1975 FARRER MEMORIAL ORATION

"LEGUMES AND AUSTRALIAN AGRICULTURE"

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BY

DR. J.S. GLADSTONES

SENIOR PLANT BREEDER

DEPARTMENT OF AGRICULTURE

PERTH, WESTERN AUSTRALIA

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LEGUMES AND AUSTRALIAN AGRICULTURE

Farrer Memorial Oration, delivered by Dr. J.S. Gladstones in the Great Hall, Sydney University, September 18, 1975.

Introduction: William James Farrer

The occasion of this talk is to honour William James Farrer, Australia's pioneer wheat breeder. As seems proper, I shall begin with some personal reflections on Farrer's life and work.

William Farrer was born in County Westmoreland, England, the son of a farmer. Early childhood experiences doubtless contributed to his lifelong love of the land and insight into its problems. When eight years old, William was sent to the historic Christ's Hospital School in London; thence to Pembroke College, Cambridge, where he read mathematics and graduated with Honours in 1868. Thus his background combined an early childhood on the land; the rigors of a 19th century public school, away from his family at an early age; and finally, the intellectual discipline of mathematics. In such a background we can perhaps see the origins of the personal independence and single-mindedness which later were to play such an essential part in Farrer's career.

The career was founded in disappointments. Abandoning the study of medicine when he was diagnosed as having tuberculosis, Farrer came to Australia as a young man of 25 seeking a healthier climate. He aimed to become a grazier, but an ill-advised speculation lost him all his capital, and he was forced instead to take up surveying.

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From the beginning, Farrer's assessment of the colony's agriculture disturbed him. In 1873 he published a pamphlet in which he urged the development of agricultural education along the lines of the American land-grant colleges. Later, in his job as a surveyor with the New South Wales Lands Department, he was able to see the ravages of rust in the colony's wheat crops, and the general unsuitability of the varieties then available. Finally in 1886, when already over 40, Farrer resigned from the Lands Department and bought a small property on the banks of the Murrumbidgee. There, with his own and his wife's modest combined resources he devoted himself full-time to wheat breeding.

Farrer endured criticism and ridicule, but being independent he was able to follow his own ideas and develop his methods and materials within the resources at his command. Later he received grudging official support, and in 1898 was given an appointment in the New South Wales Department of Agriculture. There he suffered much frustration from unco-operative farm managers and a largely blind or sceptical beaurocracy, but in the end the success of his varieties spoke for itself. When Farrer died in 1906 his varieties were already extending wheat growing into new regions, and were providing a foundation from which much of subsequent wheat breeding in Australia has developed.

What can we learn from Farrer's example? The most important lesson, I think, and one which is echoed in the careers of so many leading scientists, is that scientific achievement is very much a product of individual personality. I am not

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speaking here of routine technology but of creative science, which remains as essential to progress today as it ever was. The mark of the true scientist is not so much that he can use the tools of science to prove or disprove given propositions - essential as these processes are. It is rather, that by observation, logic, insight and imagination he can forsee the propositions and act accordingly. In applied science such as plant breeding this may be direct action to a practical end; in more basic science, to find further logical and experimental proof or disproof of the propositions. Desirably the two approaches go together, because the one enriches the other. But whether science is applied or basic, the needed qualities of vision and an almost obsessional perseverance are the same.

William Farrer had these qualities. We honour him as one who, from his own observation and reason, deduced both needs and novel means to meet them. In doing so he gave us not only a vastly improved wheat industry, but also methods of plant breeding which, in their essence, have not been improved upon since.

<u>The Contribution of Legumes to Agriculture</u>

The main subject of my talk, legumes and Australian agriculture, may to some seem hackneyed. In recent years several Farrer Orators have discussed aspects of it at length: Professor Donald in 1964, Dr. Mark Hutton in 1968, and Professor Vincent in 1972. Yet I make no apology for rehearsing the subject once again.

Australia has for some years been passing through a period of agricultural difficulty. Perhaps due to the strength of mining exports, together with strong investment from overseas, Australia has not had to depend as much as previously on her agricultural and pastoral industries to maintain the balance of payments. The health of these industries has become of less consequence to politicians and voting public alike. Incentives for farm development have dwindled, and interest in pasture improvement has fallen accordingly. The process has been abetted throughout by low wool and recently beef prices, and in some states by adverse seasons which have exposed the limitations of the pasture legumes now available.

At the same time Australia, like many countries, has suffered from the political and industrial glamor of the nitrogen factory: not, it is true, to the same extent as in the U.S.A. and Western Europe where a few years ago legume research almost became extinct, but still enough to have reduced the effort put into legume research. The spectacular responses of the new "miracle" cereals to bag nitrogen have suggested to many that therein lies the true key to agricultural salvation.

Among agriculturists it has also long been assumed that legumes are inherently less productive than non-legumes, if only because of the supposed assimilate cost of symbiotic nitrogen fixation. Thinking may additionally have been coloured by the inverse correlation so often found in grain crops between yield and grain protein content.

In my observation, these and perhaps other factors have combined to reduce interest in legume research among Australian agricultural scientists and teachers over the last five to seven years. Some interest has been maintained in grain legumes because of their obvious possibilities as cash crops,

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but pasture legumes have become unfashionable. A scientific generation is growing up which knows not pasture legumes, or at least takes them for granted.

