SULPHATE OF AMMONIA

ITS

Characteristics & Practical Value

AS

A MANURE,

By

R. WARINGTON, M.A., F.R.S.

PRICE ONE SHILLING.

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PART I

HISTORY AND CHARACTERS OF SULPHATE OF AMMONIA

THE MANUFACTURE OF AMMONIA SALTS

The earliest forms of Ammonia with which men became acquainted were, apparently, Sal Ammoniac and Spirits of Hartshorn. The *sal ammoniacus* of Pliny, and other ancient writers, appears from their account of its origin and properties to have been simply rock salt. The true sal ammoniac (chloride of ammonium) was certainly known to the Arabians in the twelfth century, and is spoken of as imported from Egypt and India. It is mentioned in the Custom-house tariff of the city of Pisa in 1408. In 1716 the Jesuit Sicard describes the process for manufacturing sal ammoniac at Damayer in lower Egypt. The soot obtained by burning camel and cattle dung as fuel was collected, and heated in closed vessels, the sal ammoniac subliming into the upper cooler part as a solid cake. Sea salt and urine were, according to some accounts, added to the soot.

Small quantities of sal ammoniac occasionally occur as a sublimate in the crevices of volcanoes; this occurrence was first recognised by Porta towards the end of the sixteenth century.

In Europe, during the eighteenth and early part of the nineteenth centuries, ammonia was generally prepared from the alkaline liquor obtained by the destructive distillation of horn or bone. The products of the distillation consisted in part of an aqueous liquid containing much carbonate of ammonia, and in part of a fœtid oil floating above it. After removing the oil the ammonia was separated either by crystallisation as sulphate, or by sublimation as chloride. Until the introduction of coal gas for lighting purposes the distillation of horn, bone, feathers, wool, blood, soot, and other nitrogenous organic substances was the process almost universally resorted to for the manufacture of ammonia. At the present day ammonia salts are still obtained as bye-products of the distillation of such materials, but the quantity thus manufactured is relatively very small.

The use of coal gas for illuminating purposes commenced with the beginning of the present centutry; the first building—Boulton & Watt's Foundry in Soho—being lit with coal gas in 1798, and the first street—Westminster Bridge—in 1813. The ammoniacal liquid and tar produced by the distillation of coal were for many years literally *waste* products. The ammoniacal liquid appears to have been occasionally diluted and applied to land as a manure, but with unsatisfactory results. The position of affairs in 1842 may be gathered from two paragraphs in the excellent Prize Essay by Dr. George Fownes, published in the *Journal of the Royal Agricultural Society*, IV., 498. On page 541, he says:—

"The only purely azotized manure is the ammoniacal liquid of the gas works . . . . This liquid has been tried by many persons as a manure for corn, but with very variable success, as may be expected from its indefinite nature. . . . . The best mode of using this substance will certainly be to reduce it to an impure ammoniacal salt, sulphate or chloride, so as to get rid of the sulphuret, sulphite, etc., which can hardly fail to be prejudicial to vegetable life, and then to apply such salt scattered over the ground in a sparing manner; always on the supposition that the compounds mentioned have been shown to be capable of assimilation by the plant."

At the close of his essay, his knowledge of the enormous quantity of nitrogen stored in coal leads him to a prophetic utterance, which after more than fifty years have passed seems nearing its fulfillment. He says :—

"In terminating these remarks on the subject of manures, I would once more call attention to the salts of ammonia. Should these really be found to produce the beneficial effects anticipated, we shall possess at home, within the limits of our own island, resources for the improvement of agriculture, compared with which guano and nitrate of soda, and all such things, are quite insignificant; resources which only require to to be judiciously used to produce the most extraordinary results. Coal contains nitrogen. When distilled at a red heat for the purpose of getting illuminating gas, the greater part of this nitrogen unites with hydrogen, and gives rise to ammonia, which is afterwards separated more or less completely, and manufactured, although frequently in a very wasteful and imperfect manner, into ammoniacal salt. Admitting that coal contains one per cent of nitrogen which can thus be employed (a supposition probably not far from the truth), it is easy to see what a prodigious quantity of ammonia might be furnished by our coal-gas works, properly conducted."

We must now refer in a little more detail to the production of ammoniacal salts from coal, which furnishes almost the whole of the enormous quantity now manufactured, and is capable of still further development.

Coal (excluding anthracite) usually contains 1·2 to 1·6 per cent of nitrogen; the average proportion may be taken as about 1·33 per cent. Anthracite contains about 0.9 per cent. About 90 per cent of the coal annually consumed is burnt in such a way that none of the nitrogen which it contains is obtained in a useful form. It is only when the coal is heated in closed vessels that the manufacture of ammonia salts becomes possible. The most favourable conditions for the recovery of the nitrogen in the form of ammonia are those found in a gas works, but even here only a small proportion of the nitrogen originally present is finally obtained as ammonia, the proportion so obtained never exceeds one-fifth, and sometimes is no more than one-tenth of that originally present in the coal. One ton of coal containing 1·33 per cent of nitrogen should yield 149 lbs. of sulphate of ammonia if the whole of the nitrogen were recovered in this form; in fact, however, a production of 20 or 22 lbs. is considered to be a fair yield. More than one-half of the nitrogen of the coal remains in the coke; much appears as nitrogen gas; a little appears as cyanogen; some as organic coal-tar compounds; and only one-fifth, or less, is recovered as ammonia. By mixing a little lime with the coal, or by passing steam through the retorts, a considerably larger amount of ammonia may be obtained; but such methods cannot be employed when illuminating gas is desired, as they deteriorate the illuminating quality of the gas.

When, however, gas is produced simply for heating purposes, it is possible, by burning the coal in a current of steam at as low a temperature as possible, to obtain one-half of the nitrogen as ammonia; the product of sulphate of ammonia then amounts to about 70 lbs. per ton of coal. By using gas as fuel in the place of coal, large additional quantities of sulphate of ammonia might be obtained.

The ammonia is separated from coal gas partly in the mixed tarry and aqueous products condensed from the gas by cooling, and partly by passing the gas over wet surfaces in the scrubbers. The aqueous liquor, separated from the tarry matter, forms the crude ammoniacal liquor of the gas works. The ammonia in this liquor is present principally as carbonate and sulphide, and to a much smaller extent as thiosulphate, sulphocyanate and chloride. The two first-named compounds are volatile, and are separated by passing a jet of steam through the liquid; the ammonia of the fixed salts is afterwards volatilised by adding lime to the residual liquid. The carbonate, sulphide, and free ammonia thus volatilised are carried through vessels containing sulphuric acid, sulphate of ammonia is thus produced, while the mixed gases containing much sulphuretted hydrogen are conducted to a furnace to be purified by combustion. The sulphate of ammonia liquors are concentrated in leaden pans, and the sulphate obtained by crystallisation.

The sulphate of ammonia of commerce varies in colour;

it may be white, grey, brownish, or yellowish. The grey and brown tints are due to traces of tarry matter, the yellow to a trace of sulphide of arsenic; this latter only occurs when the sulphuric acid employed has been made from pyrites. Sulphate of ammonia is generally a nearly pure salt, the London made article contains about 25 per cent of ammonia, while a theoretically pure salt would contain $25\frac{3}{4}$ per cent. Country-made sulphate will contain 24-25 per cent of ammonia.

Sulphocyanate of ammonia is now seldom found in the commercial sulphate. It used to occur when the crude ammoniacal liquor had been directly neutralised by sulphuric acid, or when the ammonia salts collected by purifiers consisting of sawdust soaked with sulphuric acid were extracted with water, and the salts obtained by crystallisation. Sulphocyanates are easily recognised by the blood-red colour which they produce when a drop of a solution of ferric chloride, and a drop of hydrochloric acid, are added to the suspected solution. Sulphocyanate of ammonia contains a much larger percentage of nitrogen than the sulphate, and samples containing it are thus apt to appear abnormally good on analysis. Sulphocyanates are very injurious to vegetation, and ought therefore to be carefully excluded from all sulphate of ammonia to be employed as manure. Crude ammonia salts, containing sulphocyanates, can be safely used to some extent in the manufacture of ammoniacal superphosphates, if the ammonia salt is mixed with the ground phosphate before the addition of the sulphuric acid; under these circumstances the hydrosulphocyanic acid is liberated and volatilised during the heat of the reaction.

Sulphate of ammonia is not only produced from coal in the manufacture of illuminating gas, it is also now obtained, though to a much less extent, as a product of the manufacture of coke. In the early forms of coke-ovens the coal was allowed to undergo partial combustion in a regulated manner, and the whole of the volatile products was lost. As these volatile products have increased in value the method has been altered, and the coal is now in many cases heated in a closed vessel by the combustion of the gas produced by itself, or from other similar coking ovens. The condensable constituents of the coal gas are removed before it is consumed as fuel. The proportion of ammonia recovered in this process is very similar to that obtained in a gas works, and amounts to about 22 lbs. of sulphate per ton of coal. The recovery of the ammonia during the process of coking has made as yet but limited progress, owing to the much greater expense of the plant required when the new method is adopted. Any rise in price of ammonia salts, or tar products, would be followed by a great increase in the output of ammonia and tar in the manufacture of coke.

Large quantities of coal are consumed in the blast-furnaces of iron foundries. A successful attempt has been made to collect the gas evolved on the entrance of coal into the furnace, and to recover the ammonia which it contains. The yield of sulphate of ammonia is similar to that obtained in coking operations.

The distillation of bituminous shale in Scotland for the production of paraffin, furnishes a considerable quantity of ammonia. The proportion of the nitrogen obtained as ammonia is very similar to that yielded in the distillation of coal. Of 100 parts of nitrogen in the shale, 63 remain in the coke, 20 are found in the tar products, and 17 are obtained as ammonia.

The quantity of sulphate of ammonia produced in the United Kingdom has rapidly increased in recent years, and the production is capable of much greater development if the demand for the article should increase. The total production in the United Kingdom was in :—

1870,	40,000 tons
1875,	46,000 ,,
1880,	60,000 ,,
1885,	97,000 ,,

Since 1886, the Inspector of Alkali Works has published in his Annual Report a detailed account of the amount obtained from each source. Each year shows an increase in the total. The amounts produced in 1886, 1890, 1894, and 1897 were as follows :—

SULPHATE OF AMMONIA PRODUCED IN THE UNITED KINGDOM

	1897. tons.	1894. tons.	1890. tons.	1886. tons.
Gas Works	132,724	113,634	102,138	82,480
Iron Works	17,779	10,075	5,064	3,950
Shale Distilleries	37,153	32,891	24,730	18,080
Producer Gas, Coke Works, and carbonising operations	10,624	3,448	2,325	2,100
Total..	198,280	160,048	134,257	106,610

The greater part of the sulphate of ammonia produced in this country is exported, chiefly to France, Germany and Belgium. The Inspector of Alkali Works states that in 1886, the home consumption of sulphate of ammonia amounted to 22,000 tons; and in 1897 to 70,000 tons.

With this great increase in the quantity produced there has been a great fall in the price of the salt. The average wholesale price of sulphate of ammonia in 1881 and 1882 somewhat exceeded £20 per ton; its average price in 1896 and 1897 was £7 18s. 6d. per ton.

THE INTRODUCTION OF AMMONIACAL MANURES

That ammonia salts were capable of acting as a powerful manure was apparently unknown till modern times. The supply of ammonia salts was indeed too limited, and their cost too considerable to favour any experiments being made with them in this direction. When, at the commencement of the present century, agricultural chemistry had made some progress, it was recognised that ammonia acted as a plant food, and was capable of supplying the nitrogen needed for the formation of vegetable albumin, and the other nitrogenous constituents of plants. In Sir Humphry Davy's "Elements of Agricultural Chemistry" (1813), we find several references to the manurial power of ammonia. In his lecture on Manures of Mineral Origin he describes some experiments of his own on the subject. He says:—

"Much of the discordance of the evidence relating to the efficiency of saline substances depends upon the circumstance of their having been used in different proportions, and in general in quantities much too large. I made a number of experiments in May and June, 1807, on the effects of different saline substances on barley and on grass growing in the same garden, the soil of which was a light sand . . . . . The solutions of the saline substances were used twice a week, in the quantity of two ounces, on spots of grass and corn, sufficiently remote from each other to prevent any interference of results. The substances tried were supercarbonate, sulphate, acetate, nitrate and muriate of potassa, and sulphate of soda; sulphate, nitrate, muriate and carbonate of ammonia. I found that in all cases when the quantity of the salt equalled $\frac{1}{30}$ part of the weight of the water the effects were injurious; but least so in the instances of the carbonate, sulphate and muriate of ammonia. When the quantities of the salts were $\frac{1}{300}$ part of the solution the effects were different. The plants watered with the solutions of the sulphates grew just in the same manner as similar plants watered with rainwater. Those acted on by the solution of nitre, acetate and supercarbonate of potassa, and muriate of ammonia, grew rather better. Those treated with the solution of carbonate of ammonia grew most luxuriantly of all. This last result is what might be expected, for carbonate of ammonia consists of carbon, hydrogen, azote and oxygen. . . . . Soot doubtless owes a part of its efficacy to the ammoniacal salts it contains. The liquor produced by the distillation of coal contains carbonate and acetate of ammonia, and is said to be a very good manure. In 1808, I found the growth of wheat in a field at Roehampton, assisted by a very weak solution of acetate of ammonia."

This quotation gives a fair idea of the opinions held by agricultural chemists as to the manurial value of ammonia in the beginning of the present century. For many years no further progress seems to have been made. There was in fact no supply of cheap pure ammonia salts available for general use. Gas liquor was too impure to be used successfully as a manure; and the sulphate of ammonia made from it by the crude process of direct neutralisation and crystallisation doubtless contained sulphocyanate, and the results obtained from it were uncertain. The quotation given in the preceding section from Fownes' Prize Essay, written in 1842, shows in a striking manner how little was at that time certainly known respecting the manurial value of ammonia salts. Nor was it only the chemist who hesitated in pronouncing an opinion upon the subject. Philip Pusey, perhaps the most advanced agriculturist of his day, in his paper "On the Progress of Agricultural Knowledge during the last Four Years" (*Jour. Roy. Agri. Soc.* 1842, 169), tells us that he has, for the first time, tried on several fields of wheat "the sulphate of ammonia extracted from gas-water. It acted precisely as the nitrate of soda, darkening the colour of the plant, and lengthening the straw and the ear even more than the nitrate, but it certainly *did not pay*. Again we have the principle, and we must learn to combine it."

Numerous carefully made field experiments were, however, soon to throw light on the conditions necessary for the successful use of sulphate of ammonia. At the close of 1842, Mr. W. M. F. Chatterley described to the Chemical Society (*Chem. Soc. Memoirs* 1, 152) his very successful trials of sulphate of ammonia as a manure for wheat, oats, and pasture. After describing his results, he says:—

"From the above experiments, and several others . . I am led to believe that no cheaper top-dressing than sulphate of ammonia can be applied to wheat or oats on this land, which is generally a heavy clay upon a subsoil of London clay, when the plant requires it, either from its being sickly or thin on the ground, in consequence of the land being somewhat out of condition, whether from unusual wet, bad seed-time, uncongenial spring, or any such-like cause. I should add that equal benefit appears to have been derived from its use upon a light gravelly soil upon a subsoil of gravel, upon the same as the London clay formation. . . . The price paid (for the sulphate of ammonia) was seventeen shillings per cwt.; it is prepared at the Gas Works in Brick Lane by a patent process for purifying coal-gas by means of dilute sulphuric acid, and is very free from impurity."

In 1843, the systematic trial of ammonia salts, and other manures, for Turnips and Wheat, commenced at Rothamsted, and was afterwards extended to other crops. Ammonia salts alone, and in various combinations, have been annually employed in the Rothamsted field experiments for fifty-five years, and the results obtained furnish the most important contribution to our knowledge of their action.

The practical use of guano and nitrate of soda by English farmers somewhat preceded the employment of ammonia salts. The united effect of these manures upon the crops in our Eastern Counties was so marked that Philip Pusey in his last published paper (1855) quotes with approval the statement of a Norfolk agriculturist that "the yield of wheat has so gradually increased during the last four years, mainly through the use of artificial manures used as top-dressings, that it is difficult to define what is an average crop."

CHARACTERISTICS OF SULPHATE OF AMMONIA BEARING ON ITS EMPLOYMENT AS MANURE

Before proceeding to describe the agricultural results which may be obtained by the employment of sulphate of ammonia, a few words must be said as to its chemical properties; as to its action in the soil; and concerning its special functions as a manure.

1. **Chemical Properties.**—The sulphate of ammonia of commerce is the most concentrated nitrogenous manure at the farmer's disposal. The ordinary sulphate is guaranteed to contain 24 per cent ammonia, or 19·8 per cent of nitrogen. The best Beckton sulphate contains 25¼ per cent ammonia, or 20·8 per cent of nitrogen. The chloride of ammonium (commercially known as muriate) would be still richer in nitrogen, the proportion reaching 24·9 per cent in samples with about 5 per cent of impurity; this salt is, however, very seldom made. The commercial manures standing nearest to sulphate of ammonia in their amount of nitrogen are nitrate of soda, with 15·6-15·8 per cent of nitrogen, and powdered

horn and hoof also with 15 per cent of nitrogen. Chincha guano in its best days seldom reached 14 per cent of nitrogen. The highly concentrated character of sulphate of ammonia renders it especially suitable for conveyance over long distances; as much nitrogen can be conveyed in 10 tons of sulphate of ammonia as in 13 tons of nitrate of soda. This same concentrated character also makes the salt a great favourite with the manufacturers of mixed manures, as a higher percentage of nitrogen can be given to the manure by the introduction of sulphate of ammonia than by any other means.

The sulphate of ammonia, like many other salts of ammonia, is completely volatilised by heat; at a low red heat it rises in vapour and disappears in the air. This fact is of great use in detecting adulteration. If a sample of the salt leaves a distinct residue when maintained at a low red heat till vapour ceases to be produced, it certainly contains something besides sulphate of ammonia.

Sulphate of ammonia is not a hygroscopic salt; that is, it does not become sensibly damp by exposure to moist air. This property is a great help to its convenient use, and saves the farmer much trouble. It also enables the manure manufacturer to employ the salt freely in the preparation of mixed manures, without danger of these losing their powdery condition by storing. Any mixture of nitrate of soda with sulphate of ammonia is to be avoided, as the mixture becomes deliquescent in moist air, and easily suffers decomposition; these results are due to the formation of nitrate of ammonia.

Sulphate of ammonia is a very soluble salt, dissolving in about twice its weight of cold water. This easy solubility in water greatly aids its rapid distribution in the soil. It is often stated in popular writings that sulphate of ammonia is less soluble than nitrate of soda, and that it is the greater solubility of the nitrate which occasions its more rapid washing out of the soil in wet weather. This statement is entirely erroneous. When sulphate of ammonia is applied to a moist soil it will very speedily be brought into solution. That a fertile soil is capable of retaining ammonia in spite of the washing effect of rain is quite true; but as we shall presently see, this is not due to any difficulty in the solution of the ammonia salt, but to an entirely different cause. We may add that, as a fact, the solubility of nitrate of soda in cold water is almost the same as that of sulphate of ammonia.

Sulphate of ammonia, like all other ammoniacal salts, is decomposed by contact with lime, ammonia gas being evolved, which is easily recognised by its extremely pungent odour. If moist chalk, or some other easily attacked form of carbonate of lime, is mixed with sulphate of ammonia, a similar but less energetic action takes place, the volatile carbonate of ammonia being produced. These facts clearly prohibit the application of sulphate of ammonia at the same time as the land is receiving a dressing of lime; they equally prohibit any mixture of ammonia salts with basic phosphatic slag, wood ashes, or any other alkaline manure. If such mixtures are made, a loss of ammonia must take place.

2. **Behaviour in the Soil.**—It follows from the facts just mentioned that sulphate of ammonia should not be applied as a top-dressing to a very calcareous soil, for if the salt remains on the surface of the soil in contact with carbonate of lime a loss of ammonia must ensue. Dr. Voelcker, senior, observed a strong odour of ammonia when sulphate of ammonia was applied to some calcareous land at Cirencester, and reported this fact in a letter to Mr. Pusey (*Jour. Roy. Agri. Soc.* XIV., 382). On this land the ammonia salt failed to benefit the crop.

A. Leclerc has published some experiments (*Annales de la Science Agronomique* I., 418) on the loss of ammonia which occurs after mixing the sulphate with a calcareous soil. Except, however, as establishing the fact of a serious loss, the results are not worth quoting, the proportion of sulphate of ammonia added to the soil being far beyond anything which is employed in agriculture,* and the conditions of the experiment being such as to prevent the nitrification of the ammonia.

T. Brown, when experimenting on Norfolk soils (*Chemical News*, April 16th, 1886; *Mark Lane Express*, April 26th, 1886)

* The smallest proportion of sulphate of ammonia used was $\frac{1}{500}$ the weight of the soil, or nearly 2 tons per acre.

found that sulphate of ammonia gave a very inferior result to nitrate of soda on soils containing 10 per cent., or more, of carbonate of lime. While top-dressings of ammonia salts on such soils gave unsatisfactory results, good results were obtained when the salt was applied to crops which allowed of the salt being buried by the harrow or the plough. The odour of ammonia did not appear when the salt was covered with one inch of earth.

There can be little doubt that a profitable return from sulphate of ammonia is greatly favoured by covering the salt with the soil as soon as possible after it has been spread upon the surface. Mixing the salt with kainite, or especially with superphosphate, will also greatly aid in preventing loss from volatilisation.

If sulphate of ammonia is added to a pure quartz sand it undergoes no change; it will in this case remain in solution in the water which the sand holds, and be easily washed out if rain falls on the surface. If the salt is mixed with pure peat the same results will follow. It is doubtful whether under these circumstances sulphate of ammonia is capable of acting as a plant food, its effect at least will be very limited. For the salt to become effective as a manure it must undergo change in the soil. For this change to commence it is necessary that the soil should contain some basic matter capable of decomposing the sulphate; the only basic matter occurring in soils in considerable quantity is carbonate of lime. Thus while the presence of an abundance of carbonate of lime in the soil is unfavourable to a profitable use of sulphate of ammonia, it may be laid down as a general principle that sulphate of ammonia cannot be employed regularly with success except on soils containing a distinct amount of carbonate of lime. Soils very poor in lime may be successfully cultivated with farmyard manure, or they may receive nitrate of soda, but they do not belong to the class of soil that will give profitable results with sulphate of ammonia.

The reaction which takes place between the carbonate of lime in the soil, and the sulphate of ammonia added to it, results in the formation of a little carbonate of ammonia, and a little sulphate of lime. The action would then stop if all the products remained side by side. The power of combining with carbonate of ammonia possessed by the humus, by some of the hydrated silicates, and by the hydrated oxide of iron contained in the soil, now, however, steps in; the carbonate of ammonia which has been produced is absorbed by these substances, and as soon as it is removed from the sphere of action the reaction between the carbonate of lime and the sulphate of ammonia again goes forward, and if the supply of carbonate of lime and the absorptive power of the soil for ammonia are equal to the task the reaction proceeds till the whole of the sulphate of ammonia has been decomposed, its sulphuric acid combined with lime, and its ammonia stored up in the soil. The ammonia is now fairly fixed, and rain may fall upon the soil without removing more than an insignificant amount in the drainage water.

The ammonia has now reached a condition in which it is probably capable of acting as a food for plants. Its changes, however, are not yet over. In a fertile soil oxidation of the ammonia proceeds with considerable rapidity; the ammonia disappears, and nitrites and nitrates are successively produced. The successive stages of oxidation are effected by two species of bacteria, one of which converts the ammonia into a nitrite, while the other converts the nitrite into a nitrate. The two actions proceed simultaneously in an ordinary soil, so that a nitrate is apparently the only substance produced. The whole process is known as *nitrification*. Nitrification will not take place unless there is a base for the nitrous acid to combine with. There is thus in the nitrification of the ammonia a further consumption of the carbonate of lime contained in the soil. The final outcome of the whole reaction is the entire disappearance of the sulphate of ammonia, and its replacement by two soluble salts, the sulphate and nitrate of lime. If chloride of ammonium has been employed instead of the sulphate, the series of changes which occur will be perfectly similar, the final products being chloride of calcium and nitrate of lime.

If the field to which the ammonia salt is applied is provided with drain-pipes at no great distance beneath the surface, and rain falls frequently after the application of the salt, the composition of the successive discharges of the drain-pipes will be found to vary in a striking manner, following the course of change of the ammonia salt in the soil. If rain falls immediately after the application of the ammonia salt the first discharge of the drain-pipe may contain a little ammonia, the action of the carbonate of lime in the soil being not yet completed. For a few days after the application of the ammonia salt the drainage water will be found to contain much sulphate of lime, but only a small proportion of nitrate. The ammonia is then fixed in the soil, while the acid, with which it was originally combined, has become united with lime. In still later discharges of the pipes the sulphate of lime gradually diminishes, while the proportion of nitrate of lime rapidly increases. Nitrification of the ammonia held by the soil is now in active progress, and fresh quantities of the carbonate of lime in the soil are being brought into solution, combining in the first instance with the nitrous acid arising from the oxidation of the ammonia, the nitrite of lime being afterwards changed by further oxidation into nitrate.

The analyses of the drainage waters from the plots of the experimental wheat field at Rothamsted afford excellent illustrations of the statements we have just made. Each plot in this field has a drain-pipe laid beneath it, at a distance of about 2 feet from the surface. The drain-pipe under plot 15 had run on October 10th, 1880; the water was collected, and the amount of nitrates and chlorides which it contained was determined. On October 25th, ammonia salts, at the rate of 400 lbs. per acre, were spread broadcast on the land, and then ploughed in. The ammonia salts were a mixture of 200 lbs. of sulphate and 200 lbs. of chloride of ammonium. Heavy rain occurred on the night of the 26th, and the drain-pipe under the plot was found running on the following morning. Further rain produced a discharge of drainage water on the 28th and the 29th. The pipe did not run again till November 15th. The amount of chlorine, and of nitrogen as ammonia and nitrates, found in the various discharges of drainage water, before and after the application of the ammonia salts, is shown in the following Table.

TABLE I.

COMPOSITION OF THE DRAINAGE WATER FROM PLOT 15 IN THE ROTHAMSTED WHEAT FIELD, BEFORE AND AFTER THE APPLICATION OF AMMONIA SALTS.

Date of discharge.	Per million of Drainage Water.		
	Nitrogen as Ammonia.	Chlorine.	Nitrogen as Nitrates.
Before the application of Ammonia salts.			
October 10th	None.	22·7	8·2
After the application of Ammonia salts on October 25.			
October 27th, 6.30 a.m. ...	9·0	146·4	13·5
,, ,, 1 p.m. ...	6·5	116·6	12·9
October 28th.	2·5	95·3	16·7
October 29th.	1·5	80·8	16·9
November 15th and 16th. ...	None.	54·2	50·8

In the Rothamsted analyses of drainage water it is the chlorine of the chloride of ammonium which has been determined, if the sulphuric acid of the sulphate of ammonia had been determined a similar series of figures would have been obtained. The course of change in the drainage water is seen to follow the order already described.

