Some limitations of pasture species in southern Australia

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Summary

The dual role of legumes is acknowledged: (i) for nitrogen fixation; (ii) for raising the quality of pasture for animal production.

Following the flurry of plant exploration in the 1950's, most activity with the plants collected apparently centred on expanding the area of adaptation of perennial grass and annual legume. Many of the subsequently released grass cultivars have been agronomically successful but have not been adopted. Haifa white clover, released by the New South Wales Department of Agriculture 25 years after collection in Israel, is the only perennial legume cultivar to have been released from the early program.

The range of annual legume cultivars has extended the area of adaptation considerably, and the effectiveness of the nationally co-ordinated sub clover improvement program appears to offer opportunities for efficiency which should be seriously considered for several other programs that have national significance. The feeding value of sub clover residues in summer may be poor relative to some other annual legumes and warrants further investigation.

The legume content of pasture is considered unsatisfactorily low in many regions relative to 25 years ago. Increased rates of stocking plus increased competition from non-legumes following a lift in soil fertility are commonly associated with legume decline. Soil structure, pathogens, acidity, under- grazing and reduced use of fertilizer have been implicated in some areas. Research should therefore concentrate on management, as well as the improvement of legumes. There is a need systematically to introduce and assess a range of species, cultivars and accessions, particularly perennials. Close attention should be paid to genera that perform well in low fertility situations.

Introduction

Reviews concerning temperate pasture species in Australia and New Zealand have been presented by Donald (l) and Corkhill, Williams and Lancashire (2) respectively. In terms of animal production, the limitations of pasture have been reviewed considerably in recent times, both at the international level (3, 4) and for the high rainfall region (5). Management effects on pasture ecology have been reviewed recently (6).

In this review we shall, therefore, concentrate on the adaptation of species to our agricultural systems, identify their major limitations and list some of the more promising developments. Prominence will be given to legumes because of their significance for pasture quality (7, 8, 9) and because of our dependence on them for nitrogen fixation.

The agricultural systems

The area we shall attempt to address is that classified as the winter annuals, temperate short grass, and moist temperate perennial grass areas (10). For simplicity, we discuss two broad categories: the ley-farming areas (250 - 550 mm rainfall) and the high-rainfall zone.

The winter annuals area is the area most closely approximating a Mediterranean climate. In the adjacent temperate short grass and moist temperate perennial grass areas, one should note that summer is noticeably hotter and drier than in New Zealand and other important areas in the temperate perennial grass zone. The perennial species mature and dry off over summer, resulting in a 10 - 12 week period of low quality feed on which sheep can merely maintain weight; the perennial species must survive this drought.

In the ley farming system, pasture alternates with crop and provides fixed nitrogen (N) for both livestock and crop. The frequency of cropping varies from two years in three to (also rarely) one year in four or five. Variation in the system depends on soil type, rainfall, risk of erosion, pasture species, crop species and economic factors. For example in the sandy mallee soils of South Australia, alternate year cropping is normal: on these soils the risk of erosion is slight, annual medics can be used, and barley is the most common crop. In the red-brown earth zone north of Adelaide the rotation is usually in two phases: a pasture phase of two to four years followed by a cropping phase of up to three years. These soils are acid to neutral and better suited to subterranean clover *(Trifolium subterraneum),* a species which in South Australia has needed to be resown after the cropping phase.

Pastures in the high rainfall zone are usually grazed continuously by sheep or cattle, although a number of alternate grazing systems are used (11). There is evidence that rotational grazing favours the perennial component, certainly lucerne *(Medicago* sativa)(12) and probably phalaris *(Phalaris aquatica);* deferred grazing increases the amount of annual grass compared with subterranean clover (13). In general the system which disturbs livestock least and maintains maximum legume content is the most profitable.

A characteristic of both systems is the period of dry pasture in summer and autumn, typical of Mediterranean and related climates. Dry pasture is characterised by low voluntary intake, protein, energy, and digestibility values, resulting in loss of liveweight and occasional ill-thrift. Store sheep and beef cattle do not usually receive extra feed during this period except after drought in the preceding growing season. The poor quality of summer feed largely determines time of lambing and calving, which is mainly in autumn and winter for spring production of fat stock. If dairy cattle are milked, substantial supplementary feeding may be required at this time.

Climatic conditions are sufficiently mild to allow for year-round grazing. Pasture growth rates over winter sometimes necessitate supplementary feeding of cattle and pregnant ewes with hay produced in the previous spring. This is especially so in upland areas and in years when the first seasonal rains do not fall in the late autumn or early winter.

Our pasture species - origin and evolution

None of the sown pasture species are indigenous. Although still important in large areas of New South Wales (14), the productivity of native species is poor; they do not make full use of soil moisture, they are adapted to low soil fertility and they evolved under grazing by light-footed marsupials (l). The use of introduced species has been the result of four factors: firstly, the northern European origin of early settlement; secondly, the similarity of our climate with that of the Mediterranean zone of southern Europe, north Africa and the Near East; thirdly, the accidental introduction of many wild plants; and fourthly, the unique nature of our farming systems. These factors have together resulted in an initial phase of dependence on plants of northern European origin, a second phase of dependence on plants selected from the naturalized flora, and a third phase of selection of species adapted to our agricultural systems, particularly year-round grazing and periodic disturbance by cropping. In the process, Australians were among the first people in the world to recognize the value of pasture legumes as the main source of N in broadacre farming systems.

The historical link with northern Europe resulted in a long drawn-out attempt to persevere with familiar perennial species. Early settlers brought with them the species praised by the progressive British farmers of the early 19th century. They imported seed of red clover *(Trifolium pratense),* white clover *(T. repens),* lucerne, perennial ryegrass *(Lolium perenne),* cocksfoot *(Dactylis glomerata),* fog grass *(Holcus lanatus),* ribgrass *(Plantago lanceolata),* dogs- tail *(Cynosurus* spp.) and sweet vernal *(Anthoxanthum odoratum).* Of these original introductions only lucerne, white clover and perennial ryegrass remain important, although several others have become naturalized in favourable areas.

