An overview of the role of lucerne (*Medicago sativa* L.) in pastoral agriculture

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**Abstract.** Pastoral agriculture is unique among the world’s agricultural production systems. Lucerne (also known as alfalfa), *Medicago sativa* L. subsp. *sativa*, has a long history of playing a very important role in pastoral agriculture. That role is expanding outside traditional hay and grazing production systems into sprouts for salads, nutritional supplements, and bioenergy feedstock. It is also the forage legume of choice for delivery of new traits via biotechnologies. The use of biotechnologies in lucerne improvement will cause re-examination of research methods and will require unique collaborations that are both interdisciplinary and even cross-institutional. The Consortium for Alfalfa Improvement (CAI) is discussed as a model for this type of collaboration. Breeding programs will continue development of cultivars with the proper fall (autumn) dormancy, a broad genetic base for pest resistance, increased local adaptation, persistence, and yield, while also adding new complex traits to these base traits. Increasing nutritional quality via down-regulation of lignin genes and increasing persistence via grazing tolerance, drought tolerance, and tolerance to acid, aluminium-toxic soils are discussed as examples of the potential impacts and challenges surrounding incorporation of complex traits. However, it is the potential for lucerne to become a major part of tropical or subtropical production systems or even an important adjunct to overcome deficiencies in the widely used perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) temperate systems that begs further attention.

**Additional keywords:** acid-aluminum soils, biotechnologies, CAI, drought, new uses, lignin reduction, persistence.

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**Introduction**

There are several general aspects of pastoral agriculture known to all forage agronomists that makes it unique among agricultural production systems:

1. Although some crops are intensively managed as monocultures within pastoral agriculture, not unlike the major grain crops in that respect, most acreage is dominated worldwide by native range and low-input, extensively managed systems which are mainly polycultures.

2. There is a diversity of species with use within pastoral agriculture and literally thousands of cultivars among these species are sold worldwide.

3. The economic system associated with pastoral agriculture is complicated and undervalued, due mainly to the indirect value of the final saleable products and because most production systems are on lower priced land containing poorer soils.

4. The choosing of new species for pastoral agriculture, as well as developing cultivars within those species, requires an assessment of the effect of the plants on the animals, and importantly, an assessment of the effect of the animal on the plant.

5. Forage breeding objectives for a target species are structured around a specific region’s animal production and economic systems, climate, soils, and, especially, accepted forage management practices. This is simply an extrapolation of one of the first things that all plant breeders learn in any entry-level breeding class: ‘what are your reference population of environments and reference populations of species and genotypes?’

6. In addition to plant breeding and genetics principles, understanding proper forage management and underlying crop physiological principles is critical for both cultivar development and on-farm economic success.

7. Perennial species are used where risk can be minimised at the expense of animal performance (e.g. beef cow–calf systems), and annual systems used where short-term animal production and performance requirements are high and more risk can be accepted (e.g. high-producing dairy cows). Lucerne (also known as alfalfa) is unique in that it is a perennial that can be used for both of these production outcomes.

8. Grasses supply the persistence base in pastoral agriculture, whereas the legume component simply needs enough persistence, either on a short-term or long-term basis, or on a farm or pasture basis, so it can fulfil one of its main roles of replacing the use of nitrogen (N) fertiliser or supplementing the overall forage supply with its own dry matter yield, protein, and energy.
Lucerne’s role in pastoral agriculture

There are now some significant challenges to pastoral agriculture due to global economic and energy issues. These include, but are not limited to, significant increases in costs for three things commonly used in forage-livestock production: feed, fuel, and fertiliser (‘the three Fs’). In the past, a livestock producer needing to supplement his forage feed supply could buy feed grains at a reasonable price; if he needed to harvest and store or even plant his own forages, he could depend on cheap energy and fuel; if he wanted to fertilise the grass base, he could depend on cost-effective N fertiliser. Although still available, the cost of the three Fs is becoming less sustainable and driving up input costs to levels that cannot be sustained economically for pastoral farmers.