We will give one more illustration from the Rothamsted analyses of drainage waters, relating this time to a spring application of ammonia salts, side by side of a spring application of nitrate of soda. The manures were all applied as top-dressings to the wheat on Feb. 23, 1882. Plot 8 received 600 lbs. per acre of mixed ammonia salts; plot 10, 400 lbs.; while plot 9, lying between them, received 550 lbs. of nitrate of soda. The drain-pipes next ran on March 1st; the pipe of one of the plots receiving ammonia salts also ran on April 26th, the other two pipes did not run. The interval of six days between the application of the ammonia salts and the next running of the drain pipes was sufficient to prevent the appearance of more than traces of ammonia in the drainage water. The amount of chlorides and nitrates found is shown in the following table. The composition of the drainage waters on January 9th, the last running before the application of the manures, is also given so as to show in a clearer manner the influence of the manures on the drainage waters.

TABLE II.

COMPOSITION OF THE DRAINAGE WATERS FROM PLOTS 8, 9, AND 10, IN THE ROTHAMSTED WHEAT FIELD, BEFORE AND AFTER THE APPLICATION OF AMMONIA SALTS AND NITRATE OF SODA.

Plots and Manuring.	Before Manuring.	After Manuring on February 23rd.	
	January 9th.	March 1st.	April 26th.
Chlorine per Million of Water.			
Plot 8, Ammonia salts ...	23·8	146·4	
Plot 9, Nitrate of Soda ...	5·5	9·0	
Plot 10, Ammonia salts ...	17·8	121·5	70·5
Nitrogen as Nitrates per Million of Water.			
Plot 8, Ammonia salts ...	10·2	14·1	
Plot 9, Nitrate of Soda ...	10·0	119·2	
Plot 10, Ammonia salts ...	9·1	15·2	35·2

In the case of the two plots receiving ammonia salts we find the same result as before; that is, a great discharge of chlorides, and doubtless of sulphates, in the first running of the drainage water, accompanied with only a small increase in the proportion of nitrates; while afterwards (as shown in plot 10) the chlorides diminish, and the nitrates largely increase.

Where nitrate of soda had been applied the results are quite different; here the nitrate is from the first ready formed, and comes through in immense quantity in the first discharge of the drain-pipes. The advantage of ammonia salts over nitrate as a spring dressing, when heavy rain follows very soon after the the application of the manure, is here plainly seen ; the nitrate is wasted by the rain, while the ammonia is not. Of course as soon as the nitrification of the ammonia salts is completed, one manure is as easily washed out of the soil as the other.

What time is required for the complete nitrification of a dressing of ammonia salts in the soil ? The conditions favourable to nitrification are well known. Granted the presence in sufficient quantity of the nitrifying organisms, and of the food—phosphates, potash, etc.—necessary for their growth, the activity of the nitrifying process depends on the proportion of water, air, and carbonate of lime present in the soil, and on its temperature. Nitrification is far more rapid at a summer than at a winter temperature. It cannot take place in a dry soil, but increases in vigour as the proportion of water rises. Schloesing determined the amount of nitric acid formed in four portions of the same soil maintained for thirteen months at certain fixed degrees of moisture. His results were as follows :

Percentage of Water in the Soil.	Nitric Acid formed per Million of Soil.
9·3	157
14·6	172
16·0	397
20·0	478

The rate of nitrification rises with the proportion of water only so long as the interstices of the soil still contain air ; if the soil lacks drainage, and remains permanently saturated with water after heavy rain, nitrification will cease from the absence of oxygen, and denitrification will probably commence.

Nitrification will be greatly retarded when the soil contains only a small supply of bases (usually carbonate of lime) with which the nitrous acid first formed may combine, and will be more speedy when the supply of such bases is abundant.

In soils of ordinary character it is the conditions as to moisture and tillage which have the greatest influence on the activity of nitrification, and of these two conditions that of moisture holds the first place.

Some experiments by Wagner *(Forschungen auf dem Gebiete der Pflanzenernährung*, 1892, 440) will serve very well to illustrate the influence of the various conditions just mentioned on the nitrification of sulphate of ammonia. We shall quote only the experiments made with the smallest proportion of ammonia salts, 0·471 gram added to 300 grams of soil. This quantity was, however, far beyond anything that is employed in agriculture, amounting in fact to 28 cwts. per acre, if the surface soil is reckoned as weighing two million pounds, corresponding to a depth of about 7 inches.

Wagner used two soils. The poor loam contained 18 per cent. of water. The garden soil, richer in humus, contained 30 per cent of water. Each soil was used alone, and also with the addition of 1·6 per cent of marl. The experiments were made both in a cold and warm room. A considerable number of mixtures were made in each series of experiments, and the nitric acid present was determined every twelve days in one lot in each series. To give the results a practical bearing, we have expressed them as pounds of sulphate of ammonia nitrified per acre. The figures in the table show in a very striking manner the immense influence which moisture, temperature, and the presence of an ample supply of carbonate of lime have on the rate of nitrification of sulphate of ammonia.

TABLE III.

POUNDS OF SULPHATE OF AMMONIA NITRIFIED PER ACRE UNDER VARIOUS CONDITIONS (WAGNER).

		12 Days,	24 Days.	36 Days.	48 Days.	60 Days.
		lbs,	lbs.	lbs.	lbs.	lbs.
Poor Loam 18 p.c. Water.	Cold	—	—	63	408	816
	Cold, marled	—	—	63	471	1444
	Warm ...	251	973	1695	2072	2323
	Warm, marled	283	1915	2512	2606	2669
Garden Soil 30 p.c. Water.	Cold	125	314	628	1727	2606
	Cold, marled ...	157	659	816	2606	2700
	Warm ...	2135	2763	2794	2826	—
	Warm, marled	2763	2763	2794	—	—

As no examination of the soils was made until 12 days had elapsed, we have here no indication of the minimum time required for nitrification to commence. Wagner's method moreover always underrated the extent to which the ammonia salt had nitrified. He apparently arrived at the amount of ammonia which had nitrified by deducting from the nitric acid in the manured soil the quantity found at the same date in a similar unmanured soil. This method always leads to low results, as experiments have shown that the organic matter of a soil nitrifies very little while the nitrification of added ammonia is in progress. The action of the nitrifying organisms in a soil is in fact limited, and they attack by preference the ready formed ammonia present.

In the case of the autumn application of ammonia salts in the Rothamsted Wheat field, it is evident from the figures already quoted (Table I.) that nitrification had distinctly commenced forty hours after the dressing had been ploughed in. In Schloesing's numerous laboratory experiments, in which the ammonia salts were dissolved in water before they were added to the soil, nitrification was completed in 8 to 15 days; and this was the case when a far larger proportion of ammonia was added to the soil than would ever be used in practice. If therefore the soil is in a suitable condition of tillage, and rain falls abundantly immediately after the application of the sulphate of ammonia, so as to at once distribute it throughout the soil, we may probably assume that nitrification will be concluded in a fortnight after the application. On the other hand, in the absence of rain, or from the lack of other favourable conditions already mentioned, the time required for complete nitrification may be very considerably prolonged.

3. **Exhaustion of Lime.**—In describing the changes which sulphate of ammonia undergoes in the soil, we have seen that, in the first place, the sulphuric acid of the salt combines with the carbonate of lime in the soil; and that, in the second place, the nitrous acid formed by the oxidation of the ammonia also combines with carbonate of lime. Lime may not be demanded for these reactions if the soil contains in the place of lime other bases, as alkalies and magnesia,

in such a form that the sulphuric and nitrous acid can combine with them ; but in the majority of cases carbonate of lime is the basic material present in greatest quantity in the soil, and the one which is chiefly used in these reactions, and it will be convenient for our present purpose to speak of the base required as carbonate of lime.

A simple chemical calculation shows that 1 cwt. of commercial sulphate of ammonia will require about 82½ lbs. of dry carbonate of lime for combination with the sulphuric acid present. A portion of this sulphuric acid may be taken up as plant food, but the quantity of sulphuric acid required by crops is small, so that the greater part of the sulphate of lime produced will remain unused in the soil, and, in the majority of cases, will be finally removed in the drainage water.

In the process of nitrification the 1 cwt. of sulphate of ammonia will require a second quantity of 82½ lbs. of carbonate of lime, or its equivalent in other bases, in order to form successively the nitrite and nitrate which are the result of this operation. Of the nitrate of lime so produced the greater part may be taken up by the crop, while some will appear in the drainage water. What the plant does with the nitrate which it takes up has not yet been sufficiently studied. The plant undoubtedly retains far more of the nitrogen than of the base with which this nitrogen was combined in the soil, and we must therefore assume that a large part of the basic constituent of nitrates is returned somehow to the soil. We must, therefore, apparently not reckon the whole of the second 82½ lbs. of carbonate of lime as lost to the soil, and perhaps only a small part of it should be so reckoned in the case of cereal crops.

The exhaustion of the carbonate of lime will clearly remain the same, even if no drainage water leaves the soil. In this case the carbonate of lime will disappear, while sulphate of lime takes its place. The sulphate cannot, however, take the place of the carbonate in the fixation and nitrification of sulphate of ammonia: the exhaustion is thus nearly as serious whether drainage occurs or not.

Lime was determined by Dr. Voelcker and Dr. Frankland in ten series of analyses of drainage waters collected at various times during several years from the plots in the experimental wheat field at Rothamsted. The mean proportion of lime and magnesia found in the ten analyses, in the case of five of the plots, is shown in the following table. The quantity of lime removed annually in the drainage water is calculated on the assumption that the annual discharge of drainage water in the wheat field will amount to 8 inches per acre.

TABLE IV.

AVERAGE AMOUNT OF LIME IN DRAINAGE WATERS FROM PLOTS VARIOUSLY MANURED IN THE WHEAT FIELD at ROTHAMSTED.

Plot.	Manuring.	Lime per million of Water.	Lime in lbs. per Acre.	
			Removed each Year.	Excess due to Amm. Salts.
3 and 4	No manure	99	180	—
10	Ammonia salts 400lbs	173	314	134
5	Cinereal manure* ...	132	240	—
6	Cinereals, Ammonia salts 200 lbs. ...	171	311	71
7	Cinereals, Ammonia salts 400 lbs. ...	207	376	136

It is plainly seen from the above figures that the use of ammonia salts has in every case considerably increased the quantity of lime removed in the drainage water, and this quantity is clearly proportional to the weight of ammonia salts employed. The mean result of the ten analyses cannot of course be taken as representing the true average composition of the drainage waters, which vary extremely in their character, nor can the estimated amount of drainage be taken as strictly correct. The general teaching of the results is, however, unmistakeable. The 71 lbs. of lime removed by 200 lbs. of ammonia salts would be equivalent to 126 lbs. of carbonate of lime per acre.

The removal of carbonate of lime arising from the use of sulphate of ammonia is attended with objectionable results

* By cinereal manure is meant one supplying the ash constituents of the crop; in this case the manure supplied potash, soda, lime, and magnesia as sulphates or phosphates.

only in those cases in which the amount in the soil was originally very small. If we take the weight of dry surface soil turned over by the plough as 2,000,000 lbs. per acre, then one per cent. of carbonate of lime in the soil will amount to 20,000 lbs. per acre. The soil of the unmanured plot in the Rothamsted wheat field contains in the first nine inches, according to Dr. Dyer's analysis, nearly 3 per cent. of carbonate of lime; but there is very little in the subsoil. Plots in this field have received very large quantities of ammonia salts annually during 55 years without any falling off having been experienced in the produce from the manure where the necessary ash constituents have been supplied.

In the experiments on the old pasture land at Rothamsted exhaustion of lime has been felt. The surface soil of an old pasture is usually poor in lime. Such a soil is rich in vegetable remains, and the carbonate of lime of the original soil has been gradually dissolved and removed by the action of the carbonic and humic acids arising from the decay of vegetable matter. The experimental trials with ammonia salts, and other manures, on a portion of the Park at Rothamsted, commenced in 1856, and for many years the ammonia salts yielded a large and satisfactory increase of produce. Bare patches then began to appear on some of the plots receiving ammonia salts, notably on that receiving ammonia only, and that receiving the largest quantity of ammonia (600 lbs. of ammonia salts per acre) with superphosphate and alkali salts. This occurred notwithstanding that the dressing of ammonia salts was divided into two applications, so as to avoid if possible any direct injury to the herbage. No bare patches appeared save where ammonia salts had been applied. In 1881 a part of the plots was treated with a dressing of chalk, and this being found to remedy the condition in question, the application of lime and chalk has since been extended to all the grass land under experiment.

In the long continued experiments at Woburn the evil effect resulting from the removal of lime has apparently made its appearance in the barley field. The soil at Woburn is a fine sand, and contains very little lime. In reporting on the results obtained during twenty years, Dr. Voelcker, speaking of the plot where ammonia salts are applied alone, says:—

"It is every year found increasingly difficult to obtain a plant on some portions of the ammonia salts plot, and resowing or transplanting has had to be resorted to. . . . The failure is confined to where ammonia salts have been used, and as soon as one passes off this plot, be it to the unmanured one on the one side or the nitrate of soda plot on the other, the distinction is clearly apparent. . . . . The most probable explanation of the difference, in this respect, between the action of ammonia salts and nitrate of soda lies in the fact, known to chemists, that the application of sulphate of ammonia results in a more rapid removal of lime from the soil than is the case when nitrate of soda is employed; and the soil containing, as it did originally, but little lime, is now in all likelihood deprived of it to such an extent that there is not the requisite amount for the needs of the barley crop."

All the plots receiving ammonia salts in the barley field at Woburn show a somewhat greater falling off in produce during the later years of the experiment than is shown by the corresponding plots receiving nitrate of soda; it is probable therefore that the want of carbonate of lime in the soil is being generally felt on the ammonia plots.

In full agreement with the facts observed at Rothamsted and Woburn are the results of numerous experiments on the use of sulphate of ammonia made by H. J. Wheeler at the Agricultural Experiment Station, Rhode Island, United States. (*Experiment Station Record*, VII, 377; VIII, 571). He points out that, "a dangerous degree of acidity, or at least a fatal lack of carbonate of lime, appears to exist in (some) upland and naturally well-drained soils, and is not confined to muck and peat swamps and very wet lands, as most American and many other writers seem to assume." Experiments with such soils carried on for several years showed that "sulphate of ammonia, when applied without air-slacked lime, acted like a poison, the injurious effects increasing with the amount applied. The yields of the thirty-eight miscellaneous crops show, without exception, where no air-slacked lime was used, that the sulphate of ammonia was inferior in its action to the nitrate of soda, and in most cases probably poisonous. On the other hand, where lime was applied in connection with the two forms of nitrogen, the ill effect of the sulphate of ammonia was not only overcome, but in (the) case of several crops the yield from the limed sulphate of ammonia plots even exceeded that where lime was used in connection with the nitrate of soda. With but few exceptions the results show conclusively that the value of the lime was more due to its overcoming the natural acidity of the soil, and the acid tendency of the sulphate of ammonia, whereby the nitrogen was changed into a form available to the plant, than to its direct fertilising value. . . . Among the cereals we find that barley was less able to withstand the acid soil conditions than the oats and rye."

4. **Special Function as a Manure.**—Sulphate of ammonia is to be regarded as a purely nitrogenous manure. Its sulphuric acid is doubtless sometimes of advantage, and tends in some cases to increase the fertility of the soil, or supplies directly the demand for sulphur by the crop. Sulphate of ammonia would, however, never be employed for the sake of the sulphuric acid which it contains, as other manures, gypsum for instance, would supply this constituent at far less cost. Sulphate of ammonia is profitable when an additional supply of an active nitrogenous plant food is required in the soil. Its use is thus limited to those crops which depend for their luxuriance on the presence of a considerable supply of available combined nitrogen in the soil, and it is of no practical use to crops which obtain their principal supply of nitrogen from the atmosphere. That sulphate of ammonia could not be used with profit for leguminous crops was discovered in some of the earliest experiments with this manure, its inefficiency for such crops was indeed well known long before the cause of that inefficiency was understood. To employ sulphate of ammonia for beans, peas, vetches, clover, lucerne, sainfoin, etc., is generally to throw the manure away. Sulphate of ammonia may often be applied with advantage to mixed seeds, as clover and rye-grass, vetches and oats, but in

such cases it is always the gramineous portion of the crop that is benefited and not the leguminous.

Sulphate of ammonia being a purely nitrogenous manure, it also follows that it will frequently not produce its full effect unless some of the other essential elements of plant food are supplied with it. A purely nitrogenous manure can yield a maximum return only when the soil contains a full supply of phosphates, potash, lime, and the other essential ash constituents of plants. If the supply of these ash constituents in the soil is deficient, sulphate of ammonia must fail to give a profitable return, and may be entirely without effect. The application of superphosphate, potash salts, or of other manures supplying ash constituents, is thus often necessary if the ammonia salt is to be used to advantage. The necessity for the simultaneous use of other manures will be less when only small dressings of ammonia salts are applied, and when they are only used occasionally in the course of a rotation. The need for such additions becomes greatest when large quantities of ammonia salts are applied to the same land year after year. It is thus in the long continued Rothamsted field experiments that we find the most striking illustrations of the good effect of combining phosphates and potash with ammonia, and of the very inferior result given by ammonia salts when continuously applied by themselves. Attention to the supply of lime, alkalies, and phosphoric acid is more needed when ammonia salts are systematically used than when nitrate of soda is employed.

We may now turn to the agricultural results obtained by the application of sulphate of ammonia to crops.

PART II

AGRICULTURAL RESULTS

OBTAINED BY THE APPLICATION OF

SULPHATE OF AMMONIA TO CROPS

Our object in this section is to show what are the results to be expected from the application of ammoniacal manures to the chief crops grown by the British farmer. For this purpose we shall endeavour to bring together the various records which have been published of accurate trials in the field. As, however, the produce yielded by manures is extremely different in bad and good seasons, we shall generally avoid quoting any experiments relating to a single season, but shall rely chiefly on experiments showing the average produce of the same manure over many years. Average results are seldom of a startling character, but they are the only ones which we can safely reckon on to be maintained in actual practice.

Besides the weight of produce yielded by the use of a unit weight of sulphate of ammonia, we shall endeavour to indicate in each case what has been the influence of the manure on the quality and composition of the crop.

WHEAT

1. Experiments at Rothamsted.—The results obtained at Rothamsted, Herts, will be most appropriately mentioned first. The Rothamsted field experiments were the earliest exact trials of the effects produced by modern artificial manures, and they have been also the longest continued.

The soil at Rothamsted is a heavy loam with many flints, the subsoil usually contains more clay; it lies on the chalk, which, however, is many feet below the surface. The chalk provides a good natural drainage. The soil contains very little lime, except at the surface, where it is well provided with this substance, having received in ancient times, according to the custom of the country, many dressings of chalk.

The plan of the field experiments at Rothamsted has been to grow the same crop year after year on the same land with the same manures. This method has great advantages when the crop in question is not one which deteriorates by constant cultivation on the same land. By repeating the experiments through many seasons trustworthy average results are obtained. Any tendency to accumulation or exhaustion of fertility attending the use of different manures is also made apparent.

The wheat experiments in Broadbalk field commenced in 1843, the first harvest being in the following summer. Most of the plots in this field have an area of six-tenths of an acre.

Manures applied.—One plot has from the commencement been entirely unmanured; another has had fourteen tons of farmyard manure ploughed in every autumn; a third has received every year, except the first, a dressing of ammonia salts without any other manure. The remaining plots received in the earlier years various experimental manures, but in 1852 a constant system of manuring was commenced, and has been maintained with few exceptions ever since. We shall select as most suitable for our present discussion the results obtained on certain plots during forty years, 1852-91; these results will be found in Table V., page 33.

The superphosphate and alkali salts applied each year to plots 5, 6, 7, 8, have consisted of 3½ cwts. of bone-ash superphosphate, 200 lbs. of sulphate of potash, 100 lbs. of sulphate of soda, and 100 lbs. of sulphate of magnesia per acre. These manures have been uniformly applied in the autumn, before drilling the wheat.

The ammonia salts supplied throughout the experiments have been a mixture of equal parts sulphate and chloride. At the commencement of the experiments, 400 lbs. of mixed ammonia salts were estimated to supply 100 lbs. of ammonia. The quality of the commercial salts has however gradually improved, and during recent years the 400 lbs. of ammonia salts must have supplied 110 lbs. of ammonia. We shall have to take this varying quality of the ammonia salts into account in calculating the return obtained from the quantity of ammonia applied. The time of applying the ammonia salts to the land has varied during the course of the experiments; the influence of this factor on the produce obtained will be discussed later (p. 41).

TABLE V.

PRODUCE OF WHEAT VARIOUSLY MANURED IN BROADBALK FIELD, ROTHAMSTED, DURING FORTY YEARS, 1852-91.

Plot.	Manures applied per Acre.	Dressed Corn per Acre.				Average produce 40 years, 1852-91				
		Average first 10 Years 1852—61.	Average second 10 Years 1862—71.	Average third 10 Years 1872—81.	Average fourth 10 Years 1882—91.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia. Corn.	Return for 1 cwt. Sulphate of Ammonia. Straw
		bushels	bushels	bushels.	bushels.	bushels.	lbs.	cwts.	bushels.	cwt.
3	No manure.	15·2	13·7	10·3	13·1	13·1	58.2	10·6	—	—
5	Superphosphate and Alkalies	18·2	15·7	12·1	14·1	15·0	58.8	12·3	—	—
6	Superphosphate, Alkalies, Ammonia salts, 200 lbs.	27·2	25·5	19·2	25·0	24·3	59·6	21·8	5·0	5·1
7	Superphosphate, Alkalies, Ammonia salts, 400 lbs.	34·7	35·7	27·0	35·5	33·2	59.7	33·3	4·9	5·6
8	Superphosphate, Alkalies, Ammonia salts, 600 lbs.	36·0	40·5	31·5	39·0	36·7	59.5	40·5	3·9	5·0
11	Superphosphate, Ammonia salts, 400 lbs.	28·2	27·7	22·0	23·5	25·3	57.6	23·7	2·8	3·0
10a	Ammonia salts, 400 lbs.	21·0	24·0	16·5	19·5	20·2	57.2	18·2	1·9	2·0
2	Farmyard manure, 14 tons	34·2	37·5	28·7	38·7	34·8	60.2	32·6	—	—

Produce obtained.—A comparison of the produce of plots 3 and 5 shows that the long continued application of superphosphate, with salts of potash, soda, and magnesia, has produced very little increase in the wheat crop; the average produce on plot 5 during 40 years is, indeed, barely two bushels greater than on plot 3, left continuously without manure. The supply to the soil of the essential ash constituents of the wheat crop thus entirely fails to yield a satisfactory produce.

The results obtained on the next series of plots, 6, 7, 8, show that when ammonia salts are added to the superphosphate and alkalies the yield of wheat is immensely increased; indeed on plot 8, and sometimes on plot 7, the produce surpasses that given by fourteen tons of farmyard manure applied annually to the same land since 1843. Wheat is thus clearly a crop which may be greatly benefited by applications of ammonia salts, and such applications judiciously employed are capable of yielding a very large produce.

The long continued trials at Rothamsted teach us that the effect of ammonia salts is not transient. The ammonia is not to be regarded as a mere "stimulant," as some farmers suppose, but as a valuable plant food. The beneficial results of its application are apparently undiminished in the Rothamsted wheat field by a continuous use of more than forty years. The produce of each successive ten years during this period will be found in Table V. The second ten years embraces some particularly fine seasons, and the third ten years some particularly bad ones; the produce of the plots generally rises and falls with the character of the seasons in this middle period. On comparing the crops yielded during the fourth period of ten years with those yielded in the first period, we see that though the produce has distinctly fallen off on those plots on which the exhaustion of some essential constituent of plant food is in progress (plots, 3, 5, 11, 10*a*), yet it is fully maintained on the three plots receiving a liberal manuring of the ash constituents of the wheat crop, coupled with an annual dressing of ammonia salts; the average produce of plots 6, 7, 8, during the first ten years was in fact $32\frac{3}{8}$

bushels, and during the fourth ten years 33⅛ bushels. That the effect of the ammonia salts does not wear out is shown, however, most strikingly by the produce of these three plots in the excellent season of 1894, by which time ammonia salts had been applied to the land continuously for about 50 years. The dressed corn yielded by plots 6, 7, and 8 in 1894 amounted to 38, 48¾, and 49 bushels per acre.

Return per Unit of Ammonia.—The return given by ammonia salts under various conditions is best seen by referring to the figures in the two columns at the right hand of the table. We have here the *increase* in dressed corn and straw for 1 cwt. of sulphate of ammonia applied. In this calculation, and in all others of a similar character which follow, the sulphate of ammonia is assumed to be of the best modern quality, and to contain 25 per cent of ammonia, or 28 lbs. per cwt.*

It appears from the figures given that the smaller application of 200 lbs. of ammonia salts per acre, and the next larger application of 400 lbs., were both used with an equally profitable result, the return being about 5 bushels of wheat, and 5 cwts. of straw, per cwt. of sulphate of ammonia. When, however, the quantity of ammonia salts is still further increased, as on plot 8, although a larger crop is harvested, the return in corn per unit of ammonia is diminished, while the return in straw shows but little falling off. It is thus clear that in the wheat field at Rothamsted, with a full supply of phosphates and potash salts, dressings of sulphate of ammonia up to 4 cwts. per acre may be profitably applied, but that 6 cwts. is an excessive quantity, and produces more straw than corn.

A farmer will seldom, if ever, be able to employ so large a dressing as is profitably applied in Broadbalk field. In Broad-

*It has been already mentioned that the quality of the ammonia salts employed at Rothamsted (and elsewhere) was many years ago lower than it is at present. In calculating the return yielded by ammonia in the 40 years, 1852-91 (Table V.), a middle value has been assumed for the ammonia salts, namely 105 lbs. of ammonia in 400 lbs. of the mixed salts. In Table VI., 400 lbs. ammonia salts are taken as containing 103·3 lbs. of ammonia. In the Holkham and Rodmersham experiments, which relate solely to an earlier period, the 400 lbs. of salts are taken as containing 100 lbs. of ammonia.

balk wheat field the whole of the produce has been removed from the land since 1840, without any return of farmyard manure, save on plot 2. The condition of the land is thus entirely different to that which occurs in an ordinary rotation. In ordinary arable culture the soil is frequently being enriched by the residues of leguminous crops, by the manure of animals fed on the land, or by actual applications of farmyard manure. The various nitrogenous matters thus supplied nitrify in the soil, and the nitrates thus produced are at the disposal of whatever crop the farmer is pleased to grow. The larger is the quantity of nitrates furnished by the soil, the smaller is the quantity of ammonia salts or nitrate of soda which the farmer can profitably employ. The average produce without ammonia or nitrate was in Broadbalk field 15 bushels. Had the produce without these dressings been 24 bushels, it is clear that only 2 cwts. of sulphate of ammonia could have been profitably employed. If the natural fertility of the land had been equivalent to a crop of 29 bushels (which is about the average produce of wheat land in Great Britain) only 1 cwt. of sulphate of ammonia could have been safely used. The farmer must in every case have a just idea of what would be the produce of his land without manure, in order to answer the question, 'What quantity of additional manure can I profitably apply?'

