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The 22nd International Grassland Congress (Revitalising Grasslands to Sustain Our Communities) took place in Sydney, Australia from September 15 through September 19, 2013.

Proceedings Editors: David L. Michalk, Geoffrey D. Millar, Warwick B. Badgery, and Kim M. Broadfoot

Publisher: New South Wales Department of Primary Industry, Kite St., Orange New South Wales, Australia

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# The use of functional traits to identify grasses and fodder shrubs for domestication to suit a changing climate

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**Abstract.** There is uncertainty about future climatic predictions; however there is little doubt amongst experts that the future will be warmer. Climate change and the associated elevation in atmospheric CO<sub>2</sub> level and temperatures will provide novel challenges and potential opportunities for cultivated plant species. Plant breeding and domestication can contribute to improvements in both yield and quality of grasses and fodder shrubs. A range of key functional traits is required to cope with this changing climate. The main challenges that are discussed are new pests and pathogens; changes in the pattern of nutrient supply and forage quality; challenge associated with a shorter growing season; drought tolerance and persistence. With the domestication of any species, consideration needs to be given in terms of duty of care (weediness, anti-nutritional/toxic to animals, regulations) and the on farm adoption of new selections. Two case studies have been included in the paper, one on native grasses and the other on native shrub, old man saltbush.

**Keywords:** Functional traits, climate change, plant selection, Australian native grasses, old man saltbush, duty of care, on farm adoption.

## Introduction

Climate change and the associated elevation in atmospheric CO<sub>2</sub> level and temperatures will provide novel challenges and potential opportunities for cultivated plant species (Chapman *et al.* 2012). For 100-150 years plant breeding and domestication have contributed to improvements in both yield and quality of grasses and forages. Selection and breeding have broadened the climatic adaptation of many species far beyond their original geographic origin and their ability to evolve. In addition to adaptation to particular climatic and soil environments, plant species are bred for resistance to pests and disease, specific nutritive traits, agronomic traits such as seed retention and ease of harvesting and ecological traits such as seed dormancy traits that allow annual plants to self-regenerate after a cropping phase.

The natural rangelands, prairies of North America, pampas of South America, and areas of Australia, support animal production in extensive farming systems. In Australia, the collection and domestication of indigenous species of perennial grasses and shrubs has not received the same attention as breeding introduced species. In the case of annual legumes, lack of native options has led to a reliance on introduced germplasm. However researchers and producers realised that certain native species are adapted to local soil and climatic conditions, are perhaps more resilient to climatic extremes, poor soils (P deficient, acidic sandy and saline) and can provide good seasonal productivity (Jefferson *et al.* 2002) or nutrients for livestock at a time when they are limiting (Masters *et al.* 2007).

Australia is the world's driest inhabited continent, with half of its total land area receiving less than 300 mm annual average rainfall. Australia has a landmass of 7x10<sup>6</sup> km<sup>2</sup> and covers 33° of latitude, from 10° to 43° South. Australia's recent geological history is such that no mass extinctions of flora species have occurred such as those in the Northern Hemisphere during the Pleistocene glaciations (Mithen 2003). This lack of mass extinctions and subsequent rapid revegetation has had important implications for the breeding systems of the present indigenous herbaceous flora and the responses of individual species to ecological changes (Groves and Whalley 2002; Whalley *et al.* 2013). In this paper we use Australia as our model, as the latitudinal range of the continent is from the tropics to temperate zones.

The introduction of European farming systems to Australia has created major changes to the environment impacting on the growth of herbaceous plant species. These impacts have included increased grazing pressure from ruminants, increased soil fertility and decreased soil pH. Some species have coped extraordinarily well with these changes and are common in native or natural pastures. These species have demonstrated that they are likely to cope with future changes because they can readily adapt to new conditions. Prior to European settlement there was no history of cultivation and grazing was by macropods (such as kangaroos and wallabies) rather than ruminants. Australian soils are relatively old and weathered, and in many cases low in phosphorus fertility. On the other hand, many native species have not coped with these changes and are now very uncommon and are often listed as rare and

endangered (Whalley *et al.* 2013).

