Input into the development of Australia's Decadal Plan for Agriculture

Capability and funding constraints

Key points

- Australia Decadal Plan for Agriculture will take a multi-disciplinary, systems approach recognising the increasing need to see agriculture in a systems context in which no one element is isolated from any other.
- Traditional, disciplinary based agricultural science that delivered the transformational changes of the green revolution has been comprehensively exploited. Major breakthroughs are becoming increasingly rare; progress has become incremental and biological limits are being approached.
- Transformational change is increasingly likely to be associated with fundamental changes in systems understanding and management. Such systems research is, by definition, trans-disciplinary and addresses co-limitation imposed by interactions of various systems components.
- A fundamental incompatibility between current institutions and systems thinking creates a range of capability and funding constraints that affects Australia's ability to innovate.
- Unless these constraints are acknowledged and addressed, it is unlikely that the much needed step changes in productivity and production are achieved. This decadal plan provides a timely and unique opportunity to overcome these constraints.

Institutions

Australia's science and science-policy institutions in general are not organised to recognise the value of, or implement, systems approaches.

Academy of Sciences

- The Australian Academy of Sciences only recognises reductionist biophysical sciences, or the historical and philosophical study of these.
    - The background documents for the DP recognise the potential contribution to agriculture of "…newer approaches including biotech, ICT, maths, chemistry and physics", but not the integrative potential of economics, social sciences or the arts.
    - A narrow view of multi-disciplinarity constrains the adoption of agricultural research by reducing investment in enabling research on topics such as governance, which are essential for achieving productivity improvements.
    - An alternative is the Agricultural Innovation Systems approach developed by the World Bank that recognises the complementary interventions needed for innovation to take place. These interventions include capacity building, incentives, enabling policy frameworks and the creation of new types of public/private partnership.

Australian Research Council

- The Australian Research Council provides funding for the University sector; it emphasises the development of basic disciplinary knowledge.
    - A sole emphasis on basic, disciplinary science overlooks the essential role that complex systems (involving environments, communities, industries and governments) play in the development and adoption of agricultural technologies adaptable to local conditions.
    - The prestige granted to reductionist approaches to knowledge generation discourages the development of integrative disciplines.
    - This sole pursuit of knowledge dissociated from a more problem-oriented systems approach has led to a vast array of technological innovations that are seriously underutilised due to our inability to optimally assemble them into functional, context-specific innovation platforms.
    - To address truly complex problems we need to complement traditional science with an academic inquiry that gives intellectual priority to researching problems that are resistant to resolve by purely technological fixes.
- From 2001 to 2014 over seventeen thousand ARC projects with total funding of $5.9 billion were commissioned and completed[1]. Of these projects:
    - None contained the keywords “agricultural systems” or “agriculture, systems”
    - 39 projects (0.2%) with funding of $12.4 (also 0.2%) had the keywords “agriculture” or “agricultural”.
    - Of this 39 projects, only 3 with funding of just over $600 000 had the keywords “system” or “systems”.
    - One other project conducting research into soil acidification received funding of $300 000 had “farming system” as a keyword.
- This imbalance requires urgent attention. Agriculture, i.e. our ability to efficiently, effectively and reliably feed a rapidly growing population, epitomises the value of ‘bringing together’ of all disciplines for the benefits of our societies. In recent years agriculture has become a highly knowledge-intensive sector of our economy. Our research funding mechanisms need to be adjusted and become the enabling environment that helps creating this knowledge.

Rural Research and Development Corporations

- The RDCs do have some funding programs for systems research.
- These programs are usually restricted to the field scale – research programs at the whole farm or value chain scale are rare.
- The RDCs serve the interests of levy payers in industry. This tends to lead to research focused on short term incremental improvements to existing agricultural systems.
- There is very limited investment in creating new agricultural systems that could create industries in regions where these don’t currently exist. Yet, such research would be essential for coping with global changes such as changes in demography, environment, climate, and trade.
    - Examples include irrigated cereal production and irrigated grazing systems in Tasmania that have great potential but have so far failed to attract the funding needed to capitalise on this potential.

[1] http://www.arc.gov.au/grants-dataset

- More broadly, and across Australia, irrigation requires urgent and focused systems analytical attention. The 'just add water' approach has led to many missed opportunities and, in some cases, even disastrous systems failure.

Productivity

Australia's productivity growth has slowed in recent decades, suggesting that different R&D strategies are required.

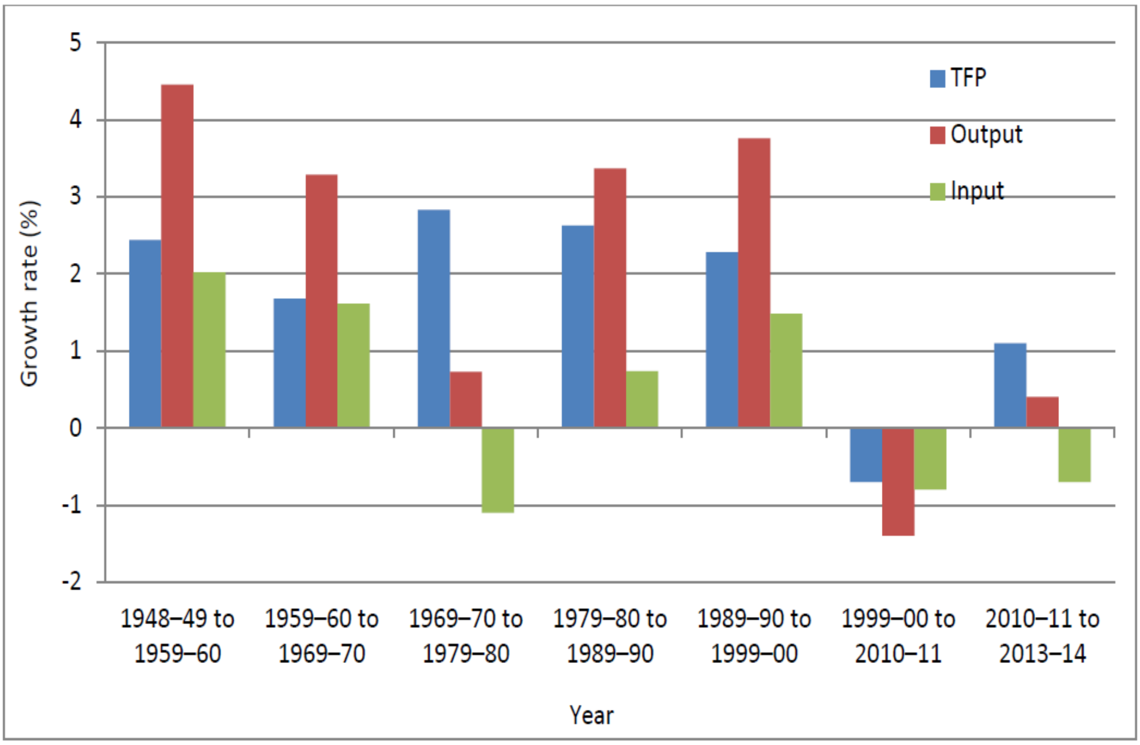


Fig. 1: Total Factor Productivity (TFP), Output and Input growth by decade, 1948-49 to 2013-14 (Sheng and Jackson, 2015, pg 31)

Australia's long-term productivity growth has been less than competing nations in world export markets (Fig. 2):

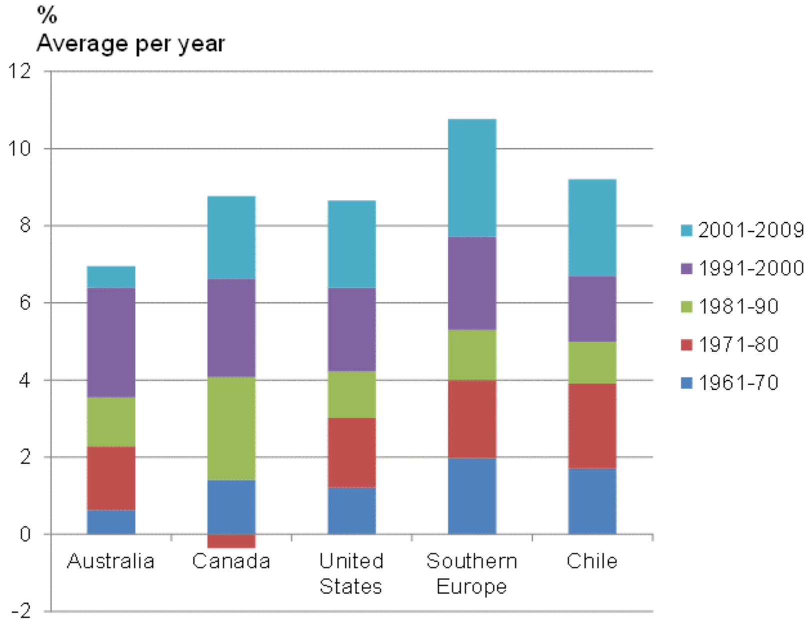


Fig. 2: Agricultural productivity growth for five selected countries by decade (Fuglie, 2010).

