OUR ADVANCING KNOWLEDGE OF SOIL FERTILITY

The Farrer Oration delivered before the Agricultural Bureau Congress of New South Wales at the Hawkesbury Agricultural College, July 21st, 1948

by Professor J.A. Prescott

My first duty is to express my sincere appreciation of the honour conferred on me in being asked to give an oration in memory of William J. Farrer and to receive the Farrer Medal. No man can work ~~to~~ by himself and I regard it also as a tribute to many who have been associated with me in the work both of the Commonwealth Soils Division and of the Waite Institute.

In terms of the trust the subject matter of the address may be concerned with any aspect of agricultural science but in choosing it I have had in mind that soil fertility was a subject in which William Farrer was himself deeply interested. Indeed in the original minute recommending his appointment as "Wheat Experimentalist" in 1898 it was stated that

"Mr. Farrer would also be able to undertake experiments to determine the best methods of managing the different soils of our Colony with the object of making them fertile and preventing their exhaustion with the minimum use of manures."

Farrer brought to Australian Agriculture in his day something quite new, a trained mathematical mind. Sometimes it is better to bring a trained mind to a new problem than it is to bring purely technical knowledge. Farrer saw clearly that if Australia and particularly New South Wales was to prosper as a wheat growing country, (1) it must have wheat varieties of appropriate quality and disease resistance adaptable to the climate and (2) the cultivation of wheat must be based on sound methods of managing the soil. With respect to the latter he wrote in 1902 :

"The agricultural progress I have in view...... is the making of such improvements in our methods of tilling and handling the soil as will enable us to increase, and if possible, give direction to the activities of the chemical and biological (bacterial) forces which are incessantly at work in it, and cause them to change potential plant foods into available forms in greater abundance than they do by means of our present methods."

In connection with the work for which his name is best remembered - the breeding of wheat - his trained mind saw clearly the advantage of cross breeding over selection within existing varieties and was confident in the ability of the method to produce stable varieties. His interest in soil fertility did not find its real opportunity until the experimental farm was established at Cowra when in 1905 the year before he died, he conducted a field experiment in association with Sutton, (Dr. G.L. Sutton of Western Australia) which conforms in conception and statistical design with the best of present day ideas of what such an experiment should be. Farrer's mathematical mind saw the need for completeness in such a design and it is today possible to analyse by modern statistical procedure the records of this field trial and to assess – what Farrer could not then do – the reliability of the results so obtained.

In one respect only is the experiment at fault and that is in the field design – it lacks what is known as randomisation. It is very evident also from his earliest correspondence that William Farrer's view of soil fertility was that it was intimately bound up with the source of nitrogen to crops. *

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* <u>Footnote</u>. The experiment (Agric. Gaz. N.S.W. (1906) <u>17</u> : 311–326) deals with a comparison of three varieties of wheat, at three rates of seeding, at three times of planting, with a complete factorial fertiliser design including no fertiliser, phosphate, nitrogen and potash, singly and in all possible combinations.

The treatments were Varieties : Federation, Russian Macaroni, John Brown

Rate of seeding : 20, 40, 60 lbs. per acre

Time of planting : 19th April, May 25th, June 27th.

The Analysis of Variance of the records gives as significant

For the unmanured treatment :

<u>Federation</u> – better than <u>John Brown</u>, better than <u>Russian Macaroni</u>

May sowing, better than April sowing, better than June sowing.

April sowing, 20 lb. seeding is best.

May sowing, 20 lb. seeding is worst.

June sowing, 60 lb. seeding is best.

For the manuring experiment sown May 25th:

Federation, better than John Brown, better than Russian Macaroni

Rate of seeding : 60 lb. better than 40 lb. better than 20 lb.

Manuring : Phosphate is better than no Phosphate in the absence of potash. Potash and Phosphate together have a depressing effect.

In 1888, the discovery of the part played by bacteria in the fixation of the nitrogen of the atmosphere by leguminous plants was first announced and already by 1891 we find that Farrer had begun experiments on the maintenance of fertility in wheat soils by the growing of leguminous crops.