Before proceeding further, we should mention that Lawes and Gilbert, when discussing the earlier results obtained at Rothamsted (*Jour. Roy. Agri. Soc.* 1864, 484), came to the conclusion that an increase of one bushel of wheat might on an average be expected for each 5 lbs. of ammonia applied, when the land was well supplied with phosphates, potash, and the other ash constituents of the wheat crop, and the quantity of ammonia employed was not excessive. The average of the 40 years' experiments shows that 5·6 lbs. of ammonia produced one bushel of wheat under the conditions just named.

Influence of Ash Constituents.—Turning now to the results yielded by plots 11 and 10*a*, shown in Table V., we see clearly that 1 cwt. of sulphate ammonia will yield 5 bushels of wheat in the Rothamsted field only when phosphates and alkali salts are also applied. When nothing but ammonia salts is applied (plot 10*a*), barely 2 bushels of wheat per cwt. of sulphate of ammonia are obtained. When superphosphate is also employed, as on plot 11, the yield becomes nearly 3 bushels per cwt. of sulphate. To reach the full return of 5 bushels per cwt., it is needful to apply the salts of potash, soda and magnesia as well as superphosphate. Other experiments in the same field, which we need not quote in detail, show that of these salts those of potash are by far the most important.

It must always be borne in mind that the profit to be obtained from the use of sulphate of ammonia entirely depends on the presence of a sufficient supply of phosphates and potash in the soil. In the case of most farms the return yielded by sulphate of ammonia will be greatly improved by the addition to it of superphosphate, and of kainite supplying potash, soda, and magnesia. The need for a supply of ash constituents to the soil will, however, generally be less than would appear from the results shown in the Rothamsted wheat field. When wheat is grown in a rotation in which a liberal manuring of farmyard manure and superphosphate is applied to the root crop; when cake is purchased and consumed on the farm, and only a part of the straw is sold; it will never be necessary to supply the large amount of phosphates and potash which has been used at Rothamsted. Whether these additional manures are required or not, and if required what dressings of them are necessary, must be ascertained by the experience acquired on each farm. Every farmer should make himself acquainted with the particular deficiencies of his own soil, without this knowledge it will be impossible for him to employ artificial manures with the greatest profit. It is easy to ascertain by trials in his own fields whether it pays to add superphosphate along with a dressing of sulphate of ammonia, and if kainite is also needed. These manures are cheap, but a farmer who aims at profit will be careful not to apply any more than is required to produce the desired effect.

Influence of Climate.—In the table already given we have seen the average effect produced by ammonia salts in forty consecutive seasons; the return here shown is by no means all that the ammonia is capable of yielding. When 1 cwt. of sulphate of ammonia produces 5 bushels of wheat grain, and 5 cwts. of straw, rather less than 40 per cent. of the nitrogen of the ammonia salts are found in the resulting crop, and under ordinary circumstances the greater part of the remainder is lost. In a superior climate, with a more equable supply of water in the soil, with abundant sunshine, and no sudden variations in temperature, the assimilating power of the crop is greatly increased, and two-thirds or three-quarters of the nitrogen in the manure may be found in the form of wheat grain and straw at harvest. The character of the climate thus greatly influences the amount of profit to be gained by the use of ammonia salts, and applications may be made in one locality or season with great profit which in another will result in loss. We cannot better illustrate the great influence of climate on the return yielded by ammonia salts than by contrasting the produce of wheat obtained in Broadbalk field in the three best seasons during the experiment with the average produce of forty years already given.

TABLE VI.

PRODUCE OF WHEAT PER ACRE IN BROADBALK FIELD. AVERAGE OF THE THREE BEST SEASONS, 1854, 1863, 1894.

Plot.	Manures applied per Acre.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia.	
					Corn.	Straw.
		bushels.	lbs.	cwts.	bushels.	cwts.
3	No manure	18·7	61·1	15·5	—	—
5	Superphosphate and Alkalies	22·0	61 5	18·3	—	—
6	Superphos., Alkalies, Ammonia salts 200lbs.	37·2	62·3	34·7	8·3	8·9
7	Superphosphate, Alkalies, Ammonia salts 400 lbs. ...	49·2	62·2	52·0	7·4	9·1
8	Superphosphate, Alkalies, Ammonia salts 600 lbs. ...	51·1	61·8	59·5	5·3	7·4
11	Superphosphate, Ammonia salts 400 lbs.	42·7	62·0	40·8	5·6	6·1
10*a*	Ammonia salts, 400lbs.	34·1	61·7	29·2	4·2	3·7
2	Farmyard manure 14 tons.	43·5	62·5	42·8	—	—

The figures in Table VI. show that Plot 7, receiving 400 lbs. of ammonia salts with phosphates and potash, yielded in the three best seasons an average produce of 49·2 bushels, or rather of 51 bushels if we take the bushel to be 60 lbs. in weight. The return for 1 cwt. of sulphate of ammonia applied is now 8·3 bushels on plot 6, and 7·4 bushels on plot 7; or 8·7 and 7·7 bushels respectively if we take the bushel at 60 lbs. There is also at the same time a return of 9 cwts. of straw. In seasons of average character the produce from the same dressings of sulphate of ammonia was 5 bushels of corn, and 5 cwts. of straw.

In a very fine season the yield of the soil, and the return from the manure applied, is so much increased, that moderate dressings of manure suffice to produce the fullest crops. The produce of plots 7 and 8 is more nearly alike in a fine season than in one of inferior character. A fine climate thus occasions a great economy in manure.

2. **Holkham and Rodmersham Experiments.**—The field experiments on wheat carried on at Holkham, Norfolk, and at Rodmersham, Kent, were repetitions of the trials made at Rothamsted; the manures employed were in each case supplied from Rothamsted. The results are of interest as made on different soils, and as showing a very different return for the ammonia applied. Reports of these experiments will be found in the *Journal of the Royal Agricultural Society*, 1855, 207; 1862, 31.

The Holkham soil is described as a light, rather shallow, brown sand loam, resting upon an excellent marl. The crop preceding the wheat was white turnips manured with farm-yard manure and guano. The turnips had been carted off. The land was evidently in high condition, the unmanured plot in the first year of the experiment yielding 39½ bushels of wheat. The addition of 400 lbs. of ammonia salts resulted in an increase of only 3 bushels. The quantity of ammonia applied was clearly far larger than the condition of the land and the character of the season could turn to profitable account. In Table VII. the results of the first season are excluded, and the average produce of the three following seasons is given.

Table VII.

Produce of Wheat per Acre at Holkham.

Average of Three Years, 1852-54

Manures applied.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia	
				Corn.	Straw.
	bushels.	lbs.	cwts.	bushels.	cwts.
No manure	18·0	61·2	11·6	—	—
Superphosphate and Alkalies	19·1	62·1	15·1	—	—
Superphosphate, Alkalies, Ammonia salts 400 lbs.	32·6	62·5	25·3	3·8	2·9
Ammonia salts 400 lbs	27·4	59·3	20·3	2·6	2·3
Farmyard manure 14 tons	30·5	62·7	23·2	—	—

We have here results of the same character as those obtained at Rothamsted. The ammonia salts with superphosphate and alkalies give a larger average produce than that obtained from farmyard manure. The good effect of the superphosphate and alkali salts is also plainly manifested, the ammonia salts supplied with these yielding an average of 5 bushels more corn than ammonia alone. The weight of straw in these experiments did not include chaff and cavings, it appears therefore to bear an unusually low proportion to the corn.

The Rodmersham soil was apparently not unlike that at Rothamsted, for it is described as a mixed clay, resting upon a chalk subsoil 4-6 ft. below the surface.

The crop preceding the wheat was beans manured with farmyard manure. The land, as at Holkham, was in too high a condition at first to justify the application of a full dose of ammonia, the produce of wheat on the unmanured plot being in the first year 32¼ bushels. Omitting this year, the average produce by the various manures in the three succeeding years was as shown in Table VIII.

TABLE VIII.

PRODUCE OF WHEAT PER ACRE AT RODMERSHAM.

AVERAGE OF THREE YEARS, 1857-59.

Manures applied.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia	
				Corn.	Straw.
	bushels.	lbs.	cwts.	bushels	cwts.
No manure	23·2	59·3	25·5	—	—
Superphosphate and Alkalies	27·0	60·5	28·3	—	—
Superphosphate, Alkalies, Ammonia salts, 400 lbs.	33·5	58·1	48·5	1·8	5·6
Ammonia salts, 400 lbs....	29·6	58·5	37·6	1·8	3·4
Farmyard manure 14 tons	30·5	60·2	33·7	—	—

The clay soil at Rodmersham was clearly better provided both with nitrogenous plant food, and with the ash constituents required by wheat, than was the case at either Rothamsted or Holkham. The produce of the plots receiving no nitrogenous manure remains fairly good even under continuous wheat culture. The advantage gained by using superphosphate and alkalies with the ammonia salts is also distinctly less. The return in corn for the ammonia applied is very poor, while the return in straw is much larger. A smaller dressing of ammonia salts would have been more profitable.

3. Comparative effect of Autumn or Spring Dressings.—In the case of autumn sown wheat it is of course possible to apply the ammonia salts either in autumn at the time of wheat sowing, or else in spring as a top-dressing. As the trials of the relative advantages of these methods which we are able to mention were made at Rothamsted and at Holkham, it will be most convenient to consider the question in this place.

It is easy to see that under certain circumstances the application of ammonia salts in the spring may have decided advantages, while under other circumstances an application in the autumn would be preferred. If the application of ammonia salts in the autumn is followed by excessive rain, the nitrates formed in the soil may be washed through, and lost as drainage water before the wheat plant commences to grow in the spring. On the other hand, if a top-dressing of ammonia salts in spring is followed by a continuance of dry weather, the manure remains for a long time ineffective. If we could foretell the occurrence of either kind of season we should know which time of application to prefer. Opinion is now generally in favour of the spring application of ammonia, but it must be admitted that excellent results have often followed an autumn application.

At Rothamsted autumn dressing was for a long time employed; it was usual for the ammonia salts to be spread broadcast, and ploughed or harrowed in before drilling the wheat. The largest return ever obtained from ammonia salts, namely the increase of 20 bushels from 200 lbs., and of 34 bushels from 400 lbs., was obtained in 1863 from autumn dressings. For the crop of 1873, and afterwards, a comparison of the effect of autumn and spring applications has been regularly made at Rothamsted. The application in spring has been as a simple top-dressing, left to be washed in by rain, and not followed by the use of a harrow. From 1878 to 1883 the ammonia salts were applied in the spring, usually in March, on all the plots save one. From 1884 to the present time, each plot, save one, has received 100 lbs. of ammonia salts in the autumn, the rest of the ammonia salts being applied in the spring. The following table shows the comparative effects produced at Rothamsted by the autumn and spring application of 400 lbs. of ammonia salts during eleven years, 1872-1883. The land always received superphosphate and alkalies, which were applied in the autumn.

TABLE IX.

PRODUCE OF WHEAT AT ROTHAMSTED BY AUTUMN AND SPRING APPLICATIONS OF AMMONIA SALTS.

	Autumn Dressing.		Spring Dressing.		Spring more or less than Autumn.	
	Corn.	Straw.	Corn.	Straw.	Corn.	Straw.
	bushels.	cwts.	bushels.	cwts.	bushels.	cwts.
1872-3 ...	22·0	18·0	32.6	27·5	+ 10·6	+ 9·5
1873-4 ...	39·5	41·5	29·1	24·7	− 10·4	− 16·8
1874-5 ...	25·9	30·5	25·5	28·5	− 0·4	− 2·0
1875-6 ...	23·5	19·7	25·5	21·7	+ 2·0	+ 2·0
1876-7 ...	19·9	16·4	33·1	24·9	+ 5·0	+ 8·6
1877-8 ...	22·1	27·4	31·2	44·2	+ 9·1	+ 16·8
1878-9 ...	5·4	8·1	16·2	26·9	+ 10·8	+ 18·7
1879-80 ...	36·2	36·0	34·5	35·7	− 1·7	− 0·3
1880-1 ...	25·2	17·6	26·6	19·6	+ 1·4	+ 2·0
1881-2 ...	29·0	36·5	35·7	51·1	+ 6·7	+ 14·6
1882-3 ...	33·0	29·0	36·1	32·4	+ 3·1	+ 3·3
Mean	25·6	25·5	29·6	30·7	+ 4·0	+ 5·2

It will be observed that only in three seasons out of the eleven is the produce greater from the autumn application, and in only one of these seasons is the difference considerable. In eight seasons the spring application proves the more profitable, and in five of the eight very decidedly so. On an average, the spring application gives a better result by 4 bushels of corn and 5¼ cwts. of straw. The spring application of the ammonia distinctly tends to increase the proportion of straw.

The experiment just quoted is particularly satisfactory, as the plots receiving the autumn and spring dressings alternated in the course of the experiment, Plot 7 receiving the autumn sown ammonia, and Plot 15 the spring sown during the first five years, while in the next six years the treatment was reversed. Any natural difference in fertility of the plots should not therefore affect the result.

In the subsequent comparison, during fourteen years, of an autumn application with an application of one quarter of the ammonia in the autumn and three quarters in March, the purely autumn application has proved the more profitable in two seasons only.

In the wheat experiments at Holkham, ammonia salts, at the rate of 400 lbs. per acre, were applied alone, during four years, to one plot in the autumn, and to another plot in the spring: the results are shown in Table X.

TABLE X.

PRODUCE OF WHEAT GRAIN AT HOLKHAM, BY AUTUMN AND SPRING APPLICATIONS OF AMMONIA SALTS.

	Autumn Dressing.	Spring Dressing.	Spring more or less than Autumn.
	bushels.	bushels.	bushels.
1850-1	44·0	41·0	− 3·0
1851-2	30·7	28·0	− 2·7
1852-3	27·2	31·5	+ 4·3
1853-4	23·6	23·3	− 0·3
Mean	31·4	31·0	− 0·4

In this short experiment the advantage is most generally with the autumn application.

The most suitable time for the application of ammonia salts clearly depends upon the character of the climate, and no fixed rule can be given. The application must be made early enough for the ammonia to become nitrified, and the nitrates distributed through the soil, before the time that the active growth of the crop commences; no earlier application is needed or desirable.

4. **Experiments at Woburn.**—The soil at Woburn in Bedfordshire is a very fine sand, of considerable depth, and good fertility, but containing as already mentioned only very little lime. The experiments conducted by the Royal Agricultural Society at this station include the continuous growth of wheat and barley with manures similar to those employed at Rothamsted. A report by Dr. Voelcker on the results of these experiments during twenty years will be found in the *Journal of the Royal Agricultural Society*, 1897, 258.

The ammonia salts employed are, as at Rothamsted, a mixture of equal weights sulphate and chloride. The salts are analysed, and the quantities applied supply every year 50 lbs. or 100 lbs. of ammonia per acre. The ammonia salts have from the commencement of the experiment been applied as a top-dressing, usually at the end of April or beginning of May.

In Table XI we give the produce of wheat during twenty years on the group of plots with which we are at present concerned. (See page 46.)

The figures show that there has been some falling off in the produce on all the plots in the second ten years as compared with the first, this falling off is however smallest on the plots receiving ammonia salts. As at Rothamsted, the employment of superphosphate and alkalies greatly increases the return yielded by the ammonia. The superphosphate and alkalies, used by themselves on plot 4, produce no increase of crop, but added to 183 lbs. of ammonia salts they raise the crop from 23·8 bushels (plot 2) to 30·2 bushels (plot 5), and in fact, as the two right hand columns show, nearly double the rate of increase obtained.

The great characteristic of these Woburn results is the very good returns obtained for the quantity of ammonia applied. As the quantity of ammonia salts employed per acre has been somewhat less than that used in later years at Rothamsted, we shall best compare the results at these stations by looking in each case at the return obtained for 1 cwt. of standard sulphate of ammonia applied. At Rothamsted the 1 cwt. of sulphate of ammonia, when applied to the best advantage, yielded an average of 5 bushels of wheat. In the three best seasons during 40 years the average return was 8·3 bushels. In the best season of all, 1863, the return on plot 6, was 11 bushels of wheat per cwt. of sulphate of ammonia. At Woburn, however, the average return on plot 5, during 20 years, is 8·5 bushels per cwt. of sulphate, or rather better than that reached at Rothamsted in the three best seasons. If we now pick out the results of the best seasons at Woburn, we find that in 1882 the return from 1 cwt. of sulphate of ammonia on plot 5 was 11·3 bushels; in 1884, 13·7 bushels; in 1889, 13 bushels; and in 1894 the return reached the extraordinary figure of 23 bushels. Both the average return, and the returns obtained in fine seasons, are thus far

Table XI.

Produce of Wheat variously manured in Stackyard Field, Woburn, during Twenty Years, 1877-96.

Plot.	Manures applied per Acre.	Dressed Corn.		Average Produce 20 Years, 1877-96.				
		Average first 10 Years, 1877-86.	Average second 10 Years, 1887-96.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia. Corn.	Return for 1 cwt. Sulphate of Ammonia. Straw.
		bushels.	bushels.	bushels.	lbs.	cwts.	bushels.	cwts.
1 & 7	No manure	17·1	13·6	15·3	57·3	15·1	—	—
4	Superphosphate and Alkalies	17·7	12·6	15·1	57·8	15·6	—	—
5	Superphosphate, Alkalies, Ammonia salts, 183 lbs.	31·5	29·0	30·2	58·7	29·0	8·5	7·5
8	Superphosphate, Alkalies, Ammonia salts, 366 lbs.	38·8	35·6	37·2	58·7	36·8	6·2	5·9
2	Ammonia salts, 183 lbs.	25·4	22·2	23·8	57·3	22·4	4·8	4·1

greater than the corresponding results at Rothamsted. To what cause should we attribute the excellence of the Woburn results?

When we come hereafter (p. 63) to consider the effect produced on subsequent crops by the residue from a previous dressing of ammoniacal manure, we shall find that while no beneficial effect is perceived in the Rothamsted wheat field from any residue remaining in the soil from a last year's application of ammonia salts, a beneficial effect from such residues is felt at Woburn, and sometimes to a surprising extent. The nitrates unused by the crop in one season at Rothamsted are apparently afterwards lost, probably through the drainpipes, or by absorption by the chalk subsoil, while at Woburn the nitrates remain to a large extent in the soil and serve for the nourishment of the next crop. Both ammonia salts and nitrates are thus in the long run used with more economy at Woburn than in the wheat field at Rothamsted. The experiments on the influence of residual manures will be described in detail by and by, the figures already given are however sufficient to lead us to the view just expressed.

If we consider the quantity of nitrogen usually present in the grain and straw of wheat, we shall find that the 28 lbs. of ammonia contained in 1 cwt. of the best commercial sulphate of ammonia cannot produce an increase of more than about 13 bushels of corn, with its equivalent of straw. The return at Woburn occasionally reaches or exceeds this figure, and in 1894 considerably overpasses it. It is clear that in these cases the result is not wholly due to a single application of ammonia salts; the return from the last application is, in fact, increased by the remainder of the preceding application. Two years of an abnormally great return can thus never follow each other, and each splendid result is usually preceded by a poor one. Of this fact the years 1893 and 1894 afford the most striking example. In the extreme drought of 1893 the produce of wheat on plot 5 at Woburn was only 13·1 bushels; in 1894 the produce on this plot was 54·4 bushels, a crop which could only have been reached by the aid of the unused residue of the manure applied in the preceding year.

We have already mentioned that the soil at Woburn consists of a very fine sand of great depth. Such soils are seldom met with. When favourably situated, and properly treated, they yield a larger return for the manure applied than any other. Hilgard, in America, has already pointed out that a sandy soil is far more fertile in proportion to its contents of plant food than a loam or clay.

It will be recollected that at Rothamsted the return from 400 lbs. of ammonia salts was as good as the return from 200 lbs., the larger dressing could thus be employed with full profit. At Woburn, where the ammonia salts yield a much better return, this is not the case; the first 50 lbs. of ammonia give an average increase of 15 bushels, the second 50 lbs. add only 7 bushels. This is what would be expected. At Woburn a smaller quantity of ammonia suffices for a crop as large as the soil and season are capable of producing, and large dressings are consequently attended with a diminished rate of profit. It happens, however, that the return from 100 lbs. of ammonia at Woburn is practically as good as that yielded by 50 lbs., although this does not appear from the figures given in the table. During the last fourteen years plot 8 has been divided, and while both halves have every year received superphosphate and alkalies, the ammonia salts have been applied on the two halves alternately. In this way the residual effect of the previous dressing of 100 lbs. of ammonia has each year been ascertained. If we add the residual effect during fourteen years to the produce mentioned in the table, we find that the return per cwt. of sulphate of ammonia is 8 bushels in the case of plot 8, as it is in the case of plot 5. On plot 5, the ammonia salts have been continuously applied, and their residual effect is therefore included in the average produce mentioned.

5. Influence of Ammonia salts on the Quality of the produce.—The use of ammonia salts for wheat does not unduly increase the proportion of straw to corn unless the quantity of of ammonia used is in excess of that yielding a maximum return of corn. Thus in the Rothamsted results (Table V), we see that in the return per cwt. of sulphate of ammonia the proportion of straw to corn is but little increased on plot 7, and is much more increased on plot 8, where an excessive dressing of ammonia salts is applied. At Woburn the proportion of straw on plot 8 is very little more than on plot 5. At Woburn, the ammonia salts yield a rather greater proportion of corn than at Rothamsted. We have already seen in Table IX., that a spring dressing of ammonia salts yields a somewhat larger proportion of straw than an autumn dressing.

The weight per bushel of the grain is improved by the use of ammonia salts, except where the supply of the ash constituents of the crop is defective. The average weight per bushel at Rothamsted during forty years was for the unmanured wheat 58·2 lbs., and for that continuously manured with farmyard manure 60·2 lbs., while for the three plots receiving ammonia salts with superphosphate and alkalies the weights per bushel were 59·6, 59·7 and 59·5 lbs. When, however, the ammonia salts were applied alone, the average weight per bushel sank to 57·2 lbs. Similar results appear at Woburn.

The wheat grain obtained in the experimental field at Woburn in 1897 has been valued by experts (*Journal of the Royal Agricultural Society*, 1898, 551). The crop that year was a very small one. The highest value was given to the wheat grown on plots 5 and 8, with sulphate of ammonia, superphosphate, and alkali salts; the price per quarter of this wheat was judged as from 2/- to 2/6 above that yielded by the corresponding plots receiving nitrate of soda. The weight per bushel is generally somewhat higher when wheat is grown by ammonia salts than when grown by nitrate of soda; this difference is more marked at Woburn than at Rothamsted.

The percentage of nitrogenous matter in the grain is very slightly affected by the use of ammoniacal manures. Lawes and Gilbert have published the average percentages of nitrogen found in the grain and straw of some of the wheat plots during twenty years, 1852-71, *Transactions of the Chemical Society*, 1884. Dr. T. B. Osborne has shown that the mixed albuminoids of wheat grain contain 17·6 per cent of nitrogen. Making use of this fact we are able to calculate from Lawes and Gilbert's figures the percentage of albuminoids in the wheat grain produced by various manures. The results are shown in the following table.

TABLE XII.

PERCENTAGE OF ALBUMINOIDS IN WHEAT GRAIN VARIOUSLY MANURED AT ROTHAMSTED.

AVERAGE OF TWENTY YEARS, 1852-71.

Plot.	Manures applied.	Percentage of Albuminoids in Dry Matter.
3	No manure	10·45
5	Superphosphate and Alkalies	10.39
7	Superphosphate, Alkalies, Ammonia salts, 400lbs.	11·19
11	Superphosphate, Ammonia salts, 400lbs.	11·10
10	Ammonia salts, 400lbs	11·27
2	Farmyard manure 14 tons	11·05

It thus appears that where ammonia has been employed as manure the percentage of albuminoids (and probably of gluten) in the grain is slightly increased.

The figures relating to the nitrogenous matter in the straw show no increase of nitrogen in the straw of plot 7, but where ash constituents are deficient, and the transference of material from the straw to the grain is therefore hindered, as in the case of the crop on plots 11 and 10, the nitrogenous matter left in the straw at harvest is somewhat increased.

AVERAGE PERCENTAGES OF NITROGENOUS MATTER ($N. \times 6·25$) IN DRY STRAW.

Plot.	Nitrogenous matter. Per cent.
3	3·16
5	3·22
7	3·09
11	3·59
10	3·53
2	2·91

6. Practical Remarks.—The wheat crop is one especially suited for treatment with ammoniacal manures. The luxuriance of the crop depends very greatly upon the supply of nitrogenous food which it finds in the soil. The stiffness of the straw also admits of larger applications of manure being given than can be safely used in the case of barley.

The wheat crop is commonly given the best place in a rotation, it is grown when the land has accumulated a supply of nitrogenous food; thus it follows clover or beans, or a heavily manured crop of mangel, or comes after a bare fallow. Grown under these circumstances only a small amount of additional manure is demanded, and an application of 1 cwt. of sulphate of ammonia, and 2 cwts. of superphosphate, per acre, will generally be found quite sufficient. Two cwts. of kainite may often be added with advantage.

In deciding whether a spring dressing of sulphate of ammonia shall be given, the farmer must take into account not only the previous manuring and condition of the field, but also the character of the past autumn and winter. If the wheat is grown in a favourable position in the rotation, and the preceding autumn and winter have been dry, little or no nitrogenous manure should be applied in the spring, as the soil will under these circumstances contain a good supply of nitrates, accumulated without loss during many months of rest. The wetter has been the preceding weather, the more thoroughly the nitrates have been removed from the soil by the percolation of rain water, the more is an application of readily available nitrogenous manure demanded in the spring.

Now, however, that the farmer has effective nitrogenous manures at his command, the cultivation of wheat need not be limited to any particular part of a rotation. If prices warrant such a course, the farmer can grow wheat successfully by means of artificial manures after almost any crop, and wheat after wheat may be taken with excellent results, as the long extended trials at Rothamsted and Woburn amply demonstrate. When wheat is grown without the previous accumulation of plant food in the soil which occurs in the ordinary practice, more artificial manure must be employed, and 2 or 3 cwts. of sulphate of ammonia per acre will become necessary. The demand for kainite and superphosphate will also be increased.