Seen in the longer perspective, this seems illogical. Economic cycles come and go, but research is a long term business, and ideally should not be allowed to be unduly influenced by short term economic considerations. The demand for pastoral products will have changed completely before ~~the results of~~ any current agronomic research, or especially breeding, can come to fruition.

We should also remember that further agricultural development, which must come in time, will largely have to be on land hitherto marginal or too poor for agriculture, and it is here that legumes have their greatest role to play as I will discuss later.

Above all, rising energy costs are making nitrogen fertilisers continually more expensive. Economics and competition from other end uses for diminishing cheap fossil fuels must again turn attention to that curious symbiosis of plant and bacteria, which takes nitrogen from the air, and turns it into edible protein without cost or threat to the environment.

<u>Potential Genetic Improvement of Legumes</u>

Can legumes be improved so as to match, or at least approach, the potential yields of non-legumes? The answer to this is crucial, since all crops must to varying degrees compete with each other for the limited land available. I believe the answer is substantially yes. One of the reasons for their present generally lower yield is that they have not yet been selected or bred as intensively as the staple cereals; nor has their selection been as exclusively for seed yield, because many have been valued as much or more for forage as for seed yield. Moreover the old idea of a high assimilate cost for symbiotic nitrogen fixation has now been fairly conclusively disproved. Work such as that of Kidby (1967) and Davidson et al (1970) indicates that it is little, if at all, higher than that for reduction of soil nitrate.

It does remain true that the canopy light relations of most crop and pasture legumes are less efficient than those of the erect-growing cereals and grasses. Due to their predominant growth habits and leaf forms, the problems of raising ceiling yields - whether by breeding, fertilizing or irrigation - are probably more intractable than in the Gramineae. Additionally, legumes, or at least those free from noxious constituents, are highly attractive to insects and other predators. They are subject to many fungal and virus diseases. Drought tolerance does not in general equal that of the Gramineae. Finally, their requirements for nutrients other than nitrogen are often high. All these factors mean greater costs and the need for a higher level of husbandry, which farmers accustomed to the simple husbandry of cereals are not always able or willing to give. Some of the disadvantages of legumes as crops may perhaps be remedied by breeding, but others are probably inherent.

Domestication of New Legume Groups

A most interesting aspect of legume improvement is that we may not yet be exploiting the botanical groups which have the greatest economic potential. Norris (1956 and elsewhere) has long ago pointed out that most existing improved legumes, together with their bacterial symbionts, are adapted to soils high in bases, in contrast to the great majority of tropical legumes and their symbionts which tolerate soils of lower pH and base content. The list of Hutchinson (1970) shows that old-established crop legumes are confined almost exclusively to two papilionaceous tribes, the Viceae and the Phaseoleae, with the sole addition of peanuts (Arachis) from the Hedysareae. Temperate pasture and forage legumes are confined to the Hedysareae and especially the Trifoleae: again mostly plants adapted to soils of at least moderate base status and fertility.

Why should this be, when the unique (more or less) feature and natural advantage of legumes is that they can fix atmospheric nitrogen, and therefore be at least largely independent of soil nitrogen? I suggest that the answer could be largely historical. The neolithic revolution was based primarily on cereal grains, which depended for their performance on a high level of natural fertility. These conditions were met on the fertile, neutral to alkaline soils of the river valleys and similar dryland soils such as the terra rossas of the Mediterranean. Because this was where agriculture developed, the accompanying genera taken into cultivation were likewise adapted to fertile, neutral to alkaline soils. Many would have occurred spontaneously as weeds among the cereals, like the tares of the bible. Additionally, the legume genera concerned were mainly herbaceous plants, amenable to cultivation and giving large, nutritious seeds and/or good forage.

Plants adapted to poor soils and other regions remained largely outside this development, including large groups of subtropical and tropical legumes. As well as being away from the sites of early plant domestication, these were typically of tree, shrub or rank climber form and unsuitable for economic use, given the technology of the time.

The genus *Lupinus* occupies an interesting an anomolous position within this framework. As a temperate outlier of the predominantly subtropical and tropical tribe *Genisteae*, lupins have retained many tropical features, including adaptation to soils low in bases and nodulation by "slow-growing" bacteria of the genus *Phytomyxa* (Graham 1964). Though evolving away from the perennial tree or shrub form of their near relatives towards an annual, herbaceous form similar to the Mediterranean *Viceae*, they have mostly retained the stout, erect main stem and miniature tree-like branching habit of their presumed ancestors: factors of direct relevance to their suitability for modern mechanized agriculture and perhaps to their highly interesting seed yield physiology (Greenwood *et al*. 1975; Perry 1975) and internal nutrient economies (Gladstones and Loneragan 1975). The hitherto incomplete domestication of lupins seems surprising except perhaps on grounds of soil preference, but as I have argued elsewhere (Gladstones 1974) they are probably of very ancient use for human food in the wild or semi wild state, and may have evolved to their present state partly under this influence.

