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Prepared by: Kevin Smith

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An analysis of opportunities for pasture plant improvement in Australia with reference to the Pastures Australia review

Abstract

Pastures Australia (PA) was formed in 2006 to better co-ordinate investment and activities in pasture plant improvement. PA is an unincorporated joint venture between five research organisations being MLA, Australian Wool Innovation (AWI), Dairy Australia (DA), Grains Research and Development Corporation (GRDC) and Rural Industries Research and Development Corporation (RIRDC). The main charter of PA was to be an industry-wide venture to ensure efficient investment in pastures research and development including:

- Genetic improvement of perennial and annual legumes, grasses, herbs and forages.
- Development of new agronomy and management knowledge for pasture species.
- Communication and extension of new knowledge to farmers.

This report summarises the feedback on PA projects that are strategically important to MLA and recommends ways to further develop these project areas; the report also presents a strategic analysis of the ways and means to increase the adoption of quantitative genetic principles in forage plant breeding in order to increase rates of genetic gain and provide producers with more informed choices regarding the value of pasture genetics.

Disclaimer

Executive summary

Pastures Australia (PA) was formed in 2006 to better co-ordinate investment and activities in pasture plant improvement. PA is an unincorporated joint venture between five research organisations being MLA, Australian Wool Innovation (AWI), Dairy Australia (DA), Grains Research and Development Corporation (GRDC) and Rural Industries Research and Development Corporation (RIRDC). The main charter of PA was to be an industry-wide venture to ensure efficient investment in pastures research and development including:

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1. *That MLA considers appointment of a forage genetics co-ordinator to manage relationships with ASF, seed companies, research providers and the education sector with a primary emphasis on raising the general awareness of forage breeding issues and the overall rate of genetic gain in forages. This position should complement the PA co-ordinator role and not duplicate it; further it is recommended that the forage genetics co-ordinator should have a strong technical knowledge.*
2. *That MLA commissions a workshop and subsequent working group to further develop and validate breeding objectives for pasture species; this workshop should initially seek a broad attendance for the purpose of disseminating information on progress to date; the working group would comprise representatives of those groups who wish to move forward with the concept.*
3. *That MLA commissions a statistical analysis of cultivar evaluation data for various target species (eg ryegrass, lucerne, phalaris) to identify the extent and nature of Genotype by Environment (GxE) interactions within the target markets for these species.*
4. *That MLA commissions development and design of a business plan for an EBV service provider for the pasture genetics industry.*
5. *That MLA continues to explore the development of a robust NVT system for pastures with good linkages to breeding program data; it is further recommended that an independent technical review of the NVT program is conducted to allow changes in trial methodology and analysis to be implemented.*
6. *It is recommended that MLA requires that all project proponents develop a 'market-failure' assessment and remediation strategy either before commencement or early into all new projects where investment is sought based on current market failure.*
7. *That MLA commissions the development of a commercial-ready mating allocation program for forage species with links to existing software and marker technologies.*
8. *That MLA liaises with Professor Mather to determine if it is possible for a relevant forage breeding module to be included in the program: <u>Plant breeding by example</u>: contextual examples linking theory with practice in plant breeding education*

9. *That MLA seeks to influence the development of a national plant breeding curriculum within one or more universities to ensure that quantitative aspects of plant breeding are adequately addressed especially through the strengthening of interactions between plant and animal geneticists.*
10. *That MLA (potentially with support from other Pastures Australia partners) considers the preparation of the "Pasture Genetics Manual" as an industry-wide resource for seed resellers and producers.*

Contents

Page

Disclaimer 2

1 Background 7

2 Project objectives 7

3 Pastures Australia review and recommendations 8

3.1 PA Review recommendations and responses 8
3.2 Comments on MLA sponsored projects from the first phase of PA raised during the review 11
3.2.1 Feasibility of a NVT trial program 12
3.2.2 Genetic improvement and evaluation 14

4 An assessment of pasture plant improvement in Australia and overseas 15

4.1 The pasture industry in Australia 15
4.2 Breeding of novel species or for niche environments 16
4.3 Breeding of major species. 17
4.4 Breeding and research programs serving the Australasian market 19

5 Opportunities for new investment in pasture plant improvement 20

5.1 Development and implementation of an objective language for plant improvement 20
5.1.1 Defining the breeding objective 20
5.1.2 Estimating breeding values in pasture species 21
5.1.3 NVT 22

5.2 Breeding in an environment of market failure 22
5.2.1 Defining market failure 23
5.2.2 Public-private partnerships 23

5.3 Improving the use of quantitative genetics in plant breeding 24
5.3.1 Mating designs 24
5.3.2 Optimising parental numbers 25

5.4 Education and training 25
5.4.1 Undergraduate 26

5.4.2 Postgraduate 27
5.4.3 Training of industry/retail staff 27
6 Conclusions and recommendations 28
7 Bibliography 30

1 Background

Pasture plant improvement in Australia has historically been funded by the public sector with some private sector funding for major species such as ryegrasses (*Lolium spp.*), lucerne (*Medicago sativa*) and to a lesser extent white clover (*Trifolium repens*) and tall fescue (*Lolium arundinaceum* syn. *Festuca arundinacea*).

Despite the development of improved varieties, particularly through shifting seasonal herbage production and/or flowering time there is not an agreed methodology for assessing the relative merit of cultivars relative to each other; nor is there a readily available means for producers to assess the economic merit of improved cultivars in grazing systems.; this is in contrast to the work that has been done demonstrating the value of improved versus unimproved pastures (eg Saul/Chapman).

Pastures Australia (PA) was formed in 2006 to better co-ordinate investment and activities in pasture plant improvement. PA is an unincorporated joint venture between five research organisations: MLA, Australian Wool Innovation (AWI), Dairy Australia (DA), Grains Research and Development Corporation (GRDC) and Rural Industries Research and Development Corporation (RIRDC). The main charter of PA was to be an industry-wide venture to ensure efficient investment in pastures research and development including:

- Genetic improvement of perennial and annual legumes, grasses, herbs and forages.
- Development of new agronomy and management knowledge for pasture species.
- Communication and extension of new knowledge to farmers.

The investors in PA commissioned a review of its performance in late 2009. This review conducted by a panel chaired by David Hudson of SGA Solutions was presented to the PA Board in December 2009.

In order for MLA to better prioritise investment in pasture plant improvement activities this report has been commissioned to provide a:

- Written response to PA Review outlining relative strengths and weaknesses of options against known strategic priorities of MLA.
- Overview of national and international activities in pasture plant improvement including SWOT analysis.
- Presentation of results to MLA (and/or other stakeholders at MLA discretion).

2 Project objectives

This project has 3 main objectives:

- Written response to PA Review outlining relative strengths and weaknesses of options against known strategic priorities of MLA.
- Overview of national and international activities in pasture plant improvement including SWOT analysis.
- Presentation of results to MLA (and/or other stakeholders at MLA discretion).

3 Pastures Australia review and recommendations

The PA review used both questionnaires and interviews to assess the views of a broad cross-section of stakeholders on the performance of PA against its stated objectives. The majority of the recommendations of the review relate to the structural models and operational procedures of PA. Whereas, useful discussion on the relative merits of specific program areas tends to be captured in responses to the questionnaire, comments on both of these areas of the review follow in sections 3.1 and 3.2 below.

3.1 PA Review recommendations and responses

Recommendation One:

That Pastures Australia continues to exist based on clearly identified needs articulated by the supply chain and that all RDC's concerned with pasture based industries support the role of Pastures Australia through investment and resourcing to the end of the next cycle which concludes in 2015 (albeit recognizing that the role of PA may evolve during this period).

Response

There was almost universal acceptance of the need for a body such as Pastures Australia, even from those who had concerns with respect to its performance to date. The challenge for MLA will be how to maintain the commitment of AWI and DA to the Pastures Australia process. AWI because they have stated that pastures research and development is not a priority for investment and DA because they have failed to date to manage any of their investment in this area through PA.

