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EXPERIMENTAL INVESTIGATION

INTO THE

AMOUNT OF WATER GIVEN OFF  
BY PLANTS

DURING THEIR GROWTH;

ESPECIALLY IN RELATION TO

THE FIXATION AND SOURCE OF THEIR VARIOUS CONSTITUENTS.

By J. B. LAWES,

OF BOTHAMSTED.

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AMOUNT OF  
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DURING THEIR GROWTH.

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OF the several natural orders of plants which yield food to man, or to the animals destined for his consumption, or other use, perhaps the most important, both as to the extent of their distribution and the amount of the products they supply, are the *Graminaceæ* and the *Leguminosæ*. There are others, however, to which we are indebted for the roots and tubers, the extended cultivation of which, in alternation with grain, so prominently characterises at least the national agriculture of the present day. The corn-plants of most extended utility in the Leguminous family are the *Bean* and the *Pea*; but we owe to it also some of the most important of our fodder-plants, such as *Clover*, *Trefoil*, *Vetches*, and others. The Gramineous family, on the other hand, supplies us with *Wheat*, *Barley*, *Rye*, *Oats*, *Rice*, *Maize*, the *Sugar Cane*, and others, besides the natural grasses of our meadows and pastures.

Between these two great natural orders of plants there are, however, many striking and obvious points of contrast as to habits, structure, and products, whilst the vastly different positions allotted by experience to the individuals which they respectively comprise in a system of alternate cropping, are such as clearly to indicate that the resources of their growth are also widely different; and it has been maintained that an explanation of them is mainly to be found in the varying mineral composition of the crops. The scattered observations, however, of many experimenters, and some of not very recent date, would seem to favour an opposite view of the question, and the vastly accumulating published results of the last few years lend an ample confirmation in the same direction.

For our own part, an extensive and systematic series of experiments, conducted both in the field and in the laboratory, leaves not a doubt in our mind that, in the ordinary practice of agriculture in Great Britain, the *exhaustion* which is suffered is prominently connected with a deficiency of "*organic*" or primarily

atmospheric, rather than the "mineral" or, more properly, soil-constituents; and especially that the supply of NITROGEN, relatively to other constituents, is defective. We have already, in the 'Journal of the Royal Agricultural Society,' indicated some striking facts bearing upon this point, in the discussion of the results of some of our experiments upon the growth and composition of Wheat and of Turnips. Beans, Peas, and Clover, as the types of the agricultural plants of the Leguminous family, have also been the subjects of experiment for several years past, and we hope before long to complete the results for publication.

Besides the experiments of a more purely agricultural scale and character, however, it was thought that the explanation of the alternation of crops would materially be aided by any additional information as to the characteristic qualitative and quantitative functional actions of some of the plants which ordinarily find a place in rotation. With this view, it was sought to ascertain, as in some degree a measure of the activity of the processes of the plants, the amount of water passed through those belonging to different natural orders, and holding different positions in rotation, both as compared one with another, and in reference to the quantitative fixation in the plants of several of their more important constituents, having regard also, as far as was practicable, to the source of these constituents—that is to say, as to whether they were derived from the soil or from the atmosphere.

The experiments, as thus far proceeded with, however, can be considered as little more than initiative, especially so far as the demonstration of those important *agricultural* problems, for the elucidation of which they have mainly been designed, is concerned: were it otherwise, indeed, the pages of this Journal would not be deemed the fittest medium for the publication of results of more purely agricultural interest. The facts already obtained, however, are not without interest to the botanist and the vegetable physiologist; and it is as a contribution to the scanty information already at command, on the subject of the amount of water given off during the growth of plants, that these results are arranged and presented to the reader. It will nevertheless be seen that they provide some important and interesting indications in reference to the more special object of our investigation, and at the same time afford some useful suggestions for its future conduct.

In deciding upon the method of procedure, the choice seemed to be between such experiments as would yield somewhat rapid, and in some points, perhaps, more direct information, though at the cost of the health and perhaps matured growth of the plant, on the one hand, and a closer imitation of the usual circumstances of growth on the other—by which, however, *inferences* rather

than *demonstration* might be elicited. The latter course was chosen, more especially as there are well-conducted experiments of the former kind on record, which it was thought might serve to check or confirm some conclusions which our own results, taken alone, might be held not fully to justify.

It was considered important to provide such conditions for the plants as should enable them to live and mature their seed, if such were the product for which they were usually cultivated—an end not very easily accomplished in the case of plants growing through a period of several months, and requiring an accurate registry of the water passing through them. This was not, indeed, in every case satisfactorily attained, as will be explained further on. But if, from this cause, any otherwise general indications should seem to be opposed by figures, at first sight discrepant, a little further consideration may perhaps show that, if these are coincident with irregularities of growth and maturation, they may be taken rather as confirmations than as contradictions of any conclusions to which the results of the more naturally developed plants might lead us. We shall, however, submit to the reader a sufficient description both of the methods of experimenting, and of the results, as they were actually obtained, whether numerically or by observation merely—leaving him, therefore, in a position to judge of the value of any suggestions we may offer, whilst the experience thus far attained will, it is expected, enable us to avoid in future some of the irregularities complained of, and the results then supplied will serve amply to confirm or correct any inferences at present hazarded.

The plants selected for experiment were *Wheat* and *Barley*, of the natural order Graminaceæ; with *Beans* and *Peas* as Corn-plants, and *Clover* as a Fodder-plant, from the Leguminosæ—these several plants, moreover, occupying somewhat important and characteristic positions in a course of rotation. A *Root-crop* would also have been taken, but for the great and manifest difficulties of arranging the experiment. These we hope to overcome, however, in the coming season.