It is this type of plant, naturally adapted to low-nitrogen soils, which has the most to give as a legume. Instead of being just another crop or pasture plant it can play a unique and indispensable role, making agriculture possible where none could exist before. This applies equally in tropical and temperate regions. With further agricultural development necessarily on land which previously has been marginal or too poor for agriculture, such plants open up a far greater role for legumes than they have played before. An enormous challenge awaits both agronomists and plant

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breeders in bringing about the necessary changes in plants and agricultural systems to make these developments possible.

Legumes in the Tropics

I wish to digress slightly to consider the particular role of legumes in the tropics, and the general question of protein supplies and needs.

Professor Underwood, in the 1967 Farrer Oration, underlined the special role of legumes in the tropics because of the generally very low nitrogen status of tropical soils. He further made the very valid point that Australian scientists have a special contribution to make in this area, because of their expertise and experience in legume research.

Why are legumes not already making the contribution to tropical agriculture of which they are theoretically capable? The reasons seem to be several-fold. One perhaps lies in the extreme contrast between the small areas of rich alluvial and volcanic soils, on which developed arable agriculture has become established, and the relatively barren upland soils which have traditionally supported only a primitive shifting agriculture. This contrast has placed an even greater barrier than in temperate areas against bringing plants adapted to poor soils into full agricultural use. A second and obvious reason lies in the nature of the upland legumes themselves, which as pointed out earlier are, as a group, less amenable to domestication than the herbaceous and often dwarf-growing legumes of the early-settled temperate areas.

The leguminous flora of the poorer tropical and subtropical soils is nevertheless exceedingly rich. The potential for protein production is there, but due to the environment and the nature of the plants, the form of agriculture must be

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very different from that of temperate arable agriculture. Leguminous trees such as Albizzia and perennial shrubby plants such as Leucaena leucocephala, together with various leguminous runners and climbers, can produce very high protein and dry matter yields/hectare. At the same time they can maintain a constant ground cover to protect against the soil degradation which inevitably follows clear cultivation of such soils in the tropical environment, and they have deep enough root systems to recycle and conserve the limited native nutrients and any others that are applied. Nitrogen, so expensive and quickly lost, does not have to be used. Such forage production can support a moderately intensive ruminant animal industry if adapted ruminants are available or can be developed. Even more, it would support a highly intensive production of extracted leaf protein by processes such as that developed by N.W. Pirie.

The crucial role of legumes in the tropics lies not merely in their ability to produce more food. That in itself is a two-edged sword if it only results in more people, to starve again at a higher population level. What is important - and this applies everywhere, not only in the tropics - is that they make possible an ecologically sound, non-exploitive and yet productive agricultural system, with which a hopefully stabilized population can live in permanent balance or better.

Protein: Legumes versus Alternative Sources

Apart from their ecological advantages, the outstanding attribute of legumes is their production of foods high in protein, whether directly or via animal conversion. Are these proteins really needed? I am not competent to weigh

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the evidence in detail, nor is this the place to do so, but most nutritionists hold that lack of sufficient high quality protein is now the most serious dietary problem in many of the world's poorer countries. There is a further body of opinion which suggests that diets higher in protein and lower in carbohydrate would be nutritionally desirable in many other parts of the world now considered to be well fed. Regardless of whether or not one accepts the latter view, projections of world food requirements indicate the need for a faster rise in protein production than for any other major dietary component.

Where is this protein to come from? More importantly, how can it be got economically? A point too often overlooked is that to be of any use the protein must be produced in an acceptable form, preferably in the countries where it is required, at a price which those who need it can afford.

Many possibilities exist for obtaining more edible protein than at present. One is that existing sources can be processed into edible forms more efficiently, e.g. by by-passing the animal. Such processes will inevitably become more prominent in time for purely economic reasons, although reaction in wealthier countries suggests that buyers able to afford animal protein will continue to prefer it. In poor countries the question is academic because most already depend directly on vegetable protein. Short of drastic changes in the world economic and power structure, it therefore seems unlikely that this source of extra edible protein will in practice make as large a contribution as might seem theoretically possible.

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Most novel sources have serious limitations of practicality or cost. Exploitation of hitherto unused marine protein sources presents enormous problems of harvesting, utilization and acceptance, while present easily used marine sources are probably approaching the limit of their safe exploitation. Various forms of microbial protein can be cultured. High protein fungae which are fairly readily utilized for food can be grown using cereals as an energy source, but this uses an already directly usable product, and from such calculations as I have been able to make, seems most unlikely to be competitive with direct cultivation of legume crops on the same land. Bacteria using hydrocarbons, particularly petroleum wastes, were stated to be competitive before the recent rises in oil price and at a time of abnormally high soybean prices, but in the long term such energy sources may be limited by diminishing availability and competition from other end uses. Parker (1973) has stressed the potential of photosynthetic blue green algae, fixing both carbon dioxide and nitrogen from the air. These, too, have practical problems, although they present interesting possibilities in the long term. All of these processes, it must be remembered, involve culturing which itself can be likened to a highly intensive agriculture. They involve high capital outlays. The products all have problems of processing to make them acceptable, and in some cases to make them safe, other than by wasteful animal conversion. It seems reasonable to conclude that they will remain uncompetitive with efficient agriculture, based on legume nitrogen fixation, for as long as the latter is able to meet demand.

