Profitable pastoral farming through genetic modification: fact or friction?

D.R. Woodfield

AgResearch Grasslands, Private Bag 11008, Palmerston North 4442, New Zealand
<Derek.Woodfield@agresearch.co.nz>

Abstract. *Pastoral agriculture in Australasia faces severe challenges to retain its international competitiveness as a low cost producer of milk, meat and fibre. Our agriculture is based predominantly on introduced forage species that have been domesticated and then sequentially improved by plant breeders. Genetic modification of forage grasses, legumes, herbs and their associated organisms (eg. endophyte and rhizobia) has delivered improvements in annual productivity, seasonality of that production, digestibility, energy content, pest and disease resistance, persistence, water-use efficiency, and in removal of animal health and welfare disorders. The various species and types produced by plant breeders have enabled farmers to optimise and intensify their farming systems so that feed supply better matches feed demand. Intensification will remain a driver of future forage requirements but will face severe environmental and social challenges. Forages that utilise scarce resources such as water and nutrients more efficiently, and that reduce greenhouse gas emissions will be required. In order to deliver these innovations, molecular and conventional breeding approaches must be effectively integrated. Currently, molecular breeding is well resourced but there is a huge gulf in the funding, and even availability, of conventional breeding capability to develop and deliver these forage innovations to the pastoral industries.*

Introduction

Farmers and research funders frequently ask what contribution plant improvement has made to Australasian farming systems and what can it contribute in the future to allow us to remain internationally competitive? The challenge for breeders working on improving their particular crop is to understand the future requirements of their target farming system. Slow adoption of some new varieties has been seen as a failure and funders in Australia have formed 'Pastures Australia' and the Cooperative Research Centres to better focus the forage breeding efforts funded by the industry bodies.

Pastoral agriculture in New Zealand, and to a large extent in Australia, is dependent on exotic species introduced over the past 200 years. Plant breeding has made a significant contribution to the economic growth of our agricultural industries over the past 50 years through domestication, and selection for improved adaptation, of these forage species. Pasture-based industries account for 44 per cent of New Zealand's exports and their contribution to Gross Domestic Product has increased from 13.5 per cent in 1990 to 17 per cent in 2005. This has been achieved despite the removal of agricultural subsidies, increased exposure to global market forces, and substantial shifts in public funding away from plant breeding. Lancashire (2006) estimated that 75 per cent of New Zealand's $14B pastoral export earnings were generated from improved forage species and that overseas germplasm incorporated into New Zealand breeding programs alone contributes nearly $1B annually. The introduction of a new ryegrass technology (ie. AR1 endophyte) alone is estimated to have been worth $74M per year in increased meat and milk production (Bluett *et al.* 2003).

The removal of agricultural subsidies has driven Australia and New Zealand down an intensification pathway to remain economically viable. Intensification and changes away from export of frozen carcasses to products that are processed and exported chilled improved the international competitiveness of the New Zealand sheep industry in the last 20 years. In 2004, 24 per cent more lamb meat was produced in New Zealand than was produced in 1990 despite total sheep numbers decreasing from 60M to 40M in that period. Intensification in the Australasian dairy industry has been even more spectacular (Table 1). The average number of cows per herd has more than doubled in both countries since 1990. While total cow numbers have remained relatively static in Australia, per cow production has increased by 37 per cent. There have also been large increases in per cow production (27 per cent) in New Zealand but by far the biggest change has been the 70 per cent increase in the number of cows since 1990. High exchange rates and high commodity milk prices have further accelerated conversion from sheep to dairying in New Zealand with a drop to 35M sheep predicted by the end of 2008.

Intensification has placed severe pressure on our traditional perennial forages such as ryegrass/clover pastures that have formed the basis of most production systems. Short-term pastures with increased yield

Table 1: Intensification of the dairy industry in Australasia since 1990 (LIC 2007; Dairy Australia 2007)

	New Zealand		Australia	
Year	1990	2007	1990	2007
Number of farms	14,595	11,630	15,396	8,055
Cows (million)	2.31	3.92	1.65	1.81
Average herd size	158	337	107	225
Cows/ha	2.40	2.81	–	–
Production per cow	259 kg MS[A]	330 kg MS	3,781 litres	5,163 litres

[A]Milksolids (fat plus protein) per cow was first measured in 1992/93 season

potential have played a greater role in lamb-finishing and dairy operations, while alternative forage species and supplementary feed-crops are being integrated to fill feed-gaps. The use of nitrogen fertiliser, irrigation (where available) and bought-in feed, has increased dramatically in our farming systems. This has resulted in erosion of the traditional low production cost advantages that we have had over international competitors. Pressure from water restrictions and the rapidly rising input costs associated with fertiliser and supplementary feed will force re-evaluation of these practices in future farming systems.

