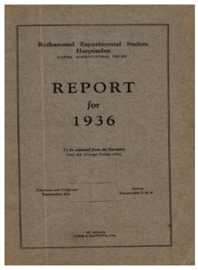
Rothamsted Report for 1936

Full Table of Content



Fermentation Department, 1913-1936

Rothamsted Research

Rothamsted Research (1937) *Fermentation Department, 1913-1936 ;* Rothamsted Report For 1936, pp 74 - 83 **- DOI: https://doi.org/10.23637/ERADOC-1-68**

field technique for measuring the starch content of leaves by decolourising, staining with iodine and comparing the colour developed with a standard tone scale. He showed that potassium sulphate increased the rate of starch production in potato leaves, while muriate of potash and " potash salts " did not. The low rate of starch production when the chlorides were given was associated with a low rate of starch removal. James(1) confirmed Maskell's results. He also found that potassic fertilisers reduced the number of leaves per plant, and delayed their yellowing and death. The chloride increased the area of individual leaflets, and this effect was ascribable to an increased water-content. James(2) also studied the changes with age in the distribution of potassium in the plant. An examination(3) of the diurnal changes of carbohydrate content in the leaves of potato plants with varying supply of potassium chloride showed that the absence of an effect of potassium chloride on the rate of starch formation was not due to the accumulation of other products of photosynthesis. The sucrose content was depressed in plants receiving potassium chloride, but only during the middle of the day. Reducing sugars were not affected. Some evidence of a sudden shift in the starch, sugar balance at sunset and sunrise was found, and this is being further investigated.

THE WORK OF THE FERMENTATION DEPARTMENT. 1913—1936.

E. Hannaford Richards

The name of this department is, perhaps, a little misleading. Its work is not concerned with any of the fermentation industries, such as brewing or the production of commercial solvents, although agricultural science is directly interested in promoting the growth of the raw materials of these industries. Rothamsted has, in fact, made notable contributions in this field. Actually the work of this department has been mainly directed towards the solution of two distinct, but closely related, biochemical problems : (1) The making and storing of farmyard manure both natural and artificial and (2) the purification of the liquid wastes arising from certain industries directly dependent on agriculture, such as beet-sugar and milk factories.

The investigations on the latter problem have been carried out for the Water Pollution Research Board of the Department of Scientific and Industrial Research jointly with the Microbiology Department. They cover a period of ten years (1927-1937) and are not included in this report.

Several studies indirectly connected with one or other of the two main divisions mentioned above will also be referred to in this review.

The plots at Rothamsted receiving annual dressings of farmyard manure return in the crop only about one-third of the added nitrogen. After allowing for loss by drainage and the amount stored in

(1) W. O. James—Ann. Bot. XLIV, 173-198, 1930.
(2) W. O. James—Ann. Bot. XLV, 425-442, 1931.
(3) D. J. Watson—Ann. Bot. L, 59-83, 1936.

the soil, a considerable amount of nitrogen is still unaccounted for and it was believed that part of this, at any rate, might be evolved as gas by biochemical changes in the soil. As the quantities of nitrogen in soil are rather small for direct experiment a parallel case was chosen where the biochemical decompositions are similar to those in soil but the quantities of nitrogen are relatively large. The manure heap loses much nitrogen under certain conditions and experiments on the nature and amount of this loss might throw light on the soil problem. Farmyard manure is still by far the most important fertiliser used in agriculture. Before the war the average farmer made two tons of farmyard manure for every hundredweight of artificial manure purchased and he spent $2\frac{1}{2}$ times as much on dung as on artificials. The position is not very different to-day. Accordingly the experiments were extended so as to give as much information as possible on the storage and use of farmyard manure, apart from the more academic enquiry arising from the loss of nitrogen in soil.

For a period of five years a series of experiments was carried out on several farms with different kinds of manure and in the laboratory with its various constituents, both singly and in combination. The results of the practical trials confirmed the best farming practice.

Shelter from rain and exclusion of air by compacting the heap gave the best yield of crops. Summer storage of manure was always wasteful and should be avoided if possible.(1)

The laboratory experiments were particularly concerned with the changes in nitrogen content of the manure, or its constituents, under aerobic and anaerobic conditions. The most important biochemical reaction when air was completely excluded was the increase in ammonia derived from proteins. This change is greatly stimulated by a rise in temperature which must be supplied from an external source since no heat is evolved under anaerobic conditions. No loss of nitrogen was observed but there was a considerable loss of dry matter as methane and carbon-dioxide.