Grasses and forage species contribute substantial value via pasture production for dairy, beef, wool, lamb and other products. In Australia, commodities that result from pasture production have been valued at \$9.3 billion per annum (ABARES 2011). These species also contribute a 'difficult-to-measure' value in providing ecosystem services, including increased water use thus correcting hydrological imbalances associated with annual cropping systems (Farrington *et al.* 1992; Barrett-Lennard 2002), improving soil stability (Le Houérou 1992), habitat for native animals (Lancaster *et al.* 2012) and amenity species in facilities such as sports grounds and golf courses as well as in residential gardens (Chapman *et al.* 2012).

This paper examines the use of domestication of native Australian grasses and shrubs to meet the challenges and opportunities under a changing climate. We are confining ourselves to the role of domestication, *i.e.* plant selection, rather than breeding. Domestication relies on selection from natural genetic variation that exists within a population.

### The changing Australian climate

While uncertainty about future climate predictions is high, there is little doubt amongst experts that the future will be warmer. Therefore the effects of these higher temperatures on the forage base are the most certain impact. Effects of rainfall are more speculative (Henry *et al.* 2012) and more localised. In the Mediterranean and cool-temperate climate regions of southern Australia, Cullen *et al.* (2009), predicted increased pasture growth rates in winter and early spring, counteracted by a predicted shorter spring growing season. Changes in rainfall patterns and incidence of large summer rainfall events will have large impacts on forage production and quality of senesced annual pastures. In many Australian Mediterranean systems, summer rainfall is a major threat, as these systems now rely on annual species for productivity. Rainfall during the summer period significantly reduces the quality of senesced annual pastures and crop stubbles. Perennials offer an opportunity to produce forage from highly variable summer rains. These systems therefore need drought tolerance and an ability to grow quickly after a large single rainfall event. Whatever happens to rainfall and its pattern, farmers will have increased risk and must try to manage it.

### The role of plant domestication

Agriculturalists have selected seed of preferred forms and culled out seed of undesirable types to produce each subsequent generation. Domestication is an evolutionary process operating under the influence of human activities (Harlan 1975). Since it is evolutionary, the progression from the wild state to a domesticated form that is different from its progenitors is slow and gradual (Harlan 1975). Domesticated plant species often differ from their wild relatives in predictable ways and these differences include:

- Higher seed germination rates and particular dormancy strategies;
- Uniform seed size (food crops);
- More predictable and synchronous germination;

- A tendency for ripe seeds to stay on the plant, rather than breaking off and falling to the ground;
- Reduced physical and chemical defences; and
- Change in biomass allocation (more in fruits, roots, or stems, depending on human needs).
- Improved nutritive traits of seeds or biomass for livestock or human consumption.

The challenge is to select plants that meet the challenges of climate change. Domesticated lines have the advantage over bred lines, in that they may have greater genetic diversity.

### Functional traits and how these suit a changing climate

#### *Adaptation to new pests and pathogens*

Climate change will influence pests and pathogens in three main ways, all with significant implications for grass and forage domestication:

- change their geographical range and distribution;
- change their population genetics and biology, including virulence spectrum and rates of evolution;
- change the effectiveness of disease resistance genes and gene networks in plants (Chapman *et al.* 2012).

If the plants are stressed due to environmental conditions, they may be more susceptible to pests and diseases.

#### *Pattern of nutrient supply and forage quality*

In Australia there are likely to be north-south differences in terms of pasture production response to climate change (Howden *et al.* 2008). In the grazing lands of northern Australia, the growing season may lengthen due to higher winter minimum temperatures and rainfall. In contrast, climate change scenarios for southern Australia indicated reductions in rainfall, higher temperatures and higher evaporation rates, which are likely to lead to lower and more variable pasture production. These changes are likely to increase the southern migration of tropical (C<sub>4</sub>) pasture species.

