The development of pasture legumes for the low rainfall cereal-livestock zone of Southern Australia

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Summary

In low rainfall wheatbelt regions of southern Australia the proportion of land occupied by annual legume-based pastures is low compared to adjacent areas receiving higher rainfall. A prerequisite for legume pasture introduction to these areas is the availability of a cultivar which will persist in the prevailing farming system. For many soils in low rainfall areas no such cultivar exists. Even where well adapted cultivars become available, farmers must be convinced that the introduction of the pasture legume can be achieved at low economic risk and that the resulting system will have profit advantages over alternative land uses.

The current lack of a full range of well adapted pasture legumes offers important opportunities for improved farm profitability. However, there is a need to target research efforts so that new pasture legumes, once identified, become widely used. Such targeting requires assessment of the performance of existing pasture legumes, the identification of niches remaining unfilled and the definition of pasture legumes which may be suitable in the identified vacant niches. Consideration has to be given to the impact on farm profit that might result from a successfully completed selection programme and to the time scale and research resources required to achieve this objective.

Programmes to develop pasture legumes span a wide range of activities and require an array of research approaches. At one extreme it involves selection, usually within a species, to identify cultivars which overcome specific deficiencies in a current, generally well adapted cultivar. At the other extreme a programme may involve the selection of new species for situations where no well adapted pasture legume exists, as is frequently the case in low rainfall zones. This latter process is more complex because it requires a preliminary phase to define the most appropriate legume species and associated root nodule bacteria prior to the development of a specific cultivar, suitable to the particular low rainfall environment. Additional research is required to define optimum establishment and management systems for the chosen legume including an assessment of the limits of its capacity to persist in a range of rotations. Follow-up extension and problem-solving research are also vital for rapid commercial implementation.

Introduction

Annual pasture legumes, mainly species of *Trifolium* and *Medicago* (1) grown in rotation with cereals have been a vital factor in improving the productivity and profitability of farms in

the cereal-livestock zones of southern Australia (2). However, the pasture legume cultivars developed to date have not been suitable for all circumstances.

The cereal-livestock zone in southern Australia is located between low rainfall rangeland areas which are too dry for cereal production and the high rainfall, permanent pasture regions (3). This zone receives annual rainfall between 250 and 500 mm. The delimiting annual rainfall range varies regionally, depending mainly on the proportion of out of growing season rainfall received and is highest in the non-Mediterranean parts of the New South Wales wheatbelt (4). Apart from the large range in rainfall experienced within the zone, the soils are also very diverse both within and between regions. This diversity of climatic and edaphic conditions combined with the requirement for variable lengths of pasture and crop phases accentuates the difficulties involved in identifying pasture legumes suited to the full range of conditions.

The requirement to undertake pasture selection and development arises because of the absence of agriculturally useful naturally occurring pasture legumes in Australia (5) This contrasts to the situation in similar climatic zones of the Mediterranean Basin where naturally occurring legumes provide both a guide to local edaphic adaption and a source of genetic material from which to select for use in more intensively managed pasture systems (6).

Farm development using annual legume pastures occurred earliest in the higher rainfall parts of the cereal-livestock zones of Australia (3). In the period from 1950 to 1970 development was very rapid and by the end of this period a large proportion of areas receiving greater than 450 mm of annual rainfall had been sown to improved pasture (7). However, towards the drier margin development has been slower and less comprehensive, with substantial areas remaining on which legume pastures have never been established (8,9). In these areas volunteer grasses and herbs dominate the pasture phase of rotations (10).

Failure of legume pastures to persist in the longer term under the operative management systems has been a more consistent feature of low rainfall areas than adjacent higher rainfall zones (9). There has been a steady decline in the area supporting subterranean clover dominant pastures in low rainfall areas following a burst of successful establishment in the 1960s based on the cultivar Geraldton. The decline has been attributed to insufficient levels of hard seed to ensure persistence, when frequency of cropping increased in response to more favorable cereal prices (11). Even the earliest maturing and hardest seeded cultivar, Nungarin, has proved to be incapable of long term persistence under these conditions (9). Under the same stresses annual medics have persisted better, largely as a result of their inherently higher levels of hard seed (12).

