at Cambridge; Professor Vito Volterra, one of the foremost mathematicians of the day; and Prof. R. W. Wood, of Johns Hopkins University, Baltimore, famous for his brilliant experimental researches in optics. These outstanding representatives of science in its various branches were presented to the Vice-Chancellor, Sir Alfred Ewing, by Prof. Whittaker (acting for the Dean of the Faculty of Law), who hit off the characteristic work of each in the happiest phrasing.

Another side issue of the British Association meeting was the Royal Societies' dinner, at which the fellows of the Royal Societies of Edinburgh entertained as their guests the fellows of the Royal Society of London, the members of the Royal Irish Academy, and eminent foreign visitors to the meeting. The Maharaj Rana of Jhalawar was also a guest. This brilliant function was held in the Masonic Hall, probably the most artistic hall in Edinburgh. Nearly two hundred were present, and the guests and hosts were arranged in such a way that those representative of any one science formed a group at one of the tables. The toasts were proposed and responded to by speakers selected on a broad international basis, and the speeches were

short, congratulatory, breezy, and humorous. One point referred to by Sir James Dewar is worth chronicling on account of its historic interest, and might have found a place in the handbook "Edinburgh's Place in Scientific Progress." Some seventy-five years ago a young extra-mural teacher, Dr. Samuel M. Brown, gave four lectures on the atomic theory and, to a large intellectual audience packed into his lecture room, broached ideas regarding the complicated nature of atomic structure which were far in advance of his day, and closely approximated to the ideas now so prevalent. Samuel Brown died at the age of thirty-nine, and Edinburgh lost a brilliant son who, had he lived, would have brought renown to his city.

For one glorious week the people of Edinburgh rejoiced in the British Association—just as profoundly as the visiting members of the Association rejoiced in Edinburgh. There was exhilaration in the very air, and the profoundest problems were tackled in a cheerful spirit. Two thousand seven hundred and sixty-eight members drawn together from all parts of the world shared in this intellectual feast of good things, the golden memories of which will be a life-long possession.

C. G. K.

Science and Crop Production.¹

By E. J. RUSSELL, D.Sc., F.R.S., Director of the Rothamsted Experimental Station.

THE beginning of much of our scientific work on crop production goes back to the year 1843, when Lawes and Gilbert set out to discover why farmyard manure is such an excellent fertiliser. Two opposing explanations were offered by the chemists of the day; the older view, coming down from the eighteenth century, was that the fertilising value lay in the organic matter; the newer view put forward by Liebig in 1840 was that it lay in the ash constituents—the potash, phosphates, etc.—left after the manure is burnt. Lawes and Gilbert considered that it lay in the ash constituents *plus* the nitrogen of the organic matter, and they devised a critical field experiment to decide the matter. They divided a field of wheat into plots of equal size, of which one received farmyard manure at the rate of 14 tons per acre, another received the ashes of exactly the same dressing of farmyard manure, a third received the mineral matter of the ashes *plus* some of the combined nitrogen that had been dissipated on burning, and a fourth lay unmanured. The results were very striking:—

Broadbalk Wheat Field, 1843.

	Grain. Tons per acre.	Straw. Cwts. per acre.
Farmyard manure	22	13
No manure	16	10
Ashes of farmyard manure ..	16	10
Mineral matter of ash <i>plus</i> sulphate of ammonia to supply combined nitrogen	26½	15½

¹ Abstract of a farmers' lecture of the British Association delivered at Edinburgh on September 7.

The ashes proved ineffective, but the ashes *plus* the combined nitrogen acted just as well as farmyard manure; it is therefore these that constitute the fertilising constituents of the manure. Thus the old controversy was decided in a way not uncommon in science; neither side proved to be entirely correct, but both sides were found to have some basis of truth. Lawes and Gilbert did not rest content with this purely judicial and scientific conclusion; they saw that they could make up this effective mixture of ashes and combined nitrogen from mineral substances without using farmyard manure. Even in their day farmers were unable to obtain sufficient farmyard manure, and it was therefore a great achievement to be able to supplement the limited supplies by this mixture. A factory was set up, and the manufacture of the so-called artificial fertilisers began. Subsequent experience showed that the ash constituents are not all equally necessary; in practice only two of them, potash and phosphates, need be supplied in addition to nitrogen.