Soil fertility is the measure of the ability of the land to produce satisfactory and profitable crops, pastures and forests and to maintain livestock in numbers appropriate to the rainfall and in a healthy condition. Sometimes the ability of the land to yield well is only limited by some factor or factors which are thoroughly understood. By the skilful use of irrigation water for example the desert can be made to "blossom as the rose". In other cases the use of a chemical fertiliser such as superphosphate may be all that is necessary to bring the land to a productive level. It is the business of agricultural science amongst other things to study the factors that are responsible for soil fertility and to ensure that the appropriate means are placed in the hands of the farming community. A very valuable concept first introduced by Liebig and developed later by F.F. Blackman is that fertility may be limited at any time by a single factor and that when one factor is limiting no increase in any other can take its place. Thus in the examples we have just quoted no amount of irrigation water will be of any value if phosphate is the real factor limiting production.

Had ~~he~~ Farrer lived a generation later, modern genetics and modern statistics and biometrics would have given him a worthy field of interest and activity.

I propose to review the steps by which our present knowledge of soil fertility has been obtained. Knowledge is never complete, that is why I have used the term "advancing". It was a philosopher early in the Fifteenth Century who first called the attention of the newly awakening scientific world that knowledge is only a step on the way to the truth and it is to this philosopher, the Rhinelander, Nicolas of Cusa, that we must first turn for practical suggestions how to begin the study of soil fertility and the source from which plants derive their substance. In 1450, Nicolas wrote a book on the use of the balance. In it he suggested that it might be possible to carry out an experiment by growing a plant in a pot of soil, taking care to weigh the soil, the seed, the water used to grow the plant, the plant when it was fully grown and the ashes left after the grown plant had been burnt.

The experiment was not actually carried out so far as we know for 200 years and it was not until 1652 that the Belgian philosopher Van Helmont gave us the result of such a pot experiment. To him and to Nicolas before him it was evident that the substance of the plant was mainly derived from the water which was used, leaving only a small amount to come from the soil. Their interpretation was wrong although their experiment was well conducted. Although Van Helmont invented the word 'gas' neither of these philosophers knew of the important part that the atmosphere plays in supplying the raw materials from which a plant builds up its substance. The most important being carbon dioxide from which the starch, the sugars, the cellulose, the oils and the proteins derive their necessary carbon.

This was not made clear for nearly another 200 years and we have to move forward to 1843 before we come to the first modern experiments with plants in pots and crops in the field which were carried out by Lawes and Gilbert at Rothamsted in England. By this time it was known that plants received their carbon from the air and some scientists thought with Liebig that they also received their nitrogen from the same source, through the absorption of ammonia by the leaves in much the same manner as carbon dioxide was absorbed. From the soil the plants received only the substances present in the ashes. Lawes and Gilbert deliberately chose turnips as an early experimental crop because of its large leaves which surely, if any leaves did, would be able to absorb ammonia from the air. They used various mineral mixtures as chemical fertilisers to represent approximately the ashes of plants and farmyard manure. They quickly found as a result of these experiments that only two of the components of their mixtures need be taken seriously as fertilisers ; the phosphates and the potassium salts - all the other constituents of the ashes were readily supplied by the soil itself. This led directly to the development of the modern fertiliser industry which is based on the patenting of superphosphate by Lawes in 1842. The early Rothamsted experiments soon showed also that the turnips and the wheat crops which were grown could not secure any nitrogen except in the form of manure or from the soil itself. This nitrogen could be supplied not only by farmyard manure, by rape cake and other organic fertilisers but also by means of nitrates and salts of ammonia, and so compounds of nitrogen were added to the list of chemical fertilisers and for many years the big three, N.P.K., that is, nitrogen, phosphorus and potassium, became dominant in the minds of farmers and agricultural scientists the world over. It was in terms of these that the responses to the older manures, the so called natural fertilisers were interpreted and by these I mean stable and farmyard manure, blood, bone, wood ashes, saltpetre and so on.

