final report

Project code: B.GSM.0004

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Date published: November 2012

ISBN: 9781741919653

PUBLISHED BY
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Potential for information technologies to improve decision making for the southern livestock industries

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

There have been significant recent investments in remote and precision technologies by a number of companies which may have medium to long term potential to improve management and profitability of grazing enterprises

Key decision points in the operation of grazing businesses were identified and then matched to appropriate technologies. Among the priority areas identified were, the development of zonal management of soil fertility, weed management, coarse stock location for stock security and auditing, fine resolution location for dam off spring and sire dam association, animal health monitoring, and feed quality and quantity assessment.

The study also looked in detail at the economic impact on grazing enterprises from having improved knowledge through precision technologies in a number of key decision areas.

Executive summary

The Feedbase Investment Plan (FIP) commissioned by MLA in 2011 defined researchable priorities in all southern agro ecological zones with a focus on increasing the profitability and sustainability of red meat production. The Feedbase R&D Plan then built the next level of detail, in which remote/precision technologies were identified as being critical to addressing fundamental gaps in our understanding of grazing behaviour, animal management and pasture performance. It also acknowledged that increasing application of these technologies could lead to better (more accurate and/or timely) tactical and strategic management decision making.

MLA subsequently commissioned this project to review and investigate the potential for a significant R&D investment in the general area of 'precision agriculture' for the southern grazing industries. Their intention was to seek a deeper understanding of the key significant on-farm tactical and strategic decision areas that lead to more efficient use of resources for meat production, and specifically those that could be enhanced through improved data/information collection.

The project focussed on three core issues (1) the key on-farm tactical and strategic decisions that might benefit from better data/information flows, (2) the potential benefit of that better decision making, (3) the data/information needs required to capture that potential benefit.

The importance of these decisions were evaluated across four production systems (set stocked, rotationally grazed, mixed farm, intensive rotational grazing) and two operation types (trading/fattening operations, breeding operations). The applicability and significance of these decisions were considered in relation to the various agro ecological zones of southern Australia.

In order to determine the potential alignment of technologies with different on-farm decision needs, two parallel streams of activity were conducted and then assimilated. Firstly, the critical decision points in different production systems were examined, documented and compared across each production system and a short-list of key management decisions that would benefit most from improved data and/or information were detailed. These were defined primarily as being key profit drivers, but the implications for social and/or environmental benefits were also considered. The data needs were determined without consideration of the technology that could be applied.

Secondly, a review of possible technologies and information streams was conducted, and a series of discussions held with commercial and R&D stakeholders to fully understand state of development, key issues and constraints, perceived on-farm applications and benefits, and future developments.

Once the key on-farm decision points were prioritized, and the initial technology audit complete, all the potential technological solutions were aligned with each decision point's specific requirements. The findings were presented to an industry workshop in June 2012 for feedback prior to an economic evaluation of case study farms being conducted to provide a snapshot of the potential impact that information and data provided by precision technology could have on key decision areas (attendance list appended).

Ten key areas where more precise data/information would benefit decision-making were identified:

1. Improved pasture production through soil fertility.
2. Improved feed allocation – allocating appropriate quality and quantity of feed to different classes of stock in a timely manner.
3. Pasture yield mapping – understanding, managing and optimising pasture production within and between paddocks.
4. Feed prediction - the mitigation of risks associated with adverse climatic conditions and opportunities associated with good seasons.
5. Weed management – timely detection and management of weeds.
6. Stock auditing and security – ability to determine location of stock, and timely alerts of theft or predator attack.
7. Dam-offspring association – phenotypic and genetic selection.
8. Sire-dam association – reducing neonatal losses and improved rate of genetic gain.
9. Animal disease identification – early detection of subclinical diseases to improve performance and welfare.
10. Individual animal production – liveweight and body condition monitoring to improve reproductive performance and animal growth rates.

Following industry consultation, the economic analysis focussed on the 4 highest perceived priorities of soil fertility, feed allocation, animal production monitoring and animal disease monitoring. Results indicate a significant potential on-farm benefit ranging from gains of $14 to $118 in GM/Ha (see table below). Note that with the exception of the feed allocation and animal production monitoring case studies where the same base farms were used, it is inappropriate to directly compare TFP growth figures between case studies as base case study farms are different.

***Table**. Net benefit of technology (Gross Margin per DSE and per Hectare, and Total Factor Productivity growth) for sheep and beef enterprise case studies for four key decision areas*

Sheep enterprise	**GM/DSE**	**GM/Ha**	**TFP Growth**
Soil fertility	-$3.26	$85	26 %
Feed allocation	$4.93	$96	11.1%
Perennial Ryegrass Toxicity	$4.85	$118	13.5%
Animal Production Monitoring	$3.74	$81	9.6%
Beef enterprise	**GM/DSE**	**GM/Ha**	**TFP Growth**
Soil fertility	-$4.97	$14	13 %
Feed allocation	$3.67	$52	9.6%
Bloat with preventative capsules	$0.29	$14	4.3%
Bloat with no preventative capsules	$0.79	$19	6.8%
Animal Production Monitoring	$2.10	$29	4.1%

Note: Results exclude capital costs of purchasing and establishing new technologies on farm.

There are a range of technologies potentially applicable for any given decision area, from commercially available systems through to those conceptually applicable with only proof-of-concept established here or overseas. These are discussed and evaluated in depth in this report. After reviewing each decision area in detail, it is clear that there are two underpinning areas of technology that enable multiple applications. Pasture monitoring technologies (for biomass and quality) underpins soil fertility, feed allocation, feed prediction and pasture yield mapping. Animal location and behaviour technologies underpin feed allocation, pasture yield mapping, soil fertility, disease detection, animal associations and stock auditing and security.

Recommendations arising from this report

Given the significant benefit possible, and the potential technological solutions available, the following recommendations for R&D investment are made to MLA (note that these recommendations are fully detailed in the following section). In addition one strategic recommendation is made below:

1. High priority
   A. **Soil fertility** – The development of zone-based variable rate applications by understanding how integrated soil, plant and animal spatial datasets can best be integrated and interpreted to predict soil constraints to production.
   B. **Pasture biomass –** The establishment of a regionally-based R,D&E program that simultaneously calibrates and validates a range of vehicle, airborne and satellite technologies to quantify pasture biomass, develops systems to integrate the data with farm management software, and demonstrates tangible applications in a commercial setting.
   C. **Animal location and behaviour** – An investment in the development of a number of applications utilising technology to monitor the location and behaviour of animals, in particular improved feed allocation (matching animal demand with feed supply), early detection of animal health, sire-dam and dam-offspring associations, and stock auditing and security. A program of work is required to deploy these technologies and establish relationships between the location/behaviour metrics and the events of interest in order to deliver an integrated solution capable of real-time data acquisition, analysis and interpretation.

2. Medium priority
   A. **Individual animal production monitoring**
   A.1. Animal liveweight – An investment is recommended to establish agreed data-handling processes for commercially available weighing systems (particularly walk-over-weighing) that enable producers to capture the full potential from the technology in not only mob-based but also individual animal management. This should include data infrastructure that captures information remotely and makes it readily available to producers in near real-time with appropriate integration with decision support systems.
   A.2 Body condition score – The current MLA investment into an imaging system for measuring p8 fat and muscularity should be supported so that its potential accuracy and reliability in on-farm conditions can be evaluated. However an investment is recommended into laser scanner technology because it actually quantifies the structure of the animal, and is less likely to be subject to errors associated with field conditions.
   B. **Animal health and rumen function –** The current MLA investment into the intra-ruminal device for measuring methane needs to be fully supported, and if successful in terms of the platform technology, then it should be extended to include key rumen health (e.g. pH, temp) and nutritional (e.g. VFA) parameters. A watching brief should also be kept on commercial developments to see if issues related to device longevity

can be overcome. The investment recommendation above in animal location/behaviour applications should also focus on early detection of animal health issues.

3. Low priority
   - **A. Pasture quality** - A relatively small investment is recommended to establish proof-of-concept in NIRS/Hyperspectral spectroscopy to estimate pasture quality parameters and to determine the potential accuracy of the information relevant for improved feed allocation, animal management and plant nutrient status.
   - **B. Weed management** – A small proof-of-concept study is recommended to examine the potential of NIRS/Hyperspectral spectroscopy to detect green weeds in green pasture swards, and to determine its capacity to quantify percentage weed infestation.
   - **C. Pasture yield mapping –** Because of the need for estimates of actual pasture productivity at the sub-paddock scale, taking into account animal intake, any investment should be delayed until other investments are concluded and the capacity to estimate pasture biomass and animal intake is known.
   - **D. Feed prediction** – A more thorough review is recommended to understand the forecast/prediction requirements for key decision points in production systems, the capacity of current forecasts, and build a strategy for ongoing R&D and delivery. A watching brief is required on advances in the climate forecast models as these are continually improving and will underpin an ability to forward-prediction feed availability and quality.

4. Strategic investment priority

   Autonomous control of livestock - Beyond monitoring technologies, we also make a case for a strategic investment in technology to autonomously control livestock. The development of a business case with market research is required to focus further work and to detail the steps required to get the current state of technology to a commercial product. This will then inform further R&D requirements in both the underpinning technology and the animal behaviour domain. It is anticipated that most R&D effort initially will be required to understand better how animals respond to different cues and controls in different circumstances, the consistency with which animals respond, and the implications for individual and mob/herd-based management.

More detailed information on these R&D recommendations is provided below:

Detailed R&D Recommendations and Approaches

HIGH PRIORITY

1. Soil fertility

Priority – HIGH

Nature of R&D – Algorithm & application development

Gap/Opportunity

Numerous studies and programs have demonstrated that in the medium to high rainfall zones large increases in productivity can be achieved by correcting soil nutritional deficiencies/acidity problems etc. The current method of assessing soil nutrient status is through the manual collection of soil samples but the time involved in collecting the samples and the cost of the analyses are limitations to extensive sampling. There is a need to develop a method for identifying spatial variation of soil nutrient status and soil pH either through direct measurement or through proxy means.

The direct measurement of soil nutrients *in situ* using on-the-go sensors remains an ongoing challenge with few suitable tools available for deployment in pastures. There appears to be a reasonable amount of research going into this field from the cropping industries although the transfer of these technologies to non-arable pastures where un-cultivated soil may damage any probes remains an issue. A key challenge remains in sensing green weed species amongst desirable green swards.

A more immediate solution to the problem would be the development of zone based variable rate application. There are a range of tools to measure spatial variability in soil, plant, animal and climate characteristics but a spatial informatics R&D approach is required to understand how these best be used to define variable rate zones

R&D objectives

- To develop an understanding of the spatial and temporal variability of soil nutrients in grazing systems and associated spatial datasets.
- To understand which spatial datasets reliably indicate soil constraints to production, how they are best integrated, and the impact of other potential constraints.
- Validation of the economic value of site specific fertiliser management in pastures.
- To develop clear guidelines for soil sampling/testing and subsequent site specific fertiliser applications

R&D approaches

- Need to address specific regions/soil types in turn, collating spatial soil, plant, animal and climate datasets to establish relationships with soil constraints to production.
- This investigation should consider the minimum data sets required for accurate development of zones, and the use of more ‘sophisticated’ spatial informatics techniques to establish the relationships.
- The outcome should be a clear process for producers to understand their optimum strategy to apply fertiliser according to requirements

Timeframe – 5 years. Requires extensive field research across regions. Program should include the establishment of field sites, 3 years of field research, and a final “harvest” year.

Risk of failure – Medium (due largely to complexity of factors influencing soil health/fertility)

Size of investment – Large ($500-750k pa) – dependent on how many regions conducted simultaneously, but likely to require significant science capacity, technical support and operating

Key partners – CRC for Spatial Information, CSIRO, UNE, CSU, State Dept Agriculture, PA consultants and service providers, fertiliser manufacturers.

Opportunities for RDC co-investment – AWI, GRDC

2. Pasture monitoring - biomass

Priority – HIGH

Nature of R&D – Algorithm development & sensor testing

Gap/Opportunity

Efficient utilization of feed for specific management objectives depends upon allocating the appropriate quality and quantity of feed to different classes of stock in a timely manner. Accurate feed allocation to meet production targets has the potential to improve not only pasture production but also to improve feed utilization. Visual assessments of feed quantity and quality are invariably subjective and objective measurements would rarely be taken on farm due to labour constraints.

There is a need to establish techniques to quantitatively estimate pasture biomass as it underpins a range of applications including feed allocation, soil fertility, pasture yield mapping, and feed prediction. There are a range of technologies currently at or close to market, including vehicle, airborne and satellite platforms. There is unlikely to be one single technology that meets the needs of all systems and user requirements. Fundamentally they all require calibration across seasons, pasture types and regions.

R&D objectives

- To simultaneously calibrate and validate a number of technologies to quantify pasture biomass, and make those calibrations available to industry.
- To develop systems to integrate the real-time biomass data into supporting farm management software, and demonstrate applications of the information in a commercial setting.

R&D approaches

- The recommendation is to design a regionally-based R&D program that simultaneously calibrates & validates several technologies to pasture biomass.
- Regions can be defined based on an initial spatial analysis of agro-climatic data and experience in other regions/countries, and the sampling protocol set up to establish how geographically disperse calibrations can be used.
- Consideration should be given to integration of this project with the national pasture variety trials.
- A component of this research should be conducted on commercial farms to demonstrate the different technological options and specific applications in a commercial setting, with a focus on improved feed allocation and defining soil fertility zones.

- Requires a component of work to ensure systems are in place to integrate the biomass data into supporting farm management software.

Timeframe – 3-4 years per 'region' to capture within and between year variation. Staggered roll-out to other regions.

Risk of failure – Low

Size of investment – Large ($500-750k pa) – dependent on how many regions conducted simultaneously, but likely to require significant science capacity, technical support and operating. Could be structured as an overarching science leader to co-ordinate regional activities.

Key partners – CSIRO, UNE, State Departments of Agric, CRC for Spatial Information, State Commercial technology providers.

Opportunities for RDC co-investment – DA, AWI

3. Animal location and behaviour

Priority – HIGH

Nature of R&D – Technology, algorithm and application development

Gap/Opportunity

An underpinning capacity to monitor the location and behaviour of animals enables several applications including improved feed allocation, early detection of animal health, sire-dam and dam-offspring associations, and stock auditing and security. The value proposition for investing in the location and behaviour technology is its capacity to yield these multiple benefits in one integrated solution.

An investment is warranted in (1) developing and delivering tangible applications from those technologies which are currently commercially available or near to market through on property testing and evaluation, and (2) the development of a research tool that integrates location with behavioural sensors such as accelerometers, magnetometers, audio (including ultrasonics), optical sensors, pressure sensors and radio-transmission to determine which sensors best relate to the behaviours of interest to deliver the range of potential benefits described above. The learning outcomes of the investment in the integrated research tool should flow directly to the commercial systems. The limitations of the commercially available sensors discovered in (1) should directly inform the development of the research tool (2).

The key requirement is to understand the natural variation that occurs in the location and behaviour metrics and establish relationships between them and specific events of interest (trends and/or deviations). For real-time monitoring applications there is a requirement for on-line data processing and interrogation systems.

R&D objectives

- To develop an integrated program of work that captures and interprets animal location and behaviour information to derive applied applications for stock location and security purposes, improved feed allocation, early detection of animal health issues, and animal association applications.
- To understand the variation in location & behaviour that naturally occurs within and between animals in different conditions in order to understand what deviation represents a specific event of interest.
- To develop data handling processes that detect anomalies and reliably indicate events requiring further investigation (egg theft, health, welfare)

R&D approaches

- Effort is required to deploy the latest technology in a demonstration setting, but as a research objective to build relationships between the metrics and specific physiological and management scenarios. An understanding needs to be established as to how the metrics vary in space and time, between animals and management regimes, and how trends and anomalies in behaviour can be detected to signify key physiological events such as animal health or feed availability/quality constraints.
- A two-tiered approach is feasible: (1) deployment of commercially available location technology on commercial and demonstration farms to test basic feasibility and accuracy and develop tangible applications such as stock auditing, landscape utilisation and security, and (2) an R&D investment on an integrated location/behaviour technology that understands the physiological implications of the metrics and develops more sophisticated applications of feed allocation and animal state (egg health, welfare).
- A multi-disciplinary approach is likely to be required that merges an understanding of animal behaviour and animal and plant physiology, with the data availability, analysis and interpretation.
- Demonstration of this capability to industry is an important component of this work, including the capacity to see and interrogate real-time information in the context of specific applications. A strong producer and service provider input is recommended to understand the potential value in the information and influence product design and delivery (including how to package and present the information, and how to integrate it with decision support systems and farm management software).
- Significant opportunities exist to leverage off current investments at Armidale NSW (Australian Centre for Broadband Innovation), Townsville QLD (QLD Smart State Digital Homestead project), and the MLA investment in Northern Australia “On-property benefits of Precision Livestock Management (PLM) technologies and applications”. Opportunities exist for co-investment in the Wool and Dairy sectors.

Timeframe – 3-5+ Years

Risk of failure – Low - Medium

Size of investment – Large. (1) Demonstration and evaluation of current or near to market technologies could be staged and scaled according to the number of regions to be targeted. A basic program establishing 3-5 sites would cost $500k pa. (2) Development and evaluation of the integrated research tool for detection of a range of key behaviours would require substantial scientific and technical support with an estimated cost of $500-750k pa.

Key partners – CSIRO, UNE, private commercial technologists

Opportunities for RDC co-investment – AWI, GRDC, DA, (private commercial funding could also be considered)

MEDIUM PRIORITY

4. Liveweight monitoring

Priority – MEDIUM

Nature of R&D – Algorithm development

Gap/Opportunity

Monitoring weights and body condition is important in managing reproductive performance and animal growth rates. Conception rates in the case of sheep and the period between calving and cycling in cattle are closely related to stock condition. Understanding whether or not animals are in a positive or negative energy balance early enough to intervene with supplementary feeding and/or increased allocation of feed can have significant effects on reproductive performance of stock. In the case of growing animals, growth targets are important in relation to achieving critical mating weights and target sale weights.

Manual weighing requires stock to be brought from paddocks to yards and is a limitation to regular stock monitoring. Technology is currently being developed through public and private investment for automatic and remote weighing of livestock and no further investment by MLA on the technology per se is warranted. However investment is required to establish agreed data-handling processes that enable producers to capture the full potential from the technology in not only mob-based but also individual animal management.

R&D objectives

- To develop clear standard operating procedures for how to analyse individual weights over time to generate accurate individual animal data with known errors.
- To ensure there is a data infrastructure that captures information remotely and makes it readily available to producer in near real-time.
- To integrate data/information with decision support systems such as BeefSpecs, and ensure optimal presentation/visualisation for ease of interpretation and adoption.
- Demonstration on commercial farms and clear establishment and visibility of applications and benefits.

R&D approaches

- Utilise commercially-available technology on commercial farms where possible.
- Run concurrent trials with cattle in both southern and northern regions, and sheep. Leverage off current installations. Try to standardise methodologies to ensure comparison and broad-scale applicability.
- Consider the use of more sophisticated data processing and statistical techniques to retain individual animal data rather than coarse filtering techniques that remove large volumes of data.
- Ensure outcomes can be applied independent of any particular commercial product, and data can be integrated into decision support and farm management software.

Timeframe – 2-3 years

Risk of failure – Low

Size of investment – Medium ($200-$300k pa for 2-3 years)

Key partners – Sheep CRC, State Departments of Agric, CSIRO, Commercial technology providers, USQ, CRC for Remote Economic Participation

Opportunities for RDC co-investment – AWI, Sheep CRC

5. Body condition score

Priority – MEDIUM

Nature of R&D – Technology and algorithm development

Gap/Opportunity

In addition to monitoring weights, body condition score is important in managing reproductive performance and animal growth rates. However manual assessment of body condition requires stock to be brought from paddocks to yards and is prone to the subjective nature of the assessments.