In the current phase of PA this has seen an unequal level of engagement in the PA board with some RDCs seeing themselves as observers or having a small commitment to "maintain a seat at the table" this is in turn has led to the perception that the PA portfolio of projects are biased towards certain industry sectors.

This situation could be best managed by PA having a strategic role rather than an investor in research projects *per se.*

Recommendation Two:

That the Board of Pastures Australia initiates an internal review of the current PA charter which governs PA's strategy and the alignment of RDC stakeholder expectations and commitment. It is proposed that the review of the charter incorporate the following elements:

• Scope of PA's vision and outcomes (e.g. Objectives, Goals and Milestones)

• Scope of individual RDC engagement (i.e. passive contribution to strategy only or active contribution to investment and strategy)

• Scope of PA's constituency (e.g. RDC stakeholders, pasture industry supply chain)

• Scope of PA's engagement (e.g. pastures, soil – plants, plants animals, fodder)

• Scope of PA's role (e.g. Industry strategy management, R, D & E project management)

Response

The current charter for PA is clear in that as projects in pasture R & D cease and new projects commence that these will be managed through PA. This has not been how PA has operated during this cycle of investment thus it is critical that the scope and charter of PA is reviewed.

There was a general view from the non-RDC respondents that the PA constituency could be expanded to include representation at board level from other participants in the pasture R&D value chain. In the absence of peak bodies for some sectors and multiple national or state based ones for others there is a real chance that this group would become unwieldy if it were a representative rather than skills based board. An alternative would be for PA to sponsor a 'Pastures Forum' to provide input into strategic direction and guidance, this forum could also encompass regional (eg Northern Tropical) or thematic (eg GM and biotechnology) task groups to develop position papers on specific issues.

These task groups would not be ongoing committees but rather 'communities of practice' that come together at the request of PA and remain in action until an issue is resolved to the satisfaction of the PA board.

This kind of model was used with some success during the Single Vision Grains Australia process particularly with respect to GM grains and biofuels and an overall strategy/vision for grains: "Towards a Single Vision for the Australian Grains Industry 2005-2025".

A diagrammatic representation of how this structure could operate is given in Figure 1 and shows the interrelationships between stakeholders, the Pastures Forum and the PA Board.

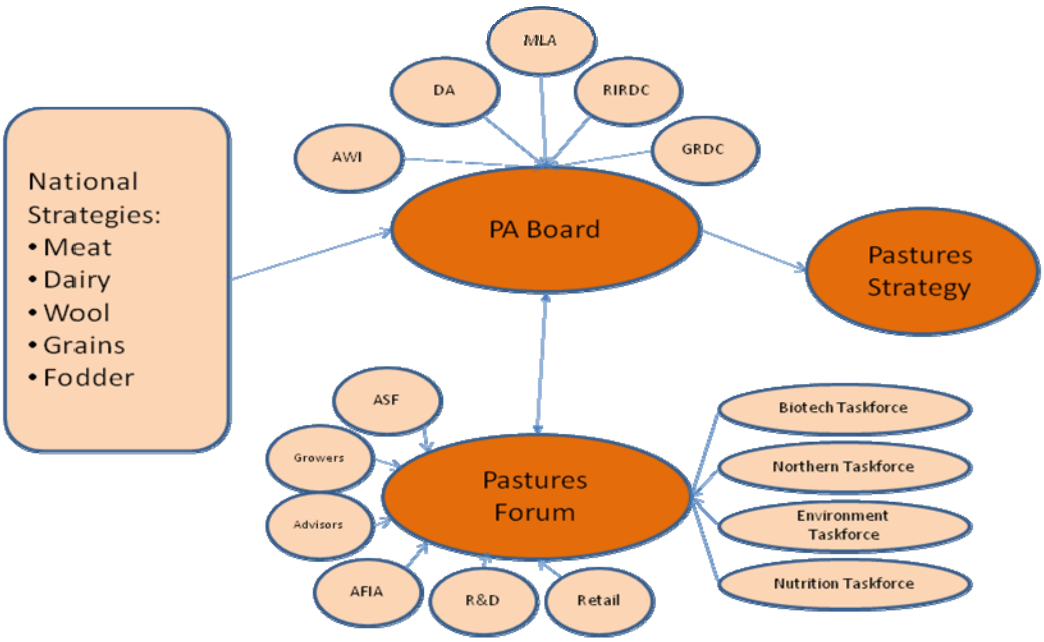

Figure 1. Operational model for PA sponsored 'Pastures Forum'.

Recommendation Three:

That the Board of Pastures Australia agree to the adoption of a strategy model which is focused on the development, delivery and coordination of an agreed National Pasture Strategy, and the effective communication and dissemination of pasture improvement information to pasture industry stakeholders ("Clearing House" Model).

Response

The model outlined in Figure 1 would facilitate the delivery of this recommendation without the necessity for the RDC stakeholders to cede control of R&D investment or project review and monitoring which appeared to be a sticking point in the operation of the first phase of PA.

Recommendation Four:

That the Board of Pastures Australia, commission the development of a Business Plan for the Clearing House PA model for the 2010 – 2012 period encompassing the following elements:

1. The re establishment of PA's role and identity within the pasture industry by way of:

> *a. The appointment of an independent chairperson to the PA board,*
>
> *b. The appointment of a full time CEO (as distinct from Coordinator),*
>
> *c. The establishment of a Operating Plan, Infrastructure Plan, Financial Plan, Communication Plan and Milestones for PA,*
>
> *d. The establishment of a communication platform (i.e. clearing house) for the consolidation of current pasture improvement information (i.e. consolidate the silo's) and delivery of outcomes from the various projects and activities undertaken by pasture industry stakeholders,*
>
> *e. The establishment of a Pasture Industry Reference Group (PIRG) with membership from across the supply chain including peak industry bodies and with specialist expertise provided by invited participants, and*

2. The coordination, development and implementation of a National Pasture Strategy which embraces the goals and objectives of all stakeholders in relation to pasture improvement and productivity.

3. The development of a plan for the RDC stakeholders to consider and evaluate as whether PA having achieved its short term objectives (2010 – 2012) should evolve into:

> *a. a peak industry body representing stakeholders within the current and future pasture industry*
>
> *b. maintain and strengthen its role of coordinating and delivering on a pasture improvement strategy for the pasture industry, or alternatively*
>
> *c. assess if PA should be wound down and the RDC's revert to self management of pasture related R, D & E investments*

Response

The model described in figure 1 is consistent with this recommendation in that the Pastures Forum would take on the role of the Pasture Industry Reference Group referred to in 1e above. If the model were successful and the long term desire for PA was the development of a peak industry body for pastures (such as Australian Oilseeds Federation) then the Pastures Forum would be a forerunner of that group.

Recommendation Five:

That the Board of Pastures Australia following the re establishment of PA's charter and model for the second cycle concluding in 2015, commission the development of a National Pasture Strategy which encompasses both the private and public sectors stakeholders and includes a clear definition as to: what constitutes the pasture industry ; its role and who its stakeholders are.

The objective of the process will be to

• identify the current pasture industry stakeholder base and the drivers for participation

• indentify and quantify the current pasture resource base and corresponding capacity

• identify the current pasture industry structures and relationships

• consolidate and align these elements and identify the priorities for the pasture industry including R, D & E priorities

• communicate the strategy and confirm "buy in" by all relevant internal and external stakeholders

• present the R, D & E strategy, including priorities to PISC for its endorsement and incorporation into the national R, D & S strategy for agriculture

Upon completion it is recommended that PA be responsible for representing and promoting the strategy when and where appropriate, as well as assuming responsibility for initiating a regular review of its direction and performance, and if required update the strategy.

Response

For a national pastures R,D & E strategy to be endorsed by PISC it would need some consideration as to who the champions of such a strategy would be as most have been led by an RDC with strong support from a state agency. It is possible that PA could fill this role as the National Horticulture Research Network (NHRN) has done for horticulture. However, NHRN is an existing entity that includes representation from RDCs (HAL) and research providers (DPIV, DEEDI, CSIRO etc) whereas PA would need to work closely with the research providers. A critical step would be to identify the key contacts within the state agencies.