The main desiderata in the arrangement of the experiments were—

- To provide the plants with soils of some known history and composition or resources, and in quantities sufficient to allow of a natural development of the roots.
- To prevent any serious amount of evaporation from the soil other than through the plants themselves.
- To have the means of supplying weighed quantities of water to the soils as it was needed.
- To determine by the balance the amount of water given off by the plant within any desired period of observation.

To determine the total amount of water passed through the plant during the entire period of its growth; and in relation to this, the amounts of dry produce, and several of its constituents, fixed in the plant.

To determine the source of these fixed constituents, whether soil, manure, or atmosphere.

We are prepared for the objections which may be raised against the means adopted for attaining the end and indications desired, and against the competency of the results, when obtained, to afford *demonstration* on some important points of the inquiry. Yet it is not unadvisedly that some of them, at least, have been risked, and especially in reference to the question of the exact composition and resources of the soils employed, do we not scruple to declare, though in opposition to the known opinions of several esteemed chemical friends, that we are more disposed, for the present at least, to rely upon the comparative indications which a natural and unanalysed but exhausted soil may yield alone, and in admixture with manures of known composition, than upon one of an artificial kind, such as pure sand, for example—or upon the results of analysis at the *commencement* of the experiments. Indeed, in proof of the dangers and uncertainty to which we are exposed in judging of the exact capabilities of a soil by its analysis, and especially of an exhausted one, wherein all the more important constituents are so small in quantity, we need only call attention to the very elaborate examination of this subject in the hands of Professor Magnus, as detailed in his account, 'Uber Versuche betreffend die Erschöpfung des Bodens.'

The knowledge we obtain by synthesis in the method adopted and described further on, with the comparisons which will in time be provided is, we believe, our safer guide. Specimens of the soil, as originally taken for the experiments, are, however, preserved for analysis at some future time, when the whole subject of the composition and properties of soils can be entered into—and when, also, by the continuous growth of the different plants as proposed, the *balance* of the constituents in the cases of the several experiments will be so far affected as to yield sufficiently wide variations, and therefore trustworthy points of comparison.

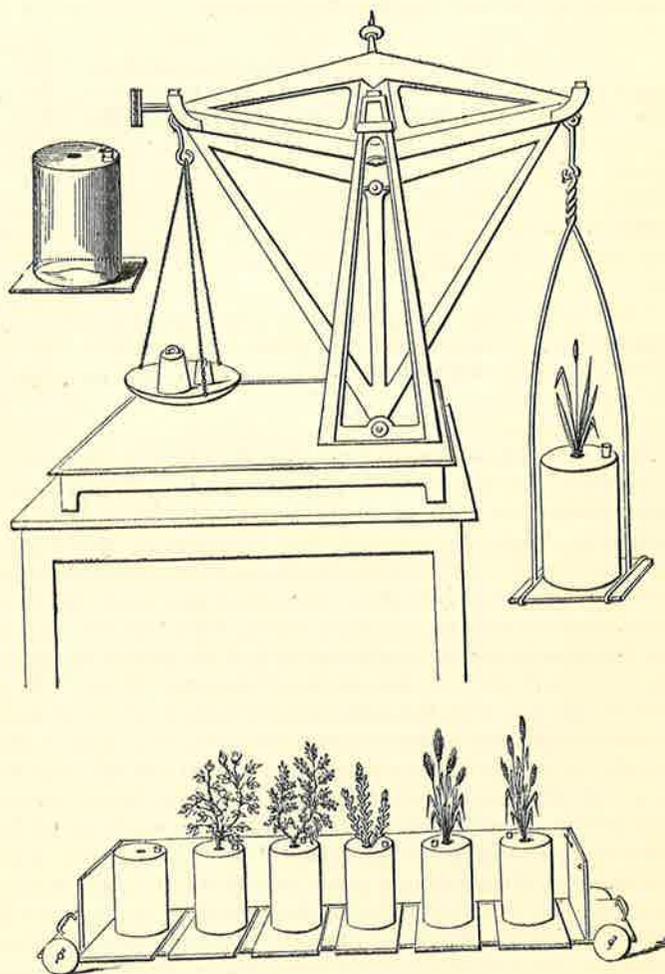
As already stated, the plants selected for experiment were—Wheat, Barley, Beans, Peas, and Clover. Seeds of the first four of these were sown in a box of mould, where they were allowed to reach the height of about 3 inches before being transferred to the experimental pots; but the Clover plant was brought direct from the field. One or more of each description of plant was grown in each of three different conditions of soil,

and each set of the five plants with the same description of soil constituted a *Series*. An inspection of the following plan will aid a conception of the arrangement of the experiments as to condition of soil and description of plant:—

Series 1 ... ..	{ Soil—from a plot of land from which ten successive grain-crops had been taken without manure (the larger stones being sitted out and the weeds picked) ... ..	{ Wheat, Barley, Beans, Peas, Clover, No plant.
Series 2 ... ..	{ Soil—as in Series 1, with mineral manure, containing Sulphate of Potash, Sulphate of Magnesia, Chloride of Sodium, and Superphosphate of Lime ... ..	{ Wheat, Barley, Beans, Peas, Clover.
Series 3 ... ..	{ Soil—as in Series 1, with the mineral manure of Series 2, and the Muriate of Ammonia added ... ..	{ Wheat, Barley, Beans, Peas, Clover.