With sheep, the presence of wool makes direct measurement difficult and there is no immediately technological solution available other than it being modelled from other parameters such as liveweight.

For cattle, imaging technology is currently being evaluated for measurement of P8 fat and muscularity and this needs to be assessed for its accuracy (is it accurate enough to improve tactical management decisions) and its reliability in field conditions (other studies suggest digital and 3D imaging is prone to errors caused by lighting, photo angles and changes in cow posture which may make it difficult to extend these technologies from saleyard to in-paddock/remote applications).

There is significant potential to use a laser scanner system because these actually quantify the structure of the animal, and is less likely to be subject to such errors.

R&D objectives

- To conclude the evaluation of an imaging system to quantify body condition score, documenting its potential accuracy and reliability.
- To assess a laser scanning system to quantify body condition score, and document its potential accuracy and reliability in on-farm conditions.

R&D approaches

- Requires relationships to be established between reference methods and technology metrics, and then validated on independent datasets.
- Reliability in different conditions needs to be assessed.
- Both technologies could be tested concurrently to allow a direct comparison in both southern and northern beef systems, and lower the cost associated with collecting the reference body condition scores.
- If successful, the technology should be integrated with real-time remote monitoring systems (egg liveweight) and integrated with farm management and decision support software.

Timeframe – 2-3 years

Risk of failure – Low-Medium

Size of investment – Medium ($200k - $300k pa for 2-3 years)

Key partners – State Depts Agriculture, Sheep CRC, CSIRO, USQ, UTS

Opportunities for RDC co-investment – AWI, DA

6. Animal health and rumen function

Priority – MEDIUM

Nature of R&D – Technology and algorithm development

Gap/Opportunity

Responses to animal health management are either preventative (such as vaccination) or reactive when there are clinical indications of disease. There are many situations where subclinical diseases impact on performance or where they are a precursor to clinical symptoms. Early intervention in these situations can have a significant impact on performance, profitability and welfare.

Current methods of disease detection depend on the appearance of clinical symptoms or sometimes, changes in behaviour. There is a need for constant real-time monitoring of altered metabolic state, temperature anomalies or behavioural characteristics that might indicate disease processes initially on a herd/flock basis but with the potential to monitor individual high value stock.

There are several intra-ruminal devices commercially available for livestock (e.g. for rumen temperature, pH, pressure) but the key technical constraint is longevity - reportedly accurate for up to 40-50 days. There is also a significant effort between collaborating Australian RDCs, including MLA, into the development of a rumen bolus for measuring methane led by CSIRO.

A key knowledge gap in implementing these devices is understanding the biological significance of the signal – that is, what change in a parameter(s) actually signifies a physiological event requiring intervention. Further effort is required to understand how specific applications can be extracted from these data streams given the potential variability of the information.

R&D recommendation

That a watching brief be kept on commercial development of intra-ruminal devices, however if the MLA (and other RDC) investment in the CSIRO et al. bolus proves successful in terms of the platform technology, it should be expanded to include key rumen health parameters such as pH and temperature, and consideration given to key nutritional parameters (e.g. VFAs).

If the accuracy and longevity of the devices are sound, the focus should be on understanding natural variation and what anomaly in the parameter(s) signifies a physiological event (as described below).

R&D objectives

- To establish the accuracy and reliability of intra-ruminal devices for measuring key rumen parameters.
- To understand the naturally occurring variation in rumen parameters, and what anomaly signifies a physiological event.
- To determine if anomalies can be reliably detected with known false negatives and positives to build a business case for disease detection.
- To develop data processing techniques for real-time anomaly detection.

R&D approaches

- Once developed, intra-ruminal devices need to be deployed in key classes of stock in sufficient numbers to allow baseline variation to be established (within & between animals, management, climate etc).
- Response of rumen parameters to a range of factors needs to be determined so that an event of interest can be detected reliably from other ‘normal’ events.
- Devices can be deployed in concurrent projects to capture background data.
- Should consider advanced informatics techniques such as anomaly detection in order to develop a system of on-line data processing.

Timeframe – 3-5 years

Risk of failure – High (given complexity of factors influencing rumen environment)

Size of investment – Medium - Large (no investment until platform technology available, and then requires extensive animal experimentation to understand response functions of rumen parameters. Should be deployed in other animal-based projects)

Key partners – CSIRO, AWI, Univ Sydney, commercial technologists

Opportunities for RDC co-investment –AWI, DA

LOW PRIORITY

7. Pasture monitoring - quality

Priority – LOW (Proof-of-concept)

Nature of R&D - Technology and algorithm development

Gap/Opportunity

In the context of improved feed allocation, the key requirements for quality assessment of pasture are protein content and metabolisable energy. There is a strong theoretical basis for using hyperspectral/NIRS technology for estimating pasture quality on a range of platforms with greater accuracy than simple NDVI-type indices and there is some proof-of-concept in different vegetation types. A commercially-available business model is likely to be 5-10 years in the future given R&D requirements, current technology availability and cost, and satellite deployment. Analytical accuracy and reliability needs to be established.

R&D objectives

- To evaluate the potential accuracy and reliability of hyperspectral/NIRS spectroscopy *in situ* for estimating pasture quality parameters.

R&D approaches

- Initial investigation to establish proof-of-concept should be conducted with proximal sensor(s), with some spatial satellite and/or airborne remote sensing included at key times to explore if quality can be quantified from remote spatial platforms.
- A spectral analysis should be conducted to see if specific wavelengths can be selected for future implementation in simpler active optical sensors.

Timeframe – 18-24 months duration to capture seasonal variation and establish proof of concept only in selected pasture types (Postgraduate study – 3 years. Or science investment – 2 years)

Risk of failure – Medium

Size of investment – Small ($100k-200k pa) for proof-of-concept only. Could be set-up as a small component within the pasture biomass project.

Key partners – CSIRO, UNE, Massey University (New Zealand Centre for Precision Agriculture).

Opportunities for RDC co-investment – DA, AWI, GRDC

8. Weed management

Priority – LOW

Nature of R&D - Technology and algorithm development

Gap/Opportunity

Scattered pasture weeds may have little impact on productivity, but often these weeds have the potential to spread rapidly and have a significant effect on pasture productivity and impose significant long term control costs. The dilemma faced by producers is whether to spot spray or spray the whole paddock, with implications on amount of chemical used, cost and collateral damage to the underlying pasture.

Optical sensing systems for on-the-go spot spraying used in the grains and municipal applications are directly transferrable to pasture-based systems where the issue is the management of green weeds in fallows or senescent swards. There are currently no commercial systems available for automatically detecting and controlling green weeds in growing (green) pasture swards. Hyperspectral/NIRS and digital imaging technologies require proof of concept. The key success criteria will be the ability to differentiate the reflectance spectra of the weed species compared to the background sward.

It may be possible to use remote-sensed hyperspectral imagery to detect the presence and abundance (%) of different plant species, as an aid to early detection and to inform preferred management methods (e.g. spot spraying verses blanket application). This technique would also rely on being able to differentiate the spectral signature of the weed species in a timely manner. Some proof-of-concept has been established overseas but is required in our pasture systems

R&D objectives

- To determine the capacity for NIRS/hyperspectral signatures and proximal digital image analysis to detect green weeds in green pasture swards.
- To determine the potential accuracy of the technology in quantifying the percentage weed present.

R&D approaches

- The target weed species needs to be a priority industry threat, and tested across a range of pasture swards to ensure the spectral signature of the target weed species can be adequately distinguished from different backgrounds.
- For a higher success rate, a weed species that is likely to have a different spectral signature should be chosen (e.g. a broadleaf weed in a grass/clover sward).
- For proof-of-concept, the project should involve *in situ* sensing with hand-held or vehicle-mounted proximal systems to control the field of view. Airborne and satellite platforms can be considered pending success with proximal sensors

- The study should include pasture ecology knowhow to better understand the physiological factors impacting on the ability to detect weeds and levels of infestation.

Timeframe – 18-24 months duration to capture seasonal variation and establish proof of concept only for key weed species in key pasture types.

Risk of failure – Medium-High

Size of investment – Small ($200k pa) for proof-of-concept only.

Key partners – USQ, CSIRO

Opportunities for RDC co-investment – AWI, GRDC, DA

9. Pasture yield mapping

Priority – LOW

Nature of R&D – Technology, algorithm and application development

Gap/Opportunity

Crop enterprises have the opportunity through yield monitors on their harvesters to map the productivity of their farms. No such tool exists for the grazing industries. Large differences in pasture production have been observed within and between paddocks. Knowing that these differences exist would provide the incentive to better understand why they occur and encourage the adoption of strategies to optimise production and utilisation per hectare.

Pasture biomass measurements record only what is in the paddock but not what has been eaten. There is a need for pasture yield maps at a sub-paddock scale that quantifies actual pasture productivity, taking into account animal intake.

R&D objectives

- To integrate measures of pasture biomass and animal intake to generate pasture yield maps at the sub-paddock scale.
- To demonstrate the use of pasture yield maps to identify underpinning constraints to production, and then opportunities for cost-effective amelioration.

R&D recommendation

That a specific investment only be made pending the success of both the pasture biomass monitoring and the estimation of intake from animal location and behaviour monitoring technology.

10. Feed prediction

Priority – LOW

Nature of R&D – Algorithm and application development

Gap/Opportunity

Climatic risk is the major risk faced by producers. The ability to predict future likely pasture growth with accuracy would provide producers with the ability to take pre-emptive decisions (particularly in poor years) but also to be able to fully capitalise on the opportunities offered by above average seasons. Tools such as the MLA's rainfall to pastures outlook tool provide some basis for decisions but are generic and do not relate to specific farms. All predictive tools suffer from confidence in their predictions. Studies suggest that current seasonal rainfall forecasts are not accurate enough to base farm management decisions on, but forecast skill (e.g. POAMA) is continually being improved and further investigation of its role will likely be warranted in the future.

R&D objectives

- To understand the forecast/prediction requirements for key decision points in production systems, the capacity of current forecasts, and build a strategy for ongoing R&D and delivery.

R&D approaches

- A detailed review is required that describes how a predictive capacity can improve the timeliness and/or accuracy of key decision points in different production systems, and how current forecast skill aligns to these requirements. This should include identifying the requirements for both forecast accuracy and length of forward prediction. The review should ensure it considers the findings of recent studies, viz "Farming Systems R&D and Modelling for the Southern Feedbase" (Rogan *et al*. 2012), "Improving the Rainfall to Pasture Growth Outlook Tool – scoping study" (Platzen *et al*. 2011), and "Matching grazing decision points based on soil water and skill of seasonal forecasts" (Cullen and Johnson, 2012).
- Keep a watching brief on advances in forecast skill in the context of the above review.
- Consider how a data-model fusion approach of integrating higher level modelling systems with on-farm sensor data and maps of underlying spatial variability can be used to downscale the predictions to a sub-farm scale.

Timeframe – 12 months

Size of investment – Small (<$100k) (Review only)

Risk of failure – Low

Key partners – CSIRO/BOM

Opportunities for RDC co-investment – AWI, GRDC

STRATEGIC INVESTMENT PRIORITY

11. Autonomous control of livestock

Priority – MEDIUM

Nature of R&D – Technology, algorithm and application development

Gap/Opportunity

Beyond precision livestock technologies to **monitor** soil, plant and animal characteristics, a capacity to remotely and autonomously **manage** livestock in the system offers a further suite of applications, particularly for more precise matching of pasture supply with animal demand at any spatial and temporal scale. A capacity to remotely manage livestock offers potential benefits in many production systems, including (but not limited to) labour savings in extensive grazing systems, precision livestock management for improved feed allocation (spatial & temporal) in both extensive & intensive systems, and optimising sheep grazing management in large paddocks of mixed farming systems where farm layout is optimised for crop production often at the cost of being able to manage livestock optimally.

Although this remains somewhat of a visionary concept with a commercial product unlikely to be available in the next 5 years, Australia has been a global leader in development of the technology and has established an understanding of animal behaviour responses, welfare implications, and has demonstrated a capacity to autonomously control cattle in the field.

A strategic investment is required to continue the development of 'virtual fencing' technology. With the most recent advances in power management (energy harvesting and power consumption), and concurrent work in animal location and behaviour, some of the key technical constraints can be addressed leveraging off other investments. Further work is required to understand how animals respond to control measures in different applications, and how to optimise cues and controls.

The requirements for getting a product to market would be informed by development of a business case for southern Australia with market research conducted jointly with a commercial partner with expertise in product design and delivery.

R&D objectives

- To design the path to market for autonomous animal management technology.
- To develop an underpinning technology that can deliver long-term autonomous control for R&D and then commercialisation purposes
- To understand how animals respond to control measures in different applications, and how to optimise cues and controls.

R&D approaches

- The development of a business case with market research is required to focus further work (e.g. cattle or sheep) and to detail the steps required to get the current state of technology to a commercial product. This will then inform further R&D requirements in both the underpinning technology and the animal behaviour domain.
- It is anticipated that most effort will be required to understand better how animals respond to different cues and controls in different circumstances, the consistency with which animals respond, and the implications for individual and mob/herd-based management. This understanding will then inform further technology development requirements.

Timeframe – 3-5+ years

Risk of failure – High

Size of investment – Small ($100k) (Business case) then likely to be Medium-Large ($250-$500k pa) for on-going R&D and commercialisation

Key partners – CSIRO, Private commercialisation partner

Opportunities for RDC co-investment – AWI, GRDC, DA

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1. Introduction

In 2010, MLA acting as agent for the Red Meat Co-investment Committee (RMCiC) commissioned the development of a Feedbase Investment Plan (the FIP) that followed on from the PISC process of developing national beef and sheep industry RD&E strategies. The development of these national strategies has required a new “collective development” model. This new model is aimed at improving coordination and investment efficiency by addressing the research fragmentation in livestock production.

The focus of the FIP was to determine researchable priorities in all southern agro ecological zones – this involved an industry wide survey followed by extensive consultation. Barriers to adoption (of technologies that would increase meat production) were identified, as were research opportunities to further increase the profitability and sustainability of red meat production.

While the FIP identified the key R&D priorities, there was insufficient detail in the FIP to move directly to commissioning projects. To build the next level of detail, MLA commissioned the Feedbase R&D Plan. In this plan, three key R&D Pillars were defined. In two of these, the “Productive & Sustainable Pastures” and the “Grazing Management & Production Systems” pillars, remote/precision technologies were identified as being critical to addressing fundamental gaps in our understanding of grazing behaviour, animal management and pasture performance. Increasing this knowledge and application of these technologies may also deliver data/information flows that could lead to better (more accurate and/or timely) tactical and strategic management decisions, as well as better guidelines that may not involve the continued use of the technology at all.

The recommendation from this process was that *MLA and the RMCiC partners undertake a major ‘background investigation process’ with the aim of identifying the potential for a significant R&D investment in the general area of ‘precision agriculture’. This is more than a literature review – the challenge is can these novel technologies be integrated and delivered in ways that underpin better (more timely, more informed etc) management decisions and a supporting business case for development and delivery. Value must be determined, ensuring this is a demand and not supply driven development. This major ‘industry investigation of remote and precision technologies’ was then recommended to be broadened to include data capture to support strategic (systems design) as well as tactical decisions.*

2. Objectives

MLA is interested in investing to develop a deeper understanding of the key significant on-farm tactical and strategic decisions that lead to more efficient use of resources for meat production and which could be improved through improved data/information collection. New information technologies could improve data/information collection on the performance of farm systems and this may allow further improvement in those key decision points. How these current and potential technologies are (and can be) positioned to deliver to improvements needs to be investigated. The outcome is identification and brief description of specific project areas for further investment.

The project was to specifically assess the technologies that might have value in the following 4 general systems.

1. Set stocked (or only occasional movement) (mixed wool and lamb, cattle)
2. Rotationally grazed (mixed wool and lamb operation, cattle)
3. Mixed farm (cropping and livestock)
4. Intensive rotational grazing (eg techno grazing)

2.1 Key questions

MLA proposed the following key questions:

- What are the key on-farm tactical and strategic decisions that might benefit from better data/information flows. The focus is on pastures, forages, grazing management, supplement intake and animal nutrition, but needs to consider other factors such as soils, the landscape, infrastructure, animal management and ultimately how the technology affects and fits within the whole farm system.
- What is the potential benefit of that better decision making, in relation to increased pasture/animal productivity, decreased input costs, labour saving, increased efficiency of feed utilisation or conversion, improved risk management, animal health or welfare, environment benefits, meeting market specifications, meat quality and so on.
- What are the data/information needs required to capture that potential benefit and what are the requirements to integrate the information flow with other decision support and technologies
- What are the current remote and precision technologies available now and potentially within the next five years and what is the extent of their current applicability?
- What the key biophysical questions that these technologies need to address at an operational level (day to day), tactical (short-term seasonal) and strategic (longer term) level

In addition to considering the above key questions, the objective was to:

- Develop a case of economic benefit for the four production systems that describe potential value (economic benefit) from improved decisions.
- Develop a recommended R&D plan aimed at improving producer decisions at both a strategic (system design) and tactical (day to day) decision making levels.

3. Method

3.1 Project oversight committee

The project was overseen by an industry steering committee (see Appendix A for membership) whose role was:

- To assist MLA and the project team with key decisions and linkages;
- At project commencement, to help ensure that the project team get the direction ‘right’ so we can have confidence in the project having the best chance of success;
- Provide a broader perspective to the project than individuals or their individual organisation can bring;
- Assist with focusing and finalising the project findings and recommendations;
- Assist around process – including who and how to engage more broadly with industry;

- Respond as requested any time the project team feel input would be useful.

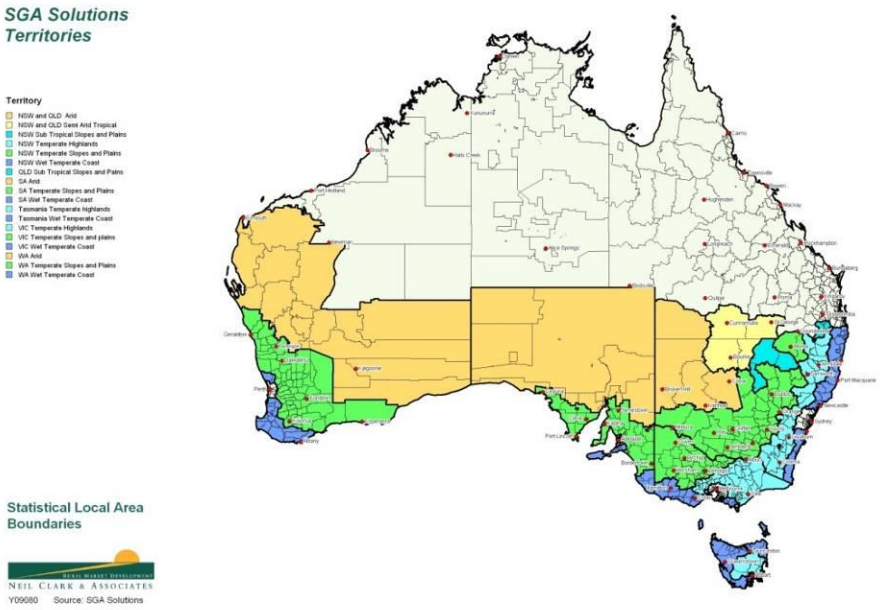
3.2 Geographical regions considered

Five key agro-ecological zones were studied in the context of this project (Figure 1):

1. Wet Temperate Coast
2. Temperate Highlands
3. Temperate Slopes and Plains
4. Sub-tropical Slopes and Plains
5. Semi-arid Sub-tropical Plains

Figure 2 and Figure 3 respectively show the distribution of sheep and beef cattle in Australia. The pastoral zone shown in Figure 1 was not considered in this project due the relatively low stock numbers, and more so because the concurrent review of precision and remote technologies in Northern Australia will review technologies applicable to the very extensive nature of these enterprises.