This begs the question: what is lucerne’s current and future role in pastoral agriculture? First, it is unique among the world’s forage and pasture crops in that its overall acreage, commercial value, yields, and management inputs in many countries mimics that of crops such as maize and wheat. However, its use and history as a perennial are firmly entrenched in pastoral agriculture where traits such as yield, nutritive quality, dependability, and persistence are paramount. Second, since the roles of the legume in any pastoral production system are to reduce N fertiliser costs and supplement nutrition (protein and digestible energy) for the grass base, lucerne is unique in that it is a high-yielding perennial that can be used for both of these production outcomes. Finally, lucerne has recently become the forage crop of choice for delivery of traits via biotechnologies (Bouton 2001). It is the only forage legume where such a trait, Roundup Ready, has been successfully commercially deployed (Anon. 2011). All this makes lucerne’s role very important in assisting farmers to overcome the costs of the 3 Fs, and solidifies its position in the future of pastoral agriculture.

This review is brief for such a broad topic and emphasises mainly lucerne improvement. As such, there is no in-depth treatment of the crop’s physiological research, which has been very substantial. Lucerne’s very specific role in Australian pastoral agriculture (especially in the context of dryland grazing systems) is likewise not discussed in depth. However, that topic was reviewed by the author as part of a recent Farrer review (Bouton 2012). It is therefore suggested that Farrer review be read in conjunction with this brief paper.

History, acreage, uses

Lucerne has been spreading worldwide as an important forage crop since the days of the Roman Empire. In fact, reference to the crop is recorded by Virgil: ‘But let him who longs for milk bring with his own hand lucerne and lotus in planting and salted herbage to the stalls’. From its centre of origin in the Caucasus, north-western Iran, and north-eastern Turkey, it spread first throughout Europe and Asia and then finally into the Americas and Australasia.

The crop was estimated during the late 1980s to be cultivated worldwide on ~32 Mha, mostly within the temperate regions of both the Northern and Southern Hemispheres (Michaud et al. 1988). The USA, Argentina, and the southern portion of the former USSR (central Asia, Transcaucasus, and Ukraine) comprised the majority of the acreage, with next greatest amount found in France, Italy, Canada, and China. World acreage areas have not been estimated recently. However, in 2001, decreases in traditional growing areas were estimated to be offset with increases in China and Australia, leaving 32 Mha as probably still the best estimate for world production at that time (Bouton 2001).

Important developments for lucerne use during the past century were summarised as follows (Bouton 2001):

- Local varieties and landraces were used as base populations for cultivar improvement that capitalised on the very important roles of natural selection and adaptation in the success that modern lucerne cultivars enjoy today.
- Intensive research was conducted on the management and physiology of the crop.
- A major seed industry developed worldwide.
- Since insect and disease pests are numerous in lucerne, development of cultivars with the proper fall (autumn) dormancy and a broad genetic base for pest resistance provided increased adaptation, persistence, and yield.
- Introduction of more complex genetic traits into these multiple-pest resistant, dormancy-specific cultivars is the latest trend.
- Lucerne has become the main forage legume species for delivery of traits via biotechnologies.

A major development that enhanced the role of lucerne was the formation of the North American Alfalfa Improvement Conference (NAAIC; www.naaic.org). This is a venue for meeting and for sharing research, outreach, and commercial information (McCotlin 2001). Its proceedings are published online at the web address and remain the best current information. In some cases, results are available even before publication in scientific journals. A major development made possible by the NAAIC was the use by lucerne breeders worldwide of the standard tests for screening and selection for various diseases, insects, and nematode pests; in addition, agronomic tests for fall dormancy, salt tolerance, winter hardiness, relative feed value, and grazing tolerance were also a major development made possible through the conference (NAAIC 2004). These standard tests, along with seed for the differential checks, are used extensively to develop commercially successful cultivars.