Glass jars, 14 inches in depth and 9 inches in diameter, and which were capable of holding about 42 lbs. of soil, were the vessels employed. Six of these were filled with the soil as described for *Series 1*; five with that of *Series 2*; and five with that of *Series 3*: there being in all, therefore, sixteen separate experimental jars. Into these, excepting the sixth jar of *Series 1*, the plants raised, as described above, were transferred; those from three seeds each of the Wheat and of the Barley being taken, and one plant only of the Beans, Peas, and Clover. A glass plate having a hole in the centre about three-quarters of an inch in diameter for the plants to grow through, and another nearer the side, by which to supply water as it was needed, and which was at other times closed by a cork, was then firmly cemented upon the top of each of the sixteen jars. The sixth jar of *Series 1*, however, though provided with soil and closed with a lid as the rest, was left without a plant, as indicated in the tabulated plan above, in order to determine the amount of evaporation from the centre orifice. Each jar was placed upon a varnished board, for the convenience of attachment to the arm of the balance, and, as thus fitted and mounted, weighed little short of half a hundredweight. The jars on their stands constituting a *Series* were placed upon a truck, by means of which they were sometimes drawn into a green-house for the night, and under the balance when it was desired to weigh them, and on to a grass-plot during the day for free exposure to sun and air; a canvas awning being provided, however, to protect them in case of rain. These arrangements will be clearly understood on inspection of the

annexed drawing, in which is represented a *Series* of the jars with their plants, fixed upon their scale boards, and placed upon their truck.



The balance employed for weighing the plants was constructed for the purposes of these experiments by Mr. Oertling of London, and is calculated to turn with the third of a grain when loaded with from half a hundredweight to a hundredweight in each pan. A drawing of them is also given with a jar and plant as in process of being weighed. The knife-edge of the balance was relieved in the usual way by a support to the beam when not in

actual use; this being removed or applied at pleasure by means of a lever, the arrangement for which is not, however, indicated in the drawing. The whole was, moreover, covered by a frame of glass, provided with a door by which to gain access to the weight-pan, and another for the attachment of the loose arm by which the jar and plant are suspended. A standard counterpoise, consisting of two leaden weights, was kept in the weight-pan, the deviations only above and below this amount being determined by weights—a set of which, from ten thousand grains down to one-tenth of a grain, was provided for this purpose. As will shortly be seen, however, the amounts of water given off by the plants were very large; and after a time it was not deemed necessary in practice to determine the weight within one grain, or frequently even two.

Between the time of planting and the full growth of the plants more than twenty weighings of most of them were taken; and weighed quantities of water were supplied whenever it seemed to be required.

The collected results of the water supplied, or given off by the plants, are exhibited in the following tables:—

In the Table (No. I.), page 10, as well as in those which follow it, the results are arranged in two sections; the upper one bringing more prominently to view the comparisons between the different plants with one and the same condition of soil, and the lower one those of the same description of plant with the varying conditions of soil.

The summary of the total water given off during the growth of the plants, as shown in the third column of this Table, is, of course, chiefly of interest in connection with the coincident accumulation of vegetable substance, and it will therefore be repeated, and further considered, when we come to treat of that part of the subject. Attention may here be called, however, to the evidence afforded by a glance at the figures of this column—whether in the upper or the lower section—at the much greater regularity in Series 1 without manure, and in Series 2 with mineral manure only, than in Series 3 with both mineral and ammoniacal manures. Indeed, from the beginning, the plants of Series 3 were unhealthy, and, as indicated in the tables, only the wheat and the barley survived to the end of the experiment, and these even gave a produce far inferior to the same description of plants under the other conditions, though the ammonia provided by the manure amounted in this case to only about 0.1 per cent. upon the weight of the soil.

It is seen that, in the cases of the healthy plants, there has been an average of about 100,000 grains of water given off by them during their growth, an amount far greater than was anticipated

TABLE I.—SHOWING the TOTAL AMOUNTS of WATER supplied, derived from the SOIL, and given off, during the entire period of the growth of the PLANTS. Quantities given in grains.

Entire Period of 172 days, from March 19 to Sept. 7.

		Total Water supplied.	Total Water obtained from Soil.	Total Water given off.
Unmanured ...	Wheat ... ..	79,800	33,727	113,527
	Barley ... ..	88,800	31,225	120,025
	Beans ... ..	87,800	24,431	112,231
	Peas ... ..	81,800	27,282	109,082
	Clover (cut June 28th)	28,500	26,593	55,093
With Mineral Manure ...	Wheat ... ..	85,800	12,206	98,006
	Barley ... ..	97,800	30,554	*128,354
	Beans ... ..	95,800	22,069	117,869
	Peas ... ..	86,000	10,405	96,405
	Clover (cut June 28th)	36,500	17,223	53,723
With Mineral and Ammoniacal Manure ...	Wheat ... ..	57,700	...	55,996
	Barley ... ..	74,300	10,824	85,124
	Beans (died) ... ..	...	...	...
	Peas (died) ... ..	...	...	...
	Clover (cut July 4th)	24,300	...	13,671

Wheat ... ..	Unmanured ... ..	79,800	33,727	113,527
	Mineral Manure ...	85,800	12,206	98,006
	Min. and Am. Man....	57,700	...	55,996
Barley ... ..	Unmanured ... ..	88,800	31,225	120,025
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Beans ... ..	Unmanured ... ..	87,800	24,431	112,231
	Mineral Manure ...	95,800	22,069	117,869
	Min. and Am. Man....	(died)	...	...
Peas ... ..	Unmanured ... ..	81,800	27,282	109,082
	Mineral Manure ...	86,000	10,405	96,405
	Min. and Am. Man....	(died)	...	...
Clover ... ..	Unmanured ... ..	28,500	26,593	55,093
	Mineral Manure ...	36,500	17,223	53,723
	Min. and Am. Man....	24,300	...	13,671

\* The glass lid was broken by the pressure of the plants, and the soil therefore partly exposed.

anticipated when the arrangements for the experiments were made; and it will readily be understood that, with such quantities as these, it was seldom necessary to conduct the weighings with the nicety for which we were prepared.