A further factor complicating the role of pasture legumes as part of the farming system in cereal-livestock zones has been the development of continuous crop rotations which include crop legumes such as lupins and peas (13,14). In higher rainfall areas crop legumes have partly substituted for pasture legumes in rotations while, in the lower rainfall areas they have been used in situations where no pasture legume option has been available (15).

Improvement of farm profitability through the continuing development of pasture legumes for use in rotations with cereals is widely regarded as a high priority, particularly in low rainfall wheatbelt areas (14). This paper will focus on strategies and problems associated with pasture legume selection for areas receiving less than 400mm annual rainfall.

Setting priorities for the development of new pasture legumes

Our ultimate objective is to have a productive pasture legume capable of persistence within the existing or likely rotational systems for each edaphic niche in a region. The degree to which this objective is achieved with available cultivars varies within the low rainfall wheatbelt regions of Australia but deficiencies have been recognized in all areas (14). Given the likelihood of limitations in research resource, not all these problems can be dealt with simultaneously. Some assessment of the priority of the various options for developing pasture legumes needs to be undertaken at both a regional and national level.

The process of priority assessment should encompass several key elements. Initially a review of the performance of existing legumes in pastures should be undertaken. This process will often involve a non-experimental approach using techniques such as formal or informal surveys and consultations with farmers (16) with the aim of defining the situations in which current cultivars perform adequately, where their performance is sub-optimal and where they are not in use. A second stage is an assessment of the likelihood of matching available genetic resources to the requirements of each of the identified problem niches. A third stage is an economic analysis of the costs and likely benefits that might flow from the development of a pasture legume for each of the competing niches.

Reviewing the status of current pasture legumes

The current status of pasture legumes within a region usually fits three categories. The first is where the cultivars are performing well as part of the existing farming system. The performance of cultivars of *M.truncatula* such as Jemalong and Cyprus on alkaline soils in all low rainfall wheatbelt areas of Australia prior to the arrival of pests such as the blue green aphid *(Acyrthosiphon kondoi)* fits into such a category (17,18,19). These cultivars now fit into the second category in which cultivars, although in use, perform sub-optimally often due to some clearly identifiable factor (20). The third category is that in which pasture legumes are not in use.

The reasons behind the absence of a pasture legume from land use systems have important implications for future selection programmes. In some circumstances a suitable pasture legume may be available but the costs involved with its establishment, when combined with the risk of failure during the introduction phase, discourages its adoption (8). This will be most likely when the alternative land uses available are particularly profitable and stable. The introduction of crop legumes such as lupins into cereal-livestock regions has provided a competitive land use on some soils from which pastures are excluded for economic reasons rather than for the lack of suitable cultivars (14,15). Another explanation for the absence of pasture legumes is the lack of a cultivar capable of growing and persisting on the particular soil and under the prevailing management conditions. Only in this instance is the absence of a pasture legume likely to justify research input.

Assessing the feasibility of cultivar development

The second stage of priority development involves a review of available genetic resources. Two circumstances have already been identified in which the development of new pasture legume cultivars might contribute to improved farm profit. These are where the existing cultivar is performing sub-optimally or where there is no cultivar available for an identified niche. In the case of sub-optimal performance, selection is likely to take place within the already identified species as long as genetic diversity is exhibited in the characters thought likely to contribute to improved persistence. Background ecological knowledge about the species, combined with specific information relating to material held in genetic resource collections may be enough to give a clear indication of the probability of producing a superior cultivar through breeding or selection.

If present pasture legume species are unsuitable, a wider review of available genetic resources is necessary. The need for flexibility in the rotation system dictates that the selected species be capable of persistence in close rotations with cereals. As a consequence only species with a high leve1 of hard seed can be considered. In addition, species with small seed size may have an advantage in situations where seed reserves come under severe grazing pressure during summer (21), partly because a higher proportion of small seeds survives passage through the grazing animal (22).

The genus *Medicago* is likely to remain a fruitful source of genetic diversity for soils which range from mildly acid to alkaline. The wide range of edaphic adaptations available within the genus, together with the large variation within most species in important characters, such as maturity, represents a large pool of diversity making it likely that cultivars suited to any low rainfall wheatbelt environment can be selected. Further, our existing knowledge of the establishment and management requirements of medics will simplify the introduction process should a suitable cultivar be selected.