New roles for tomorrow’s lucernes

The main uses for lucerne continue to be hay and silage production and pasture for livestock, but its ability to fix atmospheric N₂ enhances its ability to be a companion legume in mixed pastures, or part of crop rotations to enhance productivity of subsequent grain crops. Inter-seeding lucerne into bermudagrass (Cynodon dactylon L.), the main perennial grass hay crop of the southern USA, is a good example of an expanded role as a companion legume for perennial grass stands to offset N costs and increase the nutritive quality of the hay. Other large-scale hay production systems elsewhere that are grass–N-fertiliser based should also examine this approach. Finally, the sod seeding of Roundup Ready lucerne into tall fescue (Festuca arundinacea Schreb) or perennial ryegrass (Lolium perenne L.) paddocks containing toxic endophyte should result in a method for maintaining a good forage supply while at the same time killing the toxic grass base with Roundup herbicide. This will
allow later reseeding with the same grasses containing nontoxic endophytes with little land disturbance.

Lucerne’s traditional role of hay, silage, and pasture crop has also expanded to include uses such as sprouts for salads, nutritional supplements for human diets, as a bio-remediation system for removal of harmful nitrates, a source of pulp for paper manufacturing, a ‘factory’ for production of industrial enzymes, and a bioenergy feedstock (Bouton 1996).

From recent NAAIC proceedings (www.naaic.org/Meetings/National/index.html), it is apparent that new traits receiving emphasis are herbicide tolerance; drought tolerance; resistance to disease and insect pests heretofore not easily screened; tolerance to acid, aluminum (Al)-toxic, and/or saline soils; tolerance to cold or freezing injury; expression of plant genes controlling nodulation and N₂ fixation; increasing nutritional quality of alfalfa via down-regulation of lignin genes; flowering control; increased biomass yield; and reducing bloat and bypass protein via incorporation of genes to express condensed tannins. These traits will all have high impact in both enhancing and expanding lucerne’s current important roles in pastoral agriculture.

The new biotechnologies are also at the centre of the main tools being employed to enhance these high-impact traits. Their use in crop improvement therefore presents both an opportunity and challenge for lucerne improvement and use that will surely cause re-evaluation of research priorities, methods, and collaborations (McCaslin 2010). It will require collaborations that are both interdisciplinary and cross-institutional, with structural challenges in the treatment of confidential information and intellectual property. The CAI is a partnership model of government, private non-profit, and private profit entities needed to advance long-term, high-risk science that potentially will develop large payoffs for ruminant livestock producers (Bouton 2008; Martin 2010). Briefly, CAI members—USA Dairy Forage Research Center/ARS-USDA, The Samuel Roberts Noble Foundation, Inc., and Forage Genetics International—meet on a regular basis to identify key research projects. They then prioritise research efforts, coordinate scientific resources, and develop potential collaborations, both within CAI and external to CAI (www.agweb.com/assets/import/files/2008PressRelease.pdf). Finally, although CAI has a main goal of developing cultivars with improved yield and nutritional characteristics, its members are free to publish research findings in major scientific journals.

**Lignin down-regulation to improved ruminant and biofuel use**

The CAI is initially committed to redesigning lucerne by reduction of cell wall lignin via down-regulation of genes in the lignin pathway. During proof-of-concept studies, reduced-lignin transgenic lucerne hay fed in total mixed diets with corn silage demonstrated increased fibre digestibility in both lactating dairy cows and rapidly growing lambs (Martin 2010). One transgenic event was found to increase 3.5% fat corrected milk production over the null controls by 2.86 lb (1.30 kg) head⁻¹ day⁻¹. Late-harvested COMT and CCOMT down-regulated lines also demonstrated the same neutral detergent fibre digestibility as their control populations harvested 8–12 days earlier. This means that producers should be able to delay harvest while maintaining nutritive quality, with a potential to reduce the number of annual harvests while increasing annual yield (Martin 2010).