Figure 1: *Agro-ecological zones*



Key

Wet Temperate Coast	Temperate Highlands	Temperate Slopes and Plains
Sub-tropical Slopes and Plains	Semi-arid Sub-tropical Plains	Pastoral

Figure 2: *Estimated population distribution of sheep in Australia (million head) (2008).*
Source: National Sheepmeat Production RD&E Strategy, Jan 2010, PISC

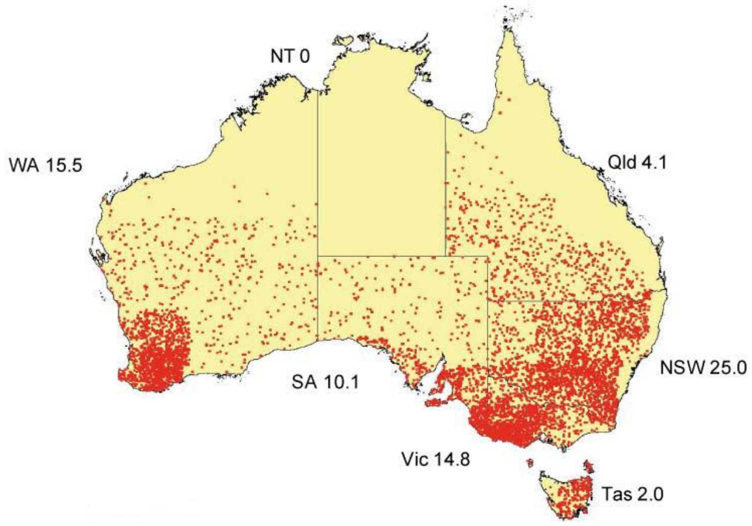
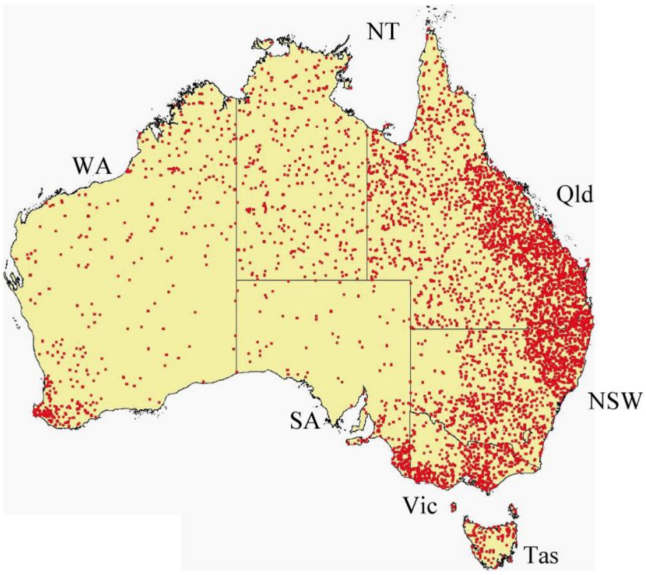


Figure 3: *Estimated population distribution of beef cattle in Australia (million head) (2008). Source:* National Beef Cattle Production RD&E Strategy, Jan 2010, PISC



3.3 Production systems and farm operation types:

Four production systems and two operation types were considered across the 5 agro-ecological zones:

Production systems

a. Set stocked (or only occasional movement) (mixed wool and lamb, cattle)
b. Rotationally grazed (mixed wool and lamb operation, cattle)
c. Mixed farm (cropping and livestock)
d. Intensive rotational grazing (eg techno grazing)

2 operation types:-

e. trading/fattening operations
f. breeding operations

3.4 Methodology for determining potential technological solutions for key on-farm decision points:

In order to determine the potential alignment of different technologies with different on-farm decision needs, two parallel streams of activity were conducted and then brought together. These were broadly (1) identifying the key on-farm decisions that will most benefit from better data/information, and (2) reviewing possible technologies and information streams. The following describes the project methodology and key components:

*3.4.1 **Documenting*** the ***key on-farm tactical, strategic and operational decisions that will benefit from better data/information flows***

The strategic, tactical and operational decisions were considered under the following definitions:

Strategic decisions: those decisions that affect the long-term direction of the business. These decisions may involve the purchase of additional land, selection of enterprise, breeding objectives, etc.

Tactical decisions: those decisions which focus on more intermediate-term issues, and which help move the company closer to reaching its strategic goal(s). Examples of tactical decisions would include time of lambing/calving, pasture development programs, selection of appropriate sires, paddock subdivision, etc.

Operational decisions: those decisions which focus on day-to-day activities. Decisions made at this level help to ensure that daily activities proceed smoothly and therefore help to move the business toward reaching the strategic goal(s).

It was considered that the major applications of remote and precision technologies will be either tactical or operational. There may be some strategic decisions that would be improved by remote and precision technologies, such as farm productivity assessments (in the case of property purchase), but these decisions would likely flow from the successful operational and tactical application of the technologies.

The critical decision points in different production systems were collated, documented and compared across each production system to derive a short-list of key management decisions that would benefit most from improved data and/or information. These were defined primarily as being key profit drivers, but the implications for social and/or environmental benefits were also considered. The data needs were determined without consideration of the technology that could be applied – the objective at this stage was to determine the data needs for key on-farm decisions.

The data requirements included 'what' would be required, 'when and how frequently', as well as how readily the information could be applied (with and without further decision support).

The applicability or relevance of this intervention was then assessed across each of the agro-ecological zones and each production system type.

3.4.2 Review possible technologies and information streams

The project team conducted an initial audit of relevant technologies and allocated them into the following framework:

Sensing or monitoring technologies

- *Landscape*
- *Soil*
- *Plant*
- *Animal*
- *Climate*
- *Human*
- *Other*
- *Platforms*

Management or action technologies

- *Landscape*
- *Soil*
- *Plant*
- *Animal*
- *Climate*
- *Human*
- *Other*

Platforms

- *Data management, processing and visualisation technologies*
- *Data management*
- *Visualisation*
- *Modelling tools*

Data transfer, communication and telemetry platforms

For each technology, any commercial and R&D stakeholders were identified, and background information collected. A series of conversations were then conducted with those stakeholders to fully understand stage of development and delivery, key issues and constraints, perceived on-farm applications and benefits, and future developments. To guide the conversations, a set of questions were used (Appendix B). The questions were a guide only, as different technologies varied in their stage of development, and commercial confidentiality constrained some freedom to provide information.

3.4.3 Matching key on-farm decisions with technology solutions

Once the key on-farm decision points were prioritized, and the initial technology audit complete, all the potential technological solutions were aligned with each decision point's specific requirements.

3.4.4 Economic benefits study

The analysis of the on-farm decision points across different production systems will result in a consolidation of key technologies; case studies were developed for four production systems to demonstrate the potential impact of the adoption of the technologies on the performance of these systems.

3.4.5 Industry engagement and recommendations of areas for further investment

The findings were presented to an industry workshop on 25 May 2012 for feedback (see Appendix C). Following the workshop, the findings and recommendations were further refined and the economic case studies finalised.

4. Key on-farm tactical, strategic and operational decisions that will benefit from better data/information flows.

4.1 Optimising stocking rate

The number of animals run per hectare is a major driver of farm productivity and profitability. The major determinant of the stocking rate of any grazing enterprise is the quantity of feed grown. While the upper limit of growth is environmentally determined by the rainfall/length of growing season and is influenced by the pasture/herbage composition, whether or not this potential is reached depends on the soil physical and chemical characteristics and then on the method of grazing.

4.1.1 Improved pasture production through soil fertility

4.1.1.1 *The issue*

Numerous studies and programs have demonstrated that in the medium to high rainfall zones large increases in productivity can be achieved by correcting soil nutritional deficiencies/acidity problems etc. (GPP/Triple P).

In the case of phosphorus application, decision support systems (DSS) such as 5 Easy Steps exist that allow fertilizer decisions to be based on sound economic principles, which consider not only the physical response to the fertilizer but also the risk preference of the producer. Reasonable guidelines exist for lime application and other nutrients, but are not as well codified as the phosphorus DSS.

The identification of nutrient deficiencies (and soil acidity levels) has in the past relied on soil tests for the major nutrients and on plant tissue tests for trace element assessments. Occasionally, fertilizer test strips are used to assess the response to applied nutrients. Despite the usefulness of these tools they remain grossly underutilized, often with the results of one or two paddocks per farm being used as the basis for a whole farm program. Nutrient analysis of paddocks on a farm generally show marked differences between paddocks and there is increasing data (eg J Shovelton, pers. com., R Simpson, pers.com.) that demonstrates nutrient and acidity variation within paddocks, particularly those paddocks where sheep have historically been run.

The consequences of these observations are that many paddocks or parts of paddocks are being under or over-fertilized resulting in either reduced productivity in the case of deficiencies, or potentially adverse environmental outcomes and wasted resources in the case of over fertilization. Expenditure on fertilizers and lime represent the single largest expenditure on farm, excluding labour and feeding costs in droughts. The identification of those areas of paddocks which require increased inputs of nutrient to optimise pasture production or those which would suffer no production loss from the omission or reduction of fertilizer would therefore improve resource allocation and the efficiency of production.

4.1.1.2 *Current methods available*

The current method of assessing soil nutrient status is through the manual collection of soil samples. Paddocks selected for sampling generally fall within three categories: paddocks that are considered to be "representative"; paddocks where performance is below par; and those which are to be resown. Within a paddock samples are generally taken at random while avoiding obvious high fertility areas.

The time involved in collecting the samples and the cost of the analyses are limitations to extensive sampling. Errors can also be introduced by soil sample depths being inconsistent or incorrect.

Soil analyses without interpretation cost between $80 and $120 per sample, with collection taking around half an hour per sample.

4.1.1.3 *The need*

The identification of the spatial variation of soil nutrient status and soil pH either through direct measurement or through proxy means. The nutrients of major concern are phosphorus, potassium and sulphur. Nitrogen is not widely used on beef and sheep properties currently but may have an increased role in the future in intensive grazing systems and should be considered.

4.1.1.4 *When would the data be needed*

Fertilizer is generally applied prior to the start of the growing season to ensure that early growth is promoted. Time of collection of the information is not critical provided the results are available prior to the application time and the results are appropriately calibrated to the conditions when the assessment was made. For example, the nutrient status of soils is likely to be lower during periods of rapid growth due to the accumulation of nutrients in plants, than prior to the start of the growing season. Because of the longer lead time for lime response, timing of data collection and application of lime is less critical.

4.1.1.5 *How frequently*

Soil nutrient status varies slightly between years, as does soil pH. Assessment on a 3-4 year interval would be adequate. Provided management remained consistent between paddocks over this period, indicator paddocks (ie paddocks representative of other paddocks) could be used at this interval to monitor and adjust nutrient applications.

4.1.1.6 What *data* is needed

Soil nutrient status in the 0-10 cm zone is required for most situations. The interpretation for soil tests in most states is based on a calibration of tests taken to 0-10cm. Some Tasmanian interpretations are calibrated on 0-7.5 cm samples. However, samples are taken at depth (down to 45cm) to assess soil acidity levels when acid-sensitive pasture species are being sown. Nutrients are not assessed at these depths.

Most fertilizer/lime decisions require some external expertise for the formulation of appropriate recommendations. The development of these recommendations needs to consider the particular farm's production settings, risk profile and potential productivity as well as a knowledge of the response function for the particular parameter being measured. In the case of phosphorus, the response function is influenced by the phosphorus buffering index, while in others texture is important. As these factors change little over the medium term, standard values for a soil type or the results of reference samples should be sufficient to allow the interpretation of remotely collected/determined soil test data.

4.1.1.7 *What is its applicability between enterprise types*

Management of within paddock fertility is applicable across all enterprises, but likely to be of greater significance in sheep production systems (due to their camping behaviour) and in set stocked enterprises because of the greater opportunity for stock to transfer nutrients to one location.

4.1.1.8 *What is its applicability between agro-ecological zones*

The major application will be in the medium to high rainfall zones because of the greater intensity of production and therefore the higher nutrient requirements per hectare for fertilizer.

4.1.2 Improved feed allocation

4.1.2.1 *The issue*

Efficient utilization of feed for specific management objectives depends upon allocating the appropriate quality and quantity of feed to different classes of stock in a timely manner.

There are two components to this – firstly assessing the quantity of feed and quality of feed, in terms of energy content and protein levels, and secondly the allocation of feed to stock. In the case of extended grazing periods, an estimate of pasture growth rate would be required. For intensive rotational grazing systems, pasture growth rates would be unnecessary.

The ability to accurately allocate feed to meet production targets has the potential to improve not only pasture production but also to improve feed utilization.

4.1.2.2 *Current methods available*

The allocation of feed to different animal classes is based on matching feed quality and quantity to the specific requirements of those animals at that time. Assessments of feed quantity and quality are invariably subjective. Rarely would objective measurements be taken on farm due to labour constraints and in the case of feed quality, expense. Skill levels have been developed through courses such as Prograze etc. which provide broad guidelines for estimating feed parameters. The accuracy of decisions are generally assessed by monitoring animal performance after the event. While there has been a significant improvement in the skill level of producers, the assessments are approximate and have significant errors, particularly in the assessments of dry feed quality and quantity.

4.1.2.3 *The need*

Accurate assessment of the distribution of feed quality and quantity, spatially and temporally.

4.1.2.4 *When would the data be needed*

Data would need to be provided throughout the year at intervals that allowed decisions to be made in a timely manner such that the data provided was still relevant.

4.1.2.5 *How frequently*

Frequency of data would depend on the intensity of the production system. For intensive systems weekly data of quantity and quality would be required, but for less intensive grazing systems, 2 – 3 week intervals may be adequate.

4.1.2.6 *What data is needed*

Quantitative value of pasture biomass (kg/ha), its quality (energy and protein) and estimates of growth rates (kg/ha/day).

4.1.2.7 *What is its applicability between enterprise types*

Applicable to all grazing enterprises, the main difference being the frequency of measurements.

4.1.2.8 *What is its applicability between agro-ecological zones*

Higher applicability in the wet temperate coast, temperate highlands, and the higher rainfall areas of the temperate slopes and plains because more intensive management systems can better capture the benefits of improved feed allocation.

4.2 Pasture yield mapping

4.2.1 The issue

Crop enterprises have the opportunity through monitors on their harvesters to map the productivity of their farms. No such tool exists for the grazing industries. Feed on offer measurements record only what is in the paddock but not what has been eaten such that a high feed level may be the result of under-grazing on a section of the paddock and vice versa. Large differences in pasture production have been observed within and between paddocks. Knowing that these differences exist would provide the incentive to better understand why they occur – are they due to fertility differences, grazing behaviour, etc, - and encourage the adoption of strategies to optimise production and utilisation per hectare.

4.2.2 Current methods available

None currently available

4.2.3 The need

Yield maps for paddocks that quantify actual pasture productivity, taking into account animal intake.

4.2.4 When would the data be needed

The data derived would be used strategically for medium to longer term planning so that the point of time at which the data is required is not critical. However data collection would need to be undertaken during the growing season but assessed over a number of seasons to assess variability, and hence risk, across years.

4.2.5 How frequently

The frequency of assessment would need to be gauged. It is likely that there will be climatic influences that will result in different feed profiles in different years. For example the paddock feed profile is likely to be influenced by waterlogging in wet years.

4.2.6 What data is needed

A combination of feed on offer and feed consumed by animals over a range of contrasting seasons.

4.2.7 What is its applicability between enterprise types

This data would be primarily designed to assess pasture productivity, with the animals being used to provide information on the feed consumed. The data would be applicable to all enterprises as it would be designed to address the pasture productivity underpinning the grazing system.

4.2.8 What is its applicability between agro-ecological zones

Likely to be more applicable in the higher to medium rainfall zones because of a greater impact on productivity and applicability of interventions.

4.3 Feed prediction

4.3.1 The issue

There are two components to this issue. Firstly, the mitigation of risks associated with adverse climatic conditions (especially drought) and secondly the opportunities associated with good seasons.

The major risk faced by producers is climatic risk. In the past, dry seasons have had major impacts on profitability through the necessity to feed retained stock. Examination of price trends in previous droughts show that there is a point in the year when there is a realisation that seasonal conditions are adverse and where producers de-stock. This de-stocking is accompanied by a progressive decline in sale prices until an equilibrium is reached, generally 4 – 5 months after the start of the de-stocking process. Contrary to expectations, prices have not spiked significantly with the return to normal conditions in autumn when compared with the pre drought prices. The timing of de-stocking has a marked effect on cash flow and profitability. The ability to predict future likely pasture growth with accuracy would provide producers with the ability to take pre-emptive decisions.

Conversely, producers rarely fully capitalise on the opportunities offered by above average seasons. Once good seasons become evident, prices have usually risen and there is underlying concern by producers about the likely continuation of the good growing conditions.

4.3.2 Current methods available

Tools such as the MLA’s rainfall to pastures outlook tool provide some basis for decisions but are generic and do not relate to specific farms, and all predictive tools suffer from confidence in their predictions.

4.3.3 The need

The ability to anticipate future pasture production in a range of seasons.

4.3.4 When would the data be needed

In southern Australia the critical growth period for drought management is spring. Historically, stock prices begin to collapse in September in drought years when it becomes evident that spring rains will fail. Data for drought management would therefore be required late winter/early spring. Above average seasons are generally associated with early breaks to the season, indicating that data for this purpose would be required late summer- early to mid autumn.

4.3.5 How frequently

Annually

4.3.6 What data is needed

Prediction of feed availability medium (1-2 months) and longer term (3-6 months)

4.3.7 What is its applicability between enterprise types

Applicable to all pasture types

4.3.8 What is its applicability between agro-ecological zones

Applicable to all agro-ecological zones

4.4 Weed management

4.4.1 The issue

There are many situations where pasture weeds are scattered throughout a pasture. While they remain scattered, they have little impact on productivity, but often these weeds have the potential to spread rapidly and have a significant effect on pasture productivity and impose significant long term control costs. The dilemma faced by producers when addressing these scattered infestations, is whether to spot spray or spray the whole paddock. While spraying the whole paddock will ensure that the weeds are controlled, more chemical is used and there is generally collateral damage to the underlying pasture even when selective sprays are used. However, there are some weeds for which there are no selective sprays (eg serrated tussock) necessitating spot spraying (often with less than 100% effectiveness) or the complete renovation of the pasture.

4.4.2 Current methods available

As indicated above, control is either by overall application of a selective herbicide or spot spraying where infestations are scattered or no selective herbicide is available. Some “Weedseeker” technology is available for weeds growing in fallows.

4.4.3 The need

Selective control of nominated weeds in mixed pastures and the integration of the data at spraying.

4.4.4 When would the data be needed

At the time of herbicide application.

4.4.5 How frequently

Potentially annually for some weeds, less frequently for other weed species.

4.4.6 What data is needed

Differentiation and identification of specific weed species in a mixed sward to allow selective spraying of weeds.

4.4.7 What is its applicability between enterprise types

The applicability of this technology would be independent of enterprise type.

4.4.8 What is its applicability between agro-ecological zones

Likely to have most applicability in the wet temperate coast, temperate highlands and temperate slopes and plains.