Hoepfner and Dukes (2012) investigated responses of an herbaceous community to two years of a combination of warming (up to 4°C) and precipitation regimes (drought, ambient and additional rainfall). They found that warming suppressed total production and species richness only in the drought treatment; plant biomass was not influenced by the higher temperature unless water was deficient. The biggest impact of climate change may be due to the combinations of species that are planted and their interaction with drought. A transition from predominantly annual to mixed annual/perennial and from C<sub>3</sub> to mixed C<sub>3</sub>/C<sub>4</sub> based systems in southern Australia will change the pattern of nutrient supply for livestock. Current annual dominated, C<sub>3</sub>-based systems are characterised by an excess of high-value feed in spring and deficit in summer, autumn and early winter. Perennials have been promoted as an opportunity for green forage to alleviate nutrient shortages during these feed gaps (Masters *et al.* 2007; Burnett *et al.* 2012). At the farm scale, changes in the pattern of forage

and nutrient supply will have different impacts on profitability, depending on the mix of livestock enterprises. Byrne *et al.* (2010) showed that changing farming systems from wool production to meat production enabled greater economic benefits from adoption of lucerne. Variable summer rainfall events will increase year-to-year variability in forage production and will require more flexible livestock management systems to exploit it (Moore *et al.* 2009).

Feeding value is defined as ‘the animal production response to grazing forage under unrestricted (i.e. unlimited biomass) conditions’ (Ulyatt 1973) and impacts on production of meat, milk and wool. Feeding value is dependent on voluntary feed intake (VFI, what the animal chooses to eat and the quantity eaten) and the nutritive value of ingested biomass. Increased CO<sub>2</sub> concentrations and warming of ambient temperatures may influence the nutritive value of biomass. Lilley *et al.* (2001) investigated the nutritive value and symbiotic nitrogen fixation of pure and mixed swards of subterranean clover and phalaris in field tunnels. They found that elevated CO<sub>2</sub> increased the non-structural carbohydrate content of herbage whereas warming (+3.4°C) decreased it. Increasing structural fibre generally reduces the digestibility and VFI of forage. The crude protein concentration of both species was decreased by elevated CO<sub>2</sub> and unaffected by warming.

*Annual life cycle of grasses and fodder shrubs – shorter growing season, seed yield and seed production (ease of harvest)*

Plant phenology, especially flowering time and extent, has a significant impact on grassland production, forage quality and persistence (Humphreys *et al.* 2006). Many temperate (C<sub>3</sub>) native perennial grasses will grow throughout the year in some climates (Lodge and Whalley 1989) provided soil water is available and have indeterminate flowering in that they will flower at any time in response to suitable rainfall events. Others have determinate flowering in that they will only flower once per year, usually in the spring-early summer (Lodge and Whalley 1989). Tropical (C<sub>4</sub>) grasses have both determinate and indeterminate flowering and both groups flower in summer following rainfall events sufficient to stimulate growth. The main cues for initiating flowering are vernalisation (low) temperatures (C<sub>3</sub>) and, or day length (C<sub>3</sub> and C<sub>4</sub>). In future climates temperatures are likely to rise. This may reduce floral initiation of some C<sub>3</sub> species in some regions, but not C<sub>4</sub>'s giving the latter a competitive advantage. Stem elongation and flowering will occur earlier as is already being recorded for other species. This earlier initiation of the reproductive phase has potential impacts on both forage quantity, quality and seed production.

#### *Drought tolerance*

Drought and more extreme high temperature events are two of the most significant features of future climate projections for Australia; they can be devastating for most cultivated plant species, especially if they do not have appropriate adaptations (Chapman *et al.* 2012). There is some potential in developing adaptation strategies, such as the use of deeper rooted plants and plants with drought tolerance

mechanisms in Mediterranean and temperate environments to mitigate the effects of climate change (Cullen *et al.* 2009). Some native grasses have different strategies for coping with drought such as an early senescence of leaves as soils dry (Whalley and Davidson 1969; Harradine and Whalley 1978). Native shrubs such as old man saltbush (*Atriplex nummularia* Lindl.) are native to the semi-arid interior of Australia and while their production potential is less than many grasses they could be used in regions that become drier. Drought tolerance mechanisms of old man saltbush include deep roots (>4 m), osmotic control and slow growth when water is scarce (Barrett-Lennard 2003; Norman *et al.* 2010b).