Plant breeding must play a role in assisting with overcoming the ongoing environmental issues (eg. greenhouse gas emissions, water availability and quality, salinity), economic issues (eg. profitability of pastoral systems and reducing fertiliser and supplementary feed input costs) and social issues (eg. food miles and acceptability of genetically modified foods) that face pastoral agriculture.

Genetic gains in forages

Genetic improvements of about 1 per cent per year for herbage yield, nitrogen fixation, and animal performance have been reported in forage legumes and each one per cent improvement in clover yield has been estimated to be worth more than $20M (Woodfield 1999). Similarly, improvements in herbage yield, rust resistance and heading date of the main forage grasses have also been reported (Easton *et al.* 2002). These improvements are due to selection for improved yield potential and to reducing the effects of yield-limiting factors such as pest and diseases. Improvements in the herbage yield of perennial ryegrass have tended to be slower (0.6 per cent per year for annual yield) than in legumes due to the confounding effects of endophyte. The value of genetic improvements in grass performance to farmers does tend to be greater simply because grass generally contributes around 80 per cent of the diet. The greatest single innovation in forages has been the identification of novel endophytes that have overcome ryegrass staggers and fescue toxicosis (see below). Another important innovation over the past 20 years has been the diversification of ryegrass varieties from persistent perennials through to annual Italian types that offer farmers flexible management options due to differences in heading date and seasonal production characteristics. Tetraploid varieties have become more important and appear to be providing better persistence under Australian conditions (R. Hill, unpublished data).

New varieties of other grasses (tall fescue, cocksfoot, timothy, phalaris, brome) have also been developed. These have found their place in more difficult environments where ryegrass does not persist and/or in specialist pastures. The recent development of Mediterranean tall fescues has provided a viable alternative to phalaris in drier Australian environments. During the past decade the use of Italian ryegrass, hybrid ryegrass, chicory and forage brassicas in specialist finishing pastures has also increased dramatically.

Annual and perennial legumes are incorporated into pastures to provide nitrogen, and to improve nutritive value and intake rates. More recently, varieties of herbs such as chicory and plantain have been commercialised for their nutritive value. White clover varieties suited to a wide range of environmental conditions and farming systems have been released. These include varieties such as Trophy white clover which maintains better clover content in drought-prone Victorian and New South Wales environments (Ayres *et al.* 2008; Jahufer *et al.* 2008). Selection for increased stolon density has been important in improving the persistence of white clover varieties such as Tribute and Kopu II. Varieties released in recent years have been shown to have better persistence but pasture establishment and management remain the keys to maintaining good clover content even with improved varieties available.

Genetic resistance to pests and diseases are key improvements as it is rarely economic to use chemical controls on-farm. In perennial ryegrass and cocksfoot, selection has been successful in combating the ability of crown and stem rust races to evolve and overcome existing resistance mechanisms (Easton *et al.* 2002). Sources of resistance to three nematode species in white clover have been identified and incorporated into current breeding programs (Woodfield and Easton

2004). The release of a red-legged earth mite resistant subterranean clover (SM029) this year from the National Annual Pasture Legume Improvement Program is a significant innovation for dry-land systems.

Impact of new varieties on animal production

Improvements in the annual and seasonal yield of pastures are vital, but the translation of these improvements into milk, meat and fibre is far more important. Most forage varieties are released into the market based on their agronomic merit without any animal evaluation. The reasons for this are simple; the cost of running these trials is prohibitive for most of the commercial seed companies that currently fund the majority of forage breeding in Australasia. Despite this constraint, a number of new forage varieties have been evaluated in grazing trials. The results of these trials can be inconclusive, showing little impact of a component product in the overall system. Poor results can be due to performance gains observed in small scale plots not translating into similar gains when evaluated in paddock-scale grazing trials or they can be due to poorly planned and executed grazing trials that do not allow the benefits to be captured. Decision rules about stocking rates, use of supplementary feed, and the timing and duration of grazing can all influence the final outcomes. Despite these difficulties a number of technologies have produced strong results in grazing trials (see below). The ultimate test for any technology is always whether it fits into whole-farm systems and improves profitability.