The first and second columns of the Table show the sources of the water given off, from which it is seen that an amount varying from 10,000 to 30,000 grains has been derived from the soil, the remainder having been supplied as the experiment proceeded. It should be remarked, however, that before the commencement of the experiment, 30 fluid ounces, or between 14,000 and 15,000 grains of water, were added to each of the jars of soil, which, by exposure to the air for some time with shelter from the rain, and by the process of sifting, had become somewhat dry. The figures in the table therefore overstate, by nearly the quantity just mentioned, the amount obtained from the normal soil. Nevertheless it is believed that the wheat and the barley plants suffered to some extent during the latter period of the experiment for want of a freer supply of water, and that to this cause may in part be attributed a defective development of their seeds as compared with those of the beans and peas.

We have not prepared any detailed account of the periodical supply of water, which was regulated, both as to time and quantity, in part by the amount given off by the plants, and partly also by their apparent or supposed requirements. It may be stated, however, that none was added during the first few weeks of the experiments, and that the doses given varied from 250 grains to as much as 1, 2, 3, 4, 6, or even 12 thousand grains as the growth of the plants progressed.

A somewhat more detailed view of the amounts of water given off by the plants may be of interest, and we have accordingly supplied, in Tables II. and III. (pp. 12,13), statements both of the total and the average daily loss during periods, in the main, as nearly approaching to one month each, as the details of our registry would permit.

The relationship of evaporation to rapidity of growth is, it is true, as yet a problem, but it may nevertheless be assumed as a general fact—and especially between plant and plant of the same description—that the comparative rate of the evaporation of water, or its amount within any given period, to some extent indicates the comparative activity of the processes of the plants; yet, since, with the advance of the season, and increased intensity of heat and light, the surface for evaporation was also constantly increasing, it is difficult to determine whether the increasing loss up to a certain period, as indicated in the tables, is, to any extent, materially due to the *external* influence referred to, *irrespectively* of a corresponding enlarged surface and rapidity of fixation of constituents.



constituents. So far, of course, as the process is one of *simple evaporation*, will an increase of temperature determine a greater loss of water; still the question arises whether—supposing there be no actual deficiency of the necessary and available constituents—this increased passage of water through the plants, carrying with it in its course many important materials of growth from the soil, and probably also influencing the changes in the leaves of these, as well as of those derived from the atmosphere, will not be accompanied with an equivalently increased growth and development of the substance of the plant. Upon this point some light may be thrown by an examination of the circumstances attending the development of “Roots,” the more active growth of which is generally coincident with a declining and not an increasing temperature, as in the case of the seeding crops now under trial.

Until, however, the relationship of the quantity of water given off to the amount of dry substance or its constituents fixed, under varied and known circumstances, be experimentally determined, any detailed consideration of the indications of the thermometer in connection with results of so initiative a kind would be unavailing, though a more or less complete registry was kept of the temperature during the period of the growth of the plants, and this point will not be neglected in our future progress.

As might have been anticipated, it is seen by the Tables, that though, as the season advanced in temperature and the mass and surface of the plants increased, the amount of water daily given off was also greater up to a given time, yet towards the end of the experiment it rapidly and considerably diminished. It is probable that, from the time of this apparent decline in the rate of passage of water through the plant, the processes of acquirement of material were less active, those of the ripening and elaboration of its contents having commenced, and that the time of most active circulation, as indicated by the daily rate of water evaporated, was also that of the greatest *accumulation*. Some experiments which we conducted a few seasons ago, with the view of determining whether there was, in the formation and ripening of the cereal grains, any diminution in the amount of nitrogen previously stored in the plant, seemed, indeed, to show, that though there was no appreciable change in the amount of the nitrogenous compounds upon a given area of land after the time of flowering, yet the amount of *non-nitrogenous* vegetable substance accumulated after this time had been very great; it is not, however, necessary to conclude that the rapid accumulation of carbon from the atmosphere at this period, though coincident perhaps with an apparently less succulent condition of the plant, was in reality attained with any less degree of activity of the fluids within it,

or of watery exhalation from it, than during the earlier stages of its growth. Upon this point some information will probably be afforded by our results as we proceed.

The daily rate of evaporation in the cases of the two more healthy clover plants—those, namely, of Series 1 and 2—is seen to be in the main higher, up to the time of their being cut, than in those of the other plants; in explanation of which, it must be remembered that the clover experimented upon, being the produce of seed sown in the previous season, these plants were, at the commencement, more advanced than those with which they here stand in comparison.

The total evaporation from the jar without a plant is seen to be 3844 grains during the entire period of the experiment. This total loss from the hole in the glass lid is certainly considerable, but it amounts on an average to little more than 3 per cent. of the entire quantity given off from the jars containing the plants, and it seems unsafe on several grounds to attempt to correct the indications of the latter by the deduction of the amount of loss from the no-plant jar. Thus, the loss from the centre-hole of the no-plant jar might be supposed to exceed that from the rest, since in these the orifice was nearly closed by the stems of the plants; but, on the other hand, the much less active circulation of air through the unplanted jar would tend to an opposite result, as also would the fact, that in the absence of a fresh supply of water in this case, the surface of the soil would, after a time, become somewhat dry. That this was the case would appear from the figures in the Table, which show that though the rate of loss from the no-plant jar increased for a length of time as the season advanced, yet afterwards it to some extent diminished. It may be remarked, however, that there was frequently in this case, as well as in the others, a condensation of water on the under surface of the lid. Upon the whole, then, we are inclined to decide, that the indications of this experiment should serve rather to prevent any too nice application of the numerical results obtained in relation to the plants, than as providing any available means of correcting them.