A profitable extension of the growth of wheat by artificial manuring is of course practically limited to certain soils and climates; thin soils, with a gravel or chalk subsoil, cannot be relied on to yield a profitable return from soluble manures.

The number of accurate experiments are at present too few for any exact statement as to the average return to be expected from the use of sulphate of ammonia, the details of the experiments we have already given show how greatly this return is affected by the special characters both of the soil and season. In the brief experiments at Rodmersham, we have an average return of only 1·8 bushel from 1 cwt. of sulphate of ammonia. At Holkham, the return is 3·8 bushels. Mr. F. J. Cooke also gives 3 bushels as the general return obtained in three years' experiments on several Norfolk farms having a thin soil, with a sandy, gravelly, or chalky subsoil. At Rothamsted the average return in 40 years is 5 bushels for 1 cwt. of sulphate of ammonia. Mr. Cooke also names 5 bushels as the return obtained during three years on Norfolk farms having a deep loam as their soil. At Woburn we have during 20 years the excellent return of 8 bushels of wheat for 1 cwt. of sulphate of ammonia. This first-rate return we have already seen is probably connected with the exceptional retention of nitrates in the Woburn soil, a deep fine sand, which allows any unused nitrates of one season to remain available in the soil for the next crop. A return of five bushels from 1 cwt. of sulphate of ammonia is perhaps the nearest approach to an average result which the figures before us seem to warrant.

For the profitable growth of wheat by artificial manures it is of course essential that the land shall be kept clean; the crop and not the weeds must make use of the plant food given if a money profit is to be realised.

While the superphosphate and kainite, which form part of the artificial dressing, are best applied to the land and harrowed in before drilling the seed, the sulphate of ammonia will generally do best when given as a top-dressing in the spring. When possible, large dressings should be applied early, in the south of England in March, and a light harrow at once taken across the land to help cover the manure. If the harrow is not to be used, the fair intervals of showery weather should be chosen for manure sowing. Small dressings may be applied later than large dressings.

BARLEY

1. **Experiments at Rothamsted.**—The continuous growth of barley by various manures, after the plan already described in the case of the wheat experiments, commenced in Hoos Field, Rothamsted, in 1852, and has proceeded uninterruptedly down to the present time. The soil of the field is similar, but somewhat lighter, than that of the adjoining wheat field.

The manures applied may be taken as the same in quantity and quality as those already mentioned as employed in the wheat field (p. 32), unless the contrary is stated. The cultivation is that usual for barley. The land is ploughed in the autumn, but no manures are applied till the spring. The whole of the manures, including the ammonia salts, are spread on the land in February or March, and are then ploughed in.

Produce Obtained.—For a study of the produce obtained from the various manures we select the results of the same forty years, 1852-91, which have already been made the subject of discussion in the case of wheat.

The use of manures supplying only the ash constituents of the crop produced but little effect in the wheat field, in the barley field the effect of such manures is seen to be much more considerable. The effect produced by these cinereal manures is chiefly due to the superphosphate which they contain.

The produce on the unmanured plot, and on those plots receiving ash constituents only, is seen in Table XIII (p. 54) to have largely fallen off during the forty years of the experiment, a result different from that observed in the wheat field. This different result is largely due to the spring tillage which the land receives in the case of barley, but not in the case of wheat. This spring tillage brings about an active nitrification of the nitrogenous matter in the soil, and thus at the same time brings about the utilisation and diminution of the soil nitrogen.

Table XIII.

Produce of Barley in Hoos Field, Rothamsted, during Forty Years, 1852-91.

Plot.	Manures applied per Acre.	Dressed Corn per Acre.				Average Produce, 40 Years, 1852-91.				
		Average first 10 Years, 1852-61.	Average second 10 Years, 1862-71.	Average third 10 Years, 1872-81.	Average fourth 10 Years, 1882-91.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia: Corn.	Return for 1 cwt. Sulphate of Ammonia: Straw.
		bushels.	bushels.	bushels.	bushels.	bushels.	lbs.	cwts.	bushels.	cwts.
1 O	No manure	22.2	17.7	13.6	12.8	16.5	52.0	9.3	—	—
2 O	Superphosphate	28.0	23.0	18.0	17.5	21.7	53.1	10.7	—	—
4 O	Superphosphate and Alkalies ...	30.5	24.5	17.7	16.7	22.3	53.0	11.3	—	—
4 A	Superphosphate, Alkalies, Ammonia salts, 200 lbs.	46.2	46.2	41.0	40.5	43.5	54.0	25.8	11.3	7.7
2 A	Superphosphate, Ammonia salts, 200 lbs.	45.7	48.2	40.6	36.3	42.7	52.8	23.8	11.2	7.0
1 A	Ammonia salts, 200 lbs.	33.5	31.5	27.2	24.0	29.0	52.0	16.0	6.7	3.5
7^2	Farmyard manure, 14 tons	45.0	51.5	50.5	47.5	48.6	54.2	29.0	—	—

The addition of 200 lbs. of mixed ammonia salts to the superphosphate, or to the superphosphate and alkalies, is seen to increase the produce of barley by an average of 21 bushels.

During the first twenty years the produce of barley by 200 lbs. of ammonia salts and phosphates was fully maintained, and practically equal to that given during the same period by an annual application of 14 tons of farmyard manure. In the second twenty years there is a distinct falling off in the produce by the ammonia salts. The falling off is naturally greatest where no ash constituents have been supplied with the ammonia (plot 1A), and is least where a full supply of these ash constituents has been regularly given (plot 4A).

Return per unit of Ammonia.—If we deduct the produce of the unmanured plot from that given by the ammonia salts alone (plot 1A), and deduct the produce by superphosphate from that given by superphosphate and ammonia salts (plot 2A), and further deduct the produce by superphosphate and alkalies from that given by similar manure with ammonia salts (plot 4A), we obtain the *increase* of crop apparently yielded by the use of ammonia. In two columns at the right hand of Table XIII., will be found the average increase yielded on each plot for 1 cwt. of sulphate of ammonia applied. Where the ammonia salt has been used alone, the average return has been 6·7 bushels of barley for 1 cwt. of sulphate of ammonia. Where superphosphate has been regularly applied with the ammonia, the return is greatly increased, amounting to 11·2 bushels per cwt. of ammonia salt. Where the sulphates of potash, soda, and magnesia, have been added to the superphosphate, the average return from the sulphate of ammonia is slightly further increased, being now 11·3 bushels.

The excellence of the return yielded by the ammonia salts in the Rothamsted barley field is at once evident, the return is in fact far better than that obtained in the adjoining wheat field. On plot 6, in the wheat field, receiving 200 lbs. of ammonia salts with ash constituents, the return is only about 40 per cent of that theoretically possible if the whole of the nitrogen of the ammonia had been assimilated by the wheat crop. On plot 4A of the barley field, receiving exactly the same quantities of manure, the return during the same forty years has amounted to about 60 per cent of that theoretically possible. How are we to explain this great difference? We must first remark that the apparent increase by ammonia in the barley field is probably somewhat above the truth. During this long continued experiment the yield on plots 1 0, 2 0, and 4 0, has considerably diminished; that is to say, the base line from which the increase by ammonia is calculated has steadily fallen, and the *apparent* increase by ammonia has consequently risen. This is best shown by a comparison of the produce of plots 4 0 and 4A, as in this case the results are not affected by any exhaustion of ash constituents in the course of the experiment. The increased produce plot of 2A over plot 2 0, and of 4A over plot 4 0, when calculated as the return given by 1 cwt. of sulphate of ammonia, has been in the four successive periods of ten years as follows:—

RETURN FOR 1 CWT. OF SULPHATE OF AMMONIA.

	On Plot 2A.	On Plot 4A.	
First 10 years	9·9	8·8	bushels.
Second 10 years	13·7	11·8	,,
Third 10 years	11·8	12·2	,,
Fourth 10 years	9·6	12·1	,,
Mean	11·2	11·2	,,

The cause of this increase in the return during the later years of the experiment is to be found in the impoverishment of the soil where no nitrogenous manure has been applied. The soil of plots 2 0 and 4 0 had originally a similar composition to that of 2A and 4A, it is now poorer in nitrogen, and the produce of the two series of plots is no longer strictly comparable. This difficulty in calculating accurately the increase given by the ammonia occurs more or less in all field experiments, but it is especially marked in the long continued barley experiments now before us. We have already remarked that the spring tillage employed in barley culture determines a specially rapid diminution of soil nitrogen where no nitrogenous manure is applied.

The facts just referred to only however reduce to a moderate extent the return obtained from the use of ammonia salts in Hoos Field, it still remains 9 or 10 bushels per cwt. of sulphate. I venture to think that the much better resul obtained from ammonia in the barley field than in the wheat field, is largely due to the different mode of applying the salt in these two experiments; and also to the fact that the wheat field has drain-pipes through which nitrates may be lost, while the barley field is provided with no artificial drainage. The mode of applying the ammonia salts in the barley field seems on the whole the best which can be employed to secure a full utilisation of the ammonia. The ammonia salts are spread on the land at the end of February, or beginning of March, and at once ploughed in. Loss by volatilisation is thus as far as possible prevented, as the salt is at once covered with the soil, while the conditions necessary for nitrification are certainly supplied even if dry weather should follow. In the wheat field the ammonia salts are either applied before wheat sowing in autumn, and are then liable to loss from autumn and winter drainage; or they are applied as a simple top-dressing in the middle of March, when the salt lies on the surface, waiting for some shower to carry it into the soil. Under these circumstances some loss by volatilisation may occur, and nitrification and distribution may be unduly delayed in a dry season.

From the consideration just urged it would seem that spring corn is a crop especially adapted for the economic use of sulphate of ammonia.

In Table XIII we have only mentioned the results yielded by 200 lbs. of ammonia salts. In the first six years of the experiment a whole series of plots received 400 lbs. of ammonia salts per acre. This heavier dressing of ammonia was clearly excessive, the crop was generally more or less laid, and the return per unit of ammonia was much less than that yielded by the smaller application. It will be recollected that in the wheat field the 400 lbs. of ammonia salts yielded a return equal to that given by 200 lbs. What is the reason of this difference between wheat and barley? It is determined in part by the essential difference in the tillage adopted for these two crops. If the same soil is cropped with wheat and barley, the spring tillage employed for the latter crop renders available for assimilation by the plant a certain amount of soil nitrogen which remains unavailable when wheat is grown. The barley is thus better supplied with soil nitrogen, and can therefore employ profitably only a smaller quantity of nitrogenous manure. A second reason lies in the better utilisation of the ammonia salt employed in the barley field: this point has been already fully noticed.

Influence of Ash Constituents.—On the Rothamsted soil, a full return from the use of ammonia salts for barley is only obtained when superphosphate is also applied. The addition of 3½ cwts. of superphosphate to 200 lbs. of ammonia salts has on an average increased the produce by 13·7 bushels. The addition of superphosphate has indeed been far more effective with barley than with wheat. On the other hand, the alkalies which had such a considerable effect on the wheat crop produced at first no increase of barley, and it was only after the first thirty years of the experiment that the produce of plot 4A, receiving alkalies and superphosphate, became distinctly larger than that of plot 2A, receiving only superphosphate with the ammonia. We shall see presently, however, that the alkalies have for a considerable time much influenced the quality of the grain.

The time of ripening of the barley on the various plots is very different, and is largely determined by the supply of ash constituents. The produce of the most complete and best balanced manure is always that which ripens earliest and most thoroughly, provided the manure is not used in excessive quantity. With ammonia salts alone ripening is delayed. When superphosphate is added to the ammonia ripening is much accelerated. In the later years of the experiment the ripening has been earliest and most complete when both alkalies and superphosphate have been used with the ammonia.

Influence of Climate.—Following the mode of discussion adopted when considering the wheat experiments, we give in Table XIV (p. 59) the average produce of barley upon the plots already mentioned in the five seasons of greatest produce, 1854, 1857, 1863, 1864, and 1880.

TABLE XIV.

PRODUCE OF BARLEY IN HOOS FIELD, ROTHAMSTED.

AVERAGE OF FIVE BEST SEASONS, 1854, 1857, 1863, 1864, 1880.

Plot.	Manures applied per Acre.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia.	
					Corn.	Straw.
		bushels.	lbs.	cwts.	bushels.	cwts.
1 O	No manure	25·3	53·2	13·7	—	—
2 O	Superphosphate	33·0	54·4	16·6	—	—
4 O	Superphosphate and Alkalies	35·6	54·7	17·2	—	—
4 A	Superphosphate, Alkalies, Ammonia salts, 200 lbs.	56·7	55·5	32·9	11·6	8·6
2 A	Superphosphate, Ammonia salts, 200lbs. ...	58·6	54·8	32·1	14·1	8·5
1 A	Ammonia salts, 200 lbs.	40·4	53·3	21·0	8·3	4·0
7 2	Farmyard manure 14 tons	58·9	55·1	33·4	—	—

The crops yielded by every plot in these fine seasons are seen to be much above the average, but the return per unit of sulphate of ammonia supplied is by no means increased to the extent we observed in the wheat experiments. The ordinary produce in the barley field is, in proportion to the ammonia supplied, so much better than that yielded in the case of wheat, that much less margin is left for the increase due to a special season. Nevertheless, we find that the return for one cwt. of sulphate of ammonia, employed with superphosphate, is now 14·1 bushels. The return where alkalies were also applied is distinctly less. On this point we have to recollect that four out of the five seasons selected fall in the early years of the experiment when the alkali salts produced no beneficial result, and indeed in some years distinctly diminished the crop. In 1858 the quantity of alkali salts supplied in the manure was diminished in consequence of the ill effect observed; it was still many years before any beneficial effect was perceived from their use on plot 4A.

2—**Experiments at Woburn.**—The continuous cultivation of barley with various manures has been carried on in the same field, and with precisely similar manures, as those employed in the wheat experiments already described. The superphosphate and alkali salts are applied to the land before sowing the seed. The ammonia salts are put on as a top dressing after the corn is up, usually about the middle of May.

The produce of barley on the plots receiving ammonia salts during the first ten years, and the second ten years of the experiment, will be found in Table XV. (p. 61). The produce yielded by the ammonia salts has shown a considerable falling off in the later years of the experiment; this special falling off on the ammonia plots is attributed by Dr. Voelcker to the exhaustion of the lime contained in the soil. This exhaustion of lime in the soil would at first have the effect of retarding the nitrification of the ammonia, and, when the exhaustion became complete, would altogether prevent its utilisation by the crop. This subject has been already discussed on page 27. In consequence of this deterioration in the effect of the ammonia salts, we shall take the average produce of the first sixteen years as the basis

TABLE XV.

PRODUCE OF BARLEY IN STACKYARD FIELD, WOBURN, DURING TWENTY YEARS, 1877–96.

Plot.	Manures applied per Acre.	Dressed Corn.		Average Produce, 16 Years, 1877-92				
		Average first 10 Years, 1877-86.	Average second 10 Years, 1887-96.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 cwt. Sulphate of Ammonia.	
							Corn.	Straw.
		bushels.	bushels.	bushels.	lbs.	cwts.	bushels	cwts.
1 & 7	No manure	25·0	17·6	23·0	51·2	13·1	—	—
4	Superphosphate and Alkalies	23·3	21·7	23·8	51·7	12·8	—	—
5	Superphosphate, Alkalies, Ammonia salts, 183lbs.	43·0	35·1	42·5	53·4	24·4	10·5	6·5
8	Superphosphate, Alkalies, Ammonia salts, 366lbs.	51·2	39·7	50·4	52·7	31·8	7·4	5·3
2	Ammonia salts, 183lbs.	39·4	27·7	37·5	52·2	21·1	8·1	4·5

of our discussion, instead of the average of the whole twenty years.

Return per unit of Ammonia.—On plot 5 the return per cwt. of sulphate of ammonia of 10·5 bushels of barley is very nearly the same as the return obtained on the corresponding plot 4A, in the Rothamsted experiments. The Woburn return is thus not considerably above that obtained at Rothamsted, as it was in the case of the wheat experiments, but nearly equal to it. The causes of the better return from ammonia salts at Rothamsted in the case of barley have been already noticed.

The double dressing of ammonia salts on plot 8 gives apparently a much less profitable return than the smaller dressing on plot 5; if, however, we take into account the effect of the residue of the ammonia salts applied on plot 8, the return from the ammonia is greatly improved. Plot 8 in the barley experiments at Woburn was divided after the first six years, and the ammonia salts were subsequently applied alternately to the two halves, as in the wheat experiments already described. We have thus each year a means of estimating the effect of the residue of the manure applied in the preceding season. If we add the increase of crop produced by the residues of manure on plot 8 to the crop credited to this plot in Table XV., we have an average produce of 56·5 bushels of barley in the sixteen years, and a return of 9·2 bushels for each cwt. of sulphate of ammonia employed. It by no means follows, however, that if the larger dressing of ammonia salts, plus the residue of the preceding dressing, had been every year available on the same plot, that an equally good return would have been obtained; the crop would probably under these circumstances have gone down, and an inferior return would have been obtained.

Influence of Ash Constituents.—On the Woburn soil the application of superphosphate and alkalies is apparently much less necessary than at Rothamsted. At Rothamsted the addition of superphosphate and alkalies to 200 lbs. of ammonia salts increased the crop by an average of 13·7 bushels during the first twenty years. At Woburn the same quantities of superphosphate and alkalies only produce an average increase of 5 bushels in the first sixteen years. This fact is very instructive. In the experiments at Cirencester, to be presently mentioned, the effect of cinereal manures is still smaller. No rule can thus be given as to the use of superphosphate and potash salts, every farmer must ascertain for himself whether their application pays or not on his own land.

Influence of Climate.—The five best seasons for barley at Woburn have been, 1880, 1883, 1884, 1890 and 1892. The average produce in these five seasons was as follows:—

TABLE XVI.

PRODUCE OF BARLEY IN STACKYARD FIELD, WOBURN. AVERAGE OF FIVE BEST SEASONS.

Plot.	Manures applied.	Dressed Corn.	Return for 1 cwt. Sulph. Amm.
		bushels.	bushels.
1 & 7	No manure	27·0	—
4	Superphosphate and Alkalies	29·4	—
5	Superphosphate, Alkalies, Ammonia salts, 183 lbs. ...	50·3	11·7
2	Ammonia salts, 183 lbs. ...	43·4	9·2

We see that though the produce of barley was largely increased in the best seasons, yet the return per unit of ammonia was not greatly raised. This result is similar to that already remarked in the Rothamsted barley field. The increase of produce in fine seasons is indeed in many cases more largely due to the increased fertility of the soil than to an improvement in the return from manure, and this is especially true in the case of crops receiving spring or summer tillage.

3. **Residues of Ammoniacal Manure.**—As the principal evidence relating to the effect of residues of ammonia salts upon subsequent crops is derived from the experiments at Rothamsted and Woburn with wheat and barley crops, the results obtained may be appropriately discussed in this place.

At Rothamsted there is very little evidence of any practical effect being produced on subsequent crops from the unused residue of a previous manuring with ammonia salts.

We have seen that in the wheat field at Rothamsted, where at present 100 lbs of ammonia salts are applied in autumn and 300 lbs. in March, only about 40 per cent. of the nitrogen of the ammonia appears, in an average season, in the increase of crop obtained. What becomes of the remaining 60 per cent. we do not exactly know. What we know is that by the month of June nitrates generally cease to be found in the drainage waters from such plots as 6 and 7, where a full supply of ash constituents is joined with the ammonia. On such plots, but not on others, the nitrates have thus apparently disappeared at this time from the upper two or three feet of soil. In agreement with this fact we find that the following wheat crop, if grown without nitrogenous manure, shows no effect from any unused supply of nitrates remaining in the soil. We must however bear in mind that the evidence of the drainage waters is confined to those seasons in which the drains run, that is to say, it is limited to seasons in which there is no deficiency of rain. In seasons of drought, or on plots receiving a deficient supply of ash constituents, there must be some residue of unused nitrate left in the soil at harvest.

During forty years, an application of 400 lbs. of ammonia salts has alternated each year between plots 17 and 18; there is thus every year a crop grown without any application of ammonia, but with the residue remaining of the previous year's manure at its disposal. The average of the forty crops with ammonia salts has been 30·6 bushels, the average of the forty crops following an application of ammonia has been 15·2 bushels. The average of forty crops on plot 5, which has received no ammonia salts whatever in the whole period, is 15·0 bushels. No residue of the ammoniacal manure thus remains to benefit the next season's crop. In only one instance in Broadbalk field, where an immense dressing of 800 lbs. of ammonia salts had been applied on plot 16, was there a distinct effect produced on a subsequent unmanured crop.

In the wheat field at Woburn no practical effect is produced by any residue of nitrate of soda applied to the preceding crop. When, however, the larger quantity of ammonia salts is made to alternate on the two halves of plot 8, a very distinct effect is obtained from the residue of the ammonia salts put on the preceding year. The increase obtained from the ammonia salts amounts, on an average of eleven years, to 24·1 bushels of wheat in the first year of their application, and to 5·2 bushels in the following year. The value of the residue was thus 17·8 per cent. of the whole effect of the manure.

In the Rothamsted barley field, a residue of ammonia salts has produced a distinct though not large effect on the following crop. A series of plots had for six years received annually 400 lbs. of ammonia salts per acre, the dressing was then reduced to 200 lbs. By comparing the produce of the first year with the reduced manuring, with that given in the same season by plots which had received 200 lbs. of ammonia salts from the beginning, we find on plots 2 AA and 4 AA an excess of produce amounting to 5 bushels of barley, chiefly due apparently to a residue of the manuring previously applied. That this excess was due to a residue of nitrates in the soil is made more probable by the fact that plots 1 AA and 3 AA showed a still greater excess of produce—8 and 6 bushels respectively—and on these plots a greater amount of unused nitrates should have been present, owing to the absence of phosphates in the manure, and the smaller produce per acre.

In the Woburn barley experiments the effects produced by residues from the larger dressings both of nitrate of soda and ammonia salts become quite considerable. On the alternating plots 8 and 9, 20·7 per cent. of the effect of the nitrate of soda appears, on an average of eleven years, in the season after its application, and 26·8 per cent. of the effect of the ammonia salts. The amount of residue is much the greatest after a dry season, which has retarded the nitrification and distribution of the nitrogen of the ammonia.

The facts now mentioned show a greater effect of residues from ammonia salts than of residues from nitrate of soda; a greater amount of residue in barley than in wheat culture;

and a much greater residue at Woburn than at Rothamsted. Can we explain these facts ?

The far greater unused residue remaining in the soil after the growth of a crop with ammonia salts at Woburn than appears in the Rothamsted experiments is surely connected with the much later date at which the ammonia is applied at Woburn, and with the poverty of the Woburn soil in lime. Both of these facts must tend greatly to retard the completion of nitrification, and the subsequent distribution of the nitrates. As wheat and barley do not apparently assimilate nitrogenous food after flowering is completed, any nitrates formed after this stage of growth would remain unused in the soil, and if not subsequently lost, be available for the nourishment of the succeeding crop. It will be recollected that the ammonia salts are applied to the wheat at Rothamsted in March, but at Woburn at the end of April or beginning of May. The ammonia salts at Rothamsted are ploughed into the barley land at the end of February, or commencement of March ; at Woburn they are usually top-dressed in the middle of May. There is thus apparently a good reason why a greater unused residue should occur in the Woburn experiments.

We have to account, however, not only for the occurrence of a residue, but also for its preservation through the winter at Woburn, and not at Rothamsted. The different character and circumstances of the soils seems to explain this. At Rothamsted the natural drainage provided by the chalk sub-soil, aided in Broadbalk field by drain pipes, must greatly tend to prevent any nitrates washed through the soil by autumn or winter rains from returning to the surface so as to be of use to the next crop. In the deep fine sand at Woburn the nitrates may sink without being lost, and a rise in the water level of the sub-soil, or capillary action, may bring them again within the reach of the next crop.

The greater residue from ammonia salts than from nitrate of soda will be also due to the facts already mentioned. The nitrate of soda is ready for immediate consumption as soon as it reaches the soil. The ammonia salt must be nitrified, and the nitrates distributed, before its nitrogen can be largely taken up by the plant. If therefore no nitrate is assimilated after a certain stage of growth is reached by the crop, it is the nitrate of soda of which the smallest proportion will remain unused, while the nitrate from the ammonia salts may be to a more considerable extent left unconsumed.

The larger residue from the ammonia salts left by barley than by wheat in the Woburn experiments is doubtless partly due to the somewhat later date at which the top-dressing of ammonia is applied in the case of barley, but it is also probably in part due to the much greater root development of the autumn sown wheat plant at the time when the top-dressing of ammonia salt is applied, and to the consequently more rapid powers of assimilation of the wheat crop.

The valuers of the unexhausted manures left in the land by an out-going tenant are not in the habit of attaching any money value to a supposed residue of ammonia salts, or nitrate of soda, when these have been applied to a preceding cereal crop. The facts before us show, however, in an unmistakable manner, that when a liberal application of ammonia salt is applied late to the land, and especially to a soil poor in lime, a considerable residue may sometimes, and notably in a dry season, remain in the soil after harvest.

4.—**Experiments at Cirencester**.—At the Royal Agricultural College, Cirencester, experiments on the continuous growth of barley with various manures were conducted for seven years, 1885-91. The soil was a rather calcareous loam, irregularly mixed with clay, and belonged to the oolite formation. Analysis showed that both soil and subsoil were well provided with nitrogen, potash, and phosphoric acid. In these experiments the farmyard manure was ploughed in in the spring. The superphosphate and kainite were harrowed in before sowing the seed. The sulphate of ammonia was applied as a top-dressing to the growing crop about the middle of May.

In the following table the average produce during six years, 1885-90, is given; the crop of 1891 is omitted, having suffered much from weeds and birds. Each produce mentioned in the table is the mean of two plots.

TABLE XVII.

PRODUCE OF BARLEY BY VARIOUS MANURES AT CIRENCESTER.
AVERAGE OF SIX YEARS, 1885–90.

Manures applied.	Dressed Corn.	Return for 1 cwt. Sulph. Amm
	bushels.	bushels.
No manure	24·2	—
Superphosphate, 3 cwt.; Kainite, 3 cwt. ...	23·7	—
Superphosphate, Kainite, Sulphate of Ammonia. 175 lbs.	35·5	7·6
Sulphate of Ammonia, 175 lbs.	34·5	—
Farmyard manure, 14 tons	32·7	—

The amount of produce is low on all the plots, including the one receiving 14 tons of dung.

