how far to the exhaustion of the organisms necessary for the bringing about of the fixation of free nitrogen?

For further particulars on the Question of the Fixation of Free Nitrogen, see No. 92, Series I. (in the list of papers at page 14), pages 119–145; or, No. 93, Series I., pages 137–166.