Yet, despite this slowing, Australia's agricultural productivity growth is consistently higher than that of other sectors such as mining, manufacturing, construction and financial services (Fig. 3). This strengthens the argument for investing in enabling systems approaches within the agricultural sector. Not only are the returns on such research investments likely to be higher than from other sectors, it would also allow Australia to regain its competitive advantage relative to our key competitors.

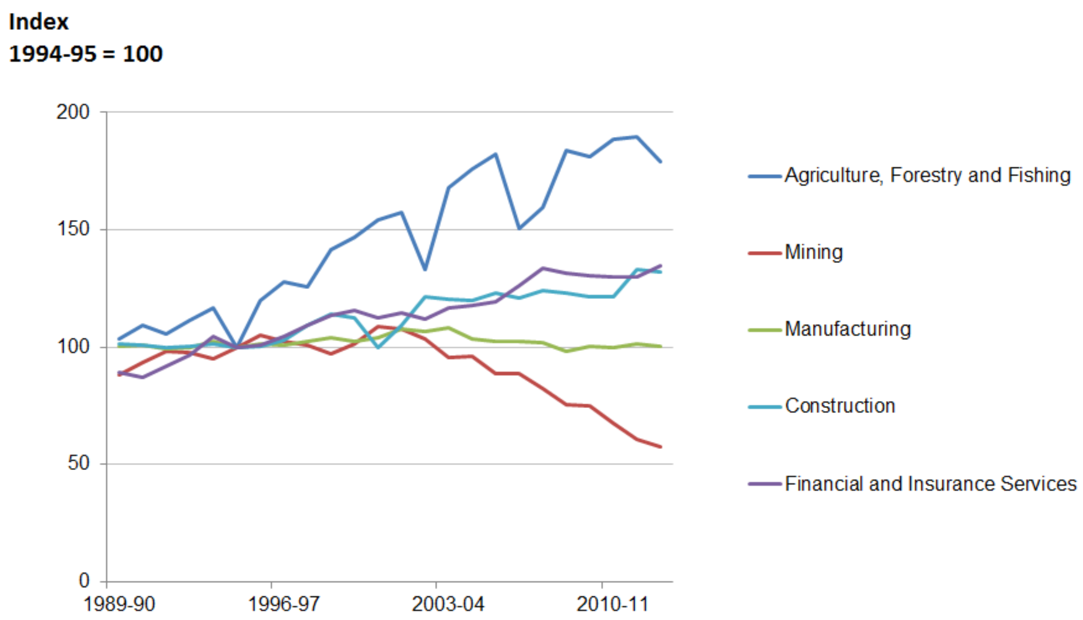
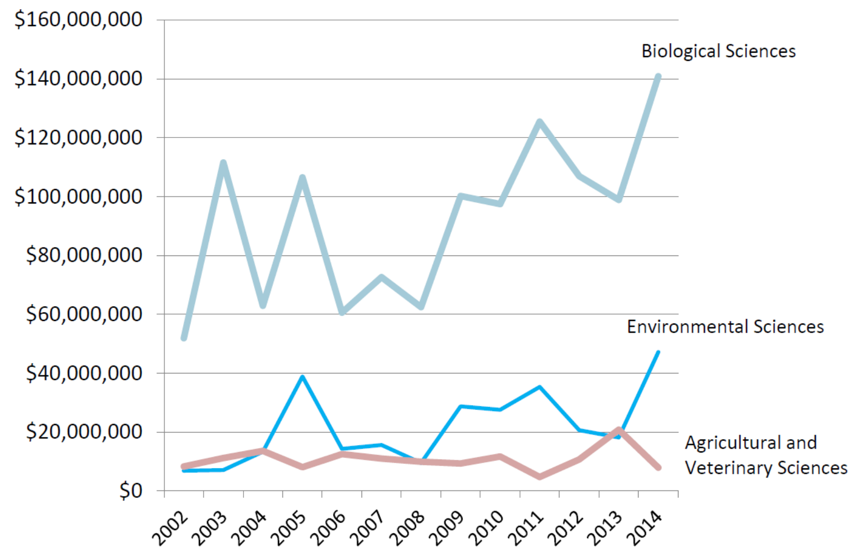


Fig. 3: Australia's relative productivity growth by sectors from 1989 to 2013 (ABS)

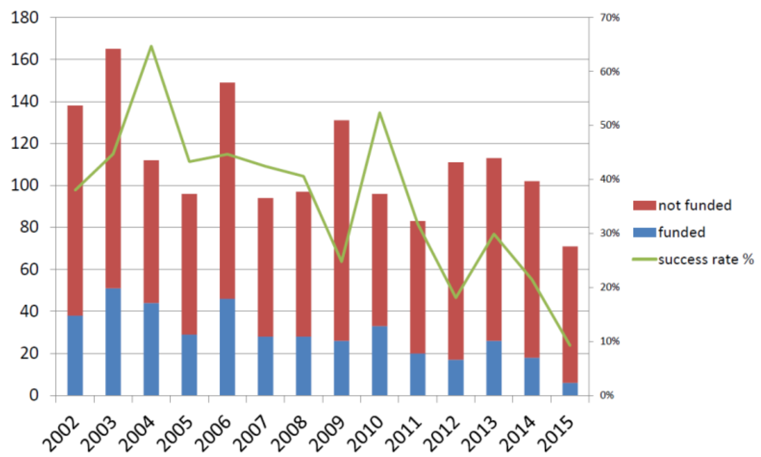
RESEARCH FUNDING ARRANGEMENTS

The ACDA notes the strong support for continued agricultural R, D & E and for the RDC system of research funding including the levy scheme. The ACDA commends this and supports the proposed regular five-yearly review of the RDCs as a good quality assurance measure. However the ACDA considers that there is potential to increase the effectiveness and quality of research carried out by RDCs which can be facilitated by requiring competitive project tenders and ongoing programs to be submitted to national/international peer review, and by ensuring that greater representation of independent academic expertise (determined by recognised measures of research excellence and impact) is included within RDC governance. These principles already apply to funds occasionally provided by the Australian Government under special programs via the Australian Research Council (e.g. Linkage and Discovery programs). Unfortunately funds provided for agricultural research under these programs are disproportionately small relative to other sectors. Despite its strong role in the economy, **agricultural science is poorly represented** over a long period in ARC grants (see below).

ARC NCGP funding by Fields of Research 2002–2014



Agricultural and Veterinary Sciences—Success Rate



Furthermore, the pattern in recent times with ARC is a dramatic fall in the number of grants to agriculture and the very low success rates achieved by applicants in agriculture (see above). Given that the RDCs show little interest in funding basic or strategic research the provision, or lack thereof, of funds by the ARC raises real concerns for research that underpin future development. A low emissions economy and the community keenness to have bio-based products replacing e.g. petrochemical inputs are likely to create opportunities for agriculture. Biotechnology and other enabling technologies may also create opportunities for marginal rural production and increase productivity and sustainability of other enterprises. Further, joint approaches with other sectors such as health are likely to have community pay-offs. However unless there is investment in the basic and transformational research areas, such opportunities are likely to be foregone for agriculture and the Australian economy.

It is the view of the ACDA that research funding arrangements need to address this shortfall. There should therefore be a reasonable allocation of funds towards strategic projects and cross-sectoral issues which would allow entry of new players and ideas from within and outside the sector. To this end there is an increasing case a change to the funding arrangements to address basic and transformational research, together with systems and value chain related aspects mentioned earlier. It is the ACDA view therefore that a proportion of the matching funds from government should support such a new arrangement, perhaps through the ARC, with clear guidelines that are complementary to the activities of the existing RDCs. The focus of this new funding arrangement should be on the longer term, more complex agricultural systems-related problems that are currently stifling innovation, holding back transformational change and are inhibiting efficiency gains across the agricultural sector. **At least 10% of such matching funds** should be directed to this agenda.