Finally, I should again mention bag nitrogen. This will undoubtedly continue to play an important role in intensive agriculture, despite rising costs due to high energy input in its manufacture. But it should be stressed that the main function of nitrogen fertilisers is to boost the yield of low protein crops, rather than to increase their protein content. To this extent it makes low protein crops more competitive for prime land, and so if anything exacerbates the shortage of high protein agricultural products. Some progress has been reported in breeding non-legumes more responsive in their protein content to high levels of nitrogen supply. The economic efficiency of nitrogen conversion, and the extent to which high protein content can be attained without loss of potential yield, remain to be properly demonstrated. Perhaps more promising is the breeding of cereals with higher protein quality, although even this has tended so far to entail some sacrifice of yield.

In summary, I conclude that at least for the time being, and probably for many years, nitrogen-fixing legumes and their bacteria will remain the most efficient and economic primary source of food protein. Their cultivation forms a basis for an ecologically sound, permanent, productive agriculture. In some environments they are the only basis on which economic agriculture is possible. But many times the present investment in legume research and breeding will be needed if ever their potential is to be realised on the scale that the world will be needing in the years ahead.

Legumes for Southern Australia

The rest of my talk will be about legumes for southern Australia, and specifically about legumes adapted to medium to light soils. Three such legume groups with which I have myself been directly concerned are the lupins, the serradellas (Ornithopus spp.), and subclover. Of them, I have chosen to speak in detail about subclover.

The choice may seem surprising, but is deliberate. The serradellas are so far only of minor interest outside Western Australia, although this may change in future. They form a highly interesting, and to my mind unduly neglected group of annual legumes, variably adapted to neutral or acid sandy soils marginal or too light for subclover.

As a cash crop with obvious potential and an equally obvious need for much further work, lupins can speak for themselves. Also, although their role is ecologically important, they lack the ecological imperative of the pasture legumes.

Pasture legumes and superphosphate are the basis of improved agriculture in southern Australia. Apart from a diminishing role of superphosphate on old land with built-up phosphate reserves, nothing exists in present or forseeable technology to indicate that this will change in the next hundred years. Among the pasture legumes, subclover is pre-eminent as the most widely adapted and useful. Again, we have no reason to think that this will change in the forseeable future.

Some may ask whether all the work already done with subclover may not have exhausted the possibilities of improvement. My reply is that it is true we have learned, or are learning, a great deal about the agronomy, ecology and physiology of subclover. But the task of genetic improvement has barely begun. Our growing knowledge of the plant is now enabling us to see, I hope clearly, that very great scope exists for its improvement as a safe, productive, reliable and more widely adapted pasture plant. Particularly, there is scope for improvement in wheatbelt areas, where its adaptation at present tends to be marginal.

Our growing knowledge also warns us that without effort we are in danger of losing even the level of benefit from subclover we already have. The appearance of diseases such as Kabatiella caulivora in high rainfall districts, viruses, and root rots of various kinds throughout the subclover range remind us that no crop or pasture plant can be grown continuously in one place without diseases becoming a limiting factor. We have been lucky with subclover until now, but the signs are that more than luck will be needed in the future. We know that sources of tolerance or resistance to many diseases are available within the known genetic range, but much work over and above that needed to improve other agronomic features is needed if resistance is to be incorporated into fully adapted commercial varieties.

In the following discussion I will initially try to estimate the present and potential contribution of subclover, and will then discuss some of the selection criteria I think are important in realizing that potential.

The Contribution of Subclover

Underwood (1951) and Donald (1965) summarized the benefits from including Dwalganup subclover in the rotation on sandplain soils at Wongan Hills in the Western Australian wheatbelt (annual rainfall 350 mm). Stock carrying capacity more than doubled, and wool per sheep increased some 10 per cent. Cereal yields also approximately doubled, with accompanying improvements of up to 20 per cent in both protein and vitamin B1 contents of the grain. Donald (op. cit.) cited similar responses on a property studied at Rosedale, South Australia (annual rainfall 450 mm). These results appear fairly typical of medium to light soils in southern Australia where subclover can be successfully grown.

Particular additional advantages of subclover as an annual pasture legume include its tolerance of a variety of pasture managements, including heavy continuous grazing, and its outstanding effectiveness in preventing soil erosion. The latter is due partly to the dense ground cover it forms both during and after the growing season; but very importantly also to the dense mat of burrs it forms in and on the ground surface. Additionally the dense, rather shallow root system, although undoubtedly a liability on deep sandy soils, is highly effective in medium-textured soils for building up soil nitrogen and organic matter, and physical structure. A final advantage of subclover is its relative tolerance of waterlogging. Overall, the characteristics of subclover are such that it is the logical preferred pasture legume for southern Australia wherever it grows and persists well enough.

Yet subclover is still grown on only a part of the area in Australia to which it is suited. Morley (1961) estimated a potential area of close to 40 million hectares. Davies and Eyles (1965) considered that about 45 million hectares in southern Australia were suited to pasture improvement, and on perhaps three quarters of that, subclover would be the preferred legume. Their estimate is possibly conservative in that it assumed a minimum annual rainfall of 375 mm.