The return for the ammonia applied is distinctly less than that obtained at Rothamsted and Woburn, being only 7·6 bushels of barley for 1 cwt. of sulphate of ammonia. The most striking result is the absence of effect from the cinereal manures. The sulphate of ammonia applied alone gives only one bushel of corn less produce than when phosphates and potash were added to it. This fact emphasizes the statement already made, that every farmer must ascertain for himself whether phosphates or potash are needed on his own land.

5.—**Influence of Ammonia on the Quality of Barley.**— The employment of ammonia salts as a manure for barley is shown both by the Rothamsted and Woburn experiments to considerably increase the proportion of straw, and the proportion of straw rises with each addition to the quantity of the ammonia. With 200 lbs. of ammonia salts per acre, the proportion of straw to corn has been at Rothamsted very similar to that yielded by the annual application of 14 tons of farmyard manure.

The weight per bushel of the barley is distinctly increased when ammonia salts in moderate quantity, with a full supply of ash constituents, are employed. At Rothamsted, the average weight per bushel on the unmanured land is 52·0 lbs., and on plot 4A, receiving 200 lbs. of ammonia salts with superphosphate and alkalies, 54·0 lbs., while on the farmyard manure plot it is 54·2 lbs. At Woburn, the weight rises from 51·2 lbs on the unmanured land, to 53·4 lbs. with a manuring of 183 lbs of ammonia salts with superphosphate and alkalies, but sinks to 52·7 lbs. when the quantity of ammonia is doubled. The presence of a full supply of available ash constituents has a considerable influence on the weight per bushel. When the ammonia salts are used continuously alone, the weight per bushel falls 2 lbs. at Rothamsted, and 1·2 lb. at Woburn. The quality of barley is much more affected by the conditions of manuring than is the quality of wheat.

As the price of good malting barley is very much higher than that of ordinary feeding barley, it becomes important to inquire—What is the influence of manuring on the production of the higher priced grain? In considering this question it must be understood at starting that the most essential factor in the production of a good quality of malting barley is the character of the climate or season rather than the character of the manure employed. A fine quality of malting barley consists of large thoroughly matured grains of pale colour, in which the storing up of starch has been carried to its utmost limit, and which has been harvested in fine weather, so that no commencement of germination has taken place. In order that the grain should be fully matured it is necessary that the manuring should be of a moderate and well balanced character; any deficiency in any of the elements of plant food will hinder the formation of a large and perfect seed, while any manuring producing great luxuriance of growth will prevent the final complete ripening of the crop. A heavy crop will never yield the finest barley.

The use of nitrogenous manures tends to increase the percentage of albuminoids in the grain, and generally to diminish the proportion of starch. The effect is very small with moderate dressings of manure, and increases more rapidly as the quantity of nitrogenous manure becomes greater. The percentage of nitrogen in the corn and straw of the Rothamsted barley was determined during the first six years of the experiment, when both 200 lbs. and 400 lbs. of ammonia salts were employed (Watts' *Dictionary of Chemistry, Third Supplement*, Barley, p. 148). Multiplying the percentage of nitrogen in the grain by the factor proposed by Osborne as proper for barley grain, and the percentage of nitrogen in the straw by the conventional factor, 6·25, we obtain the percentages of albuminoids given in the following table:—

TABLE XVIII.

PERCENTAGES OF ALBUMINOIDS IN THE DRY MATTER OF BARLEY GRAIN AND STRAW, VARIOUSLY MANURED, AVERAGE OF SIX YEARS, 1852-57.

Manures applied.	Corn.	Straw.
	per cent.	per cent.
Cinereal manures	9·3	2·9
Cinereals and 200 lbs. Ammonia salts ...	10·0	3.1
,, and 400 lbs. ,, ,, ...	11·8	3·9

It will be seen that the smaller dressing of ammonia salts, used with superphosphate and alkalies, has had very little effect in increasing the percentage of albuminoids in the barley grain, while as we have already learnt, it has greatly increased the produce of grain per acre and much improved the weight per bushel. With such manuring the general malting character of the barley has rather improved than deteriorated. When the larger dressing of ammonia salts is employed there is a much greater increase in the percentage of albuminoids, the weight per bushel falls somewhat, and the malting character of the barley is deteriorated. When the ammonia salts were used without superphosphate and alkalies the deterioration of the malting qualities became still more marked.

Munro and Beaven, in their excellent paper on the influence of manurial conditions on malting quality (*Journal of the Royal Agricultural Society*, 1897, 65), have given determinations of nitrogen in the barley grain harvested in 1894 and 1895 from several of the Rothamsted plots; multiplying this nitrogen by the factor already used we obtain the percentages of albuminoids shown in the next table.

TABLE XIX

PERCENTAGES OF ALBUMINOIDS IN THE DRY MATTER OF BARLEY GRAIN, VARIOUSLY MANURED AT ROTHAMSTED.

Plot.	Manures applied.	Albuminoids per cent. of grain.	
		1894.	1895.
1 O	No manure	7·6	9·1
2 O	Superphosphate	7·4	9·1
4 O	Superphosphate and Alkalies... ...	7·6	9·9
4 A	Superphosphate, Alkalies, Ammonia salts, 200 lbs.	7·9	9·6
2 A	Superphosphate, Ammonia salts, 200 lbs.	9·0	10·0
7 2	Farmyard manure, 14 tons	8·6	10·4

We see here again that when a moderate quantity of ammonia is used with a full supply of ash constituents, as on plot 4 A, the percentage of albuminoids is not raised to any considerable extent; while an excess of nitrogenous manure (plot 7^2), or a lack of some essential ash constituent on a plot receiving ammonia (plot 2 A), at once determines a notable rise in the percentage of albuminoids.

Munro and Beaven determined the weight of 1,000 grains, and the proportion of grains having a mealy appearance when broken, in the partially dried samples of barley grain from the harvests of twenty four years, 1872-95, preserved at Rothamsted. The results were as follows:—

TABLE XX.

QUALITY OF BARLEY GRAIN GROWN AT ROTHAMSTED WITH VARIOUS MANURES. AVERAGE OF TWENTY-FOUR YEARS, 1872-95.

Plot.	Manures applied.	Weight per Bushel.	Weight of 1,000 Corns.	Mealy Corns.
		lbs.	grams.	per cent.
1 O	No manure	52·5	36·7	62
3 O	Alkali salts	52·2	39·1	62
2 O	Superphosphate	53·2	39·3	71
4 O	Superphosphate and Alkalies ...	53·0	39·1	69
4 A	Superphosphate, Alkalies, Ammonia salts, 200 lbs.	54·2	42·1	67
2 A	Superphosphate, Ammonia salts, 200 lbs.	52·5	38·6	55
3 A	Alkalies, Ammonia salts, 200 lbs. ..	52·7	41·4	53
1 A	Ammonia salts, 200 lbs.	52·2	40·3	54
7 2	Farmyard manure, 14 tons ..	54·4	44·7	48

These average results exhibit again the excellent position taken by the barley produced on plot 4A. For weight per bushel, and the size of the barley corns, it is only exceeded by the barley grown with farmyard manure; while in the proportion of mealy grains—one of the chief characteristics of a fine malting sample—it is far superior. The good quality of the barley immediately suffers if either the superphosphate or the alkalies is omitted from the manure. Messrs Munro and Beaven, discussing the average results just given, say: "This plot (4A) gives the best average malting quality of the whole series." Second to the produce of this plot they place that of plot 2 O, grown with superphosphate only. And third in order of merit the produce of plot 4AA, grown with nitrate of soda, superphosphate and alkalies.

The excellent effect of potash manures upon the malting quality of barley has been recently recognised in Norfolk experiments.

6.—Practical Remarks.—It is most usual to grow barley after roots. If these have been fed off on the land with cake it will generally be unadvisable to apply any nitrogenous manure to the following barley. If, on the other hand, the roots have been carted from the field and consumed elsewhere, the barley will probably be much benefited by the application of sulphate of ammonia and superphosphate. If the roots have received a good dressing of farmyard manure, 1 cwt. per acre of sulphate of ammonia will probably be quite sufficient to raise the produce of barley to a full crop. If the turnips have been grown with superphosphate only, and then removed from the land, 2 cwts. of sulphate of ammonia, with 2 cwts. of superphosphate, and perhaps 2 cwts. of kainite, would be a suitable manuring.

When barley is grown for malting purposes it is not unfrequently taken after wheat, artificial manuring is then the most appropriate treatment. In this case about 1½ cwt. of sulphate of ammonia would usually be a maximum dressing, and superphosphate and kainite would be added to ensure the best quality of grain which the character of the season would allow. An even distribution of the manure is of great importance if an even ripening of the crop is to be attained. This even distribution may be accomplished by thoroughly mixing the ammonia salt with a considerable bulk of dry soil in fine powder, and applying broad-cast in two operations, one broad-cast sowing crossing the other. If, however, the sulphate of ammonia is applied to the land before drilling the barley, which seems the best plan, the ammonia salt may be well mixed with the superphosphate and kainite, and the whole applied together. A late application of ammonia is very undesirable if a high quality of barley grain is wished for.

The returns obtained from the application of ammonia salts in the various experiments we have quoted show a greater amount of agreement than was observed in the case of wheat. At Rothamsted the return, with an adequate supply of ash constituents, is about 9–10 bushels for 1 cwt. of sulphate of ammonia during the first ten years of the experiments, and this grows to 11 bushels if we take the average of the whole forty years, which we have already seen, we are hardly justified in doing. At Woburn the return is 10½ bushels for 1 cwt. of sulphate of ammonia, on an average of sixteen years. In the fewer Cirencester experiments the return is 7½ bushels for the same dressing of ammonia. In Mr. Cooke's eight series of Norfolk experiments, extending over three years, he found a return of rather less than 7 bushels of barley from 1 cwt. of sulphate of ammonia on light soils, for which rape cake is the favourite manure with the farmers. We may probably therefore assume that with moderate applications of ammonia salts, and a proper use of superphosphate and kainite when required, an average of from 7 to 10 bushels of barley may be expected from 1 cwt. of sulphate of ammonia, according to the quality of the soil receiving the manure.

OATS

1.—**Experiments at Rothamsted.**—The continuous cultivation of oats with various manures, on the same plan already described under the head of Wheat and Barley, has been carried out at Rothamsted from 1869 to 1878. The experiments were finally given up from the difficulty experienced in keeping the land clean, and in obtaining a sufficiently good tilth in spring, the soil of the field (Geescroft) containing a considerable proportion of clay. The results are not therefore as satisfactory as those obtained with wheat or barley.

Tartar Oats were grown. The manures were of the same kind and quantity as those already mentioned as employed in the wheat experiments. The ammonia salts, and the other manures, were applied to the land before sowing the seed, and were ploughed or harrowed in.

In the first five years of the experiment 400 lbs. of ammonia salts (mixed sulphate and chloride) were applied per acre. The quantity was then reduced to 200 lbs., and four crops taken with this manuring. In the second series of experiments one year of bare fallow occurred. We give the results of the two series of experiments separately.

TABLE XXI.

PRODUCE OF TARTAR OATS WITH VARIOUS MANURES AT ROTHAMSTED. AVERAGE OF FIVE YEARS, 1869-73.

Manures applied.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 Cwt. Sulph. Ammonia.	
				Corn.	Straw.
	bushels.	lbs.	cwts.	bushels.	cwts.
No manure	19·8	33·7	10·4	—	—
Superphosphate & Alkalies	24·5	35·0	13·4	—	—
Superphosphate, Alkalies, Ammonia salts, 400 lbs.	59·0	37·0	41·1	9·2	7·4
Ammonia salts, 400 lbs.	47·0	35·8	28·5	7·2	4·8

In Table XXI we find that the best result was given by the ammonia salts when they were used in conjunction with superphosphate and alkali salts; not only is the produce of corn and straw much larger under these circumstances, but the quality of the oats, as shown by the weight per bushel, is also much the best. We have seen similar facts already in the wheat and barley experiments.

TABLE XXII.

PRODUCE OF TARTAR OATS WITH VARIOUS MANURES AT ROTHAMSTED.

AVERAGE OF FOUR YEARS 1874-6 & 8.

Manures applied.	Dressed Corn.	Weight per Bushel.	Straw.	Return for 1 Cwt. Sulph. Ammonia	
				Corn.	Straw.
	bushels.	lbs.	cwts.	bushels.	cwts.
No manure	13·7	31·2	6·0	—	—
Superphosphate & Alkalies	13·1	31·6	6·1	—	—
Superphosphate, Alkalies, Ammonia salts, 200 lbs.	38·0	35·5	20·0	13·3*	7·5
Ammonia salts, 200 lbs.	28·8	33·2	14·1	8·1**	4·3

As in the experiments with barley, the 200 lbs. of ammonia salts proved a more economical dressing than the 400 lbs. With 200 lbs. of ammonia salts, used with superphosphate and alkalies, we have an average return of 13·3 bushels, or

*Equal to 11·2 bushels of 42lbs. weight.
**Equal to 6·4 bushels of 42lbs. weight.

472 lbs. of oats, per one cwt. of sulphate of ammonia. If instead of Tartar Oats, the common oat, *avena sativa*, had been grown, the return, as measured by bushels, would have been distinctly less, owing to the higher weight per bushel of the grain.

2.—**Glasgow and West of Scotland Experiments.** Professor R. P. Wright has carried out, in connection with the Glasgow and West of Scotland Technical College, very numerous experiments on the growth of oats with various manures. The trials have been made simultaneously on a considerable number of farms, and have continued from 1893 to the present time. Originally confined to farms in the south-west of Scotland, the scheme has latterly included others in central Scotland and Fifeshire. As the same quantities of manure have been everywhere applied, and, for the most part, the same quantities have been used every year, it is possible to calculate average rates of produce having a really wide basis.

It is evident that the experiments in question differ entirely in their circumstances from those we have just mentioned. The oat crop is now grown in its natural place in a rotation; the kinds and quantities of manure giving a profitable return are consequently those which can be immediately copied in farm practice. It must at the same time be recollected that the average figures are derived from a large number of very different results, and do not necessarily hold good for any particular soil or climate.

Oats are usually grown in Scotland after lea, that is after ploughing up the land previously laid down for two years with grass seeds and clover : this is the position usually occupied by the oat crop in these experiments. A few of the oat crops followed roots. When the land has previously been liberally treated it may be advisable to give the oat crop no additional manure ; but this is not of general occurrence, and the main object of these experiments has been to show that small dressings of artificial manure may be applied with profit in the cultivation of oats on lea land.

The standard application of nitrogenous manure in these experiments was 1 cwt. of nitrate of soda per acre; the sulphate of ammonia was used in such quantity (about ¾ cwt.) as to supply the same weight of nitrogen. The superphosphate was applied at the rate of 2 cwts. per acre. The potash salt used in 1894 and 1895 was 1 cwt. of the commercial "muriate"; in 1896 and 1897 2 cwts. of kainite were substituted. The cinereal manures, and the sulphate of ammonia, were applied to the land before sowing the seed; the nitrate of soda was put on as a top-dressing after the plant was up. At the present time we have simply to deal with the return given by the use of ammonia salts.

As the oats grown were of different kinds, and of different weight per bushel, Professor Wright gives in every case the total weight of corn in pounds, and when bushels are mentioned reckons them as 42 lbs. in weight. The following table shows the average amount of increase over the unmanured produce obtained each year by the application of the ammoniacal manures.

Table XXIII.

Increase of Oat crop on Scotch farms by various manures.

Season.	Number of Farms.	Sulphate of Ammonia alone.		Sulphate of Ammonia and Superphosphate		Sulphate of Ammonia, Superphosphate Potash salts.		Farmyard manure, 10 tons.	
		Corn.	Straw.	Corn.	Straw.	Corn.	Straw.	Corn.	Straw.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1893	9	—	—	449	789	—	—	—	—
1894	13	429	992	644	1265	717	1529	624	1212
1895	15	325	456	454	363	533	485	—	—
1896	14	291	529	329	498	406	761	—	—
1897	11	—	—	—	—	339	528	—	—
1894-6	—	348	659	476	709	552	925	—	—

The average results at the foot of the table relate only to the three years in which all the ammoniacal manures were employed.

We have to recollect that not only the character of the season differed in each year, but also, to a very considerable extent, the localities on which the experiments were made;

no precise agreement is thus to be expected in the results obtained in different years.

It will be noticed that the addition of superphosphate to the ammonia salts generally increased the yield of corn, but by no means in every case the yield of straw. On individual farms, as those in Fifeshire in 1896, superphosphate had no beneficial effect.

The addition of potash salts produced generally a considerable increase of crop. It was noticed that the crop always stood up much better and ripened earlier where kainite and superphosphate had been employed. The proportion of light corn was also reduced by the use of kainite. When oats were grown after roots manured with dung the addition of potash salts appeared to be unnecessary, the dung supplying the potash needed by the crop. A double dressing of kainite was used in some cases without advantage.

In order to compare these Scotch results with those obtained at Rothamsted already quoted, we have calculated the increase obtained from 1 cwt. of sulphate of ammonia. This calculation, can, however, only be made in the case of the Scotch plots receiving sulphate of ammonia alone, as the experiments do not generally include plots receiving superphosphate and potash without ammonia salts.

AVERAGE RETURN FOR 1 CWT. OF SULPHATE OF AMMONIA.

	Corn bushels	Straw cwts.
1894	13·3	11·5
1895	10·1	5·3
1896	9·0	6·2
Mean	10·8	7·7

The return for sulphate of ammonia used alone is thus considerably better than that shown in the Rothamsted experiments with 200 lbs. of ammonia salts used alone, namely 6·4 bushels of corn and 4·3 cwts. of straw, and is about equal to the return obtained at Rothamsted when superphosphate and alkalies were added, namely 11·2 bushels of corn, and 7·5 cwts. of straw. The supply of phosphates and potash in land cultivated as an ordinary rotation is of course generally much superior to that found in land from which, as at Rothamsted, the whole of the produce has been systematically removed.

Wright has calculated the money profit per acre from the use of each manure, or mixture of manures, with the following result:—

Table XXIV.

Profit per acre from the application of Ammoniacal Manures to Oats.

	Sulphate of Ammonia alone.			Sulphate of Ammonia and Superphosphate.			Sulphate of Ammonia, Superphosphate and Potash salts.		
	£	s.	d.	£	s.	d.	£	s.	d.
1893		—		0	17	9		—	
1894	1	6	5	1	19	10	1	19	11
1895	0	13	7	0	12	8	0	10	6
1896	0	15	0	0	9	10	0	13	3
1897		—			—		0	7	11
1894-96	0	18	4	1	0	9	1	1	3

The amount of profit realised from any application of manures varies of course immensely in different seasons. It is not only influenced by the productiveness of the season, but by the market prices of the manure used, and of the corn and straw which form the saleable product. In each season, however, the use of ¾ cwt. of sulphate of ammonia for oats on lea land shows a distinct profit, and the profit increases when superphosphate, and superphosphate and kainite are used in addition.

In 1897, one of the experimental plots received a double dressing of sulphate of ammonia, namely 1½ cwt. The extra amount of ammonia salt paid for its application, the double dressing yielding more than four bushels of dressed corn, and nearly five cwts. of straw, more than the single dressing.

Wright points out that the greater luxuriance of the oat crop resulting from artificial manuring tends to keep down weeds.

Farmyard manure was only used on some of the farms during these experiments. The return from 10 tons of farmyard manure was generally somewhat less than that from $\frac{3}{4}$ cwt. of sulphate of ammonia, with superphosphate and kainite.

3. **Influence of Ammonia on Quality.**—The higher weight per bushel obtained in the Rothamsted experiments, as a result of a complete manuring with ammonia salts, superphosphate and alkalies, has been already referred to; the same fact was observed in the Glasgow experiments. The weight per bushel was somewhat higher than when nitrate of soda was employed.

Determinations of nitrogen made at Rothamsted in oat corn and straw, grown with and without ammonia salts (Watts' *Dictionary of Chemistry*, *Second Supplement*, Oats, p. 867), enable us to calculate the average percentage of albuminoids which they contained. Osborne's factor has been used in calculating the albuminoids of the grain.

ALBUMINOIDS IN 100 DRY MATTER.

	Corn	Straw
Cinereal manures	11·1	2·9
Cinereals and Ammonia salts 400 lbs.	12·3	3·0

We have here, as in the experiments with other cereal crops already quoted, a distinct increase in the percentage of albuminoids in the grain resulting from the use of ammonia salts as manure.

4. **Practical Remarks.**—As the oat plant is capable of ripening its grain in a cool, wet summer, the crop is much cultivated in Scotland, and in the North of England. In such localities it may take the place in the rotation which is occupied by wheat in a southern climate, and it is frequently grown after grass seeds and clover. At other times, and frequently in the south, the oat crop may take the place usually allotted to barley, and may follow roots, or wheat. Much that has been already said under the heads of wheat and barley might therefore be repeated here. The manuring for the oat crop must clearly be regulated in each case by the condition of the land, determined by its previous history, cropping and man-

uring. The Scotch experiments furnish an abundant supply of facts as to the profitable manuring of oats grown after lea. If we may assume that the return from 1 cwt. of sulphate of ammonia would be at the same rate as that found for $\frac{3}{4}$ cwt. in four years' experiments carried out on 53 farms, we should conclude that a dressing of 1 cwt. sulphate of ammonia, with 2 cwt. superphosphate, and 2 cwt of kainite, would, on an average, increase the crop by about 15 bushels of corn (reckoned at 42 lbs. a bushel), and nearly 10 cwt. of straw. When a good dressing of farmyard manure has been applied to the preceding crop, the kainite may generally be omitted.

If oats follow another corn crop, not manured with farmyard manure, the dressing of sulphate of ammonia may be increased to 2 cwts., or to a still larger quantity, and 3 cwts. of superphosphate and 4 cwts. of kainite be used with it.

The ammonia salt will be best applied to the land before sowing the seed; this plan has proved successful both in the Rothamsted and Scotch experiments.

GRASS LAND

In the case of a hay meadow, a pasture, or of land temporarily laid down with grass seeds and clover, the results produced by the application of manures are extremely complex. We have no longer to do with a single species of plant, as in the case of our other farm crops, but with a mixture of species belonging to very different botanical classes. These various plants are very differently affected by different manures. If any manure is applied to a previously unmanured meadow some marked change in the herbage is sure to occur; and if different parts of the same grass land are persistently treated with different manures, the differences in the nature of the plants appearing on the various portions become soon so marked that it is difficult to believe that the whole meadow was originally covered with the same herbage. Any one who has visited the grass plots at Rothamsted shortly before the hay is cut, will not have forgotten the marvellous differences which the continuous application of particular manures has effected. The unmanured plot is the one which exhibits the greatest variety of herbage. Every manure tends to simplify the produce, one or more species of plant becoming prominent, while other species disappear.

As different manures thus produce hay of a different botanical character, it becomes difficult to ascertain with accuracy the comparative value of particular manures, the mere weight of hay obtained being insufficient to answer the question.

It may be stated generally that the use of lime, chalk, or of cinereal manures supplying potash, tends greatly to increase the proportion of leguminous plants, as white clover, red clover, trefoil, and meadow vetchling; while a heavy dressing of nitrogenous manure, and especially of ammonia salts, applied with or without ash constituents, tends, on the other hand, to the development of a purely grass herbage, the clovers, vetches, and some of the weeds, disappearing.

In a pasture, a liberal development of the clovers, with an absence of weeds, constitutes the highest class of herbage, the one having the greatest feeding value for stock; to apply ammonia salts to such a pasture would entirely spoil it. In a hay meadow the case is quite different; here the weight of the hay crop is the primary object, and a heavy weight of hay is only to be obtained by a luxuriant growth of grass, for the production of which ammonia salts are well fitted. Temporary grass land, in the case of which there is no time to develop a fine pasture, may also often be advantageously treated with ammonia salts.

1. **Experiments at Rothamsted.**—A portion of the Old Park, which has certainly been in grass for three centuries, is divided into plots, and has been treated continuously with various manures since 1856. The superphosphate and the alkali salts are usually applied as a top-dressing in January, the 400 lbs. of ammonia salts are put on towards the end of February.

Owing to the small percentage of carbonate of lime originally in the soil, and its removal by the ammonia salts (see p. 27), it has become necessary in the later years of the experiment to apply lime to the land. A preliminary trial with chalk at one end of some of the plots was made in 1881. In November, 1883, lime was applied to one half of all the plots; and in November 1887, lime was applied to the remaining halves, except in the case of plot 5, one half of which remained without lime till 1896. The weights of hay given in the following table are the mean produce of both halves of each plot.

During the first 19 years of the experiment only a single cutting of hay was taken; the autumn growth was either fed off by sheep receiving no other food, or was occasionally cut and spread on the land. From 1877 to the present time the second growth has generally been made into hay; when weather did not permit of this it has been cut and weighed, and the dry matter determined in the laboratory, from which its equivalent in hay has been calculated. In Table XXV (p. 84) the produce given for the first 20 years is the weight of the first or main crop of hay; for the second 20 years the weight of hay in both first and second crops is given.

The produce of the unmanured plot, and of that receiving superphosphate only, is seen to have been very moderate, amounting in the first twenty years to an average of 21-22 cwts. of hay per acre, and in the second twenty years, in which the autumn growth is included, to 25-26 cwts. per acre.

When salts of potash, soda, and magnesia are added to the superphosphate, there is a large rise in the produce, the average for the first twenty years being 35 cwts., and for the second twenty years 44 cwts. This remarkable crop, obtained without any nitrogenous manure, is due to the extraordinary development of leguminous herbage produced by the mixture of alkalies and superphosphate. Agriculturists are now familiar with the fact that leguminous plants obtain a great part of the nitrogen which they require from the atmosphere. Nor do they obtain this nitrogen for themselves alone, for the annual decay of the leguminous plants enriches the soil with nitrogenous matter which can be made use of by the grasses, and by other plants which are themselves unable to feed on atmospheric nitrogen. The independence of a clover crop of nitrogenous manure, and

TABLE XXV.

PRODUCE OF MEADOW HAY, VARIOUSLY MANURED, AT ROTHAMSTED, DURING FORTY YEARS, 1856-95.