Let us now turn our attention to the amount and composition of the produce obtained from the experimental jars. The wheat plants in all three of the jars appearing sickly from the time of transplanting, were cut down twelve days afterwards, viz., on March 31st, in the hope that they would then grow up more vigorously. These cuttings, when dried at 212°, in neither case weighed one grain, but they were saved, and their quantities are taken into account with the rest of the produce. Stems were also cut from the wheat grown by the unmanured and the mineral manured soil, as well as from all of the barley jars, on May 26th;

the holes in the glass covers having become in these cases quite choked up. These cuttings were much more considerable in quantity than the former, and of course also considered as a part of the experimental product.

The several clover plants were respectively cut when in full flower. The pea with mineral manure was cut on August 4th, and that in the unmanured soil on August 11th. All the other plants, viz., wheat, barley, and the beans, were harvested on September 7th.

The corn of the peas and beans was well developed and tolerably ripened: that of the wheat and the barley was by no means so much so, especially that of the wheat. This was supposed partly to arise from a want of water, the plants having an appearance of drying up rather than healthy ripening. It is seen, indeed, by reference to Table I., at page 10, that the amounts of water derived from the soil were greater in the cases of one of the wheat jars and two of the barley jars than in the others, though the exhaustion, in this respect, of the beans, one of the peas, and one of the clovers, was not much less. It had been remarked, however, from the commencement, that the apparent demand for supplied water was much greater in proportion to that given off in the cases of the graminaceous plants than in the several leguminous ones; but it seems generally to have been found by experimenters, that the cereals were much more difficult to bring to maturity under the somewhat artificial circumstances usually provided in experiments of this kind, than any other plants.

The irregularities of cuttings and want of uniformity in the final maturation of the produce will be guarded against as far as possible in our future experiments. To these indeed may probably be chiefly attributed any want of definiteness or consistency in the results about to be considered; and it was on account of them deemed unnecessary to take the *fresh* weights of the produce of the jars.

The plants cut level with the surface of the perforated lids, shortly after being taken from the jars, were dried in a stove at about 140°, and then carefully stored for future examination.

Recurring to the subject for the purpose of this paper, the corn plants were carefully dissected—the seeds from the straw, chaff, &c. Each of them was then exactly halved. The one portion of corn, and one each of straw, chaff, &c. (the latter being mixed together), were fully dried at 212°—the weight taken and then burnt to ash, and the other specimens, the corn separately from the straw, chaff, &c., being reserved for the determination of their nitrogen. The cuttings were also halved and treated in

like manner, those taken at different periods from the same plant having been mixed.

In Tables IV., V., and VI., are given the results of the dryings and burnings of the produced plants.

TABLE IV.—QUANTITIES (in grains, tenths, &c.) of DRY MATTER fixed in the several parts of the PLANTS, and in the Total Produce of the Jars, &c.

Description of Plants and Manure.	In Corn.	In Straw and Chaff.	In Cuttings.	In Total Produce.	Proportion of Corn to 100 of Straw, &c.	
Wheat {	Unmanured ... ..	148.5	302.8	7.6	458.9	47.84
	Mineral Manure ... ..	111.2	321.9	7.6	440.7	33.74
	Mineral and Ammon. Manure	65.4	206.2	0.3	271.9	31.67
Barley {	Unmanured ... ..	188.7	253.74	23.1	465.54	68.16
	Mineral Manure ... ..	179.0	297.0	24.6	500.6	55.66
	Mineral and Ammon. Manure	112.8	170.6	29.8	313.2	56.34
Beans {	Unmanured ... ..	282.6	254.9	...	537.5	110.86
	Mineral Manure ... ..	299.0	238.8	...	537.8	125.20
Peas {	Unmanured ... ..	214.7	206.3	...	421.0	104.07
	Mineral Manure ... ..	213.8	243.6	...	457.4	87.76
Clover {	Unmanured ... ..	...	...	...	204.7	...
	Mineral Manure ... ..	...	...	...	234.8	...
	Mineral and Ammon. Manure	...	...	...	92.6	...

TABLE V.—QUANTITIES (in grains, tenths, &c.) of MINERAL MATTER fixed in the several parts of the PLANTS, and in the Total Produce of the Jars, &c.

Description of Plants and Manure.	In Corn.	In Straw and Chaff.	In Cuttings.	In Total Produce.	
Wheat {	Unmanured ... ..	4.22	30.62	1.65	36.49
	Mineral Manure ... ..	3.06	40.44	1.44	44.94
	Mineral and Ammon. Manure	2.16	29.74	0.048	31.948
Barley {	Unmanured ... ..	6.2	36.38	3.34	45.92
	Mineral Manure ... ..	6.8	39.22	4.6	50.62
	Mineral and Ammon. Manure	4.72	24.06	4.4	33.18
Beans {	Unmanured ... ..	9.02	40.0	...	49.02
	Mineral Manure ... ..	10.6	36.16	...	46.76
Peas {	Unmanured ... ..	6.76	36.4	...	43.16
	Mineral Manure ... ..	8.24	55.98	...	64.22
Clover {	Unmanured ... ..	...	...	...	29.24
	Mineral Manure ... ..	...	...	...	35.48
	Mineral and Ammon. Manure	...	...	...	13.10

TABLE VI.—PERCENTAGES of ASH in DRY MATTER.