Donald (1970) estimated the area in southern Australia which had been sown to subclover to be about 16 million hectares. With virtual cessation of farm development, the figure is unlikely to have increased since. In fact effectively it may have diminished. In Western Australia considerable areas of newly developed land have reverted to scrub, while many established stands have perished through the droughts of 1969 and 1972 and through increased cropping, and have not since adequately recovered or been re-sown. A substantial proportion of other existing "subclover pastures" throughout southern Australia are performing well below capacity. Foremost amongst the reasons for all these losses must be included the agronomic shortcomings of the subclover varieties now available.

The increase in subclover production that might be expected to accrue from forseeable genetic improvement must of course be speculative. My belief is that on the basis of genetic characteristics immediately or forseeably available, and taking into account both consequent increases in area of adaptation and better performance within existing areas,

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we could confidently look to a doubling of subclover pasture production. This assumes that the required effort is put into breeding, testing and promotion; also that pasture improvement again becomes worthwhile - as it must in time if only because of nitrogen fertilizer costs and the need for soil conservation. More speculatively, there is a long-term possibility of trebling or perhaps quadrupling production from Australia's subclover pastures. But this might depend on developments beyond what we can immediately forsee, and perhaps a degree of luck which no research worker has a right to expect.

Let us accept the more conservative estimate of a doubling of subclover production, which I repeat could, with present knowledge and adequate effort, be confidently seen as an attainable medium-term goal. The value in terms of fertilizer nitrogen equivalent, following the calculation method of Vincent (1972), would be approximately $1,200 million annually at present nitrogen prices. Even if one halves the assumed annual nitrogen increment of 100 kg/ha to allow for the fact that some extension would be on to previously marginal land, and for other factors, the potential gain is still enormous. Nor does it take into account other aspects of fertility build-up such as improvements in soil organic matter, physical structure, water-holding capacity, and resistance to erosion, as compared with potentially exploitive systems depending on fertilizer nitrogen.

Selection Criteria for Improving Subclover

The views expressed here are my own, but do not in general conflict with those of my colleagues in the Australian subclover breeding programme as set out previously (Francis,

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Gladstones, and Stern 1970). I omit discussion of breeding for disease resistance. The need for this in appropriate situations is self-evident, and is additional to the criteria discussed below. To the best of present knowledge (Gladstones 1967; Francis, Gladstones and Collins unpublished), no genetic or serious physiological barrier exists to recombination in any way of the characteristics discussed.

1) Extension of the maturity range, particularly at the early end to enable subclover to seed down more successfully and reliably in areas with a short growing season. So far we have had strains which flower early but mature slowly, like Dwalganup and Northam A, and others such as Geraldton which seed and mature quickly but do not start flowering as early. Combination of an early start to flowering with rapid maturation theoretically should give a substantial advance in effective earliness.

It may be argued that earliness sacrifices potential herbage production late in the season, but we believe that in dry marginal areas the reliable presence of the legume, in dense stands such as only good seed production can give, is more important than extra production in good seasons when it is needed least.

2) High seed production per se. We now have a good deal of evidence that strains of a given maturity range can differ substantially in their propensity for seed production. Well documented cases of consistently superior seed production are those of Geraldton as compared with Dwalganup (Millington 1960), and Midland B compared with Yarloop, Seaton Park and

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Dinninup (A.C. Devitt, unpublished data). The bases for differences in seed production remain to be fully elucidated, but data of Francis and Gladstones (1974) and Collins (unpublished) suggest relationships to rate of flower production, seed number per burr, and perhaps leaf distribution in the canopy and in a general way "fineness" of leaf, petiole and stem, leading to a high seed : total dry matter ratio. Some other factors possibly related to seed yield are mentioned below.

As well as being directly related to capacity for natural regeneration, seed yield is an important factor in the cost of commercial seed production, and therefore in seed price and commercial acceptance.

3) <u>Strong burr burial</u>. This in its own right is undoubtedly a factor in seed yield, because in most situations normal seed development depends on burial (Yates 1957, 1961; Quinlivan and Francis 1971). It is also probably a factor in escape from excessive seed loss in summer by grazing and fire, in addition to placing the seed in the most favourable place for germination. Hagon (1974) found at Tamworth that failure of germinating seedlings to establish was greater in surface-seeding strains than in those which buried strongly.

4) <u>Capacity to form viable seeds above ground</u> when burial is not possible, e.g. on hard, dry soil. Millington (1960) noted this as a characteristic of Geraldton as compared with Dwalganup. More recently Quinlivan and Francis (1971) and Collins and Francis (unpublished) have shown very large differences among other strains. Good above-ground seeding appears associated to some extent with fine growth habit and small seeds, and to be fully compatible with good burr burial capacity when conditions allow.

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5) Strong competitive ability. Over a sequence of years the ability to compete is strongly related to seed production, and can be predicted fairly accurately from a strain's seed production in pure stand under comparable conditions (Rossiter 1966a). Other factors modifying the long term outcome include hard-seededness, discussed below. Within a given growing season, plant factors such as petiole length can be decisive, depending on the nature and intensity of defoliation (Black 1960; Rossiter 1974). Ability to compete with other strains, whatever its basis, constitutes a sensitive index of a strain's overall fitness in a given environment.