The admission of air to the manure heap brings about quite a different series of changes. Ammonia disappears, the loss of dry matter as carbon-dioxide is relatively high and up to 50 per cent. of the nitrogen may be lost. One important transformation was observed in all the aerobic experiments in the laboratory but on the large scale in heaps of horse manure only. This change is now recognised as the immobilisation of available nitrogen, chiefly by fungi. When straw and urine were strongly aerated for a month, practically the whole of the nitrogen in the urine was converted into protein without loss of nitrogen. The proportion of straw to ammoniacal or urine nitrogen was high but the great significance of this experiment, as will be seen later, was not appreciated at the time. We now know that the reason for this immunity from loss is directly associated with the C/N ratio of the original substances.

(1) E. J. Russell and E. H. Richards—"The Prevention of Loss from Manure Heaps in Winter and Early Spring," Journ. Min. Agric. 1914, Vol. XXI. pp. 800-807. E. J. Russell and E. H. Richards—"On Making and Storing Farmyard Manure." Journ. Roy. Agric. Soc. 1917, Vol. XVII., pp. 1-36.

Differences in this ratio and the more aerobic conditions of horse manure heaps explain why no increase in protein was observed in bullock and cow manure.

No manure heap can be made either perfectly aerobic or anaerobic ; some air gets into the best compacted heap and little or no air into the centre of a loose heap but the conditions change greatly as rotting proceeds. Nitrate may be formed in manure but it was only found in a loose heap under cover. Ammonia can, of course, be lost by volatilisation or by leaching but it was also found that nitrogen is lost under partially aerobic conditions in the form of nitrogen gas. In one experiment 10 per cent. of the original nitrogen was lost in this way.(2)

When working with horse manure notable amounts of nitrogen were, apparently, fixed from the atmosphere when the solid droppings were fermented aerobically for periods of about 28 days. The increase in the original nitrogen of the faeces was sometimes as much as 45 per cent. A mixed culture of *Azotobacter* and *B. lactis aerogenes*, obtained from the soil inoculum used, was found to fix nitrogen in starch solution and in suspensions of ground straw. *Azotobacter* alone would not grow on these media. Very little nitrogen was fixed by bullock faeces and none by cow faeces. Evidently the digestive power of the animal and its diet control the quantity of nitrogen fixed. Droppings from bullocks fed on grass fixed none but when fed with cake, some nitrogen was fixed but much less than by the faeces of the corn-fed horse.(3)

These experiments and the growing scarcity of manure from town stables, as the motor vehicle replaced the horse as a means of traction, led to an attempt to convert straw into an organic fertiliser by biochemical means. Using the mixed culture mentioned above and sufficient ground chalk to keep the reaction alkaline, straw chaff was rotted until it had lost about 25 per cent. of its dry matter. Tested in pot cultures, and later on field plots, this " manure " was found to give little increase of crop. Controls with unfermented straw gave much lower crop yields than the untreated soil. Actually some nitrogen had been fixed and the furfural yielding fraction of the straw was much reduced. We now know that at least three times as much nitrogen is required to decompose the carbohydrates of the straw and produce a real " artificial farmyard manure " as could be fixed from the atmosphere by the mixed *Azotobacter* cultures.

Shortly before the war Hutchinson and Clayton working in the Bacteriological Department had begun a study of the cellulose decomposing bacteria. The discovery of *Spirochaeta cytophaga* and its food requirements revealed that the supply of available nitrogen was the most important factor controlling the amount of cellulose decomposed. In farmyard manure the necessary nitrogen is supplied by the urine, usually in great excess of the amount which can be assimilated and retained by the organisms found on the straw.

(2) E. J. Russell and E. H. Richards—" The Changes taking place during the Storage of Farmyard Manure." Journ. Agric. Sci. 1917, Vol. VIII., pp. 495-563.
(3) E. H. Richards—" The Fixation of Nitrogen in Faeces." Journ. Agric. Sci. 1917, Vol. VIII. pp. 299-311.