Recent ecological studies in Syria have shown that medics are by no means the only well adapted genus for low rainfall neutral to alkaline soils (21). The genera *Trigonella* and *Astragalus* were nominated as being typical of those worthy of further attention because of their proven survival capacity under heavy defoliation pressure.

The absence of an existing pasture legume is more common in acid soil niches. This is because the commonly used species, subterranean clover and annual medics, each have severe limitations in this particular environment. In the case of subterranean clover the limitations are primarily imposed by the inability of the species to cope with aridity rather than acidity. This is a consequence of a number of factors including a shallow rooting habit (23), poor capacity to set seed under post flowering water stress (24), reduced seed yield resulting from the failure of burrs to bury into hard setting soil surfaces (25) and lower than desirable levels of hard seed in current early maturing commercial cultivars (26,24). It is therefore not surprising that subterranean clover is rarely found in the Mediterranean region in low rainfall areas or where cropping is a prominent part of the farming system (27).

Limitations to the use of annual medics on acid soils are largely imposed by the inability of the *R.meliloti* symbiont to persist and therefore, the host plant to nodulate (28). Recent progress has been made in selecting species of medic such as *M.polymorpha* (29) and *M.murex* (30) for ability to grow on moderately acid soils when combined with acid tolerant strains of *R.meliloti (31).* However, the lack of persistence of *R.meliloti* in soils of pH less than 5.5 (1:5, soil:water) still imposes an important limitation to the exploitation of medics on acid soils.

The selection of pasture legumes for acid soils is likely to be concentrated within currently minor species such as *Ornithopus* spp. (32), or on species not yet subject to intensive assessment. In targeting genetic material for such environments attention should be given to the performance of pasture legumes in natural Mediterranean ecosystems with similar climatic (33) and edaphic conditions. Particular attention needs to be given to the rhizobial requirements of any prospective legumes. Special attention should be directed to species infected by slow growing bradyrhizobia which are likely to have an advantage in the most acid soils (34). The fact that the characteristics of previously untested pasture legumes do not always fall within current models for establishment and management should not preclude their consideration nor should species be rejected merely because they do not persist in the continuous grazing systems to which subterranean clover is so well adapted.

Economic considerations in the development of priorities

Although programmes to development pasture legumes are in direct competition with other sectors for research resources, the long term nature of their contribution to farming systems makes it desirable that their relative priority be assessed in the longer term. This is important because pasture legume development programmes, especially those involving plant selection, are also long term in nature. Such programmes can easily be disrupted by over-rapid adjustments to short term changes in profitability as dictated by changes in product prices (Table 1).

In addition, pasture legume systems provide a major long term stabilizing influence on farm incomes. As the relative product prices for livestock and cereal products vary (Table 1), the balance can be changed between the proportion of pasture legumes and crops in rotations. Furthermore, irrespective of the rotation

in use, pasture legumes contribute to the profitability of both phases.

Given their contribution to profit and stability, and the nature of research requirements, it is logical to make a stable allocation of resources to pasture legume development, commensurate with their long term importance.

Table 1 Returns for wheat ($/tonne delivered at Cunderdin, Western Australia) and wool (c/kg) expressed in 1987 prices and the ratio of wool to wheat returns for the period 1975-87.

YEAR	WHEAT PRICE ($/tonne)	WOOL PRICE (c/kg)	WOOL/WHEAT PRICE RATIO
1975	248	408	1.65
1976	171	452	2.64
1977	174	417	2.40
1978	216	422	1.95
1979	245	460	1.87
1980	215	443	2.06
1981	198	413	2.08
1982	217	383	1.76
1983	176	388	2.92
1984	177	406	2.92
1985	152	402	3.11
1986	117	422	3.84
1987	108	633	5.86

Source: J. Bartlett, West Australian Department of Agriculture.

Assuming the availability of some resources to facilitate pasture legume development, an economic assessment of identified options is necessary. For legume pastures, in common with other research areas, consideration needs to be given to both the cost of doing such research and the potential benefits which might result. Techniques available for such analysis vary greatly in formality of economic approach and their own requirement for resources (35). In practice highly quantified benefit-cost analyses are rarely undertaken on the grounds of cost and more subjective comparisons are used. Such systems are generally based around a non-quantitative check-list of factors utilized in the more formal analysis systems (36).