It was also demonstrated that lucerne lines containing the lignin down-regulated trait showed a two-fold improvement in enzymatic hydrolysis efficiency in production of ethanol for biofuels (Chen and Dixon 2007). This efficiency could therefore eliminate the requirement for costly chemical pre-treatment for sugar production. More ethanol should then be able to be produced per tonne of this low-lignin lucerne, thereby making it a very efficient biofuel feedstock. This efficiency, in turn, would allow biorefineries to pay substantially more for the delivered lucerne feedstock due to the high alcohol yield per tonne, along with the concurrent need to store lesser amounts of the feedstock at the biorefinery.

**Increased persistence**

In general, after the breeding targets of adaptation, fall dormancy, and pest resistance are met, three of the main persistence-limiting traits on a global basis are grazing tolerance to allow an expanded use of the crop into intensively grazed pasture conditions; tolerance to acid, Al-toxic soils; and drought tolerance to mitigate the heat- and water-related problems projected due to climate change (Bouton 2012). It is also interesting that the breeding approaches used to improve these traits included traditional selection approaches being successfully used to develop and deploy grazing-tolerant cultivars, and protocols that moved from traditional to more biotechnology-based protocols being used for tolerance to acid, Al-toxic soils and for drought tolerance.

**Grazing tolerance**

The development and use of the grazing-tolerant cultivar ‘Alfagraze’ demonstrated that a high level of grazing tolerance could be achieved with good yield (‘dual-purpose’), proper fall dormancy, and pest resistance (Bouton et al. 1991). This one event expanded lucerne’s ability to be used in more intensively grazed situations. Its selection protocol serves as a vehicle that increased the development of new cultivars (Moutray 2000) as well as the interest in and use of lucerne for all grazing situations (Henning 2000; Smith et al. 2000). Other researchers reported that prostrate types demonstrated the best tolerance under grazing in Australia (Humphries et al. 2001) and Italy (Pecetti et al. 2008), but again, some tolerance could be found among upright, even winter-active, types. Another similarity among all these studies was the positive role that ‘adaptation’ to the target environment played in achieving greater results that should be useful for targeting grazing-tolerant cultivars for all regions.

The grazing tolerance trait has also been extrapolated to give better ‘traffic tolerance’ with better stands found after stresses imposed by the wheels of heavy harvesting equipment in intensively managed commercial hay fields (Lawton 2002). The production and current commercialisation of two new, Alfagraze-type cultivars, Alfagraze 300RR and Alfagraze 600RR, each containing the Roundup Ready trait, an expanded pest resistance package, and in the fall dormancy categories 3 and 6, respectively, is also noteworthy. They solidify the place of
growing tolerant cultivars among modern lucerne cultivars (Bouton et al. 2006).

Acid, aluminium-toxic soils
Of the problems facing lucerne growers, acid, Al-toxic soils are the most widespread and limiting of all because lucerne is highly sensitive to these conditions and acid, Al-toxic soils are found in large areas on every continent. It is also one of the main reasons lucerne is not grown in the tropics and subtropics. Since genetic selection for acid soil and Al tolerance offered an avenue for increasing lucerne’s productivity and reducing its production costs, plant breeding programs were, and are currently, being pursued. Their objective was to develop lucerne cultivars and management systems tolerant to these conditions (Bouton and Radcliffe 1989; Hartel and Bouton 1991; Zhang et al. 2007).

However, due to genetic complexity, as well as no tolerant cultivars being produced for on-farm use via conventional selection, breeding efforts evolved into the use of biotechnologies. Tolerance genes were found in the secondary diploid gene pool, and molecular markers are now being used to transfer them into cultivated types (Sledge et al. 2002; Narasimhamoorthy et al. 2007; Khu et al. 2010).

Drought
Drought tolerance is an inherent, positive trait in lucerne, and one that has historically been associated with the crop. This view was supported recently during the 2006–07 droughts in South Australia where established lucerne stands showed some stand decline but were still able to maintain acceptable ground cover (Marshall et al. 2008). An even more dramatic response was seen after the record summer heat wave in 2011 and corresponding drought in the southern Great Plains area of the USA where lucerne paddocks showed complete autumn recovery while the adjacent tall fescue paddocks did not (Bouton 2012). Therefore, although lucerne is a drought-tolerant species, some of its acreage is produced under irrigation to achieve economic yields or under dryland conditions where lack of water commonly limits productivity.

