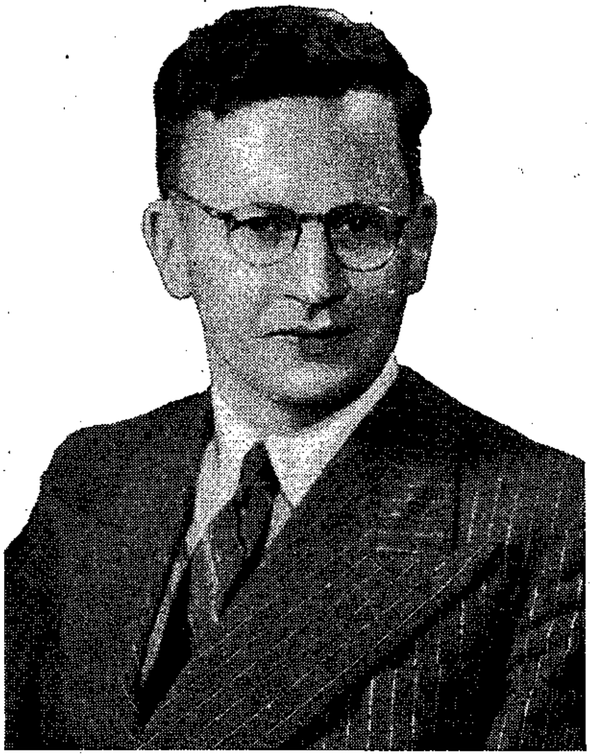
1953 Farrer Oration:

GENETICS *in the Service of Agriculture*

THOSE of us who are gathered here today, though we may represent a variety of interests, we share this in common—a sincere love of the land, a love that was dear to the heart of the man whom we honour on this occasion. Coupled with this love of the land is a responsibility for maintaining and enhancing the welfare of that greatest of all industries—agriculture. No man could have discharged this responsibility more ably and more completely than William Farrer, and his life, dominated by a spirit of service to agriculture, continues as an example and inspiration to us all.



MR. A. T. PUGSLEY, M.Sc., B.Sc. (Agr.), who was awarded the Farrer Memorial Medal for 1953. Mr. Pugsley, formerly of the Waite Agricultural Research Institute, Adelaide, and now Director of the new Agricultural Research Institute at Wagga, has gained wide recognition for his outstanding contributions to the wheat industry. The text of his Farrer Memorial Oration, delivered at the 1953 Annual Conference of the N.S.W. Agricultural Bureau, is published here. The medal was presented to Mr. Pugsley on the opening day of the Conference by the Under Secretary and Director of the Department of Agriculture, Dr. R. J. Noble, who is chairman of the Farrer Trust. Professor J. R. A. McMillan and Messrs. E. A. Southee and A. McCorquodale, members of the Trust, were also present at the function.

In selecting *Genetics in the Service of Agriculture* as the subject of this adddess I would first of all like to trace briefly some of the early developments in our knowledge of heredity in so far as they relate to the improvement of our crop plants, with some reference to the contribution of William Farrer, and the establishment of genetics as a science in the early years of the twentieth century. I propose then to select one or two examples of recent work in agricultural genetics which have a direct bearing on the present and future problems of agriculture in this country.

Agriculture, of course, is as old as civilization itself, and although genetics, as an independent science, has only recently celebrated its fiftieth anniversary, its rudiments may be traced back to the beginnings of agriculture. It was in prehistoric times, probably soon after the human race passed from the nomadic food-gathering phase into the stage of settled communities, when primitive man took the first steps in domesticating the plants and animals that lived alongside him. He appreciated in a vague sort of way that "like begets like" and for the first time we have the suggestion of conscious selection taken over by man himself from Mother Nature. However crude the process may have been, it did yield results as is testified by the remarkable fact that most of our present-day plants were improved and grown by primitive people. By the time of the Bronze Age man was already growing several kinds of wheat, oats, barley and millets and to these were to be added others by the peoples of both the old world and the new. We know that in spite of the extensive exploration of the world for new plants during the past 1,500 years, scarcely a single economic plant of any importance has been newly discovered.

Today, when one compares a cultivated crop with its nearest wild relatives, certain characteristics can be recognised as being of primary importance to successful cultivation, and in all cases these characteristics must be of extremely ancient origin. Nature had made the crosses; Nature had inbred them and provided the variants, but man had selected them. The non-shattering ear of wheat, the non-articulate grain base of oats, the peculiar type of inflorescence found in cultivated maize, the convoluted and so spinnable hairs of cultivated cottons, the edible fruit of the banana—these may all be cited as characteristics, of ancient origin and of major importance to man, which are present in the cultivated species but absent from their nearest wild relative.