An alternative approach would be to see the national pasture strategy serving the national strategies for meat, wool and dairy R, D &E with PA taking on the role to look at cross-sectoral synergies and also gaps (seed production, fodder etc) that may be overlooked within an individual commodity group.

3.2 Comments on MLA sponsored projects from the first phase of PA raised during the review

During the PA review process respondents were asked to rate their awareness of and perceived relevance of a range of research projects undertaken by PA (Figure 2). The Genetic Improvement and Evaluation project was ranked most favorably with respect to relevance (>60% of respondents rating this project as relevant or very relevant), in contrast the views of respondents to the NVT project were polarized with approximately 40% seeing this as not being a relevant activity for PA and 50% seeing it as relevant or highly relevant. It is interesting to reflect on these rankings and experiences with these project areas during the first phase of PA.

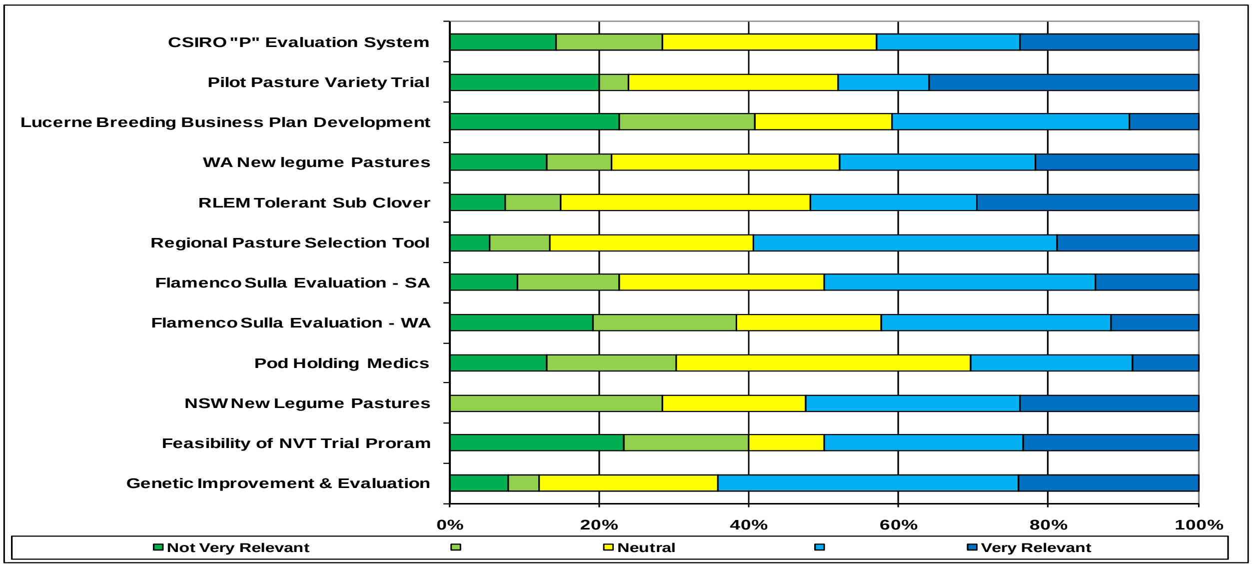

Figure 2. Summary of responses with respect to the PA research portfolio (source Pastures Australia Review: D Hudson 2009).

3.2.1 Feasibility of a NVT trial program

The NVT program has always polarized stakeholders and been the subject of passionate debate. Some of the perceived pros and cons that have been debated are listed in Table 1.

Table 1. Pros and Cons of a NVT program for pastures

Pros	Cons
Objective	One size fits all
Accessible	Expensive
Uniform language	Diminishes company trials
Consistent management protocols	Lack of agreement on protocols
Impartial	Allows 'freeloaders' to get data

There are several key features of an NVT system that would need to be incorporated for it to be accepted by industry and producers:

- scientifically robust
  - trial layout
  - replication/power
- agreed measurement protocols
  - cutting frequency
  - yield measurement methodology
  - nutritive value
  - other attributes
- appropriate trial environments
- auditable
- ability to incorporate company trials

It is also worth noting that the last attempt at centralized cultivar testing in pastures: Australian Pasture Plants Evaluation Committee Inc (APPEC) which was at a time of decreasing public sector evaluation and increased evaluation by the private sector (Coles 1994, APPEC 1996) was not successful for a number of reasons including poor performance of trial managers and lack of agreement on trial protocols and management procedures. For instance, the trials were randomized complete block designs (RCBD) with between 4 – 6 replicates and periodic mowing despite the known value of spatial designs in crop evaluation (Gleeson and Cullis 1987; Cullis and Gleeson 1989; Cullis and Gleeson 1991). Post-hoc analysis of the data from APPEC perennial ryegrass trials (Clark *et al.* 1994) showed that the lsd when expressed as a percentage of the trial mean ranged from 4 to 255% with 56 of 72 data points having an lsd > 10% of the trial mean (Smith and Kearney 2002), demonstrating the relatively low discriminating ability of these trials given the rates of genetic gain reported in ryegrass of between 0.3 and 0.5% *per annum* (Van Wijk and Reheul 1990; Humphreys 1998).

There are relatively few reports on the use of modern statistical procedures to improve trial design in pasture evaluation. However, when the data have been analyzed the benefits have been obvious; spatial analysis (nearest neighbor analysis, lattice designs, row-column analysis etc) has been shown to increase the relative efficiency of trials by 5 – 35% (Casler 1999a, 1999b, Smith and Casler 2004), the use of repeated measurements analyses has been shown to reliably reduce the antedependence of plot effects from one harvest to the next (Collins *et al.* 1996; Culvenor *et al.* 1996; Smith *et al.* 1998) and the simple act of increasing the number of replicates in a trial from 4 – 8 has been shown to increase the likelihood of a 16% difference in mean yield of cultivars being assessed as significant at 95% probability from 45% to 70%.

Despite this most cultivar trials still have a RCBD with 4 to 6 replications. To some extent this is based on historic practices and the fact that those who design trials do not seek to determine the precision that will be required ie. 'What is the likely difference between test entries and controls?.

It is common when variety trials are discussed that the major items of discussion are around minor technical issues such as potential differences when measuring yield with plate meters vs capacitance probes at the expense of really redesigning the trials to be robust, effective and cost-efficient. There following section of this report describes four possible scenarios for pasture variety testing in Australia:

- *Status quo*. This scenario will see a continued reduction in public sector investment in variety testing in the absence of an NVT with a known set of comparators and agreed methods and descriptors. Private companies will continue to evaluate their own germplasm on research farms or farmer collaborator sites without effective means of pooling data across sites and companies, inadequate description of GxE and different methods for describing cultivar performance making farmer choice difficult.
- *'Field of Dreams' Model.* This scenario is based on the premise that the best way to break the current deadlock in implementing a pastures NVT in Australia is for an agency/or group of agencies to build a sound NVT system and forge ahead with its implementation. If the NVT were successful and well run and used effectively as a communication tool to farmers it is likely that companies would begin to use it. If it continues to remain difficult to gain effective seed industry engagement with an NVT program this may be the best way to progress. However, it would be expensive and subject to criticism from the industry from the beginning and there is a real risk that there are few agencies with the skills set to run such a program if it did not include the current players from commencement. This kind of centralized agency run NVT program is most common in countries in Europe where 'official lists' are still common and registration on the official list is required for commercialization.
- *'Pilot Study' Model.* In this model a limited scale (sites, species, entries etc) is implemented as a means of illustrating the value of an NVT program to industry (seed and meat). Whilst this model is relatively inexpensive it has the potential to compromise a range of technical issues such that the quality of the data produced is not of the standard

required to adequately describe the merits of cultivars across environments or adequately define differences between them.