Chemists are rightly proud of artificial fertilisers, for they have proved extraordinarily successful in augmenting crop production all over the world. The demand for them is enormous, and in consequence prices have risen considerably within the last thirty years. Agricultural chemists are always looking out for new substances, and even during the war a new fertiliser, ammonium chloride, was added to the list and new plant has been erected for its manufacture. Modern

manufacturing facilities are, perhaps, adequate for present demands, but it is certain that much more fertiliser could be used, and that as farming improves the demand will increase.

Progressive farmers have long passed the stage when it was necessary to demonstrate that artificial manures increase crop production; the position now is the much more difficult one of deciding how much money it is wise to spend on fertilisers. The old view was that the crop yield was proportional to the manurial dressing—i.e. that the more the manure the bigger the crop. Lawes and Gilbert showed this was not altogether correct, and that the yield fell off after a certain sized dressing was reached; this relationship is expressed by a straight line which ultimately becomes a curve. A later view set up by Mitscherlich was that the effect of the manure is propor-

Date of application of manure	Increased yield of grain. Bushels per acre.			Increased yield of straw. Cwts. per acre.		
	Feb. 10	Mar. 6	May 10	Feb. 10	Mar. 6	May 10
Single Dressing	.. Nil.	0.9	2.7	2.7	6.9	9.4
Double Dressing	.. 7.0	—	3.7	11.7	—	12.7

This experiment ought to be repeated in many districts, for it is by no means certain that farmers generally are using the most profitable quantities of fertiliser at the most effective time. It is, however, necessary to take into account something more than the quantity and the time of application of the fertiliser. It is essential also to have a suitable mixture. In the old days this question was thought to be fairly simple. Chemists used to think that if they knew the composition of the ash of plants they would know what manure to use; it should supply all the ash constituents in the quantities present in the plant. This is now known to be wrong; the composition

of the ash affords no guidance to manurial requirements, as was, indeed, shown by Lawes and Gilbert in 1847. The distinguished French chemist, Georges Ville, emphasised the fact that only properly conducted field trials would ever settle the question. Vast numbers of such experiments have been made, and they show that the problem is more complex than Ville thought. It is now known that no single formula expresses the fertiliser needs of a crop; every district, almost every farm, has its own special requirements.

Still further difficulty is introduced by the fact that the various artificial fertilisers not only increase crop yields, but also influence the composition and habit of growth of the crop. Nitrogenous manures tend to a vegetative growth of large, deep-green leaves which are somewhat liable to be attacked by fungoid pests. Phosphates improve root development, and are therefore of special value for swedes and turnips; they also hasten ripening of grain, and are therefore

particularly useful in late districts; they increase the feeding value of crops, and are therefore useful for fodder crops; and they have a remarkable effect on the development of clover, which is not yet fully understood, but which has revolutionised the treatment of pastures in this country. Potassic fertilisers improve the vigour of the plant and increase its power to resist fungus attacks. These and other special properties of fertilisers are now well established, and advantage is taken of them in drawing up fertiliser schemes to suit the special requirements of each farm.

It has already been pointed out that this work on artificial fertilisers arose out of Lawes and Gilbert's discovery that the wheat crop of 1843 grew just as well when supplied with the ash constituents *plus* combined nitrogen as when supplied with farmyard manure. They repeated the experiment year after year; periodically the results

FIG. 1.—Curves showing relationship between crop yield (plotted on vertical axis) and quantity of fertiliser used (plotted on horizontal axis).

tional to the decrement from the maximum obtainable; that therefore the first dose of manure has a large effect; but that further doses have progressively less action. This relationship is expressed by a logarithmic curve. The present view is that the effect is at first small; then it increases and then decreases; this relationship is expressible by a curve resembling that for autocatalysis. The important practical consequence is that moderate dressings are more profitable than small ones, but they are also more profitable than much larger ones (Fig. 1). There is no difficulty about the general rule; the difficulty arises when one tries to define a moderate dressing. The problem is further complicated by the fact that the effect of the dressing is greatly influenced by the time when it is put on to the land. In our own case the results have been as follows:—

were collected, and even after fifty years on an average the artificials had done as well as the farmyard manure. In consequence of this and other experiments many agricultural chemists developed the view that artificial manures were at least as good as farmyard manure for ordinary use on the farm; but wider knowledge has shown that this is not the case; it is only a first approximation to say that artificial fertilisers are equally as good as farmyard manure; we now know that farmyard manure produces effects of the highest importance to the land which no known combination of artificial fertilisers will bring about.

