AW HOWARD MEMORIAL ORATION

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"Legumes, Livestock and livelihood in the Australian Mixed Farming System"

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(AW Howard Memorial Medal Recipient, 2013)

Legumes, livestock and livelihoods in the Australian mixed farming system

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Abstract. This Howard Oration describes the pathway that I have taken towards my specialisation in 'big picture' agriculture. A simple protocol is presented for the analysis of agricultural systems by using descriptive or quantitative indicators of five system properties: productivity, sustainability, profitability, social wellbeing and political acceptability. These properties are further illustrated by considering four important issues in the Australian sheep-wheat belt, a distinctive world food production system. The issues are the supply of and demand for legume nitrogen for crops, reconciling agricultural and natural resource objectives, the low profitability of farms in relation to production and marketing risks, and the conflict between enterprise specialisation (simplicity, scale) and diversification (complexity, resilience). Agricultural R&D has removed important technical constraints to progress in the sheep-wheat belt but insufficient attention has been paid to the economic and social issues embedded in this mixed farming system. I conclude that further progress will come from an integrated approach that encourages more effort on solving the social, economic and political issues in Australian agriculture, rather than a strict focus on agricultural productivity and sustainability.

Keywords: Agricultural system, sheep-wheat belt, productivity, sustainability, profit, social, political.

AW Howard Trust

The AW Howard Memorial Trust was established by the Australian Institute of Agricultural Science (now Ag Institute Australia) in 1964 to commemorate the unique contribution of Amos Howard, a nurseryman, in the use of subterranean clover as a pasture plant in Australia. The aim of the Trust is "to encourage and promote research and investigation in the fields of natural science and social science, including economics, which relate to the development, management and use of pastures". Since its inception, the Trust has each year awarded at least 4 and up to 18 travel assistance grants for pasture researchers to undertake study tours and attend national or international conferences. From 2003/04, the Trust has also awarded one or two research fellowships each year, each in the form of top-up postgraduate stipends of $5,000 per annum for up to three years. A group of prominent agriculturalists administer the Trust, currently chaired by Professor Pauline Mooney of the South Australian Research and Development Institute and assisted by a small secretariat. One of the keys to the success of the Trust has been the financial acumen of the stock-broker member, originally Brian Cole and currently Jeff Glasson. On behalf of all recipients who were assisted by the AW Howard Memorial Trust, I thank the establishment committee and the trustees, past and present, for their expertise and effort in fostering the careers of pasture scientists, thereby contributing to pasture research, extension and policy in Australia. Many of the Howard scholars and fellows are in the audience at this Congress, and I am proud to join them as the second recipient of the AW Howard Medal, following Dr James Ridsdell-Smith in 2011, an entomologist.

Career highlights

Higher degree studies

My interest in pastures was kindled by the then Senior Lecturer at the University of Sydney, Frank Crofts, who ensured that we read the scholarly writings of Professor Colin Donald on pasture agronomy. I went on to occupy a Teaching Fellowship position at the University of Sydney from 1963 to 1965 inclusive, and in 1967 was awarded a Master of Agricultural Science degree for my thesis on the seasonal production and response to nitrogen of a range of temperate perennial grasses. Near the end of these studies, I regarded my plant science skills as quite sound but I knew that my knowledge of pasture utilisation by grazing animals was weak. Hence, I enrolled myself in a week-long school on pasture utilisation, held at a site handy to CSIRO Canberra, where several of the gurus in pasture systems (Bill Willoughby, Dr Fred Morley and Dr Graham Arnold) were located. This experience both broadened and deepened my understanding of pasture agronomy and I enthusiastically absorbed the knowledge of these mentors on how pastures could be converted into meat, wool and dollars. This knowledge set me up to apply for a most interesting PhD assignment at the University of New England (UNE), where they were looking for someone to evaluate and understand grass-clover relationships during pasture development and their relevance to cattle bloat. At UNE (1966-71), I came under the influence of Professor

Alec Lazenby, as well as a great band of postgraduate students in the Department of Agronomy and a talented academic team in the Faculty of Rural Science, led by a systems man, Professor Bill McClymont.

Research with NSW Agriculture

By the time I completed my PhD work at UNE, the Department of Agriculture whisked me off to the Agricultural Research Institute at Wagga Wagga in southern NSW, to tackle a vaguely-stated problem, maintaining the productivity of improved pastures (subterranean clover + superphosphate, Smith 2000) on high rainfall (600+ mm per year) grazing country south and east of Wagga. Those early years at Wagga were notable for the following matters:

- First, I failed in what I was sent down there to do – discover a reason for pasture ill-thrift. My early experiments were inconclusive, primarily because I did not understand the underlying problem, which was a soil pH decline in pastures treated with the then universal prescription of sub clover and super, a decline that triggered toxic quantities of aluminium and manganese ions into the soil solution. Fortunately, as pasture group leader at the time, I was able to encourage the early efforts of other scientists at Wagga (see Scott *et al.* 2000) to understand the susceptibility/tolerance of pasture and crop species to these toxic ions and to discover how the problem could be ameliorated by liming.
- Second, Wagga Agricultural College needed a part-time lecturer in the subject of 'Ecology', and I moonlighted to perform this role. The further that I explored the subject of Ecology, the more I appreciated the excellent texts available on ecological principles (Odum 2005, 5th edition) and ecosystem concepts (Van Dyne 1969). Ecology provided me with a new framework for my agricultural knowledge and thought, and once again my knowledge deepened and broadened.
- Third, I revelled in the complexity of the mixed farming system of the Riverina region, part of Australia's famous and remarkable sheep-wheat system in which years of leguminous pastures were grown to replenish soil fertility and break disease cycles after several years of crop growth. With my colleagues, who by then included Roger Southwood, Des FitzGerald and David Hall, we tackled topics such as lucerne + subterranean clover mixtures for the production of beef (Wolfe *et al.* 1980) and lamb (Hall *et al.* 1985), dual-purpose (grazing + grain) cereal crops and evaluating a new range of low-oestrogen subterranean clovers for use in southern and central NSW (Wolfe 1985).

These were busy times, towards the end of which I spent an 11-month period in 1980 as the Reserve Bank Research Fellow at the University of Western Australia (UWA) in Perth. Here, I interacted closely with plant scientists who were dedicated to subterranean clover improvement. This team comprised the core of the National Subterranean Clover Improvement Program, of which we were an important node in southern NSW from 1972. The program was funded in part by the wool, meat and wheat industries. The WA members of subterranean clover team who were of most influence and assistance to Roger Southwood and me were Professor Walter Stern and Dr Bill Collins of UWA, Dr Reg Rossiter of CSIRO, and Drs Clive Francis and John Gladstones of the Western Australian Department of Agriculture. While 1980 was for me a most enjoyable year away, at around the same time my Wagga colleagues transferred to other jobs or different locations (Roger Southwood to Sydney as the Principal Agronomist Pastures for NSW Agriculture, Dr Des FitzGerald to Glen Innes Agricultural Research Station and Dr David Hall to Grafton ARS).