- *Scope, Implement, Refine Model.* In this model it is proposed to implement a full NVT (at least for major species) but with a clear understanding that a review and revision will be undertaken once a range of research questions are answered. It is proposed that a skills-based NVT working group be constituted to represent industry and that this group define an initial set of trial parameters and also the set of research questions that need to be answered concurrently with the implementation of the NVT, these questions could include:
  - Correlations (and hence correction factors) between contrasting yield measurement technologies.
  - Analysis of genotype x environment interactions to assist with site selection and rationalization.
  - Determination of rate of genetic gain through inclusion of historic cultivars.
  - Demonstration of the value of trial design elements on efficiency.

It is likely that the last model would work best when it is clear that there will be an NVT as it has strong support from MLA and if support could be gained from the Plant Breeding and Proprietary Marketers Committee of the ASF, it is possible that this could be achieved through asking for ASF to nominate representatives to the NVT working group. When the grains NVT system was implemented it was endorsed by the Plant Breeding and Proprietary Marketers Committee of the ASF. The ASF has experience in hosting the Australian National Turf Evaluation Program (ANTEP) although the majority of data collected in ANTEP appear to be qualitative (ratings of resistance, vigour etc) as opposed to quantitative based on a review of the 2007 and 2008 perennial ryegrass and tall fescue variety trial results (ANTEP 2009). Strong endorsement by ASF and meat producer organizations would effectively avoid any perception that the NVT was not required by industry or that it was dominated by one company or another.

3.2.2 Genetic Improvement and Evaluation

A major source of confusion during the PA review as to the success of the Genetic Improvement and Evaluation project can be directly attributed to a lack of knowledge regarding the scope of the project. It was not clear to all respondents that the project was to scope a business plan and investment information memorandum relating to future private/public investments in this area not the implementation of EBV based breeding systems *per se.*

It is not intended to reiterate the results of this project here but rather comment on the perception of this project during the PA review.

As previously stated the project was generally received positively by respondents to the review but it is fair to say that because the later stages of the project and follow on from the project largely involved discussions with companies who had expressed some interest in the program moving forward there was a lack of awareness of what had been achieved within the project, particularly with respect to the development of a generalized breeding objective for pastures. Further discussion and recommendations on how to proceed with this project follows in Section 5 of this report.

The project also spent considerable time developing a conceptual framework and implementation plan for the development of EBV-based breeding systems in pastures. Both in the project report and during the review concern was raised that one of the issues restricting progress on implementation was the lack of committed resources to the program particularly of the ability of staff contracted to DPIV to free up time to prioritize activities in this area. In this project and a number of other areas there is clearly the need for a dedicated resource to work closely with the broader industry to progress activities against agreed timelines.

4 An assessment of pasture plant improvement in Australia and overseas

Investment in pasture plant improvement in Australia and New Zealand has led the world in the reduction of public sector investment in cultivar development in most other jurisdictions both public and private programs compete with each other. In Australia investment in breeding and cultivar development is focussed on areas of perceived market failure – albeit often with a poor understanding of the market and limited assessment of the reason/s for market failure.

4.1 The pasture industry in Australia

The pasture industry in Australia can broadly be divided into 3 sectors (Figure 3 from Hudson 2009); pre farm gate, on-farm and post farm gate.

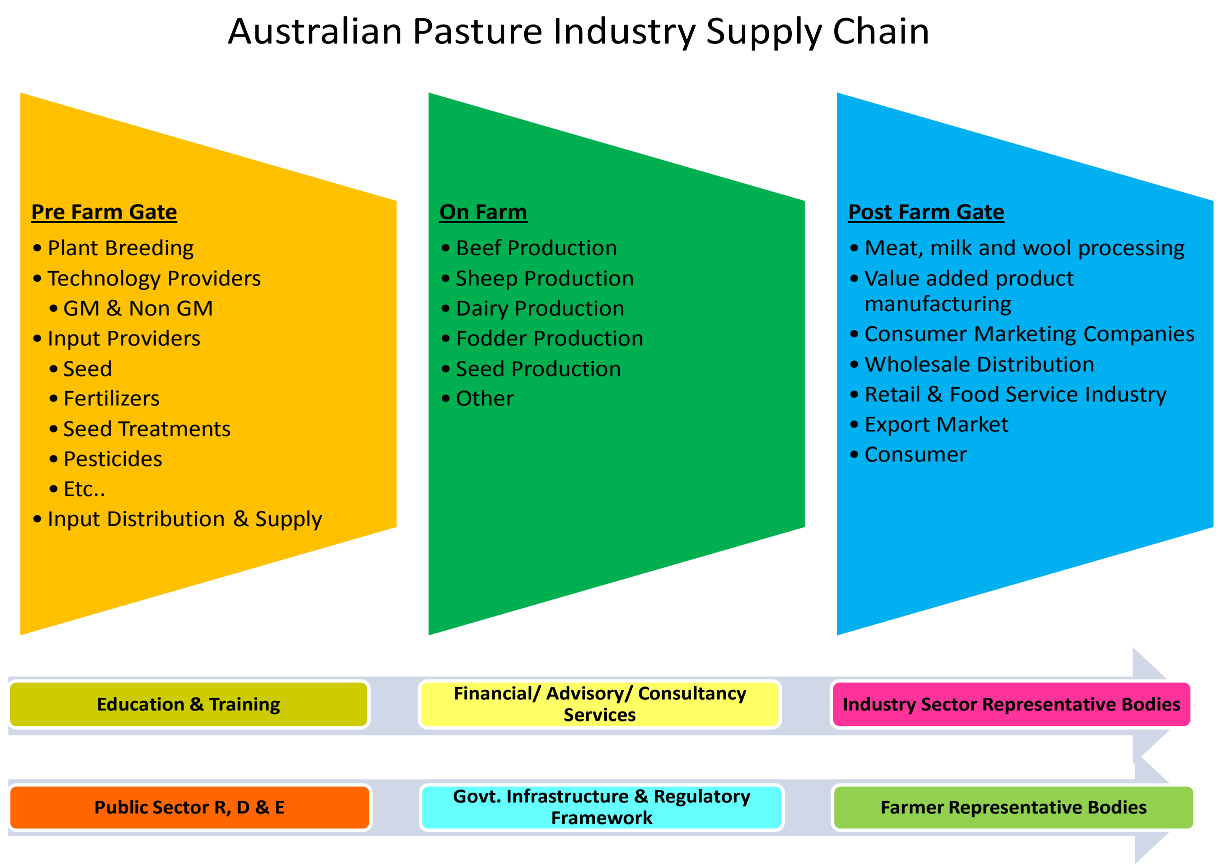

Figure 3. The Australian Pasture Industry Supply Chain (from Hudson 2009).

Pasture plant improvement, seed production and marketing are key inputs into the pre farm gate component of the pasture industry supply chain, an analysis of seed sales can be used to give a relative assessment of importance of species and environments (because of differential adaptation in this market).

Table 1. Australian Pasture Seed Market (Source Gout Report to Pastures Australia 2006)

Species	Cultivars	Sales (t/pa)	Value ($M)	Top Cultivars	Market Share (%)
Perennial ryegrass	44	2400	9.6	8	56
Short term ryegrass	48	7000	21.0	13	82
Tall fescue	20	650	3.9	7	81
Cocksfoot	8	210	1.3	2	64
Phalaris	9	180	1.1	4	69
White clover	20	600	4.2	8	56
Red Clover	8	150	1.4	3	69
Sub clover	27	1700	7.7	6	61
Other clover	28	800	2.4	4	70
Medic & serradella	33	1000	5.0		
Brassicas	30	490	2.9	5	65
Herbs	12	200	2.0	2	65
Lucerne	43	2100	14.7	7	51
Tropical Grasses	30	1100	8.8		
Tropical Legumes	26	1400	7.2		
Total	386	19980	93.2		

The data in Table 1 demonstrate that the temperate seed market is dominated by several major species perennial ryegrass, short term ryegrass, tall fescue, sub clover and lucerne as there are active private sector breeding programs in these species there has been a reduction in government support for private sector breeding programs starting with the reduction of MLA and DA funding to perennial ryegrass in Victoria in the late 1990s.