Examination of the Broadbalk data in the statistical laboratory recently instituted at Rothamsted under Mr. R. A. Fisher shows that farmyard manure differs in two ways from artificials—the variation in yield from year to year is diminished by the use of farmyard manure, as is also the deterioration in fertility due to continu-

our plots treated with artificials excepting perhaps those receiving exceptionally high dressings. This is shown on both the wheat and the barley plots, and it is greatest on those plots where one of the essential fertiliser constituents is withheld (Fig. 2).

There is a third effect, which is very marked in rotations. Farmyard manure appears to have a greater effect than artificials in increasing the growth of clover. Unfortunately the number of experiments is not very great, but, so far as they go, they show a striking superiority over artificials, and this extends not only to the clover, but also to the succeeding wheat crop.

The results at Rothamsted are:—

Manure applied to previous corn crop.	Yield of clover hay. Cwts. per acre.	Yield of succeeding wheat crop.	
		Grain. Bushels per acre.	Straw. Cwts. per acre.
Farmyard Manure	62	45	45.3
Artificials only	46	37	36.8

FIG. 2.—Effect of fertilisers on yield of barley. (Horsfield, Rothamsted, 1852-1919.)

ous cropping for eighty years. No fewer than fifteen different combinations of fertilisers are tested against farmyard manure, and while some of them come out quite well on an average of twenty-five or fifty years, they fluctuate considerably from season to season, and they show manifest signs of deterioration as the years pass by. Many farmers prefer a steady yield to a fluctuating one, and this, of course, is sound, cautious business. Farmyard manure never does badly even in the worst seasons, but, on the other hand, it does not give record crops even in the best seasons. What we should like would be something possessing the special values of farmyard manure in bad seasons, and of artificials in good ones.

Further, there is a deterioration of yield on all

At present we cannot explain all these remarkable facts. There are several possibilities:—

(1) Farmyard manure is known to exercise remarkable physical effects on the soil, causing it to become puffed up so that the empty pore spaces increase in size. The air supply to the roots thus becomes better, the water supply is more evenly regulated, the work of the tillage implements is lightened, and a good tilth is more easily obtained. The difference is well shown by the root crops—swedes, turnips, and particularly mangolds, which are very sensitive to soil conditions, and, being sown late, are liable to suffer from spring and summer droughts. The plots at Rothamsted receiving farmyard manure contain always some 2-5 per cent. more moisture than those receiving no manure or artificials only, and this enables the mangolds to keep growing during a drought which effectually checks all plants not receiving

farmyard manure.

(2) It is possible that there are chemical constituents in farmyard manure which are not present in our artificial fertilisers. The old idea that nitrates, potash, and phosphates only are necessary may be wrong. Recent work by Mazé in Paris and by Dr. Winifred Brenchley at Rothamsted show that some of the other elements may also be helpful. In the Rothamsted experiments very small quantities of boric acid added to the soil caused distinct increases in crops fully fertilised with artificial manures. We cannot as yet recommend farmers to adopt this kind of manuring with special substances, because it is very easy to overstep limits and do much damage to the crop, for the plant suffers seriously from even slight excess. With fuller knowledge, how-

ever it may prove possible to keep this special manuring within bounds.

(3) In the case of the clover crop the farmyard manure or the straw in the litter may have a special effect on the organisms living in the root, causing them to increase the amount of nitrogen fixation and thus give larger clover crops and further enrich the soil in nitrogenous organic matter.

Work on these problems is progressing; the scientific investigator has, of course, to find out exactly what is happening before he can show the practical man how to exercise control.