Research administration

For my personal research activities, worse fortune was to follow, because I was soon promoted to newly-created regional positions in research administration, first at Wagga as Director of Research (1981) and then at Tamworth as the Regional Director of Research (1983) for the New England, Hunter and Metropolitan Region, which stretched from suburban Sydney north-west to the Queensland border. Thus, the departure from Wagga of all members of the original pasture/livestock team, their involvement in new topics and my administrative duties impacted on our ability to write up properly the research work that we had completed at Wagga. Several of our joint papers, particularly those on subterranean clover evaluation and the work with dual-purpose crops, were consigned to the Journal of Bottom Drawers. Some of these losses were recovered by the appointment of an admirable successor in my pasture agronomy role at Wagga, Brian Dear, and I made sure that he had a full set of the most meaningful results from our subterranean clover evaluation program. Furthermore, I was at a later time able to pass on the information that we had won on dual-purpose crops to other agronomists and industry bodies (*e.g.*, Radcliffe *et al.* 2011). However, my warning to early career researchers is clear – ensure that your research is written up in timely fashion or forever regret not doing so!

From 1983 to 1990 at Tamworth, I had a fine time as an agriculturalist, leading teams of agronomists, soil and cereal chemists, plant breeders, plant pathologists, entomologists, livestock scientists, horticulturalists and even economists at several research centres; collaborating with a senior regional management team of specialists in research, advisory, veterinary, education and management spheres led capably by Dr Allan Smith (a soil nutritionist); undertaking three visits to Thailand and one to southern China; and interacting with a range of industry people and research corporations.

A particularly inspirational role was as a member of the Cotton Research Committee (1983-86) and its successor, the Australian Cotton Research Council (1986-89), which at that time was chaired by another former pasture agronomist who found his way into administration, Dr David ('barley grass') Smith (see Smith 2000). I remember well my appointment to the Cotton Committee – I was rung by Dr Stan Grimmett, the Department of Agriculture's Executive Director of Research and the conversation went like this:

Stan: *"Ted, the Department has been asked to provide a rep for the new Cotton Research Committee. You can do it!"*

Ted: *"Aw, c'mon Stan, I wouldn't know a cotton bush if I fell over it!"*

Stan: *"That sounds to me as good a qualification as any, Ted. You're it!"*

This appointment started a journey for me into the vibrant Australian cotton industry that, by the end of the 1980s, led the world in several aspects of this crop – cotton breeding, flood irrigation technology, soil management, insect management and grower services (provided by scientists and consultants). The cotton phase was a most satisfying period of my career.

Charles Sturt University

In 1990, NSW Agriculture went through another restructure, relocating their headquarters from Sydney to rural Orange, abandoning the regional administrative model and consolidating along industry lines (Plant Industries, Animal Industries and so on). I was fortunately saved from a regional dead-end by my selection as Professor of Agriculture at the newly created Charles Sturt University (CSU) in southern NSW. This career move took me into the arcane world of academia. Whilst there was a heavy administrative load here, too, I became reconnected to research, in part through my post-graduate students and in part through my membership of several research committees, most notably with the Grains R&D Corporation. In doing so, I was able to put from my mind one myth that is beloved by many scientists at the bench, namely, a strange belief that administrators lose all their research skills and are unable, even with abundant time, to resume a research career. I am sure that there are many like me who realise that, if anything, one's potential research skills improve with the experience of research and academic leadership. While the administrative environment may restrict personal opportunity, new skills are learnt and literature from new disciplines must be evaluated, so the potential to contribute new knowledge improves. The electronic age has further enhanced the prospects for a return to the research bench because research information can be updated so much more quickly than in pre-computer days.

Wisely, as it turned out, I decided it was important for a Professor of Agriculture to profess, and so I participated at a modest level in the teaching program, at first in my 'home discipline' Agronomy and later in Agricultural Systems subjects. With my colleagues Tony Dunn and Peter Cregan at CSU, along with the full-time and distance education student cohorts, we worked through a series of 'wicked problems' in agriculture, problems that could not necessarily be understood or solved by the application of an approach that is based solely on science. We encouraged students with a set of simple tools, such as: (1) agroecosystem analysis (Conway 1986); (2) Checkland's methodology, a protocol (Checkland 1981) that helps map the actors (players, special-interest groups) in a system, tease out their attitudes/beliefs, and devise better strategies to move toward system improvement; and (3), access to relevant journals such as *Agricultural Systems.* This experience in agricultural systems further enhanced my already high opinion of farmers, who depend on their ability to sift through the information and recommendations that come from a brace of well-meaning but often verbose specialists, technical experts, advisers and bureaucrats.

An active retirement

When I retired, in 2001, I took up a number of consultancies, roles and activities, each of which required a knowledge base as broad as it was detailed. I participated in R&D systems projects in countries such as the Democratic Peoples' Republic of Korea (2001-06, three visits), Eritrea (2005-10, three visits) and Myanmar (2012, one visit). Each of these projects was complicated by the local political environment. Another important activity was writing reviews on broad topics such as Australian pastures (Wolfe and Dear 2001, Wolfe 2010), farming systems (Wolfe and Cregan 2003), crop-livestock integration (Wolfe 2011a) and crop research (Wolfe 2011b). Furthermore, I worked voluntarily in community roles in rural and regional NSW, advocating cancer awareness (Chair, Regional Advisory Committee, SW Region, Cancer Council NSW) and Landcare (Chair, Murrumbidgee Landcare Inc.). Each of these roles was challenging and they all required the assembly and organisation of information that was wide-ranging in content (from research to information services and advocacy) and source (from evidence to beliefs). Even my recreational pursuits, travelling with my wife Sally to Europe, USA, the Mediterranean and Japan, involved hours of 'windscreen agronomy' from cars, buses, trains and planes, recognising farming patterns in the landscape.

With a diverse career behind me and my continuing location in a rural city, Wagga Wagga, it is natural that I have based the main content of my Howard Oration on two inter-related topics. The first is my approach to the analysis of agricultural systems, covering several dimensions. The second topic is a consideration of several issues that limit the performance of the most important agricultural system in Australia, the mixed farming model that operates in the sheep-wheat system of Southern Australia.

A protocol for the analysis of agricultural systems

Agroecosystems are agricultural systems in which the interrelationships between production and the environment are recognised. They comprise aggregates of more or less interconnected subsystems that produce and market crops and livestock to meet the needs of humans for food, fibre and services. Production subsystems do not operate in isolation but involve impacts on and interactions with the physical, biological and socio-economic elements of the environmental matrix. These interactions are complex and it is necessary to develop a simple framework for appreciating, describing and understanding agricultural systems.