Plot.	Manures applied per Acre.	First Crops only.			First and Second Crops						
					Third 10 Years, 1876-85.			Fourth 10 Years, 1886-95.			
		First 10 Years, 1856-65.	Second 10 Years, 1866-75.	Average 20 Years, 1856-75.	1st Crop.	2nd Crop.	Total.	1st Crop	2nd Crop.	Total.	Average 20 Years, 1876-95.
		cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts	cwts.	cwts.	cwts.
3	No manure	22·5	20·0	21·2	17·6	9·6	27·2	16·6	7·8	24·4	25·8
4[1]	Superphosphate	23·2	21·2	22·2	19·1	10·2	29·3	16·4	7·5	23·9	26·6
7	Superphosphate and Alkalies	33·8	36·7	35·2	34·0	14·7	48·7	25·5	14·2	39·7	44·2
9	Superphosphate, Alkalies, Ammonia salts, 400 lbs. ...	53·6	48·5	51·0	50·3	17·3	67·7	39·3	14·3	53·6	60·7
13	Superphosphate, Alkalies, Ammonia salts, 400 lbs. and 2000 lbs. chopped Wheat straw	55·2	59·6	57·5	54·2	22·3	76·6	44·8	18·4	63·2	69·9
10	Superphosphate, Soda, Magnesia, Ammonia salts, 400 lbs.	—	39·6	—	38·6	18·1	56·7	35·6	13·1	48·7	52·7
4[2]	Superphosphate, Ammonia salts, 400 lbs.	33·8	30·5	32·2	30·3	12·9	43·2	29·1	8·9	38·0	40·6
5	Ammonia salts, 400 lbs.	30·5	22·0	26·2	17.6	12·6	30·2	16·9	7·3	24·2	27·2

The Superphosphate is 3½ cwts. per acre. The Alkali salts up to 1878 were composed of 300 lbs. Sulphate of Potash, 200 lbs. Sulphate of Soda and 100 lbs. Sulphate of Magnesia. From 1879 to the present time the Sulphate of Potash has been raised to 500 lbs. per acre. The Ammonia salts are a mixture of equal parts Sulphate and Chloride.

the nourishment of wheat by a previous crop of clover, are facts which have been long known to farmers; the cause of these facts is now made clear by the evidence supplied by scientific investigations that leguminous plants assimilate the free nitrogen of the air. We have, in fact, to regard plot 7 as manured with nitrogen from the atmosphere.

When 400 lbs. of ammonia salts are applied, as well as the ash constituents used on plot 7, the crop rises to 51 cwts. as the average of the first twenty years, and to 60·7 cwts. as the average of the second twenty years, including the autumn growth. The crop on plot 9 is entirely different in character from that grown on the unmanured plot, and from that grown on plot 7 with a manuring of ash constituents. The unmanured hay contains only 65-70 per cent. of true grasses, about 7 per cent of clovers and vetches, and 20-25 per cent. of weeds. The produce on plot 7 may contain 23 per cent. of clovers and vetches, the proportion varying in different seasons. The produce on plot 9 contains no clovers or vetches, the weeds are much diminished, and the true grasses form about 90 per cent of the hay. The action of ammonia salts is thus to develop the grasses to the exclusion of all other forms of herbage.

Plot 10 received the same supply of ash constituents and ammonia salts as plot 9 during the first six years, but since then the sulphate of potash has been omitted. It will be seen that the omission of potash occasions a diminution in the crop amounting to 8 cwts. of hay per acre.

On plot 4^2 we have the produce of superphosphate with ammonia salts. The omission of all alkali salts from the manure occasions a falling off of 20 cwts. in the crop of hay obtained. Alkali salts have thus an importance as a manure for grass far greater than is usually observed in the case of other crops; the short roots of grass doubtless limit its power of obtaining ash constituents from the soil.

When ammonia salts are applied alone, as on plot 5, the increase obtained over the unmanured plot becomes very small, amounting to only 8 cwts. of hay per acre in the first ten years, and to nothing as the average of the fourth ten years. Thus, on the Rothamsted old park land, ammonia salts were without permanent value as a manure, unless phosphates and alkalies were supplied with them.

The best return from the application of ammonia salts to the grass is that given by plot 13. Here the same quantities of manure are applied as on plot 9, and in addition 2,000 lbs. of chopped wheat straw per acre. The average produce of the first twenty years is 57·5 cwts, and of the second twenty years 69·9 cwts. of hay. Thus, including the second crop, the manure gives an annual increase of 44·1 cwts. of hay over that given by the unmanured plot. The quality of the hay has been much superior to that on plot 9.

Return for Ammonia applied.—There are great difficulties in expressing by figures the return given by ammonia salts in these grass experiments. We can calculate the return on the inferior plots, but materials are wanting for a calculation of the return obtained on such plots as 9 and 13.

When ammonia salts are applied alone, we have in the first ten years an increase over the unmanured plot of 8 cwts. of hay, which is at the rate of 2·2 cwts. of hay for 1 cwt. of sulphate of ammonia applied. As the experiment progresses even this small return entirely disappears.

When the ammonia salts are applied with superphosphate, the increase over the crop given by superphosphate alone represents a return of 2·8 cwts. of hay for 1 cwt. of sulphate of ammonia during the first twenty years of the experiment, and a return of 3·6 cwts. of hay during the second twenty years, when the second crop of hay is included.

When we come to the much larger crop obtained when ammonia salts are used with alkalies and superphosphate we are no longer able to calculate satisfactorily the return given by the ammonia. We cannot deduct the produce of plot 7 from that of plot 9 to obtain the wished for result, because, as we have already seen, the produce on plot 7 is not the produce of cinereal manures alone, but the produce of cinereal manures plus nitrogen obtained from the air. On plot 9 there is no corresponding assimilation of atmospheric nitrogen, as there are no clovers or vetches on this plot. The nearest result to the truth we can obtain is got by taking the produce by superphosphate alone as representing the produce of ash constituents without ammonia. Proceeding thus, we have a return of 7·9 cwts. of hay for 1 cwt. of sulphate of ammonia during the first twenty years, and a return of 8·8 cwts. in the second twenty years, when the autumn made hay is included. These figures are of course more or less above the true return from the ammonia on plot 9, they are possibly, however, not too high for the return on plot 13, where the crop is considerably larger for the same amount of ammonia applied.

We may, if we like, ascertain the practical value of the ammonia salts and ash constituents applied to plot 9 by comparing the cost of the manure per acre with the value of the hay obtained. The increase of hay on plot 9 over the unmanured produce is represented by nearly 30 cwts. per acre during the first twenty years of the experiment. In the second twenty years the increase is 27·7 cwts. in the first crop, and 7·2 cwts. in the second crop, the total increase being nearly 35 cwts. We can hardly value the increase of hay on this plot at less than £5 an acre. The Rothamsted manures are not selected for their cheapness, the main object being to employ salts of definite composition. By using kainite we can, however, supply in one manure the potash, soda, and magnesia which are applied as distinct salts in the Rothamsted experiments. Substituting kainite for the alkali salts used at Rothamsted, the appropriate manure for plot 9 should not cost above 70-80 shillings per acre.

On plot 13 we have an increase over the unmanured produce of 36·3 cwts. during the first twenty years. In the second twenty years there is an increase of 32·4 cwts. in the first crop, and 11·6 cwts. in the second crop, or a total increase of 44 cwts. of hay. The money value of this hay we may probably place at £6. 10. 0. per acre. The manure applied is the same as that used on plot 9, with the addition of 2,000 lbs. of chopped straw per acre.

It is evident that on both plots there is a fair margin for profit. The character of the hay on plot 9 is moderately good, but that on plot 13 is better, and equal to all the requirements of the farmer.

The Rothamsted grass experiments excellently illustrate the many difficulties which attend the attempt to produce continuously crops of hay of good quality by means of artificial manures. They emphasize especially the necessity for an adequate supply of potash and phosphoric acid as essential both for the quantity and quality of the produce.

2. **Experiments at Cirencester.**—The experimental application of manures to a poor pasture at the Royal Agricultural College commenced in 1888, and has been continued down to the present time; the results are annually published in the *Agricultural Students' Gazette.* The superphosphate and kainite were each applied at the rate of 5 cwts. per acre. The dressing of sulphate of ammonia was 2 cwts. per acre. Farmyard manure was applied at the rate of 12 tons per acre.

The hay crop was not weighed in 1888 and 1893; the following table gives therefore the mean produce of nine years, 1889-2, 1894-98. The land was grazed by cattle in the autumn, the weights of hay thus refer to the first cutting only.

TABLE XXVI.

PRODUCE OF HAY VARIOUSLY MANURED AT CIRENCESTER. AVERAGE OF NINE YEARS.

Plot.	Manures applied.	Hay per acre, First Crop.
		cwts.
7	No manure	23·0
2	Kainite...	22·6
13	Superphosphate	25·3
5	Superphosphate and Kainite	30·3
8	Superphosphate, Kainite, Sulphate of Ammonia, 2 cwts.	37·7
4	Superphosphate, Sulphate Ammonia, 2 cwts. ...	37·8
11	Kainite, Sulphate of Ammonia, 2 cwts.	36·0
9	Sulphate of Ammonia, 2 cwts.	32·7
A & B	Farmyard manure, 12 tons...	37·2

The unmanured produce is almost the same as that at Rothamsted. Kainite and superphosphate, when applied separately, have very little effect, but when applied together there is a notable increase in the crop, the increase obtained is however not as great as that given at Rothamsted by the combined use of superphosphate and alkalies.

When we turn to the group of plots receiving ammonia salts we are met by the same fact which appeared in the barley experiments, namely, the comparatively small return obtained from the use of cinereal manures on the soil at Cirencester. The entire omission of alkali salts on plot 4 produces no diminution in the hay crop. The omission of superphosphate also produces very little effect. The entire omission of all cinereal manure reduces the crop by 5 cwts. At Rothamsted this omission produced an annual loss of 23·1 cwts. in the first ten years of the experiment.

The produce of hay by 12 tons of farmyard manure is on an average of nine years almost identical with that given by 2 cwts. of sulphate of ammonia and cinereals on plot 8.

Very little information is furnished by the Cirencester reports as to the botanical character of the herbage on the various plots.

The return for the ammonia applied is 4·9 cwts. of hay for 1 cwt. of sulphate of ammonia when this salt is used alone, and 6·3 cwts. of hay when the salt is used with superphosphate. As in these experiments the effect of alkali salts is very small, we may take the last named figure as representing the best return from the ammonia salts in these experiments.

3. **Experiments at Pumpherston.**—Trials of the effects of very various manures on the mixed herbage of land just laid down to grass have been conducted by Dr. A. P. Aitken at Pumpherston, the results are published in the *Transactions of the Highland and Agricultural Society*. The land has been divided into plots, receiving pretty continuously the same manures since 1878. From 1878 to 1887 the land was cropped as a rotation. In 1887 grass and clover seeds were sown with the barley, and the land has since remained in grass. The mixture of seeds was one suitable for the formation of permanent grass.

From 1878 to 1885 the manures applied were at the rates of 160 lbs. of phosphoric acid, 120 lbs. of potash, and 80 lbs.

of nitrogen per acre. From 1886 to 1888 no manure was employed. In 1889 manures were applied to the grass at the rate of 60 lbs. phosphoric acid, 30 lbs. potash, and 36 lbs. ammonia per acre. In the years 1890 and 1891, the manuring was at the rate of 36 lbs. phosphoric acid, 36 lbs. potash, and 36 lbs. ammonia per acre. In 1892 and 1893 the potash was raised to 72 lbs. per acre. Throughout the whole of the experiments the same character of manure was maintained on each plot although the quantity varied.

The average produce of hay per acre in the five seasons in which the grass received manure is shown in Table XXVII. The Hay was in every case the first cutting, the second growth was apparently grazed.

Table XXVII.

Produce of Hay by various manures at Pumpherston. Average of Five years, 1889-93.

Plot.	Manures applied.	Hay per acre.	Return for 1 cwt Sulphate of Ammonia.
		cwts.	cwts.
27	No manure	10·7	—
12	Superphosphate	14·7	—
22	Sulphate of Potash	18·0	—
17	Superphosphate and Potash	23·2	—
14	Superphosphate, Potash, Sulphate of Ammonia, 156 lbs.	32·8	7·5

The seasons were generally unfavourable, and the crops of hay obtained were very small. We see, as at Rothamsted, the great effect produced on grass by a manure supplying superphosphate and potash salt only. A still greater effect is produced by the addition to this manure of a small dressing of sulphate of ammonia. In these experiments we are able to make a tolerable estimate of the return given by the ammonia salt. The hay produced on the plot receiving only phosphates and potash contained but 3 per cent of clover as the average of three years' botanical analyses; we may therefore deduct the produce of plot 17 from that obtained on plot 14, in order to obtain the return from the sulphate of ammonia, without incurring any serious error. The result is that the return has been at the rate of 7½ cwts. of hay for 1 cwt. of sulphate of ammonia applied. The return would doubtless have been better in better seasons.

In the report in the *Highland Transactions*, 1894, 385, the changes in the character of the herbage, produced by the use of various manures, are described in detail. In *Transactions* 1895, 423, are observations on the grazing of the manured land by cows and horses. The stock apparently were most eager to consume the herbage richest in clover.

4. Experiments on temporary Grass and Clover.— The effect of ammoniacal manures on the mixed rye-grass and clover, sown in the course of an ordinary Scotch rotation, has been made the subject of experiment by Professor Wright. The trials were made in 1897 on five farms in Dumbartonshire. The manures used were basic slag 4 cwts.; superphosphate 416 lbs.; muriate of potash 2 cwts.; sulphate of ammonia 88 lbs.; farmyard manure 10 tons. The average weights of hay obtained at the first cutting were as follows :—

TABLE XXVIII.

PRODUCE OF RYE GRASS AND CLOVER BY VARIOUS MANURES ON FIVE FARMS IN DUMBARTONSHIRE, 1897.

Manures applied.	Hay per acre, First Crop.
	cwts.
No manure	26·7
Basic Slag and Potash salt	33·2
Basic Slag, Potash, Sulphate of Ammonia, 88 lbs.	38·0
Superphosphate, Potash, Sulphate of Ammonia, 88 lbs. ...	39·7
Sulphate of Ammonia, 88 lbs.	36·2
Farmyard manure, 10 tons	35·7

The return here from the manure applied is very good, and one that will encourage many farmers to apply manure to their seeds. The mixture of basic slag and potash salt produced a wonderful growth of clover, especially in the aftermath. The sulphate of ammonia applied alone gave an excellent return, amounting to 12 cwts. of hay per 1 cwt. of sulphate. The largest crop was reached when superphosphate and potash salt were added to the sulphate of ammonia.

On two of the farms the second crop of hay was weighed; in these cases the author has calculated the profit per acre resulting from the use of the various manures.

TABLE XXIX.

PROFIT PER ACRE FROM APPLICATION OF MANURES TO RYE GRASS AND CLOVER, MEAN OF TWO FARMS, 1897.

Manures applied.	Profit.		
	£	s.	d.
Basic Slag and Potash salt	0	11	6
Basic Slag, Potash, Sulphate of Ammonia, 88 lbs. ...	1	2	7
Superphosphate, Potash, Sulphate Ammonia, 88 lbs. ...	1	10	8
Sulphate of Ammonia, 88 lbs.	1	3	1

It will be noticed that the greatest profit was obtained when a mixture of superphosphate, muriate of potash, and sulphate of ammonia was made use of. In these calculations the cost of the whole of the manures applied, and not of the ammonia salt only, is taken into the account.

5. Influence of Ammonia Salts on the Composition of Hay.—The effect which manuring with ammonia salts has on the quality of the hay has been already noticed in part. We have seen that ammoniacal manures tend strongly to increase the proportion of the true grasses, and to reduce the proportion of clover and weeds. This effect is not very marked when only small quantities of ammonia salts are applied, as in the experiments at Pumpherston, but becomes very striking when considerable quantities are used every year, as in the Rothamsted experiments.

The presence or absence of a full supply of the ash constituents of grass determines a marked difference on the plots receiving ammonia salts. Where ash constituents are absent the growth of grass is practically limited to the production of leaf; where ash constituents are liberally supplied there is, on the contrary, a vigorous production of flowering stems. This difference in the development of the grass considerably affects its chemical composition. The leaf is the part of an immature plant which is richest in nitrogenous matter, the stem is the part poorest in such constituents. The leafy, ill developed herbage, thus always contains a larger percentage of nitrogenous matter.

The percentages of nitrogenous matter, and of total ash constituents, have been determined in the experimental hay at Rothamsted during many years. The average percentages found in the hay of some of the plots during the first 18 years of the experiments (Watt's *Dictionary of Chemistry, 2nd Supplement*, p. 528) are given in the following table:—

TABLE XXX.

PERCENTAGE OF NITROGENOUS MATTER AND ASH IN HAY, VARIOUSLY MANURED AT ROTHAMSTED, AVERAGE OF EIGHTEEN YEARS, 1856-73.

Plot.	Manures applied to Hay.	Per cent. in Dry Matter.	
		Total Ash.	Nitrogenous Matter. (N. x 6·25).
3	No manure	6·8	10·5
5	Ammonia salts, 400 lbs.	5·9	13·5
9	Cinereals, Ammonia salts, 400 lbs. ...	7·1	9·6
11	Cinereals, Ammonia salts, 800 lbs. ...	7·2	12·2

We have here the apparently curious fact that the hay grown with ammonia salts, superphosphate, and alkali salts, on plot 9, contains a smaller percentage of nitrogenous matter than the hay of the unmanured plot which has received no ammonia. The cause of this has been already noticed. The cinereals and ammonia salts produce a very large crop, averaging 52 cwts. of hay in the 18 years in question. The nitrogen assimilated from the manure is distributed in this great bulk of produce, so that its proportion in the whole becomes small. The same quantity of ammonia salts applied alone gave only 27 cwts. of hay; here the percentage of nitrogen is at its maximum. When the quantity of ammonia applied is doubled, as on plot 11, the percentage of nitrogenous matter rises considerably over that shown by plot 9.

The increase of nitrogenous matter on plots 5 and 11 probably improves little if at all the feeding quality of the hay. The nitrogenous matter will in these cases consist to a more than ordinary extent of amides, and is accompanied by a lack of development of sugar. The stemy herbage produced on plot 9 requires, on the other hand, careful management; it should be cut before it gets too ripe if hay of good feeding quality is to be obtained.

6. Practical Remarks.—We have already stated that ammonia salts are not to be recommended as a manure for good pasture land, as their use is inconsistent with the production of the highest quality of herbage. To maintain a high quality of herbage we have to maintain in the soil a liberal supply of the ash constituents of grass and clover; of these ash constituents potash is generally the most required. Nitrogen is best supplied in an organic form, a slowly acting manure disturbing the growth of clover far less than either sulphate of ammonia or nitrate of soda. The feeding of cake on the land; a dressing of well rotted farmyard manure; or the application of fish-guano, or horndust, will enrich the pasture with nitrogenous food without deteriorating the herbage.

On hay meadows sulphate of ammonia may be very useful if the soil contains a fair amount of lime. The salt should not be used alone, but phosphates and potash salts should be applied with it, excepting in the case of exceptional soils, as that at Cirencester. An autumn dressing of 2 cwts. of basic slag, and a spring dressing of 3-4 cwts. of kainite, and 2 cwts. of sulphate of ammonia, would generally be found to give good results. The return obtained from the use of 1 cwt. of sulphate of ammonia, with ash constituents, is fairly equal in the various experiments we have quoted, being 7·9 cwts. of hay at Rothamsted, 6·3 cwts. at Cirencester, and 7·5 cwts. at Pumpherston, or an average of 7¼ cwts. These figures refer to the first crop only. We should therefore expect that the manure recommended above would yield an increase of 14-15 cwts. of hay in the first or main crop, it would also make an addition of about 2 cwts. of hay to the aftermath. Both at Rothamsted, and on the farms in Dumbartonshire, sulphate of ammonia has given a distinctly heavier after math than nitrate of soda.

In the case of the rye grass and clover grown in a rotation, the use of ammoniacal manure can be still more confidently recommended. A mixture of 3 cwts. of kainite, 2 cwts. of superphosphate, and 1 cwt. of sulphate of ammonia, employed as a spring dressing, should give excellent results. The experiments made in Dumbartonshire would lead us to expect a return of at least 14 cwts. of hay from such manuring, but the crops obtained in a single season can not be taken as safely indicating what may be generally expected.

POTATOES

1. **Experiments at Rothamsted.**—The field experiments with potatoes commenced in 1876, and have been continued down to the present time. The land had previously been cropped for nineteen years with wheat, experimentally manured. The manures applied to the potato plots were generally similar in character to those previously employed when the land was under wheat, the potato experiments thus started with the soil of each plot in a special condition as to the accumulation or exhaustion of particular elements of plant food. The only exception we have to note is plot 3, which had previously been unmanured, but afterwards received farmyard manure and superphosphate for the potatoes.

The cinereal manures applied to the potatoes were superphosphate 3½ cwts, and alkali salts containing 300 lbs. sulphate of potash, 100 lbs. sulphate of soda, and 100 lbs. sulphate of magnesia per acre. The ammonia salts consisted of 400 lbs. of equal parts sulphate and chloride.

The whole of the manures are applied to the land in March or April, after the land has been ploughed and harrowed. After broadcasting the manures, the land is again harrowed, and then bouted; the potatoes are then sown in the furrow, which is lastly converted into a ridge. On the farmyard manure plots the dung is laid in the furrow before planting the potatoes.

The kinds of potatoes grown during the experiments were:- Rock, four years; Champion, eleven years; Abundance, five years.

The results yielded by the various manures during 20 years are given in Table XXXI.

TABLE XXXI.

PRODUCE OF POTATOES VARIOUSLY MANURED AT ROTHAMSTED DURING TWENTY YEARS, 1876—95.

Plot.	Manures applied.	First 10 Years, 1876-85.		Second 10 Years, 1886-95.		Return for 1 cwt Sulphate of Ammonia.	
						1st 10 Years.	2nd 10 Years
		tons.	cwts.	tons.	cwts.	cwts.	cwts.
1	No manure	2	3·1	1	0	—	—
10	Superphosphate & Alkalies	4	1·0	2	12·5	—	—
7	Superphosphate, Alkalies, Ammonia salts, 400 lbs.	7	5·4	4	12·9	16·7	10·3
5	Ammonia salts, 400 lbs.	2	8·9	1	8·5	1·5	2·2
3	Farmyard manure, 14 tons	5	3·9	5	0·5	—	—

We see from the results in the table that the produce on every plot has very considerably fallen off in the course of the experiment, except in the case of the plot receiving farmyard manure each year. The explanation is probably to be found in the fact that the potato is a crop which leaves scarcely any residue of vegetable matter in the soil. By the continuous cultivation of potatoes with purely artificial manures the soil thus loses its stock of humus, and where the soil is heavy, as at Rothamsted, it gradually deteriorates in physical condition. The results obtained during the first ten years of the experiment will represent best the return from manures which may be expected with an ordinary agricultural condition of the land, and to this portion of the results we shall therefore chiefly refer.

The increase given by a full supply of ash constituents alone (plot 10) is seen to be very considerable, amounting in the first ten years to 38 cwts. of potatoes. We have in this case, as in the barley and oat experiments, a considerable supply of nitrogen from the soil made available to the crop by spring and summer tillage.

By adding 400 lbs. of ammonia salts to the superphosphate and alkali salts we obtain a further increase of 64 cwts. of potatoes, or a return of over 16 cwts. for 1 cwt. of sulphate of ammonia employed. This is a highly profitable result. The crop obtained on this plot (plot 7) exceeds by more than 2 tons the crop given by 14 tons of farmyard manure on plot 3. The farmyard manure plot received superphosphate as well as dung during the first seven years of the experiment.

The need of a full supply of ash constituents if ammonia salts are to be used with profit is most strikingly shown by the crop on plot 5, which receives ammonia salts without ash constituents; the produce here scarcely exceeds that of the permanently unmanured land. A result of this kind is of course due to the exhaustion of the available potash and phosphates in the soil during the preceding experiments with wheat.

Influence of Climate.—The return from the ammonia salts is still better in a fine season. In the next table will be found the average produce of the plots already mentioned in the years 1878 and 1881. The potatoes grown in 1878 were the Rock, in 1881 the Champion.

TABLE XXXII.

AVERAGE PRODUCE OF POTATOES VARIOUSLY MANURED AT ROTHAMSTED, SEASONS 1871 AND 1881.

Plot.	Manures applied.	Average Produce, 1878 & 1881.		Return for 1 cwt. Sulphate of Ammonia.
		tons.	cwts.	cwts.
1	No manure	2	9·1	—
10	Superphosphate and Alkalies ...	5	0·1	—
7	Superphosphate, Alkalies, Ammonia salts, 400 lbs....	9	16·6	25·0
5	Ammonia salts, 400 lbs.	3	0·5	3·0
3	Farmyard manure, Superphosphate	7	2·7	—

We have thus in these fine seasons a return of 25 cwts. of potatoes for 1 cwt. of sulphate of ammonia.

2. **The Glasgow Experiments.**—Experiments on the potato crop, grown in its ordinary place in a Scotch rotation, have been carried out during three years, 1895-97, on several series of farms. The results are of considerable practical importance, though, from the absence of plots receiving only cinereal manures, it is only rarely possible to ascertain the exact return obtained from the sulphate of ammonia employed.

The great importance of potash salts as an ingredient of a potato manure is abundantly illustrated. The addition of 2 cwts. of sulphate of potash to a manure consisting of sulphate of ammonia and superphosphate increased the weight of dressed saleable potatoes by 9¼ cwts. on two farms in 1895; by 19¼ cwts. on two other farms in 1896; and by 27 cwts. on twelve farms in 1897. In the 1897 experiments, the addition of 4 cwts. of superphosphate, and 1 cwt. of sulphate of ammonia, to 15 tons of farmyard manure, increased the average yield of saleable potatoes by only 4¾ cwts., while a further addition of 1 cwt. sulphate of potash increased the produce by 14 cwts.

In each series of experiments farmyard manure has been applied alone, we are thus able to compare its effect with that given by ammoniacal manures. In the experiments on twelve farms in 1897, the saleable potatoes obtained from 2 cwts. sulphate of ammonia, 2 cwts. sulphate of potash, and 6 cwts. of superphosphate, were only 3¼ cwts. per acre less than those produced by 15 tons of dung. When 700 lbs. of kainite were substituted for the sulphate of potash, the ammoniacal manure beat the dung by 8¼ cwts. On two farms in 1896, 3 cwts sulphate of ammonia, 2 cwts. sulphate of potash, and 6 cwts. superphosphate, produced 22 cwts. more saleable potatoes than 20 tons of dung.

The Glasgow experiments also furnish examples of the increase over an unmanured crop which may be obtained by the use of ammoniacal manures when no dung is employed. On twelve farms in 1897, the use of 2 cwts. sulphate of ammonia, 6 cwts. superphosphate, and 700 lbs. of kainite, increased the yield of saleable potatoes by 3 tons. On two farms in 1896, the use of 3 cwts. sulphate of ammonia, 6 cwts. superphosphate, and 2 cwts. sulphate of potash, produced an increase of 3½ tons of saleable potatoes. These are profitable results.