Table 1 also demonstrates that whilst there are large numbers of cultivars in the market, a relatively small number of cultivars dominate the market in each species. Recent reviews in wheat and barley have also shown this to be true and in both instances it is broadly adapted cultivars that dominate the market despite many programs breeding for regional and sub-regional adaptation, this was particularly true of the NSW DPI barley breeding program that strongly focussed on regional adaptation. This point is critical as it is clear that companies strongly market broadly adapted cultivars whether they are bred in the private or public sector, thus while concerns are raised about G x E when programs such as EBV derivation are discussed there is a strong need for general EBVs and definition of broad differences between cultivars.

4.2 Breeding of novel species or for niche environments

Breeding of novel species or adapting existing species to stress environments has long been a feature of pasture breeding in Australia, with some notable successes such as the domestication of *Phalaris aquatica* in the CSIRO Canberra program (Oram and Lodge 2003, Culvenor 2009) and the successful commercialisation of subterranean clover, Persian and balansa clovers from a long running range of initiatives that have culminated in the recent NAPLIP and Future Farm Industries CRC programs (eg Dear *et al.* 2003; Dear *et al.* 2008). However, despite significant government investment a number of other species have repeatedly failed to find appropriate commercial success despite showing good promise in trialling and selection, such as summer dormant perennial ryegrass (Reed *et al.* 1999), sainfoin, lotus and sulla (Dear *et al.* 2003; Dear *et al.* 2008) with the potential value of these species known since at least the 1960s. Despite the large and concerted effort has been placed on alternative legume breeding and selection and the number of cultivars released the market remains small with only a few cultivars successfully commercialised (Table 1). Whilst this can be expected to some extent due to investment in market failure there is rarely an attempt to understand the cause of market failure before a breeding program is undertaken. The assumption is that the market failure is due to a lack of adapted cultivars.

A better approach would be to conduct a thorough market analysis before the commencement of a breeding program for novel species and environments to identify the reasons for existing or potential market failure so that product development funds can be spent accordingly. The development of tools for the successful remediation of market failure (Figure 4) can then commence prior to commercial release.

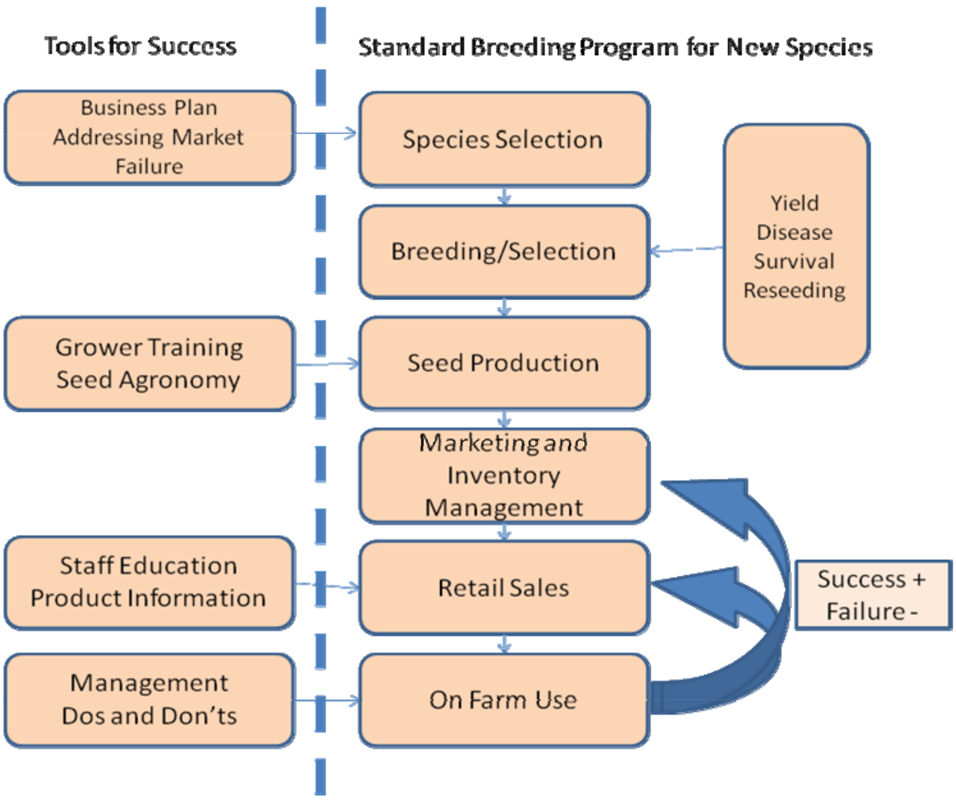

Figure 4. Schematic outline of breeding and commercialisation of new species

4.3 Breeding of major species.

Most of the major pasture species are outcrossing and the major method of breeding of synthetic cultivars with multiple parents through either open pollination or polycross methodologies. Some programs will use some form of progeny evaluation (most commonly half sibs) and most would use post-synthesis selection whereby multiple synthetics are taken forward for advanced evaluation. The relative pros and cons of these alternative methods can be summarised as follows:

- **Half-sib family evaluation**
- **Pros**
  - Large numbers of parents
  - Multi-site progeny evaluation
  - Appears 'scientific'
- **Cons**
  - Uses only $\frac{1}{2}\sigma^2_A$
  - Expensive
  - Not suited for recurrent selection
  - Either leads to a variety or it doesn't

- **Post-synthesis selection**
- **Pros**
  - Acknowledges shortcomings of HSPT
  - Relatively cheap
  - More evaluation under realistic conditions
- **Cons**
  - Reduction in quantitative data
  - Pedigrees seldom followed

The Agriseeds NZ perennial ryegrass program is illustrated diagrammatically in Figure 5 as a general example of scale and stages of testing.

Breeding Programme Outline
Perennial Ryegrass

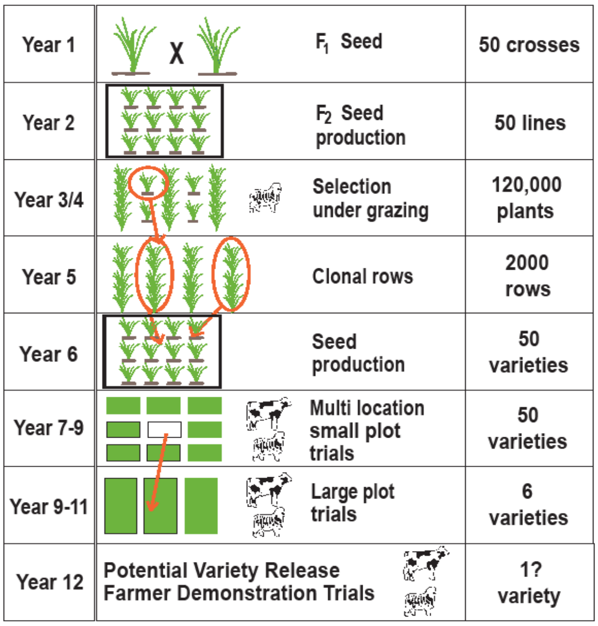

Figure 5. Diagrammatic representation of Agriseeds NZ perennial ryegrass breeding program (source Agriseeds NZ)

Some comments on the potential to improve breeding methodologies are listed in Section 5 of this report.

4.4 Breeding and research programs serving the Australasian market

There are several multinational companies/alliances that dominate seed sales in the Australasian market:

- The Royal Barenbrug Group of Companies (Barenbrug, NZAgriseeds, Heritage Seeds)
- PGGWrightson (also with AgResearch through the Grasslands Innovation Partnership in ryegrass and tall fescue)
- RAGT/Joordans/SeedForce
- DLF Trifolium
- Germinal Holdings (marketing cultivars developed by IBERS)

There are also a number of smaller companies and marketing groups such as Valley Seeds, Seed Distributors and Pristine Forage Technologies that tend to focus more on niche species/environments (although not exclusively) and generally lack the *in house* research and development capability of the major groups.

Research efforts in the private sector have largely focussed on near commercial activities related to endophyte, seed production and storage, disease resistance and selection for later flowering times. Notably there has been little application of quantitative genetic principles or economically based breeding objectives in any of these programs (see sections 4.3, 5.1).