Plants generally display three overlapping strategies to cope with drought (Ludlow 1980; Kemp and Culvenor 1994):

escape/avoidance: annuals set seed to avoid dry seasons; storage organs, rhizomes, dormant buds; resurrection leaves;

adjust/resistance: reduce leaf area – shed leaves, small leaves, leaf rolling; efficient water use- stomatal control, enhanced water use efficiency; maintain turgor-osmotic adjustment; extract more water through rooting capacity;

recover: minimal growth during drought then regrow rapidly when stress removed – bud density, dormant buds; maintain maximum number of plants, tillers and/or leaves during dry season.

These strategies can be utilised in any season to cope with stress.

*Dry matter production – tiller density, leafiness, crown diameter, regrowth after harvest*

Rising atmospheric CO<sub>2</sub> levels, increasing temperature, and changing rainfall regimes will alter pasture production (Crimp *et al.* 2010). Rainfall distribution and evaporation will have an impact on pasture production and perennial plant persistence. Cullen *et al.* (2009) predicted a 22-37% increase in dry matter production of temperate grass dominated pastures in southern Australia, simulated by raising the atmospheric CO<sub>2</sub> from 380 to 550 ppm.

#### **Duty of care – weediness, anti-nutritional/toxic to animals, regulations**

Australia has a long history of introducing forage plants from around the world to meet its agricultural needs (Cook and Dias 2006). Annual pasture legumes and grasses from the Mediterranean region have dominated the medium to lower rainfall (<600 mm) zones (Dear and Ewing 2008). In the permanent pasture zones of eastern Australian (>600 mm) the majority of the pastures sown are based on the introduced perennials, perennial ryegrass (*Lolium perenne* L.) phalaris (*Phalaris aquatica* L.) cocksfoot (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* Schreb.) (Oram and Lodge 2003; Dear and Ewing 2008).

Although there is no doubt that many valuable pasture plants have been introduced to Australia, many other introduced species have become serious weeds with significant ecological and economic impacts (Cook and Dias 2006; Stone *et al.* 2008). Many of these species were included in the pasture plant introduction programs in the

past (Cook and Dias 2006). Native species are not exempt from becoming weeds. A native species translocated from one part of Australia to another can potentially become a weed. An example of this is *Acacia* spp. (Bennett and Virtue 2005). Managing weed risk in native plants is a contentious issue, with the use of native plants seen as environmentally responsible and even patriotic (Bennett and Virtue 2005). As well as becoming weeds, native plants from different areas may genetically 'pollute' local populations and lead to decreased native diversity.

Environmental-weed risk assessment received only a passing mention in a recent review of trends in temperate Australian grass breeding and assessment (Oram and Lodge 2003). Many of the characteristics that are seen as ideal for production and persistence e.g. seed production and natural regeneration, are often the characteristics that make such species weedy (Bennett and Virtue 2005). Before more species are introduced into Australia, care must be taken that they do not become weeds.

Novel forage species present a risk to livestock. They can create physical risk through spines, calyces or burrs that can damage eyes and skin and contaminate wool. At a chemical level, novel species may be of poor nutritive value, contain chemical compounds that have a negative impact on the performance of grazing animals or taint products such as meat and milk (Norman *et al.* 2005; 2013). Addressing this risk for animal production is difficult due to the large number of potential compounds and their possible interactions (Revell and Revell 2007). Negative impacts may be minor, for example sub-optimal growth rates due to tannins restrict intake but can aid protein metabolism. Clovers (*Trifolium* L. spp.) produce phytoestrogens that reduce animal reproduction rates and other plants produce nitrates, alkaloids and cyanogens that are toxic. Duty of care issues should be considered before all new plant releases. The relative nutritive value of a new species needs to be evaluated against currently used species to assess this complexity of issues (Norman *et al.* 2005; Masters *et al.* 2006; Norman *et al.* 2013).