3. Influence of Ammoniacal Manures on Quality. The quality of a potato crop depends on the size and shape of the tubers, their freedom from disease, and on their character when cooked. When potatoes are grown, as they frequently are on the continent, for distillery purposes, their value depends on the percentage of starch which they contain. This particular of their composition is also intimately connected with their general value as food. The potato richest in starch will be the one containing the smallest proportion of water, and the one which will yield a dry, floury vegetable when boiled.

Many particulars as to the quality and composition of the potatoes grown with various manures have been regularly determined at Rothamsted. We take as our examples the average results for twelve years, 1876-87, given by Sir J. H. Gilbert in the *Agricultural Students' Gazette*, 1888, 29.

Any manure which furnishes a good supply of ash constituents, and thus allows the tuber thoroughly to mature, will give a greater proportion of large, saleable potatoes, than a manure in which the supply of potash and phosphate is deficient. The average results of twelve years at Rothamsted show that 90 per cent of the crop on plot 10, with superphosphate and alkalies, were good, saleable potatoes; nearly 89 per cent on plot 3, receiving farmyard manure, with superphosphate in the earlier years; 88½ per cent on plot 7, manured with ammonia salts, and a full supply of ash constituents; 84 per cent on plot 1, without manure; and 82 per cent on plot 5, receiving ammonia salts without ash constituents.

The proportion of diseased potatoes seems generally to follow pretty closely the bulk of the crop, the heaviest crop suffering most. On an average of 12 years, 3·2 per cent of the potatoes on the unmanured plot were diseased; 3·5 per cent on plot 10, with cinereals only; 4·9 per cent on plot 3, with farmyard manure; and 6·3 per cent on plot 7, with ammonia salts and cinereal manure.

No determinations of starch have been made at Rothamsted in the experimental potatoes, but the specific gravity of the potatoes, and the percentage of dry matter which they contain, both of which characters follow the proportion of starch, have been regularly determined. The following table shows the results of the determinations just referred to, and also the percentage of ash, and nitrogen, found in the dry matter.

Table XXXIII.

Composition of Potatoes grown with various manures at Rothamsted, average of Twelve Years, 1876—87.

Manures applied.	Specific Gravity.	Dry Matter.	In 100 Dry Matter.	
			Ash.	Nitrogen.
		per cent.	per cent.	per cent.
No manure	1·118	28·1	3·02	1·19
Superphosphate & Alkalies	1·114	26·5	4·21	0·89
Superphosphate, Alkalies, Ammonia salts, 400 lbs.	1·104	25·6	4·00	1·25
Ammonia salts, 400 lbs.	1·110	26·2	2·96	1·46
Farmyard manure, 14 tons	1·108	25·9	3·87	1·13

It will be observed that the specific gravity, and the percentage of dry matter rise and fall together. In each case the unmanured tuber is the one which stands highest in the scale in these respects. With each addition to the bulk of the crop the composition of the tuber becomes somewhat more watery.

The proportion of ash is naturally highest where only ash constituents have been supplied, and lowest where ammonia salts have been used without any supply of cinereals.

The proportion of nitrogenous matter naturally follows an inverse order to the ash, being highest where ammonia salts are used alone, and lowest with the purely cinereal manure. In the case of plots 3 and 7, receiving a well-balanced manure, supplying both nitrogen and ash constituents, there is neither an excess or deficiency of nitrogenous matter in the tuber.

The composition of the potatoes grown with sulphate of ammonia, superphosphate and alkalies, is seen to be almost identical with the composition of those grown with farmyard manure and some superphosphate. The chemical composition of potatoes is by no means so greatly affected by the conditions of manuring as the composition of mangel wurzel.

That the best results as to quality are obtained from the use of a well-balanced manure, may be further illustrated from one of the Glasgow experiments, in which a second early variety of potatoes was grown in an ordinary rotation after grass seeds. Many varying proportions of sulphate of ammonia, superphosphate, and sulphate of potash, were tried. The crops obtained were heavy, several exceeding 10 tons per acre. The best quality of saleable potatoes was obtained from manure containing 2½ cwts. sulphate of ammonia, 7 cwts. superphosphate, and 2 cwts. sulphate of potash. When the sulphate of ammonia was raised to 3½ cwts. the crop was considerably increased, but the quality of the potatoes distinctly deteriorated. Professor Campell, who conducted the experiments, concludes that a corresponding increase of potash and superphosphate should accompany any increase in the ammonia.

4. **Practical Remarks.**—The potato is a plant yielding a small crop of high feeding quality. Being a favourite article of human food it fetches a relatively high price, and its culture is for this reason often extremely profitable. Its roots being confined to the surface soil, it requires an abundance of available plant food in its immediate vicinity if a good crop is to be obtained. In order that the plant food present should give a good return, it is essential that the surface soil should be in a condition of fine tilth.

The potato crop is one that especially flourishes in a soil containing a considerable proportion of humus. The presence of this humus ensures the possession by the soil of the favourable physical condition which the potato especially requires; the humus will also increase the availability for the crop of the phosphates and potash in the soil. Farmyard manure has always been the favourite manure for the potato crop.

When the potato crop is grown upon land which has been in grass for a couple of years, the soil will be fairly supplied with humus, and the farmer need have little fear of obtaining the necessary fine tilth for the potatoes. The crop may then be successfully grown with artificials without the use of farmyard manure. Success would equally attend the cultivation with artificial manures on any kindly loam, unless the season was one of unusual drought.

The requirements of a potato crop for plant food are very much less than those of a crop of mangel, but the quantity of manure needed for potatoes is by no means so different as would appear from this consideration, the mangel crop being able to feed itself from the subsoil, while the potato derives nourishment from the surface soil only. If early potatoes are grown, an ample supply of food becomes still more necessary, owing to the short period allowed for growth.

Potatoes grown on lea land will not require the quantities of manure used at Rothamsted to yield a good produce. In the Glasgow experiments, the application of 2 cwts. sulphate of ammonia, 6 cwts. of superphosphate, and 2 cwts. sulphate of potash, without dung, gave an average crop on twelve farms of 5 tons 12 cwts. of saleable potatoes. If, on the other hand, it is desired to grow potatoes on land which has been repeatedly cropped with corn without farmyard manure, the Rothamsted mixture might be employed, with an increase in the superphosphate, as that used at Rothamsted is of very high quality. The manuring might then be 3½ cwts. sulphate of ammonia, 6 cwts. superphosphate, and 3 cwts. sulphate of potash.

When farmyard manure is employed the quantity of artificial manure will of course be reduced. For early potatoes it is usual to employ a very heavy dressing of dung, which doubtless does somewhat to raise the temperature of the soil. As very early maturity is in this case desired rather than the production of a large crop, it may be questioned whether ammonia salts are not better omitted, and superphosphate and potash salts be made the only addition to the dung. Experience must decide whether a small quantity of sulphate of ammonia is, or is not, beneficial. For the later varieties of potatoes, there is no doubt that sulphate of ammonia may be added with profit to land receiving farmyard manure, if superphosphate and potash are also employed. In experiments made in 1897 on 21 farms in Scotland, Northumberland, and Yorkshire, the average return from 1 cwt. of sulphate of ammonia, added to a dressing of farmyard manure, was 12 cwts. of saleable potatoes. Superphosphate and potash salts were used in all cases. When sulphate of ammonia and dung are used for the same crop, the former should first be mixed with the soil with the superphosphate and potash salt, and the dung finally placed in the furrow which is to receive the potatoes. The dung used should have been well rotted. In the case of very heavy land it would probably be best to plough in the dung in the autumn, as a much better tilth would then be obtained in spring.

SUGAR BEET

Sulphate of ammonia has been largely employed in Germany, Austria, France, and Belgium as a manure for the variety of beetroot from which sugar is manufactured. For manufacturing purposes it is desirable that the sap of the roots should contain as large a proportion of sugar, and as small a proportion of other soluble substances as possible. The larger is the percentage of sugar, the greater is the proportion which can be obtained in a crystallised saleable condition. For this reason some factories refuse to purchase roots containing less than 10 per cent. of sugar. Owing to the facts just mentioned, it becomes necessary in the cultivation of sugar-beet to aim at the production of roots of high quality, instead of the production of a heavy crop per acre.

The richness in sugar which is desired is obtained by cultivating varieties of beet specially selected for this quality; by growing the roots near to each other, and thus reducing their individual weight, which should not exceed 2 lbs.; and finally by employing only moderate dressings of manure. An average crop of French or German sugar-beet does not exceed 11 to 12 tons per acre. On a well managed farm it is possible at the present day to obtain 14 to 16 tons of good roots per acre, containing 14-15 per cent of sugar. The richness of the crop in sugar is considerably affected by the character of the season; maturity is essential to high quality.

The only systematic experiments made in this country upon the influence of manures on the production of sugar-beet are those conducted at Rothamsted (*Jour. Roy. Agri. Soc.* 1898, 344). In Table XXXIV will be found the average produce of roots and sugar, obtained on some of the plots during three years, 1871-73. The superphosphate was applied at the rate of 3½ cwts. per acre. Sulphate of potash was applied at the rate of 300 lbs. per acre. Plot 6, besides potash, received the sulphates of soda and magnesia. The whole of the manures, including the ammonia salts, were applied before the land was ridged and the seed sown.

TABLE XXXIV.

PRODUCE OF BEETROOTS AND SUGAR BY VARIOUS MANURES AT ROTHAMSTED, AVERAGE OF THREE YEARS, 1871-73.

Plots.	Manures applied.	Roots per Acre.	Sugar Produced.		
			Per cent. Roots.	Per Acre.	For 1 cwt. Sulph. of Amm.
		tons.		lbs.	lbs.
5	Superphosphate	5·9	13·1	1731	—
4 & 6	Superphosphate and Potash... ...	5·9	13·0	1704	—
4A & 6A	Superphosphate, Potash, Ammonia salts, 400 lbs.	15·0	12·2	4063	630
5A	Superphosphate, Ammonia salts, 400 lbs.	13·5	11·9	3563	490
1	Farmyard manure, 14 tons	16·3	11·8	4309	—
1A	Farmyard manure, Ammonia salts, 400 lbs.	22·3	10·8	5413	295

The use of 400 lbs. of ammonia salts is seen to have given an average increase of over 9 tons of roots when superphosphate and potash were also applied. When the potash is omitted (plot 5A) the increase by ammonia salts is only 7·6 tons.

The percentages of sugar found at Rothamsted are not so high as would be obtained at the present day in a good season. During the last 25 years a considerable improvement has been effected both in the sugar-producing character of the beetroot, and in the mode of its cultivation.

The very small crops yielded by the purely cinereal manures are seen to have contained the highest percentage of sugar. When ammonia salts are used with superphosphate and potash the percentage of sugar is but little diminished, while the quantity produced per acre is more than doubled. The profitable use of the ammonia salts is, however, plainly dependent on the supply of a potash manure, when that is omitted the return of sugar per unit of ammonia is considerably decreased. The addition of ammonia salts to farmyard manure increases the weight of the crop rather than the production of sugar; Plot 1A is indeed an example of the inferior quality of roots always obtained by over-manuring.

In the Rothamsted experiments nitrate of soda gave a larger produce per acre than a corresponding quantity of ammonia salts, but the roots grown with nitrate of soda contained a smaller percentage of sugar. Thus while the average percentages of sugar in the roots grown on plots 4A and 6A, and 5A, were 12·2 and 11·9, the percentages in the roots on the corresponding plots with nitrate of soda were 11·0 and 10·7.

In France the beetroots cultivated for sugar are grown in a three-course rotation of beets, wheat, oats. The land intended for beetroot receives farmyard manure at the rate of 14 tons per acre in September. The manure is ploughed in thus early to ensure its thorough decomposition in the soil. Next spring the land receives 3 to 5 cwts. of superphosphate, and if potash is needed 1½ cwt. of chloride of potassium, with either 2 to 3 cwts. of nitrate of soda, or 2 to 2½ cwts. of sulphate of ammonia. The seed is planted in rows 16 inches apart, and one plant is allowed to grow in each 10 or 12 inches in the row.

MANGEL WURZEL

This variety of beetroot is grown for cattle feeding and not for the manufacture of sugar; the object to be borne in mind in its cultivation is thus the production of a large amount of food per acre, and the percentage of sugar in the root becomes a matter of secondary importance.

In the soils and climates suitable to it, mangel is a crop of extremely vigorous growth, and when well supplied with food is capable of yielding an enormous produce. The quantity of ash constituents required to produce a large crop of mangel is very great; a crop of 22 tons will probably contain in root and leaf 300 lbs. of potash. The mangel crop is a good feeder, and is much better able than most crops to obtain a supply of phosphates and potash from the soil. When grown on a soil fairly supplied with cinereal plant food, the bulk of the crop depends mainly on the supply of available nitrogen, and concentrated manures such as sulphate of ammonia, and nitrate of soda, produce a striking effect. There is probably no crop that responds more abundantly to applications of purely nitrogenous manure than mangel wurzel.

1. **Experiments at Rothamsted.**—The field experiments with mangel wurzel began in 1876, following those with sugar-beet, and were carried out with the same manures, and on the same land. The plots in the mangel field had indeed received the same manuring for many years previous to the commencement of the mangel experiments, and the accumulation or exhaustion of various elements of plant food had thus already made considerable progress upon the various plots. We shall confine our attention to the results which illustrate the effect of ammonia salts.

The whole of the manures for the mangel plots are applied to the land and harrowed in before the final ploughing which forms the ridge on which the seed is dibbled. The farmyard manure is applied immediately before the final bouting, and thus occupies at last the centre of the ridge which carries the crop. Superphosphate is used at the rate of 3½ cwts. per acre. The alkali salts are composed of 500 lbs. sulphate of potash, 200 lbs.

sulphate of magnesia, and 200 lbs. common salt. The ammonia salts, as in the other Rothamsted experiments, are a mixture of equal parts sulphate and chloride.

TABLE XXXV.

PRODUCE OF MANGELS VARIOUSLY MANURED AT ROTHAMSTED, AVERAGE OF SEVENTEEN YEARS, 1876-84, 1886, 1888-94.

Manures applied.	Average Produce.		Return for 1 cwt. Sulphate of Ammonia.	
	Roots.	Leaves.	Roots.	Leaves.
	tons. cwts.	tons. cwts.	tons. cwts.	tons. cwts.
No manure	4 18	1 3	—	—
Superphosphate	5 4	1 2	—	—
Superphosphate and Alkalies ...	5 11	1 3	—	—
Superphosphate, Alkalies, Ammonia salts, 400 lbs.	16 8	3 1	2 16	0 10
Superphosphate, Ammonia salts, 400 lbs.	8 16	3 5	0 18	0 11
Ammonia salts, 400 lbs.	7 1	3 1	0 11	0 10
Farmyard manure, 14 tons	17 17*	3 0*	—	—
Farmyard manure, Ammonia salts, 400 lbs.	23 15*	5 14*	1 10*	0 14*

* Average of sixteen years only.

On the plots receiving no nitrogenous manure the average produce amounts to about 5 tons of roots. The addition of 400 lbs. of ammonia salts to the cinereal manures at once raises the produce to over 16 tons.

The necessity for a full supply of ash constituents, and especially of potash, if the ammonia is to produce its full effect, is strikingly shown in these experiments. The ammonia salts used alone, on a plot exhausted of ash constituents, produce only 7 tons of roots. The addition of superphosphate raises this to 8¾ tons. The further addition of alkali salts increases the crop to 16 tons. That potash was the most important constituent of the alkali salts used is proved by a further experiment not quoted in the table; in fact, the omission of the sulphate of magnesia and common salt from the manure diminished the crop by only 1 ton 4 cwt. On a series of plots receiving a double amount of nitrogenous manure (both ammonia salts and rape cake), the addition of sulphate of potash to the superphosphate more than doubled the crop.

The crop produced by 14 tons of farmyard manure very little exceeds that obtained from 400 lbs. of ammonia salts with ash constituents. The addition of 400 lbs. ammonia salts to the dung increases the crop by 5 tons 18 cwts. of roots. This increase is clearly much less than that obtained from the same quantity of ammonia salts on the plots well supplied with ash constituents. It is probable that the potash supplied by the farmyard manure was insufficient for this abundant nitrogenous manuring. The addition of superphosphate to the mixed farmyard manure and ammonia salts produced no increase in the crop.

Some German investigators have recently called attention to the smaller return obtained from ammonia salts when these are used together with farmyard manure, and they regard this result as due to a destruction of the nitrates formed from the ammonia, or even to a destruction of the ammonia itself, by means of micro-organisms contained in the farmyard manure. We cannot here enter fully into this question, which will be found thoroughly discussed in the pages of the *Royal Agricultural Society's Journal*, 1897, 577, but we may mention that with farmyard manure and ammonia salts used as in the Rothamsted experiments, there is no evidence whatever of a loss of nitrogen from the ammonia. The quantity of nitrogen contained in the root and leaf produced on the mangel plots was determined for many years at Rothamsted, and it appears that the proportion of the nitrogen of the ammonia salts recovered in the crop is quite as great when the ammonia salt is used with farmyard manure as when the same salt is employed with only superphosphate and alkalies. The increase given by the ammonia salts when used with dung is so much smaller, because the produce of this manuring is more highly nitrogenous in composition, and the crop at harvest contains a very large proportion of leaf. This delayed development of root is characteristic of excessive nitrogenous manuring, the absence of a proper supply of ash constituents, or of the deficiency of sunshine and warmth during the season of growth.

Return per Unit of Ammonia.—It will be seen from Table XXXV (p. 107), that when the ammonia salts are used to the greatest advantage, there is an apparent return of nearly 2¾ tons of roots for 1 cwt. of sulphate of ammonia employed.* The return from the ammonia greatly falls off when the supply of ash constituents is deficient. It is also considerably less when the ammonia salts are used with a good dressing of farmyard manure, a result which is in part due to the deficiency of potash in such a mixture.

It will be observed that the proportion of leaf is smallest, and of root greatest, when the ammonia is used with a full supply of ash constituents; any deficiency in these produces an imperfectly developed crop including a large proportion of leaves when harvested.

Influence of Climate. The return obtained from the manure varies much in different seasons. The crop can attain to an enormous growth only when the circumstances in which it develops include an adequate supply of rain and sunshine. Examples of the results yielded by the manures already mentioned when the season admits of a large growth will be

* This figure is probably somewhat above the truth, as the plot receiving only superphosphate and alkali salts, the produce of which is used to ascertain the increase by ammonia, is in a specially exhausted condition, due to its long cultivation without nitrogenous manure, and the exhaustion of soil nitrogen by spring and summer tillage.

found in the next table, which shows the average produce of mangels in three fine seasons, 1876, 1890 and 1894.

TABLE XXXVI.

AVERAGE PRODUCE OF MANGELS VARIOUSLY MANURED AT ROTHAMSTED, IN THREE FINE SEASONS, 1876, 1890, 1894.

Manures applied.	Average Produce, 1876, 1890, 1894.		Return for 1 cwt. Sulphate of Ammonia.	
	Roots.	Leaves.	Roots.	Leaves.
	tons. cwts.	tons. cwts.	tons. cwts.	tons. cwts
No manure	6 11	1 7	—	—
Superphosphate	6 11	1 7	—	—
Superphosphate and Alkalies ...	6 19	1 8	—	—
Superphosphate, Alkalies, Ammonia salts, 400 lbs.	22 7	3 17	3 19	0 13
Superphosphate, Ammonia salts, 400 lbs.	11 11	4 5	1 6	0 15
Ammonia salts, 400 lbs.	11 5	4 3	1 4	0 14
Farmyard manure, 14 tons	22 15	3 13	—	—
Farmyard manure, Ammonia salts, 400 lbs.	30 5	7 2	1 19	0 18

These figures are very striking. We have exactly the same teaching as in the average results during seventeen years already given, but every point is brought out with added clearness. The return given by the ammonia salts when employed to the best advantage is now nearly 4 tons of roots per cwt. of sulphate of ammonia. It is clear that in a fine climate a specially good return from the manure used may be expected.

2. **Bath and West of England Experiments.**—It is not usually advisable to found any conclusion as to the economic value of a manure upon results obtained in a single season; the influence of weather upon the growth of a crop is so great that success or failure may be largely determined by this circumstance only. In the case, however, of the experiments on mangels carried out by the Bath and West of England Society in 1890, (*Journal* 1891, 163), we have results obtained in a fair season by the use of identical manures on 23 different farms, occupying various soils and districts; the average result of the manures thus employed is consequently of great practical interest.

The mangels in these experiments in every case followed wheat or some other corn crop. The plots were all one quarter of an acre in extent. Each series of experiments had two unmanured plots. The manures with which we are at present concerned were: dung, 20 loads; superphosphate, 4 cwts; and sulphate of ammonia, 3 cwts. per acre. Two-thirds of the ammonia salt was applied at the time of sowing the seed, the remainder as a top-dressing after singling. The following table gives a selection of the average results obtained :—

TABLE XXXVII.

AVERAGE PRODUCE OF MANGELS VARIOUSLY MANURED ON TWENTY-THREE FARMS, IN 1890.

Manures applied.	Average Produce of Roots per acre.	
	tons.	cwts.
No manure	15	14·4
Superphosphate, Sulphate of Ammonia, 3 cwt. ...	24	6·6
Farmyard manure, 20 loads...	23	10·3
Farmyard manure, Superphosphate	24	9·8

As the mangels were in this case grown on land in an ordinary agricultural condition the unmanured produce is very much larger than is shown at Rothamsted, and the manured produce reaches in consequence a higher level. The crop grown by 3 cwts. of sulphate of ammonia and superphosphate is seen to be practically equal with that grown by 20 loads of farmyard manure with superphosphate. The increase yielded by the ammonia salt and superphosphate is 8 tons 12·2 cwts. Towards this increase the superphosphate contributed but little. On the nitrate of soda plots the 4 cwts. of superphosphate increased the crop only 1 ton 17·6 cwts. above that yielded by nitrate of soda alone. On the dunged plots, superphosphate added only about 3 cwts. to the produce. If we reckon the superphosphate to have produced the same effect with the sulphate of ammonia as it did with nitrate of soda the return for 1 cwt. of sulphate of ammonia is 2 tons 5 cwts of roots. If we disregard the effect of the superphosphate, the return is 2 tons 17·4 cwts. of roots. These returns are quite similar to the average return at Rothamsted.

There can be no doubt that if alkali salts had been used in these experiments the return from the sulphate of ammonia would have been considerably better. On other plots, the addition of 4 cwt. of common salt to nitrate of soda and superphosphate increased the crop by 2 tons 8·8 cwts. The condition of the mangels receiving sulphate of ammonia also pointed to a deficient supply of ash constituents, as the crop on this plot was generally greener and more leafy at harvest than on the other plots.

3. **Influence of Ammonia salts on Quality.**—The remarks already made under the head of sugar beet will have indicated much that has to be said in this section. It is impossible to considerably increase a crop of mangels by nitrogenous manuring without to some extent deteriorating the quality of the roots. As the roots become larger they become more watery and more saline, while the percentage of sugar, and of feeding material, diminishes. The deterioration in quality is least when a well-balanced manure is employed, so as to favour the early maturity of the root. Much may also be done by growing the roots near together, so that the final crop may consist of a large number of moderately sized roots, rather than a fewer number of large roots.

The figures in the following table will give some idea of the effect which the manures employed at Rothamsted have upon the composition of the roots. The percentages of water, ash and nitrogen are the mean of five years' determinations; the percentages of sugar are the mean of four years' determinations.

TABLE XXXVIII.

PERCENTAGES OF WATER, ASH, NITROGEN AND SUGAR IN MANGEL ROOTS GROWN WITH VARIOUS MANURES AT ROTHAMSTED.

Manures applied.	Average Results, 1878-82.			Average, 1877-80.
	Water.	Ash.	Nitrogen.	Sugar.
	per cent.	per cent.	per cent.	per cent.
Superphosphate and Alkalies ...	85·3	·865	·128	9·4
Superphosphate, Alkalies, Ammonia salts, 400 lbs.	86·7	·929	·147	8·0
Farmyard manure, 14 tons	86·6	·928	·166	8·0
Farmyard manure, Ammonia salts, 400 lbs.	87·7	·959	·202	7·2

There is seen to be little difference in composition between the roots grown with ammonia salts, superphosphate and potash, and those grown solely with farmyard manure. The manuring on each of these plots may be described as a well-balanced manure. When the farmyard manure is enriched by 400 lbs. of ammonia salts, without a corresponding addition of ash constituents, the composition of the roots distinctly alters for the worse. Mangels manured with nitrate of soda are somewhat more watery, and contain a distinctly less proportion of sugar than those manured with ammonia salts.

We have already pointed out that in the case of the mangel crop it is the quantity of feeding material produced *per acre*, rather than the percentage composition of the roots, which demands the first consideration. In the case now before us the falling percentage of sugar is attended with a great rise in the quantity of sugar per acre, and the inferior percentage composition consequently ceases to be an argument against the manures employed. The figures are as follows:—

	Sugar. per cent.		Sugar per Acre. lbs.
Superphosphate and Alkalies ...	9·4	...	1066
Superphosphate, Alkalies, Ammonia salts, 400 lbs....	8·0	...	2567
Farmyard manure, 14 tons	8·0	...	2358
Farmyard manure, Ammonia salts, 400 lbs.	7·2	...	3409

We have seen in Table XXXVIII that the use of nitrogenous manures distinctly increases the percentage of nitrogenous matter in the root. The nitrogenous matter in mangel roots is a mixture of many substances, nitrates, amides and albuminoids; we cannot therefore take the total quantity of nitrogen found as representing feeding material. The percentage of albuminoids in the root does however rise by the employment of nitrogenous manures, and as the percentage of sugar at the same time falls, it follows that the albuminoid ratio of the feeding constituents in a mangel root differs very much according as nitrogenous manures are, or are not, employed. The use of ammonia salts will always tend to narrow the albuminoid ratio.

4. **Practical Remarks.**—The cultivation of mangel in the United Kingdom is limited to certain soils and climates. It is very a valuable crop on the deep loams of the midland and eastern parts of England, but is little grown in the western or northern parts of the Kingdom, where swedes are found to be better suited to the climate. Being planted earlier than other root crops, and having deeper roots, the mangel crop is especially fitted to resist drought.

Mangel usually receives a heavy dressing of dung, which is often supplemented by artificial manure. It may not unfrequently be desired to grow mangel without dung; this can be easily and effectively done by using as manure a mixture of sulphate of ammonia, or nitrate of soda, with kainite and superphosphate. The Rothamsted experiments show that, on an average of a great many years, 4 cwts. of sulphate of ammonia, with alkali salts and superphosphate, will give a crop quite similar in quantity and composition to that produced by 14 tons of dung. On a farm, the ammoniacal manure would give a better result than this quantity of dung; indeed, in the Bath and West of England experiments 3 cwts. of sulphate of ammonia produced the same effect on the mangel crop as 20 loads of dung. We have to recollect that at Rothamsted the dung is used to great advantage, the dunged plot having received the same dressing of dung every year for a great many years; the crop produced on it is thus to a considerable extent due to the residues of the previous manuring.