Optimisation of the grass-endophyte association in ryegrass and tall fescue has provided productivity gains in both sheep and cattle. Varieties with novel endophytes retain protection against a range of damaging pasture pests (eg. Argentine stem weevil, black beetle, pasture mealybug, root aphids) while alleviating ryegrass staggers (eg. AR1), reducing the severity of ryegrass staggers (eg. AR37) and overcoming fescue toxicosis (eg. Max Q™, MaxP™) by eliminating the toxic alkaloids. Extensive trialling has shown that animals grazing ryegrass pastures containing AR1 endophyte are free of staggers and produce more meat (47–108 g/head/day more) and milk (9–14 per cent) than animals grazing ryegrass containing the wild-type endophyte (Woodfield and Easton 2004). AR1 is now the industry standard and is present in most modern ryegrass varieties.

AR1 has provided resistance to Argentine stem weevil and pasture mealy bug but has shown more susceptibility to black beetle and root aphid than the wild-type endophyte in Northern New Zealand and Southern Australia. A recently released ryegrass endophyte, AR37, overcomes these pest susceptibilities but is not completely animal safe. Animals grazing AR37 have exhibited occasional staggers events, but they are generally short in duration and animals recover rapidly when transferred to other feeds (Fletcher 2005). Perennial ryegrass swards with AR37 produced about 17–36 per cent more herbage dry matter (DM) than ryegrasses containing either AR1 or wild-type endophyte (Hume *et al.* 2007). AR37 had its greatest DM advantage in summer and autumn. Grazing trials with AR37 are underway in New Zealand and Australia. Preliminary data after 18-months under dairy grazing in the Waikato suggests that milk yield with AR37 may be slightly lower than the animal safe AR1 but better than the wild type endophyte, although to date these differences are not significantly different over the full lactation. Importantly, the agronomic advantages in terms of tiller density and persistence were clearly evident after the recent drought. Ryegrass staggers has been observed with the wild-type endophyte but not with AR37 (Easton *et al.* 2007).

MaxP™ (called Max Q™ in USA) endophyte in tall fescue has also provided increased animal performance in comparison to tall fescue with wild-type endophyte. The live-weight gains are similar to those achieved with endophyte-free material but without sacrificing persistence (Bouton 2007). Economic returns were estimated to be between US$36 and US$55 per cow per year in Southern USA (Bouton 2007). Tall fescues containing MaxP have been used successfully for several years in Australia.

Diploid ryegrasses with sugar levels that are comparable to the levels normally found in tetraploids are being marketed in Australasia. There has been substantial variation in the animal performance response reported from a range of European and New Zealand trials with high sugar grasses (reviewed by Edwards *et al.* 2007). The most favourable results in milk and meat production have been in United Kingdom trials where these grasses were developed. Under New Zealand conditions a three-year dairy trial found no milk production response in spring although a 10 per cent increase in milk yield was found in one of the two autumn periods (Cosgrove *et al.* 2007). Increased animal production has been attributed to improved protein utilisation with less nitrogen excreted in urine. Expression of the 'high sugar' trait is not consistent, and is dependent on environment, as maximum expression is associated with cool night temperatures (Edwards *et al.* 2007). Further increases in sugar level will be achieved and higher and more stable expression may provide reliable animal productivity gains.

The improved persistence of new white clovers has provided substantial increases in beef production in south-eastern USA (Bouton *et al.* 2005). Pastures containing Durana white clover had 35 per cent more clover than the control pastures with Regal white clover, and cattle live-weight gains were 100 per cent and 83 per cent greater with Durana than the Regal control in endophyte-infected (E+) and endophyte-free (E–) tall fescue swards, respectively (Bouton *et al.* 2005). Increases in legume content in Australian and New Zealand pastures can provide similar animal performance benefits, with the optimal clover content for milk yield shown to be in excess of 50%.

Importance of introduced germplasm and ecotype collections to developing locally adapted varieties

Germplasm is the lifeblood of the pastoral industries. Introductions of new overseas germplasm and collections of ecotypes adapted to local environmental stresses have both contributed to genetic improvement of our forages. Perennial ryegrass and white clover are good examples of this. Initial introductions of both species from Europe were made into New Zealand prior to 1820 and by 1912 the majority of the seed used in New Zealand was locally produced. Initial breeding in the 1930s began by identifying the best naturalised ecotypes identified and these were re-selected over the next 30 years to produce Ruanui ryegrass and Huia white clover. These adapted ecotype varieties were shown to have superior performance to the best European varieties highlighting the power of the local environment to concentrate the best genes. The identification of the Mangere ryegrass ecotype in the late 1960s led to the development of Nui and Ellett ryegrasses. These varieties have had a profound impact on ryegrass breeding as they have formed the basis of all ryegrass breeding pools in Australasia. The incorporation of north-west Spain germplasm over the past decade has been equally important providing better winter growth, rust resistance and improved forage quality in varieties such as Impact, Tolosa, Bealey and Banquet (Stewart 2006).