Conway (1986) was one of few people to write about the process of gathering and analysing information on the functional properties of agroecosystems. He defined and used four properties – 'productivity' (production efficiency), 'stability', 'sustainability' and 'equitability' to analyse agricultural systems at local, regional and world scales. According to Conway, 'stability' is a measure of the

ability of the system to maintain productivity in spite of normal small-scale variations in environmental variables such as climate (affecting crop yield) or economic conditions (affecting farm profit). His definition of 'sustainability' refers to the ability (resilience) of an agricultural system to resist or recover from stresses (regular, small and predictable disturbances) or perturbations (irregular, infrequent, relatively large and unpredictable). Conway considered 'equitability' in the sense of the distribution of benefit (or cost) amongst farmers/graziers ($ per family), for example between agricultural systems or along the chain from production to marketing.

The above properties are useful for evaluating the behaviour of natural, agricultural and social systems but they alone are insufficient to describe agricultural activities at local, regional, national and world scales. Furthermore, there is conjecture about how Conway applied 'stability' and 'sustainability' in relation to forces that occur within or outside the farm boundary. The concept of 'sustainability' in agriculture –development that is designed to meet present needs while also taking into account environmental impacts and resource depletion, now and in the future – is now much broader than Conway's original definition (see Table 1), while still including aspects of resilience and stability. Likewise, 'equity' (fairness along the chain from producer to consumer and/or the proportion of total value) is but one feature of the 'people' factor in agriculture, a factor that has economic, social and political elements. These elements are important considerations in any local, regional and world analyses of agricultural systems.

I believe the features of agricultural systems are best summarised by a simple protocol of measures and/or observations that are grouped according to five main

Table 1. The main properties of agricultural systems together with a list of possible indicators that can be used to rate or measure the performance of the sheep-wheat mixed farming system in Australia

PROPERTY (DIMENSION)	**INDICATORS** (this is not necessarily a full list of the potential indicators)
PRODUCTIVITY (the production dimension) **Used by:** Scientists, government departments, statistical agencies (ABS, ABARES) and farmers	Measures of production and production efficiency Seasonal stocking rates (sheep/ha) on pasture types, land classes and whole property Animal efficiency (lambs per ewe, weight of lamb turned off per ewe, per ha or per farmer (or farm family) Crop yields (kg/ha), between and within paddocks Crop efficiency (kg/ha per farmer; kg/ha per mm of growing season rainfall; kg/ha per ML of irrigation; kg/ha per 100 L of diesel fuel; kg/ha per $1000 of inputs *etc.*)
SUSTAINABILITY (the environmental dimension) **Used by:** Scientists, government departments, statistical agencies (ABS, ABARES), environmental departments and farmers	Measures of resource degradation or restoration over time Water runoff (ML/ha per 100 mm rainfall) Soil erosion rate (kg/ha/year) Change in soil pH (from x to y) Change in measures of soil fertility (*e.g.*, kg N/year) Changes in groundwater quality Changes in air pollution index, greenhouse gas emissions, C sequestration Use of fuel or electrical energy by agricultural enterprises Level of biodiversity (e.g., insects, birdlife, vegetation, microbial) on farms Ratio of supply and demand for agricultural and other relevant graduates per year
PROFITABILITY (the economic/financial dimension) **Used by:** Agricultural economists, statistical agencies, farm management consultants, bankers, agribusiness	Economic indicators: Physical indicators (area of land operated by farm family; total numbers of livestock; area of crops; production of grains, meat or milk) Financial indicators Terms of trade Total cash receipts, total cash costs, net income Farm business profit ($), rate of return on capital Farm business debt ($), debt/equity ratio Liquid assets, off-farm income Risk analysis based on accumulated cash flow analysis Financial equity (proportion of the farm business owned)
SOCIAL WELLBEING and/or ACCEPTABILITY (the social dimension) **Used by:** Rural sociologists, farm management consultants, rural counsellors, (statistical agencies)	Social indicators (a work in progress) Equity (natural justice, fairness) of production/distribution Distribution of costs and returns between producers, middlemen and consumers Statistics on farm people, families Number and age distribution of farmers and rural people Their education level, physical and mental health, happiness Social well-being of rural families (indices are needed for the attributes listed below): Standing, status and/or reputation of individuals and families Availability of services (rural vs urban) Strength of local networks (building and bridging) Opportunity (farm families vs non-farm families) Adaptive capacity, a collective term implying resilience, which may include a range of indices Conflict(s) between groups, sectors
POLITICAL ACCEPTABILITY (the political dimension) **Used by:** Political parties, govt. departments, agri-business, voters	Level of acceptability of a change in policy to government and political parties Internal flak rating (how will our employees and stakeholders react?) External flak rating (how will other sectors in the community react?) Acceptability to vested interests (*e.g.*, farmer organisations or consumer groups), individuals farmers and the community

properties, each representing a specific dimension – *productivity, sustainability, financial performance, social well-being* and *political acceptability*. These properties are self-explanatory and easy to remember, and could be used by all agricultural professionals when collecting information about a new location, situation or problem. Taken together, the properties and suitable indicators that measure them (Table 1) provide a 'rich picture' of any agroecosystem encountered by agriculturalists. The properties align reasonably well with the ideas of Nelson *et al.* (2010) about the types of capital that are needed to sustain rural communities and enhance livelihoods – physical (infrastructure, technology), natural (soil, water, biodiversity), financial (assets, cash), human (health, education) and social capital (connectivity and links between and within groups and networks in society).

So far as the indicators of properties are concerned, they are routinely collected and used in the case of the first three properties (productivity, sustainability and financial performance) but they are much harder to define and measure in the case of social well-being and political acceptability. Where indicators cannot be found, simple statements may be made through collecting information on the stakeholder's beliefs (from interviews, newspaper articles, personal surveys *etc.*). The development of a property-indicator matrix to describe the agriculture in an area, or to compare two or more agricultural systems, is useful to build up a personal picture of these systems, and to tease out the key constraints, conflicts and issues that are operating across time, space and geography. Such analyses also are useful in considering the current operation of a particular agricultural system, and how the system could function following the implementation of ideas to improve (or change) system performance.

Issues in Australian mixed farming

I turn now to a contemporary analysis of the predominant mixed farming system in Southern Australia, the sheep-wheat belt that lies inland from the coasts of southern Queensland, NSW, Victoria, South Australia and Western Australia (Figure 1). Here, the majority of farms are mixed (crop and livestock enterprises occur on each farm) rather than integrated (crop and livestock production are conducted as separate businesses that are spatially apart, such as one or more cropping farms supplying grain to a cattle feedlot). The reasons for and against mixed or integrated farming systems are discussed for several countries by Wolfe (2011a). The relatively infertile nature of Australian soils is the key reason locally for the popularity of mixed farming, either as ley farming (annual cycles of leguminous pastures and crops, Puckridge and French 1983) and/or phase farming (each phase of the pasture-crop cycle lasting for several years, Reeves and Ewing 1993). A legume pasture and livestock phase provides farmers with opportunities to exploit the natural synergies of mixed farming (Schiere *et al.* 2006, Wolfe 2011a), such as the provision of high quality fodder, the concurrent improvement in soil nitrogen content and a reduction in the exposure of the farm business to the higher levels of production and marketing risks associated with crops *vs* livestock. On the other hand, there are farmers