Description of Plants and Manure.		In Corn.	In Straw and Chaff.	In Cuttings.	In Plant (Clover).
Wheat	Unmanured ... ..	2.84	10.11	21.71	...
	Mineral Manure ... ..	2.75	12.56	18.95	...
	Mineral and Ammon. Manure ... ..	3.30	14.42	16.0	...
Barley	Unmanured ... ..	3.28	14.34	14.46	...
	Mineral Manure ... ..	3.80	13.20	18.70	...
	Mineral and Ammon. Manure ... ..	4.18	14.1	14.1	...
Beans	Unmanured ... ..	3.19	15.69	...	...
	Mineral Manure ... ..	3.55	15.14	...	...
Peas	Unmanured ... ..	3.15	17.64	...	...
	Mineral Manure ... ..	3.85	23.0	...	...
Clover	Unmanured ... ..	...	...	...	14.28
	Mineral Manure ... ..	...	...	...	15.11
	Mineral and Ammon. Manure ... ..	...	...	...	14.15

In Table IV. the *dry matter* in the several *parts* of the specimens is given, the quantities being calculated upon the entire produce of the jars. Excluding the clover-plants, which do not compare fairly with the rest, and those also having the ammoniacal manure, which were evidently injured by it, we see at least some general uniformity in the amount of dry matter produced; the beans, however, which were of all the plants the most healthy, yielding not only an amount almost identical with the unmanured and the mineral-manured soils, but higher than any of the rest. And if we refer to the last column of the Table, we see that in their cases especially, but also notably in those of the peas, the seed (which in both is so highly nitrogenous) shows a *much* higher proportion to the entire produce than in the cereals.

These *actual quantities* of dry matters produced, though indicating, perhaps, to some extent the healthy development of the several plants under the conditions provided for them, will be more conveniently studied in their relationship to the amount of water given off, when calculated to a uniform standard, as in the Table which will shortly follow.

The figures of Table V., indicating the actual amounts of *mineral matter* fixed in the plants, are also of little independent interest. Those of Table VI. show the percentage of *mineral matter* in the gross dry substance in the several plants and parts of plants, and indicate it to be in every instance higher than is usual; though less so in the Leguminous seeds than in the

cereals, and more in the wheat than in the barley. The proportion is seen, moreover, to vary in the same description of plant with the different conditions of soil, it being generally higher where mineral manure was employed than with no manure. This general excess of mineral matter may be taken as being connected, to a great extent, with the defective state of ripening of the plants, and between plant and plant of the same description the amount of it may indicate their relative qualities in this respect.

TABLE VII.—TABLE of Actual Experimental RESULTS.

Description of Plant and Manure.	Number of Grains of Water given off.	Number of Grains fixed in the Plant, of—		Mineral Matter (Ash).	
		Dry Matter.			
		Inclusive of Ash.	Organic only.		
Unmanured ... ..	Wheat ... ..	113,527	458.9	422.41	36.49
	Barley ... ..	120,025	465.54	419.62	45.92
	Beans ... ..	112,231	537.50	488.48	49.02
	Peas ... ..	109,082	421.00	377.84	43.16
	Clover ... ..	55,093	204.70	175.46	29.24
Mineral Manure ... ..	Wheat ... ..	98,006	440.7	395.76	44.94
	Barley ... ..	128,354	500.60	449.98	50.62
	Beans ... ..	117,869	537.80	491.04	46.76
	Peas ... ..	96,405	457.40	393.18	64.22
	Clover ... ..	53,723	234.80	199.32	35.48
Mineral and Ammoniacal Manure ... ..	Wheat ... ..	55,996	271.90	239.952	31.948
	Barley ... ..	85,124	313.20	280.02	33.18
	Clover ... ..	13,671	92.60	79.50	13.10

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	Mineral Manure ... ..	98,006	440.7	395.76	44.94
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Barley ... ..	Unmanured ... ..	120,025	465.54	419.62	45.92
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	Mineral Manure ... ..	53,723	234.80	199.32	35.48
	Min. and Ammon. Manure... ..	13,671	92.60	79.50	13.10

In Table VII. (p. 19) the total amounts of water given off during the growth of the plants, and the total amounts of dry matter, both inclusive and exclusive of ash, and of the ash itself, are given side by side. The relationship of the water given off to the matter fixed in the plant is, however, more clearly indicated in Tables VIII. and IX.

TABLE VIII.—SHOWING the Quantities of SUBSTANCES fixed to a Standard Amount of WATER given off.

Description of Plant and Manure.	Number of Grains fixed in the Plant for 100,000 Grains of Water given off, of—			
	Dry Matter.		Mineral Matter (Ash).	
	Inclusive of Ash.	Organic only.		
Unmanured ... ..	Wheat ... ..	404.2	372.0	32.14
	Barley ... ..	387.8	349.6	38.26
	Beans ... ..	478.9	435.2	43.67
	Peas ... ..	385.9	346.4	39.57
	Clover ... ..	371.5	318.5	53.07
Mineral Manure ... ..	Wheat ... ..	449.7	403.8	45.85
	Barley ... ..	390.0	350.6	39.44
	Beans ... ..	456.3	416.6	39.67
	Peas ... ..	474.4	407.8	66.61
	Clover ... ..	437.0	371.0	66.04
Mineral and Ammoniacal Manure ... ..	Wheat ... ..	485.6	428.5	57.05
	Barley ... ..	367.9	328.9	38.98
	Clover ... ..	677.3	581.5	95.82

Wheat ...	Unmanured ... ..	404.2	372.0	32.14
	Mineral Manure ... ..	449.7	403.8	45.85
	Mineral and Ammoniacal Manure ...	485.6	428.5	57.05
Barley ...	Unmanured ... ..	387.8	349.6	38.26
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Beans ...	Unmanured ... ..	478.9	435.2	43.67
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Clover ...	Unmanured ... ..	371.5	318.5	53.07
	Mineral Manure ... ..	437.0	371.0	66.04
	Mineral and Ammoniacal Manure ...	677.3	581.5	95.82

TABLE IX.—SHOWING the Quantities of WATER given off to a Standard Amount of SUBSTANCES fixed.