### On farm adoption

It has been recognised that it is now difficult to get land managers to sow pastures (Barr 1996; Trapnell *et al.* 2006) even with species and technologies that are known, due to increasing costs and management difficulties. So why would a farmer adopt practices that are relatively untried and could be expensive? The impetus for adoption of new practices may be climate change. But that will only be implemented if there is sufficient information available with the release of new cultivars/species to make the change profitable. There is the need for the development of extension packages for farmers and agribusiness to maximise potential benefits from using new cultivars and the need to incorporate whole farm management. The management strategies need to maximise productivity and persistence.

Essentially, if it can not be demonstrated how these newer species/cultivars can increase profit or reduce risk and be established at a suitable cost, there will be very low uptake of these new technologies. For example, seed yield is low and cost of production is high for native grasses, due

to the non-uniform times of seed production and the rapid seed shedding (Oram and Lodge 2003; Cole and Johnston 2006). Therefore, in many instances the only high-return industries, such as parks, landscaping and mining can afford to pay the full market price to sow native grasses. There may well be a trade-off between nutritive value, biomass production in an ideal season and biomass production during a poor season. We suspect that we will need some perennial plants that persist and provide moderate feed of low to moderate quality with some annuals that are highly productive but risky.

### Case study 1: Australian native grasses

The domestication of native grasses for forage and other purposes was stimulated when the first Australian Plant Variety Rights Bill was introduced in 1975; though the Plant Variety Rights Act was not passed until 1987. The result was several industry-funded projects aimed at selecting and registering species of perennial native grasses under this legislation, including species of wallaby grass (*Danthonia* DC., syn *Austrodanthonia*, now *Rytidosperma* Steud.) for forage use or amenity plantings and weeping grass (*Microlaena stipoides*) for turfgrass, amenity plantings or forage purposes. These projects led to the registration of a number of varieties of native grasses under the 1987 Act and subsequent Plant Breeders Rights legislation (Anonymous 1992b, 1992a, 1995b, 1995a, 1997). There do not appear to have been any varieties of native Australian grasses registered under the Plant Breeders Rights legislation since 1997. The seed production of these and other varieties selected by different agencies proceeded but the seed produced was very expensive and the establishment of field stands proved difficult (Lodge 1996).

The native grass seed industry has developed slowly since the 1990s and is primarily directed at the production of seed for revegetation projects following highway construction and mining. The use of commercially available seed for revegetation purposes has been restricted because of the insistence in some areas of using seed of local provenances (Whalley *et al.* 2013). Native turf grasses have also been of interest. However, the grazing industries have not been interested in using the seed of native grasses in sowing mixtures because of the very high cost of the seed and the uncertainty of obtaining successful establishment.

A broad scale evaluation trial was conducted for three years during the 1990s comparing the survival, recruitment and herbage mass production of 31 accessions of a range of species of native grasses at eight sites spread across temperate Australia (Garden *et al.* 2005; Norton *et al.* 2005; Sanford *et al.* 2005; Waters *et al.* 2005; Whalley *et al.* 2005). In general terms, the performance of individual accessions at particular sites could be predicted by comparing the environments of the sites in which they were collected with those of the sites in which they were tested. However, there were numerous exceptions when the performance (survival and growth) of individual accessions either exceeded or were very much worse than expectations of their performance at particular sites. Where multiple accessions of one species were compared, selected varieties

of *Rytidosperma caespitosum* (*Austrodanthonia caespitosa*) and *R. bipartitum* (*A. bipartita*) had greater biomass production than their locally sourced progenitors (Garden *et al.* 2005; Waters *et al.* 2005); while, the survival and recruitment of a Tasmanian accession of *M. stipoides* was not as good as accessions collected on the northern and southern tablelands of NSW (Garden *et al.* 2005; Waters *et al.* 2005).