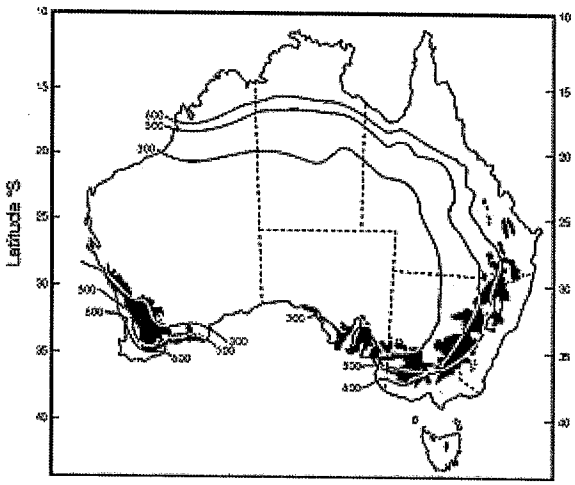

Figure 1. The Australian sheep-wheat belt. In 2011, this zone had 22% (30,000) of Australia's broadacre farms – Australian Bureau of Statistics (ABS, 2013). The 300, 500 and 600 mm average annual rainfall isohyets are shown.

who prefer to specialise, particularly towards the cropping enterprise of the overall mixed farm business, and they cite economies of scale and simplified management. Note that diversification also may occur within the main enterprises of crops (*e.g.*, wheat, oilseeds, pulses) and sheep production (*e.g.*, wool, fat lambs, Border Leicester x Merino ewes and/or a terminal sire stud).

For a range of reasons, the sheep-wheat system in Southern Australia is under threat. From my experience and knowledge of the literature, farming and farmers, I nominate four topics on system performance that must be addressed for the future. These topics are summed up in Table 2 and they are explored under separate headings, below. They are not necessarily the most important issues confronting farmers, scientists and industry leaders in the sheep-wheat belt; other individuals are free to nominate their list of significant generic and specific issues, such as climate change, the increasing age of Australian farmers and animal welfare. However, each of my nominated issues is important and interacts with others on the list. Collectively, they illustrate well the breadth and complexity of the challenges ahead for this farming zone.

Issue 1. Soil nitrogen supply to crops from pasture leys or phases

In Australia, average wheat yields declined towards 500 kg/ha in 1900 due to nutrient exhaustion and crop diseases. During the next century, yields increased over three stepped phases (Angus 2001) – 1900 to 1950, with average national wheat yields rising to a new plateau of 800 kg/ha due to new cultivars, superphosphate fertilizer and water conservation (with fallows); 1950 to 1990, to an average of 1.4 t/ha due to better varieties, legume nitrogen and timely sowing; and 1990 to 2000, 2.0 t/ha, due to break crops, selective herbicides, N fertilizer and no-tillage farming. However, progress since then appears to have stalled, a development that was assumed at first to be a result of several drought years during the first decade of the new millennium. Lake (2012a) removed drought from these

Table 2. Four issues that limit the performance of the sheep-wheat system in Southern Australia.

Issue	Specific description	Dimension:
Soil N supply to crops	The ability of leguminous pastures in meeting the nitrogen (N) demand of crops.	Production: productivity of pastures and crops
Agricultural and NRM objectives	Natural resource management (NRM) on Australian farms – reconciling producer pain with society gain.	Environmental: sustainability, biodiversity
Farm profitability	Will farmers ever be adequately rewarded for the production and marketing risks that they bear?	Economic/financial: business management
Striving for simplicity or coping with complexity?	There is conflict in Australian farming between enterprise intensification (scale, simplicity) and diversification. What are the characteristics of, and techniques for, enhancing farm management and team leadership?	Social: business model, farm family dynamics, organisation, control, skill

recent annual wheat yield records by a statistical averaging process but the yield plateau in Australia persisted, in contrast with an incrementally upward trend in world wheat productivity. Lake (2012b) concluded that the decrease in yield trend (kg/ha/year) during the most recent decade was due to an induced nitrogen deficiency, a consequence of a lower systemic reliance by farmers on legume leys in the cropping rotation and, furthermore, an insufficient replenishment of biologically fixed N with fertiliser N. Stephens *et al.* (2012) arrived at the same conclusion by way of different statistical pathways, as did Angus and Peoples (2012) through their understanding of N dynamics in Australian farming systems.

Prior to these analyses, Angus (2001) evaluated the supply and demand situation for dryland cereal crops in the sheep-wheat belt. Angus (2001) noted:

- In crop rotations that incorporated pulse crops and pasture legumes, there was a winter-spring deficit in N supply and the crop demand for N; and
- A strong increase in the overall demand for fertiliser N in wheat production occurred during the 1990s, due to a decreased capacity for soil N supply from N fixation following changes in crop rotations (more cropping, less pastures, displacement of pulse crops from the rotation by canola).

However, with a relatively dry decade from 2001 to 2010 and the escalating cost of inorganic fertilisers, Australian N fertiliser demand has since fallen from a peak of 950-1050 kt N in 1997-2004 to a little over 800 kt N in 2010 (Angus and Peoples 2012).

Lake (2012b) recommended that farmers reintroduce pasture leys into their rotations, mentioning a favorable outlook for sheep production. The same message is advocated by Angus and Peoples (2012), who highlighted declines in several indices of pasture quality and management of wheat belt pastures, such as stocking rates, superphosphate usage and sales of pasture legume seed. They found perplexing, during the decade to 2010, the apparent rise in the proportion of land growing crops in the sheep-wheat zone, above their calculated N-balance point of 60% and 40% of the arable farm area sown to crops and lucerne-based pastures respectively, when the economic indicators increasingly favoured mixed farming. This trend (see also Table 4 below) suggested to them that the residual value of biological N_2 fixation by pastures in a mixed farming system is not sufficiently appreciated or valued by farmers and their advisers.

My view is that farmers are rational people and their decisions, on crop/pasture balance and on whether or not to apply sufficient N fertiliser to replace the deficit in N fixation, are complicated by several factors, including the difficulty of monitoring or estimating crop N requirement, the much higher cost of N fertilisers in recent years, strategic practices by farmers to delay or cancel their commitment to additional fertilizer N unless rainfall in winter-spring is favorable and funds are available, the depletion of the cash reserves of wheat growers due to droughts, and the need to recover investments in machinery for cropping. The desirable proportion of cropland and legume pasture in farm rotations is a complex systems issue that was mentioned by several farmers and/or their advisers in a recent textbook on rainfed farming systems (*e.g.*, Kirkegaard *et al.* 2011, Long and Cooper 2011, and Ingold 2011). To add to the confusion, Angus and Peoples (2012) pointed out several deficiencies in the method and definitions used by the Australian Bureau of Statistics (ABS) to collect data on land use – ABS last sought information on the area of 'fertilised' pastures, an imperfect surrogate for 'improved pastures', in 2002; it does not now collect any useful pasture information[1]. The 'grazed area' on each farm can be inferred (total area less the cropped areas) but this area includes rocks, hills, uncleared woodland and some semi-arid areas. Present indications are that farmers should be encouraged to reduce their crop area, pay more attention to improved pasture management and livestock production, and improve their approaches to the tactical use of nitrogen fertilizer. How farmers might rethink the pasture/crop balance issue is dealt with further, below.