Many forms of nitrogen were tested and all were found capable of rotting straw but some were less suitable than others. Besides nitrogen the other factors necessary to secure a rapid break-down of the straw are (1) a moisture content of about 75 per cent. (2) air supply and (3) alkaline or neutral reaction. It was observed that ammonium carbonate was the best form of nitrogen for the purpose. Ammonium sulphate quickly developed an acid reaction which checked further action. Sodium nitrate promoted vigorous decomposition but much nitrogen was always lost.[4]

By far the most important information gained in this work, carried out jointly with the Bacteriological Department, was the discovery of the quantitative relationship between the cellulosic substance e.g., straw, and the amount of nitrogen which can be immobilised as organic nitrogen and held without loss, not only in bottles in the laboratory, but in manure heaps exposed to the weather. The amount of nitrogen held by 100 parts of plant material varies from 0.1 to 1.3 parts. This figure, or " nitrogen factor," has proved useful in many ways. For cereal straws it is close to 0.75 part. By using the information obtained in these experiments the dung-making capacity of a given number of stock can be considerably increased and the loss of nitrogen in making and storing manure reduced to a minimum.

The quantitative relation of available nitrogen to carbohydrate decomposed was first disclosed in 1919, and a definition of the composition of the plant material if it is to make a satisfactory manure in 1924.[5] The latter problem has been the subject of much subsequent investigation.

The only serious obstacle to the production of well-rotted compost on the large scale was the reluctance of straw to take up the essential amount of water. In the early trials many partial failures were due to this cause. Even to-day when long experience has made the process as reliable as most other farm operations, the water problem remains a difficulty in many cases.

Directions for the making of compost are found in the earliest writings on agricultural practice. The Chinese in particular were experts in this branch long before the beginning of European civilisation. The value of materials rich in nitrogen e.g., animal or fish waste and canal mud, as accelerators of cellulose decomposition, was well known. Only the absence of control by chemical analysis and supplies of artificial nitrogen and other compounds prevented these ancient farmers from making artificial farmyard manure as known to-day. The modern interest in this subject dates from the publication of the Rothamsted work in 1921. Since then a considerable literature, comprising many hundreds of papers on the theoretical or practical aspects of cellulose decomposition, has grown up. Some of the more important references will be found in the bulletin on " Organic Manures " published by the Imperial Bureau of Soil Science at Rothamsted.[6]

---

(4) H. B. Hutchinson and E. H. Richards—" Artificial Farmyard Manure." Journ. Min. Agric. 1921, Vol. XXVIII., pp. 398-411.

(5) B.P. Nos. 152387 and 219384.

(6) S. H. Jenkins—" Organic Manures ". Technical Communication No. 33. Imperial Bureau of Soil Science, 1935.

One interesting application of the study of the fermentative changes of nitrogen and carbon is the possibility of recovering for use as manure the very dilute ammonia in domestic sewage. A trial on the practical scale at Wainfleet, Lincs., for a period of one year proved very successful. When 2 lbs. of straw per head of population per day can be supplied to the filter plant about 80 per cent. of the nitrogen in solution in the sewage can be recovered. The resulting manure was of the highest quality and gave crops as good as the best farmyard manure. Unfortunately straw is rarely available in quantity near sewage disposal works so that little use has been made of this modification of the process.(7)

As a result of the widespread interest in the discovery, often exaggerated, that waste materials of many kinds could be converted into artificial farmyard manure, many enquiries and samples of vegetable residues were received from all parts of the world—particularly from the Tropics. Failing any proved method of deciding by chemical analysis whether these materials were likely to be suitable or not, each sample was tested by experimental rotting in an incubator for one month. Observation of its behaviour and analysis of the end product enabled an answer to be sent to the enquirer which must have saved many useless trials on the large scale.

The biochemical studies in the laboratory as well as the practical trials on farms have received substantial financial support from Lord Iveagh throughout the period of 23 years covered by this review. His personal interest in the laboratory studies and the facilities he provided for large scale experiment have ensured the success of the work. In order to prove the possibility of making artificial farmyard manure on the large scale, Lord Elveden, as he then was, founded the organisation now known as Adco Ltd., for the commercial development of the process.(8)

The difficulties referred to above have prevented its general adoption on arable farms but in horticulture and tropical agriculture the name Adco is now well known all over the world. The company does not trade for private profit ; any surplus is used for the benefit of agricultural research.

The fact that a high proportion of digestible carbohydrate and a small amount of lignin were favourable to rapid rotting was disclosed in the second Adco specification, as already mentioned, but it was not until later that the composition of plant materials in relation to their resistance to decomposition was seriously studied.