There are also a number of strong public sector research agencies in forage improvement internationally, they all tend to have similar objectives and strong linkages with the private sector

- DPI Victoria/MPBCRC/DFCRC strong focus on developing technologies across a range of traits such as forage quality, biotic and abiotic stress resistance to support breeding of species for the particularly for the high rainfall and dairy sectosr: partnerships with a range of companies including PGGWrightson and the Barenbrug Group.
- IBERS strong focus on breeding white clover, tall fescue and ryegrass for the UK market and extensive programs in carbohydrate metabolism (leading to the ‘High Sugar’ cultivars AberDart and AberMagic that are marketed in Australia/NZ) and delayed leaf senescence (with release of the ‘Stay Green’ trait in turf cultivars such as AberNile; and research on the role of ‘Stay Green’ on improved protein metabolism in ruminants).
- AgResearch NZ has historically been a world-leader in forage genetics and is widely recognised as the world leader in white clover genetics and breeding and the development and commercialisation of endophyte technologies with (broad patent positions in this area). The breeding programs have had a strong emphasis on germplasm introduction and incorporation into elite germplasm and the selection of cultivars that perform well under grazing. In recent times AgResearch has directly partnered/funded its research though a number of public-private sector alliances such as Pastoral Genomics and Grasslands Innovation.

5 Opportunities for new investment in pasture plant improvement

New investment in pasture plant improvement and genetics will be critical to both maintain and improve the rate of genetic gain in pastures to support profitability of grazing industries. With the declining public sector investment in cultivar development there has been an increased emphasis on investing in particular traits and technologies as part of a tool-box to support breeding programs. Recent examples of this include:

- Research into summer-dormancy as a tool to develop persistent cultivars
- Endophyte technologies
- Development of molecular marker technologies
- Development of GM technologies for disease resistance and forage quality

There has been a general trend that companies have been more willing to partner with programs that have a trait outcome, perhaps because they are more experienced in marketing cultivars based on specific attributes rather than genetic gain (GM programs are included here as it will be the trait that is marketed not the methodology through which it was achieved).

There have been fewer programs that attempt to more generally improve the process of breeding or seek to integrate technologies into systems and methods that lead to both the integration of these new technologies in breeding programs and also system-wide improvements in the rate of genetic gain. One exception to this has been the recent planning within the MLA co-invested MPBCRC program to implement molecular markers and the linking of that project to the work done on genetic improvement methodologies within Pastures Australia. Future investments should seek to complement this project through either broadening the focus and capturing outcomes that would not be achieved the project itself or through adapting the methodologies for use in a broader range of target species and environments.

5.1 Development and implementation of an objective language for plant improvement

Pastures Australia has recently commissioned an extensive scoping study for the development of an integrated genetic improvement and evaluation program for pasture plants (Barlow and Fennessy 2008) and this has recently been advanced and revised as part of the project development for a new phase of the *Candidate Gene Based Markers for Pastures* project within the MPBCRC/DFCRC. It is not proposed to extensively repeat these findings in this report but rather how this work may be expanded/broadened into other species/areas/breeding companies.

The PA project had at its cornerstone a nursery that combined many of the elements inherent in an efficient breeding program that was enabled through the use of molecular markers and quantitative genetic principles.

5.1.1 Defining the breeding objective

A sound breeding objective is the basis for commercial success of most breeding programs. However, in forage breeding programs the objectives are often trait/output based (disease resistance/altered flowering time) as opposed to improved gain against an economically valid index.

There is a feeling that ‘forage breeding programs are too complex and the environments too diverse’ for the economically based breeding objective approach to work in pasture plant breeding. To change this paradigm it will be necessary to counter both of these arguments.

Forage programs too complex?

The basis of a successful pasture is the consistent supply of nutritious fodder, with profitability of pasture based systems a function of yield, quality and utilisation averaged over the life of the pasture. From first principle it can be seen that this is similar to any lifetime profitability index for livestock. Given the work that has already been done through PA (Barlow and Fennessy 2008) the basic principles for defining a breeding objective in forages have been defined so there is no need to start again from first principles. Rather the approach should be to expose a broader group of breeders to these principles and challenge them so that the principles may be refined. It is proposed that MLA commission a working group to explore the development of these breeding objectives and that this working group initially have a broad representation from the commercial sector. If it becomes clear that only some companies are truly interested then they will become the champions of the project, this situation would then be analogous to the early stages of modern animal breeding where some breed societies adopted breeding objectives and quantitative assessments before others.

It is important to note that the Jan/Feb 2010 issue of the Australian Dairy Farmer magazine has a one page advertorial for a seed company that uses the following quotation:

"Most farmers now use EBV's in selecting genetics for their herds, so why not grasses?"

The article then goes on to describe an attempt at integrated data analysis and conversion of yield and quality into an economically based indicator of the relative merit of Italian ryegrass cultivars.

Given the broad knowledge of the PA project among commercial seed companies and the general acceptance of its relevance it is interesting to see this topic at least getting a mention from a commercial company in a trade journal and may indicate that there is the start of a 'mood for change'.

Recommendation: That MLA commission a workshop and subsequent working group to further develop and validate breeding objectives for pasture species. This workshop initially to have a broad attendance for the purpose of disseminating progress to date and the working group to comprise representatives of those groups who wish to move forward with the concept.

Target environments too diverse

Unlike attempts to characterise environments and patterns of GxE in cereals at both regional (Cullis *et al.* 1996) and global levels (Mathews *et al.* 2007) little has been done to statistically review forage variety performance across environments in Australia and internationally. Smith *et al.* (1999) found that whilst family x location interactions were often significant in a dataset from perennial ryegrass they tended to be associated with non-rank change interactions suggesting that selection for performance across environments should be possible. Further evidence comes from the continued selection and commercialisation of cultivars with broad adaptation as evidenced by the wide use of cultivars such as Banquet/Banquet II perennial ryegrass across all dairy environments, or the adaptation of sub-clover cultivars within rainfall isohyets.

Recommendation: That MLA commission a statistical analysis of cultivar evaluation data for various target species (eg ryegrass, lucerne, phalaris) to identify the extent and nature of GxE within the target markets for these species.

5.1.2 Estimating breeding values in pasture species

The statistical methodologies for estimating breeding values are the same for plants as for animals although issues such as polyploidy and plants with both sexual and asexual forms of reproduction can mean that some customisation of algorithms will be required.

The major limiting factors to moving forward in this area are both technical and logistical:

Technical issues

- Development of algorithms for pasture species
- Development and validation of 'novel' methods for pseudo-pedigree estimation
- Lack of knowledge of genetic correlations between traits and methods of measuring/estimating traits.

Logistical issues

- Companies may lack the technical expertise for detailed data collection and management
- Current capacity in statistical analysis and reporting is focussed on animal industries
- Companies have limited experience with/trust in existing data analysis providers
- Companies require data security and 'in house' flexibility for design of selection indices

Whilst these issues are not immediate problems for resolution as 'pilot scale' programs and nurseries can manage data capture and analysis on an individual project basis they will rapidly become issues as the program grows.

Recommendation: That MLA commission development and design of a business plan for an EBV service provider for the pasture genetics industry.

5.1.3 NVT

The design and implementation of an NVT program for pastures has been extensively discussed in Section 3.2.1. It is obvious that any NVT system that derives investment from the public sector should be scientifically robust and well managed. However there are some other issues that should be considered to extract full value from the trials:

- Linkages between cultivar trials and breeding nurseries (ensures sward performance data can be linked to early generation data)
- DNA for survival comparison/mixed sward trials (very often the yield dynamics of a perennial pasture are as important as the time point data, eg what species/cultivar contributed to yield and quality when? It may be that the surviving species/cultivars are there due to lower yield potential or forage quality.

Recommendation: That MLA continue to explore the development of a robust NVT system for pastures with good linkages to breeding program data. This NVT program should have a strong and independent technical review to allow changes in trial methodology and analysis to be implemented.