As an agronomic trait, competitive ability can hardly be over-emphasized. It is a *sine qua non* for new, e.g. low-oestrogen, strains being introduced into areas where other strains are already established. A poorly competitive strain is doomed to failure and eventual extinction. Similarly it seems logical to assume the importance of being able to compete aggressively with non-clover pasture components, and thereby to maintain a good proportion of clover in the pasture and defer the onset of excessive grass or herb dominance. The longer this takes the more rapid, presumably, will be the nitrogen build-up; and the higher will be the soil nitrogen level, and therefore total pasture productivity, when legume/non-legume equilibrium is finally reached.

6) Hard-seededness. Some seed coat impermeability is needed to ensure seed survival through premature germinating rains in summer or early autumn. The "genetic" level of hard-seededness necessary for this depends on interactions with summer temperatures and aridity, together with the

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statistical likelihood of such rains (Quinlivan 1971a). Beyond that the required level depends on cultural treatments to which the pasture is subject.

In some favoured environments it has become traditional to take several successive crops and to undersow subclover with the last crop. Here only enough hard-seededness is needed to ensure continuance of the undisturbed pasture until the next crop cycle. Too much can detract by slowing the attainment of a high clover density in the pasture phase.

The issue is quite different in tougher environments where seeding down of subclover sown with the last crop cannot be relied on, due to moisture competition from the crop in spring; or if it is to be attained, an earlier and less productive subclover variety must be used than the environment would otherwise support. This applies to much of south-western Australia, and probably the drier regions to which subclover is capable of extending in eastern Australia.

The alternative of sowing subclover in the first pasture year involves an undesirable extra year of cultivation, together with very high seed cost if anything like an adequate clover density is to be attained in the first year. As well, the delay in autumn planting necessary to ensure seedling survival means in itself a large sacrifice of pasture production in the first year.

By contrast an adapted subclover variety with high seed production and especially hard-seededness makes possible a shorter and simpler and, it seems to me, better rotation

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by eliminating the need for regular clover re-seeding and allowing regeneration of a full clover stand in the first pasture year. One or perhaps two crops can be taken without the need for nitrogen application, followed by perhaps two years under clover. In some environments a continuous pasture/crop alternation may be satisfactory. The short pasture phase could be expected to maintain a maximum tendency to clover dominance and therefore maximum nitrogen fixation and yield response in the cereal crop.

I find it hard to believe that a strongly persistent clover type would not be the better even in favoured environments, provided that it is free from oestrogens or similar defects. Certainly it opens up to growers a wider, cheaper, and more reliable range of management options than is possible with doubtfully persistent varieties.

There is a further argument in favour of hard-seededness which, to the best of my knowledge, has not previously been put forward. This is, that with a high level of hard-seededness a later-maturing variety can safely be grown than would otherwise be the case. Periodic failures of seed production are of less consequence if a good bank of hard seed remains in the soil. Thus it is possible to exploit the greater producitivity of late varieties in average and better seasons without sacrificing reliability. Given that otherwise adapted strains of comparable maturity probably do not differ much in dry matter production, this is potentially the greatest source of increased subclover producitivity available to us.

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7) Physiological seed dormancy. Previously stated breeding aims (Francis *et al*. 1970) have included physiological dormancy to give protection against premature summer germination of seeds which have already softened. The effectiveness of dormancy has subsequently been questioned (Quinlivan 1971a, b; Hagon 1974), although field evidence of Taylor and Rossiter (1967) and Taylor (1972) does suggest some role supplementary to that of impermeability. It may be relevant that commercially proven highly persistent cultivars such as Geraldton and Dinninup have high levels of both impermeability and physiological dormancy. In the absence of better evidence I feel it would be wise as far as feasible to incorporate at least moderately high dormancy into improved cultivars. This poses no great practical problem.

8) Edaphic and other forms of adaptation. Major differences in soil adaptation and waterlogging tolerance are known among the three delineated subspecies of subclover, viz. sspp. *subterraneum*, *yanninicum* and *brachycalycinum*. What is not yet known is the extent to which similar differences might occur within subspecies, particularly within ssp. *subterraneum*, which besides having a wide geographical range is highly polymorphic. Recent and continuing unpublished work by my colleague Dr. W.J. Collins and myself strongly suggests that natural sub-groupings do occur within the subspecies, and that these have a geographical, and in some cases possibly ecological basis. Any such differences can hardly fail to be significant in agriculture: particularly so in a self-regenerating pasture plant growing under competition, where subtle differences become magnified over the years and long-term competitive success is critical.

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Some regions of origin in the Mediterranean may not be represented among the naturalized strain population of Australia, while among the strains present, those that have succeeded best may in many cases have done so through accident of their site of establishment, or for other reasons irrelevant to potential success in agriculture. Thus although successful naturalization in Australia probably has some significance for adaptation to the local environment (Gladstones 1966, 1967), we cannot afford to place too much reliance on it as a basis for evaluation. Much work remains to be done in collecting and screening exotic genotypes before we can be sure of having the best possible basis for adaptation and genetic improvement. Nor has the naturalized subclover flora of Australia yet been fully explored.