The claim that in ripe plant materials pentosans (hemicellulose) form the most important food for micro-organisms has not been entirely upheld by subsequent work.(9) It is however, true that this fraction is among the first to be attacked and is a very suitable food for fungi which are particularly active in the earlier stages of breakdown. Bacteria alone, unaided by fungi, were shown to be relatively slow rotting agents. Fungi alone, in fact, did practically all that could be done in this way by a complete soil flora.

(7) E. H. Richards and M. G. Weekes—"Straw Filters for Sewage Purification." Proc. Eng. Conf. Inst. Civil Eng. 1921, Sec. VI.

(8) Journ. Min. Agric. 1922, Vol. XXVIII., pp. 961,962.

(9) R. D. Rege—"Biochemical Decomposition of Cellulosic Materials." Ann. Appl. Biol. 1927 Vol. XIV., pp. 1-43.

In a series of papers by a specially qualified bio-chemist who worked for a time in the Fermentation and Mycology Departments the whole field of biological decomposition of plant materials under aerobic conditions has been envisaged.(10) Cellulose is now shown to be the chief source of carbonaceous food or energy material for the organisms. Lignin was found to be the resistant factor, thus confirming the earlier views on this point. An improved formula or ratio for predicting the " decomposability" of plant materials was put forward and found to agree well with experimental results.

Since the amount of nitrogen required to convert waste vegetation into artificial farmyard manure is of considerable economic importance, a quick method of calculating the " nitrogen factor " is much to be desired. Unfortunately it has not been found possible to suggest a formula in terms of the constituents of the plant material. Each value must be determined by experiment. A new term, "nitrogen equivalent", is suggested as a measure of the efficiency of the organism or mixed flora effecting the decomposition. This figure relates the amount of organic matter removed to nitrogen immobilised.(11)

The analytical difficulties associated with these studies have led to several improvements in the methods of estimating the various constituents of plant materials. Cellulose and lignin have received much attention. The former can now be determined accurately by a comparatively simple method.(12)

The determination of lignin is subject to disturbance by the presence of certain carbohydrates and proteins in the plant material under examination. Methods for reducing the errors so caused have been described.(13)

These improved methods of analysis have been used to examine the composition of the growing crop. The changes in the structural constituents of the barley plant during growth have been followed from the seedling stage to maturity. Following an initial increase both ash and protein showed a steady fall with the age of the plant. Cellulose increased from 30 to 53 per cent. while lignin also increased steadily until the last week of growth.(14)

The biochemistry of certain constituents of plant materials not concerned directly with their agricultural importance, especially

---

(10) A. G. Norman—" The Biological Decomposition of Plant Materials." I. " The Nature and Quantity of the Furfuraldehyde yielding substances in Straws." Biochem. Journ. 1929, Vol. XXIII., pp. 1353-1366. II. " The Role of the Furfuraldehyde yielding Substances in the Decomposition of Straws." Biochem. Journ. 1929, Vol. XXIII., pp. 1367-1384.

(11) A. G. Norman—IV. " The Biochemical Activities on Straws of some Cellulose-decomposing Fungi." Ann. Appli. Biol. 1931, Vol. XVIII, pp. 244-259. E. H. Richards and A. G. Norman—V. " Some Factors Determining the Quantity of Nitrogen Immobilised during Decomposition." Biochem. Journ. 1931, Vol. XXV., pp. 1769-1778. IV. " The Effect of Hydrogen Ion Concentration on the Rate of Immobilisation of Nitrogen by Straw." Biochem. Journ. 1931, Vol. XXV., pp. 1779-1787. VII. " The Nature of the Residual Hemicelluloses of Rotted Straw." Biochem. Journ. 1932. Vol. XXVI., pp. 573-577.

(12) S. H. Jenkins—" The Determination of Cellulose in Straws." Biochem. Journ. 1930. Vol. XXIV., pp. 1428-1432. A. G. Norman and S. H. Jenkins—" A New Method for the Determination of Cellulose, based upon observations on the removal of Lignin and other Encrusting Materials." Biochem. Journ. 1933, Vol. XXVII., pp. 818-831. " Lignin Content of Cellulose Products." Nature 1933, Vol. CXXXI., p. 729.

(13) A. G. Norman and S. H. Jenkins—" The Determination of Lignin. I. Errors introduced by the presence of certain Carbohydrates." Biochem. Journ. 1934, Vol. XXVIII, pp. 2147-2159. II. " Errors introduced by the presence of Proteins." Biochem. Journ. 1934, Vol. XXVII, pp. 2160-2168.