Perennials

Until the recent release of cv. Haifa, the two most widely used cultivars of white clover were naturally selected forms of the early northern European introductions to New Zealand (cv. Grasslands Huia) and Australia (cv. Irrigation). However, since white clover is endemic to all European countries and is present in north Africa and western Asia (15), its natural population must present great opportunity for the selection of strains more suitable to Australian conditions. Cv. Haifa, which originated from north-eastern Israel, and possibly other ecotypes from similar areas, appear to have the potential of extending the use of this important species of temperate agriculture (16, 17).

Lucerne was one of the most successful of the original introductions to Australia, perhaps because the early strains were of Mediterranean origin (18). At any rate, it was sown on the alluvial flats of the Hunter and Peel Rivers where, through natural selection, the cultivar Hunter River was derived. This cultivar showed truly amazing adaptation and is now widely grown in regions as different from its first Australian habitat as the deep sands of south-eastern South Australia and the red-brown earths of central western New South Wales.

Nevertheless, limitations associated with lack of genetic diversity are slowly being appreciated. In colder environments it has been outyielded by winter- dormant strains (19,20) and in the more Mediterranean climates, it is now known to yield less than Spanish and North African strains with greater winter activity (19,21). Despite these results, the development of cultivars for varying environments has been slow. Although attention to the limitations posed by pests and diseases was rapid for the recently-arrived spotted alfalfa aphid *(Therioaphis trifolii* f. maculata), for older problems such as stem nematode *(Tylenchus dipsoci)* (22) and bacterial wilt *(Corynebacterium insidiosum)* (23), plant improvement was given little attention. Clarification of the role played by diseases (24,25) will help to stimulate interest in the development of cultivars for places presently considered unsuitable. The Medicago sativa-glutinosa-falcata complex has a great genetic diversity, offering seemingly unlimited possibilities for its extension into new areas (26).

Ryegrass, perhaps our most important perennial, became naturalised in all states. Three naturalised ecotypes - Victorian (ex. Vic.), Tasdale (ex. Tas.) and Kangaroo Valley early (ex N.S.W.) account for virtually all the seed sown in Australia. Considerable genetic variation is obvious within Victorian and Kanagaroo Valley early. *Phalaris aquatica,* now widely established, has under-gone little, if any, ecotype variation during its first 90 years of cultivation. The original strain released is considered to be of Italian origin and has been given the name "Australian". McWilliam *et al.* (27) consider its evolutionary conservatism and apparent lack of ecological adaptation is due to the longevity and adaptability of individual plants, and - in contrast to perennial ryegrass, and especially sub clover - the absence of natural regeneration and thus a reduced scope for natural selection.

Annuals

Southern Australia's naturalized flora are mainly annual species native to the Mediterranean basin, the Near East (including south-west Asia) and western Europe. They include at least 40 grasses, 70 legumes and 50 other species (l). The most abundant genera are, among the *legumes,Trifolium, Medicago, Trigonella* and *Melilotus;* the grasses *Hordeum, Vulpia, Avena, Bromus, Lolium* and *Poa.*

Most of the naturalized genera are adapted to grazing but successful use of the ley farming system is especially dependent on the use of annual medics (Medicago spp.) and subterranean clover. As will be discussed later, these species possess attributes of importance in maintaining self-regenerating pastures in a rotation in which pastures and crops alternate. Of other Mediterranean annuals most of the genera in intensive grazing are represented in ley farming but differences occur at specific level: in ley farming *Bromus rubens* and *B. madritensis* largely replace rip gut brome *(B. diandrus)* and soft brome *(B. hordeaceous), Hordeum glaucum* replaces *H. leporinum* (barley grass), and *Avena fatua* (wild oats) replaces *A. barbata.* Annual ryegrass *(Lolium rigidum)* is of far greater significance in ley farming while *Trigonella* and *Melilotus* among the legumes, and *Erodium* and *Echium* among the herbs, are more common in the high-rainfall zone.

Between 1923 and 1935, when valuable Australian ecotypes of sub clover, white clover, perennial ryegrass and cocksfoot were identified, Harrison pointed out time of flowering variation in sub clover (28) and initiated seed certification in Australia. Our cultivars of sub clover include some which form seeds as early as late September and some which form seeds as late as mid- December. The genetic diversity of this character, and of seed-setting ability, are two of the more important attributes which have led to the outstanding success of the species in Australia (29). Over 100 biotypes have successfully become colonized in Australia; most of them were probably introduced over 100 years ago and about 20 have been commercialized. Only two of the four bred cultivars are in common use; both have been developed as low-oestrogen cultivars (i.e. Trikkala, Nungarin). Valuable Australian ecotypes are still being found (30). It was previously thought that the Australian ecotypes were all introductions (31,34) but local evolution has also occurred (33). In low- rainfall areas, only early flowering introductions have persisted. However, in areas with more than nine months of effective rainfall, a range of early to very late flowering strains has persisted (191). Significantly, the most widespread cultivar in the high rainfall area is Mt. Barker - the first cultivar to be commercialised. When 199 biotypes were collected in the Mediterranean basin, none was found to be identical with any of the 60 strains previously collected in Australia (34). It is clear that a vast number of distinct biotypes exist and it would be unlikely that we have necessarily found all the most valuable ones. There is clear evidence that Mt. Barker is not particularly productive. The current screening of a vast collection represents a new step in Australia's development of sub clover; systematic collection and testing is taking over from *ad hoc* discovery of local ecotypes.