But in the meantime it is necessary for us to be practical and to do something, and the most obvious line of action is to increase the amount of farmyard manure or similar substances on the farm. We can proceed in two ways; first, waste can be cut down. We estimate that the farmers of the United Kingdom make about forty million tons of farmyard manure a year, and waste about ten million tons. We have shown that the best results are obtained when manure is made under cover and the amount of litter properly adjusted to the amount of nitrogen in the animal excretions. Correct adjustment is a counsel of perfection, but a great improvement is possible over the present haphazard methods. In practice nitrogen is always lost through exposure to weather, greatly to the detriment of the manure. The provision of some shelter for the heap is not difficult, and, as Prof. Berry has shown at Glasgow, it is distinctly advantageous.

Another method is to increase greatly the amount of farmyard manure or similar substances produced on the farm. This could be done by running on more animals. The number of livestock per acre could be much increased by the general adoption of the methods of some of the Scottish and Danish farmers, who keep their animals largely on the produce of their arable land. The problem is closely bound up with financial considerations, but the experiments of Mr. J. C. Brown at the Harper Adams Agricultural College show that more profit is obtainable from the soiling system than from the older methods of the south.

At Rothamsted we are examining possible substitutes for farmyard manure, green manuring, and the activated sludge method of producing manure from sewage, both of which seem quite promising. We tried using straw as manure, but without success; so soon, however, as the straw was rotted, much more promising results were obtained. The conditions for the proper rotting of straw, investigated at Rothamsted by Dr. H. B. Hutchinson and Mr. E. H. Richards, were found to be proper air and moisture supply, suitable temperature, freedom from acidity, and the proper proportion of soluble nitrogen compounds. All these conditions are easily obtainable on the farm, and it is now possible to make an artificial farmyard manure from straw without the intervention of animals. So far the results seem quite satis-

factory. Arrangements are being made for demonstrations on an extensive scale during the present season.

All these problems I have been discussing represent work of interest to the present generation of farmers; but the scientific investigator cannot be restricted to problems of present-day interest. Some of the best work of to-day may never reach the farmer in our time, and, indeed, unless it is developed, it will never reach the farm at all. We now know that the farmyard manure and the green manure put into the soil are not really agents of fertility, but only raw materials out of which fertility is manufactured. The work is done by myriads of living creatures in the soil, which are too small to be seen by the naked eye, and only incompletely revealed even by powerful microscopes. Some of them are useful to the farmer and some not, many of them taking their toll of the valuable plant food in the soil. Their activity fluctuates daily, almost hourly, and their numbers are counted and their work is watched in our laboratories. Much of their activity is helpful to the farmer; it makes nitrates, indispensable for the growth of plants. Much of their time, however, is spent in undoing the good work they have done, and results in the destruction of a large proportion of the nitrates made. We are studying this population, and with fuller knowledge we hope to control it and make it serve the farmer just as horses, sheep, and cattle do; but we are a long way from that yet.

Finally an attack is being made on a much more difficult problem. The growth of a crop is like the movement of a motor-car; it cannot go on without a continuous supply of energy. In the case of the car the energy comes from the petrol; in the case of the growing crop it comes from sunlight. The plant as we grow it, however, is not a very efficient transformer; a crop of wheat utilises only about half of 1 per cent. of the energy that reaches it. During the last eighty years the growth of crops has been improved, thus increasing their efficiency as utilisers of energy; but we are still a very long way from the 30 per cent. efficiency which the motor engineer has attained. Better developments of our present methods will no doubt carry us further than we have yet gone, but some wholly fresh ideas are necessary before we can hope to bridge the enormous gap that now exists between the actual and what is theoretically possible. There seem to be at least six ways in which we might improve crop production:—

(1) We can hope for further improvements by the use of new varieties capable of making better growth than those ordinarily cultivated. Plant breeders all over the world are attacking this problem with much success, and many of the new sorts show considerable promise.

(2) Much can be done by control of plant diseases. Unfortunately we have no means of knowing how much is lost each year by pests or disease, but it is undoubtedly considerable. Laboratories for studying plant pathology have

been set up at Rothamsted and elsewhere, and we are hoping to achieve good results; much valuable information has already been obtained.