(14) A. G. Norman—" Preliminary Investigation of the Development of Structural Constituents in the Barley Plant." Journ. Agric. Sci. 1933, Vol. XXIII., pp. 216-227.

that of pectin and two gums—Arabic and Tragacanth, has been studied here and in the Biochemistry Department, Birmingham University.(15)

The fate of green manures in soil is a problem of special interest in view of the anomalous results obtained for many years past in the classical experiments at Woburn. One aspect of this problem was studied by determining the changes in the various plant constituents when buried in Woburn soil. Young tares, young and mature mustard and sugar-beet tops were all tested by methods similar to those used for decomposition studies *in vitro*. The order of decomposition of the constituents was also similar ; hemi-cellulose and cellulose accounted for most of the loss of organic matter observed. The speed of rotting varies directly with the C/N ratio so that young materials with abundance of nitrogen decay more quickly than mature tissue. For the same reason young tissues are liable to lose nitrogen ; in the absence of sufficient carbohydrate to immobilise the excess, nitrates accumulate and are washed out of the soil unless they are utilised immediately by a growing crop. A method of determining cellulose in soil was devised to suit the conditions of these experiments. The fertilising value of the three young plant materials was also tested both by pot cultures and by the use of beet tops in field plots. All three manures gave increases of both grain and straw in a barley crop. The best yield was obtained when the beet tops were buried at once in the soil. If composted or allowed to lie on the soil surface before digging in, the yield was reduced. In other words the crop is controlled by the amount of nitrogen in the green manure as turned under.(16) These results are in agreement with the well established rules for the making of compost from mixed refuse first put forward by W. Auton after considerable experience in the making of artificial farmyard manure as described earlier in this review. If straw or leaves had been mixed with the composted sugar-beet tops there would almost certainly have been little or no loss of nitrogen.

It has long been observed that straw in some manure heaps becomes sticky as it rots ; in other heaps no adhesive properties are apparent. The production of mucus in artificially rotted straw was investigated and the degree of stickiness measured by a physical test similar to that used for testing the same property in soils. If the straw is rotted with a mixed natural flora, the stickiness is controlled by the reaction of the final product. An alkalinity as high as *p*H 9.5-10.0 and the presence of much fungal tissue gave the maximum adhesion values. The addition of alkali to a neutral end product increased the stickiness. Biological control of the decomposition of sterile straw with cultures of various fungi and bacteria singly and in various combinations was also attempted. Most mucus was

(15) A. G. Norman. "The Chemical Constitution of the Gums. I. The Nature of Gum Arabic and the Biochemical Classification of the Gums." Biochem. Journ. 1929, Vol. XXIII., pp. 524-535. II. "Tragacanthin The Soluble Constituent of Gum Tragacanth." Biochem. Journ. 1931, Vol. XXV., pp. 200-204. "The Biochemistry of Pectin." Science Progress 1929, 94., pp. 263-279; A. G. Norman and J. T. Martin—"Studies on Pectin. V. The Hydrolysis of Pectin." Biochem. Journ. 1930, Vol. XXIV., pp. 649-660.

(16) J. A. Daji—"The Decomposition of Green Manures in Soil." Journ. Agric. Sci. 1934, Vol. XXIV., pp. 15-27. "The Fertilising Value of Green Manures Rotted under Different Conditions." Journ. Am. Soc. Agron. 1934, Vol. XXIV., pp. 466-475. "The Determination of Cellulose in Soil." Biochem. Journ. 1932, Vol. XXVI., pp. 1275-1280.

https://doi.org/10.23637/ERADOC-1-68

produced by the action of fungus followed by bacteria.(17)

When strawy unrotted farmyard manure is applied to a soil containing a reserve of nitrate the organisms have a choice of using either the ammoniacal nitrogen in the urine-saturated straw or of calling on the soil nitrate. In order to see if any preference was shown for either form of nitrogen experiments were made with various combinations of ammoniacal and nitric nitrogen in contact with moist straw. With equal initial concentrations under conditions favourable for decomposition there is a definite preference in the earlier stages of breakdown for ammonia rather than for nitrate. When nitrate is present, even in small proportion, there is always some loss of nitrogen.(18)