There has been some speculation on the origin of annual species. Some considered that, based on their earliness, Australian populations of sub clover came from the drier, eastern part of the Mediterranean (35). Gladstones, however, argues that since it must have been introduced before the Suez Canal opened its origin is probably western Europe (34). Other recent evidence supports Gladstones: the predominance of early strains in Australia is easily explained by the presence of early strains in high rainfall parts of western Europe (36); subspecies *yanninicum,* originally thought to be restricted to the eastern Mediterranean (in particular, Greece) is now known to occur in Spain; and the Australian strains of subspecies *brachycalycinum* are all variety *flagelliforme,* the only variety growing in the western Mediterranean.

Other annual species appear to have the same origin as subterranean clover. For example, coastal silver grass *(Vulpia fasciculata),* an inhabitant of deep sandy soils in southern Australia, is a British species: *V. membranacea,* a very closely related Mediterranean species, is apparently absent from Australia. Of the 12 species of annual medics native or adventitious in France, Britain and the Low Countries, ten grow in Australia. Only one Australian species, *M. orbicularis,* is absent in western Europe, and even this species grows in the western Mediterranean. The evidence suggests therefore, that the so-called Mediterranean species of southern Australia are the result of natural selection in Australia on a population mainly of western European origin.

There are some clear exceptions: *Arctotheca calendula* is a native of South Africa, and *Hordeum glaucum* is apparently restricted to the eastern Mediterranean. The latter, however, has been subject to much mis-identification (37), and it may well also occur in the western Mediterranean. Its presence in Britain or western Europe seems rather unlikely since its distribution in Australia is restricted to the drier margin of the Mediterranean zone and to subtropical New South Wales and Queensland.

Perennials or Annuals?

Except where lucerne is sometimes used, pasture in ley farming systems consist of annual species. In areas of 500-700 mm rainfall, where Moore (38) has suggested a role for perennial grasses, early work reviewed by Reed (7) showed little benefit in terms of animal production when perennial grasses were compared to annual ryegrass or volunteer species such as barley grass, soft brome, capeweed, erodium and fog grass. Subsequent workers have obtained benefits of from 0-15% (39-44). The value of output per hectare for 89 farms in a 600-700 mm rainfall area of Western Victoria was found to be strongly related to stocking rate and superphosphate use, but not to the area of the farm sown to perennial grass (45).

Where grazing pressure is very high, the proportion of perennial ryegrass often declines; it is replaced by naturalized species less productive than those mentioned above however (e.g. *Poa annua, Trifolium glomeratum* etc.) (46,47).

In this situation, a severe penalty in wool production has been recorded where the perennial component fell below 35% (D.C. Conley and K.F.M. Reed, unpubl. data) - a figure similar to that found to be critical in a survey of Welsh farms (48). In such a situation the ability of perennial ryegrass to regenerate from seed removes the necessity of pasture resowing in all but the most extreme cases (41,47).

Apart from animal production, other benefits sometimes claimed for perennial grasses include prevention of soil erosion, less weeds and better hay crops. During the period of seed maturity, awned seed of barley grass and erodium can reduce animal performance (49). Probably all the benefits of a perennial could just as well be provided by a legume as by a grass; research has been directed mainly at the latter. There remains a need to evaluate a range of alternative perennial legumes.

Above 750 mm rainfall, perennials such as white clover, cocksfoot, fog grass perennial ryegrass and the South American species, *Paspalum* dilatatum and *BrOMUS* uniloides, have become naturally established in the more fertile areas of the region. Kikuyu grass *(Pennisetum clandestinum),* introduced from Africa, has become naturalized on the East coast. In the absence of perennial grass, white clover is capable of fattening sheep right through summer, but where perennial grasses are sown, the clover succumbs to moisture stress and the feeding value of the pasture is poor over summer (50).

The introduction in the 1950's of perennial grass strains from the Mediterranean basin appeared to offer great scope for extending the perenniality of pastures. Currie, Brignolles, Berber and Kasbah cocksfoot, Sirocco phalaris, Medea Perennial ryegrass and Melik tall fescue are more summer-dormant than older cultivars and would appear to be far better adapted to the Mediterranean zone.

Their limited success may reflect doubts regarding the requirement for perennial grasses in the 500-700 mm zone. The other potential role for Mediterranean genotypes of perennial grass is as a source of increased winter growth within the (less doubtful) higher-rainfall or irrigated areas (52, 135).

Adaptation

Climate

Development of new pasture species in Australia has primarily been concerned with climatic adaptation. The unsuitability of the original northern European perennials in the high rainfall regions has been partly resolved by (i) natural selection leading to better adapted ecotypes (e.g. Kangaroo valley perennial ryegrass) and (ii) the introduction of summer dormant strains (e.g. Currie cocksfoot). In the Mediterranean climatic zone the same problem has been resolved by natural or artificial selection of previously-undomesticated perennial (e.g. *Phalaris aquatica)* and annual species (e.g. annual ryegrass, subterranean clover and the annual medics).

Among Australian annual pasture species, the first effect of climate on adaptation is illustrated by the relationship between flowering time and length of growing season observed in cluster clover *(Trifolium glomeratum),* subterranean clover, and the barley grasses (53,31,37 respectively). As Donald (l) pointed out for subterranean clover, the relationships are far from perfect, strains originating from moderate to long growing seasons being not necessarily late. That this also occurs in the native habitats was shown by Crespo (36), who found both early and late strains of subterranean clover in a favourable Portuguese environment. Indeed, Rossiter (54) expressed doubt that flowering time had any effect on persistence at Kojonup, a favourable Western Australian environment; although Cocks et al. (55) have recently found that mid-season strains may be favoured at the expense of late strains in the very favourable environment of Kalangadoo, **South Australia.**

Of other physiological adaptations to the Mediterranean climate, the attributes of dormancy and hardseededness have long been considered vital for survival.