Locally adapted ecotypes have been important in developing white clover varieties for marginal environments. Durana (southern USA tall fescue belt), Prestige and Tahora (moist New Zealand hill country), and Nomad (dry New Zealand hill country) are all successful varieties based on collected ecotypes. In Australia, the introduction of overseas collections led to the release of Siral (Algeria) and the widely used Haifa (Israel). Subsequent breeding efforts have combined Mediterranean, Southern European and local ecotypes to develop superior varieties such as Tribute and Trophy. Incorporation of Mediterranean germplasm has provided improved winter-activity in several species including ryegrass, tall fescue, cocksfoot, phalaris and white clover.

The next frontier will be in better utilising the genetic resources that sit within the wild relatives of our major forages. The majority of these related species have poor agronomic value but contain genes for useful traits such as drought tolerance, salinity tolerance, pests and disease resistance, establishment vigour and forage quality. New clover hybrids between white clover and several wild relatives are being assessed to identify perennial drought tolerant material for zones that are traditionally the domain of annual legumes.

There are many potential forage species sitting in our gene banks that with intensification and climate change represent a significant opportunity. A change in focus is required as current breeding and agronomy efforts are concentrated around a few economically important species. The chronic instability and low funding of underpinning genetic resources research and field breeding represents a major threat to the future viability of Australasia's pastoral industries. The value of new germplasm to the industry is unequivocal and we must work within international treaties and biosecurity constraints to maintain access to new germplasm. The reality is that breeding programs with elite germplasm will be strongly positioned to help the pastoral industries remain competitive and to deliver innovations that arise from biotechnology and genomics.

Future direction of conventional and molecular breeding

Molecular biology and genomics research in Australia and New Zealand offer considerable promise; the problem is that in forages, they have been long on promise and short on outcomes over a 20-year investment period! Undoubtedly there are target traits that require molecular approaches, unfortunately too often investment has been made into traits that could have been more developed by conventional means had the resources been made available. A case in point is virus resistance in white clover. More than 20 years effort has produced transgenic white clovers with resistance to white clover mosaic virus, alfalfa mosaic virus, and clover yellow vein virus. Transgenic plants have been field tested in New Zealand and Australia but they have not yet been commercialised. Given the current opposition to even simple technologies such as Round-up Ready alfalfa and a very costly regulatory framework, it is unlikely that we will see them in the foreseeable future either. The sad part is that good sources of natural genetic resistance exist to at least two of these viruses, and had even a fraction of the investment been put behind a conventional breeding effort then commercial varieties would already be available to farmers.

Molecular efforts need to focus on challenges that are beyond conventional breeding. Stable increases in expression of forage quality components such as lipid and condensed tannins, and increases in digestibility through modification of fibre composition are all areas that could provide quantum industry benefits within the next decade. Beyond that horizon, forages that utilise scarce resources such as water and nutrients more efficiently, and that reduce greenhouse gas emissions will be required. Climate change predictions indicate more variable rainfall and more frequent and severe droughts in many of our main pastoral environments. Germplasm with better water-use efficiency will be critical to deal with moisture constraints.

In order to deliver these innovations, molecular and conventional breeding approaches must be effectively integrated. Currently, molecular breeding is well resourced but there is a huge gulf in the funding, and even availability, of conventional breeding capability to develop and deliver these forage innovations to the pastoral industries. Public plant breeding has increasingly concentrated on a core group of economically important forages (ryegrass, tall fescue, white clover, red clover, lucerne and forage brassicas) where there is strong partnership with industry. In Australia, there is reasonable breeding capability working in species for the drier environments, but there is a scarcity of capability in species for the higher rainfall zones. The converse is true in New Zealand. In both countries, however, many of the existing plant breeders will reach retirement age in the next 10 years and training of new breeders is very low. Increasingly, Australian pasture requirements will be met by international breeding groups who specialise in a particular species or genus. The combined impact of a stringent regulatory environment together with poor integration of molecular and breeding capability is that Australasia's primary industries are likely to be followers rather than leaders in capturing the economic benefits that can be delivered from genetically modified crops.