When the nitrogen changes during the anaerobic decomposition of farmyard manure were being studied small amounts of hydrogen gas were found as well as much larger quantities of carbon dioxide and methane. Subsequently Rothamsted was asked by a Government Department to report on the possibility of producing hydrogen by fermentation on a large scale in the Tropics where waste vegetation was abundant but facilities for the manufacture of hydrogen by chemical processes were lacking. Accordingly experiments were carried out with wheat straw and Nile Sudd fermented anaerobically at different temperatures under both acid and neutral or alkaline conditions. The maximum yield of gas, 4,400 cubic feet per ton of straw and 9,360 cubic feet per ton of Sudd, were obtained at temperatures of between 35° and 40°C., in the presence of some available nitrogen compound under slightly alkaline conditions. Little or no hydrogen was produced in this way. By making the medium definitely acid the proportion of hydrogen was greatly increased but the total yield of gas was so reduced that no commercial application was feasible.(19) Gas derived from cow manure was, however, used on the large scale at Pyrford Court, Woking, where the kitchens were supplied with gas for cooking from this source for many years in the absence of any public supply at that time. Unfortunately the yield of gas depends on the maintenance of the optimum temperature so that in winter it is necessary to heat the digesters by coke or other fuel thus making the process uneconomic.

Although the decomposition of plant residues in the soil occurs normally under conditions which are mainly aerobic, in the cultivation of swamp rice in India and China many changes in the soil are brought about by micro-organisms acting in the presence of small amount of air. Under anaerobic conditions rice straw decomposes in two stages : (1) the formation of organic acids, acetic and butyric acid and (2) the conversion of these into gaseous products, carbon dioxide and methane. The nitrogen requirement for anaerobic digestion is low, only about one seventh of the aerobic nitrogen factor for the same material. Just as with aerobic experiments inoculation proved no advantage. The organisms are present on the straw and

(17) J. G. Shrikhande—" The Production of Mucus during the Decomposition of Plant Materials." Biochem. Journ. 1933, Vol. XXVII., pp. 1551-1574. "The Degree of Humification of Manures Measured by the use of Hydrogen Peroxide." Soil Sci. 1933, Vol. XXXV., pp. 221-228.

(18) E. H. Richards and J. G. Shrikhande—" The Preferential Utilisation of Different Forms of Inorganic Nitrogen in the Decomposition of Plant Materials." Soil Science 1935, Vol. XXXIX., pp. 1-8.

(19) Richards and Amoore (1920). Unpublished data.

F

grow vigorously at a temperature of 30-35°C., *p*H 7.5-8.0, and a high water content of about 10 to 1 of straw. The loss of dry matter is reduced by exclusion of air and much of the final organic nitrogen is soluble in water. The individual loss of the constituents of a wide range of plant materials was found to depend on their nitrogen content. Materials rich in nitrogen, as grass cuttings, produce more butyric acid and methane than ripe cereal straws or bracken. Cellulose and hemicellulose are the main constituents to suffer loss. Lignin is only slowly fermented and a large proportion of this compound in the original material inhibits the decomposition of protein and other constituents. A new method for determining carbon and nitrogen in the same sample of solid residue or extract was devised and tested on a number of soils, plant materials and proteins. In the course of this work it was found that the decomposition of nitrogen compounds by chromic acid is closely related to their structure. Thus substances having their nitrogen atoms attached to different carbon atoms yield a theoretical recovery of nitrogen, while at the other extreme compounds like hydrazine derivatives lost almost the whole of their nitrogen as elementary nitrogen.[20]

Sewage disposal and agriculture.

For the first fourteen years of this century the problems of sewage disposal were under constant investigation by the Iddesleigh Royal Commission. Field trials on the fertilising value of various kinds of sewage sludge were carried out for the Commission at Rothamsted, among other centres, on two occasions. The anaerobically produced sludges of those days were of little value as plant food although they added some organic matter to the soil.