To grow mangels without dung, we might apply 4 cwts. of sulphate of ammonia, 3 cwts. of superphosphate, and 5 cwts. of kainite. If the land was poor in potash, it might be necessary to replace 1 cwt. of the kainite with some concentrated potash salt; if, on the other hand, it was rich in potash, the kainite might be reduced in quantity. This manuring should give an average increase of 10-12 tons of roots.

When farmyard manure is employed, but in insufficient quantity to yield a full crop, we have further to consider the nature of the additional manure. Ten tons of farmyard manure will supply from 100-150 lbs. of potash, only a part of which can be assimilated by a crop in the first season. As an ordinary crop of mangel will contain about 300 lbs. of potash, and a large crop much more, it is evident that when less than 20 tons of dung per acre are employed, the additional manure should usually be one containing potash as well as nitrogen. Recent field experiments on the economical use of manures have frequently shown that the use of very heavy dressings of dung is not profitable, and that it is better to employ a smaller quantity, and supplement it by artificial manure. Supposing that 10 tons of farmyard manure are employed for the mangel crop, we should probably do right to use with this, 2 cwts. of superphosphate, 4 cwts. of kainite, and 3 cwts. of sulphate of ammonia. This will of course be a more liberal manuring than that previously mentioned.

Recent research has pointed out that when ammonia salts, or nitrate of soda, are to be applied to land which also receives farmyard manure, the latter manure should be well rotted. If fresh manure is used it should be applied to the land a month or more before the nitrate or ammonia salt. In the case of moderate dressings of farmyard manure, and in ordinary seasons, there is little evidence that any injury is to be feared, but as the danger of denitrification would increase if continued wet weather followed, it is wisest to avoid any chance of loss by adopting the precautions named.

The thorough mixing of the ammonia salt and other artificial manures with the soil before sowing the seed, which has been the plan employed at Rothamsted, will in most cases be found the best plan to adopt.

TURNIPS

The character of the turnip crop, and its behaviour towards manures, are in several important points very different from those of the crops previously noticed. The land which is to bear a turnip crop receives an ampler preparation by tillage than is afforded to any other crop in the rotation; and this tillage is continued by hoeing far into the summer. The process of nitrification in the soil is thus pushed to its extreme limits, and much of the accumulated nitrogenous organic matter in the soil is converted into available plant food. Not only is the supply of nitrates provided by the soil for the turnip crop thus especially large, the turnip crop is also exceptionally capable of turning this supply to good account. The period of growth of the crop is a long one, and continued far into the autumn; the crop is thus able to make full use of the nitrogenous food furnished by the soil. As a consequence of these facts, the turnip crop is not one benefited by large applications of nitrogenous manures. On land in good agricultural condition, and well tilled, very fair crops of turnips may frequently be obtained without the use of any nitrogenous manure; and on such soils only small quantities of ammonia salts could be applied with any profitable return. To apply more manure than a crop can turn to account during its period of growth is seldom economical, and is certainly never economical in the case of active soluble manures such as sulphate of ammonia. Any liberal use of ammoniacal manure for the turnip crop must thus be reserved for the special case of soils poor in nitrifiable matter.

While the turnip crop occupies such a strong position in regard to its supply of nitrogen, it is, on the other hand, of all farm crops the one least able to supply itself with phosphates. Phosphatic manures have thus for the turnip crop a special value and importance.

A full crop of turnips demands a large quantity of potash. The crop has, however, frequently little difficulty in obtaining what it needs from the soil. Potash manures are thus not, like phosphates, generally essential for successful turnip culture; their use is especially profitable when farmyard manure is not employed, or when very large crops have to be grown.

1. **Experiments at Rothamsted.**—The field experiments on the turnip crop commenced in 1843 with Norfolk White Turnips. Trials with ammonia salts were made from the first, but during the early years the manuring of the plots was of a miscellaneous character, and little suited to illustrate the return which ammoniacal manures will yield when used to the best advantage. In 1845 a part of all the plots received a cross dressing of 3 cwts. of sulphate of ammonia. Excepting in the case of a few plots which had received

potash as well as phosphates, this dressing of ammonia salts produced no increase in the weight of the roots, and indeed frequently diminished the crop, but it produced a considerable increase in the weight of leaf, amounting on an average of all the plots to more than two tons per acre. This action of the ammonia salts demands our consideration, as it will be found continually occurring in experiments on the turnip crop.

In the life history of the turnip crop the leaf is produced first, and the root is afterwards constructed out of the organic matter prepared by the leaf. A turnip crop having a large proportion of leaf at harvest is thus a crop imperfectly developed. This imperfect development may be due to the total supply of plant food being greater than the plant can turn to account : and this will be especially the case in wet and cold seasons, in which the vital actions of the plant are depressed. The imperfect development is however more frequently due to an ill-balanced food supply, and especially to an excess of nitrogenous food over ash constituents. It is when nitrate of soda or ammonia salts are applied alone that the excessive proportion of leaf is seen in its greatest extent, while this characteristic will entirely disappear if all the ash constituents of the crop are supplied in proper proportions, and the quantity of nitrogenous manure is kept within the limits of profitable use.

Many of the published experiments on the use of ammonia salts for turnips are by no means fair to the manure, as they give no account of the weight of leaf at harvest. The leaf is of course an excellent sheep food, and its amount should be taken into account in estimating the value of the crop.

The variations in the proportion of leaf to root, due to differences in the nature of the manure, are far smaller in the case of swedes than in the case of turnips.

The Rothamsted experiments on roots have not been published in detail. The summaries of the earlier experiments published in the Memorandum sheet do not relate to definite continuous applications of ammonia. In the later experiments with swedes the quantity of ammonia salt was far too large to afford a profitable return. In the last ten seasons, 1861-70, the addition of 400 lbs. of ammonia salts to superphosphate and alkalies increased the crop by an average of only 2 tons of roots and 8 cwts. of leaves. The turnip and swede are not crops which flourish when grown year after year on heavy land like that at Rothamsted, and the produce of the plots consequently became very small. The evil arising from the gradual exhaustion of the humus in the soil was clearly shown in the later swede experiments, when manuring with rape-cake proved far more effective than manuring with ammonia salts, a result which has not appeared in field experiments with any other crop at Rothamsted.

In the Rotation field at Rothamsted good crops of swedes are obtained, and the beneficial effect of nitrogenous manures is strikingly shown. The rotation is the usual one of swedes, barley, clover or fallow, and wheat. The average of eleven crops of swedes, on the portion of the field from which all the produce is carted, is as follows :—

TABLE XXXIX.

AVERAGE PRODUCE OF SWEDES IN ELEVEN ROTATIONS AT ROTHAMSTED.

Manures applied.	Roots, per acre.		Leaves, per acre.	
	tons.	cwts.	tons.	cwts.
No manure	—	19⅛	—	3½
Superphosphate and Alkalies	8	2½	—	12¾
Superphosphate, Alkalies, Ammonia salts and Rape Cake	16	16½	1	11

Thus while the permanently unmanured land produced barely one ton of roots, a purely cinereal manure, consisting of 3½ cwts. of superphosphate, with, in the later years, salts of potash, soda, and magnesia, produced more than 8 tons, a result which remarkably illustrates the ability of the turnip crop to obtain nitrogen from exhausted land if only it is supplied with phosphates.

The mixed ammonia salts and rape cake supplied 141 lbs. of nitrogen, and consisted of 200 lbs. ammonia salts, and 2000 lbs. of rape cake. If we take the whole of the nitrogen as of equal manurial value, the return of the nitrogen in 1 cwt. of sulphate of ammonia is 28 cwts. of swede roots, and nearly 3 cwts. of leaves.

2.—**Miscellaneous Experiments on Farms.**—It is probable that a greater number of field experiments have been made on the turnip crop than on any other crop grown by the farmer. The returns obtained from the manures applied are very various in different farms and seasons, which is perhaps the reason why these experiments are so often repeated. Little or no effort is generally made to trace out the cause of the peculiar results which frequently appear. The action, or want of action, of the manures is not studied in relation to the physical or chemical condition of the soil, and in some cases no reference is made to the character of the weather during the growing period. It is extremely difficult to deal with this mass of heterogeneous results, and little can be done in sorting and classifying them, because so little is stated as to the special conditions of each experiment.

The addition of sulphate of ammonia to the other turnip manures used in these experiments has sometimes given the farmer a considerable increase of crop; more usually the increase is small; sometimes the sulphate of ammonia has produced no increase in the weight of roots, and the weight of leaf is seldom recorded; finally in not a few cases the weight of roots is diminished by the use of the salt. Similar results are obtained when the experiments are made with nitrate of soda.

The common reason of the failure of sulphate of ammonia is clearly that the crop had all the nitrogen it could make use of without this additional manure. This reason is sometimes plainly indicated by the weight of the crop obtained without ammonia. Thus in the experiments on nine farms made by the University College of North Wales in 1897, it appeared in every case that the addition of one cwt. of sulphate of ammonia to a dressing of 6 tons of dung, 4 cwts. of superphosphate, and 2 cwts. of kainite, produced no increase of crop; but in these experiments the average produce without ammonia was 25 tons of swedes per acre! We can readily understand that a full crop being obtained without ammonia, the addition of ammonia was superfluous and produced no effect. That the crop was already a maximum one was further shown by the fact that doubling the dung also occasioned no further rise in the produce. Again, in the Glasgow and West of Scotland experiments, the average result on 9 farms in 1893 shows no gain by adding $\frac{3}{4}$ cwt. of sulphate of ammonia to 6 cwts. of superphosphate used without dung ; but in the following year the average result on 15 farms was a gain of $46\frac{1}{4}$ cwts. of roots by this small addition of ammonia. The first set of experiments was made in what is described as a very good season, the crop grown by 6 cwts. of superphosphate alone amounted on an average to 24 tons 14 cwts. of roots. In the second season the same quantity of superphosphate yielded 18 tons 9 cwts. There was thus in the latter case an opportunity for further increase by the use of an ammoniacal manure.

The amount which constitutes a full crop of turnips in any season is limited by the physical condition of each soil, by the supply of water, and by the sunshine and temperature which occur during the growing period. No supply of plant food can push the crop beyond the limits assigned by these conditions.

A soil equally fertile as those of the Welsh and Scotch farms just referred to may yield an excellent return from sulphate of ammonia when the conditions admit of a larger produce. At Cockle Park, in Northumberland, in 1896, the produce obtained from 10 cwts. superphosphate, and 2 cwts. sulphate of potash was 21 tons, 15 cwts. of Yellow Turnips ; when to this manure 1 cwt. of sulphate of ammonia was added the crop became 26 tons 8 cwts. ; when 2 cwts. sulphate of ammonia were employed the crop reached 30 tons 16 cwts. Here there was an unusually excellent return from the ammonia, notwithstanding the largeness of the crop grown without nitrogenous manure.

The size of a crop is not only limited, as we have already seen, by the external conditions which attend its growth, it may also be limited by the scanty supply of an essential part of its plant food. In the culture of turnips at the present day it is an almost universal practice to employ a manure supplying phosphates, it is, however, by no means usual to make use of artificial manures supplying potash. It will thus sometimes happen that a turnip crop is limited in its development by a deficient supply of potash in the soil.

The points now mentioned go far to explain the diversity of results obtained in the use of ammonia salts. The ammonia can only give a full return when the soil, or the manures employed, furnish (1) a sufficient supply of ash constituents to the crop, and (2) an insufficient supply of nitrogen; and when these conditions are fulfilled, there is also required (3) the external conditions of light, heat, moisture, and tilth in the soil necessary to produce a crop corresponding to the supply of plant food. A failure in any one of these conditions will effectually prevent a profitable return from the ammonia salts applied.

As our present object is to ascertain what return may be expected from sulphate of ammonia when used under conditions reasonably favourable to its success, we will discard all groups of experiments in which it produced no increase in the crop of roots, and confine our attention to those in which some benefit was obtained. In some of the groups admitted to use there are individual farms giving no return from sulphate of ammonia, these have not been struck out, as errors of experiment may clearly occur both in the direction of deficiency and excess. The experiments have next been divided into four classes: (1) Experiments made without dung, but with phosphates and potash salts; (2) Experiments made without dung, with phosphates only; (3) Experiments made with dung, and phosphates and potash; (4) Experiments made with dung, and phosphates only. In calculating the average return from sulphate of ammonia in each class, a value has been given to the results in each group of experiments corresponding to the number of farms on which the experiment was made. (p. 122).

A large majority of the experiments were made in Scotland. Those belonging to the Edinburgh centre were conducted by Dr. Aitken, and will be found described in the *Transactions of the Highland Society*. Those belonging to the Glasgow centre were conducted by Professor Wright, and are taken from his *Annual Reports*. The Newcastle experiments were conducted

Table XL.

Produce of Turnips or Swedes from Ammoniacal Manures on Various Farms.

1.—*Experiments without Dung, with Phosphates and Potash.*

Season.	Experimental Centre.	Number of Farms.	Return in Roots for 1 cwt. Sulphate of Ammonia.
			cwts.
1886	Norfolk	3	55¾
1894	Newcastle...	9	55¾
1896	,, ...	1	90½
	Mean of three seasons	13	58

2.—*Experiments without Dung, with Phosphates.*

Season.	Experimental Centre.	Number of Farms.	Return in Roots for 1 cwt. Sulphate of Ammonia.
1886	Norfolk	3	50
1891	Edinburgh	26	42
1892	,, ...	42	61¼
1893	,, ...	25	57½
,,	,, ...	15	39
1894	,, ...	22	52½
,,	Glasgow	15	57½
1895	,, ...	34	24
	Mean of six seasons	182	47½

3.—*Experiments with Dung, Phosphates and Potash.*

Season.	Experimental Centre.	Number of Farms.	Return in Roots for 1 cwt. Sulphate of Ammonia.
1882	Edinburgh	9	28¾
1888	,, ...	15	43¾
	Mean of two seasons	24	38

4.—*Experiments with Dung and Phosphates.*

Season.	Experimental Centre.	Number of Farms.	Return in Roots for 1 cwt. Sulphate of Ammonia.
1882	Edinburgh	9	22
1888	,, ...	15	41¼
,,	,, ...	15	37
1892	,, ...	46	23¾
1893	,, ...	15	30
	Mean of four seasons	100	29

by Dr. Somerville, the details will be found in his *Reports*. The Norfolk experiments were conducted by the Norfolk Chamber of Agriculture, and are described in their *Reports*.

The turnips (usually the Scotch Yellow turnip) or swedes, were in all cases grown in their ordinary place in the rotation. The quantity of sulphate of ammonia applied per acre only reached 2 cwts. in the case of a single farm; in a few cases it was 1¼ cwts., 120 lbs., and 1 cwt.; in the majority of cases the amount applied was about 90 lbs. per acre.

It will be noticed that the number of experiments in which potash salts were added to the phosphates was much smaller than the number in which phosphates were used alone; the mean results obtained with and without potash do not therefore admit of an exact comparison. The general order of the results is nevertheless exactly what we should expect. One cwt. of sulphate of ammonia gives an average return of 58 cwts. of roots when both phosphates and potash are supplied. The return falls to 47½ cwts. when potash is omitted. It falls still further when a liberal dressing of dung (frequently 20 tons per acre) is employed; the return amounting to 38 cwts. when phosphates and potash are used with the dung, and to 29 cwts. when potash is omitted. The advantage of employing potash salts when full crops of turnips are to be grown, especially when dung is not used, is thus plainly indicated. Nevertheless in some of the Scotch experiments the use of potash salts with farmyard manure resulted in the production of a smaller crop, and "potash depression" is frequently spoken of in the Edinburgh Reports. One would like to inquire how the potash salt was applied in these cases. Both potash salts and superphosphate tend to retard the decomposition of farmyard manure, and are frequently used in Germany to check the fermentation in a dung heap; it is obvious therefore that they should not be spread on the dung, but mixed with the soil before the dung is brought on to the land.

Best Time for Application. The experiments organised by Dr. Aitken furnish also information as to the best time for applying sulphate of ammonia to the crop. In 1891 an experiment was made on 26 farms, in which all the plots received phosphates without dung, while on four plots 86 lbs. of sulphate of ammonia per acre were applied at various dates. The experiment was repeated in 1892 upon 42 farms with some variation as to the times of application. The results of these experiments were as follows :—

TABLE XLI.

EFFECTS OF APPLYING SULPHATE OF AMMONIA AT VARIOUS DATES TO TURNIPS.

1.—*Experiments on* 26 *Farms in* 1891.

Manures applied.	Roots, per acre.	
	tons.	cwts.
Phosphates only	13	1
,, Sulphate of Ammonia applied at sowing...	14	13½
,, Sulphate of Ammonia, ½ at sowing, ½ at singling	14	10¼
,, Sulphate of Ammonia, ⅓ sowing, ⅓ singling, ⅓ six weeks later	14	5
,, Sulphate of Ammonia, ⅓ sowing, ⅓ six weeks, ⅓ twelve weeks later	13	16½

2.—*Experiments on* 42 *Farms in* 1892.

Manures applied.	Roots, per acre.	
	tons.	cwts.
Phosphates and Potash salts	18	14
,, Sulphate of Ammonia applied at sowing ...	19	19
,, Sulphate of Ammonia, ten days after singling	19	2
,, Sulphate of Ammonia, six weeks after singling	18	3
,, Sulphate of Ammonia, ½ sowing, ½ six weeks after singling	19	7

The two seasons were very different. In 1891 there was a prolonged drought in June and July, followed by very wet weather. The season of 1892 is described as somewhat dry, cold and backward. It will be seen that in both seasons the advantage lies with the earliest application of the ammonia salts.

In some other experiments the sulphate of ammonia was applied to the land with good results as early as March or April.

3. **Influence of Ammonia Salts on Quality.**—Much that has already been said about mangel wurzel under this head might be recapitulated here. We cannot greatly increase the size of a turnip crop without some deterioration in the feeding quality of the roots; with moderate manuring the alteration in composition is but small, but when a heavy dressing of dung and artificial manures is employed the deterioration may become considerable.

In the following table will be found the percentages of water, ash, and nitrogen in the roots of white turnips and swedes grown at Rothamsted with various manures. The results for turnips are the mean of two years, 1847-48; those for swedes are the mean of four years, 1849-52. (Watts' *Dictionary of Chemistry*, *Second Supplement*, p. 1056).

TABLE XLII.

COMPOSITION OF WHITE TURNIPS AND SWEDES GROWN WITH VARIOUS MANURES AT ROTHAMSTED.

Manures applied	White Turnips.			Swedes.		
	Water.	In 100 Dry.		Water.	In 100 Dry.	
		Ash.	Nitrogen.		Ash.	Nitrogen.
	per cent.	p. c.	per cent.	per cent.	p. c.	per cent.
Superphosphate	91·3	7·1	—	88·6	4·0	1·44
Superphosphate & Alkalies	91·6	7·4	1·63	88·1	4·6	1·38
Superphosphate, Ammonia salts	92·3	8·5	—	88·7	4·0	1·90
Superphosphate, Alkalies, Ammonia salts... ...	91·7	8·0	2·57	88·2	4·7	1·59
Superphosphate, Ammonia salts, Rape cake ...	92·3	8·9	—	89·4	4·2	2·30
Superphosphate, Alkalies, Ammonia salts & Rape cake	92·4	9·1	2·49	89·4	5·1	2·14

A beneficial effect of the potash on the quality of the roots is plainly indicated by these figures. The addition of much ammonia salts to superphosphate leads to the production of a more watery turnip, but when alkalies are supplied the deterioration is much less. Ammonia salts, by themselves, do not greatly increase the proportion of water, but when the quantity of nitrogenous manure is doubled by the addition of rape cake to the ammonia salts the effect becomes more marked.

The proportion of ash tends to rise with ammoniacal manuring, more so in the case of turnips than of swedes; it also rises where alkalies are applied. The application of alkali salts at Rothamsted was a very liberal one. Any increase of ash diminishes of course the proportion of organic matter available as food.

The nitrogenous manures considerably increase the proportion of nitrogenous matter in the root, the alterations produced are best seen in the results obtained in the case of swedes. Here again the supply of potash tends to limit such changes in composition by enabling the plant to produce a larger quantity of organic matter.

In the four-course rotation at Rothamsted the swedes are grown, as we have already mentioned, on one plot with superphosphate and alkalies alone, and on another plot with the same manures plus a liberal dressing of ammonia salts and rape cake. As the first named plot has received no nitrogenous manure for a great many years the swedes are produced with a minimum supply of nitrogen; the contrast in the composition of the roots grown on the two plots is thus very marked. The average of nine crops shows 88·7 per cent. of water in the superphosphate swedes, and 89·4 per cent in the highly manured roots. The percentage of nitrogen in the dry matter was 1·89 in the superphosphate swedes, and 2·32 in those receiving ammonia salts and rape cake in addition. In a season of great production the percentages of nitrogen in the roots are much lower; in 1880 the percentage of nitrogen in the dry matter of the superphosphate swedes was 0·984, and in the highly manured roots 1·539.

The condition of the nitrogen in the roots is of great importance in relation to their feeding value. The albuminoids are the only nitrogenous bodies capable of forming flesh, the amides are useful for little more than the production of heat and muscular work. The superphosphate swedes grown at

Rothamsted in 1880 contained 0·518 per cent of albuminoid nitrogen in their dry matter, while those grown with the liberal nitrogenous manure contained 0·720 per cent. The use of nitrogenous manures has thus an important influence on the composition of the turnip. Sheep could not have been fed on the above named superphosphate swedes, with merely the addition of straw chaff, without losing weight, the quantity of albuminoids supplied by the roots being too small for their sustenance, but they might have been maintained in condition by the highly manured roots.

Some analyses of turnips by Dr. Aitken (*Trans. Highland Society*, 1889, 252) will supply further details as to the composition of variously manured turnips. The whole of the land received in this case a dressing of dung. The sulphate of ammonia was applied at the rate of 120 lbs. per acre.

TABLE XLIII.

PERCENTAGE COMPOSITION OF TURNIP ROOTS VARIOUSLY MANURED (AITKEN)

	Dung alone.	Artificial manures added.		
		Phosphate and Potash.	Phosphate Potash and Ammonia.	Phosphate and Ammonia.
Water	91.04	91·63	91·98	92·75
Albuminoids	·59	·58	·63	·67
Non-albuminoid nitrogenous matter	·35	·30	·42	·31
Carbohydrates	6·43	5·97	5·36	4·75
Fibre	·93	·89	·90	·81
Ash	·66	·63	·71	·71

These figures show that the increase of water in the turnip is by no means a peculiar property of nitrogenous manures, a similar effect is produced by superphosphate; any manure in fact which considerably increases the size of the root will also increase the proportion of water which it contains.

The influence of sulphate of ammonia in increasing the percentage of albuminoids, and of the other nitrogenous constituents, is plainly seen.

The favourable effect of potash manures on the composition of the root is again apparent. The roots grown with phosphates and ammonia, without potash, are the most watery in the series.

4. **Practical Remarks** :—Ample illustrations have been given in the foregoing pages of the wonderful capacity of the turnip for obtaining nitrogen from the soil when grown on land well prepared by tillage, and of the handsome return which is consequently obtained under favourable circumstances from manures supplying only phosphates, or phosphates and potash. There is no doubt that this capacity of the turnip for obtaining the nitrogen which it requires from the soil has not been realised by farmers. The directors of the numerous experiments which have recently been made on turnip culture in Scotland and the North of England all unite in condemning as unprofitable the very large applications of dung and artificials which are frequently employed by farmers, and point out that instead of putting the whole of the manure for a rotation on the turnip crop, much greater profit may be obtained by distributing a part of this manure among the crops following the turnips.

That farmyard manure is an excellent manure for turnips no one can deny, and on some land it is indispensable for the production of a full crop; nevertheless, when reckoned at its money value, the return yielded by farmyard manure in the crop produced is generally but small.

On land in a favourable physical condition, and good heart, and in a district not usually suffering from drought, turnips can be economically produced by phosphatic manures, to which potash and ammonia salts may generally be added with decided advantage. If, however, the ammonia salt is to give a profitable return it must be used only in small quantity. Mr. F. J. Cooke of Norfolk, speaking of swedes, says: "3 to 4 cwts. per acre of superphosphate, 1 cwt. of sulphate of ammonia, and ½ cwt. of muriate of potash, is an admirably complete and economical dressing for general use." Professor Wright of Glasgow recommends to the Scotch farmers, 6 cwts. of superphosphate, 1 cwt. of sulphate of potash. with 1 cwt. nitrate of soda, or 86lbs. of sulphate of ammonia. Dr.

Somerville of Newcastle, speaking of the experiments conducted in the North of England, says:—"As the result of our experiences during the past four years, the following mixture may be confidently recommended for application to turnips:

Broad-cast in Autumn	Slag	1 cwt.
	Kainite	3 ,,
Broad-cast in Spring	Superphosphate ...	3 ,,
	Dissolved Bones ...	¾ ,,
Applied in the Drill	Fish Meal ...	½ ,,
	Sulphate Ammonia	¼ ,,
	Nitrate of Soda ...	½ ,,

The above quantities may be used per acre without dung, or one quarter may be applied with an average dose of dung." The object of this elaborate scheme of manuring is to furnish continuous supplies of plant food during the whole period of growth of the crop.

When farmyard manure is produced in large quantity on a farm its free use for the turnip crop will follow as a matter of course. The use of farmyard manure is especially indicated when the soil is too open in texture, and retains moisture with difficulty through the summer.

The very numerous experiments on farms which have been already referred to do not encourage the use of sulphate of ammonia with a full dressing of dung. Mr. Cooke recommends that when dung is used for swedes, 3 cwt. of superphosphate only should be drilled with the seed. It is pointed out, however, both by Professor Wright and Dr. Somerville, that dung may be used with much greater profit if a moderate dressing is given to the turnips with some artificial manure. Professor Wright's recommendation appears to be 10 tons of dung, with 4 cwts. of superphosphate, and ¾ cwt. of sulphate of ammonia, or 1 cwt. of nitrate of soda.

The farmer's knowledge of the history and character of his fields must clearly determine the precise quantity of manure to be employed. There is one consideration, however, which should not be omitted;—To what purpose will the roots be put? If the turnips are to be given in large quantities to sheep, bullocks or cows, with the addition of but little other food, it becomes very desirable that the roots should be grown with a good supply of nitrogen in the manure, in order that they may contain a proportion of albuminoids suitable for animal nourishment. If, on the other hand, much oil-cake is given to the animals, the richness of the turnips in albuminoids becomes a matter of indifference. It thus appears that the addition of sulphate of ammonia to a turnip manure may in some cases be clearly desirable, although the increase in the weight of the crop may be but small.

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