Many centuries were to elapse before we can record the next major contribution to plant improvement—perhaps the first that we could credit to science.

The Beginning of Plant Hybridization as a Science

The seventeenth and eighteenth centuries brought with them a spirit of scientific scepticism against the mystical philosophy of the past, and a tremendous impetus to the study of heredity was given by the invention of the microscope and by the clarification of the mechanism of sexual reproduction. Male cells, the spermatozoa, were recognized in the latter half of the seventeenth century and their function as initiators of development of the egg was demonstrated experimentally by Spallenzani in Italy early in the eighteenth century. In the plant kingdom, although the Greek and Roman writers of natural history (Aristotle, Pliny, and Theophrastus) had vague ideas of the supposed existence of sex in plants, it remained for Camerarius, in 1694, to produce convincing experimental evidence that plants are sexual organisms. Camerarius worked with several dioecious plants, *i.e.*, those having the sexes on different plants, and also with maize. Maize had been introduced to Europe from America and grown for two hundred years before this simple fact was learned—that the removal of the pollen-bearing flowers from the tassels of isolated maize plants prevented fertilization and subsequent development of the seed.

The significance of Camerarius' discovery, however, remained quite unappreciated for nearly seventy years, when the German botanist, Kolreuter, in 1761-66, published the results of his extensive experiments in the crossing of plants. He dispelled any lingering doubts that seeds were produced by a sexual process similar to that prevailing in animals, since when two different forms were crossed, the hybrid partook of the characteristics of both parents. Another phenomenon that he noticed, one which incidentally was to lead to remarkable practical results in the twentieth century (as we shall see later), was that very often the hybrid grew more vigorously than either parent. Unfortunately, however, the essential nature of the hereditary process escaped him.

Other significant events of this time were the inbreeding experiments of Robert Bakewell and others, which laid the groundwork for the development of modern breeds of livestock. Watt's invention of the steam engine, and Jethro Tull's invention of the seed drill, mark the beginnings of the machine age soon to be ushered in and destined to revolutionise both primary and seconary industries.

FARRER MEMORIAL MEDAL

The Farrer Memorial Medal is presented each year—

(1). To perpetuate the memory of William Farrer.

(2) To reward one who has rendered distinguished service to agricultural science.

The Nineteenth Century

Looking back over the years it is somewhat difficult for us to realise that separated from this period is a small gap of some eighty years which brings us to the year 1845, when Farrer was born at Docker, near the town of Kendal in the beautiful Lakes District of England. This was the England where Charles Darwin, stimulated by the reading of Malthus' work on population and of what he saw during the voyage of the "Beagle" (1831-5), had already formulated his theory of evolution through natural selection, although fifteen years were to pass before the world heard of it in 1859. This was the England, too, which saw the foundation of Rothamsted by Lawes and Gilbert, while in far away Australia, on the wheat fields of the Adelaide plains, Ridley and Bull's stripper was ushering in a new agriculture based on that pioneer crop plant, wheat. On the Continent of Europe at the time of Farrer's birth, Gregor Mendel, then aged 23, had entered the Augustinian monastery at Brunn, but had not yet commenced his experiments on plant hybridization. When Darwin published his *Origin of Species* he had found it necessary to say that "the laws governing inheritance are for the most part unknown"; yet at this very time the answers to his questions were being worked out by Mendel. Unfortunately, however, Darwin died, never to hear of Mendel's work.

In both England and Australia the farm crops, like those of some countries today, consisted of heterogeneous populations which provided favourable material for the selection and isolation of distinct types which we now call varieties; indeed, the story of crop improvement throughout the nineteenth century was largely that of devising methods for selecting the superior forms. Fortunately, most of the crops were self-pollinated so that little trouble was experienced in the "fixing" of selected types. The guiding principle of selection was at first essentially Lamarkian, as is typified by the work of Hallet, who tried to secure a continuous improvement year after year by growing his wheat plants under the best possible conditions and choosing the highest yielding plant each year, hoping that the luxurious growth induced by these mthods of cultivation would tend to be passed on to the offspring. With our knowledge we should not have expected these methods to have succeeded, and this appears to have been the case. Le Couteur, on the Isel of Jersey, also made single plant selection, but on a different basis, testing one line against the other and selecting the highest yielding one. The scientific basis of Le Couteur's method of selection was established later by the Danish biologist Johannsen, in 1903.