9) Grazing tolerance. Subclover is outstanding among annual legumes in its tolerance of grazing, which is thought to have been a factor in its recent evolution in the Mediterranean (Katznelson and Morley 1965). Nevertheless an examination of growth habits among locally naturalized and introduced genotypes suggests that considerable variability still exists in this characteristic, both among and within subspecies. By no means all types are necessarily adapted to Australian commercial conditions of maximum and often continuous grazing. We have, in fact, substantial grounds for thinking that adaptation to commercial grazing systems can be improved.

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Black (1964) calculated for the Adelaide environment that in practice two thirds or more of the potential production of a pure subclover sward is lost through a combination of insufficient photosynthetic leaf area in the seedling stage, and, even more importantly, through above-optimum leaf area and excessive internal shading in the spring. Allowing that both are unavoidable to the extent that stock numbers cannot be manipulated nearly enough to match seasonal changes in pasture growth, nevertheless certain deductions logically follow. The first is to stress, once again, the importance of seed production and survival over summer, as the major determinant of clover sward density at the beginning of the next season. The second is that one should select for short, prostrate seedlings, which can escape excessive defoliation and maintain maximum photosynthetic area through the inevitable period of over-grazing early in the season.

The final conclusion is that improved plant growth form to increase light penetration into the over-grown sward in spring might help to improve total productivity. Most importantly it might specifically improve seed production, because in normally grazed pastures, particularly of mid-season or late maturing cultivars, flowering and seed development occur almost entirely under conditions of above-optimum L.A.I.. It might be hypothesized that seed production of strains with fine, narrow, erectly held leaflets and dispersed vertical leaf distribution should be less affected by insufficient defoliation during seed development than those with broad leaflets and more uniform leaf height. Recent experimental results of Collins (personal communication) have given tentative support to this idea.

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10) <u>Oestrogenic isoflavone content</u>. While not, as far as we know, a direct factor in subclover productivity, this is obviously important for sheep production and is properly one of the main selection criteria in subclover breeding. Dominant stands of highly oestrogenic varieties can result in very drastic symptoms of difficult birth, dead lambs, prolapse of the uterus, and within two or three years more or less complete sterility of the ewes, with lambing percentages falling to 20 per cent and less. At lower levels of oestrogen intake the more alarming symptoms are largely absent, but there can still be significant reductions in lambing, particularly towards the end of the ewes' reproductive life. The fact that these losses are easily overlooked does not remove their economic significance in an industry whose profitability is often marginal.

It is now fairly definite that the isoflavone formononetin is the chief oestrogenic principle. Cultivars highly oestrogenic to sheep normally contain one percent or more on a dry matter basis, while those containing 0.25 per cent or less have been considered generally safe (Quinlivan <u>et al</u>. 1968). However, it is not known how low a level is needed before all adverse effects are eliminated, nor whether the two other isoflavones present, genistein and biochanin A, might in practice have minor additional effects. Given the problem of measuring small fertility differences reliably, this may never be known. Prudence suggests that improved cultivars should be bred with as low an oestrogen content as possible, so long as it is not at the expense of fitness in other respects. At least for formononetin there is no suggestion of this being likely, because a sizeable proportion of natural strains already have low to very low contents. An added reason for seeking genetically very low formononetin levels is that with steeply rising superphosphate prices we can from now on expect reduced topdressing of subclover pastures and consequently greater clover dominance (Rossiter 1966b) together possibly with increased formononetin concentrations in the plants (Rossiter and Beck 1966; Rossiter 1970).

11) Marker characters. The presence of visible marker characters to distinguish a cultivar visually from others greatly facilitates both commercial use and experimental testing. Fortunately such markers are readily available in subclover.

Problems of Evaluation

You may have noticed that nowhere have I mentioned selection for herbage yield. The omission is deliberate. Subclover, like most other pasture plants, contributes normally as part of a mixed sward. As a legume it enhances the productivity of the whole pasture and that of subsequent crops through nitrogen fixation. Its first value is in remaining prominent enough in the pasture to maximize these functions, and this is more likely to depend on persistence factors such as seed production and hard-seededness, and ability to survive heavy early grazing, than on measurable herbage production in pure sward. In any case it is hard to imagine an adapted, heavy-seeding strain producing very much less herbage than another, even in the one season, while over the life of the pasture its reliability and cumulative production will almost inevitably be greater.

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I therefore conclude that long-term competitive ability against standard strains, under realistic conditions of grazing (over-grazing early, under-grazing late) and, where appropriate, cropping constitutes the best experimental measure of a strain's adaptation and value. Prior screening can be on observable or easily measurable traits such as suitable maturity, plant habit as far as it is known to be relevant, burr burial, viable seed production when burr burial is prevented, hard-seededness, formononetin content, and where necessary disease resistance, followed by small plot measurement of seed production with only mild defoliation. Plot measurement of harbage yield is irrelevant and may even be misleading.

What, then, of grazing trials to measure animal production? The need for these in assessing pasture plants has become part of agronomic conventional wisdom, but I believe that these, at least in their usual form, are equally irrelevant when applied to testing subclover strains. (I except the application of varying grazing pressures to mixtures of strains, the relative success of whose individual components is being followed over a number of seasons.)