There was one well known method of improving soil fertility, the use of lime in its various forms - chalk, ground limestone, slaked lime, marl and so on, which did not fit into this picture. Quantities were used far in excess of the known needs of crops for lime and the term amendment rather than fertilizer was used. Lime as such and later gypsum, that is sulphate of lime, were used to improve the behaviour of the soil, to improve the texture or to remove soil acidity or sourness but it was not until modern physical chemistry (Arrhenius 1887) had shown us the nature of soil acidity and alkalinity that we were able fully to understand the full reason for these effect.

The increasing need of the world for chemical fertilisers began to cause anxiety towards the end of the nineteenth century particularly so far as supplies of nitrogen were concerned. The only visible supplies then were the great deposits of Nitrate of Soda in Chile and the by-product Ammonia from gas plants and coke ovens in industrial countries. It was the technical advances in fixing nitrogen from the air that removed immediate anxiety on this score but even today the world could use much more than is available : 4 million tons of nitrogen against a production of 3 million tons (Chile exports 278,000 tons).

In one respect however, the Rothamsted results were puzzling. Agricultural chemists had begun to draw up farm balance sheets taking into account the fertiliser elements provided in the manures and those taken off the farm in the way of produce and taking into account also the reserves in the soil. It was evident from these that more nitrogen was being used by the crops than was being supplied by the farmer and that somehow or other the leguminous crops were those independent of the farm supply. Many experiments were conducted at Rothamsted particularly round the year 1857 by Pugh but there was no information in these experiments that could explain matters.

It was not until 1888 that the explanation came from the work of the German bacteriologists Hellreigel and Wilfarth. The bacteria that live in the nodules of leguminous plants are able to fix nitrogen from the air. I have already told you how Farrer quickly siezed on this new discovery in an endeavour to make use of these plants - peas, beans, clovers, lucerne - in improving the fertility of wheat soils. He wrote in 1894 -

"if we could hit upon a leguminous plant that can be economically grown with wheat the yield of the latter would be so greatly increased that wheat-growing would become a highly profitable industry."

It is only of recent years in South Australia for example, that we have paid serious attention to this particular problem. At Roseworthy College the soil and climate is suited to the growth of the several medics, and wider rotations have been developed which give higher yields of wheat and at the same time provide an abundance of forage for making ensilage or hay and for the grazing of livestock. At the Waite Institute with a higher rainfall, the leguminous crop has proved to be peas and our main alternative is to put down the land for a period of years into a pasture based on Phalaris tuberosa with subterranean clover as the principal leguminous plant. The use of peas in the rotation has the effect of maintaining wheat yields and increases the carrying capacity of the land for stock four to five fold. We have still much to learn about the best type of grazing to combine with wheat and peas and realise that there will always be a place for the judicious use of nitrogenous fertilisers in the agricultural rotation. I would agree with Farrer that in the long run nitrogen is the key to the problem of soil fertility in the wheat areas.

The importance of bacteria in nitrogen fixation has naturally led to a great deal of work on soil bacteriology. Some of these organisms work independently of leguminous plants; they are free-living and are known as Azotobacter but so far do not seem to play the important part in agriculture of southern Australia as do the nodule organisms now known as Rhizobium. In all the Australian States cultures of appropriate strains of these bacteria are now sent out regularly to farmers particularly when growing a leguminous crop for the first time on new land. In South Australia for example in the year 1947, 1600 cultures were sent out to nearly 300 farmers.

We may anticipate a little at this stage. About 1930 a German bacteriologist began to study the special food needs of the nitrogen-fixing bacteria Azotobacter. By a clever piece of scientific detective work he found that this organism grew much better if the solution in which it was growing was supplied with a minute trace of molybdenum. We have now every reason to believe that this element plays a very important part in the process of nitrogen fixation.

The first practical application of this discovery was an Australian one and I hope later to enlarge on it.