4.5 Stock auditing & security

4.5.1 The issue

The ability to determine the position of stock could have significant benefits. Understanding where stock are on a property would enable regular inventories of stock to be undertaken. Movement of stock outside a designated area would alert the owner to either stock theft, ingress to a neighbour's property, etc. Rapid changes in the position of stock could also alert the owner either to theft or predator attack.

<u>Stock Auditing</u>

As a general observation, most farmers have poor records of stock on their property and only undertake stock counts at key management times during the year – with varying accuracy. Understanding what stock are in what paddock and for what period of time would enable closer management of stock, assist in developing feed budgets, provide early alerts to missing stock and assist in stock reconciliation throughout the year.

<u>Stock Theft</u>

A survey (McCall 2003) in 2001-02 identified the most common type of on-farm crime to be livestock theft. In this survey, livestock theft was experienced by six per cent of all Australian farms and was estimated to cost the industry $72 million. A major issue in obtaining accurate information is that in 26 per cent of all cases of livestock theft recorded in the 2001-02 National Farm Crime Survey, the farmer was not sure whether the livestock was actually stolen or simply missing. While most farmers have some type of identification on their livestock, the frequency with which stock are checked and the difficulty in accurately identifying the rate at which stock are lost to natural causes makes it difficult to determine whether or not stock were actually stolen.

One of the key methods highlighted by producers for the reduction and prevention of stock theft was the introduction of a National Livestock Identification Scheme (NLIS). Two-thirds of respondents believed that the NLIS would be highly beneficial in reducing livestock theft (McCall and Homel, 2003).

In reality, the tagging of sheep offers little protection as the tags can be replaced prior to sale with the result that there are very few convictions for stock theft in any state. Once the stock have left the property it is unlikely that they will be traced.

Prevention of predation

A parallel issue is that of predation. The annual cost of stock predation is estimated to be $66 million (Anon).

4.5.2 Current methods available

Stock reconciliation is undertaken manually on most properties with stock being counted at key management activities and records of stock losses (deaths, etc) assumed to be the difference between consecutive counts. More recently technology to record stock numbers electronically as stock pass by a RFID reader has been developed. This method still requires the stock to be mustered.

There are no effective measures of protecting against stock theft. Double fencing of boundaries offers some protection but is expensive and not fool proof. It is impractical to monitor stock around the clock due to the infrequent transient nature of stock theft.

Electric fencing has been used to control dog and fox attacks of stock. While this needn't be expensive it will depend on the existing fence construction, and its effectiveness relies on maintaining the integrity of the electric fence. Again, around the clock monitoring is available but impractical.

4.5.3 The need

Stock location and the identification of abnormal movement patterns that may indicate theft or predator attack.

4.5.4 When would the data be needed

Data would need to be in real time and be capable of being transmitted to the producer or some other agency. In most instances it would be in the form of an automated alert and would not require frequent interrogation by the producer.

4.5.5 How frequently

Constant monitoring would be required

4.5.6 What data is needed

All stock may not need to be locatable, rather an appropriate number of “sentinel” animals based on animal behaviour characteristics.

4.5.7 What is its applicability between enterprise types

The technology would be applicable across all grazing enterprises.

4.5.8 What is its applicability between agro-ecological zones

Applicable to all agro-ecological zones

4.6 Dam – Offspring association

4.6.1 The issue

The ability to associate off-spring with their mother has a number of applications in both phenotypic and genetic selection.

In the prime lamb industry a key measure of profit is the weight of lambs sold per ewe. Similarly in the beef industry there are large differences in the ability of cows to grow calves. Matching offspring to its dam is essential to identify those high producing mothers.

In the sheep industry, there is a high repeatability of the ability of ewes to raise lambs to weaning. Identifying those ewes which successfully raise lambs to weaning and culling those ewes from the flock that do not has the ability to lift reproductive performance. There is a growing trend in the wool industry to select young stock on objective measurements of fleece weight and micron at their second shearing. This phenotypic selection has errors associated with it because it cannot account for the influence of birth type or age of dam. Ewe-lamb association would allow identification of these factors and provide greater confidence in selecting high performing off-spring for genetic improvement.

4.6.2 Current methods available

Traditionally in the sheep industry pedigreeing has only been done in studs where animals are manually tagged at birth and the tag recorded against the mother. In commercial cattle herds it is more common but not without OH&S issues if done at birth. Recently, Pedigree Matchmaker (DPI NSW) has been used to allocate offspring to mothers in sheep flocks based on the association of ewes and lambs over a minimum three week period. The method requires stock to pass an EID reader a number of times during that period. Because of equipment limitations, the realistic maximum number of breeding stock (sheep) that can be assessed in this way is around 300 head. While this technology has not been taken up in the cattle industry, there are potentially large gains to be achieved in this industry because of observations regarding the variability and consistency of between year performance of calves from the same dam. Major limitations of the current technology are that there needs to be an attractant (generally a water source or supplementary feed) to encourage the stock to pass by the EID reader and the stock need a period of training prior to undertaking the exercise.

4.6.3 The need

A system that would allow the matching of off-spring to dam remotely that would not require training of stock and would not need an attractant.

4.6.4 When would the data be needed

The data would need to be collected between tagging and weaning while offspring were on their mothers. In cattle this provides a relatively long period of time for data collection, but with sheep there would be a collection window of around six weeks. The data collected would be used outside this period for selection purposes of the dam or offspring retention.

4.6.5 How frequently

Annually

4.6.6 What data is needed

Proximity data that will allow offspring to be associated with their mothers with a high level of confidence.

4.6.7 What is its applicability between enterprise types

The technology would be applicable across all reproductive enterprises but with particular emphasis on larger scale enterprises.

4.6.8 What is its applicability between agro-ecological zones

The technology has application in all agro-ecological zones.

4.7 Sire – Dam association and time of conception

4.7.1 The issue

Sire – dam association has a number of potential applications.

Recent analysis has shown that the prevention of neonatal losses in sheep flocks has a far greater economic impact than increasing conception rates. Data from Victorian DPI Sentinel Flock program indicated a neonatal loss of 20% across 20 flocks in Victoria. These flocks included a range of lambing dates and breeds. In this study the average lambing percentage was 107%. When merinos are considered, the losses are considerably higher. Across all flock these losses represent a significant financial penalty and have implications for animal welfare.

The ability to more accurately determine the date of birth would allow producers to undertake precautionary measures, such as putting those stock due to lamb in protected areas or even in sheds to reduce neonatal losses. While neonatal losses in cattle due to exposure are generally low, the ability to more accurately determine the time of birth would have the potential to improve management, particularly of heifers. Most interventions at birth occur with first calvers and the ability to monitor the stock at times when birth is likely to occur should result in labour saving.

The dam-offspring association discussed above, enables identification of high performing dams. Most commercial operations have multiple sires in joining groups so it is not possible to easily identify the sire of a particular progeny. The ability to select for the performance of both sire and dam provides the opportunity to improve the rate of genetic gain.

4.7.2 Current methods available

In stud situations and in some commercial cattle operations sire – dam association is known as a result of single sire matings. Most commercial operations join with multiple sires as insurance against the failure of one or more sires and because there are often limited paddocks for single sire mating. In cattle herds, chin ball markers can be used to detect cows on heat. In sheep flocks, harnesses with different coloured raddles are available. These can be used to determine which ram has served a ewe where rams have different colours, or time of serving where different colours are used during the mating period.

4.7.3 The need

The identification of probable time of conception and the sire to which the dam was mated.

4.7.4 When would the data be needed

The data would need to be collected during the joining period (generally 5-6 weeks for sheep and 6-9 weeks for cattle) and analysed post weaning.

4.7.5 How frequently

Annually

4.7.6 What data is needed

Proximity data that will allow identification of sires who have mated with dams with a high level of confidence.

4.7.7 What is its applicability between enterprise types

Applicable across all reproductive enterprises but with particular emphasis on larger scale enterprises.

4.7.8 What is its applicability between agro-ecological zones

The technology has application in all agro-ecological zones.

4.8 Animal disease identification

4.8.1 The issue

Responses to animal health management are either preventative (such as vaccination) or reactive when there are clinical indications of disease. There are many situations where subclinical diseases impact on performance or where they are a precursor to clinical symptoms. Early intervention in these situations can have a significant impact on performance, profitability and welfare.

Such a situation may arise in the early detection of ryegrass staggers, as an example. These outbreaks are episodic, but in 2001 in Victoria it was estimated that 30,000 sheep and 40 cattle died. No estimate is available of the subclinical losses although these have been demonstrated experimentally.

Factors which indicate disease status are core temperature, imbalances of Mg/K/Na (resulting in grass tetany), low calcium status (milk fever) and imbalances of Cu/Mo/S (causing copper deficiency/toxicity). Rumen pH and ammonium status would provide guidance on optimising rumen function, not only for metabolic diseases but also more generally to optimise animal performance from a nutritional perspective. The optimal rumen pH is 6.0-6.2. The impact of acidosis in ruminants has been extensively reviewed by the Australian Veterinary Association in 2007 (Anon, 2007). Clinical effects are severe but subclinical acidosis which results in reduction in milk fat content, feed conversion efficiency, feed intake and decreased digestion of fibre, laminitis causing lameness, liver abscessation and scouring is often unrecognised and undetected.

4.8.2 Current methods available

Current methods of disease detection depend on the appearance of clinical symptoms or sometimes, changes in behaviour.

4.8.3 The need

Early detection of disease processes and metabolic disorders initially on a herd/flock basis but with the potential to monitor individual high value stock.

4.8.4 When would the data be needed

The data would be required in real time or near real time.

4.8.5 How frequently

Constant monitoring would be required. Consideration could be given to the use of sentinel animals rather than monitoring all animals.

4.8.6 What data is needed

Altered metabolic state, temperature anomalies or behavioural characteristics that might indicate disease processes.

4.8.7 What is its applicability between enterprise types

The technology would be applicable across all grazing enterprises.

4.8.8 What is its applicability between agro-ecological zones

The applicability is likely to be greater in the medium to high rainfall zones because of the greater prevalence of metabolic disorders in those areas.

4.9 Individual animal production monitoring – Liveweight & Body Condition

4.9.1 The issue

Monitoring weights and body condition (because there is a relationship between weight and condition score) is important in managing reproductive performance and animal growth rates. Conception rates in the case of sheep and the period between calving and cycling in cattle are closely related to stock condition. Understanding whether or not animals are in a positive or negative energy balance early enough to intervene with supplementary feeding and/or increased allocation of feed can have significant effects on reproductive performance of stock. Similarly, maintaining body weights/condition in times of surplus feed by only allocating sufficient feed for production targets can significantly improve the level of feed utilization if additional stock are introduced to use the created feed wedge.

In the case of growing animals, growth targets are important in relation to achieving critical mating weights and target sale weights.

4.9.2 Current methods available

Manual condition scoring and/or weighing. This requires stock to be brought from paddocks to yards and is a limitation to regular stock monitoring. Some preliminary work has been done with walk over weighing in the field and systems are commercially available.

4.9.3 The need

Remote assessment of stock weight/condition.

4.9.4 When would the data be needed

There is likely to be an on-going requirement during the year.

4.9.5 How frequently

Intervals less than two weeks are unlikely to be of benefit. Longer intervals may be appropriate in some situations. This would be seen as a trend analysis as snap shot data would not indicate whether or not stock were gaining or losing weight at that time.

4.9.6 What data is needed

Stock weights and/or condition to indicate weight loss or gain.

4.9.7 What is its applicability between enterprise types

Applicable to all grazing enterprises with lesser emphasis in non-breeding production systems.

4.9.8 What is its applicability between agro-ecological zones

Applicable to all agro-ecological systems.

4.10 Applicability summary

The applicability of the various interventions is shown in tables 1-3 below.

4.10.1 Enterprise Applicability

***Table 1**. Applicability of interventions for different enterprise types.*

		Beef Cattle Breeding	Meat Sheep Breeding	Wool Sheep Breeding	Trading
Optimising stocking rate	Soil fertility assessment	****	****	****	****
	Improved feed allocation	****	****	***	****
	Pasture yield mapping	***	***	***	***
Stock association	Dam-offspring association	****	****	****	*
	Sire-dam association	***	****	****	*
Individual animal performance	Weight monitoring/condition scoring	****	****	****	****
Animal disease identification	Metabolic diseases, rumen function, core temperature	***	***	***	***
Stock auditing and security	Stock auditing	***	***	***	***
	Stock theft	*	**	**	**
	Predator control	**	***	***	***
Risk management	Feed prediction	****	****	****	****
Weed management	Selective control in mixed swards	**	**	**	**

*	Not applicable	**	Limited applicability
***	Moderate applicability	****	High level of applicability

4.10.2 Farm systems applicability

***Table 2**. Applicability of interventions for different farm systems*

		Set stocking	Rotational grazing	Mixed cropping grazing	Intensive rotational grazing
Optimising stocking rate	Soil fertility assessment	****	****	****	****
	Improved feed allocation	**	****	***	****
	Pasture yield mapping	****	****	****	****
Stock association	Dam-offspring association	****	****	****	****
	Sire-dam association	****	****	****	****
Individual animal performance	Weight monitoring/condition scoring	****	****	****	****
Animal disease identification	Metabolic diseases, rumen function, core temperature	***	***	***	***
Stock auditing and security	Stock auditing	***	***	***	***
	Stock theft	**	**	**	**
	Predator control	***	***	***	***
Risk management	Feed prediction	****	****	****	****
Weed management	Selective control in mixed swards	**	**	**	**

*	Not applicable	**	Limited applicability
***	Moderate applicability	****	High level of applicability

4.10.3 Agro-ecological zone applicability

***Table 3**. Applicability of interventions for different agro-ecological zones.*

		WTC*	ST S&P	TH	TS&P	SA STP
Optimising stocking rate	Soil fertility assessment	****	**	****	***	*
	Improved feed allocation	****	**	****	****	**
	Pasture yield mapping	****	**	****	***	*
Stock association	Dam-offspring association	****	**	****	****	**
	Sire-dam association	****	***	****	****	**
Individual animal performance	Weight monitoring/condition scoring	****	****	****	****	***
Animal disease identification	Metabolic diseases, rumen function, core temperature	***	**	***	***	*
Stock auditing and security	Stock auditing	***	***	***	***	***
	Stock theft	***	***	***	***	***
	Predator control	***	***	***	**	**
Risk management	Feed prediction	****	****	****	****	****
Weed management	Selective control in mixed swards	**	*	**	**	*

- WTC – Wet temperate coast
- STS&P – Sub-tropical slopes and plains
- TH – Temperate highlands
- TS&P – Temperate slopes and plains
- SASTP – Semi-arid subtropical plains

5. Industry consultation

An industry workshop, consisting of producers, consultants, the steering committee and MLA representatives, was held to validate and test the key intervention areas identified above (Appendix C). There was general agreement with the issues identified, although there was some difference in emphasis.

It was thought that the initial uses of these technologies would be in tactical and operational decisions and that the results from these applications would migrate eventually toward strategic decision making.

As a broad conclusion, the ability to spatially locate stock was seen to have many applications from stock security, as a component of pasture yield mapping, and stock behaviour, etc. Proximal analysis of stock to associate dam and offspring, and dam and sire association was considered to have limited benefit for genetic improvement, but was seen to be of value in the identification of poor performing animals, the removal of which would lift the overall performance of the flock or mob. For example the identification of those animals for temperament or other reason that continually fail to raise off spring or all off spring born, would have a significant impact on the overall weaning percentage. Similarly annual phenotypic selection for litter weight weaned of 0.35kg/ewe for a flock of 300 breeding ewes would result in a gross increase of 525kg after 5 years. Although the heritability of estimates for litter weight weaned are low, response to selection is enhanced by the large phenotypic variation of the trait, which can result in large selection differentials, especially if intense selection of sires and dams is applied. (Snowder and Fogarty, 2009)

The concept of yield mapping of pastures (a combination of feed consumed and feed remaining) was seen to be of great value in identifying where paddock interventions may be required. Soil fertility is a major production issue and fertilizers are a major cost. The ability to identify soil fertility characteristics at least on a zonal level for more efficient fertiliser application strategies was seen to be of great benefit. The most appropriate means may not be direct measurement of soil fertility, but an iterative approach based on indirect measurements such as yield maps.

There was a view supported by most of the producers that selective weed management in mixed swards could result in significant labour savings with minimal impact on non-target species.

The importance of stock monitoring –body weight/condition score and disease processes – was also accepted as a valuable objective. The producers stated that having this information would decrease the risk associated with increasing intensification of farming systems by providing early warnings about changes in animal condition and the ability to intervene to manage issues.

Those present agreed that accurate feed prediction was a worthwhile goal but because it was perceived to be reliant on climate forecasts, questioned the reliability of it during most of the year and the ability to predict feed levels greater than 2 – 3 weeks out. However, there was a potential role in predicting feed levels at the end of the season which may have advantages for decision making regarding finishing stock. The comment was made that unless there was a high level of accuracy in the prediction, there may be little confidence in acting on the predictions because of the risk of getting the decision wrong.

Those producers running intensive grazing systems placed a lot emphasis on being able to accurately allocate feed between different classes of stock to improve the efficiency of feed utilization.

One of the key outcomes from the workshop was the opportunity for these technologies to de-skill the labour component of farm management and reduce the reliance on highly skilled labour in farming systems. While this suggestion may seem counter intuitive, if the data from remote and precision technologies is developed and presented in a form that is intuitive and easily understood, it would allow people with lower skill levels to assess the data and recommendations readily. If however the data formatting is not easily understood then of course highly skilled people would be required. The example is analogous to the early introduction of computers. They only became useful to the general public with the introduction of simple operating systems and the lack of need to use programming languages to undertake tasks. As stated for this goal to be achieved the outputs of the technologies need to be simple and the required responses readily identifiable and actionable.

6. Technological solutions aligned to priority on-farm needs

This section addresses each of the key on-farm applications identified above and aligns potential technological solutions to each one. The technologies are described in terms of their applicability and stage of development.

6.1 Optimising stocking rate

6.1.1 Improved pasture production through soil fertility

Managing spatial variability of soil nutrients in agricultural systems is a key issue with a significant body of RD&E going into quantifying and managing this across industries such as cropping and horticulture. In contrast little has been done to investigate the variability of soil nutrients in grazing systems and even less in quantifying the benefits of making management decisions aimed at taking advantage of this variability.

Currently the most obvious solution to understand soil nutrient variability is to take a number of soil samples across a paddock in a regular grid and then turn this into a map. Whilst this would give the most accurate data it is time consuming and expensive using the current techniques of taking a soil core and sending it away for laboratory analysis.

There are two schools of thought to overcome this problem: 1) develop rapid infield analytical techniques that allow direct measurement of soil nutrients; or 2) develop systems that enable an informed soil sampling protocol to be undertaken e.g. zonal monitoring and management strategies. This second technique of zonal monitoring is now widely applied in the cropping and horticulture industries whilst the first remains largely in development. Across 10 cropping properties surveyed Mayfield *et al.* (2008) reported average fertiliser savings of $8/ha and average increase in production of $7/ha through the application of zonal management strategies.

6.1.1.1 *Direct in-field assessment of soil nutrients*

There are some in-field wet chemistry and radiometric techniques being developed however it is unclear when they may be commercially available and what their cost may be. It should be noted that there is significant interest in the development of these technologies from the cropping and horticultural industries with most of the research driven by these sectors. One of the key limitations of sensors developed for cropping is that they are mostly suitable for cultivated and the sensor platform may not be durable in non-arable soils.