LAND GRANT UNIVERSITIES – THE AUSTRALIAN VERSION

Background

Much has been written in Australia in recent years about the land grant university model in the US agricultural system and its merits. This is due in large part to the demise of the traditional extension services provision by the Australian state departments of agriculture or primary industries. It is clear that the US system is not transposable to Australia in its entirety and so it raises the question as to what an Australian version might be. Firstly some consideration of what has been written recently in this space is needed.

A. The NSW Government's Agriculture Industry Action Plan (AIAP)

The AIAP taskforce stated (i) that there is an opportunity for government to support an enhanced model for extension and uptake of R&D; and (ii) that a range of international models for the delivery of agricultural education and extension warrant further investigation with a view to developing and piloting an appropriate system.

> **AIAP Recommendation 11*: Industry and government to investigate different models in the tertiary education sector (for example the 'land grant university' model) for application to NSW*.**

B. The Australian Council of Deans of Agriculture response to the Australian Government's Green Paper on Agricultural Competitiveness

"In respect of extension the ACDA noted in its response the concern about the future role and capacity of agricultural extension and that lack of effective support will limit the take-up of R&D and limit productivity gains. ACDA is also concerned that private advisory services will 'cherry-pick' those services for which there is a financial benefit and that public good and market failure issues will not be addressed. ACDA supports incentives for Universities to participate (in partnership with industry/other RDE organisations) in the innovation function. The University sector has at several roles in agricultural innovation:

- Educate and train future agricultural advisory workers and people in the RD&E system (e.g. researchers) in R&D adoption theory, professional practice and skills (including private sector, not for profit sector, public). This should be further supported by undergraduate scholarships to specialise in innovation education;
- Active participation in R&D implementation – in partnership with other organisations (public and private); and

- Undertaking R&D in novel and redefined adoption methodology in collaboration with public and private entities Extension and innovation, as well as associated research, are still not recognised as legitimate activities at Australian universities. This needs to change. The Government could facilitate change quickly by making some resources for agricultural innovation available under Category 1 education funding. Strong policy statements about the importance of, and support for, public-private partnerships (PPPs) that include the university sector would help considerably.

Example: Pilot of Drought Reform Measures in Western Australia

This project was guided by innovative adaptive extension, governance and research methodology through direct engagement with the university sector driving a PPP. The pilot delivered major and unprecedented producer response and outcomes, including significantly improved understanding and actions relating to the impacts of increasing volatility in: business and financial environments; markets; natural

While the US has invested considerable resources into their universities via the much talked about Land-Grant University System, Australian universities cannot draw on such resources. However the model deserves closer scrutiny as aspects of the Land Grant system might still be applicable to the way university farms, for example, are or could be governed. Adequately resourced with modern technology and well-trained staff, these facilities could effectively link R&D implementation with research and education and provide further opportunity for PPPs.

The notion of regional centres of excellence that serve broad agricultural regions based around regional universities deserves additional attention. These institutions often have the breadth to address scientific and technical challenges as well as socioeconomic issues. However their resources are spread thinly across the landscape and this limits the effectiveness of the services and outcomes and often makes it difficult to attract staff. Collocation is likely to provide synergistic opportunities and a critical mass of professionals in regions where the issues occur.

ACDA considers that expectations on new graduates to have the wisdom, breadth of knowledge, experience and network to be a proficient advisors are unrealistic. The professional development and mentoring of extension officers previously provided in state departments no longer exist as extension services have declined. These roles are increasingly provided by private operators. Professional development opportunities such as short courses or a professional Masters should be developed to encourage and enable mid-career professionals to move into an R&D implementation role. This would include the role of the internet as it is increasingly important to monitor and advise on rural production. Further, as they give advice on matters that could have significant economic

implications (just like other professionals e.g. accountants, financial advisers, engineers, teachers) agricultural providers should be accredited or registered.

ACDA thus supports a national strategy for agricultural innovation education across Australia (focusing on both the private and not-for-profit sectors) to boost the currently *ad hoc* and under-resourced efforts. In higher education, a University network could coordinate offerings in undergraduate and postgraduate innovation education, in partnership with organisations such as the Australasia-Pacific Extension Network (APEN) and their education sub-committee. Of concern is that some private providers now offer short-courses in extension with no background theory or professional practice credentials.

> **ACDA Recommendation*: Government fund a coordinating study of innovation services, including a comprehensive evaluation of all services currently provided by state agencies, the applicability of the US land-grant model in Australia, the innovation services that could be offered by universities, the prospects for PPPs and the delivery of holistic R&D implementation outcomes."***

C. Australian Farm Institute Report: Optimising future extension systems in the Australian grains industry

This report provides the following extract:

"Initially, each US State established a Land Grant College under the provisions of the Morrill Act of 1862, and the system was further expanded under subsequent legislation enacted in 1890 and then several further pieces of legislation enacted throughout the twentieth century. The Hatch Act of 1881 resulted in the development of agricultural research stations in each state, and subsequently the Smith-Lever Act of 1917 tied the Colleges and the state agricultural experimental stations into the Cooperative Extension Service (CES).

Agricultural research and extension activities at Land Grant Universities are supported by a range of different funding mechanisms administered by the USDA. These include formula funds (funds allocated on the basis of specific formulas defined in the various pieces of federal legislation that dictate the annual federal appropriations for this purpose), competitive grants and special-purpose grants.

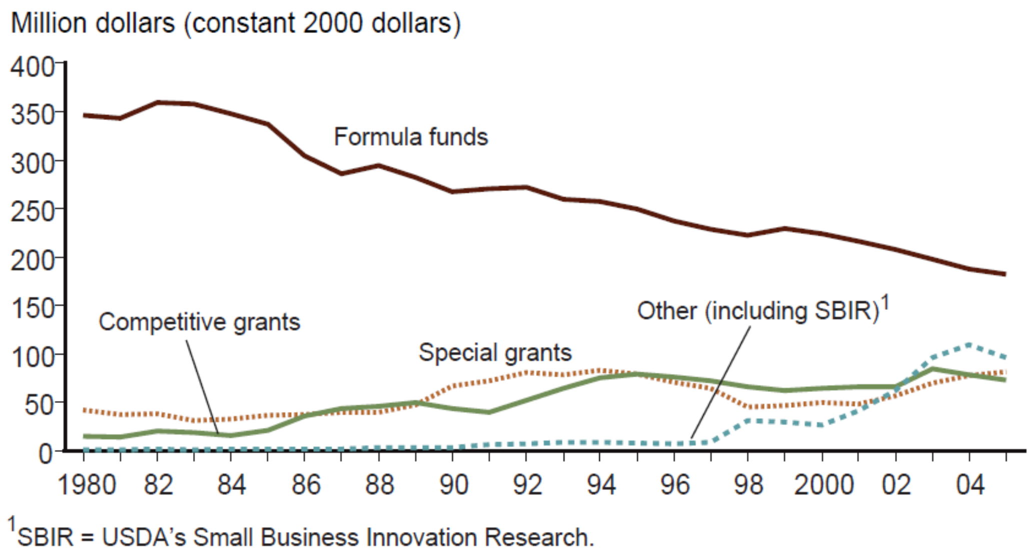


FIGURE 1 USDA NIFA FUNDING PROGRAMS FOR AGRICULTURAL R&D 1980-2005 (SOURCE: SCHIMMELPFENNING AND HEISEY, 2009)

In most instances, the respective state governments have an obligation to contribute between fifty cents and one dollar for every dollar of formula funds received from the federal government.

The extension activities of land grant institutions vary, depending on their location, and the nature of farm enterprises at that location. Throughout the corn/soybean belt the main activities appear to be 'advising the advisors' through workshops and training days dealing with specific crop production issues, and also providing information to farmers via field trials and regional conferences. The information provided at these farmer events includes economic and farm business information, in addition to some crop production advice. The University extension personnel do not generally provide one-on-one advice to farmers, although on occasions they appear to become involved in specific disease or pest outbreaks.