In the case of grasses, dormancy is often expressed as delayed germination (56) - seeds are prevented from germinating unless rain is prolonged. Delayed germination appears widespread among annual grasses (J. Reis, pers. comm.), being present in barley grass, silver grass *(Vulpia myuros),* annual ryegrass and rip gut brome, although apparently not in soft brome. As with embryo dor- mancy in subterranean clover (57,58), delayed germination decreases with time and seeds germinate promptly at the usual time of first winter rains.

Hardseededness has not been shown to be ecologically important in the grazing situation (54,29,55), except by Quinlivan (60). Lack of importance of hard- seededness may be partly due to problems of definition and partly to lack of knowledge about demography in annual pastures. Hardseededness is of clear significance where pastures are used in ley farming systems.

Burr burial is an important mechanism whereby seeds are protected from climate and grazing (61). Seeds that germinate after light rains are more likely to produce seedlings if they have soil cover.

We have as yet shown little concern with the less obvious temperature variation within a region. For example, even within south western Victoria, the mean winter temperature is 6?C higher at the coast than in the central highlands.

In many European countries, where there is a wide range of cultivars available, the extended range of latitude and climate in which many of our perennial cultivars have been, or continue to be, used in Australia would be considered most unusual (cf. Victorian perennial ryegrass, Demeter tall fescue, Australian phalaris, Hunter River lucerne). The situation contrasts markedly with the range of sub clover and cereal cultivars available to Australian farmers.

The hybridization of Italian *(Lolium multiflorum)* and perennial ryegrasses in New Zealand (62) demonstrated the potential of Mediterranean genotypes for in- creasing winter growth. Subsequent developments regarding increased winter growth, where cultivars were released and then fell into obscurity despite much preliminary selection and testing, include Medea perennial ryegrass (63, 52) and Melik tall fescue (64). More recent releases with superior winter growth relative to earlier cultivars, and which may prove more popular, include Haifa white clover (Table 1) and Redquin red clover (171).

Table 1: Winter yields of white clover on two soil types at Hamilton, Vic. Plots sown in 1978; 4 year mean, 1978-81.

Cultivar	Clover dry matter (t ha^{-1})	
	Silty loam	Gravelly loam
Grasslands Huia	0.44	0.28
Haifa	0.72	0.68

Soils

Adaptation to particular soils can be seen in the evolution of tolerance to heavy metals. Races of *Agrostis, Festuca* and *Anthoxanthum* developed on the tailings of old mines in South Wales. The boundary between genetic tolerance and intolerance in the grasses precisely paralleled the presence or absence of toxic levels of copper, lead and zinc in the soil (65). The effect of soil pH on the distribution of medics and subterranean clover in southern Australia (66) is well known. This is partly associated with distribution of the two rhizobia species. Tolerance to low levels of molybdenum and high levels of manganese at low pH also characterises clovers,while ability to absorb zinc at high pH may characterise medics. Tolerance to aluminium may also be involved (67). Among subterranean clovers,preferdnce of sub clover subspecies *brachycalycinum* for heavier soils than subspecies *subterraneum* has often been observed, and this too may be associated with ability to absorb zinc at high pH (68).

Drainage affects distribution. The adaptation of sub clover subspecies *yanninicum* cv. Yarloop to poorly drained sites is well known (59). Its success is associated firstly with high activity of the enzyme alcohol dehydrogenase which prevents the accumulation of ethanol, and secondly with shallow distribution of roots (69). It is capable of greater substrate oxidization by roots (70). Because of a high oestrogen content in cv. Yarloop, Beale and Crawford (71) examined aerial-seeding species of Trifolium as alternatives on waterlogged lateritic podsols. For forage production, several lines were as productive as cv. Yarloop. Under grazing they were less competitive. Subsequent work in S.A. has identified material from a range of Trifolium species with considerable promise for fodder production. Attributes include good winter growth, resistance to the clover scorch fungus, *Kabatiella caulivora,* and deep root systems resulting in an extended growing season. Promising material includes lines of *T. resupinatum, T. balansae, T. lappaceum, T. purpureum, T. cherleri, T. isthmocarpum, T. constantinopolitanum* and *T. nigrescens* (72,71). Workers in the south east of South Australia are systematically assessing a comprehensive collection of legume species for calcareous sands, siliceous sands, solidized solonetz and ground-water rendzinas (E.C. Crawford, pers. comm.). Over 100 Trifolium species have been grown at Grafton in N.S.W. and 12 of the annual species that were listed for further evaluation included three of the above species; *viz. T. constantinopolitanum, T. isthmocarpum* and *T. resupinatum* (73). Persian clover *(T. resupinatum)* first became popular in South Australia when farmers saw it growing in seed crops for re-export. Despite poor regeneration from seed, its adaptation to a wide range of soils, its productivity and its quality for summer grazing (17,74) have now made it a widely-used species in S.A. and Victoria, particularly as an annually-sown irrigated pasture/hay crop, and also as a break crop in ley-farming systems.

Burr-medic tolerates poor drainage better than other medic species (75). The perennial, strawberry clover *(T. fragiferum),* is well adapted to poor drainage and to soils of high pH such as the groundwater rendzinas. It can make excellent summer pasture (74). T. *clusii* and *Trigonella ornithopoides* appear to be adapted to even wetter soils than cv. Yarloop, and tolerance of *T. dubium* to poor drainage lies between that of cv. Yarloop and other subterranean clovers (P.S. Cocks, unpubl.). Low tolerance to drainage is often listed as a significant reason for poor persistence of lucerne and there is clear need for investigation of the waterlogging tolerance that exists in some wild (76) and developed (77) lucerne.

Large areas of deep siliceous sands occur in most states. With lime and fertilizer, lucerne and sub clover may be established. A number of other legumes are able to grow in this habitat, one of the more important being serradella *(Ornithopus compressus).* This annual Mediterranean species has deep roots which greatly extend the growing season compared with sub clover; it is noted for its ability to grow well in low fertility situations (78-81), but shortage of seed and lack of suitable cultivars are limiting the use of the species. Other legumes to grow well in these soils are woolly pod vetch (Vicia villosa ssp. dasycarpa) (16), disc medic (M. tornata) and several annual species of Trifolium (E.J. Crawford, pers. comm.).