According to Sinfield *et al*., (2010) there are several analytical techniques that could be applied to measure key nutrients in the field. For Nitrogen (N) these include: 1) Spectrophotometric/spectroscopic techniques such as copper/cadmium reduction (CCR), Near-infrared reflectance spectroscopy (NIRS), Mid-infrared Fourier transform attenuated total reflectance spectroscopy (FT-IR ATR) and Morphology-dependent stimulated Raman scattering (MDSRS); 2) Electrochemical techniques such ion specific electrodes (ISE), ion selective field-effect transistor (ISFET) and combinations of CCR and ISE techniques; and 3) biological techniques such as Nitrate Biosensors (BS). Of these it appears that NIRS and ISE are the closest to commercial reality. Less research seems to have been undertaken for phosphorus (P); what has been investigated include: 1) similar spectrophotometric/spectroscopic techniques as used for N such as MDSRS and NIRS; 2) Electrochemical techniques such as Phosphate ISE, Phosphate coated wire field-effect transistor (CWFET); and 3) biological techniques such as Phosphate biosensors (BS). Like N and P sensors for Potassium (K) include those based on: 1) Reflectance spectroscopy; and 2) electro-chemical techniques such as Potassium Ion Specific Electrode and Potassium selective field-effect transistors. Sinfield *et al*., (2010) suggests that there is currently no systems currently nearing commercial availability that will measure K.

There are some systems commercially available which allow scanning of the visible, near-infrared and mid-infrared sprectal profile of soils. These include penetrating probes (Kweon *et al.* 2008), tyne-mounted sensors (Bricklemyer and Brown 2010) or handheld instruments (e.g. ASD Agrispec). Although the literature suggests that NIRS may provide a good overall platform for nutrient sensing there seems to be some contention with experts in the field suggesting that whilst good for carbon, correlation for other nutrients may not be as sound (Chris Guppy UNE and Brett Whelan U Syd, pers comm.).

There has been some development of mobile Ion Specific Electrode integrated for multiple nutrients in Australia. Systems such as the Multi-ion Measuring System (MIMS) developed by University of Sydney and CSIRO have potential to deliver rapid in-field assessment of specific nutrients such as nitrate, sodium and potassium (Lobsey *et al*. 2010). However the development of this system appears to have stalled with little information currently available on the likely commercialisation of this sensor platform (Brett Whelan, pers comm).

Another technique being investigated more recently is the application of X-ray fluorescence (PXRF) spectrometry. These portable systems could be developed so that they can be applied to soils (McLaren *et al*. 2012) however they will at best provide an estimate of the total element and not the available levels of the nutrients (Chris Guppy, UNE pers comm.). PXRF systems currently cost between $40 and $70k.

One of the key problems is that, apart from tine mounted NIR probes none of these sensors are available as on-the-go platforms. This means that these sensors need to be applied at a high enough resolution to facilitate mapping of the spatial variability of the nutrients across the landscape. To monitor change over time these systems would also require continued sampling at the same spatial scale although it may be possible to move to a zonal management strategy after an initial survey was undertaken.

6.1.1.2 *Indirect measurement of soil nutrients: towards zonal management*

In other industries protocols have been established (within the field of Precision Agriculture) which step producers through the process of managing spatial soil nutrient variability at a sub paddock scale. In the case of cropping this is a four-step process: 1) landscape variability is initially mapped by satellite biomass imagery, grain yield maps or soil survey (most commonly EM38) from which production zones are created; 2) These zones are subject to soil sampling to determine limiting constraints for which ameliorating management strategies are targeted, for example P is often limiting in yield areas of a paddock where it has been consistently exported in grain; 3) These limiting factors can then be addressed (e.g. P top up for deficient areas and lime for low pH areas); 4) Once the limiting factors have been addressed a nutrient replacement strategy is implemented where the amount of nutrient removed from a given zone (as measured by yield monitoring) is replaced in subsequent zonal fertiliser applications.

This four-stage strategy has some potential for pasture paddocks however grazing systems include animals which are known to have a significant effect in terms of their impact on plant biomass and nutrient redistribution. This complicating factor has serious implications for the way we seek to monitor spatial variability in soil nutrients at a sub paddock scale in pastures.

It is worth noting here that spatial variability that naturally occurs in landscapes often does not fit to the zonal management strategies imposed in Precision Agriculture systems. In some agricultural systems spatial variability is managed at the sub metre scale (e.g. real-time in-season nitrogen application in corn) or even the individual plant scale (e.g. horticulture). Whilst zonal management does not truly accommodate the spatial variability in a field it is probably the necessary first step to enable optimised soil nutritional management in pastures.

Although research is still required in exactly how this process should be undertaken it is worth examining the technologies in terms of the 4 steps outlined above. 1) Monitoring landscape variability to develop zones, 2) collecting soil sample data, 3) variable rate application of ameliorants, and 4) ongoing monitoring for nutrient replacement strategies.

1) Sensors that can provide measures of landscape production variability in pastures

The key criterion here is that the sensor or combination of sensors can provide zone categorisation that correlates with the underlying soil variability.

a) Soil Sensors

➢ Electromagnetic induction (EMI)

EMI instruments have been extensively used in cropping and the derived apparent electrical conductivity (eCa) is known to have a relationship with a number of soil properties including soil moisture, soil texture, soil depth and ion content (Corwin and Leschm 2005). The limited reports of their application in pastures demonstrated some relationships between eCa and plant species, soil characteristics and pasture productivity (Guretzky *et al*. 2004; Serrano *et al*. 2010). EMI instruments can be used across vegetation however it is unclear how much influence pasture biomass might have.

➢ Gamma ray spectrometry (GRS)

GRS involves the measurement of gamma radiation from the radioisotopes of potassium, uranium and thorium (Minty 1997), all of which have been found to relate to soil parent materials and their weathering (Dickson and Scott 1997). GRS has been found to provide good local correlations with specific nutrients particularly potassium along with other soil textural characteristics (Pracilio *et al*. 2006; Wong and Harper 1999). However, little research has investigated the usefulness of this data in pastures. It is worth noting that large areas of Australia have been mapped using airborne GRS (although the resolution is coarse at >100metre transects) and this data is freely available to the public and for some states is offered to producers free of charge through the PASource farm mapping and data management program (http://www.pasource.com.au).

- Veris mobile pH Sensor

The Veris mobile pH sensor works by measuring pH in water using an antimony electrode (Schirrmann *et al*. 2011). The sensor is attached to the back of a quad bike and gridded soil samples taken across the paddock. The sensor is not considered accurate enough to prescribe lime, instead the data is used to create zones from which soil samples are taken for laboratory analysis (Andrew Whitlock pers. comm.). This sensor has not been applied in perennial pastures but has been widely used in paddocks subject to pasture rotation in mixed farming systems. According to Andrew Whitlock (Pers comm..) the sensor could be applied when there is pasture present by simply scraping it out of the way.

- Other techniques

There are other techniques for mapping soil variability e.g. Ground penetrating radar, Veris Electrical conductivity meter, soil tine compaction sensors which are used in arable soils, however the use of these will have limitations in pasture paddocks. The use of GPR has not been extensive in cropping industries presumably due to its cost and difficulty in data interpretation. Any tine based sensor (Veris EC meter, soil compaction sensors) will be limited in non-arable situations.

- The limitation of mapping soil with sensors

It should be noted that mapping soil variability using remote and proximal sensors does not directly measure the nutrients of interest. In most cases these sensors are measuring variability in parent material, soil texture or soil moisture. Therefore these sensors may not provide good correlation with soil nutrients. This may particularly be the case in grazed pastures as livestock will have had an effect on the natural distribution of nutrients associated with soil characteristics (e.g. parent materials) that are being captured by the sensors. However they may in combination with other platforms provide key information.

b) Plant sensors

There are a number of plant/pasture sensors that are described in detail in Section 8.1.2 “Improved Feed Allocation”. They are relevant here because they can provide spatial information on pasture biomass that can in turn assist in defining fertility zones. As discussed later, these technologies have their own mix of spatial and temporal characteristics, useability, and reliance on 3rd party provision. Compared to the need to quantitatively measure biomass for more accurate feed allocation, its use for defining fertility zones may be achieved qualitatively, and hence reduce or potentially eliminate the need for quantitative calibration.

There has been some recent and specific research undertaken which investigates the potential for proximal hyper-spectral sensing to predict plant phosphorus and potassium and relate this to soil P and K in New Zealand (Kawamura *et al*., 2011). The early results have demonstrated good correlation using ambient sunlight however further research is being undertaken using an independent light source that may yield even better results (Keith Betteridge, pers comm.).

- The limitations of biomass mapping

A limitation of biomass mapping is that the low biomass areas are not necessarily the poor performing areas but could be those areas which are preferentially grazed by the livestock. This is discussed in more detail in the Pasture Yield section (8.2) below.

c) Animal sensors

It has been suggested that monitoring the spatial activities of livestock may lead to a better understanding of the spatial variability in soil nutrients in pastures (Trotter *et al*. 2009). If the intake of animals could be detected it would be possible to determine where nutrients are being removed from the pasture. In addition there is known to be a link between the time animals spend in an area and the frequency of urination and defecation which may enable modelling of nutrient redistribution. A full review of Autonomous Spatial Livestock Technologies is provided in sections 8.5 and 9.2.

d) Landscape sensors

One very simple characteristic of pasture paddocks which can be easily quantified is the spatial variability in elevation, this can be turned into aspect and drainage maps all of which are known to affect pasture production. Course elevation data (highest resolution is 30m) is available through Geoscience Australia and is currently offered free to producers through the PASource farm mapping program. Correlations between key soil nutrients and elevation have been reported (Stefanski and Simpson, 2010).

e) Developing zones

There are several established techniques that can be used to establish zones given the correct data. The key R&D gap is determining which data layers best correlate to the soil nutrients of most interest.

It should also be noted that several studies have demonstrated that the innate knowledge carried by producers can also be used to zone landscapes and should be considered as a potentially useful input in developing research in this area.

2) Collecting soil sample data

Once zones are established soil samples need to be collected and analysed to provide the amelioration recommendations. Whilst standard laboratory tests are probably going to remain the best short and medium term option it is worth noting that several in-field techniques for assessing soil nutrients are being examined. This includes ion specific electrodes (work by Sydney University ACPA) and X-ray florescence (current work by UNE) (see Section 8.1.1.1 above).

3) Variable rate application of ameliorants

There are several basic techniques for applying variable rate ameliorants or fertiliser. These include simple manual adjustment of rates “out the back of spreader” to more automated VR spreading techniques. Much of the technology required is already in use in cropping Precision Agriculture.

4) Ongoing monitoring for nutrient replacement strategies

Most of the benefit from managing spatial variability in soil nutrients in pastures is likely to come about through the initial two steps. That is mapping the current nutrient levels and developing a variable rate ameliorant or fertiliser strategy to fix these problems. Monitoring the ongoing nutrient balance across a grazing landscape would provide benefits as nutrients could be applied to those areas being depleted and not to those areas where they are being deposited through urination and defecation.

The direct measurement of soil nutrients *in situ* using on-the-go sensors remains an ongoing challenge with few suitable tools available for deployment in pastures. There appears to be a reasonable amount of research going into this field from the cropping industries although the transfer of these technologies to non-arable pastures where un-cultivated soil may damage any probes remains an issue.

A more immediate solution to the problem would be the development of zone based variable rate application. There are a range of tools to measure spatial variability in soil, plant and animal characteristics but a spatial informatics R&D approach is required to understand how these best be used to define variable rate zones.

6.1.2 Improved feed allocation

The core measurement components identified for improved feed allocation are quantitative measures of pasture biomass, growth rate and quality. Each of these will be discussed separately below. We propose that the first priority is investment in technologies to measure pasture biomass because they are either at, or closer to, market, and in isolation of pasture quality measurements can provide significant benefits to improved feed allocation. Conversely, if pasture quality measurement was provided in isolation of concurrent information on biomass, the impact is low without that concurrent biomass information.

Compared to pasture growth rate and quality, the priority need is to deliver solutions to quantitatively measure pasture biomass. These technologies are at, or closer to, market than pasture quality technologies and deliver immediate benefit for improved feed allocation.

6.1.2.1 *Pasture Biomass*

There are a number of technologies that can estimate pasture biomass, all with their unique mix of spatial and temporal resolutions, accuracies, infrastructure costs, labour requirements and stage of commercial availability. These are summarised in Table 4. The information is indicative only, but shows the breadth of potential technology solutions available.

As a summary statement, we propose that visual and hand-held sensors are too subjective and labour intensive to warrant a priority solution in practice, but are valuable tools in validating other methods. They are included below for comparative purposes. The focus of this project is on the automated/remote systems (vehicle mounted, airborne and satellite) because they provide the greatest opportunity given the spatial and temporal requirements of feed allocation, and when properly validated are reported to be as accurate as ground-truthing methods[1].

A key point is that all of these technologies measure indirect sward characteristics (eg pasture height, density, leaf area index) and require calibration across seasons and pasture types. This calibration requirement is irrefutable and cannot be avoided. Rennie *et al*. (2009) demonstrated this calibration requirement for the Rising Plate Meter and bike-mounted rapid pasture meter in New Zealand. They clearly showed that accuracy increased significantly when calibrated specifically to a region (compared with generic calibrations) and the impact of time during the season on prediction errors.

In considering any further calibration and validation work, it is critical that it be designed specifically for spatial measurements to ensure accuracy and reliability. This needs to take into account spatial resolution, temporal alignment between remote estimates and ground-truthing data collection, and the accuracy of image/pixel location. Improper experimental design can lead to perceptions that the remote estimates are inaccurate, but are more-so an artefact of the design.

The geographical extent of a region that can use a single calibration will depend on the heterogeneity of that region (particularly variability in climate and vegetation). Assessment of this variability as part of the project design will optimise the methodology and cost structures.

Fundamentally, the different technologies do measure different biological characteristics of the sward. Those technologies that measure pasture height will be estimating total above ground biomass and hence potentially both green and senescent material. Optical sensors utilising NDVI measure photosynthetically active material. Other indices from optical sensors have been shown to qualitatively describe different vegetation characteristics such as green/dry ratios.

The potential attractiveness of the different technologies will also vary between end-users. Some of the technologies require lower set-up costs, but ongoing running costs and user input. For example, the bike-mounted technologies can be purchased outright, require labour for ongoing measurement, but can be operated independently of 3rd parties. In comparison, satellite-based systems are provided as an information service (after initial digitisation of the farm), and do not require ongoing labour investment to collect data.

A key issue for many end-users will be reliable access to timely and frequent information as required. This may necessitate a solution that uses several technology sources (eg satellite for full spatial information at key times of the year, with vehicle-mounted systems providing the more regular information in-between), or a data-model fusion approach (data collection at key times, and pasture growth modelled in-between).

[1] Validation data not available for all technologies still in development

There is unlikely to be one single technology for measuring pasture biomass that meets the needs of all systems and user requirements. For those managing highly improved arable pastures (dairy like swards) technologies already exist that will enable on demand biomass estimates (c-dax pasture meter and Ellinbank pasture reader). However, these swards make up only a small fraction of the pastures being used by beef and sheep graziers and a more robust technology is required that can provide estimates of both green and dead fractions of both improved and native swards. Satellite based biomass estimations have previously been explored however there remains some potential for further research to refine these systems (e.g. Pastures From Space). New developments such as the increased spatial and temporal resolution of multi-spectral systems and developments in RADAR systems should be taken into account. Proximal sensors such as LiDAR and Active Optical Sensors will provide on demand measures of sward characteristics and some early research has demonstrated the potential for these technologies however further basic development work is required.

In all cases calibration of the sensor is required. There is potential for a cleverly designed regionally-based R&D program that can simultaneously calibrate & validate several technologies, and ensure that they are integrated into supporting farm management software. Such a program of work would allow producers to tailor a solution to their own needs and provide industry with objective and independent technical reliability.

***Table 4**. Key characteristics of pasture biomass technologies*

Platform	Technology & what it actually measures	Brand examples	Key characteristics
Visual	Observations	ProGraze	• Subjective • Heavily reliant on the skill of the operator • Difficult to be independently verified • Unlikely to detect differences in DM below 10% unless the operator is highly skilled (MLA Final Report, 2011) • Requires training and skill updates • Low set-up cost • Measurements can be taken 'on-demand' • Can be labour intensive to get ongoing measurements
Hand-held	Rising Pasture Meter - measures pasture height (influenced by sward density/ rigidity)	• FarmWorks (NZ) • The Meter Man	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each species • Can be labour intensive to generate calibration equations and to collect data • Data can be taken on transects or randomly, not fully "spatial" although maps can be generated from point data • Can be susceptible to errors in highly heterogeneous swards (requiring high sampling rates) and pugging, but easy to take a large number of readings. • Low set-up cost • Measurements can be taken 'on-demand' • Predictions errors (RMSE) reported to be between 441-773 kgDM/ha when regionally calibrated (King *et al*., 2010).
	Electronic Capacitance Probe - – measures conductivity and sward density	• GrassMaster II (GrazeTech) • Jenquip (NZ) • Technipharm (NZ)	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each species • Can be labour intensive to generate calibration equations and to collect data • Data can be taken on transects or randomly, not fully "spatial" although maps can be generated from point data • Can be susceptible to errors in highly heterogeneous swards (requiring high sampling rates), moist conditions and variable plant moisture conditions • Low set-up cost • Measurements can be taken 'on-demand'

	Optical sensors (eg NDVI)	• Greenseeker • Crop Circle	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each species • Data can be taken on transects or randomly, not fully "spatial" although maps can be generated from point data • Can be susceptible to errors in highly heterogeneous swards (requiring high sampling rates), Labour intensive to generate calibration equations and to collect data • Data only collected on transects, not fully spatial • Measurements can be taken 'on-demand'
Vehicle Mounted (including quad-bike)	Optical sensors (eg NDVI)	• Greenseeker • Crop Circle	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each species • NDVI measures photosynthetically active material only • Can be labour intensive to generate calibration equations • Data can be taken on transects or randomly, not fully "spatial" although maps can be generated from point data (can be GPS integrated) • Measurements can be taken 'on-demand'
	Light (NIR) beam measures pasture height.	C-Dax (NZ) Pumps and Sprays (Aust)	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each pasture type (the calibration requirements for different species mixes is unclear) • Pasture height collectively includes green and senescent plant material, and all plant parts. • Can be labour intensive to generate calibration equations. Some calibration equations provided by supplier, but not applicable for Australian pastures. • Data can be taken on transects or randomly, not fully "spatial" although maps can be generated from point data (can be GPS integrated) • Rapid data collection • Prediction errors (RMS) similar to RPM - reported to be between 437-668 kgDM/ha when regionally calibrated (King *et al*., 2010; Rennie *et al* 2009). • Integrated with some pasture/farm management software • GPS enabled
	Echo-sound	Automatic Pasture Reader, Naroaka Enterprises	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each pasture type • Can be labour intensive to generate calibration equations. Some calibration equations provided by supplier, but developed for dairy pastures

			• Data can be taken on transects or randomly, not fully "spatial" although maps can be generated from point data • Rapid data collection • Correlations with pasture cuts (R^2) of approx 0.9 reported. • Can be GPS integrated
	Lidar measures pasture height	R&D development (CSIRO)	• Likely to require a calibration equation to convert to pasture mass - should be generated seasonally for each species • Pasture height collectively includes green and senescent plant material, and all plant parts. • Data can be taken on transects or randomly, not fully "spatial" although maps can be generated from point data. However device sideways looking, and angle can be varied for potentially greater field of view
Sensor networks	A network of *in situ* nodes with potentially any sensors mounted	R&D development (CSIRO)	• Sensors can be fitted to stationary or moving fixtures (eg posts and animals). • Range of sensors can be fitted, will still require a calibration equation to convert to pasture mass - should be generated seasonally for each species • Variable field of view possible • Sampling rate variable and 'on demand'. • Higher infrastructure/set-up cost
Airborne (including UAVs)	Optical sensors (eg NDVI)	E.g. SpecTerra Systems	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each species • Fully spatial • Large adjustable field of views (manipulated by flight altitude), but this impacts also on spatial resolution • Higher cost per image • Third-party provider – highly specialised • Data collection must be pre-scheduled • Some delay between data collection and delivery to client
Satellite	Optical sensors (eg NDVI & hyperspectral sensors)	Pastures from Space	• Requires a calibration equation to convert to pasture mass - should be generated seasonally for each species • Constrained by cloud • Reliant on satellite availability and timing • Fully spatial • Large spatial footprint, spatial resolution varies with satellite

			• Accuracy reported to be similar to that of a RPM, with Standard Errors of 260-315 kgDM/Ha (Edirisinghe *et al.* 2011, 2012) • Some delay between data collection and delivery to client (24-48 hours)
	Radar	R&D development	• Likely to require a calibration equation to convert to pasture mass - generated seasonally for each species • Not constrained by cloud cover • Reliant on satellite availability and timing • Fully spatial • Some delay between data collection and delivery to client • Proof-of-concept stage only

6.1.2.2 *Pasture growth rate*

Pasture growth rate (PGR) (kgDM/ha.day^{-1}) can be derived in two ways:

1. Calculated as the difference between two biomass measurements (where no grazing or harvesting has occurred). This is a retrospective measure, and depending on the seasonal conditions may not be representative of a future period.
2. Modelled.
   The Pasture from Space program integrated satellite-based NDVI measurements (to effectively estimate leaf area index) with a plant growth model to predict PGR 1-2 weeks in advance. Donald *et al*. (2010) reported that the estimates had an error of 10 kgDM/ha.d^{-1} over the range of PGR from 5 to 90 kg DM/ha.d^{-1} for individual paddocks in south-west Western Australia. Edwards *et al*. (2007) and Handcock *et al*. (2009) validated PGR estimates in south-east South Australia and Victorian dairy pastures respectively.
   The PGR information is available weekly, free, on a regional basis (www.pasturefromspace.csiro.au) and commercially available on a farm basis (paddock by paddock) integrated into the PastureWatch farm management software supplied by Fairport. The regional PGR information freely available over the internet averages over 660 unique visitors per month, with visitors to the site increasing since its inception in 2003.
   A range of models can also be used to estimate PGR, such as GrassGro and the Sustainable Grazing Systems (SGS) model. The resolution and accuracy of these will always be constrained by that of the inputs (eg climate variables). There is potential to integrate real-time sensors with models, and this will be discussed in more detail in Section 8.3 “feed prediction”.