On the positive side, as well as new varieties of subterranean clover and annual medic, there is now a much more diverse array of pasture legumes available to farmers (Nichols *et al.* 2012), including perennial legumes and harder-seeded, deeper rooted annual legume species such as for example serradella (*Ornithopus* spp.) and biserrula (*Biserrula pelicinus*). Much of the credit for this diversity goes to Professor Phil Cocks who, during his tenure (1996-2004) of the Professor of Agriculture post at the University of Western Australia, reshaped agricultural thinking towards sustainability (Cocks 2003) and away from the reliance on subterranean clover and medic (Cocks and Bennett 1999).In many regions of the sheep-wheat belt, dryland lucerne (alfalfa) is more productive than annual legumes in terms of pasture growth and N fixation, and it

[1] This dearth of information on grazing lands is a significant constraint to grassland research and management in Australia, and the deficiencies need to be rectified. The ABS comes up short in monitoring social indicators, too.

Table 3. Management principles and thresholds defined by McIvor and McIntyre (2002) for managing temperate grassy eucalypt woodlands for resilience, compared with estimated values in the sheep-wheat (slopes and plains) and intensive grazing (tableland) agricultural landscapes (average annual rainfall, mm) of the Murrumbidgee catchment, southern NSW.

Management principles	Threshold/actual values for well-managed landscapes in southern NSW		
	Threshold for resilience	Actual, sheep-wheat landscape (400-600 mm)	Actual, moderately grazed landscape (600-900 mm)
Exposure to bare ground	<30%	<30% (was 50% in 1960)	<30%
Native grass content	Up to 60-70%	<5%	40%
Extent of intensive land use	<30%	+95%	+75%
Woodland or forest cover	30%	<5%	<20%
Size of woodland patches	Min. of 5-10 ha per patch	Median is <5 ha	Median is <5 ha
Core conservation areas	At least 10% of property	0-5%	5-10%

reduces problems from groundwater recharge. However, dis-advantages of lucerne are its sensitivity to grazing management and acid soils, competition between lucerne and annuals for moisture during the critical weeks of seed-set (spring) and germination (autumn) (Dear *et al.* 2007), and a lack of deep soil water for crops after the lucerne phase. Species such as French serradella (*O. sativus*) and biserrula are more hardseeded and water-efficient than other annuals and they offer additional weed control options (Loi *et al.* 2005); however, their greater adoption, especially in Eastern Australia, is constrained by: (1) an ongoing lack of investment in pasture R, D & E (Virgona *et al.* 2012), including the development of regional packages to improve pasture legume uptake; and (2), recent cuts to the numbers of extension staff.

Issue 2. Reconciling agricultural and natural resource management objectives

During my career, there have been several occasions when I have seen a clear division between the agricultural sciences and the environmental sciences. There is no structural need for this division since both are areas of applied science that can be organised under the discipline of Ecology. Hence, I believe that our respective silos reflect a number of matters, including:

- Different tribes. The agricultural development of the Australian continent was characterised by a level of disdain by the settlers for the native people, animals and vegetation of the landscape. I have previously written (Wolfe 2010) about several phases in the agricultural history of Australia, from the early exploration phase (1788-1850) of white settlement to exploitation (1850-1900), consolidation (1900-1950), amelioration (1950-80) and restoration phases (1980-present). To purists, many of whom take for granted the benefits from food/fibre production and export, 'agricultural development' continues to represent the degradation and disruption of natural ecosystems. For them, sustainable agriculture may never be regarded as balanced and restorative.
- Funding issues. Australia has pursued a strong policy of public investment in agricultural R&D by State Departments of Agriculture and the CSIRO, at a level that was much higher than the funds devoted to natural ecosystems or environmental reconstruction. Furthermore, the Australian Government matches $ for $ the production levies that are collected from various agricultural industries; these funds are managed and distributed by industry-dominated corporations. Hamblin (2004) offered constructive criticism of the bias in research funding towards agriculture rather than other industries, and towards production research rather than alternative pathways such as the proof of application and commercialisation of innovations, post-farm value-chain and food processing, or building social and environmental sustainability in rural Australia.

Forthright analyses like that of Hamblin (2004) have triggered impacts, some that are positive (*e.g.*, the creation of a Terrestrial Ecosystem and Research Network in Australia – see http://tern.org.au/), some negative (*e.g.*, the disbandment of Land and Water Australia in 2009) and some unpredictable in outcome. An example of the latter is the recent proposal by the Minister for Primary Industries in NSW to combine three functions of state- and ratepayer-funded rural services (catchment management, agricultural advisory services and biosecurity) into a single body designated as 'Local Land Services'. This proposal, which is scheduled to be in place by 2014, is an opportunity to address with landholders and the community the joint management of agriculture and natural resources on the slopes, tablelands and coast of NSW. Unfortunately, the potential number of experienced LLS staff has also been reduced by staff cuts and reclassifications.

Table 3, for the sheep-wheat belt and the tablelands of the Murrumbidgee River catchment, compares the gap between the agricultural landscapes, as they are now (an agricultural extreme, softened by an emphasis on sustainability) and as they could be if managed and conserved as resilient grassy woodlands (the environmental ideal). The principles and threshold values have been adopted from McIvor and Macintyre (2002). While there is some agreement between environmental scientists and landholders in one measure of land use, *i.e.* the desirability of maintaining vegetative cover to reduce soil erosion (Objective 1), there is a divergence between other indicators, especially in terms of Objective 2 (using introduced legumes to raise soil fertility and agricultural productivity in the sheep-wheat belt situation, Smith 2000) and in Objective 3 (the proportion of the landscape that is devoted to 'intensive', mainly agricultural, land use). In a world that is facing problems in food production and

distribution, one can imagine that the sheep-wheat belt will be managed indefinitely for the prime purpose of producing meat, wool and grain. However, there may be useful conservation gains to the resilience and amenity of this landscape if the small proportion of it currently devoted to natural biodiversity was strategically increased from, say, 2% towards 5%. If the areas converted from production to conservation/amenity were the least productive areas in the landscape, modest biodiversity targets could be achieved without necessarily reducing overall production. Careful planning and implementation is needed, since a modelling study undertaken by House *et al.* (2008) on three wheat belt farms in southern Queensland (two farms) and northern NSW (one farm) indicated that small changes to the production base in order to implement conservation based approaches can have large potential impacts on farm enterprise profitability.