Largely as a result of adding superphosphate, pastures have changed from dominance by native perennial grasses, through dominance by introduced legumes,to dominance by a mixed population of Mediterranean grasses and legumes. The ingress of Mediterranean grasses is usually associated with increased soil fertility resulting from the growth of legumes (82,83). However, the grasses themselves show some variation in accomodation to the new levels of fertility. For example, barley grass and silver grass respond in opposite ways to high applications of phosphorus (84). Rip-gut brome responded to higher levels of phosphate than silver grass in a study which also showed that the requirement of subterranean clover for phosphorus is equal to brome (85). Interest in this potentially powerful method of manipulating botanical composition appears to have decreased in recent years.

Micro-environment

A study of evolution in a 40-year-old mixture of Mt. Barker and Dwalganup sub clovers found that 60% of the individuals differed genetically from the original strains; late-flowering strains colonized the wettest sites and early strains the driest sites. Isolines could be drawn connecting sites whose inhabitants flower at the same time (P.S. Cocks, unpubl.). The linking of polymorphism in flowering time with site heterogeneity is probably the main reason for the poor relationship, at the regional level, between flowering time and length of growing season, which was referred to earlier. Adaptation to micro-environments has not been studied in depth in Australian pastures. Principles are available from extensive English (86) and American (87) studies, and warrant our attention.

Disruption by Cropping

Cropping disrupts the normal reproductive cycle of pasture. Pasture in a rotation with crops must survive at least one year of greatly reduced seed production. In effect, the reproductive cycle more nearly approaches the pattern of ephemeral arid communities, where rainfall is not seasonal, than it does the strongly seasonal patterns of Mediterranean communities. Nevertheless, the species used are of Mediterranean origin; perhaps their adaptation to cropping systems is a result of the proximity of their native habitat to the arid zone. The ecophysiology of plants specifically adapted to survival in crop/pasture rotations has not been widely studied. Our knowledge of adaptation of annual legumes in Australia is a result of studying the continuous grazing system, and our ideas of their relevance to cropping systems have been achieved through extrapolation.

Hardseededness, of doubtful importance in the grazing situation, would seem to be of great significance in the survival of species in a ley-farming system. Seeds can survive for extended periods (60,88,89). Questions which remain unanswered include what is the rate of field breakdown, the relationship between environment and seed survival, the effect of seed burial and other aspects of tillage on hardseededness, and other demographic aspects of seed survival.

How important is natural seed burial in a ley-farming system? While buried seed will still be protected from summer grazing, good seed-soil contact, at least in a simple rotation of one year of crop and one year of pasture, will be achieved through tillage. The important ecological question is therefore from what depth can the buried seeds emerge. In view of the relationship between seed size and hypocotyl length (90), possession of large seeds by a species may be more important than ability to bury seeds. No matter how effective hardseededness is in protecting seed populations, there will be heavy losses of seeds during the cropping phase. It follows that ability to produce large quantities of seed may be far more important in cropping systems than appears to be the case in systems of continuous grazing. Furthermore, plant populations are likely to be much lower during the pasture phase of a cropping system than in continuously-grazed pasture and therefore the importance of individual plant growth rates will be of greater significance than in a system where plant density is normally extremely high.

Soil organic matter content and available nitrogen are likely to be lower after a crop than after pasture. This should increase the likelihood of legume dominance. However, ley farmers are currently concerned about the lack of legume dominance in the pasture phase. Increased cropping frequency during the past decade has put pressure on southern Australian pastures by expecting the pastures to carry many of the displaced stock. In many areas, dry seasons plus the arrival of the new aphid pests, and the use of herbicides, have combined with the increased stocking rate to reduce severely both the feeding value of pasture, and its fertilizing value to subsequent crops. Consequently, there is now increased use of both N fertilizer and legume crops in the rotation to improve soil fertility (e.g. lupins, peas and vetches) (91,92). In irrigated areas, farmers are interested in summer legume crops to improve the soil in between winter cereal crops so that precision-levelled land is fully utilized. Other approaches centre around increasing the legume component in the pasture phase by, e.g. increased use of lucerne (93), or a reappraisal of ley management (94,95).

Limitations to pasture growth

The potential productivity of pasture is very high. Temperate plants are able to convert light to herbage dry matter at a rate approaching 5% of photosynthetically-active radiation. Cooper (96) lists a number of authors who reported peak growth rates of 150 kg ha^{-1} day^{-1} or more. The literature abounds with reports of conversion efficiencies between 1.5 and 3%, representing potential production at Adelaide of 14-28 t ha^{-1}. More recently Cocks (97), by maintaining leaf area index as close as possible to optimum, achieved a yield of 16.4 t ha^{-1} from clover (4.5% conversion) and 17.3 t ha^{-1} from grass (5.5% conversion) from single sowings in a shortened season at Kybybolite in South Australia.

Grazing Management

How does the growth of grazed grass-clover pasture compare with the theoretical potential? In terms of dry matter, and using monthly measurements from pasture cages, the annual net primary production (i.e. true growth - decay) of research station pastures in the 600-700 mm rainfall area is usually between 4 and 14 t ha^{-1},with lower values occurring in poor seasons and at high stocking rates (13,47,98-101). Cocks (102) has obtained similar yields to the above and has calculated them to be less than 50% of potential. Part of the discrepancy may be due to decay; where herbage decay has been measured, estimates of true growth have increased considerably over estimates of net growth (100). Herbage losses increase as stocking rate is reduced, and net primary production may decline (103-5). Critical stocking rates will vary depending on soil and pasture potential, and need defining in terms of grazing pressure and LAI. The effect of stocking rate on net primary production in the studies referred to appears to be small except at extreme rates of stocking.