Although the work of the English wheat breeders was well known to Farrer it was to Darwin that he looked for inspiration in approaching the problems facing the Australian wheat industry in the 1880's. Darwin's life came to a close in 1882 and in that very year Farrer, following upon a controversy with the *Australasian Newspaper* on the possibility and best manner of securing varieties of wheat which would satisfactorily resist rust, commenced his work. The study of variability and selection were clearly seen to be the key to the problem. During the closing years of the century Farrer stated:

> The principles on which the work should be carried on were then seen clearly, and everything which has been done since has been nothing more than a natural development of the views which were formed then. The principle on which the work is founded is exceedingly simple. It is merely that whenever well directed attention is given to the improvement of a domesticated plant in any quality in which it is variable, that quality can be increased and developed to an indefinite extent. I saw that the wheat plant varied in the amount of resistance it offered to the different rust parasites and that it was for that reason, capable of being improved. During the time I have had the work in hand I have seen no reason whatever for changing that opinion, but much to confirm it.

Farrer combed the world for his material and extended its range of variability through hybridization, basing his choice of parents on the individual characteristics which each contributed. He concentrated his attention on the more complex physiologic qualities of disease and drought resistance and the various factors associated with the bread-baking qualities of wheat flour. The success he achieved is well known to you all, but more perhaps than this is the human story of a life lived in the service of the new profession of agricultural science which many have since been called upon to follow.

Farrer possessed those rare qualities of the scientifically trained mind, disciplined to pursue its objective with a singleness of purpose, formulating working hypotheses, but always ready to reject them unless critical evidence could be found for their support. He lived with his plants and developed a genuine love for them so that he became possessed of an almost instinctive sense in appraising their various qualities.

Through his contacts with colleagues overseas, Farrer did much in fostering the international collaboration between scientists of which today we are so justly proud. While travelling overseas in 1948 it was my privilege to represent Australia at the eighth International Congress of Genetics, at Stockholm, and there to meet men of a dozen countries who identified Australia with the name of its pioneer plant breeder, William Farrer. Again while in the western States of the U.S.A. one could see many crops of Federation wheat still being grown by farmers who valued this variety for its productivity on the soils of this foreign land.

The Twentieth Century.

The last two decades of the nineteenth century saw tremendous advances, not only in the scientific study of heredity, but in other related sciences as well. This culminated in the almost explosive birth of a new science following the re-discovery, in 1900, of Mendel's classical investigations, which had been completely ignored by the scientific world for a third of a century. The new science was given the name of Genetics in 1906, since when it has grown from strength to strength, so that today it stands as the great unifying science of biology.

As with other sciences genetics has brought with it a number of new words to our vocabulary, and it is not possible to go far in understanding this science without becoming familiar with words like genes and chromosomes. These two words have a deep significance to biology, quite analogous with words like atoms, molecules, protons and electrons to the physical sciences, though of course, they fail to capture the imagination of the man in the street. We live, I would remind you, in the Atomic Age!

Farrer's approach to wheat improvement had always been Mendelian in outlook and the pattern of procedure which he established was based on the concept of the independent inheritance of specific characters followed by their re-combination in the progeny of succeeding generations. We know that many of the characters which he studied are of the continuously varying kind conditioned by a number of genes, the effects of which are characteristically much modified by the external environment. However, in recent years improved statistical techniques have led to the formulation of new methods for measuring the heritable components of this variation which in turn may be expected to lead to more effective systems of selection.

So far this work has found little application in Australia, but its importance to future breeders cannot be over-estimated. Past experience has shown us that progress in any field of applied science inevitably follows, be it ever so slow sometimes, upon the development of new concepts in the related basic science. If the breeder is aware of these developments he is in the position to meet the new problems which continually arise, either on the farm or in the associated industry which uses the farmer's produce as its raw material. One aspect of the breeder's programme, often overlooked, is that his work usually requires say ten to twelve years for its execution. This being so, everything should be done to help him in his rather difficult task of anticipating future developments and requirements. The appraisal of the problem must come first, then follows the designing of appropriate techniques and the assembly of the parental materials. Thus equipped the breeder is in the position to apply the basic principles of the new science of genetics.

It would not be correct to suppose that the advent of genetics led to an immediate change in plant-breeding procedures, and some years had to elapse before the new knowledge could be assimilated and translated into practice. Recent years have seen many advances, but it is sufficient to select two examples which serve to illustrate the way in which the new principles are being applied at the present time. The first is in the breeding of disease-resistant varieties, and the second is in the application of the principles of hybrid vigour in the improvement of cross-fertilized plants.