Early in the twentieth century the scientific foundations of the fertiliser industry appeared to have been well laid. Superphosphate particularly was being introduced for wheat growing in Australia. The scientific basis was not only in the pot experiments and field trials but also our increasing knowledge of the nutrition of plants based on solution cultures. In these cultures, plants are grown in water to which various salts providing the necessary elements have been added. If certain of these are omitted the plants refuse to grow. The methods of preparing pure water and pure salts were not then so refined as they are today and no new substances beyond the nitrogen, phosphate, potash, lime, magnesia, sulphur and iron were discovered to be necessary. There was however, one exception that gave a hint of what was in store. In 1862, Louis Pasteur, the famous French scientist who was then a Professor at the Teachers' College in Paris, suggested to his assistant Raulin that he should attempt to grow a mould aspergillus in a purely synthetic solution based on sugar and ordinary salts. In this the assistant was reasonably successful. Raulin became a high school teacher and could only devote his vacations to continuing his work on the salts needed for the most successful growth of this mould. In 1864 he came to the conclusion that "apart from oxygen, water, sugar, tartaric acid, nitrogenous matter, phosphates, potash, magnesia, sulphates, there exist other elements which added to the medium made up of these others, will notably increase the yield of the mould."

The greater the purity of his chemicals the lower the yield he obtained. He then tried in turn the addition of wood ashes to his solutions, then manganese and iron, and later copper, zinc and silver and was able in 1869 to publish a very important paper for which he received a prize from the Parish Academy of Sciences. From our point of view the most important fact is that Raulin added zinc to the list of elements required for the growth of the lower plants but it was not until well into the 20th Century that its importance was first suggested for a plant of agricultural importance, again by a former associate of Pasteur working on maize.

From this stage on our knowledge of soil fertility, so far as it concerns the ability of the soil to feed the plants, has grown out of two kinds of studies - the first of solution cultures using purer and yet purer water and chemicals and the second the study of a number of plant and animal diseases that could not be related to infections by bacteria, fungi, viruses or other parasites. Wherever infertile soils are now encountered which hitherto have not responded to the older fertilisers it has become customary to experiment also with the newer elements known to be necessary as plant foods and in some cases quite spectacular results have been obtained. Because of the small quantities needed, they are known as trace elements.

The first modern experiments to prove conclusively that plants need more than the standard elements was that published in 1923 by Katherine Warington at Rothamsted, 80 years after the first trials by Lawes and Gilbert. She was able to show that broad beans will not grow unless they are supplied with boron, the element characteristic of borax. It seemed at the time as if this discovery would be of little practical value but it was not long before diseases such as Internal Cork in apples in New Zealand and Heart Rot in sugar beet in many parts of the world were shown to be due to boron deficiency and that they could be cured by the use of borax as a fertiliser.

We now know by means of solution cultures that manganese, copper and zinc are also needed in quite small amounts for the growth of plants and that quite frequently soils occur in which these elements are deficient or at least not easily available. Sometimes liming the soil may make some of these elements less available and diseases show up in consequence. This applies particularly to boron and manganese. The question of manganese deficiency was first studied in Australia by Samuel and Piper and their work was published in 1929. In oats manganese deficiency shows itself as "grey-speck disease," a disease well known in Europe and first officially recognised in Western Australia in 1927 and also about the same time in South Australia.

Copper was used in Holland to cure the "reclamation disease" that affects crops on peaty land first brought into cultivation and similar experience was obtained in Florida in reclaiming some of the peat lands of the Everglades for vegetable growing. Also in Florida - a die-back or Exanthema of orange trees had been cured by spraying with Bordeaux mixture which of course contains copper. In Australia it has shown itself as a useful fertiliser mainly in parts of South Australia and Western Australia. An oat crop suffering from copper deficiency shows symptoms well described as "Wither tip".

The value of zinc as a fertiliser has been recognised since about 1931 and was first used to cure diseases such as "rosette" in pecan nuts, "little leaf" in peach trees and "mottle leaf" in orange trees in California. It is now used over a wide area in Australia on a commercial scale in the treatment of pine trees, citrus trees and vines and on crops and pastures in South Australia and Victoria. In the cases of trees it is not customary to treat the soil, it is found to be better to spray the trees. In the case of vines the painting or swabbing of the pruning cuts is more effective than other treatments.