In general the costs involved in undertaking a pasture development programme can be reliably estimated, although care needs to be taken to include both direct and indirect cost (36). However, benefits derived from the introduction of legume pastures or improvements in their performance are more difficult to estimate.

The difficulties arise because pasture legumes are used as part of a rotational system on farms with a range of complex and interactive land use activities. Improvement in legume pastures can have an impact on farm performance in a number of ways. It can lead to increased livestock production, an improvement in cereal yield and often a reduction in the requirement for nitrogenous fertilizers. The overall benefit resulting from pasture improvement is best measured as a change in farm profit following the introduction of the innovation. An estimation of benefits of pasture legumes made in isolation from the rotation and the rest of the farm is likely to be misleading.

Whole-farm modeling has proved to be a useful means of investigating the profit implications of changed pasture production. An example of such an approach involved the use of the MIDAS model (37) in the low rainfall wheatbelt of Western Australia. The study investigated the effects that increases in pasture production might have on land use and farm profit (38). Results showed that increasing pasture production had a quite different impact on profit for each of the identified soils. The outcome relied heavily on the relative profitability of the existing optimum land use and the optimum land use where pasture was part of the system. For one soil type (mildly acid loamy sands) increases in pasture production of up to 60% had no impact on farm profit because such increases were insufficient to change the optimum land use away from a lupin-wheat rotation to one containing pasture. By way of contrast, even small increases in pasture production on sandy clay loam soils gave rise to increased profit because pastures were already the most profitable land use for this soil. This was the result of the productive nature of pastures grown on this soil and the relatively poor performance of other land use options such as lupins.

Irrespective of the methods of assessment used to define priorities, projects to develop pasture legumes are likely to be undertaken which have a considerable range of resource requirement and vary in duration and certainty of outcome. These can be divided into two broad groups, cultivar replacement programmes and the development of pasture legumes for currently unfilled niches.

Cultivar replacement

The broad steps involved in cultivar replacement are set out in Figure 1. The dominant position of annual medics and subterranean clover as the legume component of pastures in cereal-livestock zones means that cultivar replacement, in the current context, applies to these species. The central importance of genetic resources to this activity has led to the concentration of the mass screening and breeding functions at the South Australian *(Medicago)* and West Australian *(Trifolium* spp.) Departments of Agriculture. At these locations the most comprehensive germplasm collections are maintained. The importance of annual medics to low rainfall areas combined with the emergence of a general threat to existing cultivars in the form of aphids has precipitated the development of a national approach to medic cultivar replacement (20). Although this national approach arose in response to a specific threat, it is important for future improvements that the focus continues to broaden to encompass changing priorities.