5.2 Breeding in an environment of market failure

There is a trend for public sector funds to be used to support breeding activities in areas of perceived market failure. Generally market failure is perceived to have occurred when there are not private sector breeding activities targeting a particular market or species. However, there are various other reasons why 'market failure' may exist including

- The market may be too small to be commercially viable
- Other species/environments have enough general adaptation to the target that companies seek to market those species into the target region for economies of scale
- Previous attempts to domesticate/commercialise the species have failed
- Existing germplasm lacks management packages/marketing plans for commercial success

The provision of further germplasm is unlikely to solve any of these causes of perceived market failure.

5.2.1 Defining market failure

Before any investment occurs into the breeding of novel species there should be a thorough market assessment that addresses a range of technical and commercial aspects that seek to define the reason for the market failure and hence public sector investment and how these are proposed to be overcome. Too often these issues are not addressed until germplasm is ready for commercialisation. It may not be appropriate for all solutions to be defined in advance of the commencement of breeding activities but they will have been identified and a plan in place to address them. Such issues include (along with examples where they limited the commercial success of a species):

Technical

- Absence of antiquality factors to prevent release (eg coumarins in *Melilotus*)
- Assessment of weediness and likelihood for invasiveness (eg removal of landcare incentives for tall wheatgrass).
- Seed production (this has been a problem with numerous species/cultivars)
- Rhizobial requirements (eg Sulla and other alternative legumes)
- Grazing/management requirements

Commercial

- What market size is required for commercial success in this species
- How will seed production/inventory be managed?
- How will the new concept be marketed to overcome current market failure?

It is recommended that MLA require all project proponents develop a 'market-failure' assessment and remediation strategy either before commencement or early into all new projects where investment is sought based on current market failure.

5.2.2 Public-private partnerships

There generally needs to be some form of public-private partnership for the successful utilisation of genetic innovations in forage systems.

Traditionally this has been though the private sector licensing a technology late in the product development cycle whilst this process can prove to be simple in terms of contractual and relationship management it has proved to be unsuccessful for many publicly funded plant varieties and the realistic economic returns to investors are small given the likely royalty (5-10% of wholesale seed sales) and the small market size for most cultivars particularly niche species.

Several large public sector research agencies have sought to remediate this problem by forming partnerships with private sector companies that encompass a range of products/technologies (Section 5.4; Appendix1), these models are having some success with the development of technologies but tend to see that the public sector R&D is tied to one company or group of companies with few examples of cross-licensing yet to be seen in forages. The cross-licensing of technologies is more common in major crop species such as corn and soy where technologies will be made available to a broad range of companies (eg Roundup Ready) or for the stacking of traits in individual cultivars.

There is much more limited experience of public-private partnership models where there is the clear desire of the public sector investor to see that the technology is made available to all who choose to license/adopt it. One model that warrants further exploration is where the broad concept of a technology (eg EBV) is communicated to and adopted in principle by an industry peak body (such as the proprietary seed breeders and marketers group of the ASF) with the knowledge that the technology will be made available to all (subject to whatever licensing conditions) but there are clear advantages for early adopters. This approach would ensure that there are not allegations of bias on how technologies are made available and the need for multiple individual discussions with companies during the formative stages of concept development.

5.3 Improving the use of quantitative genetics in plant breeding

There is limited use of quantitative genetics in most forage breeding programs as highlighted in a recent review commissioned by MLA (McRae *et al.*). As well as the move to EBV based systems as discussed in section 5.1 there are several specific issues relating to forage breeding where the improved use of quantitative genetics could improve rates of gain.

5.3.1 Mating designs

The reproductive biology of most forage plants allows the use of detailed mating designs that facilitate the better estimation of the breeding value of an individual and are more efficient than the commonly used half-sib progeny test (HSPT) (see Section 4.3) (Vogel and Pedersen 1993) eg:

- Restricted recurrent phenotypic selection (RRPS)
- Between and within family selection (B&WFS)
- Recurrent multistep family selection (RMFS)

The relative advantages of these systems over HSPT is described in Tables 2 and 3

Table 2. Comparison of time requirements for recurrent breeding schemes applicable in cross-pollinated perennial plants

	Time (Year)			
Activity	RRPS	HSPT	B&WFS	RMFS
Establish source/Selection nursery	1	1	1[b]	1[b]
Evaluation of nursery	2	2	2[b]	2[b]
Polycross selected genotypes	3	3	3[b]	3[b]
Replicated progeny test		4,5,6[a]	4,5,6[a,c]	4,5,6[a,c]
Recombine selected plants		7	7	7,7[d,d]
Initiate cycle 2	4	8	8	8

[a] One establishment year followed by two years of evaluation

[b] These steps needed only to commence scheme

[c] Families evaluated on a plot basis in the first evaluation year followed by within family selection in the following year

[d] Two nurseries must be established

Table 3. Expected genetic gain (ΔG) per cycle and per year for recurrent breeding schemes applicable to perennial plants

Breeding Scheme	Expected gain/cycle	Gain/year

		(% of σ^2_A)	
RRPS	$\Delta G = k\, \sigma^2_A\, (\sigma_{PS})^{-1}$	33.3	
HSPT	$\Delta G = k\, ½\, \sigma^2_A\, (\sigma_{PFM})^{-1}$	7	
B&WFS	$\Delta G = k_1\, ¼\, \sigma^2_A\, (\sigma_{PFM})^{-1} + k_2\, ¾\, \sigma^2_A\, (\sigma_{PW})^{-1}$	25	
RMFS			
- B&WFS	$\Delta G = k_1\, ½\, \sigma^2_A\, (\sigma_{PFM})^{-1} + k_2\, ¾\, \sigma^2_A\, (\sigma_{PW})^{-1}$	25	
- HSPT	$\Delta G = k\, ½\, \sigma^2_A\, (\sigma_{PFM})^{-1}$	12.5	37.5

A further advantage of these systems is that they have much reduced rates of inbreeding compared to HSPT.

The major impediment to the commercial acceptance of these mating structures appears to be the relatively low knowledge of quantitative genetics principles among breeders and the lack of precision with which rates of gain are measured and marketed. This is only likely to change when the issues described in Section 5.1 are addressed.

5.3.2 Optimising parental numbers

Most cross-pollinated pasture species suffer from inbreeding depression and breeders have traditionally avoided this problem by being conservative with the selection of parents which in turn reduces genetic gain. There have been studies in lucerne where theoretical optimal numbers of parents are compared to commercial practice. Between 1973 and 1982, over half of the lucerne (alfalfa) (*Medicago sativa* L.) cultivars released in the U.S.A. were developed using more than 40 parental genotypes (Hill, Jr. *et al.* 1988) with many having more 100 parental genotypes (Sledge *et al* 2003). Several studies have been conducted on the optimization of parental number in lucerne, but the exact optimum number of parents has been shown to vary from population to population (Kidwell *et al.* 1999; Hill, Jr. and Elgin, Jr. 1981; Sledge *et al.* 2003). Hill and Elgin (1981) observed small differences in yield between 4-, 8- and 16-parent derived synthetics, possibly due to inbreeding depression caused by the method used for seed generation. The results indicated that the optimum number of parents was greater than four and less than 16, eight parents being the optimal estimated number

A major impediment to the management of inbreeding forage breeding has been the lack of reliable pedigree information to enable the derivation of relationship matrices and to estimate co-efficients of kinship and inbreeding. The recent development of molecular marker technology for major pastures species allows for the estimation of relatedness in the absence of pedigree information. The combination of these marker-based estimates of relatedness with further development of commercial software such as TGRM or Abacus Accelerator packages will allow pasture breeders to select parents to maximize diversity and minimise inbreeding. The major impediment to seeing this activity find commercial acceptance is the lack of a co-ordinated effort to develop commercial-ready application through combining technologies from plant and animal genetics. MLA is a co-investor in the molecular marker technologies for ryegrass, white clover and tall fescue and a number of markers are publicly available for lucerne.

Recommendation: That MLA commission the development of a commercial-ready mating allocation program for forage species with links to existing software and marker technologies.