In winter and early spring, pasture growth increases as the initial yield of pasture present is increased (106). *Phalaris aquatica* grows poorly when subjected to continuous heavy grazing (107; D. Conley and K. Reed, unpubl.) or frequent cutting (108, 51); tall fescue may be more tolerant of such management (109,110). In spite of these challenging observations, animal production has rarely benefited from rotational grazing compared to continuous grazing (111).

Plant Nutrition

Most Australian soils are deficient in phosphorus in their native state and some areas are deficient in potassium and trace elements. Despite the considerable quantities of superphosphate already applied, phosphorus is a common limitation to pasture growth (112-114) and animal production (98,101,115-117). In the pasture phase of legume-ley farming systems, the surface application of superphosphate can be worthwhile (118,119), but in dry situations the response can be slight (120) and if substantial previous applications have been applied, the legume may be suppressed by grass (121) and subsequently animal production may be penalised (122-124).

It is sometimes assumed that legume-containing pastures are unresponsive to nitrogen fertilizer, but this is unlikely where the legume content is below 20% (9). While the general use of nitrogen fertilizer may be uneconomic (125), Cocks (102) considers N deficiency to be a widespread limitation. He found that a 40 year old sub clover pasture at Kybybolite responded to nitrogen at all times of the year. The elimination of this deficiency doubled the efficiency of light utilization (to 3.8%). The proportion of sub clover through the season varied from 11% to more than 50%. Although the total amount of nitrogen in the soil was 3.7 t ha^{-1}, the shortfall in nitrogen supply was 0.4 t ha^{-1}.

Basic studies into the nitrogen limitation at Kybybolite has eventually led to a considerably increased research activity with legume species and cultivars. General concern about the decline of legumes from their initial dominance of newly-improved pasture is now widespread. Decline has been associated with a range of variables within Australia.

Competition from both annual (121,124) and perennial grasses (50) suppresses clover. As soil fertility improves, and particularly when the opening rains are late, the widespread cv. Mt. Barker is likely to be increasingly disadvantaged by competition because of its poor winter growth (17).

At high rates of stocking, particularly on perennial ryegrass rather than phalaris pasture, the density of sub clover is severely reduced (126,46,47) although the contribution of *T. cernuum* and *T. glomeratum* may increase. For annual legumes, there is a need to define critical seed reserves and the strategic management required for adequate establishment under grazing, such as is being attempted with medics (127).

It is difficult to find recent quantitative information on insect attack; the significance of old pests (e.g. red-legged earth mite, *Halotydeus destructor)* should not be underestimated. In the old cropping districts soil structure and soil acidity and associated rhizobia problems have been associated with clover decline (94), while in some areas root rots and nematodes have been implicated (128,129).

Pests and Diseases

Quantitative surveys and reports on the effects of insects and diseases on pasture productivity are relatively scarce - a most interesting point in view of the effort to incorporate resistance into our pasture plants. Wallace and Mahon (130) increased carrying capacity by about 14% when they controlled red legged earth mite. With high rates of stocking, the economic significance of this mite, which can quickly reduce seedling density, must increase. Recently Allen (131) found that he could increase available pasture by controlling the pasture cockchafer *(Aphodius tasmaniae),* but he did not increase animal production. The above authors recognized that very heavy infestations will cause greater damage. Serious pests such as the spotted alfalfa aphid *(Therioaphis trifolii),* the sitona weevil *(Sitona humeralis),* the white fringed weevil *(Grapognathus leucoloma)* and the black field cricket *(Teleogryllus commodus)* are capable of large reductions in productivity, but the effects of non-epidemic levels of pests and diseases, including possibly unrecognized virus, nematode and mollusc problems cannot be established. For example, root rot of sub clover and Medics is causing considerable interest in Victoria at present and may be a potentially serious problem (F.C. Greenhalgh, pers. comm.). The economic effect of a pest on the agricultural system can only be crudely estimated until bioeconomic models can be constructed,as Auld et a/. (132) have attempted with the weed *Silybum marianum.*

Soil Conditions

Circumstantial evidence suggests that on many of our soils winter waterlogging is reducing productivity. At Glenormiston, Reed (50) measured net primary production of 18 t ha^{-1} yr^{-1} on an extremely well-drained volcanic ash soil close to a typical basalt soil where, over the same year, similar well-fertilized pasture produced less than 11 t ha^{-1} (47). Similarly, between-year comparisons of pasture growth curves show that on the basaltic soil, in years with particularly high rainfall in August and September, the high rates of pasture growth which begin in spring were delayed by nearly six weeks (47). In such years, the surface tlooding of perennial ryegrass-sub clover pasture, with 10% of its area classed as surface depression, reduced clean fleece weight by from 13 to 35% depending on stocking rate and year. On phalaris-sub clover pasture, there was no significant effect of surface depressions on fleece weight (133). Modification of the soil structure may reduce this limitation. Amelioration of a red-brown earth at Kyabram has resulted in herbage yields of 27 and 38 t ha^{1} for irrigated white clover and *Paspalum dilatatum* respectively. These yields more than double those previously obtained in the district (134).

Other soil attributes can greatly affect the nature of pasture but not necessarily its growth. High pH changes genus of legume from *Trifolium* to *Medicago;* poor drainage encourages *Medicago polymorpha* at the expense of some other medics (75). In South Australia the annual grass *Vulpia fasciculata* grows only on deep sandy soils (Cocks, unpubl. data),as it does in Britain (136). One of the authors (P.S. Cocks) has observed that rip-gut brome also prefers sandy soils; in fields where sandy soils co-exist with heavier soils, the brome grows in sand and is replaced by silver grass in loams. Such relationships have significance on productivity when attempts to grow poorly- adapted pasture plants fail.