6.1.2.3 *Pasture quality*

In the context of improved feed allocation, the key requirements for quality assessment are protein content and metabolisable energy (ME). Numerous studies have reported correlations between remotely sensed NDVI and nitrogen content from *in situ* (hand-held) sensors for both crops (eg Islam *et al*. 2011) and pastures (e.g. Albayrak 2008; Pullanagari *et al*. 2011, Starks *et al*. 2006). Despite being statistically significant, these correlations can explain anywhere between 31% and 92% of the total variation and are unlikely to have the accuracy required for feed allocation or diet formulation. Further, the correlations with NDVI are likely to be associative, not causative, and are confounded by many variables, particularly outside of the experimental calibration/validation sample set. This is not surprising given the reflectance at NDVI wavelengths is not directly influenced by protein-related molecules.

There is less evidence that NDVI can predict ME or digestibility. Islam *et al*. (2011) reported no relationship between NDVI and ME of forage maize at any leaf stage. Others however have shown that other spectral information from multi- or hyper-spectral hand-held sensors can be used to estimate IVDMD (eg Starks *et al*. (2008) reported RMSE=0.53).

In a laboratory setting, Near Infrared Reflectance Spectroscopy (NIRS) systems are proven to accurately predict quality parameters (eg CP, ME, ADF, NDF). Plant samples are routinely dried and ground to remove the effect of moisture and homogenise the sample. The theoretical basis of estimating parameters such as protein bonds using near-infrared reflectance is well established (e.g. Osborne, 2006; Kokaly 2001), and taking this to a remote application has been demonstrated. For example, Starks *et al.* (2004) concluded that nitrogen concentration of Bermuda Grass swards could be quantified with a field hyperspectral radiometer with equivalent statistical accuracy as lab-based NIRS (R^2 0.82, standard error of prediction 0.42%). Pullanagari *et al*. (2012) used a field hyperspectral radiometer to estimate pasture quality and reported validation error values (RMSE) of 0.46 for ME and 2.33 for CP. The most recent work by Thulin *et al*. (2012) concluded that digestibility of Victorian pastures could be effectively predicted using a hand-held spectrophotometer (R^2 = 0.82, root mean square error of prediction (RMSEP) = 3.94), but the accuracy for crude protein and cellulose was more applicable for qualitative assessment (R^2 = 0.62, RMSEP = 3.18 for CP; R^2 = 0.73, RMSEP = 2.37 for cellulose); the results for lignin were poor (R^2 = 0.44, RMSEP = 1.87).

These hyperspectral technologies have also been evaluated in airborne and satellite systems. Youngentob *et al* (2011) used airborne spectroscopy (HyMap) to estimate the nutritional quality of Eucalytpus foliage and demonstrated a capacity to estimate Digestible Dry Matter with Calibration Standard Errors of approximately 6% units. Bowman *et al* (2007) concluded that "the chemical composition of growing rice crops can be measured directly from remote satellite and airborne sensors using many wavelengths in the near infrared portion of the electromagnetic spectrum. This is an important advance over the current remotely sensed imagery, which uses only two broad wavelength bands in the visible and very low infrared, and so provides a measure of vegetative growth and not an actual measure of chemical composition". They reported that using satellite-based Hyperion hyperspectral imagery N% could be estimate with a standard error of prediction of 0.228%N.

However it is necessary to understand the differences that the use of fresh plant tissue will make to spectra and the analytical error, and the impact of atmosphere and other interferences as the sensing platform becomes more remote. The presence of water (in fresh tissue) is likely to mask some spectral features and influence analytical errors for some tissue constituents.

Currently field hyperspectral/NIRS technology (eg ASG, GER) is priced towards R&D applications and there are no well-proven standardised calibration equations for converting the reflectance to vegetation quality parameters. There is a lack of security around the future availability of hyperspectral satellite imagery and a lack of standardised processing routines for the imagery. It is difficult to see a commercially implementable delivery system direct to industry within the next 5 years, but it is that sort of timeframe that would be required in calibration development to ensure accuracy and reliability of derived estimates.

NIR spectroscopy has also been applied to faecal analysis in order to directly predict attributes of the diet of herbivores such as crude protein and fibre contents, proportions of plant species and morphological components, diet digestibility and voluntary DM intake (Dixon and Coates, 2009). The spectral measurements are made not on the material of interest (i.e. the diet), but on a derived material (i.e. faeces).

Dixon and Coates (2009) concluded that the errors and robustness of faecal NIR (F.NIR) calibrations to predict the crude protein concentration and digestibility of the diet of herbivores are generally comparable with those to directly predict the same attributes in the forage. This is now offered as a commercial service in Northern Australia (www.symbioalliance.com.au). The key considerations for F.NIR are that the results represent the diet previously selected by the animal not on the feed available for selection, faeces is collected randomly and not allocated to individual animals (individual animals cannot be monitored across time), and importantly the estimates are retrospective (diet consumed) and do not necessarily represent the current or future plane of nutrition.

There is a strong theoretical basis for using hyperspectral/NIRS technology for estimating pasture quality on a range of platforms with greater accuracy than simple NDVI-type indices. There is some proof-of-concept in different vegetation types (eg mixed Victorian temperate pastures, New Zealand Perennial ryegrass/white clover based pastures, bermuda grass, Sainfoin pasture, Eucalytpus foliage, rice). A commercially-available business model is likely to be 5-10 years in the future given current technology availability and cost, and satellite deployment. Analytical accuracy and reliability will need to be established.

There is an opportunity to explore which specific wavelengths within the full spectral signature most accurately estimate quality parameters, and then use those specific wavelength filters in more simple active optical sensors for implementation (akin to how NIRS is used at grain receival points to measure grain quality).

6.2 Pasture yield mapping

The above discussion concerning pasture biomass, growth rate and quality focussed on technologies for near-real time monitoring. As such, they measure what is available and not what was removed by animals or harvesting. Estimation of total pasture yields must include the component of pasture growth that was consumed or removed. The requirement is for spatial information at the sub-paddock scale, with differentiation across seasons.

Total pasture yields may be able to be estimated in three ways:

6.2.1 Direct measurement by remote or proximal sensing

It would be theoretically possible to take measurements of pasture biomass before and after grazing events to provide a measure of differential pasture intake. In practice this would be difficult to undertake as proximal sensors would need to be deployed as full paddock surveys before and after grazing. Remote sensing data (e.g. calibrated NDVI) might provide a better solution however this would need to be integrated with grazing records to identify before and after images. The only viable remote sensing platform with sufficient temporal resolution (daily) has a course spatial resolution (MODIS = 250m pixels). There is some current work being undertaken by the CRC for Spatial Information (CRCSI) looking at the potential for alternative processing techniques to be used to produce pasture yield maps from combinations of both MODIS and the higher resolution Landsat data.

6.2.2 Down-scaling models to sub-paddock scale

Pasture growth models such as SGS, ApSim and GrassGro can be used to estimate total pasture growth using both historical and up-to-date climate information. However they are usually of coarser spatial resolution by virtue of the coarse inputs (eg regional climatic data, broad soil type information) and generalised pasture growth algorithms.

It is possible to downscale the model outputs using finer resolution data such as real-time proximal and remote sensed data. For example, sensor networks as deployed at CSIRO and UNE demonstration farms measure attributes such as climate, soil moisture, vegetation state in real-time that could inform more localised production models. It might also be possible to integrate these models with some sort of remote sensing imagery to provide better pasture yield maps (Donald *et al*. 2010).

This approach offers more application in predicting feed availability (Section 8.3) than in pasture yield estimation because it is unlikely to achieve the spatial resolution required for understanding sub-paddock variation in productivity.

6.2.3 Integrating real-time pasture and animal measurements

Pasture yield mapping could be achieved by integrating measurements of the spatial variability in plant biomass and growth with measurements of the spatial variability in in-take by livestock.

Plant biomass and growth monitoring have been discussed previously and there is potential to use sensor platforms currently available to either directly measure or model these parameters.

The missing link to date has been our ability to measure livestock intake. There are currently no tools available that remotely monitor intake. However CSIRO are currently developing a research tool (SMART Ear Tag) which will carry several sensing platforms which will potentially provide measures of feed intake. There still remains the need for a sensor that can provide a measure of feed intake at a spatial scale in a commercial situation.

There is potential to measure animal behaviours associated with intake that may prove sufficient correlation with feed intake to enable pasture yield mapping. Course resolution spatial data from GNSS collars have been used along with allied sensors to predict grazing behaviour in several studies (Rutter *et al*., 1997; Trotter *et al*., 2012). A small scale research program is currently being undertaken by the CRCSI and UNE in the development of grazing behaviour algorithms for spatial monitoring technologies.

It would be reasonable to look to integrate the high level research being undertaken by CSIRO in the development of the SMART Ear Tag with the development of a commercially based grazing monitoring system.

It should be noted that the development of pasture yield maps could be undertaken using real-time sensing platforms but might be equally useful using simple GPS tracking collars and historical remote sensing imagery.

There is a current proposal submitted to MLA that aims to develop research tools that use real-time, sensor technologies (embedded in ear tags that include accelerometers, light sensors, audio, pressure and location sensors) to provide the capacity to characterise metrics for behavioural, nutritional and physiological parameters, from which algorithms that estimate pasture intake in free-ranging ruminants with a high degree of precision. This is a strategic project that is likely to be at least 5 years in implementation.

Pasture yield mapping will require measures of both pasture biomass grown and estimates of animal intake at a sub-paddock scale. There are a number of ways of developing the measures of pasture biomass which should be explored as part of other technology development needs (e.g. biomass monitoring and feed prediction). Whilst directly monitoring feed intake would be ideal it may be sufficient to monitor behaviours associated with intake such as eating and ruminating behaviour. The development of research level tools for monitoring intake should be pursued through current research projects (eg CSIRO proposal with by MLA). This research should be integrated with a further research program aimed at taking the findings from the SMART tag project through to a commercial environment through partnerships with commercial animal monitoring platforms. This is a strategic area requiring proof-of-concept, with benefit unlikely to be realised within the next 5 years.

6.3 Feed prediction

The above discussion about pasture biomass, growth rate and quality focussed on technologies for near-real time monitoring. The discussion on pasture yield mapping then added the component of what was consumed by animals to give a measure of total pasture produced. All of these considerations were a present and historical time frame, however a key consideration when optimising stocking rate and forward feed budgeting is having increased confidence in <u>future</u> pasture growth.

The options considered here all utilise some modelling component. The period of time the forecast is required differs depending on the application, and as a general rule will be become less reliable the further ahead the prediction.

The Pastures from Space (PfS) program described above not only developed near real-time pasture growth rate (PGR) estimates from satellite remote sensing, but also demonstrated that satellite reflectance from pastures could be forecast 1 week ahead by integrating satellite remote sensing estimates of green lead area with the GrowEst pasture growth model. They reported that at an individual paddock level, between 74% and 92% of the actual growth rate recorded over the seven-day interval was explained by the prediction (AWI Final report, 2004). This is a relatively simple approach with a short prediction timeframe, but it does demonstrate a conceptual ‘data-model fusion’ approach of integrating real-time pasture measurements with growth models.

There is potential that PFS PGR model would also benefit from localised meteorological predictions derived from on farm sensor networks. This current and forecast climate data could also be integrated with measures of underlying soil spatial variability to provide sub-paddocks scale predictions of feed growth (Donald *et al*., 2010).

The MLA Rainfall to Pasture Growth Outlook Tool is likely to provide a useful platform. Platzen *et al* (2011) reviewed the tool and concluded that a freely available support tool that provides pasture growth information through a simple and intuitive platform would be a useful addition to existing sources of information that are available to support decision making. They made a number of recommendations viz (1) updating with the Sustainable Grazing Systems (SGS) pasture model, (2) an updated web application, and (3) a customised email service to provide regular tailored updates.

The same outcome could be achieved by better utilising the ApSim/GrassGro models that are becoming the Australian standard common modelling protocol. In fact, activities are already in place to subsume the core components of the SGS pasture growth model into the ApSim framework.

Another approach is to use climate forecasts such as POAMA (Predictive Ocean Atmosphere Model for Australia). There appears to be a lack of industry confidence in the accuracy of these models for long-term forecasts, although they are greatly improved in recent years compared to recent models (Wang *et al*. 2011). A more thorough assessment of the accuracy and reliability of these models is required, and the feasibility of integrating them with production models to predict the growth and availability of feed at key times.

Cullen and Johnson (2012) report in their MLA study that producer feedback suggested seasonal rainfall forecasts are not accurate enough to base farm management decisions on, but that the pasture growth projections based on soil water content alone showed promise to improve decision making at key times in autumn and spring. They concluded that further research is needed to assess its value in farm systems decision-making and that POAMA forecast skill is being improved and further investigation of its role will likely be warranted in the future.

A more thorough review is required of the key decision points in different production systems and how they can be improved by provision of a feed prediction. These requirements then need to be aligned with the capacity of current forecasts and models to inform a development plan.

Given the accuracy and reliability of any feed prediction system will largely be reliant on the accuracy of climate forecasts, a watching brief needs to be maintained on forecast models such as POAMA.

Consideration also needs to be given to how a data-model fusion approach of integrating higher level modelling systems (e.g. POAMA with Apsim or SGS) with on farm sensor data and maps of underlying spatial variability can be used to improve feed prediction accuracy at the sub-farm scale.

6.4 Weed management

Technology for the precision control of weeds is available and being used in other industries such as the broadacre grains industry. Technologies such as WeedSeeker® and WeedIT work on the principal of detecting green plants in fallows, where bare soil is the background (eg between rows or crops or plantations), or in infrastructure such as pavements and roadways; when a green ‘signal’ is detected it delivers a spot spray of herbicide. Such a technology is directly transferrable to the grazing industries if the objective is to identify green weeds in an otherwise senescent or fallow paddock.

In a similar way, GreenSeeker® technology responds to different levels of ‘green’ (it actually measures NDVI) to deliver nitrogen applications. The underlying assumption is that NDVI is a measure of crop health and indicates the amount of nitrogen required to optimise yield.

The issue in pasture swards is reliably identifying green photosynthetically-active weeds in a green photosynthetically-active pasture sward. Sensors that use NDVI will not be able to detect green weeds in a green pasture sward. There is a body of work predominantly in the USA that has explored the use of more detailed optical reflectance information (predominantly hyperspectral imagery) for detecting infestations of invasive weeds. The key success criterion is the weed species of interest having a spectral signature that can be discriminated from the background sward. Studies clearly show that a knowledge of the biology of the system is critical so that this discrimination can be maximised at particular physiological states (eg flowering).

Two requirements for improved weed management are discussed below:

6.4.1 Weed infestation levels

A rapid assessment of the level of weed infestation is required to allow producers to make an informed decision whether to spot spray or spray the whole paddock. There are currently no known commercial remote assessment methods available.

Conceptually, it may be possible to use hyperspectral imagery (from any platform) to detect the presence and abundance of different plant species. The critical success factor would be the weed species of interest having a reflectance spectrum that is significantly different to the overall sward. A process called ‘spectral unmixing’ can be used to decompose any pixel in an image into a collection of constituent spectra (or ‘endmembers’), and a set of corresponding fractions, or abundances, that indicate the proportion of each endmember present in the pixel.

Several studies have shown the capacity to detect and map leafy spurge infestations using hyperspectral airborne and satellite sensors. Different sensors could detect infestations to varying degrees, depending largely on the spatial resolution of the imagery. The Hyperion satellite with a spatial resolution of 30m was unable to resolve infestations <500 m2 or mixed pixels with <35% leafyspurge. AVIRIS airborne imagery with a spatial resolution of 17m could map infestations of ~160m2, whilst the CASI (Compact Airborne Spectrographic Imager) with a 4-m spatial resolution could map infestations as small as $9m^2$ (Turner *et al*. 2003).

Further, Mundt *et al.* (2005) demonstrated the capacity for endmember analysis of airborne hyperspectral imagery to detect hoary cress weed infestations, reporting infestations were detectable with cover as low as 10%, but 30% hoary cress cover was necessary to produce accuracies useful for management applications. Lass *et al*. (2005) reported detection accuracies of known spotted knapweed and babysbreath infestations of 57% and 97% respectively using a limited-range airborne hyperspectral image.

Bryson and Sukkarieh (2011) reported that image recognition algorithms on UAV systems could distinguish some woody weeds (e.g. Prickly Acacia, Parkinsonia and Mesquite) from native farmland species in QLD. Further work was identified to be able to accurately discriminate between the weed species themselves.

These studies focus on the detection of invasive plant species, and it remains unclear if infestation levels could actually be quantified using similar approaches. Any system would need to eliminate or greatly diminish the need for paddock inspection.

The other approach is to monitor changes in growth (greenness) across time – this relies on the growth pattern of the weed species differing from the background sward, and hence will be species and time dependent.

6.4.2 On-the-go spot spraying

The weedseeker-type technology that is used in the broadacre grains industry (and other municipal uses) is directly applicable in fallows and senescent pastures.