5.4 Education and training

One of the clear issues facing forage plant breeding and genetics is the lack of training that most staff involved in the supply chain have had in plant breeding generally and in quantitative plant breeding in particular. For instance there may be only one PhD trained plant breeder operating in the private sector in Australia and only 3 or 4 in NZ. This situation is unlikely to change when there are few staff with experience in forage plant breeding lecturing in Australian universities an exception to this trend may be UWA where through the links with CLIMA there is staff with forage-based experience with a particular strength in genetic resource characterisation and utilisation.

There is an acknowledged world-wide shortage of tertiary trained plant breeders (Baenziger 2006; Gepts and Hancock 2006; Guimarares and Kuenemann 2006) and approximately 50% of the crop breeders in Australia are over 50 years old (Fellowes 2006) creating strong competition for graduates and a tendency for them to join well resourced programs in the major food crops.

5.4.1 Undergraduate

The following universities have traditionally had strong groups teaching plant breeding at undergraduate level:

- University of Adelaide
- University of Western Australia
- University of Sydney
- University of Queensland

Each of these groups has historically had several senior academic staff with a very strong emphasis on the breeding of self-pollinated cereal crops such as wheat and barley or around genetic resource characterisation and utilisation strengthened by the need for continual acquisition of novel disease resistance and quality alleles in these species.

It is worth noting that Victoria has not historically had a strong 'school' of plant breeding academics in either of its major agricultural universities (Melbourne or LaTrobe) where there has usually only been one senior academic at any given time and now there is only a part-time position at the University of Melbourne.

There has also been little 'cross-fertilisation' between animal genetics and breeding which has tended to be more quantitative in its approach and plant breeding although the University of Melbourne did run a combined genetics and breeding unit for many years, perhaps facilitated by limited staffing in both the plant and animal genetics disciplines.

The opportunity to influence change in these areas needs to be assessed against the background of a declining number of students enrolling in agriculture in general and the 'harder' subjects in particular such as breeding and genetics that is viewed to be more difficult due to a strong statistical basis.

Exposure

In order to increase the number of undergraduate students interested in forage plant breeding it is necessary to provide them with exposure to the discipline and its subsequent career opportunities. As part of attempts to develop a national plant breeding curriculum, Professor Dianne Mather from the University of Adelaide is leading a project: *Plant breeding by example: contextual examples linking theory with practice in plant breeding education.* There is currently no plan to develop a forage breeding module in this program that will be available to students across Australia.

It is recommended that MLA liaise with Professor Mather to determine if it is possible for a relevant forage breeding module to be included in the program: Plant breeding by example: contextual examples linking theory with practice in plant breeding education.

Teaching

In the longer-term it will be necessary to have academic staff teaching quantitative plant breeding and this can best be achieved initially through forging links between academics in plant and animal breeding. However, for these linkages to be successful there is still the need to have staff with forage expertise within the university system. Further efforts could be made similar to those recently used by LaTrobe University and DPI Victoria where a number of senior DPI staff in Biosciences now have joint appointments with LTU (which unfortunately does not have a strong history of plant breeding education). The advantage of this system is that these scientists may already have well-resourced research programs negating the need to resource a 'start-up' chair or similar position.

Another option is for MLA to support and promote the appointment of a senior scientist into an adjunct role within a university with the aim of influencing the national plant breeding curriculum and forging linkages between plant and animal geneticists within the university system and value adding to existing MLA funded initiatives in pasture plant genetics.

It is recommended that MLA seek to influence the development of a national plant breeding curriculum to ensure that quantitative aspects of plant breeding are adequately addressed especially through the strengthening of interactions between plant and animal geneticists.

5.4.2 Postgraduate

MLA, along with other RDCs, have been consistent investors in postgraduate education and with the consolidation of research activities into national programs and CRCs there are many opportunities for prospective students and projects to gain support for post-graduate research programs. Given that most plant breeders will be employed by the private sector one avenue that has not been fully explored is the possibility of having postgraduate students embedded within a commercial program, this would allow them practical experience with 'hands on' breeding but also access to datasets etc that would be beneficial for their PhD program, the chance for international travel as part of this program would also prove attractive to would be students. It is possible that the MLA donor company model could provide a mechanism for funding these scholarships.

5.4.3 Training of industry/retail staff

The lack of genetics knowledge/training among industry and retail staff is most likely the largest impediment to the consistent dissemination of knowledge within the pasture genetics supply chain. Most sales and technical staff are trained to degree or diploma level with limited or no post-secondary training in genetics. They have been trained to be sellers of products or concepts and not genetic gain. Whether or not a product is stocked on a retail shelf can be more related by rebates and sales margins than differences in performance. All of the incentive is for agronomists and sales staff to recommend what they can supply for both economic and technical reasons as producers often seek this advice when they are ready to sow. There is also a high turnover of staff at the retail level and it is unlikely that this will change; therefore staff will need to have ready access to quality information. One mechanism for providing this information would be through the development of a *"Pasture Genetics Manual"*. MLA has experience with developing tools such as the *MLA More Beef from Pastures – The Producers Manual* and the Tips and Tools sections of the MLA website. The *Pasture Genetics Manual* would contain sections on:

- species choice and adaptation
- interpreting trial performance data
- endophyte technology

- tetraploid technology
- developing economic-based indicators of genetic performance
- a glossary of technical terms and definitions
- descriptions of other technologies – molecular markers, gm etc as they near commercial application

The aim of this document would be to provide general information rather than recommend individual cultivars *per* se. A document somewhat like this existed some years ago in New Zealand that had been printed by NZ Agriseeds for distribution to retail agronomists but also included information on company specific products.

Some of this information already exists but the aim of the "*Pasture Genetics Manual*´ would be to keep the information up to date and in one place (both hard copy and electronic forms) for ease of access.

6 Conclusions and recommendations

This report summarises the feedback on PA projects that are strategically important to MLA and recommends ways to further develop these project areas; the report also presents a strategic analysis of the ways and means to increase the adoption of quantitative genetic principles in forage plant breeding in order to increase rates of genetic gain and provide producers with more informed choices regarding the value of pasture genetics. As a result of this analysis, 10 specific recommendations are made for further consideration/development:

1. *That MLA considers appointment of a forage genetics co-ordinator to manage relationships with ASF, seed companies, research providers and the education sector with a primary emphasis on raising the general awareness of forage breeding issues and the overall rate of genetic gain in forages. This position should complement the PA co-ordinator role and not duplicate it; further it is recommended that the forage genetics co-ordinator should have a strong technical knowledge.*
2. *That MLA commissions a workshop and subsequent working group to further develop and validate breeding objectives for pasture species; this workshop should initially seek a broad attendance for the purpose of disseminating information on progress to date; the working group would comprise representatives of those groups who wish to move forward with the concept.*
3. *That MLA commissions a statistical analysis of cultivar evaluation data for various target species (eg ryegrass, lucerne, phalaris) to identify the extent and nature of Genotype by Environment (GxE) interactions within the target markets for these species.*
4. *That MLA commissions development and design of a business plan for an EBV service provider for the pasture genetics industry.*
5. *That MLA continues to explore the development of a robust NVT system for pastures with good linkages to breeding program data; it is further recommended that an independent technical review of the NVT program is conducted to allow changes in trial methodology and analysis to be implemented.*
6. *It is recommended that MLA requires that all project proponents develop a 'market-failure' assessment and remediation strategy either before commencement or early into all new projects where investment is sought based on current market failure.*

7. *That MLA commissions the development of a commercial-ready mating allocation program for forage species with links to existing software and marker technologies.*
8. *That MLA liaises with Professor Mather to determine if it is possible for a relevant forage breeding module to be included in the program: <u>Plant breeding by example</u>: contextual examples linking theory with practice in plant breeding education.*
9. *That MLA seeks to influence the development of a national plant breeding curriculum within one or more universities to ensure that quantitative aspects of plant breeding are adequately addressed especially through the strengthening of interactions between plant and animal geneticists.*
10. *That MLA (potentially with support from other Pastures Australia partners) considers the preparation of the "Pasture Genetics Manual" as an industry-wide resource for seed resellers and producers.*

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