Across the wheat states, the role of university extension personnel appears to be more hands on, and involves the provision of crop production advice as well as other farm production and business information. University extension staff appears more likely to be involved in delivering crop production workshops for small groups of farmers, as well as managing and reporting on the results of field trials via publications aimed at farmers and at field days. University extension personnel also appear to be more closely engaged with individual farmers and small farmer groups, in conjunction with other CES staff.

The various state CESs all have extensive websites which provide access to libraries of factsheets, as well as detailed reports on trial results and variety trials (see http://www.oces.okstate.edu/crops for example). Some of the CES have developed decision support tools and smart-phone applications for use by farmers. The CESs also have training programs available to enhance their extension skills.

Recommendation 4: ***The Grains Research and Development Corporation should develop a requirement that, as part of the obligations on university researchers who are the recipients of major grains research funding, the researchers be required to allocate a minimum period of time annually working on the ground with grower groups, providing them with advice and support.***

Total public-sector funding for agricultural research and extension activities in the US was estimated in 2009 to be approximately $US 5.2 billion, of which $US 1.5 billion was funding for intramural (internal) research conducted by the USDA's Agricultural Research Service. Total funding on

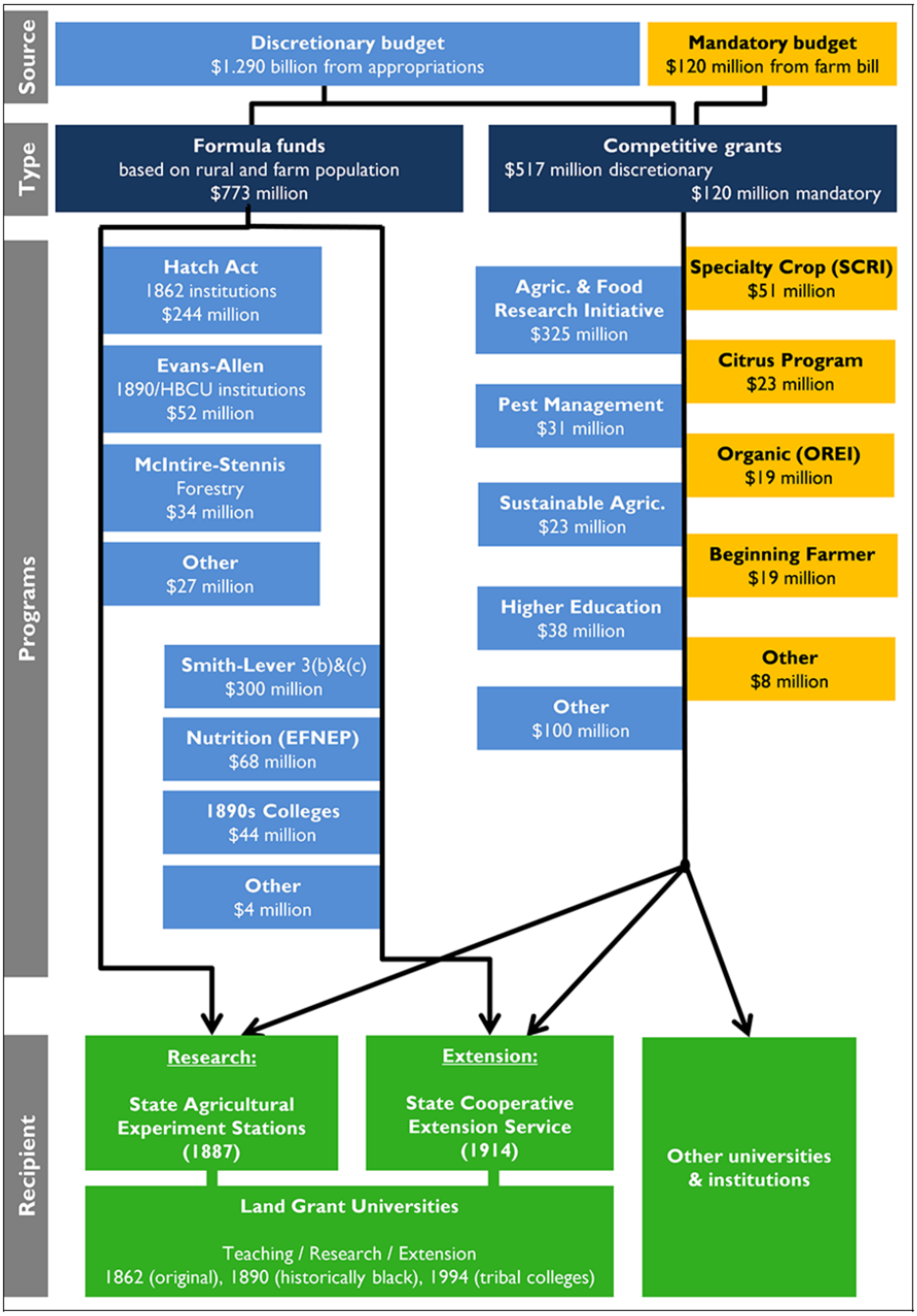
cooperative extension services was estimated to be $US 1.8 billion in 2006 (the last year for which complete data are available), noting that extension services deal with information about a range of different government policies and services, and are not just confined to agriculture (Pardy *et al.* 2013)."

COMPARISON OF THE US AND AUSTRALIAN SYSTEMS

In the United States, the Land Grant University model has provided a strong link between University research and teaching about research from all sources and extension and adoption. University skills and assets in teaching provide a strong and natural base for the continuing adult education that we often call extension. Academics often hold joint or partial appointments specifically in extension with percentages allocated for research, teaching and extension. Personal relationships are typically established by academics with future leaders while they are students that last for decades, enhancing the knowledge transfer process.

The USDA has responsibility administering funds for research and extension activities. These funds amounted to $2.726 billion in 2015 fiscal year of which a large proportion went to land-grant colleges of agriculture.

Figure 2 National Institute of Food and Agriculture (NIFA) budget (FY2015 budget authority), (J Monke, Congressional Research Service 7-5700)



Source: CRS, based on USDA FY2016 Budget Summary.

Notes: AFRI=Agriculture and Food Research Initiative; EFNEP=Expanded Food and Nutrition Education Program; OREI=Organic Agriculture Research and Education Initiative; SCRI=Specialty Crop Research Initiative

More than $1 billion is provided to the land-grant colleges including the formula funding indicated in Table 1.

Table 1 Examples of Government Funding for Land Grant Universities (2015)

EXAMPLES OF US LEGISLATION FUNDING FOR LAND GRANT UNIVERSITIES	ANNUAL VALUE
The Hatch Act 1862 – formula funding; as amended by the National Agricultural Research, Extension, and Teaching Policy Act of 1977 and other bills http://www.csrees.usda.gov/business/awards/formula/hatch.html http://www.csrees.usda.gov/business/awards/formula/allocationltrs/06_hatch.pdf	~$244m
The Smith-Lever Act of 1914 established the Cooperative Extension Service (Federal and State authorities working in knowledge transfer) and provides federal funds for cooperative extension activities http://www.csrees.usda.gov/business/awards/formula/smithlever.html http://www.csrees.usda.gov/business/awards/formula/allocationltrs/06_smithlever.pdf	~$300m
McIntire-Stennis formula funds support state designated institutions' cooperative forestry research programs http://www.csrees.usda.gov/business/awards/formula/mcintire_stennis.html (http://www.csrees.usda.gov/business/awards/formula/06_mcintire_stennis.pdf)	~$34m
Evans-Allen formula funds support agricultural research at the 1890 land grant institutions (which began as mostly African American colleges) http://www.csrees.usda.gov/business/awards/formula/evansallen.html http://www.csrees.usda.gov/business/awards/formula/allocationltrs/06_evansallen.pdf	~$52m

Table 2 Comparison between US Land Grant system and the Australian university system

US LAND GRANT SYSTEM	APPLICABILITY TO AUSTRALIA
USDA provides cash support of over $1billion annually to Land Grant Universities - Formula based, cash non-competitive grant - Normalised for Australia's population this would be around $75 million to Australian universities	No funding scheme exists federally Budget in universities derived from student teaching load Never been a scheme to fund on-going extension support. Extension is an extra unfunded activity for staff and it is not recognised internally or externally Limited grants are short term and project based
States provide cash contributions to their own state universities	No funds are provided by state governments No matching arrangements in place

Matching funds by State of 50c to $1	
State and federal agriculture departments contribute substantially to teaching	Limited and spasmodic at best
USDA funds National Research Initiative Competitive Grants	Occasional short-term programs funded by Federal Department (e.g. climate change)

As discussed further below, most of this is in formula funds, i.e., a straight cash non-competitive grant. It does not include cash contributions by the states to their own state universities or informal contributions from state or federal agriculture department staff to teaching, both of which are substantial. Normalised for Australia's smaller population, the federal cash support alone is still on the order of AU$80-90 million.