The principals of these systems can be extended to green weeds in green swards however further R&D is required to explore whether particular weeds have a unique signature to the rest of the sward. NDVI will not have the capacity to do this; Hyperspectral/Near-infra-red spectra and UV-fluorescence may. For example, Longchamps *et al*. (2010) reported a 91.8% classification success rate in detecting both monocotyledonous and dicotyledonous weeds in a corn crop using UV-induced fluorescence.

The above discussion about hyperspectral imagery for infestation levels (Section 8.4.1) is also applicable here – having an *in situ* sensor mounted on a vehicle significantly reduces the field of view, thus allowing the 'scene' to be potentially classified to a particular reflectance signature.

Optical sensing systems used in the grains and municipal applications are directly transferrable to pasture-based systems where the issue is the management of green weeds in fallows or senescent swards.

There are currently no commercial systems available for automatically detecting and controlling green weeds in growing (green) pasture swards. Hyperspectral and NIRS technologies require proof of concept. The key success criteria will be the ability to differentiate the reflectance spectra of the weed species compared to the background sward.

It may be possible to use hyperspectral imagery to detect the presence and abundance (%) of different plant species, as an aid to early detection and to inform preferred management methods (eg spot spraying verses blanket application). This technique would also rely on being able to differentiate the spectral signature of the weed species in a timely manner. Some proof-of-concept has been established overseas but is required in our pasture systems.

6.5 Stock auditing & security

The obvious solution for stock auditing and security is being able to geolocate animals and having real time data analysis to identify an anomaly in location or behaviour that raises an alert.

Autonomous Spatial Livestock Monitoring (ASLM) technologies have been in development as a research tool for several years (Swain *et al.*, 2011). In recent years there has been significant private sector investment in systems focussed on delivering this technology to the commercial livestock grazier (Stassen, 2009; Andrews, 2010) using either GPS (e.g. Sirion and Wandering Shepherd) or terrestrial radio triangulation systems (e.g. Taggle).

A viable system for producers would entail a single life-time tag, affordable, durable, reliable, and delivering an easily implemented solution with demonstrable return on investment.

1. GPS-based systems:

   Current commercial GPS systems come as both tags and collars. GNSS (global navigation satellite system) collars are commercially available however the majority of these are targeted at research applications and cost well in excess of $2,000AUD. One manufacturer of GNSS collars (Hotgroup SA) has developed a collar targeted at producer use however these cost over $1,200 per unit and at this stage will only work within GSM (mobile phone) range.

   GPS based positioning ear tags have been developed within a research context (Schleppe *et al*. 2010) however these have only been used for very short deployment periods (weeks). There are other ASLM technologies being developed, most notable are the Sirion and Wandering Shepherd systems which both claim to be based on GPS positioning and satellite telemetry. These systems are likely to provide accurate location data but are yet to have a demonstrated presence in the industry perhaps due to the lack of a clear value proposition for producers to improve decision making from them (the focus of this report and recommendations).

   In Australia, CSIRO have developed a cattle collar for R&D purposes that is solar powered and appears to be able to run indefinitely sampling GPS location at approx once per second, collecting a number of data flows from inbuilt sensors, and fully integrated into a real-time sensor network.

   The key characteristics/differences between these systems are:
   - Size and weight – influenced largely by battery requirements.
   - Cost.
   - Some simply store location data on the device for download at a later time (may be applicable for auditing applications), others transmit the location in real-time (necessary for theft and predation alerts).
   - Spatial accuracy – influenced by the quality of the GPS and the length of time the device is left on to determine its location (longer sampling times increase accuracy).
   - Power consumption and battery life – Higher sampling rates (times per second the device seeks to determine its location), and transmission of data remotely increases power consumption and reduces battery life. Some systems can be remotely programmed to change their sampling rates etc.
   - Operational life of the device – the length of time the device operates without changing batteries is largely determined by the batteries themselves, the sampling rate, and the data transmission requirements.
2. Tower triangulation systems
   These systems work using an ear tag which acts as a radio beacon emitting a radio pulse. This pulse is detected by stationary towers that are strategically located

around the property. The time of flight of the radio pulse to each tower is recorded and the position tag is triangulated. A minimum of 3 towers are required to enable triangulation however 4 towers provide a more accurate positional solution.

These require a higher initial investment for the towers but currently a lower per-tag cost. For example Taggle currently have an ear tag available for cattle (22grams) but none for sheep. Each tower costs approximately $4,000 and each ear tag is likely to cost around $20 depending on overall uptake. The spatial accuracy of this system is potentially lower than GPS, and whilst sufficient for detecting animals have moved off the property, it may be limited for identifying changes in behaviour due to imminent predatory attack.

The towers may provide additional services including short data streaming from low power sensors. These could include simple soil moisture probes, temperature probes and other devices such as “gate open/closed” and “vehicle crossing grid” alerts. Depending on the geographical and landscape attributes over which the properties extend, and the density of properties in a region, is it possible that cooperating producers with neighbouring properties could share infrastructure (towers) to reduce the initial capital expenditure.

6.5.1 Stock auditing requirements

For auditing purposes alone, technology for geolocating animals is the primary requirement along with software integration to bring stock location into farm management software. There is less requirement for real-time transmission of location, and could operate at a coarser spatial resolution with less frequent sampling. Less data analysis is also required, because the critical information is location x time.

6.5.2 Stock theft & predation

For theft and predation applications, there is an additional requirement for both real-time data acquisition and analysis. The analysis would need to constantly monitor animal location and be able to detect when there is an anomaly that may indicate a threat to the herd/flock (eg animals suddenly congregate). The number of false positive alerts would need to be minimised. Such analysis would require much greater sampling frequency and spatial resolution. It is unclear to what extent the location data alone would be sufficient, and whether it requires other behavioural information, however it is likely that the additional behavioural information would provide for a more robust and reliable system.

Anomaly detection has been researched within diverse research areas and application domains such as fraud detection for credit cards, insurance, health care, intrusion detection for cyber-security, fault detection in safety critical systems, and military surveillance for enemy activities (Chandola *et al*. 2009). A key criteria here is the processing of data as it arrives and the incremental updating of the model (rather than requiring the entire test data before detecting anomalies). ‘Complex systems science’ approaches should be investigated to allow interrogation of multiple system components and their interactions (Bronstein *et al*. 2001).

Immediate adoption of commercial GPS systems is constrained by the price (too high for fitting on all animals in a herd/flock), battery-life expectancy of the devices, but also the lack of an easily implementable system that has demonstrable value proposition. In the future, the preferred outcome is that location tags will be integrated with NLIS or other behavioural tags to reduce cost/labour.

The gaps that require addressing are:

1. Getting the underpinning technology to a stage that it is affordable, lifelong, and spatially-accurate.
2. Developing and proving the data analysis processes that extract reliable alerts from location and behaviour data.
3. Establishing the value proposition for specific applications for different key stakeholders.

Stock auditing can be achieved with relatively coarse-scale location data. It does not require high sampling frequency, high spatial resolution, or constant data transmission.

In comparison, theft and predation applications require higher spatial resolution and constant monitoring (during times of threat). It is also likely to require a combination of location and behaviour data. The key will be establishing what change in location and/or behaviour signifies a threat.

The value in location/behaviour monitoring technology is beyond a single application such as auditing, and hence the recommendation is to consolidate these applications into an integrated program of applied work.

Anomaly detection and complex systems science techniques should be investigated for on-line data processing and interrogation of multiple system components.

6.6 Dam – Offspring and Sire – Dam association

Potentially, the physical association between two animals can be detected using both GPS and proximity loggers.

Proximity loggers are devices that are fitted to both animals and can detect the number of times, and duration, that animals come into a certain distance of each other. They are commercially available from companies such as Sirtrack (NZ), but generally not priced currently for deployment on large numbers of animals. They reportedly have sub-10m accuracy but the inter-animal distance that is recorded as an encounter can be adjusted by varying the transmission power setting of the device. Swain and Bishop-Hurley (2007) used them at a 7m contact range and concluded that they have the potential to provide useful data on animal affiliations such as cow-calf interactions to identify maternal parentage, behaviour, mismothering and neonatal survival.

Rather than purpose-built proximity loggers, the same capacity can be provided in ear-tag systems that utilise a radio-transmitter to communicate over a network. The transmission power of the radio transceiver can be adjusted in software, bringing the level down to a point that you know has a short range and broadcast some kind of "contact" radio packet. When another animal detects that signal, the information is logged.

GPS technology can also achieve the same spatial accuracy as that reported for commercial proximity loggers. However, some off-the-shelf commercial GPS offerings are programmed to conserve battery and as a result do not achieve a spatial accuracy sufficient for evaluating the association between animals.

Pedigree MatchMaker is a currently available walk by system with associated software that uses animal RFID data to estimate association between dams and their lambs, and ultimately provide an accurate pedigree match. It is estimated to cost between $3-$4 per lamb. Pedigree is determined by association – as animals pass a reader, the time-ordered sequence of tags is recorded and the parentage is predicted by observing the frequency of certain ewe and lamb associations/combinations. Four to six weeks of recording is recommended for predicting pedigree (90-96% accuracy). This compares to recording for just one week which reportedly has 70-80% accuracy, for two weeks 80-92%, and three weeks 85-95% accuracy. Set-up cost is $3500 for a basic system up to approx $9500 for a fully remote system. Associated fencing/yard infrastructure is required and sheep must be trained to use the system.

The potential advantage of using ear-tag, GPS and/or proximity technology is that no additional infrastructure is required, sheep would not require training as data is collected as sheep naturally roam paddocks, and should have the same level of accuracy in the association data but over a shorter period of time. Having an integrated tag with multiple technologies and applications would enable a single mustering for tagging, and drive down cost for any given outcome.

There are some commercially available systems (e.g. Pedigree MatchMaker) to determine ewe-lamb association. Proximity loggers as a standalone technology may be used to obtain data on animal association, but are currently priced more towards R&D applications and wildlife uses.

An investment in a GPS-based technology or radio-enabled ear tag would provide the same capability and underpin a range of additional applications.

The key R&D requirement is to determine what frequency of contact and proximity measures accurately define association between dam-offspring and/or sire-dam for pedigreeing and conception data applications respectively.

6.7 Animal disease identification

The detection of subclinical disease using continuous monitoring technologies can be categorised according to (1) the detection of specific diseases, and (2) monitoring of parameters that are symptomatic of one or more disease states.

6.7.1 Biosensors for detecting specific diseases

The concept of detecting specific diseases using biosensors was explored in 2005 by the Australian Biosecurity Cooperative Research Centre for Emerging Infectious Disease. They conducted a scoping study to assess the availability of biosensor technology platforms specifically for use as implants in animals to detect either pathogen or anti-pathogen antibodies (Parkinson and Pecjic, 2005). They found that there were no biosensor technologies at a stage of development that would permit their experimental application to detect pathogens or anti-pathogen antibodies, either *in vitro* or *in vivo*. At that time, a decision was made by the CRC to not proceed with the development of biosensor platforms. To our knowledge, no significant advances have been made in this area.

6.7.2 Monitoring symptoms of disease

Symptoms of disease state can take many forms, particularly if metabolic disorders and nutritional imbalances are included. The difficulty is that any given parameter may have multiple underpinning causes, so at best will indicate that an animal is somehow compromised and will require further investigation. Such parameters include rumen health (eg pH, temperature, pressure) and animal behaviour (eg changes in ruminating, walking).

6.7.2.1 *Rumen monitoring*

There are several intra-ruminal devices commercially available for livestock. They are predominantly for measuring rumen temperature, pH and pressure using an indwelling device that wirelessly transmits data to a receiver. Examples include:

- SmaXtec Animal Care pH bolus
- E-cow rumen analyser (pH, temperature, Redox)
- Kahne rumen sensor (pH, temperature, pressure)
- SmartStock rumen temperature bolus

There is also a significant effort between collaborating Australian RDCs, including MLA, into the development of a rumen bolus for measuring methane led by CSIRO.

The key technical constraint currently with the commercial devices is longevity – they are reportedly accurate for up to 40-50 days before losing accuracy (eg Phillips *et al* 2010). Commercial companies appear to be investing in improving the life of the devices.

Evidence does suggest a relationship between rectal temperature (a key veterinary indicator of illness) and rumen temperature (e.g. Bewley *et al*. 2008B), and that rumen temperature boluses are able to detect animal health events in feedlots such as exposure to bovine respiratory disease (e.g. Timsit *et al*. 2011) and bovine viral diarrhea virus (e.g. Rose-Dye *et al*. 2011).

A key knowledge gap in implementing these devices is understanding the biological significance of the signal. All the studies above indicate that parameters such as rumen temperature can indicate a range of underlying causes (eg the animal drinking) and would require further clinical examination, however they may assist in early detection. Further effort is required to understand how specific applications can be extracted from these data streams given the potential variability of the information.

For many health issues, there are other parameters that would be more directly applicable, such as specific volatile fatty acids (VFAs) for acidosis, and skin temperature for heat stress.

There is a case for including intra-ruminal devices in key projects to better understand the variability and response to different management and environmental conditions. A watching brief should be kept on commercial technology developments. If the MLA (and other RDC) investment in the CSIRO *et al*. bolus proves successful in terms of the platform technology, it should be immediately expanded to include key rumen health parameters such as pH and temperature, and consideration given to key nutritional parameters (eg VFAs). This is an area identified for cross-RDC investment.

6.7.2.2 *Animal behaviour monitoring*

The application of animal behaviour monitoring to detect animal health events is well established (Frost *et al*. 1997). As discussed above for the intra-ruminal devices, the monitoring of animal behaviour can be caused by a number of factors and at best can identify an animal (or animals) that require further interrogation.

There are commercially available systems, predominantly in the dairy industry where the value of an individual animal is high. For example, the SCR™ HR-Tag™ (also marketed through Lely and MilkLine) contains a motion sensor and microphone that is marketed to be able to detect a cow's rumination time, chewing rhythm and time between feed swallows as well as a “general activity index which quantifies all animal movement and movement intensity (walking, running, laying, standing up, head movements etc)”. Applications are reported to be detecting a loss in appetite as a result of eating too much concentrate per kilogram effective fibre, is in heat, or is suffering from sub-clinical ketosis, acidosis or mastitis. The only peer-reviewed publications we found validating these technologies reported rumination times to be correlated with visual observations with R^2 of between 0.77 and 0.87 (Burfeind *et al.* 2010; Schirmann *et al*. 2009).

Acoustic monitoring more generally has been shown to be effective in monitoring chewing behaviour, which has then been used to estimate intake – Galli *et al.* (2011) reported chewing behaviour to account for 92% of the variation in dry matter intake of grazing sheep, and similarly, Laca and WallisDeVries (2000) reported 90% of the variation in intake of grazing cattle.

In beef systems, Guo *et al*. (2009) demonstrated a capacity to model individual animal movement and behaviour using individual animal monitoring technology (accelerometer, high sample rate GPS and magnetometer data). Although the study did not attempt to derive any animal health indicators, it did demonstrate a capacity to monitor individual animals *in situ* at a high temporal frequency.

Potentially, detecting a change in an animal’s behaviour or state in a dairy or feedlot system is easier than in an extensive sheep or beef grazing system because in the former the animals are exposed to a more consistent plane of nutrition (both direct grazing and supplementary feed intake) which allows a baseline to be established and any anomaly from the ‘norm’ detected. It is this variability in extensive beef and sheep systems that requires further understanding, and smart informatics approaches developed, to extract useful knowledge about an animal’s physiological state.

As discussed above in animal security (Section 8.5.2), anomaly detection has been researched within diverse research areas and application domains. For animal health application, the data must be processed as it arrives and the model incrementally updated. 'Complex systems science' approaches may allow multiple system components to be interrogated in near real-time (Bronstein *et al*. 2001).

There is technology to monitor the behaviour of individual animals as an option for detecting anomalies as indicators of animal health. The key challenge will be accurate detection of a behavioural 'anomaly' amongst a potentially highly variable background. Anomaly detection and complex systems science techniques for on-line data processing and interrogation of multiple system components should be considered as part of the technology development.

Given there may be a number of underlying causes of this anomaly, the outcome would be early identification of animals requiring further investigation.

This underpinning technological capacity for monitoring animal behaviour is discussed further in Section 9.2 in the context of how it can be used utilised across multiple applications.

6.8 Individual animal production monitoring – Liveweight & Body Condition

The focus of this discussion will be on remote/automated measurement of liveweight and body condition. Manual weighing systems are currently available but this requires stock to be brought from paddocks to yards and is a limitation to regular stock monitoring.

6.8.1 Weighing systems

There is enough evidence to suggest that remote weighing systems can be used to accurately measure individual and herd liveweight of cattle under both walk-over and walk-in systems. Charmley *et al*. (2006) were one of the first authors to assess a remote weighing system in beef cattle under grazing conditions using a walk-in design where animals entered the weighing platform and stayed on it while drinking water. Authors found a high correlation (R^2 = 0.92) between the remote system and ground scales (conventional) although weights were 20kg lighter in the remote system; importantly, the weight change rate was similar among them.

Alawneh *et al*. (2011) found an almost perfect accuracy (r=0.99) to measure liveweight in dairy cows using the Tru-Test XR2000 WOW placed in the race at the exit of the milking parlour and controlling cow flow. These authors recommended to measure day-to-day changes in weight to detect health problems and oestrus whereas they recommended the change in weight over 7-d periods to detect nutritional responses and adjust feeding programs. More recently, Brown *et al*. (2012) have used the Tru-Test WOW system in sheep to assess the value of mob-based walk-over weighing (no reader panel and RFID ear tags needed) compared to individual LW. They reported an R^2<0.89, concluding it was sufficient to aid with the nutritional management of the mob. It is important to note that all these studies have developed algorithms to filter the data from outliers and approximate to the 'real weight' as close as possible.

Another key conclusion for most of these systems is that a single weight should not be used with any great reliance in isolation from previous readings for that animal. For example, Alawneh *et al*. (2011) recommended that liveweight be recorded daily but for managerial purposes (eg for adjusting the herd feeding program) that a 7-day decision interval be used to effectively monitor significant changes in liveweight. This may not be as significant an issue if the objective is to understand whether or not animals are in a positive or negative energy balance early enough to intervene. Further, accuracy is increased if more frequent measurements can be acquired (Richards *et al*. 2006).

Several companies around the world are currently marketing automatic weighing systems (e.g. Tru-Test, Gallagher, Growsafe, S.A.E, etc). However, the most important lack of these systems is the application of such technologies to make them work in a friendly and useful fashion for the producer. Further research and development in this area is needed in order to get the most out of these systems.

Recently (June 2012), the Sheep CRC called for expressions of interest for the development and commercialisation of an integrated walk over weighing system for sheep. The CRC has developed and tested the proof of concept and has the necessary software for data management. The next step is to develop a cost-effective weighing system with integrated software and data storage that will provide a simple 'turn-key' solution for sheep producers.

The CRC for Remote Economic Participation (CRCREP) currently has a project focussed on developing a remote WOW with data streaming to an interface that integrates with remote sensing data. Whilst the WOW platform is well developed the data presentation and remote sensing integration platform remains in its infancy.

Our conclusion is that technology is currently being developed for automatic and remote weighing of livestock and no further investment on the technology *per se* is required. However there is a lack of clear standard operating procedures for how to analyse individual weights over time to generate accurate individual animal data with known errors. Any further development should focus on developing these guidelines (including implications for accuracy) as well as defining applications of the technology, and establishing the value proposition. Value-adding to the liveweight systems with remote assessment of body condition score is warranted as discussed below.