Local farmers do recognise their role as stewards of the land. They appreciate the amenity (shade, shelter), improved function (*e.g.* biodiversity benefits) and visual appeal that accompany a less aggressive approach to agriculture. Such qualities may even translate into an increase in property value. However, farmers respond poorly to authoritarian approaches, so the problem lies in how to incentivise these changes in land use. Most farmers will defend their current position on the basis that "it isn't easy to be green when you are in the red!" Also, there are other problems, such as how to manage conservancy areas, crop residues and grasslands in a manner that promotes biodiversity and minimises the risk of fire, a risk that is a prime consideration for the occupants of local landscapes if a 2-3°C rise in average temperatures occurs during the next two decades. On the positive side, Mendham *et al.* (2012) indicated that close to 50% of rural properties are expected to change hands between 2006 and 2016, and new landholder families appear more willing (or more able?) than long-term farmers to embrace conservation and natural resource management.

The present Australian Government invests in NRM on agricultural lands (*e.g.*, Caring for our Country program) and it is currently boosting funds towards what is termed a 'carbon farming future'. However, the future funding of the CFF program is threatened politically, and many of the protocols necessary for Australian farmers to earn carbon credits will need further evaluation and testing. Storage of carbon in soils is a particularly complex issue (see for example Conyers *et al.* 2012, an excellent paper), and fire may undermine carbon sequestered in crop stubbles, grasslands and woodlots. While the political environment is currently unstable in this election year, most Australians live in coastal environments and they are already aware of the risks inherent in climate change (frequency of violent storms, bushfires and rising sea levels). With a steadily reducing number of mainstream farmers in rural areas, there is room for an expansion of government incentives for NRM management, such as support for community programs (*e.g.*, Landcare) and stewardship payments to landholders, perhaps inspired by successful initiatives in other countries (*e.g.*, in Canada, Robinson 2006). House *et al.* (2008) provided a balanced discussion of the issues and options available in Australia, where the rural population is small but the areas are vast. There are conflicting outcomes from management for conservation, which may produce long-term ecological gains for society but at an economic cost (short- to medium-term pain) for the landholder.

In several parts of the Australian wheat belt, notably in the sandy soils of Victoria, South Australia and Western Australia, the original mallee (*Eucalyptus* spp.) vegetation was over-cleared (70-100%) for pasture and crop production. In these areas, there has been a strong imperative to reduce deep drainage of seasonal (winter-dominant) rainfall beneath the root zone of crops and pastures, thereby slowing the rise in groundwater levels and the salinization of tracts of low-lying land. The Cooperative Research Centre for Future Farm Industries, a sponsor of this Congress, has funded research that is investigating how perennial pasture species and belts of mallee eucalypts, strategically located and managed, can be reintegrated into these landscapes to reduce groundwater recharge and to contribute to NRM objectives.

Issue 3. Farm profitability - coping with production-marketing risks in the sheep-wheat belt

The most recent available analysis provides a sombre picture of the financial performance of Australian grain producing farms (Lubulwa *et al.* 2012). In 2010-11, a drought year in WA but wetter than average in the Eastern Australian states, the average farm comprised a total of 2,420 ha with 771 ha sown to crops (principally wheat), 1,519 sheep and 146 cattle – these statistics[2] have remained static over the past five years. Total cash receipts were $615,308 and total costs $433,227, producing a farm business profit of $109,152 (farm cash income plus build-up in trading stocks less depreciation and the imputed value of the labour provided by the farm family). This profit compared with a loss of $16,009 in 2009-10 (a drier than average year) and a forecast profit of $62,843 in 2011-12 (an average rainfall year). In this representative survey, the proportion of farms with a negative farm business profit was 64% in 2009-10, 44% in 2010-11 and 49% in 2011-12). When Lubulwa *et al.* (2012) de-aggregated these statistics according to the cropping intensity of the farms surveyed, more than half the low-medium intensity farms always recorded a negative farm business profit over a five year period (2006-07 to 2011-12), with the high and very high intensity grain farms faring a little better (Table 4). These statistics highlight a situation that is obvious to most Australian grain farmers – they are inadequately rewarded for their labour and investment, primarily due to the difficulty of managing the production and marketing risks that they face.

Tim Hutchings (unpublished PhD manuscript), a Riverina farmer turned consultant who has a much better ability than me to appreciate farm finances, recently based his PhD studies on the farm financial performance records available for farmers located in areas of the sheep-wheat belt in NSW and Victoria. His analyses included case studies of representative farms and also the farm business records held by a major Australian bank. Modelling techniques, similar to those used in progressive farm

[2] Broadacre farms with at least 40 ha of cereal, pulse and oilseed grain crops, and with an estimated value of agricultural operations of more than $40,000.

Table 4. Proportion (%) of Australian grain farms that recorded a negative farm business profit, by year and cropping intensity.

Year	April-Oct. rainfall	Cropping intensity (% of arable farm area sown to crops)			
		Low (<20%)	Med. (20-40%)	High (40-70%)	V. high (>70%)
2006-07	Drought	82	84	75	70
2007-08	Below average	65	65	57	51
2008-09	Below average	67	75	57	42
2009-10	Below average	63	73	64	52
2010-11 (provisional)	Dry (WA), above average (SA, Vic, NSW Qld)	51	55	37	29
2011-12 (estimated)	Average	45	56	45	55

accounting businesses, were used to generate farm cash flow performance over at least three years, with a drought year often included as a stressor in these analyses. Hutchings' findings were:

- Gross margin analysis was a poor indicator of farm business performance since it excluded key information on fixed farm costs, capital costs (machinery, innovations), living expenses and taxation.
- Cash flow projections during 2002 to 2007, which included several drought years, indicated a serious decline in cumulative cash flow to negative levels, even though farmers were achieving near the water-limited yield potential of crops. Declining terms of trade, highly variable incomes due to rainfall and market fluctuations, and the rigidity of farm costs (they are more rigid than in urban businesses) contributed to the financial predicament of farm businesses.
- Farms with a high proportion of crops to pastures (and livestock) showed most variability from year to year in income. A greater content of the pasture-livestock enterprise in the overall farm business buffered this variability and contributed to greater stability but the farm cash balance at the end of several years was more negative.
- The current business models of most mixed farms in Australia are not viable and they need to be overhauled for farms to survive. A recent reversal in the upward trend of land values, a trend that has for some years masked poor business performance, is forcing industry adjustment.
- There is a need to re-define farm financial management practices into a new cash flow format so that farmers can understand their real situation from year to year and identify strategies early enough to minimise their risk of financial loss.

A recent analysis of land ownership in rural Australia did not indicate panic in the sheep-wheat belt, which is characterised by relatively low land ownership churn and relatively high rates of land aggregation (Pritchard *et al.* 2012). While there is not yet an overall crisis in farm ownership, farmers these days must choose good advisers, weigh carefully every decision they make and make their time count. Providing better business management education to farmers and agribusiness professionals is a preferred solution to the problems of inappropriate business structures and water-limited output. Financial services are best provided by specialists such as farm management advisers and accountants. Lending institutions should have a vested interest in ensuring the success of their clients. An unresolved problem is the mismatch in supply (low) and demand (high) for agricultural graduates (Pratley 2012), especially for agribusiness specialists who are sought eagerly by metropolitan firms as well as by those that are rural-base.