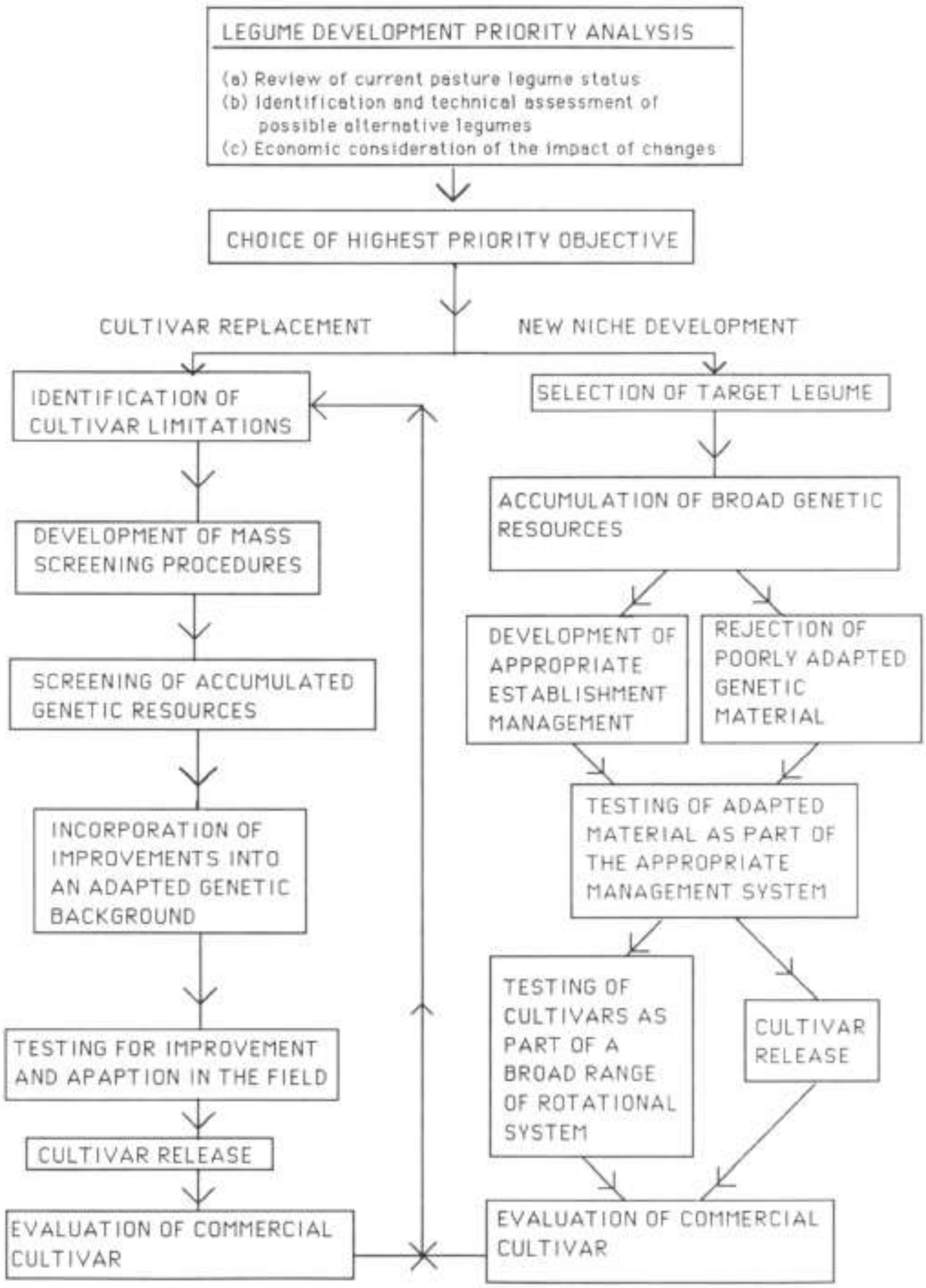

Figure 1. sequence of events in the development of a pasture legume cultivar for the low rainfall wheatbelt

Success in such programmes can best be judged in terms of the speed of response to emerging threats to existing cultivars. Efficient operation relies initially on rapid recognition of field problems. This involves coordination of input from farmers, extension workers and specialist scientists. A second step involves the communication of the identified problems to the central unit. There is a need to have sufficient organizational flexibility to incorporate these new ideas into an existing priority structure and to balance the sometimes conflicting requirements of the various low rainfall regions of Australia. Examples of flexibility in response to changing priorities include the addition of *M.polymorpha* and *M.murex* to insect screening programmes following their identification as important commercial species, the downgrading in importance of sitona weevil *(Sitona humeralis)* and the upgrading of red-legged earth mite *(Halotydeus destructor)* and lucerne flea *(Sminthurus viridis)* as targets for resistance selection.

The central breeding unit requires adequate resources and specialist technical support in key areas such as entomology, plant pathology and rhizobiology. These resources can be used to facilitate the establishment of mass screening systems capable of identifying genetic material for the necessary hybridization programmes. The centrally selected material should then be distributed into well organized regional testing programmes aimed at ensuring selection of locally adapted cultivars. Cultivars identified in the regions may then be rapidly seed increased and released with appropriate extension support.

Although of much lower overall priority in low rainfall regions, cultivar replacement programmes for subterranean clover should concentrate on characteristics likely to improve persistence. Improvements in seed yield, especially when subject to spring water stress, and increased levels of hard seed are essential (24). Given that cropping is likely to be part of most land use systems, it has been estimated, using a seed dynamics modelling approach, that well adapted cultivars will need at least 60% hard seed at the end of the first summer (G.B.Taylor pers. comm.).

The development of cultivars for new niches

Cultivar development for new niches (Figure 1) requires a different research approach from that used in cultivar replacement programmes.