Wheat Improvement in South Australia

In South Australia twenty years ago farmers were growing high-yielding drought-resistant varieties; Nabawa was the leading variety although it was in the process of being replaced by Bencubbin and Ranee. All varieties were susceptible to rust and were mediocre to poor in their bread-baking qualities. Bunt was effectively controlled by copper carbonate, but at a recurring cost of some considerable amount.

Roseworthy College and the Waite Institute were charged with the responsibility of carrying out the improvement programme. Improvement of baking quality was achieved in rather an interesting way, for the breeder had to work, as it were, with one hand tied behind his back. The Australian wheat marketing policy, together with the husbandry methods practised by wheat farmers at that time, imposed certain rather severe limits on the way in which he could proceed. Yield standards had to be maintained at all costs. Accepting these restrictions he set to work using selection techniques based on the wheatmeal-fermentation-time test, supplemented by Farinograph tests, and a rigid screening-out process of large scale yield trials. The results were quite remarkable. For example, in the production of Javelin, Breakwell, at Roseworthy College, produced a variety that measured up to the standards of both the farmer and the baker. Here was a variety that can equal Bencubbin in yield over a wide range of conditions, at the same time excelling that variety in bread-baking qualities. Equally successful varieties (such as Dirk, Ridley, Scimitar and Warigo) were produced and the stage was set for the next step, the incorporation of disease resistance in these varieties.

It is here that basic genetical studies have so admirably served the breeder and his work can now be carried on with mathematical precision. Genetical studies have shown that as a rule resistance to disease is simply inherited, so that provided the breeder possesses satisfactory parental material, straightforward techniques enable him to transfer resistance from one variety to another with comparative ease. With the collaboration of oversea workers Australian breeders have located and identified a number of useful "resistant" genes and have already incorporated some of them in standard commercial varieties through the technique known as backcrossing.

Briefly the procedure with respect to stem rust of wheat is this—the standard variety, say Javelin, is crossed with the resistant donor parent and the progeny again crossed to Javelin. The same procedure is repeated for four or five generations, all the time artifically testing individual plants for resistance. Eventually one secures a new strain of Javelin, differing from the old only in this one characteristic of rust resistance. In fact, in the absence of rust, it is quite impossible to distinguish between the two. The effectiveness of this procedure has been demonstrated on a number of occasions, particularly during the last rust epidemic which occurred in 1947. It may interest you to know that much of this work was conducted in collaboration with the late Mr. F. Coleman of Saddleworth, who also assisted Farrer in the testing of Federation and other wheats on this same farm in 1901. Having added resistance to rust through backcrossing, the process may be repeated again and again for other diseases, the greatest limitation of the method being the non-availability of satisfactory sources of resistance.

One very disturbing factor that has been brought home to us on more than one occasion recently is the faculty which micro-organisms have of evolving new and more virulent forms so that hitherto resistant varieties may once more succumb to attack. This problem is exercising the minds of research workers at the present time; its solution is dependent upon a thorough understanding of the evolutionary processes which take place in nature. It is work that demands our whole-hearted support.

Through backcrossing, other objectionable features of otherwise acceptable varieties may be corrected in a like manner, examples being the removal of objectionable barbs from awned barleys, the removal of toxic alkaloids from the seeds of certain forage legumes, and the introduction of a non-shattering type of seed pod in various crop plants. So-called "marker" genes may also be added as an aid in seed certification. The addition of awns to beardless wheat varieties may prove helpful in identifying certain strains and although some farmers may object to their presence, there is evidence that, in the adding of awns to a completely bald wheat, both the yield and the bushel weight of that variety may be increased.

There is little doubt that many genes of potential value to the breeder remain yet undiscovered, existing as they do, quite unnoticed by man in both wild and cultivated plants scattered throughout the world. Only quite recently have we secured, and this largely by chance, a gene which will protect (in Adelaide at least) the home gardener's tomato patch from the ravages of the spotted wilt disease. More than any other country, we in Australia are so utterly dependent on oversea sources for both the kinds of crops grown and for the material used in the improvement of those crops. The value of a single gene carried in an otherwise nondescript plant may quite conservatively be estimated as being of the order of several thousand pounds, so that it would never be difficult to present a case for the expenditure of money on additional plant exploration work, provided of course that it is supplemented by a soundly based breeding programme.

Cross-pollinated Crops

The experiences of Farrer and his contemporaries in establishing breeding techniques with self-pollinated plants like wheat is reflected in the work of present-day breeders in Australia who have devoted most of their attention to the improvement of selfpollinating crops to the neglect of others like the pasture grasses, many of which are wind-pollinated, and as a consequence different systems of breeding must be employed.