Issue 4. Organising farm management and team leadership to cope with the conflict between enterprise specialisation (simplicity) and diversification (complexity) in the sheep-wheat belt

I have previously written about conflict between the need to encourage diversity in on-farm enterprises and the pressure on farmers to simplify their enterprise mix in response to the drive towards larger scale (Wolfe 2011a). The 'specialise or diversify' conflict is perhaps at the heart of the slow strangulation of the sheep enterprise on Australian mixed farms, since this enterprise is less 'glamorous' to young farmers, more labour demanding, a year-round responsibility and, compared with the cropping enterprise, it is difficult to enhance productivity by substituting capital for labour. Consequently, many farm families are apathetic towards sheep, regarding them as a necessary nuisance. The overall standard of management of the sheep enterprise on sheep-wheat farms is poor (Robertson and Wimalasuriya 2004), below the good standard of management applied to crops and below the benchmark practices of experienced livestock managers in the specialist grazing districts of the high rainfall zone (*e.g.*, the NSW Tablelands, situated further east towards the coast). This 'sheep apathy' could contribute to the standard of pasture management and the 'nitrogen crisis' in mixed farming referred to above, and to a general 'decision paralysis' that affects a proportion of farmers, especially those who are stressed, depressed and confused about the way forward.

The conflict between scale and complexity on mixed farms could be addressed in ways other than by turning a blind eye to the management requirements of productive pastures and the sheep enterprise. First, when farms become bigger there are extra opportunities to delegate management responsibilities to individuals in the family, allocating them a specific enterprise to manage while still preserving the family partnership in mixed or integrated crop-livestock production. A second possible way of allowing specialisation within Australian mixed farming systems may be to sever or vary the traditional link between livestock ownership/control and land ownership, and develop new partnerships that place crop and livestock

Table 5. A short list of studies undertaken to segment farmers.

Study authors – Topic of study and definition of farmer segments	**Farmer segments identified**	**Relevance to the sheep-wheat belt**
Morrison *et al.* (2008) Market-based incentives for NRM Segments were defined by the four variables that had the most consistent influence on participation in NRM activities viz., business orientation, trust, social connectedness and information seeking behaviours.	**Mainstream farmers, yet disconnected** (23.2% of sample) – Mainly full-time farmers who have moderate levels of business orientation, trust and information-seeking behaviour but distinguished by a low level of social connectedness. **Quality operators** (24.2%) – high scores for business orientation, information-seeking behaviour and connectedness, moderately high score for trust. Neither capital nor time constrained. **Profit first** (24.2%) – strong focus on profit but lower scores for business orientation and information seeking. Time constrained. **Small, disconnected hobby farmers** (19.4%) – Score low on profit focus, innovation, business orientation and use of farmer information channels. **High end, community-minded hobby farmers** (8.9%) – wealthier, well-educated, lower business orientation and information seeking behaviour.	Partly relevant. Only one (Central-west NSW) of the five areas surveyed had sheep-wheat farmers. These farmers tended to be distributed into the quality operator category (>50%, followed by Profit first then Mainstream groups.
Hogan *et al.* (2011) Adaptation to climate change Segments were defined primarily by five concepts based on belief in climate change, desire for financial assistance and advice, social connectedness, information-seeking behaviour and adversity of farm conditions.	**Cash-poor long-term adaptors** (55% of sample) – Actively seeking to adapt their farming practices to manage climate change. Younger farmers, healthy, socially-connected, information seeking, believed in climate change, resilient but resource-poor. **Comfortable non-adaptors** (26%) – Older, socially well-connected farmers, asset-rich with few farm-related pressures, not oriented to the need to adapt to climate change. **Transitioners** (19%) – Farmers under considerable farm and family-related pressure, high levels of debt and a lack of social capital (connectedness), too. Poor overall adaptive capacity.	Partly relevant. The survey covered 4000 farmers working in horticulture and broad-acre farming. No details were given about the representativeness of the dataset, collected by the Bureau of Resource Sciences in 2008.
Wilkinson *et al.* (2011) Likely use by farmers of DPI Segments were defined by farmers' aspirations and attitudes, age, personal/family circumstances, and capacity to invest	**Selling out** (13% of sample) **Phasing down** (17%) **Not productivity oriented** (8%) **Productivity constrained** (14%) **Productivity, not scale, oriented** (32%) **Expansion oriented** (16%)	Partly relevant. A representative sample of 1300 Victorian farmers in four industry sectors (meat and wool, dairy, grains, horticulture) were interviewed by telephone.

operations in the care of enthusiasts. For example, a livestock specialist could be responsible for livestock production on (say) 5–6 mixed farms, providing livestock services to crop specialists while exploiting economies of scale through larger flocks and the consolidation of livestock facilities (yards, shearing sheds, supplementary feeding set-ups) across several farms.

Helen Burns and her NSW DPI colleagues (see Casburn *et al.*, this Congress) recorded insights into how leading farmers coped with the dilemmas of mixed farming. In 2012, a panel of five farmers and one farm consultant were carefully selected after screening a number of mixed farmers in terms of their apparent success in managing their farm. A public forum was conducted at Wagga Wagga NSW, where an edited video version of each farm business 'snapshot' was played, questions were put to each panel member by an informed audience (n=80), and the opportunities and challenges facing mixed farming businesses were explored. It was clear that the members of the panel operated businesses that shared a number of common features. Critical to the success of each farming business was the partnership between family members: spouses, siblings and generations. On the farms of panel members, the complexity of multiple farm enterprises was addressed by at least two individuals specialising within the farm business, to ensure that each enterprise received the attention to detail that is required to maximise business success. These producers shared an absolute commitment to seeking out and evaluating information; they were not necessarily early adopters and they controlled costs tightly. Peer support was also an important aspect of the mixed farming business: support from family, friends and business partners (including contractors, share-farmers) as well as support from paid consultants including accountants. The forum highlighted the need for farmers in the livestock industries, particularly the wool industry, to improve productivity. A good understanding of existing pasture technology plus a willingness to seek and exploit new technological advances in pasture types, sheep genetics and livestock management were important for improving total farm productivity in the long term.

If some leading farmers in the sheep-wheat belt have the answers, what is the situation for all farmers in this zone? This question cannot be answered definitively. Analyses of economic data (as in Table 4 and Lubulwa *et al.*, 2012) reveal nothing about the contributions of social attributes and attitudes of farmers to their economic success or otherwise. While occasional surveys help uncover some farmer attributes in relation to contemporary issues (Table 5), there has never been a full socio-economic analysis of farmers in the sheep-wheat belt. Such an analysis is needed. The opinions of consultants and advisers indicate that farmer segments do exist but, as in dairy farming, there are few laggards left in the sheep-wheat belt, at least in terms

of their technical prowess in cropping.