About US$53 million of the $1 billion annually historically has been used specifically and explicitly for higher education (see third to last page of "08 USDA Uni budget"). Much of the USDA funding is nominally directed toward research or "Cooperative Extension" (Federal and State staff working together in knowledge transfer), but clearly supports the kinds of activities commonly undertaken by Australian agriculture and land management faculties without the benefit of the US Land Grant model.

For example, Hatch Act funds are provided for on an annual basis under the Hatch 'Bill' of 1862, as amended by the National Agricultural Research, Extension, and Teaching Policy Act of 1977 and other bills. These funds are distributed according to a statutory formula. Although nominally for agricultural research, the scope of the agricultural research which may be conducted under the Hatch Act is very broad. It includes research on all aspects of agriculture, including soil and water conservation and use; plant and animal production, protection, and health; processing, distribution, safety, marketing, and utilization of food and agricultural products; forestry, including range management and range products; multiple use of forest rangelands, and urban forestry; aquaculture; home economics and family life; human nutrition; rural and community development; sustainable agriculture; molecular biology; and biotechnology.

Thus, there is a broad and long standing appreciation across the US and in both major political parties that agricultural higher education deserves support not only from the federal Department of Education, but also from the Department of Agriculture, whose portfolio the agriculture and life science college system supports. Further, the USDA has appreciated and helps pay for the critical and often basic research undertaken by universities (see the National Research Initiative Competitive Grants total), as well as the knowledge transfer activities undertaken by University staff.

An Australian Focus

Abundant research by Australian economists Pardey and Alston has demonstrated that the lag between research and broad-scale adoption in agriculture is on the order of 10-20 years. Adoption of research requires persistent effort by champions of the technology, often closely linked to researchers, to demonstrate benefits against years of entrenched experience. Delays in the adoption of new practices represent a substantial lost opportunity cost to the efficiency and competitiveness of our agriculture. The nexus between productivity and research, education and extension is an important one as demonstrated below.

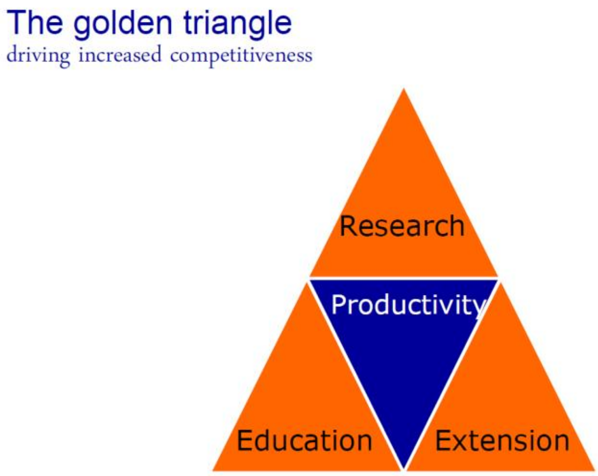


Figure 2. The golden triangle of productivity (Rabobank, undated)

Since universities undertake the education and training of the sector's professional workforce and perform about 30% of agricultural research in Australia it follows that continued links with the implementers of that research is an imperative. With the demise of much of the public extension system in Australia and the incomplete extension delivery of the private providers, there is a strong argument for ensuring the agricultural universities are involved in and contribute to the implementation phase of the process. This however should not be in isolation but rather through the development of strong public/private partnerships.

A key problem however is that no such US-style funding exists in Australian universities. Universities are funded primarily for teaching by student numbers, and any grants are short term for specific projects. Budgets in agricultural faculties and schools are constrained, typically in deficit. In contrast to state agencies and CSIRO, there has never been a funding scheme to facilitate continued contact post grant funded research between academics and research users; no funds exist for travel and accommodation, brochures, videos, websites, field demonstration sites, and related needs.

Australian universities, to be on par with US counterparts, therefore need a scheme to fund more extensive contact between academic researchers and primary producers. A simple proposal is to modify the US model and commit specified funding (at least $20 million) direct to agriculture departments on the basis of full time academics (continuing appointments at Level B and above) who are documented to be engaged in agricultural research, with annual concise reporting on accomplishments. Such funding could then be used to as leverage to attract private investment for greater impact.

Alternative approaches: It is opportune to review the range of options available that could be available to the sector in terms of R&D implementation support for universities. These include:

1. Funding of specialist extension personnel within the universities – these would have some student teaching responsibilities but have the requisite expertise to provide formal training courses to the range of advisers to primary producers. As well they would be expected to undertake research in implementation practices relevant to the regional, national and international sectors and have strong industry engagement.

2. The option exists for postgraduate courses in R&D Implementation. This could provide the basis for accreditation of advisers. It is interesting to note that such courses existed in times

past but the transformation of the sector in this regard in recent times suggests that consideration of the provision of postgraduate courses could be revisited, perhaps with inter-university cooperation.

3. Industry buy out of academic time to ensure availability of subject expertise for short workshops focused on local issues and applications. A network of universities would be involved. Such courses could be part of an accreditation process. This has the advantage of creating the links between local practitioners/advisers and the academic expert for ongoing mutual benefit and applies to all universities working in their environment. RDCs should invest over a reasonable term to ensure a sustainable relationship with the universities of relevance to each RDC.

4. Development of a university smart farms network whereby such farms are geared up with the latest technology including remote sensing. Producers and advisers could undertake regular visits and could remotely access the progress of demonstrations and attend webinars. Most agricultural universities have farms or farm access. A further advantage is that such sensing technology could be used for primary and secondary school education as well.

An attempt at preliminary costs is given in Table 3. The contents are based on 15 agricultural universities relating to the membership of the Australian Council of Deans of Agriculture.

Table 3 Provisional costs for university extension capability

EXTENSION OPTION	ACTION	BY WHOM	BASIS OF COSTING	TOTAL COST
US model for Australia	Specially directed formula funds	Federal Department of Agriculture perhaps in conjunction with state governments	$20m +	$20m+ annually
Funding of specialist extension academics	Special funds	Federal Departments of Agriculture, Education and Innovation perhaps in conjunction with state governments	15 universities x $150K	$6.25 m annually

Introduction of formal postgraduate courses	Fee paying &/or Industry sponsorship	Student &/or industry	Standard university fees	As needed
Industry buyout of specialist staff	Contractual arrangements	Industry, presumably RDCs	15 universities by 0.3 FTE per speciality Assume minimum of 3 specialities per university	$2.03 m annually
Smart farms	Special grants	Federal Department of Agriculture perhaps in conjunction with state governments	Average $3 million per university based on applications over 3 years	$15m annually for 3 years.

In summary therefore the following can be said:

- Adoption of R&D has an extensive lag which can be shortened by effective innovation support
- Universities do about one third of agricultural R&D in Australia but there is market failure with the lack of ongoing innovation capacity in the universities
- There is a national network of agricultural universities which could operate as an adapted version of the US Land Grant System
- A source of funding for innovation in universities is needed as there is no such funding at present
- Ideally an annual sum of $20m would enable the university sector to deliver an R&D implementation program
- Alternatively the annual provision of $8.3m would enable the appointment of specialist innovation staff and buy out of specialist staff to provide the basic suite of R&D implementation activities
- A special grant (e.g. $45m over 3 years) to bring university farms up to leading edge operations for demonstration and education would have significant outcomes for the industry and agricultural education in general.

Importance of Animal Welfare research

In extensive livestock farming systems typified by northern Australian beef cattle operations the biggest driver of production is reproductive performance, the single biggest cost is labour and the single biggest opportunity to increase profit is to maximise the price of product. Autonomous monitoring and management systems have the opportunity to increase reproductive rate, enable options to get more value from labour and enable more proactive marketing that will lift the price of product.