My objections are several-fold. Grazing trials are enormously costly and difficult, and highly subject to cumulative mishap when continued for more than a short time, which they must be to be of real use. By definition the number of strains that can be included is very small. Crucial decisions as to which strains go in must already have been made on other bases, which if properly done leaves a vanishing likelihood of significant differences being found under grazing. Note again that I am speaking here of grazing trials

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to compare finally the best of a range of prospective improved cultivars. Trials including contrasting plant types as a research tool are of course valid within their limits.

Should differences be found, they may well appear to favour the wrong kind of strain. For instance seedling growth prostrate enough to escape excessive defoliation or seedling loss could adversely affect animal performance early in the season (cf. Smith et al. 1972). Strong seeding ability could initially reduce animal performance in summer, both through a more complete translocation of nitrogen into the seeds and through greater grazing escape by strongly buried seeds. Finally, enough hard-seededness for safe long term persistance in a pasture/crop rotation might reduce production significantly in the second year. All these factors are beneficial in the long term, but could result in the best strains being discarded if too great a reliance is placed on initial grazing trial results.

My final objection to grazing trials for evaluating any pasture genotypes is that they are highly specific to site and experimental management. Interactions with soil type, moisture relations, and the whole range of management decisions or accidents, even if quite subtle, can be decisive over the pasture's lifetime because they are cumulative.

How, then, should subclover strains be evaluated? I suggest that we can get better results by very simple means. Once past the initial row screening and perhaps limited seed yield measurements, all potentially suitable genotypes should be sown out in long rows or strips (depending on seed supply) in as many environments as possible, both in pure stand and in competition with a standard cultivar for the area. Segregating crossbred populations can be sown at the same time to undergo natural selection. The pure genotypes and mixtures can be observed over, or after, a number of years under normal grazing with and without cropping over. The best will be those that persist and compete best at the greatest number or variety of sites. The top few can if necessary be sampled for size of the seed bank built up. The best strain or strains, if better for any significant environmental range than the cultivars already available, should be bulked and released forthwith for commercial trial and evaluation. The last step is essential. Only in farmers' paddocks, over many years, can final answers emerge.

The Ideotype

Throughout the discussion I have built up a subclover ideotype which I think comes closest to meeting the needs of arable agriculture in Mediterranean climatic regions of southern Australia. The main characteristics in summary are as follows, and apply as far as possible within each of the subspecies for their respective soil environments.

A range of maturities to cover different climatic belts, including earlier maturity than currently available for short-season districts. Disease resistance as necessary. Formononetin less than 0.10 per cent and preferably less than 0.05 per cent. A fairly fine growth habit, with short prostrate seedlings, and narrow leaflets and dispersed vertical leaf distribution. High seed production, particularly at above optimum L.A.I. High competitive ability. Strong burr burial when this is possible, but strong capacity to form viable seeds when burial is prevented. High level of hard-seededness for a given maturity. Moderate to high physiological seed dormancy. Distinctive leaf markings or other morphological characteristics to distinguish readily from other cultivars.

Final Remarks

To conclude, I will return briefly to my original theme of the legumes' present and potential contribution to Australian agriculture.

Like the several distinguished Farrer orators who have spoken previously about legumes and their symbionts, I believe nodulated legumes must continue to play a major and probably increasing role in Australia's agriculture. Grain legumes such as soybeans in the subtropics and lupins in the south have become firmly established, and will continue to increase depending on markets and improvements in adaptation. The lupins are perhaps of special interest because of their capacity to produce very high protein yields from poor soils.

But the greatest need and challenge lies with the pasture legumes. Upon these depend not only our future pastoral industries, but also our cereal industries and the very integrity of the land.

I will finish with two quotations. The first is from the late J. Griffiths Davies' presidential address in 1952 to the Australian Institute of Agricultural Science. "Australia must consciously and actively retain a pastoral agriculture. Animals, particularly cattle and sheep, must always remain a dominant feature of our agriculture, and they must be preponderantly fed on legume-based pastures. Failure to do this will eventually be disastrous, our land will become derelict, our soils eroded, and our rural population reduced

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to coolie status. The rise and fall of nations and civilizations seem to be closely associated with the rise and fall of soil fertility."

The second quotation is from a letter written by William Farrer in 1893, and cited by Professor Donald in his 1964 Farrer Oration. "I will conclude this letter by expressing my belief that if we 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."

To conclude, may I express my sincere appreciation to the Chairman and members of the Farrer Memorial Trust of the great honour they have done me in the award of the Farrer Memorial Medal. I would like also to acknowledge the help and forbearance of many colleagues, especially Drs. C.M. Francis, W.J. Collins and R.C. Rossiter, who through their work and in discussion played a large part in development of the ideas expressed on subclover, and the inspiration given by the late Mr. A.M. Stewart who first persuaded me to work with lupins.

Finally and particularly, I want to record my thanks to the wheat growers of Western Australia, who through the W.A. Soil Fertility Research Trust and later the W.A. Wheat Industry Research Committee contributed most of the research funds which supported my work from its beginning in 1954 until I joined the W.A. Department of Agriculture in 1971. The foresight of those W.A. farmers who, with Professor E.J. Underwood, organized the original wheat industry research levies, and their wisdom in adminstering them to support all types of research benefiting cereal growers, has in my view not yet been adequately recognized.

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