We can now return to molybdenum which you may recall was first proved to be important for soil bacteria about 17 years ago. Solution cultures also showed that it might be important for plants but really good tests have still to be made. Molybdenum was tried many times in Australia in connection with other problems before it was found to be the element concerned in the unthriftiness of subterranean clover on certain ironstone soils in South Australia and Tasmania. Responses have since been found in similar areas in the Capital Territory and in New South Wales. It is used in the form of molybdate or even of roasted molybdenite ore. There are three interesting things about molybdenum. They are (1) that only very small quantities are required - perhaps one ounce to the acre. (2) That the molybdenum does not act directly on the clover, but only by its action on the nitrogen fixing bacteria in the root nodules and (3) that liming increases the availability instead of decreasing it as with manganese and boron.

In addition to these trace elements some of the older known elements are sometimes required in special localities. Magnesium has been used on tobacco and on fruit trees and sulphur on tea plantations. Sometimes iron is not available and iron salts must be used.

We can now turn to the less direct effects of soil fertility - those that operate through the plants on the livestock that feed on the plants. We are not concerned here with just carrying capacity but with the health of the stock and the quality of animal products. Sometimes the plant can secure a sufficient amount of an element from the soil to meet its own requirements but not enough to keep stock healthy. In some cases even we have no evidence that these elements are needed for plant life at all.

The most important of these elements so far are iodine, cobalt and copper. We are apt also to overlook the fact that animals must also get their salt in this way unless they are able to find natural salt licks or have the salt specially provided. We know something about the factors, mainly meteorological, that control the presence of iodides and salt in the soil. Cobalt deficiency plays a very important part in determining the health of sheep and cattle in many parts of the world. We are more familiar with its importance in Australia and New Zealand where it was found to be associated with Coast Disease in South Australia, Wasting Disease in Western Australia and Bush Sickness in New Zealand.

Copper is also associated with Coast Disease, and its deficiency was found to cause a type of rickets (Ataxia) in lambs in South Australia and Western Australia. It also plays a part in maintaining quality in wool. Both in Queensland and in South Australia copper deficiency plays a part in the occurrence of straight steely wool. In Sweden the need of copper for dairy cattle has been known in a practical way for two or three generations and bluestone has been added to the drinking water. Of more recent years we have been told that cows and calves are even fed copper coins occasionally just to keep them healthy.

It is not always that soils are infertile through lack of something or other. Quite often the infertility is due to an excess. Just as soils may be made to produce more by means of irrigation, so they may at times be made more productive by drainage to remove excess of water. In most irrigation areas it has proved necessary to do both for the supply of irrigation water needs great skill and it is easy to overdo it.

We are concerned however, with excessive amounts of other things - by far the most common is common salt and the other salts usually associated with sea salt. Salt sometimes affects the yield of ordinary agricultural crops. I have seen this occur particularly in Western Australia but it is also to be seen occasionally even in Tasmania. It is always worse, however, in irrigation areas because it is the dry countries where irrigation is most needed that salt is most likely to be present in the soil. The management of salt affected land calls for great skill and may involve quite expensive drainage systems to remove the salt. Another type of infertility closely associated with salt is what is scientifically known as "solonisation". The lime which is ordinarily combined with the clay in the soil is replaced to a certain extent by soda. Such soils may occur quite naturally and if the replacement is too excessive the soils become sticky and impervious and even quite alkaline. The condition is usually remedied by treating the soil with gypsum or sulphur, but there are some difficult cases where even this treatment has not been successful.

If the soil is heavily leached through high rainfall or regular flooding, the combined lime which we have just mentioned finds its way into the drainage waters of the country and the soils become acid. Soils that are infertile through acidity are not very common in Australia and very often the economic solution of the problem is to choose a crop to fit the degree of soil acidity rather than to attempt to correct it by using lime. Many of you will be familiar with the term : pH. This is a very useful device invented in 1909 to indicate precisely the degree of acidity.