A greater focus on digital technologies for pastoral based production systems will facilitate industry led innovation. While there has been a promise and some limited developments now is the time for researchers to partner with industry collaborators and to focus on engendering confidence in the adoption of a new wave of digital technologies.

For pastoral farmers to be able to participate in the digital revolution requires research and development that links a combination of digital platforms and explores novel business models that will empower them in their business. In particular there is a need to explore how integrated data acquisition can be used to lift production, reduce costs of production and most significantly create greater opportunities for cattle producers to lift the value of their products through more collaborative marketing strategies.

Finding solutions to the key industry challenges will facilitate a move towards the pastoral industry adopting fully autonomous monitoring and management systems. The industry benefits are derived from:

- Greater participation in quantitative genetic improvement programs. Currently measuring quantitative traits in extensive pastoral based systems is difficult, costly and poorly refined.

- Improved and more proactive marketing strategies. Real time monitoring of livestock performance will enable producers to develop forward marketing options including implementing management regimes that optimise price. Wide scale autonomous monitoring within cooperative arrangements will allow farmers to engage in delivering specialised products to meet specific market requirements and enable them to move from price takers to price setters.

- More timely intervention strategies to facilitate improved animal health and welfare standards. The increased interest in welfare standards and the obvious losses associated with animal health issues can be addressed through autonomous monitoring and early warning strategies. The link between more regular updates on cattle performance will be increasingly integrated with autonomous management systems (e.g. auto-drafting) to deliver more timely and welfare friendly livestock management.

- Creating tools that can be used within a risk management framework to manage better labour input as well as addressing wide scale climate variability and natural disasters - More timely autonomous livestock monitoring will provide farmers with greater confidence on the state of their business. Labour input will be focused on high value activities rather than routine monitoring. The opportunity to continuously monitor the state of the business will form part of an overall risk management framework.

Participation in emerging information technology innovation requires skills in digital technologies, agriculture, business and marketing. Computer science and engineering skills are needed in order for

sensor networks to mature, but these skills need to be firmly grounded in the business of pastoral farming. There is a strong need for research that can develop creative systems orientated solutions within a contemporary sensor network framework.

Importance of Soils research

Soils underpin food security in all nations. The often old and impoverished soils in Australia require specific focus and attention to ensure that they remain productive, both in terms of food production and ecosystem health. Whilst much research and activity currently surrounds the soils of Australia, to date there has not been a coordinated framework that brings together the most important, and often connected issues related to soils.

The release of the National Soil Research, Development & Extension Strategy provides this framework. The National Soil RD&E Strategy Implementation Committee's aim is to develop strategies and priorities within such a framework, to improve and maintain soil ecosystems for the benefit of the nation. We have developed 5 key priorities that cut across research, innovation, data and information, extension and education, and policy. Importantly, we recognise there are dependencies and linkages between each priority, and cross talk between these priorities is required. These priorities are listed in no particular order. We also recognise the importance of these priorities as underpinning all of the agricultural productivity and contributing to the ecosystem services within Australia.

5 key priority Soil RD&E areas – Soil RD&E Strategy

SHORT DESCRIPTION OF THE PRIORITY	DESIRED OUTCOME
Find solutions to soil-based constraints to agricultural productivity · Improve our understanding of soil function, soil formation, erosion rates remediation and restoration processes so we can design ways to achieve sustainable soil management. · Develop rapid diagnostic systems for detection and response to soil-based constraints to root growth in crop, pasture and irrigation. · Improve the rhizosphere (the soil-plant-interface) to enhance plant productivity and soil function, including by improving soil structure, supporting breeding programs for plants with improved root systems, storing carbon and learning to manipulate microbial diversity. · Develop economically viable biological, chemical and/or physical methods to ameliorate unfavourable subsoil rooting conditions (e.g. compacted and dense soils, lack of macroporosity, acidified layers).	Farmers are diagnosing when soil function is sub-optimal and is impacting yield and productivity. · Farmers have cost-effective options to ameliorate soil-based constraints (e.g. compaction) in locations where plant production is below the intrinsic potential. · The condition (health) and productivity of managed soils is improved using practical, well-verified, system-based strategies incorporating biological, chemical and physical process understanding. · Rates of soil loss are reduced as a result of improved soil condition, greater levels of plant cover, and appropriate land use.
Improve nutrient and water-use efficiency to increase productivity and	

minimise negative impacts (including acidification, eutrophication, leaching and agricultural greenhouse gas emissions) · Find new ways to improve nutrient-use efficiency, especially of nitrogen and phosphorus, in managed landscapes (e.g. improved fertiliser management that addresses the amount, form, placement, timing and potential for bio-enhancement). · Find new ways to optimize soil water-use in managed landscapes and improve the integrated management of water and nutrients in irrigation systems. · Determine current rates of soil acidification and identify feasible remedies. · Rebuild the stocks of organic carbon in Australian soils. · Develop efficient strategies for reducing soil greenhouse gas (GHG) emissions.	· Increased total factor productivity in crop, irrigated, pasture and livestock industries. · Reduction in agricultural nutrients entering the environment. · Greater ability of agricultural industries to adapt to variable and reduced rainfall and water availability. · Soil acidification is ameliorated, avoiding environmental impacts and widespread loss of agricultural productivity. · Increased carbon is stored in agricultural soils resulting in improved soil structure and plant productivity as well as significant carbon offsets. · Landholders are implementing efficient strategies for reducing emissions of GHG from agriculture.
More effective soil and land use policy · Support policy and planning with credible science to effectively identify and protect good quality agricultural land (e.g. better management of tradeoffs with urban expansion, mining and energy developments, forestry and biodiversity). · Develop complementary policies in the national interest that address climate, agricultural and environmental objectives. · Support education policies and programs that lead to a better understanding of soils and the ecosystem services they provide in rural and urban communities. · Find policy solutions that address market failure in relation to the collection, management and provision of soil information. · Develop adaptive management frameworks that enable soils information and knowledge to be better utilised in land planning, policy implementation and industry growth.	· More efficient and equitable use of Australia's soil and land resources. · Reduced conflict over land use and management and the impact of agriculture (e.g. on water quality). · Actions to prevent and reduce the risks of long term soil and land degradation. · Lessening of the urban-rural divide in Australia with citizens having a better understanding of agricultural production systems. · Creation of a sustainable business model for soil data collection and management that recognizes that soils are both a public and private good.

The Outlook for Agri-Intelligent Systems

Robotics, autonomous systems, and data, combined with a systems view of agricultural production systems and their interactions with the natural, economic, and social environments

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Context

Since the 1960s, agriculture has benefited from increased use of agrochemicals and significant advances in crop and animal genetics, agricultural mechanisation, and management practices. These technologies have been at the core of increased productivity and will continue to provide future incremental improvements. However, the drive for higher yields is pushing against the current boundaries. There is, hence, an urgent need to expand the scope of food production management to include objectives related to sustainability and improved use of finite resources. So the question is: *what will fuel the next agricultural revolution?*

Managing complex systems, such as food production systems, and their interactions with natural, social, and economic environments requires a delicate blend of novel technologies and a systems view. We foresee that the integration of key technologies related to robotics, autonomous systems, sensors, computer-human interaction, economic and business tools, and data analytics with a systems view of the farming enterprise and the agri-food value chain will trigger the next wave of innovation in agriculture. We call this *Agri-intelligent Systems*.

Over the next ten years we expect to see *agriculture transitioning into the digital age* and realizing the tremendous potential for *better understanding opportunities and risks* arising from data and integrated management operations, whilst ensuring sustainability. Leaders who can integrate deep agricultural knowledge with cutting edge technology, data and systems science will be central to the next agricultural revolution. This will also require changes in the workforce.

Agri-Intelligent Systems

The optimization of isolated processes (irrigation, management crop nutrients, animal health, etc.) will enable the transition more towards a holistic system view of food production. These Agri-intelligent systems, which are enabled by a combination of robotics, autonomous systems, and data, combined with a systems view of agricultural production systems and their interactions with the natural, economic, and social environments.