Species selection

An initial critical step is the choice of species within which to focus detailed selection efforts. The natural distribution of pasture legume species in climatically and edaphically similar areas, and their performance if utilized in previous pasture development programmes, offer some guidance as to potentially useful species.

Comparisons among legume species can often be handicapped by a lack of knowledge of their optimum establishment and management requirements. Potentially useful material is likely to be rejected unless a paralle1 programme of agronomic development accompanies the genetic review (32). Such a programme is most likely to be required with species such as *Ornithopus* (39) which vary significantly in their agronomic requirements from the currently used species such as subterranean clover and annual medics.

The lack of availability and knowledge of suitable strains of root nodule bacteria is frequently a limiting factor in legume species development, and may lead to the inappropriate rejection of otherwise well adapted species. The lack of suitability of the commercially available strains of *R.meliloti* originally led to an underestimation of the potential of *M.polymorpha* and *M.murex (31).* It is also likely that for many acid soil environments, the performance of root nodule bacteria may be the most limiting element in the symbiosis. These considerations emphasis the desirability of a rhizobiological input into all pasture legume development programmes.

The availability of seed supplies will often determine the cultivar choice for inter-species comparisons. In many cases such material will be far from optimal in characteristics such as maturity. This is often the case for low rainfall areas because, historically, pasture development efforts have been concentrated in higher rainfall environments. In these situations assessments should be limited to an examination of the ability of the representative cultivars of each species to grow under the edaphic conditions of the target environment. The species identified as having the greatest potential should then be subjected to a more intensive genetic review.

Successful selection within a species depends heavily on the availability of a wide range of germplasm. For pasture legumes other than *Trifolium* and *Medicago* this is often difficult and time consuming because material has to be sought from a variety of sources, or specially collected from the its natural environment. The usefulness of targeted collection has again recently been demonstrated through the collection of early maturing lines of *M.murex* from Greece (30) and the collection of strains of *R.meliloti* from acid soils in Sardinia for use in analogous situations in Australia (40).

Cultivar selection

Initial assessment of assembled genetic material, which is logically combined with seed increase (41), is *a* resource intensive phase of the selection process. Plants are generally grown as individual spaced plants, in rows or as mini-swards. Although the low density and often undefoliated growth conditions at this stage can vary significantly from regenerating field pastures, relative cultivar performance can be a useful indication of their potential to perform under more realistic conditions.

Under low rainfall conditions seed production is considered the key measure of persistence and productivity (42). Production varies greatly from season to season (Table 2, Ewing unpublished data) with only a very small proportion of the total seed pool being contributed in below average rainfall seasons. Most of the seed is produced in a few favourable seasons (eg 1984, Table 2), when pasture growth rates are greater than livestock consumption for an extended period in spring and flowering and seed set takes places under favourable conditions. The large biomass produced under these circumstances gives the potential for high seed yield. Thus, pasture legumes that are to succeed in this environment must have the potential to exploit favourable seasons for seed production.

Conditions of low effective defoliation and large biomass accumulation are often produced in the artificial circumstances associated with the early stages of accession comparison. By comparing seed yield performance under these conditions it is possible to reject a substantial proportion of the test material.

Early maturity is a general requirement of cultivars for low rainfall environments (11,21). It is of particular importance in the relatively soft seeded species such as subterranean clover whose persistence strategy relies on some seed being produced in most seasons. For harder seeded genera such as *Medicago* persistence is less dependent on seed production in any one year. Their long term persistence and productivity depends on maximizing seed production in the long term which is more likely to result from efficient exploitation of favourable seasons rather than a capacity to produce seed even in poor seasons. Excessive early maturity may be of little benefit under these conditions. This is consistent with data in Table 2 which indicates that the earliest maturing cultivar Serena (43) did not produce the highest long term seed yield. The superior performance of the cultivar Santiago over the earlier and later cultivars emphasizes the importance of undertaking the final stages of testing using management systems likely to be operative in the target region.

TABLE 2 The influence of total and growing season rainfall (mm) on the grazed and ungrazed seed yield (kg/ha) of three *M.polymorpha* cultivars grown on a sandy loam soil at Merredin between 1984-87 (seed yield as a % of the four year total in parenthesis).