Conclusions

The drivers of change

Schiere *et al.* (2006) emphasised the importance in agriculture of events and processes that interact rather than behave in a straightforward manner. These interactions may trigger 'non-linear paradigm shifts' or 'mode changes' in agriculture, producing rapid rather than incremental changes in the productivity and sustainability of agricultural systems. In Australia, such events have included the high wool prices in the early 1950s that stimulated pasture-livestock research along with investment into the ubiquitous use of subterranean clover and superphosphate on Southern Australian farms, the advent of herbicides for cropping systems, the development of minimum tillage, and the development/use of broadleaf 'break' crops to control the root diseases of cereal crops. In addition, there has been a steady stream of innovations from R&D that have contributed to the incremental progress in the productivity of grasslands, crops and livestock.

Along this development trajectory, mixed farms in the Australia sheep wheat belt have increased their levels of productivity (output of food energy per farmer or per hectare), specialisation and scale. Unfortunately, greater farm profitability is not necessarily associated with any of these attributes. Furthermore, current agricultural production is sensitive to shifts in the availability of resources and the business-political environment, especially in the world's industrialised economies that depend heavily on energy for farm power, fertilisers to replenish extracted nutrients and chemicals for the protection of plant/animal populations from disruptive influences (pests, diseases and weeds).

Rickards and Howden (2012) highlight climate change as an issue that will require a significant restructure in all aspects of agriculture and land management – requiring changes at not only the agricultural system level (systemic change) but also the higher socio-ecological system level ('transformational' change) rather than mere 'adjustment' or incremental changes in activities. They highlighted some of the potential costs involved in planning and managing transformational change, such as the human energy that must be invested in change, the opportunity cost of various change pathways, the avoidance of unintended consequences, optimising the level of adaptation, and optimising the timing of the changes. Communities have seen these costs play out in discussions and policies for irrigation, domestic and environmental water in the Murray-Darling Basin of Australia. Another example for consideration is the potential consequences of converting portions of the sheep-wheat belt to forests if no account is taken of potential impacts on catchment hydrology, the risk of fire or the experience of the local workforce. Australian farmers, who have lost much of their political clout, feel vulnerable. Rickards and Howden (2012) supported government assistance towards coping with major shifts in the rural environment. They also noted that "conventional insular agricultural research is increasingly inadequate in the face of growing complexity and uncertainty", with transformational change requiring forms of research that are both interdisciplinary and transdisciplinary, the latter involving the integration of non-academic knowledge through participatory processes, consultative policy development and governance. Their views are in line with Hamblin (2004) and with those of Beilin *et al.* (2011), who criticised an attitude of 'policy incrementalism' that prevails in current agricultural R&D, an attitude that reinforces tinkering at the reductionist end of the research spectrum, oblivious to systemic logic. Beilin and her colleagues argued that a 'business as usual' R&D approach of making minimal changes to current policy directions and settings will produce a 'maladaptation'condition, which could have potentially disastrous consequences on agricultural production systems when the theoretical scenarios of climate change and peak oil become real during the next few decades. Furthemore, consumer groups and social scientists frequently express considerable concern about negative aspects of the consumptive approaches and free-market ideologies that underlie the agricultural and food policies in developed countries. In addition, there is increasing interest of community (non-farming) groups in topics such as animal welfare, farm viability, water policy, equity and ethical matters.Hence, the current approach to agricultural R&D must be rebalanced from productivity towards systemic survival. Individual researchers need to devote some of their energies to appreciating the 'big picture', beyond their immediate disciplinary focus.

Changes in the sheep-wheat belt

Leaving aside for the moment the external threats, there is mounting evidence that the Australian mixed farming system is failing to maintain productivity improvements in line with worldwide farming systems, it falls short of world standards in biodiversity, and the majority of farm businesses are underperforming with a 'sizeable proportion' of families under financial (partly documented) and emotional (largely undocumented) stress. Potential solutions include a rethink on land use, more attention to the financial risk of cropping; encouraging zeal, expertise and enthusiasm in expanding the pasture base for livestock enterprises (especially wool and fat lambs); and easing the shortage of labour available to operate mixed farms.

The discussions above make it clear that a combination of causes are to blame for the poor performance of this mixed farming system, ranging from underinvestment in the supply/demand relationships for nitrogen on the farm; possible imbalances in R&D funding from public and private sources to sustain the legume breeding and development pipeline; insufficient monitoring of selected indicators of the state/health of the productive, environmental, economic and social properties of mixed farms; and the failure to detect and bypass industrial limitations such as the available levels of investment, leadership and manpower. Mention has already been made about declines in the number and quality of agricultural graduates (Pratley 2012).

In short, generational change is happening in the sheep-wheat belt. At the farm level, some of the changes are positive. Rickards (2011) has related how many farm

families on mixed farms in central Victoria have successfully adapted after the stresses of the string of droughts during the 2000s. However, a recent negative development is the loss of many experienced scientists and advisers, who are retiring or being forced out of leaner and meaner institutions. Fewer, less experienced scientists, managers and farmers lack knowledge about past research findings, farm business experience and/or lifetime 'rules of thumb'. People just forget. While some resources (*e.g.* electronic scientific journals and books, farm records) are still preserved and accessible, there is concern about the 'fit' of past evidence and experience with a generation that expects things to be delivered to their iphone instantly. An evidence-depleted environment is one where shonky entrepreneurs and dodgy lobby groups, unmotivated by evidence, truth or ethics, have a 'licence to operate'.

What needs to be done to replace the partial failure of mixed farming in Australia with success? Although Australia is an important food-exporting nation, currently less than 2.5% of the national product is agriculturally related. Any reduction in Australian food production will have little effect on world food consumption (Clements 2012) but, because of the large areas involved, the effects of stewardship on the global environment may be more significant. Governments could shake up bodies like ABS (to collect useful statistics on 'pastures' and 'social well-being') and R&D Corporations (Hamblin 2004, above). However, the future also depends on individuals. Researchers need to learn about and keep in mind the attributes of the agricultural systems in which they work, perhaps by adopting the framework recommended above for broadly appreciating agricultural systems. Better access to and communication with agricultural scientists around the world is essential to attract 'spill-in' benefits. Improved collaboration is possible between production scientists and environmental scientists, and between the academic, research, agribusiness and farming sectors. Private and public organisations and government departments could usefully think more about the pros and cons of tenure *vs* contract employment in (1) attracting and holding on to career policy-makers, researchers and managers, and (2), ensuring agility in thinking about and responding to the issues in socio-ecological systems.

In conclusion, the benefits that may come from innovation in the economic, financial and social aspects of agriculture are as important as refining the technology of production. In the Australian sheep-wheat belt, R&D policies must take into account agricultural stability and community well-being. Comparative analyses – technical, economic and systemic – are needed on the issues defined above, and to develop policies for a nation-building approach to land management.

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