Temperature

The two most significant aspects of climate, rainfall and light, are embodied in the definition of potential productivity and therefore cannot further restrain growth. The effect of a third aspect of climate, temperature, is less clear. Donald (137) defined a frost boundary which limits the distribution of subterranean clover; the possibility exists then that frost incidence within the boundary limits the growth of sub clover. Frost limits the growth of barley grass compared with annual ryegrass (138). The data of Fitzpatrick and Nix (139) suggest, at first sight, that frost may severely limit growth throughout temperate Australia, with frosty periods varying from 50-150 days over most of the region. The actual number of frosts is much lower and, as McWilliam (140) points out, most temperate plants can 'harden' themselves to frost.

Low temperature restricts most plant processes, and most temperate plants have an optimum of 20-25?C (141-143). Temperatures below this reduce the rate of germination (144), early vegetative growth and probably the growth of heavily- grazed pasture. But in the absence of frosts, low temperature does not affect growth at winter temperatures experienced in most of southern Australia because of the onset of inter-plant competition for light (143,145).

Pasture limitations to animal production

With our great dependence on year-round grazing, the climatic restrictions result in a period of pasture scarcity in winter and a period of poor quality pasture in summer. The first limitation can and has been addressed by using better-adapted species, especially Mediterranean genotypes as discussed previously. Lucerne, phalaris and cocksfoot offer considerable genotypic variation in winter dormancy. Whether or not differences exist within white clover (146) and sub clover (147) populations, there is evidence of differences at the sward level (Table 1; 17,148). For the annual species, these results may reflect the importance of high seed yields for winter production.

A recent example of improved winter feed due to choice of species is the increased lamb growth rate and fleece weight (Table 2) when autumn-lambing ewes were run for three years on *T. yanninicum* rather than *T. subterraneum* pasture on a solodized solonetzsoil at Kybybolite. Seed yields were greater on the *yanninicum* treatment, and the autumn, winter and spring months were associated with significant treatment differences in the yield of clover. Other limitations, which have also been discussed previously but which are particularly relevant to the feed scarcity in winter, include plant nutrition, water-logging and temperature.

Table 2: Fleece weights of ewes grazed on two pasture types at Kybybolite, S.A., 1980 (A.D. Craig, pers. comm.) (kg)

Stocking Rate (ewes ha^{-1})	*Trifolium subterraneum* cv. Mt. Barker	*T. yanninicum* cv. Trikkala
8	5.7	6.2
13	5.2	5.9
18	5.1	5.4

The second limitation, that of poor quality in summer, is perhaps best recognized for the problems it causes with young sheep in particular. Early emphasis was given to supplementary feeding, fodder crops and time of lambing (32, 59). New Zealand work (192) highlighted surprisingly large differences between species in feeding value during early summer. Subsequently the superior nutritive value of legumes has been emphasized for sheep, beef and dairy cattle (7,9,73,149,150).

Alternative pasture species are receiving increasing attention as a means of improving the quality of summer pasture. Perennial grasses with an extended season, such as tall fescue cv. Demeter, may have some advantage during this period of the year relative to perennial ryegrasses (151), but for a high feeding value, legume species (152-154) or annual fodder crops (155,156) are required. The benefits of legume species are associated with their fast rate of breakdown in the reticulo-rumen (8,157),and a pasture of high feeding value can still be provided in a dry summer from carry-over spring feed because the nutritive value of perennial legumes declines slowly relative to grasses (74).

By comparison the feeding value of sub clover over summer has been relatively poor in grazing trials (154,158-160) and research is needed into the factors which make some other annual clovers superior to sub clover in this regard (e.g. Rose clover *(Trifolium hirtum)* (1611; Persian clover (741). There appears to have been little research into intraspecific variation in nutritive value with sub clover. Special-purpose lucerne pasture can be a valuable component within a fat lamb production system (162). Possible benefits of such special- purpose pasture in sheep systems include greater carrying capacity consequent on the increased feasibility of later (i.e. spring) lambing (163).

Widespread understanding of the nutritive differences between grasses and legumes will possibly lead to renewed interest in fodder conservation. Many conclusions concerning the economics and feeding value of hay have been restricted to grass-dominant hay. Feeding value is frequently equivalent to only a maintenance standard but can be increased by cutting early between ryegrass ear emergence and flowering (164). With forage legumes such as lucerne and Persian clover, hay need not be made early in the season to ensure good intake charateristics and feeding value for sheep (G.R. Saul and P.C. Flinn, pers. comm.). At present, information on the management, yields and longevity of various legumes is needed before the potential value of legume hay, or indeed silage (165), in farming systems can be accurately predicted.

One major limitation to the greater adaptation of legume species is the problem of bloat. Overseas workers are attempting to tackle the problem by plant breeding. Surveys of tannins in Australian legume collections are continuing (166). The use of non-bloating species such as birdsfoot trefoil *(Lotus corniculatus*) and sainfoin *(Onobrychis viciifolia),* which may also have valuable resistance to pests (167), in place of lucerne would appear limited owing to the poor spring growth of the former and the narrow soil requirement of the latter. The development of *Lotus* pedunculatus cv. Maku may represent an important bloat-free alternative to strawberry clover on flood-prone flats (168). One potentially serious limitation to the use of red clover for breeding sheep (169) has now been removed with the development of the low oestrogen-cultivars Red- west (170) and Redquin (171).

Recent emphasis on the potential danger to sheep fertility from lucerne has given a new priority to lucerne breeders, *viz.* leaf diseases (172). Limited overseas observations have indicated that reproductive efficiency in cattle may improve on legume-based pasture (9). In recent studies at Hamilton, improved liveweight gain of ewe weaners has been associated with an early start to cycling when they were grazed on perennial legume rather than grass-dominant pasture (173). Other animal production problems, *viz.* intestinal worm burdens of cattle (174) and sheep (175), hypomagnesemia (176) and meat taint (177), have been found to be significantly reduced on legume-dominant pastures.