Figure 1 shows the three key components of our agricultural food production: the farming enterprise, the value chain, and enabling infrastructure. The figure also shows some of the external influencing factors. In each of the key components, there are objectives to optimise. Farmers seek to minimise input use. At the same time, they seek to maximise yield, quality, and the health of their produce. This optimisation must be accomplished in the presence of uncertainty related to climate, crop/livestock health, and input costs as well as market volatility. In order to make their production systems robust, farmers use feedback mechanisms (sense, think, act). Data from various sensing modalities (visual, satellite, remote sensing, agronomic sampling, weather, markets, etc.) are analysed, and decisions are made on how to apply inputs (water, nutrients, herbicide, and pesticide) in order to achieve desired objectives – or system behaviours.

The above is paralleled in the value chain. Operations seek to maximise food quality, traceability of products and market impact. This optimisation must be accomplished in the presence of uncertainty related to market volatility, new and competitive markets, changes in national and international policies and legislation, as well as changes in the habits of consumers. This is accommodated, again, by the use of feedback mechanisms (sense, think, act).

The infrastructure necessary to enable food production also seeks to optimise its operation in terms of communications, transport, energy, data volume, data rate, data availability, and purpose of analytics. This infrastructure must be maintained in the presence of uncertainty, evolving technologies, changes in national policies and legislation, and workforce capabilities. Once more, this is accommodated by the use of various feedback mechanisms (sense, think, act).

Figure 1 depicts only a simplified version of reality. It fails to capture the interactions among the key components and their feedback loops. Within the next ten years we hope to see a better use of information in the implementation of the individual loops and perhaps the beginning of the transition into a single integrated system, where the thinking is based on information about the state of all key components and not just single ones. This will achieve a *true optimized and robust food production system from paddock to plate*.

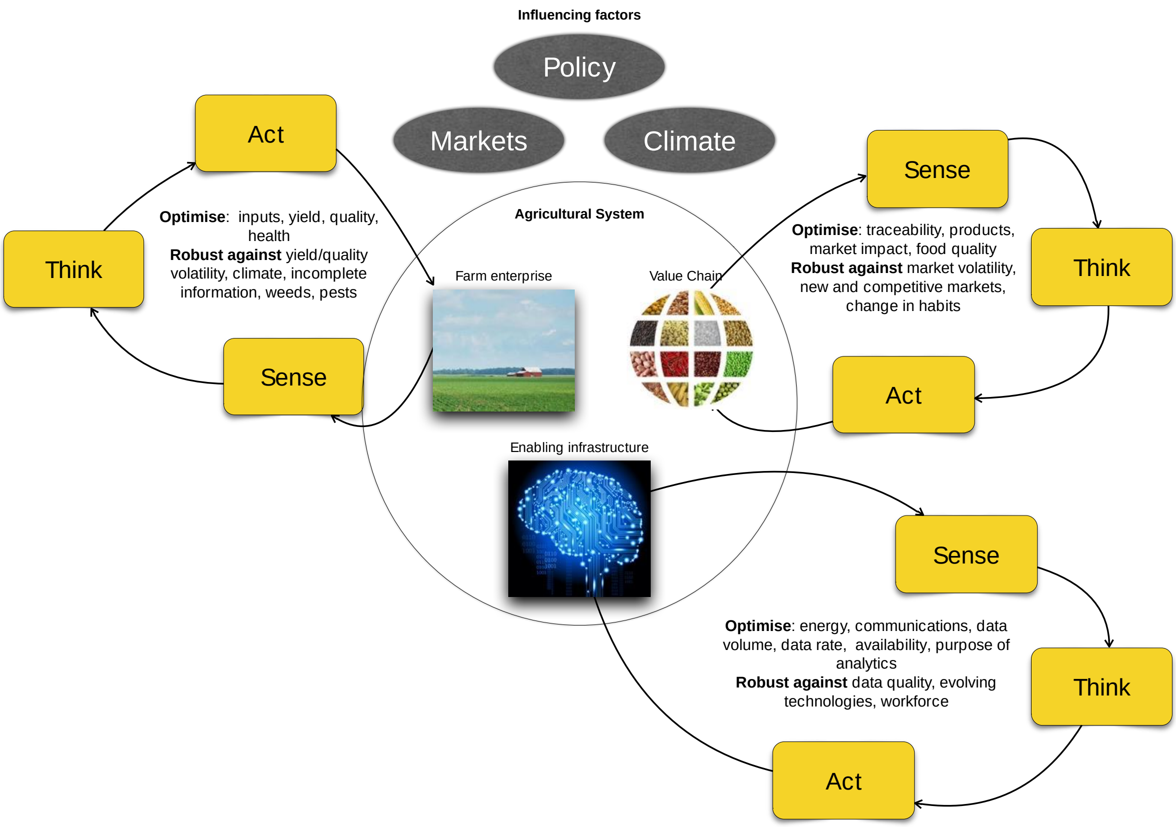

Figure 1. Main components of the agricultural food production system together with influencing factors and feedback mechanisms (sense-think-act) for ensuring resilience to shocks and uncertainty

The following are areas in which significant contributions leading to high impacts are yet to be made. Hence, we expect advances in these areas in both the near- and the long-term futures:

- *Discovery from data*
  In cases where big datasets exist, data can be analysed to discover new insights and increase situational awareness. There are opportunities for developing analytics and applying specialised frameworks, models, and artificial intelligence for pattern recognition. Agriculture processes have different scales and not all are described by this scenario, which is what most people think when the term 'big data' is used. For example, there may be aggregates of yearly yield data at a farm and even region level, but little data related to specific processes during season.

  Within the next ten years, we will see an increase of spatio-temporal data in farming systems as well as along the value chain. This will enable the use and specialization of technology for big-data analytics already being used in sectors such as sociology, national security, financial, and insurance.

- *Informed decision making*
  Data *per se* is not information. The latter needs to be extracted from the data and used to reduce uncertainty. The management of a food production system involves making decisions under uncertainty. A decision maker (whether a human, an autonomous agent, or a combination of both) must choose an action from a set of alternatives. The choice must take into account the consequences of the potential outcomes, which depend not only on the action taken, but also on relevant attributes that in many cases are uncertain at the time of decision making. Uncertainty makes decision making difficult. Uncertainty can be reduced by learning from purposefully collected data combined with sophisticated mathematical models to extract information – analytics. Assisting farmers, managers, and SME service providers to collect, merge, and analyse large amounts of data, as well as to extract valuable information in the context of their decisions, communicate uncertainty, and appreciate the full range of potential consequences are areas in need of much development in agriculture.

  Within the next ten years, we envisage the adaptation of existing methods for extracting key information from increased amounts of data in order to reduce the risk of decisions in food production systems. We also anticipate an increasing expansion in objectives and constraints in decision making to include not only yield and quality, but also aspects of sustainability.

- *Agricultural cybernetics*
  In many management situations, there is a need to make decisions sequentially in time using information feedback – this applies to any of the sense-think-act loops in Figure 1. This type of decision making process falls within the realm of *cybernetics* – the study of systems capable of receiving, storing and processing information and its use it for controlling desired behaviours. Feedback is a key tool for achieving desired behaviours in systems; however, if not properly understood and handled, feedback can give rise to *fundamental limitations* in sensing and in action effectiveness, as well as leading to undesirable behaviours. There is a significant body of system science results applied to engineering and finance that can be adapted to food-production systems. This is what we refer to as having a systems view.

  When it comes to state-of-the-art agricultural cybernetics, there has been a significant body of research in the area of protected cropping, where decisions for controlling nutrients, irrigation, pest and diseases, energy, and residuals in soil as well as climate are considered. A key challenge is to extend these practices to the field.

Within the next ten years we hope to see developments in agricultural cybernetics beyond protected cropping. Within longer horizons, we should see applications of agricultural cybernetics not only in the farming enterprise, but also integrated along the value chain.

- *From decision making to infrastructure design*

  When data, or the right data, is not available, we can work backwards from decision to infrastructure design. By taking a decision problem into consideration (starting with the end in mind), we can determine the key information that can take the risk (the compound of consequences and their likelihood) into levels that are acceptable to the decision maker. This can then be used to adopt the data and data quality needed to extract the required information. Such analysis can be used to specify the technical requirements for data generation and capture, storage, communications, and access. To date, there is tendency among certain sectors to believe that more and more data is needed to improve decisions. Whilst more data cannot hurt the decision maker, the value of information these data contains may not help, and in the case of agriculture collecting data is not cheap due to spatio-temporal characteristics of the underlying processes. This can also critical to avoid fundamental limitations due to feedback as mentioned above in Agricultural Cybernetics.