Description of Plant and Manure.	Number of Grains of Water given off for One Grain fixed in the Plant, of—			
	Dry Matter.		Mineral Matter (Ash).	
	Inclusive of Ash.	Organic only.		
Unmanured ... ..	Wheat ... ..	247.4	268.8	3111.2
	Barley ... ..	257.8	286.0	2613.8
	Beans ... ..	208.8	229.7	2289.5
	Peas ... ..	259.1	288.7	2527.3
	Clover ... ..	269.1	314.0	1884.2
Mineral Manure ... ..	Wheat ... ..	222.4	247.6	2180.8
	Barley ... ..	256.4	285.2	2535.6
	Beans ... ..	219.2	240.0	2520.7
	Peas ... ..	210.8	245.2	1501.2
	Clover ... ..	228.8	269.5	1514.2
Mineral and Ammoniacal Manure ... ..	Wheat ... ..	205.9	233.4	1752.7
	Barley ... ..	271.8	304.0	2565.5
	Clover ... ..	147.6	172.0	1043.6

Wheat ...	Unmanured ... ..	247.4	268.8	3111.2
	Mineral Manure ... ..	222.4	247.6	2180.8
	Mineral and Ammoniacal Manure ...	205.9	233.4	1752.7
Barley ...	Unmanured ... ..	257.8	286.0	2613.8
	Mineral Manure ... ..	256.4	285.2	2535.6
	Mineral and Ammoniacal Manure ...	271.8	304.0	2565.5
Beans ...	Unmanured ... ..	208.8	229.7	2289.5
	Mineral Manure ... ..	219.2	240.0	2520.7
Peas ...	Unmanured ... ..	259.1	288.7	2527.3
	Mineral Manure ... ..	210.8	245.2	1501.2
Clover ...	Unmanured ... ..	269.1	314.0	1884.2
	Mineral Manure ... ..	228.8	269.5	1514.2
	Mineral and Ammoniacal Manure ...	147.6	172.0	1043.6

In Table VIII. there are shown the amounts of gross dry substance, of dry organic matter, and of mineral matter fixed, for every 100,000 grains of water carried off from the soil by the plants, and in Table IX. the amount of water given off for the fixation of one grain of each of these is indicated.

The indications of these Tables are certainly not without the appearance of discrepancy: yet when we remember the circum-

stances of irregularity of growth already fully detailed, and also the greatly varying products, of which the substance of the plants is in several cases made up, the *general* uniformity of the figures is sufficiently striking, and calculated to lead to the expectation of much more definite results in future, and more carefully conducted experiments.

Referring first to Table VIII., and taking the upper section of it, we see that the amounts of dry matter produced to 100,000 grains of water given off by the plant, range in the case of the wheat, the barley, the pea, and the clover, in the unmanured soil, between 371 and 404 grains; or, excluding the clover, between the latter number and 386 grains, an approximation sufficiently indicating some definite relationship between the passage of water through the plant and the fixation in it of some of its constituents. The *bean* in this series seems to be an exception, the amount of dry substance produced in this case being about 479 grains, or nearly one-fourth more than the average of the other unmanured plants. When we remember, however, the much larger amount of *nitrogenous* compounds which this product would contain than any of the other specimens, we see that, with this variation in the amount of vegetable growth to a given quantity of water evaporated, there is, at least, coincident variation in the composition of the product itself; and the particular facts would lead to the suspicion, that the water evaporated had a more definite quantitative relationship to the fixation of the *non-nitrogenous* than to that of the *nitrogenous* constituents of the plants.

Looking at the results of the second Series (with mineral manure), we see a generally higher amount of dry substance produced for a given circulation of water than in Series 1; and also, the barley excepted, a much greater uniformity than in the former Series. The cause of this discrepancy in the barley may perhaps be explained by the fact already mentioned, that the lid of the jar in which it grew had been broken during a considerable period of the experiment; and though the pieces were cemented together, yet it is more than probable that water was lost from the soil by evaporation through the crack, in which case the amount of product would necessarily appear low.

In the case of this Series, too, it is seen that the product of beans is exceeded by the peas, and nearly reached even by the wheat. On the view referred to above, therefore, it would be necessary to suppose that, provided the results are to be relied upon, the composition of the several products as regards nitrogen would be more nearly equal in the case of this Series than in the former one, and also that the percentage of it was higher in the

specimens of the second Series than in those of the first—a result which would have to be attributed to the more or less direct influence of the manure.

The plants of *Series 3*, having an ammoniacal manure, were so manifestly unhealthy that the results afforded in relation to them must not be allowed much weight, and indeed they appear to be little worthy of confidence.