The trace elements are, as their name indicates, needed only in small amounts. Their presence in the soil can be also harmful even if the amounts present are small as compared with the standards established for common salt. Boron is one of the elements that can be present in amounts harmful to crops. I have not heard of any cases in Australia but such are known in California. Two other cases I wish to mention where livestock are harmed by excessive amounts. The first is molybdenum which we have just considered - excess of molybdenum in the pastures, and by excess, we do not mean really large amounts - something of the order of 20 parts per million - is believed to be responsible for a scouring disease of cattle in the West of England known as "Teart".

In the western United States, another stock disease is caused by an excess of selenium which is concentrated in certain species of plants. This disease was first described by Marco Polo during his visit to China but its cause was not then known. Although we have no record of selenium poisoning stock in Australia, it would not be surprising to find it sooner or later in our desert regions.

You will note that so far I have paid little attention to the organic matter or humus and its contribution to soil fertility. Organic matter has a triple role to play in the soil. In the first place it acts as a reserve of plant foods. Natural organic manures are usually slow acting when they are used principally as a source of nitrogen. It is interesting however that recently slowly acting chemical nitrogenous manures have been developed which may well play a special part when the opportunities for their use have been more fully tested. As the organic matter originally comes from the soil so generally speaking what has been taken up can be returned in what is likely to be a more readily available form. In the second place it provides energy - food if you like - for the great population of micro-organisms that play their part in converting complex organic residues to the simple chemical substances that make the actual food of plants. And finally it assists in forming the structure of the soil which is so important in the preparation of the seed bed and in absorbing moisture and maintaining an air supply in the soil itself. Roots breathe and need oxygen. The search for a cementing agent in humus to play a part in maintaining soil structure has not been very successful and we are increasingly inclined to look upon grass roots and the structures of the growing fungi to keep the crumbs together that make the ideal structure. Loss of structure means poorer penetration of rain and consequently greater run-off leading possibly to erosion. It means also frequently the loss of good conditions for seed germination. It is most easily destroyed by cultivation and most easily restored by putting the land back to pasture - much more easily this way than by green manuring. At the Waite Institute in South Australia, the greater part of the soil structure built up over the centuries of native conditions was destroyed in four years of cultivation.

The use of humus to build up soil fertility is often advocated these days as being preferable to the use of chemical fertilisers. It will be obvious to you from what I have said today that plant remains whether as humus or as ashes will be more complete than many or any chemical fertiliser. But on any given farm or piece of land there are only one or two or possibly none of the plant foods in insufficient amounts to produce satisfactory crops. The use of the proper chemical fertiliser in itself guarantees the proper accumulation of organic matter in the soil and there is no evidence at all in a properly constituted crop rotation of cereal and legume or in an equally well constituted pasture that the use of chemical fertilisers speeds up the decline in humus content, rather to the contrary.

In conclusion may I say a word about the rate at which our knowledge has been increasing and has been applied to practical farming. It took 400 years before the simple pot experiment of Nicolas to find out how plants grow found its practical application in the development of the chemical fertilisers of modern agriculture, but these were also based on practical farming experience. The use of phosphates, potash and nitrogen were established by farmers long before a scientific reason could be given and even the use of copper was discovered by practical men before the scientist was able to show that it was really essential for the growth of plants.

The scientific importance of zinc in life was first suggested about 1870 and it was sixty years before it found practical application. It took 30 years before the ideas of the theory of electrolyte dissociation found their practical application to the study of the pH values of soils and it was another 10 years or more before farmers became familiar with the idea. In the case of molybdenum there was only about ten years between the laboratory discovery and the field application. In the cases of manganese and cobalt the scientific work and the practical application were worked out together. It is the speed and certainty with which technical advances follow scientific discovery that has made scientific research in agriculture such a sound investment today. We are far from understanding everything that takes place in the soil nor do we have a full understanding of the needs of plants or of the basis of soil fertility, but I think you will agree with me that our knowledge is advancing and that it is on the basis of such knowledge that a prosperous agriculture and livestock industry must be built. I feel sure that you will agree with me that none would have appreciated more this advancing knowledge than William Farrer, himself, whose memory we honour today.

JAP.PAH
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