  Within the next ten years, we hope to see more systematic approaches taken in making decisions about infrastructure design based on concepts developed in system science.

- *Sensors and Sensor Networks*

  Sensors provide data that can contain useful information – where 'useful' is term relative to the decision or managing problem being solved. The spatio-temporal characteristics of the underlying processes we seek to monitor and learn in agriculture require networks of sensors distributed in space and collecting data a various time scales.

  We expect the trend toward low-price of sensing technology to continue. At the same time, novel sensors are being developed. Artificial vision systems for agriculture, for example, are yet in need of much development in order to satisfy the required operational conditions (lighting changes being the most critical one.)

  The solution to sensing problems (to gain the required data contain the right information) may not always come from new sensors. There is an opportunity to use advances genetics and management practice to improve sensing capabilities. We humans use the sense of vision to collect information that enables our movement. However, we often move in order to improve our vision. There is a parallel in what can be achieved in agriculture by modifying the signature of crops and animals to various sources of stress in order to be best captured by sensing technologies. So the information needed may be enabled by a combination of sensing technology and improved signatures (chemical, visual, etc.) of crops and livestock as well as management.

- *Robotics and Autonomous Systems*

Robotics and autonomous systems are making a significant impact in efficiency and safety as well as enabling new operations in sectors such as mining, health, manufacturing, transport, and financial. We are starting to see some of these technologies being developed for agriculture, albeit at a prototype conceptual stage.

There are three areas where robotics and autonomous systems can make an impact in agriculture:

- Robot-enabled sensing;
- Robot-enabled thinking;
- Robot-enabled acting.

Figure 2 shows some of the tasks associated with these areas. Robotic technology is mature in automated manufacturing, where the environment in which robots operate has been artificially structured for the robot – think, for example, about the layout of automated production lines. This is not the current scenario in farms, where the operational environment is largely unstructured and challenging. Hence, the maturity of these technologies is lower than what general public tend to think.

Robot-enable sensing is a low-hanging fruit. Robots can carry sensors that can collect a variety of data, which can then be analysed for decision making and discovery purposes. Contrary to dedicated sensor networks, robotic sensing can be flexible and adaptive in space – this can be critical for adaptive sampling and the detection or pest and diseases. Within the next ten years, some of the tasks detailed in Figure 2 are believed to become available.

Robot-enabled thinking refers to the assimilation of information and its use in decision making for managing food production systems (soft-bots). We envisage an increase in the level of automation in sensing and low-level management decisions, as well as the use of robotic technology to generate likely scenarios with their associated uncertainties to assist human decision makers. This can be seen as a hierarchical setting in agricultural cybernetics.

Robot-enabled acting in highly unstructured environments is the holy grail of robotics. This is the area where expectations today are too high, and robotics may not able to deliver these expectations within the next ten years.

We are starting to see applications for robotic weed management, pest control agent application, and harvesting of particular horticultural crops. Also there is an increasing level of automation in farm packing houses. These are expected to increase within the next ten years.

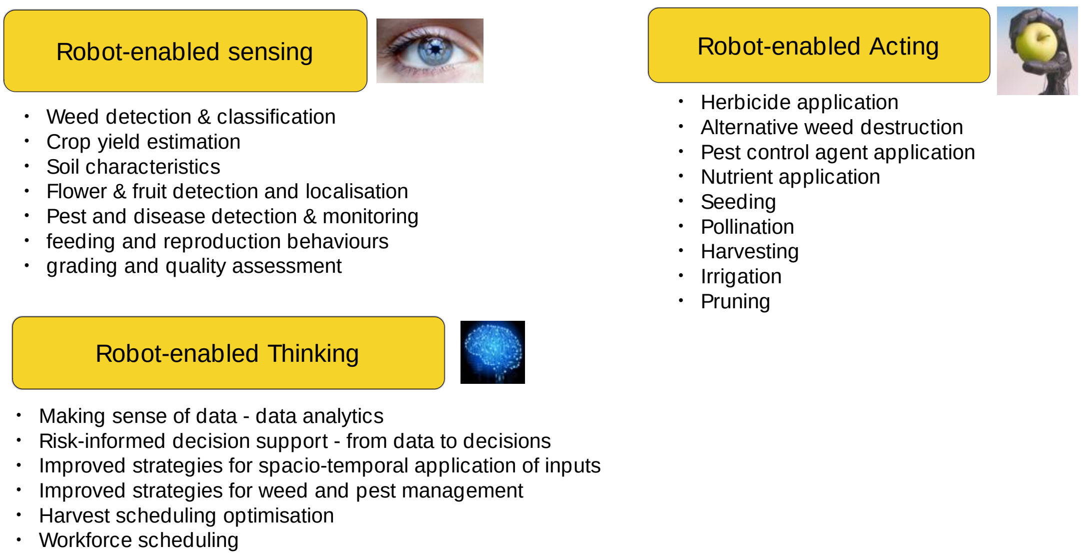

Figure 2. Robotics and Autonomous Systems in Agriculture

Enabling Factors

Thus far, we have focussed on technology. However, the technology described is to be used by humans. Due to the complexity associated with the management of food production systems, we do not anticipate humans being out of the management loop neither in short nor in the long term. Instead human capabilities for management will be enhanced by the use of Agri-Intelligent Systems.

For the successful adoption of Agri-intelligence, key enabling factors need to the brought to maturity:

- Platform technologies;
- Economics and business;
- Risk and regulations;
- Social aspects.

Figure 3 shows the four enabling factors and the issues within each that require further development for the adoption of Agri-intelligence. This figure also shows the dominant stakeholders associated with the enabling factors.

It is only through progress in all these areas that the next agricultural revolution will be achieved, and with that food security and sustainability.

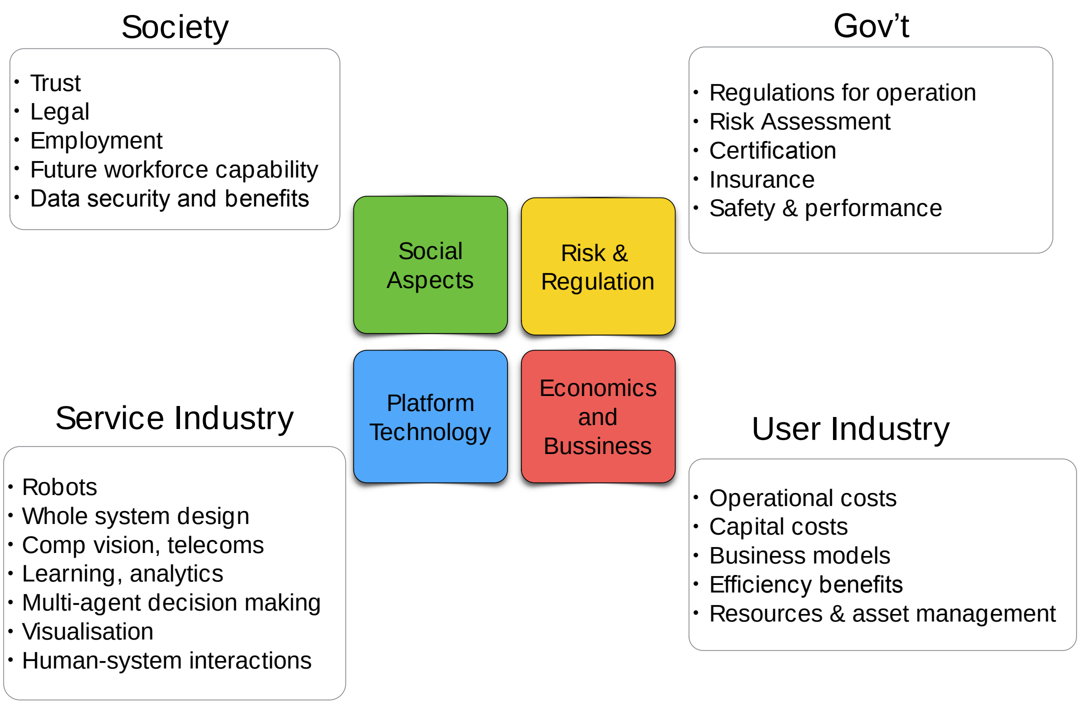

Figure 3. Enabling factors for the uptake of Agri-intelligence technology