(3) We are also looking to the tractor to achieve great things on the farm. It will allow considerable development of cultivation implements, enable us to improve our tillage and to keep down weeds, a very serious trouble in the southern part of England. Good Scottish farmers in that region have told me that farming in Scotland is much easier than in England, because the rigorous northern winters keep weeds in check, while the mild southern winters encourage their growth.

(4) It is possible that certain substances, such as boric acid, the fluorides, etc., studied by Gautier and Claussmann in France, may help in raising crop growth.

(5) It is possible also that special methods may

prove of value, such as the high-tension discharge tested by Miss Dudgeon at Lincluden, Dumfries, and ably and critically studied by Prof. V. H. Blackman.

(6) Finally, it seems probable that some wholly new method may be found for increasing crop growth. In most civilised countries there are now research institutes where the ways of plants and the properties of soils are being studied. Men of science, as a rule, do not care to risk prophecies or to attempt to create sensations, and I certainly am not going to break this wholesome rule. Something, however, has already been done; in spite of the decreased labour spent on cultivation, the yields tend to go up, while the new knowledge that is now being gained is adding greatly to the pleasure of farming and giving both masters and men an interest in their work that they never had before.

Applied Geography.¹

By D. G. HOGARTH, M.A., D.Litt., C.M.G.

THE term "applied geography" has been in use for some years as a general designation of lendings or borrowings of geographical results, whether by a geographer who applies the material of his own science to another, or by a geologist or a meteorologist, or again an ethnologist or historian, who borrows of the geographer. Whether geography makes the loan of her own motion or not, the interest in view, as it seems to me, is primarily that, not of geography, but of another science or study.

Such applications are of the highest interest and value as studies, and, still more, as means of education. As studies, not merely are they links between sciences, but they tend to become new subjects of research, and to develop with time into independent sciences. As means of education they are used more generally, and prove themselves of higher potency than the pure sciences from which or to which, respectively, the loans are effected. But, in my view, geography, thus applied, passes, in the process of application, into a foreign province and under another control. It is most proper, as well as most profitable, for a geographer to work in that foreign field; but, while he stays in it, he is, in military parlance, seconded.

Logical as this view appears to me, and often as, in fact, it has been stated or implied by others (for example, by one at least of my predecessors in this chair, Sir Charles Close, who delivered his presidential address to the section at the Portsmouth meeting in 1911), it does not square with some conceptions of geography put forward by high authorities of recent years. These represent differently the status of some of the studies, into which, as I maintain, geography enters as a secondary element. In particular, there is a

school, represented in this country and more strongly in America, which claims for geography what, in my view, is an historical or ethnological or even psychological study, using geographical data towards the solution of problems in its own field; and some even consider this not merely a function of true geography, but its principal function now and for the future. Their "new geography" is and is to be the study of "human response to land-forms." This is an extreme American statement; but the same idea is instinct in such utterances, more sober and guarded, as that of a great geographer, Dr. H. R. Mill, to the effect that the *ultimate* problem of geography is "the demonstrative and quantitative proof of the control exercised by the earth's crust on the mental processes of its inhabitants." Dr. Mill is too profound a man of science not to guard himself, by that saving word "ultimate," from such retorts as Prof. Ellsworth Huntington, of Yale, has offered to the extreme American statement. If, the latter argued, geography is actually the study of the human response to land-forms, then, as a science, it is in its infancy, or, rather, it has returned to a second childhood; for it has scarcely begun to collect exact data to this particular end, or to treat them statistically, or to apply to them the methods of isolation that exact science demands. In this country geographers are less inclined to interpret "new geography" on such revolutionary lines; but one suspects a tendency towards the American view in both their principles and their practice—in their choice of lines of inquiry or research and their choice of subjects for education. The concentration on man, which characterises geographical teaching in the University of London, and the almost exclusive attention paid to economic geography in the geographical curricula of some other British universities tend in that direction.

¹ Abridged from the presidential address delivered to Section E (Geography) of the British Association at Edinburgh on September 8.