Future trends for improving species

High priority must be accorded legumes. Studies to examine further limitations on their adaptation are needed in most regions. A program to develop appropriate management to maintain legumes in our pasture-based systems of animal production must continue. In the area of plant improvement, there seems a surprisingly strong case for a systematic and nationally co-ordinated introduction and assessment of species, cultivars and accessions from selected regions. Plant breeding would appear to be mainly important for incorporating pest and disease resistance.

Pests and Diseases

The improvement of sub clover for disease resistance has now produced cultivars resistant to clover stunt virus and clover scorch. Resistance to root rots (e.g. *Rhizoctonia solani, Fusarium avenaceum, Pythium irregulare)* are needed,

as is resistance to the red-legged earth mite. Little has been published about the extent and severity of the viruses of our perennial grasses. Overseas work has shown that viruses may lower the quality of perennial ryegrass (178), but screening and development of naturally-resistant strains (179) has not yet been attempted in Australia. Advanced breeding techniques may prove effective (180) f transferring immunity to viruses from *Trifolium ambiguum* to white clover (181). Microorganisms are increasingly being linked to pasture problems - e.g. annual ryegrass toxicity (182), summer fescue toxicosis (183), perennial ryegrass stagge and plant resistance to insects (184). Future plant improvement in this area will obviously require inter-disciplinary co-operation.

Feeding Value

Mention has been made of intra and inter-specific variation in feeding value of *Trifolium* species. Generally, breeding for increased feeding value has only become possible in recent years as a better understanding of the relevant parameters has emerged. In the U.S.A., a tall fescue breeding program has increased beef liveweight gains by over 40%. This improvement is believed to be associated with herbage quality or anti-quality factors (185) and should stimulate future breeding programs.

Lower Fertilizer Requirements

In recent years the price of superphosphate has trebled. As a result, many farmers are using less of it. It is becoming increasingly important to find pasture plants that can grow and persist with low inputs of superphosphate. There is some evidence that Lotus species are better adapted than clovers to low phosphorus and high exchangeable aluminium levels in acid soils in New Zealand (186). The evidence that strains of subterranean clover differ in their phosphorus requirement is not convincing, although this may be due to difficulty in detection. The one example we know of is Millikan (187), who concluded that the cultivar Clare may require less phosphorus than the naturalized strain Edenhope. Godwin and Wilson (188), who reviewed the prospects of selecting plants with increased phosphorus efficiency, concluded that the best chance of success was to select plants which contained low intracellular concentrations of organic and inorganic phosphate compounds. They pointed out, however, that there is a need for more biochemical and physiological data on the use of phosphorus in deficient conditions before rational selection criteria could be applied in breeding programs. In view of the known adaptability of plants to soil chemical conditions (189), it would seem appropriate that programs involving natural selection should be attempted. In this way it may be possible to isolate strains persistent at low soil phosphate levels before complete knowledge of the biochemical strategies adopted by such plants is known.

Greater Specifity to Local Environments and Farming Systems

It is our belief that plant breeders have attempted to find single genotypes that are broadly adaptable. In the developmental phase of agriculture, such a philosophy was sound and, indeed, has been most successful. For probably 40 years, Mt. Barker subterranean clover succeeded in a wide range of soils in the 500-800 mm rainfall zone. Fortunately Mt. Barker is resistant to some diseases (e.g. clover scorch), but increasingly it faced difficulties in the presence of a wide range of invading grasses and herbs. Similarly, Dwalganup opened up new regions and for a long period was the most successful clover in the drier margins.

Increasingly new cultivars are being selected for specific requirements. Although perhaps not consciously selected as such, the cultivars Yarloop and Clare are more suitable for poorly-drained and more alkaline sites respectively, while the cultivar Nungarin has been consciously selected for the pasture phase of cereal rotations in low-rainfall regions. The specificity objective probably receives second priority to the resistance objective, but we believe that, in the longer run, cultivars to fit specific situations will become increasingly important. For example, strains capable of persisting under grazing by beef cattle may differ significantly from those grazed by sheep. Clover cultivars suitable for augmenting winter productivity of lucerne pastures, for persisting at high or low stocking rates, for surviving frequent wet or normally dry summers, for increased winter or hay production, are all realizable objectives. The important thing with such cultivars will be that they are sold as part of a management or regional package.

Greater Use of Genetic Diversity

Significant diversity is present in Australian populations of subterranean clover. Cocks and Phillips (33) collected 435 divergent strains in South Australia. The frequency of divergent strains was such that it was considered impossible for them to have originated overseas. Studies at four sites indicate that new strains develop in mixed pastures at a rate of about 1.5% of the total population per year, this rate being maintained for at least 40 years (P.S. Cocks, unpubl. data). The clover populations are diversifying, something that they would only do if the original genetic diversity was insufficient to cope with the environment.

Cock's results should not be surprising in view of the great diversity exhibited in natural populations, and in old populations, of white clover (190,86). Genetic diversity evolves to cope with environmental diversity. Indeed, if the population was in balance with its environment, the Hardy-Weinberg equation (the frequency of any gene in a population will remain constant for generation after generation) would apply.

If we desire maximum adaptability of a sub clover population, we will need greater initial diversity. Future farmers may sow a complex mixture of screened genotypes, selected for their particular region and system, and designed to fit a wide range of micro-environments. This mixture may be genetically robust enough to cope with invasion by new diseases and pests. In the year following such an invasion many individuals will be lost, but in the event that genetic resistance occurs in the population, natural selection will rapidly result in population resistance. Secondly, the population will evolve to suit a particular farmer's management. Should he stock heavily, genotypes resistant to grazing will be selected and will predominate. Should he change his management, previously sub-dominant genotypes will be selected. The practice should assist in lowering the population of non-leguminous species, and produce a more stable and productive pasture.

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