The biggest gains from the genomics investment to date have been in the expansion of knowledge about genome structure and function, and in the development of better tools that plant breeders can use. High density genetic maps have been developed for white clover, red clover and perennial ryegrass that open the door for cost-effective marker-assisted selection, introgression of traits from wild relatives, and dissection of complex traits. The first forage varieties developed through application of these tools are currently undergoing seed multiplication in New Zealand.

References

Ayres JF, Caradus JR, Murison RD, Lane LA, Woodfield DR (2008) Grasslands Trophy – a locally adapted white clover for dryland environments. In 'Proceedings of the 23rd Annual Conference of the Grassland Society of NSW.' (Eds SP Boschma, LM Serafin, JF Ayres) (Grassland Society of NSW Inc.: Orange) pp. 116–119

Bluett SJ, Thom ER, Clark DA, Mac Donald KA, Minnee EMK (2003) Milksolids production from cows grazing perennial ryegrass containing AR1 or wild endophyte. *Proceedings of the New Zealand Grassland Association* **65**, 83–90.

Bouton JH (2007) The economic benefits of forage improvement in the United States. *Euphytica* **154**, 263–270.

Bouton JH, Woodfield DR, Hoveland CS, McCann MA, Caradus JR (2005) Enhanced survival and animal performance from ecotype-derived white clover cultivars. *Crop Science* **45**, 1596–1602.

Cosgrove GP, Burke JL, Death AF, Hickey MJ, Pacheco D, Lane GA (2007) Ryegrasses with increased soluble carbohydrate: evaluating the potential for grazing dairy cows in New Zealand. *Proceedings of the New Zealand Grassland Association* **69**, 179–185.

Dairy Australia (2007) Australian dairy industry in focus 2007. Melbourne, Australia.

Easton HS, Amyes JM, Cameron NE, Green RB, Kerr GA, Norris MG, Stewart AV (2002) Pasture plant breeding in New Zealand: where to from here? *Proceedings of the New Zealand Grassland Association* **64**, 173–179.

Easton HS, Thom ER, Bluett SJ, Hume DE, Popay AJ (2007) Endophyte technology for dairy pastures. In 'Proceedings of the Australasian Dairy Science Symposium, September 2007, Melbourne.' pp. 293–306.

Edwards GR, Parsons AJ, Rasmussen S (2007) High sugar grasses for dairy systems. In: Meeting the challenges for pasture-based dairying. In 'Proceedings of the Australasian Dairy Science Symposium, September 2007, Melbourne.' pp. 307–334.

Fletcher LR (2005) Managing ryegrass-endophyte toxicoses. In '*Neotyphodium* in Cool-Season Grasses'. (Eds CA Roberts, CP West, DE Spiers) pp. 229–241. (Blackwell: Ames, IA)

Hume DE, Ryan DL, Cooper BM, Popay AJ (2007) Agronomic performance of AR37-infected ryegrass in Northern New Zealand. *Proceedings of the New Zealand Grassland Association* **69**, 201–206.

Jahufer MZZ, Clements R, Durant R, Woodfield DR (2008) Evaluation of white clover commercial cultivars and experimental synthetics in South west Victoria. *Australian Journal of Experimental Agriculture* (submitted)

Lancashire J (2006) The value of exotic germplasm to the NZ livestock industry. *Grassland Research and Practice Series* **12**, 5–9.

Livestock Improvement Corporation (2007) New Zealand dairy statistics 2006–2007. Hamilton, New Zealand. 44p.

Stewart A (2006) Genetic origins of perennial ryegrass (Lolium perenne) for New Zealand pastures. *Grassland Research and Practice Series* **12**, 55–62.

Woodfield DR (1999) Genetic improvements in New Zealand forage cultivars. *Proceedings of the New Zealand Grassland Association* **61**, 3–7.

Woodfield DR, Clifford PTP, Baird I, Cousins GR, Miller JE, Widdup KH, Caradus JR (2003) Grasslands Tribute: a multi-purpose white clover for Australasia. *Proceedings of the New Zealand Grassland Association* **65**, 157–62.

Woodfield DR, Easton HS (2004) Advances in pasture plant breeding for animal productivity and health. *New Zealand Veterinary Journal* **52**, 300–310.