Several research organisations are currently investigating ways to increase lucerne use in dryland conditions as well as improving drought tolerance and water-use efficiency. Gene candidates for drought tolerance are now being expressed in lucerne. One of these is the WXPI transgene discovered by scientists at the Samuel Roberts Noble Foundation, where ‘proof-of-concept’ experiments demonstrated that insertion of WXPI increased lucerne’s ability to be productive, or even recover more quickly, after periods of limited water (Zhang et al. 2005).

In a related genomics project, Noble Foundation scientists are collaborating with others at New Mexico State University to identify genetic mechanisms associated with drought tolerance within cultivated lucerne. Molecular markers associated with yield under drought conditions were initially identified that can be used in selecting genotypes for the production of new drought-tolerant cultivars (Han et al. 2008). This approach also brings the power of genomics technologies to bear in the process without the regulatory and public perception problems associated with transgenics.

Conclusions
It is apparent that lucerne plays a very important role in current pastoral agriculture. This is now expanding to include new roles outside traditional hay and grazing production systems, as well as lucerne being the main forage legume to commercially deliver traits via biotechnology. However, the crop could assume an ever larger role if producers and experts are able to stand back and examine some of the limitations of their current traditional systems and lucerne’s potential to help.

For example, one important question remains (Leach and Clements 1984): can lucerne become a viable crop in the tropics and subtropics? To be successful at producing a tropical lucerne, it was speculated that the following factors need to be capitalised upon: (1) the availability of very non-dormant, winter-active cultivars which allow forage production on a year-round basis; (2) the wide availability of pest-resistant germplasm and screening and selection methods for the many disease, insect, and nematode pests; (3) the increasing interest and need in dairy production and high-quality grazing in the subtropics and tropics; and (4) the advances in research which may allow the crop to be grown in problem acid, Al-toxic soils (Bouton 2001). An ability to provide a non-dormant, acid soil tolerant, high pest resistance cultivar would be a big step towards establishment of widespread ‘tropical lucerne’ systems.

The perennial ryegrass–white clover (Trifolium repens L.) system is a good base production system indeed. In fact, livestock producers in all of the world’s geographies would love to have this as their main production base. But, have countries that currently employ perennial ryegrass and white clover as their main base system, especially their dairy industry where daily production is paramount, become too reliant on it to supply most of their current and future needs? Are breeders of these current major species up against the biological and genetic limits of these species to dramatically improve them for persistence problems, especially in a future of increased temperature and drought as predicted due to climate change? Can a drought-tolerant species like lucerne be considered to add to this base and increase high-quality forage during the base system’s off-season or during times of environmental stress? On a personal note, I remember standing in a lucerne field in the Canterbury Plains right outside Christchurch, New Zealand, during a dry period. All the ryegrass–clover pastures as far as the eye could see were dry and brown, yet the lucerne was up to my knees in green growth with lambs happily grazing. I asked my companion, a very well-respected New Zealand pastoral scientist: ‘Why, in this context, is there not more lucerne used in New Zealand?’ His answer was: ‘In this context, I cannot explain it!’

In the USA and Argentina, lucerne is an integral part of their dairy production systems. Why? Because it is a nitrogen-fixing, drought-tolerant legume capable of very high yields of quality forage over a very long growing season. Lucerne is, simply, in these two countries a major crop, right up there in acreage with maize and soybeans (Glycine max L.), with a long history of intensive and productive research, including breeding in both the public and private sectors, with a major transgene (Roundup Ready) even successfully deployed commercially, and an estimated direct annual impact value to USA agriculture alone of US$8.1 billion (www.naaic.org/Alfalfa/Importance.html). So,
the question of why lucerne is not expanding its role in all countries will remain a pertinent one for the foreseeable future.

References

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