In 1934 an enquiry by the Ministry of Agriculture from 85 local authorities indicated that the position has changed little in this respect during the past thirty years. There are signs, however, that the composting of sewage sludge with selected garbage from dustbins is being tried by some enterprising towns. There is no doubt that a good organic fertiliser can be made in this way.[21]

Further experiments were made at Rothamsted for the Ministry of Agriculture in 1919-1920 to see if the newer aerobic process for purifying sewage by activated sludge recovered more of the nitrogen than the other methods; what was the source of the high nitrogen content of activated sludge and was this nitrogen in a form available as plant food? The results showed that much more nitrogen was recovered in activated sludge than in either precipitation or septic tank sludges, that this extra nitrogen came from the ammonia in the sewage, not from the atmosphere as had been suggested by some workers, and that the availability of the nitrogen in the dried sludge was comparable with that in nitrate of soda. Field trials with wet

(20) C. N. Acharya—"Studies on the Anaerobic Decomposition of Plant Materials. I. The Anaerobic Decomposition of Rice Straw (Oryza sativa)." Biochem. Journ. 1935, Vol. XXIX., pp. 528-541. II. "Some Factors Influencing the Anaerobic Decomposition of Rice Straw (Oryza sativa)." Biochem. Journ. 1935, Vol. XXIX. pp. 953-960. III. "Comparison of the Course of Decomposition of Rice Straw under Anaerobic, Aerobic and Partially Aerobic Conditions." Biochem. Journ. 1935, Vol. XXIX., pp. 1116-1120. IV. "The Decomposition of Plant Substances of Varying Composition." Biochem. Journ. 1935, Vol. XXIX. pp. 1459-1467. "Determination of Carbon and Nitrogen by the action of Chromic Acid under reduced pressure." Biochem. Journ. 1936, Vol. XXX. pp. 241-247. "Structure in relation to Chromic Oxidation of Nitrogenous Substances." Biochem. Journ. 1936, Vol. XXX., pp. 1026-1032. "Structure and Oxidation of Nitrogenous Substances." Nature, 1935, Vol. CXXXVI., p. 644.

(21) E. H. Richards—"The Manurial Value of Sewage Sludge." **Journ. Min. Agric. 1935.**, Vol. XLII. p. 737.

activated sludge on the Rothamsted farm gave good yields with hay, potatoes and barley but the effects were less uniform than with the dried sludge tested in pots.(22)

Rainwater and Drainage Water.

In the early history of Rothamsted much attention was paid to the composition of rainwater as a source of nitrogen for plant life. From 1877 to 1916 the analytical work was done first by Warington and then by Miller. The latter left many years of accumulated data for rainfall and drainage water from the famous drain gauges at Rothamsted. These figures were collected and published shortly after Dr. Miller's death which prevented the completion of his projected monograph on this subject. Besides the determinations of nitrogen as ammonia and nitrate and also of chloride made regularly for many years, the content of dissolved oxygen in rainwater was measured in 1915 and 1918. No great changes were noted in the average composition of the rain falling at Rothamsted. The tendency for both nitrate and chlorine to rise has continued over the last period of these observations. It was suggested that changes in domestic and industrial consumption of fuels might put more nitric and less ammoniacal nitrogen into the atmosphere. Dissolved oxygen plays a leading part in the biological activities of the soil and is essential for the root aeration of growing crops. In winter, rain is nearly saturated with oxygen but in summer, when its temperature is above 15°C., the dissolved oxygen is always below saturation, sometimes as much as 25 per cent.

The loss of nitrogen from uncropped soil by the action of rain was studied simultaneously with the composition of rain so that a balance could be struck after a period of 47 years. The accuracy of the data was checked by the chloride figures for rain and drainage water. The slow loss of nitrogen as nitrate ranges from 40 lbs. at the start to 21 lbs. per acre at the end of the 47 year period. At this rate it would take about 200 years to exhaust all the nitrogen from uncropped and unmanured soil. There was no evidence of either fixation or loss of gaseous nitrogen.(23)

---

(22) W. E. Brenchley and E. H. Richards—" The Fertilising Value of Sewage Sludges." Journ. Soc. Chem. Ind. 1920, Vol. XXXIX., pp. 177T-182T; E. H. Richards and G. C. Sawyer—" Further Experiments with Activated Sludge." Journ. Soc. Chem. Ind. 1922, Vol. XLI., pp. 62T-71T.

(23) E. J. Russell and E. H. Richards—" The amount and Composition of Rain Falling at Rothamsted." Journ. Agric. Sci. 1919, Vol. IX., pp. 309-337. " The Washing out of Nitrate by Drainage Water from Uncropped and Unmanured Land." Journ. Agric. Sci. 1919., Vol. X. pp. 22-43; E. H. Richards—" Dissolved Oxygen in Rainwater." Journ. Agric. Sci. 1917, Vol. VIII., pp. 331-337.