If we take maize or corn as our example of a cross-pollinating plant it is possible to report striking advances over recent years. In reviewing the progress of corn breeding in the U.S.A. during the nineteenth century Webber and Bessey, in the U.S.D.A. Year Book for 1899, have this to say: "Corn has been greatly modified and improved by hybridization but no improvement stands out as marking a distinct epoch". Who could have known at that time that in less than forty years, in the 1936 Year Book, we were to read this: "Hybrid corn has been developed as a result of researches in genetics and provides the most outstanding example of the influence of theoretical scientific research in revolutionizing the production practices of an agricultural crop."

The story of its development is a fascinating one. The early workers were interested in the theoretical aspects of inbreeding in this normally cross-pollinated plant. Inbreeding was shown to result in a progressive reduction in vigour and yet, when suitable inbred plants were crossed together, the original vigour was more than restored. Compared with the normal open-pollinated varieties, yield increases were of the order of ten bushels per acre, which represents a nett annual increase of the order of 850-million bushels, equivalent to more than four times Australia's total wheat production.

As one would expect the general applicability of this technique for other cross-fertilizing crops has been examined and successful results reported with lucerne, sugar beet, sorghums, onions, tomatoes and even forest trees. For most of these crops the production of commercial hybrid seed raises practical difficulties which, however, are being overcome by rather ingenious means. With maize, the accepted procedure for the production of hybrids has been to remove by hand the pollen-bearing tassels from one parent in order to ensure pollination by the other parent. In supplying United States farmers with hybrid seed an annual cost of six million dollars is involved which must, of course, be debited to the cost of the seed. However, recent research suggests that by the use of rather subtle genetic techniques it will be possible, and it is hoped practicable, to produce male sterile inbreds and thus obviate the need for de-tasselling. Similar techniques are being worked out for other plants.

It is well to emphasize that the heritable qualities with which the breeder works are assembled by him from pre-existing materials which Nature has made available during the past long evolutionary period. This simple principle was first fully appreciated by plant breeders in the Soviet Union, headed by Vavilov. Vavilov made extensive world collections of agricultural crop plants together with their wild relatives, and the detailed study of these collections led him to formulate certain laws governing the distribution of plants and of the range of variability that one may expect to find in each. Various "missing links" were postulated and subsequently discovered after prolonged searching. We now have evidence which suggests that our modern bread wheats have evolved from three ancestors belonging to the genera Agropyron, Triticum and Aegilops. Present-day representatives of these genera possess characteristics of value to the breeder and techniques have been worked out whereby new synthetic species are first made and then used in crossing with commercial varieties. In some instances distant hybridization has been made possible by the neat technique of dissecting-out the young hybrid embryos and growing them on artificial nutrient medium in test tubes.

Not always being content with the naturally occurring range of genes found in the cultivated and wild species, geneticists have sought the means for creating quite new heritable qualities. Until 1927 the sporting or mutating of genes had been regarded as being an occurrence both rare in its incidence and quite uncontrollable by man. In that year, for the first time, Muller showed that the mutation processes could be speeded up by about two hundred times by the use of X-ray irradiation. Although most of the new variants that arise from X-ray treatment are harmful to the plant, recent work in Sweden has led to the production of new mutations of value to the breeder in crops like barley, flax and lupins.

Likewise the chromosomes, too, which carry the genes, have lately proved amenable to treatment in the laboratory. Certain chemical drugs (notably colchicine) when applied to actively growing tissues like germinating seeds or young shoots, may result in a doubling of the number of chromosomes in the plant cells, with which are associated various changes in the growth habits of the plants themselves. Treated plants are frequently more vigorous and usually produce larger flowers, fruits and seeds, but the total yield is usually reduced because of the sterility which frequently accompanies these changes. If propagation is possible by vegetative means, as with certain fruits, problems of fertility are less important. Since most of our crop plants are propagated by seed the doubling of the chromosomes is not sufficient in itself and must be supplemented by further inter-crossing and selection for increased fertility.

These examples serve to illustrate some of the newer approaches to improvement work, but in its essence future progress is dependent, just as it was in Farrer's day, on the further detailed study of variation and selection. Genetics, with the sister sciences of physiology, cytology and biometry, have much to offer in this direction and future progress depends on our ability and willingness to relate this basic knowledge to the varied problems that arise in the field and on the farm.

Australia is a land with a rich agricultural potential and the extent to which this is realised rests with the whole community no less than with those specifically engaged in day-to-day agricultural research.

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