In the lower section of Table VIII. the comparison is made between the individuals of the same description of plant under different conditions of soil. A considerable difference is here shown to be coincident with the variations of manuring condition, and, setting aside the clover, more especially in the cases of the wheat and the peas. The composition of these when determined may, to a great extent, elucidate the fact; indeed, the varying proportion of seed to straw in the several cases indicates a probable difference in this respect; and analogy would also lead us to believe that, with the varying observed degree of ripeness and the experimentally ascertained varying amounts of ash, the percentage of nitrogen in the several specimens of the same kind of plant would also vary very greatly. In support of this opinion we may state that analyses already made of some of the products show that some of the cereals contained nearly twice the ordinary amount of nitrogen. The coincidences in this section are most striking in reference to the beans, and these, as has been already stated, were the most healthy and matured plants obtained from the experimental jars. The three barley plants, it is true, show a considerable uniformity, but, as has already been explained, the figures given for the mineral manure plant are probably somewhat in error.

Notwithstanding these discrepancies, as yet not fully and satisfactorily explained, we cannot but recognise in the results thus far obtained a very encouraging significance; and, indeed, it seems to us more than probable that future experiments may fix a definite relationship between the amount of water given off and that of the *non-nitrogenous* proximates fixed in the plant, and this even probably to a great extent irrespectively of their exact composition, provided their source were mainly in each case the *atmosphere*, as in the instances of the seeding plants now under consideration, and accumulating, as they are known to do, their chief supplies during the period of the most powerful influence of heat and light upon the plants.

In Table IX. the amounts of water passing through the plant for each grain of substance fixed are given—the indications being the inverse of those we have just been considering; and the differences are of course dependent on the same circumstances as those already alluded to.

It is a striking fact, that (excepting a single clover plant, which was always unhealthy) there is in every case more than 200 grains of water passed through the plant for one grain of material accumulated.

Referring to the column of water evaporated to mineral matter fixed, we see the amount of the former to be, on an average, 2000 times that of the latter. Whatever other explanation, therefore, we may receive as to the conditions of assumption by the plant of some mineral substances occurring in it, in insoluble combinations, we have here evidence sufficient to show that few of the substances required by plants, and which are generally assumed to be insoluble, are incapable of being taken up by them in an adequate quantity in rain water.

It was our hope to have given in this paper the results of the determinations of nitrogen, in the various specimens grown in the pots, with the view of showing what relation subsisted between the amount of nitrogenous proximates fixed in the plant, and that of the water passed through it. Unfortunately, however, the laboratory work in connection with this branch of the inquiry is as yet not so far advanced as to justify the discussion of the numerical results on this occasion, nor will our allotted time allow us to do so. We may, however, state that, as far as our results have gone, it would appear that, whilst for a given quantity of water evaporated the amount of *non*-nitrogenous substances fixed in the plant is within somewhat narrow limits identical, in the specimens now under experiment of the two natural orders of plants, that of the *nitrogenous* proximates fixed is, on the other hand, about *twice* as great in the Leguminosæ as in the Graminaceæ. This is indeed a significant fact, as bearing upon the distinctive functional characters of the various plants which enter into rotation. It is, moreover, perfectly consistent with the results of our experiments in the field with wheat and beans respectively, which show that, under the same circumstances of growth, as to manure, &c., and in the same season, the acreage yield of nitrogen is twice or thrice as great in beans as in wheat.

It cannot be supposed, however, that with the larger amount of nitrogen harvested in the Leguminous crop the soil would be proportionally exhausted of it, for common practice sufficiently teaches that, other things being equal, a larger produce of wheat would be obtained after a bean than after a wheat crop, notwithstanding its known dependence on the supply of nitrogen in the soil.

It may be supposed, indeed, that here we have evidence of a superior power in the Leguminous as compared with the Graminaceous plants, of obtaining their nitrogen from the atmosphere

rather than from the soil. However this may be, many experiments of our own have convinced us that, especially in the growth of the Graminaceous grains, there is never an increased acreage yield of nitrogen in any degree approaching that supplied by manure; and, independently of results of a more direct and practical kind, it has been observed by several experimenters, that during the growth of plants there is a constant evolution of nitrogen from their leaves.

Thus De Saussure, in his 'Recherches Chimiques sur la Végétation,' pp. 40-43, gives the results of experiments on this subject, and he comes to the conclusion that the amount of nitrogen given off bears a direct relation to that of oxygen assimilated by the plant from the absorbed carbonic acid. His experiments, moreover, were made with the *Velch*, which, as will be remembered, is a member of the Leguminous family of plants, in which, as compared with the Graminaceous family, we would suppose the evolution of nitrogen to be less considerable.

Daubeny, again, in his 'Memoir on the Action of Light upon Plants, and of Plants upon the Atmosphere,' in the 'Philosophical Transactions for 1836,' Part I., arrives at a somewhat similar result; whilst more recently Draper, in his 'Chemistry of Plants,' pp. 184, 185, and context, ascertained in several experiments the amount of nitrogen given off during the growth of plants, and seeks to establish the following conclusions: that "when the leaves of plants under the influence of light decompose carbonic acid, they assimilate all the carbon, and a certain proportion of oxygen disappears; at the same time they emit a volume of nitrogen *equal to that of the oxygen consumed*.\* This disappearance of oxygen and appearance of nitrogen are thus connected with each other: they are equivalent phenomena. The emission of nitrogen is thus shown not to be a mere accidental result, but to be profoundly connected with the whole physiological action. . . . At this stage of the inquiry a remarkable analogy appears between the function of digestion in animals and the same functions in plants. Liebig has shown how, from the transformation of the stomach itself, food becomes acted upon, and is turned into chyme; an obscure species of fermentation, brought about by the action of nitrogenized bodies. So in like manner, in plants, the decay of a nitrogenized body is intimately connected with the assimilation of carbon; for, as I have stated, the process here under discussion is a true digestive and not a respiratory process. And as there are facts which seem to show that the primary action of the light is not upon the carbonic acid, but upon the nitrogenized ferment, the decomposition of the gas

\* The italics are those of the author.