	1984	1985	1986	1987
	Rainfall (mm)			
Total Rainfall	336	273	308	273
Growing Season (April-October)	253	174	249	207
	Seed Yield (kg/ha)			
Serena-ungrazed	686(39)	345(20)	628(36)	103(6)
Serena-grazed	601(65)	40(4)	266(29)	13(1)
Santiago-ungrazed	1059(50)	355(17)	585(28)	110(5)
Santiago-grazed	626(54)	124(11)	397(34)	22(2)
Circle Valley-ungrazed	532(41)	249(19)	448(35)	53(4)
Circle Valley-grazed	260(48)	34(6)	246(45)	7(1)'

Apart from seed yield and hard seed level, a number of other attributes which are readily measurable in nursery rows have been identified from an analysis of the characteristics of successful medic accessions grown under field conditions (44). These include short petioles, long peduncles, small seeds, short internodes, high mass of pod/plant and low pod retention. In addition characters such as pod spininess can be assessed.

Material passing the initial selection phase of testing is then available, following seed increase, for inclusion in an intensive test phase. Here, comparisons, focusing primarily on persistence, can be made using the best available management systems. Pasture legumes under comparison should be maintained as part of the rotation with cereals considered most likely to apply following cultivar release. During this phase continuing efforts should be made to fine tune establishment and management systems and use any improvements as part of the testing procedure.

Post release support and research

Cultivars developed for completely new niches are likely to require substantial support and extension inputs following release, to ensure rapid adoption by farmers.

Production of large quantities of commercial seed is an important prerequisite of rapid adoption. Where totally new species are being used, a paralle1 research effort to establish new methods of seed production, collection and processing may be required. The current development of *Ornithopus* spp. is an example of a situation where plant selection has run ahead of the support activities, and commercial development is being limited by the lack of adequate seed supplies.

In certain circumstances the lack of well organized extension efforts has been identified as an important factor limiting both the rate and the level of acceptance of new pasture legume technologies (8). Where a pasture legume is being advocated for a particular situation for the first time, a wide range of associated management information is required covering such aspects as sowing technique, fertilizer and grazing requirements (16). This process of information transfer can be started during the final stages of cultivar testing so that innovative farmers can plan small scale tests with the new cultivars as soon as they become available.

New pasture legumes are usually tested under a single or narrow range of rotational intensities. The chosen test rotation is often strongly influenced by the prevailing economic conditions which dictates the frequency of cereal cropping. Changes in economic conditions often lead to a requirement for different combinations of crop and pasture in the rotation. Cultivar information is therefore required which defines its capacity for productivity and persistence and its limits under a wide range of rotational and tillage practices.

Information of this sort is usually collected by undertaking rotation experiments. However, such undertakings are extremely resource intensive and slow to produce results, especially where long pasture phases are included as treatments. A more efficient approach involves experimentation directed at the development of seed dynamics models. This approach allows predictions to be made about the persistence of a cultivar in a wide range of rotational and management situations.

Mode1 development and validation can be enhanced by observations of pasture performance on the farms where the new cultivar is first adopted. This activity is compatible with the need to maintain a constant communication between progressive farmers and researchers to allow feedback of information about cultivar deficiencies. This information may then form the basis for future selection programmes for cultivar replacement.

Conclusions

Although selection of pasture legume has been least comprehensive in low rainfall parts of the cereal-livestock regions of Australia, sufficient genetic diversity is recognized to exist amongst Mediterranean pasture legume species to fill most remaining technical needs. However, resource limitations demand a concentration of research effort into areas which are likely to have most economic impact. In some instances this will involve selection to replace existing sub-optimally performing cultivars, while under other circumstances priority should be given to problems caused by the total absence of a well adapted pasture legume cultivar.

Cultivar replacement programmes require centralization because of their heavy reliance on existing genetic resource facilities. The strongest immediate priority should be given to the incorporation of resistance to a range of insect pests.

While wide scope exists for pasture development in new niches in low rainfall wheatbelt areas the challenges are significant because deficiencies in the current cultivar range tend to occur in the most unfavourable soil environments, particularly acid soils. Successful legume introduction requires an integrated approach involving inputs from a wide range of researchers including rhizobiologists, agronomists, animal nutritionists, economists and extension workers.

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