Knowledge of the breeding system and ploidy level of a species that is the target of domestication is critical (Smith and Whalley 2002) yet little is currently known for most grasses (Whalley *et al.* 2013). Breeding systems of native grasses are many and varied and range from obligate outcrossing species to obligate apomicts (Groves and Whalley 2002; Whalley *et al.* 2013).

### Case study 2 – Old man saltbush

Old man saltbush is native to the low rainfall zones of southern Australia and is naturally well adapted to drought and soils that are infertile and/or saline. It is deep rooted, has a C<sub>4</sub> photosynthetic pathway and uses out-of-season rainfall, providing forage for sheep during summer and autumn (Barrett-Lennard 2003; Norman *et al.* 2010b). Historically, old man saltbush was a key component of extensive wool enterprises in the low to medium rainfall zones of southern Australia but cultivation and overgrazing has led to its decline. Overgrazing of native stands may have led to inadvertent selection for low digestibility and plant secondary compounds that discourage herbivory. Old man saltbush is perhaps Australia's most significant forage plant contribution to the world; it is used as a drought reserve or to fill annual feed shortages within grazing systems in southern Europe, the eastern Mediterranean, Asia and South America (Le Houérou 1992; Ben Salem *et al.* 2010).

There has been little systematic effort to domesticate old man saltbush and the majority of commercial plantations are derived from 'wild' seed lines. Unlike many forage plants used in southern Australia, old man saltbush is already well adapted to low rainfall and drought, so it is an ideal plant to buffer the impact of a variable climate. An added advantage is that it grows on marginal soil types and therefore does not compete with cropping enterprises. Its greatest value within systems is as a protein, sulphur, mineral and antioxidant supplement for ewes and weaners grazing cereal stubbles or senesced pastures. On the negative side, it has a persistent rather than competitive ecological strategy so productivity can be low, establishment from seed can be difficult and feeding value for livestock is variable. Whole-farm economic modelling suggests that low digestibility of the edible biomass (48 to 52% organic matter digestibility, OMD) is the critical trait influencing profitability and is now a target for plant improvement (O'Connell *et al.* 2006; Norman *et al.* 2010a). Plant improvement is difficult as old man saltbush is octoploid and dioecious.

In 2006 seed from 27 populations of old man saltbush was collected from across its native range. Sixty thousand seedlings were grown in 3 nursery sites in NSW, SA and WA (Hobbs and Bennell 2008). All plants were assessed for a range of agronomic traits and nutritive value was

investigated at the provenance level. This involved a two year program of *in vivo* animal house sheep feeding experiments, development of *in vitro* analysis tools and calibration for Near Infrared Spectroscopy (Norman and Masters 2010; Norman *et al.* 2010a). Each of the nursery sites was grazed with Merino sheep to assess relative palatability. This is perhaps one of the first times that animals have been used in the initial stages of plant selection programs to identify plants with higher nutritive value. The sheep at each site demonstrated clear preferences for plants originating from specific populations and subsequent nutritive analyses indicated that these plants had higher OMD and crude protein (Norman *et al.* 2011). From sixty thousand plants, 90 'elite' plants were vegetatively propagated and planted in a second generation of field trials and assessed for 3 years. In 2011, the 12 best genotypes were vegetatively propagated for extensive GxE testing at a further 13 sites across Australia. These plants had OMD values of 58 to 65%, a significant improvement in terms of sheep production (Norman and Jessop, unpublished). In 2013 the project team plan to commercialise several genotypes and these will be sold to producers as nursery raised vegetative cuttings and to undertake work to select elite seed lines.

### Conclusions

The domestication of any species is an incremental and cyclic process of selecting. Fortunately many of the traits that are required to cope with the environment under future climate scenarios are already considered as part of current domestication programs or in the case of old man saltbush already present in populations. There is uncertainty around exactly what future climates will be like. There needs to be a useful level of certainty around these predictions before we change the direction of domestication programs. However breeding/domestication programs typically have lead times of at least ten to fifteen years before material is released. As many forage species are perennial, they need to be assessed over a number of years to adequately assess traits such as persistence. Breeding for adaptation to new climatic environments is challenging.

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