6.8.2 Body condition score

There is a body of scientific literature exploring the use of image analysis for automatic objective measurement of body condition score in a range of livestock species including cattle, buffalo and pigs. The conclusions of this work are that digital imaging systems appear to have application for measuring key anatomical characteristics but are not yet robust enough to reliably acquire BCS assessments. Bewley *et al.* (2008A) applied digital imaging to assess BCS in dairy cattle and concluded that although there was a clear relationship between angles calculated by using digital images and BCS, this relationship may or may not imply a relationship with actual body fat content. Krukowski (2009) demonstrated the potential of 3D images to assess BCS of dairy cows, but reliability decreased significantly when tested on an independent validation set. Coffey *et al*. (2003) surmised that any system that uses shape to assess body condition may be prone to error because the protrusion of bones on a cow may not necessarily mean she is thin.

There is currently a proof-of-concept project funded by MLA investigating the use of image analysis to estimate P8 fat and muscularity. The ability to measure frame size has been proven (McPhee *pers comm*.). Both Bewley *et al*. (2008A) and Krukowski (2009) note the errors caused by lighting, photo angles and changes in cow posture using digital and 3D imaging, which may make it difficult to extend these technologies from saleyard (more controlled environments) to in-paddock/remote applications. An alternative approach using laser scanners would actually quantify the structure of the animal, and is less likely to be subject to such errors.

Laser scanners are commodity items commonly used by the surveying industry to make three-dimensional maps of infrastructure (e.g. roads and buildings). The 2D laser scanner is typically spun while mounted on a tripod and the laser is swept over a scene. The advantage of using laser scanners over imaging (where the imaging uses cameras) is that a laser scanner measures the structure of the object it is viewing directly - i.e. it measures the range and bearing to physical objects. In imaging, these measures are inferred from the image (pixels) and hence are subject to many potential sources of error. Imaging is susceptible to challenging lighting conditions and the actual visual content of the scene (i.e. some objects being imaged may not be easily seen due to their texture being too similar to that of the background or to them having not enough texture to observe).

Because of the added complexity of wool in sheep systems, it is difficult to see how any of these techniques can be directly applied to sheep except when immediately off-shears. However this constrains its use for regular monitoring. There may be associated body shape/form measures that are related to condition, but this requires further investigation.

There is currently an MLA investment exploring the development of an imaging system for P8 fat and muscularity in cattle. Consideration should be given to exploring the use of a laser scanner system as it actually quantifies the structure of an animal surface directly and may be more robust for in-paddock applications.

6.9 Summary of best-bet technological solutions

The table below (Table 5) summarises each on-farm application and the ‘best-bet’ technological solutions available. Comments are provided to put the technologies into context.

***Table 5**. Key technologies as they align to identified on-farm needs.*

Issue/Need	'Best-bet' technology solution	Comments
Soil Fertility	Zonal variable rate analysis using integrated soil, plant & animal spatial data sets.	• Direct measurement of soil nutrients using on-the-go sensors remains an ongoing challenge with few suitable tools available for pastures. • More immediate solution is zone based variable rate application but the key challenge is understanding how these spatial datasets can be integrated and useful information extracted that actually predicts soil constraints to production.
Feed Allocation	• Pasture biomass - Range of indirect sensors applicable, from hand-held, vehicle, airborne and satellite platforms.	• Compared to pasture growth rate or quality, priority is the quantitative measurement of pasture biomass - these technologies are at, or closer to, market and can be used independently of growth rate and quality for improved feed allocation. • There is unlikely to be one single technology for measuring pasture biomass that meets the needs of all systems and user requirements. They all require calibration across seasons, pasture types and regions. A regionally-based R&D program can simultaneously calibrate & validate several technologies, ensure they are integrated into supporting farm management software, and allow producers to tailor a solution to their own needs.
	• Pasture quality – NDVI optics and hyperspectral/NIRS sensing	• NDVI-type indices are likely to be less reliable than hyperspectral and NIRS sensing where there is some proof-of-concept in different vegetation types. There is an opportunity to explore which specific wavelengths within the full spectral signature most accurately estimate quality parameters, and then use those specific wavelength filters in more simple active optical sensors for implementation. • Faecal NIRS could be used to estimate diet quality but requires extensive animal experimentation, and will only provide retrospective information on diet selected and not information on current pasture quality. • Analytical accuracy and reliability needs to be established in relevant pasture types. • A commercially-available business model is likely to be more than 5 years away given R&D requirements, current technology availability and cost, and satellite deployment.

Pasture Yield Mapping	Pasture biomass (above) plus animal location and behaviour to derive estimates of intake	• Builds on the quantitative measurement of biomass required for improved feed allocation, but also requires spatial estimates of pasture removed by animals. That estimate of pasture intake may be derived from animal location and behaviour monitoring (ie eating and ruminating behaviour) but requires proof-of-concept. • Benefit unlikely to be realised within the next 5 years.
Feed Prediction	Data – model fusion to integrate real-time pasture sensing with predictive models	• A data-model fusion approach of integrating higher level modelling systems (e.g. Apsim, SGS) with on farm sensor data and maps of underlying spatial variability holds potential to improve feed prediction accuracy at the sub-farm scale. However the accuracy and reliability of any feed prediction system based on climate forecasts will be reliant on the accuracy/skill of that forecast. • A watching brief should be maintained on the skill level of the climate forecasts so action can be taken when it is sufficient for producers to make management decisions; 70% accuracy is commonly cited as the minimum accuracy required for farmers to have confidence in a forecast (Ash *et al* 2007). • A more thorough assessment is warranted to clearly articulate the feed prediction requirements for key decision points – the timing requirements, accuracy and how far into the future the prediction needs to be.
Weed Management	• Green weeds in fallows and senescent swards – some commercial optical sensing technologies available for spot-spraying. • Green weeds in green swards - Hyperspectral remote sensing and NIRS signatures conceptually applicable	• Optical sensing systems used in the grains and municipal applications are directly transferrable to pasture-based systems where the issue is the management of green weeds in fallows or senescent swards. • There are currently no commercial systems available for on-the-go detecting and controlling green weeds in growing (green) pasture swards. Hyperspectral and NIRS technologies require proof of concept. The key success criteria will be the ability to differentiate the reflectance spectra of the weed species compared to the background sward. • It may be possible to use hyperspectral imagery from remote platforms (eg airborne, satellite) to detect the presence and abundance (%) of different plant species, as an aid to early detection and to inform preferred management methods (eg spot spraying verses blanket application). This technique would also rely on being able to differentiate the spectral signature of the weed species in a timely manner. Some proof-of-concept has been established overseas.

Stock Auditing	Animal location data	• Can be coarse- or fine- scale location data. Does not require high sampling frequency, high spatial resolution, or constant data transmission.
Stock Security	Animal location data – fine scale Animal behaviour data	• Compared to stock auditing requirements, theft and predation applications require higher spatial resolution and constant monitoring (during times of threat). Likely to require a combination of location and behaviour data. The key will be establishing what change in location and/or behaviour signifies a threat. • Anomaly detection and complex systems science techniques for on-line data processing and interrogation of multiple system components have been used in a range of other domains (outside of agriculture) and should be considered here.
Dam-Offspring & Sire-Dam Association	• Existing pedigreeing systems (eg pedigree matchmaker, DNA analysis) • Animal tags using radio-transmission capability • Animal location data using GPS or triangulation systems • Proximity loggers	• There are some commercially available systems (e.g. Pedigree MatchMaker, DNA analysis) to determine dam-lamb association. • Proximity loggers as a standalone technology may be used to obtain data on animal association, but are currently priced more towards R&D applications and wildlife uses. • An investment in a GPS-based technology or radio-enabled ear tag would provide the same capability as proximity loggers but would also underpin a range of additional applications. • The key R&D requirement would be to determine what frequency of contact and proximity measures accurately define association between dam-offspring and/or sire-dam for pedigreeing and conception data applications respectively. Note that this has been done with Pedigree matchmaker for offspring-dam association but this technology requires stock to be trained and the data has to be recorded for 6 weeks to ensure accurate data. Where monitoring does not rely on animals passing by a sensor, that data could be collected quicker and with no training. For sire-dam association, there is no process (other than raddles).
Animal disease detection	• Intra-ruminal devices (& potentially other implants) • Behaviour & location monitoring	• Whether its intra-ruminal monitoring or behaviour, both systems require understanding natural variation and what anomaly in the parameter(s) signifies a physiological event. The need for on-line data processing and interrogation of multiple system components necessitates advanced informatics techniques such as anomaly detection and complex systems science.

		• A watching brief should be kept on commercial development of intra-ruminal devices. If the MLA (and other RDC) investment in the CSIRO *et al*. bolus proves successful in terms of the platform technology, it should be expanded to include key rumen health parameters such as pH and temperature, and consideration given to key nutritional parameters (eg VFAs).
Individual Animal Production Monitoring	• Liveweight – walk-over weighing systems • Body condition score – imaging and laser scanners	• Technology is currently being developed for automatic and remote weighing of livestock and no further investment on the technology per se is required. However effort is required to develop clear standard operating procedures for how to analyse individual weights over time to generate accurate individual animal data with known errors. • Current investments into image analysis for measuring body condition (P8 fat and muscularity) require a watching brief, but consideration should be given to evaluating laser scanning technology. • For both technologies, industry requires clear guidance on applications, integration into management software such as BeefSpecs, and demonstrable value proposition for adopting.

Figure 4 shows how each technology contributes to different applications.

From Table 5 and Figure 4, there are some clear recommendations on clusters of technology that have outcomes for most applications:

1. Pasture biomass technologies
    a. Have direct application for soil fertility, feed allocation, pasture yield mapping and feed prediction
    b. Can inform the interpretation of other precision technologies that monitor animal parameters (eg location, behaviour, rumen, liveweight and condition)
2. Pasture quality technologies:
    a. Have direct application for feed allocation
    b. Are a desired input into soil fertility, and feed prediction
    c. Can inform the interpretation of other precision technologies that monitor animal parameters (eg location, behaviour, rumen, liveweight and condition)
    d. Conceptually applicable to weed detection and management
3. Animal location (fine-scale) and behaviour (eg eating, ruminating, resting) technologies:
    a. Can be applied directly to stock auditing and security, animal association, and animal health applications
    b. Are required for pasture yield mapping
    c. Are a desired input into soil fertility
4. Intra-ruminal monitoring
    a. Direct applications for animal health outcomes
    b. If the platform technology can be extended to incorporate key nutritional indicators, then it also has direct application for optimising nutrition and animal production outcomes.
5. Individual animal (liveweight and condition) monitoring has direction application for animal production outcomes.

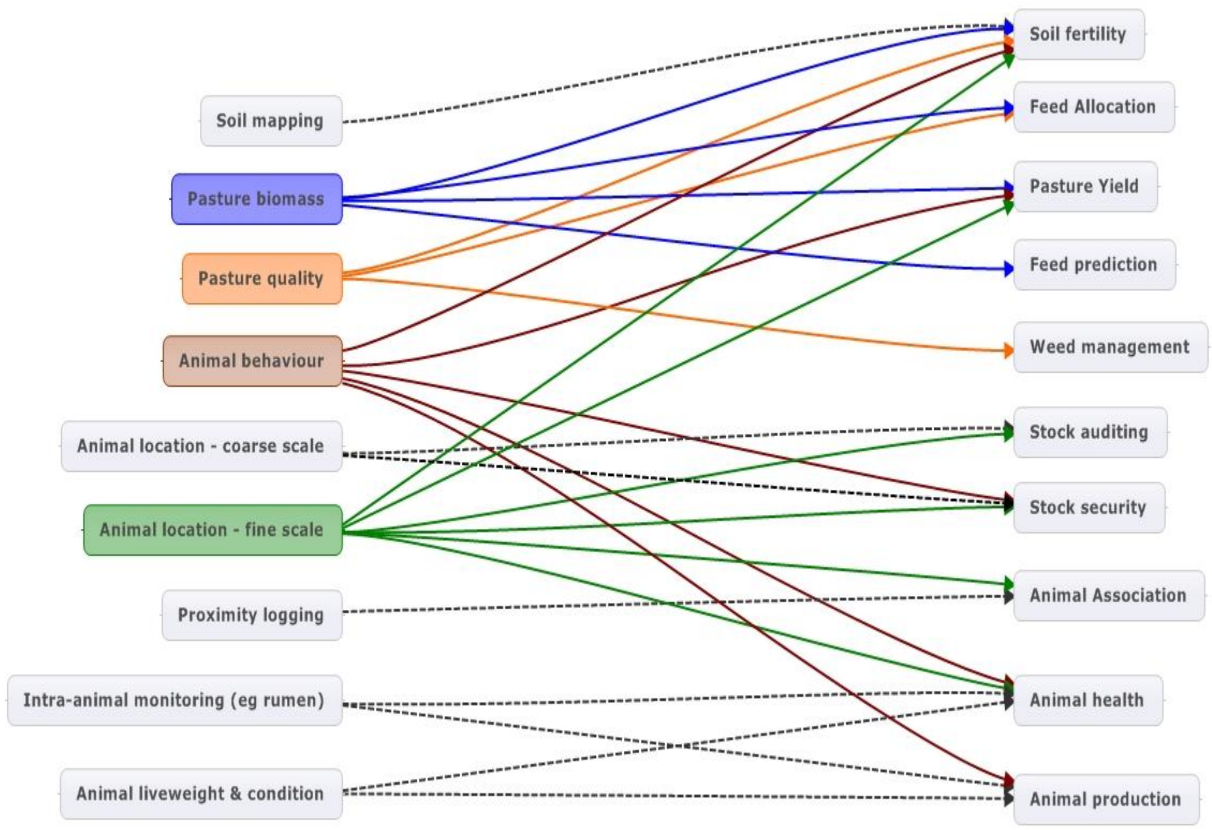


Figure 4. *Diagrammatic representation of how technologies (left hand side) may contribute to identified on-farm needs (right hand side). Solid coloured lines show technologies that align with 3 or more applications.*

7. Underpinning precision livestock technologies for multiple applications

7.1 Pasture biomass & quality for soil fertility, feed allocation, feed prediction, pasture yield mapping

As discussed above, the capacity to measure and monitor pasture biomass and quality can lead to several applications. For applications such as feed allocation, the parameter (eg pasture biomass) has direct application and relevance, but for some there are additional information or data analysis requirements. With a focus on achieving each desired outcome, Table 6 describes the additional data and analysis requirements

Table 6*. The additional data and R&D requirements to achieve desired outcomes for which pasture biomass and quality are underpinning technologies.*

Application	Underpinning technological capacity	Assumption	Other information required for implementation	R&D requirement
Soil fertility	Pasture biomass	That biomass is related to underlying soil fertility. In grazed paddocks, require estimates of animal intake	• Other plant/soil characteristics that define soil fertility zones • In grazed paddocks, animal location and behaviour data	• Understanding which spatial datasets, and how they are interpreted, relates to soil fertility • How do we interpret animal location and behaviour data that adds to our prediction of soil fertility • Designing clear management guidelines from spatial datasets
	Pasture quality	That nutrient concentrations of pasture are related to soil nutrient concentrations	None	• Understanding whether plant nutrient concentrations relate directly to soil nutrient levels • Does integrating pasture quality with other plant , soil and animal datasets improve our prediction of soil fertility
Feed allocation	• Pasture biomass • Pasture growth rate • Pasture quality	Direct application for feed allocation	None	• Developing reliable and robust calibrations of different technologies across seasons and regions • Integrating information flows into user-friendly decision support systems
Pasture yield mapping	Pasture biomass	That in addition to accurate measures of pasture biomass, the proportion of pasture consumed/ removed by livestock can be estimated	• Animal intake estimates (spatial) derived from location and behaviour data • Biomass and quality values also likely to inform animal intake estimates	• Requires calibrated biomass technology • Determining whether animal location and behaviour data can be interpreted to give estimates of pasture removed by animals on a spatial basis.
Feed prediction	Pasture biomass	That climate forecasts and/or algorithms for forecasting pasture growth are accurate	• Models of pasture growth • Climate forecasts	• A data-model fusion approach of integrating higher level modelling systems (e.g. Apsim, SGS) with on farm sensor data and maps of underlying spatial

Application	Underpinning technological capacity	Assumption	Other information required for implementation	R&D requirement
				variability. • Determination of the accuracy and reliability of the feed predictions at different times and temporal scales. • Targeted review that considers modelling options in the context of key decision points and specific requirements for feed prediction information (informed by current MLA project by Rogan *et al*.)
Weed management	Pasture quality (optical)	That NIRS/Hyperspectral signatures of weed species can be adequately distinguished from background sward	None	• Proof-of-concept that spectral signatures of weed species can be sufficiently differentiated from the background sward in the context of both on-the-go spot spraying and broad-scale weed detection and infestation estimation.
Animal behaviour applications	• Pasture biomass • Pasture quality	That pasture characteristics (quantity and quality of feed consumed) influence the behaviour of animals	Animal location/behaviour data	• Determining how the animal location and behaviour parameters are influenced by the pasture characteristics with a view to better understanding the variation in, and the implications of, animal monitoring information.
Intra-ruminal monitoring applications	• Pasture biomass • Pasture quality	That pasture characteristics influence rumen parameters of interest	• Animal location • Rumen parameters	• Determining how the intra-ruminal parameters are influenced by the pasture characteristics with a view to better understanding the variation in, and the implications of, rumen monitoring information.

7.2 *Animal location & behaviour for pasture yield mapping, disease detection, associations, stock security*

An underpinning capacity to monitor the location and behaviour of animals would facilitate several applications including improved feed allocation, early detection of animal health, sire-dam and dam-offspring associations, pasture yield mapping and stock auditing and security.

There is a significant amount of investment is being made by the private sector into developing Autonomous Spatial Livestock Monitoring (ASLM) technologies (see Section 8.5) however it is largely focussed on location metrics and in many cases it is not the primary focus of the business. Sirion, for example, is a large multi-national satellite communications company of which livestock tracking takes up less than 1% of its current business development. Similarly Taggle Systems have a focus on water system monitoring and the ASLM component of their business is a small part.

The only commercial livestock behaviour systems to our knowledge are the SCR HR Tag (also sold as the Lely Qwes tag), Afimilk Pedometer Plus and IceRobotics Cow Alert (powered by the IceCube monitoring sensor). These are all generally based around dairy systems, and aim to detect oestrus and/or early detection of sub-optimal performance. The SCR HR Tag has a motion sensor and uses an analysis of sound to identify regurgitation and rumination. Data can be downloaded at each milking so data only needs to be stored in memory for less than 24 hours; data is collected in 2-hour blocks, constant remote monitoring and transmission of data is not required, and location is not provided. The IceRobotics Cow Alert System uses a 3 axis accelerometer to monitor animal behaviour and provides similar information as the SCR HR Tag. It is not clear exactly what sensor is used in the Afimilk Pedometer Plus, however like the other two sensors it primarily monitors activity. The SCR HR Tag, Afimilk Pedometer Plus and the Cow Alert System have been primarily designed to detect oestrus in dairy cows (Holman *et al*. 2011) however there is some evidence on the distributors websites that producers are also using them for disease detection.

Whilst direct investment in the development of location technologies is not required, it is the integration of location and behavioural information that has substantial opportunity and warrants exploration. In Australia, and globally, CSIRO is a leader in the development of an integrated tag-solution that combines accelerometers, magnetometers, audio (including ultrasonics), optical sensors, pressure sensors, radio-transmission and potentially location. It is such an integrated capacity that has the potential to underpin real-time animal monitoring applications. Any investment in the technology however should be a multi-disciplinary approach that drives at specific outcomes and marries the data and interpretation requirements with technology hardware and software development.

The previous discussion on pasture monitoring techniques demonstrated that in addition to specific applications that can be derived from the information in isolation (eg feed allocation), that it was actually a building block for a range of applications that required other supplementary information. The animal location/behaviour technology is different – for most applications what is required is the core data and then targeted data analysis and interpretation to derive different outcomes.

For stock security (both predation and theft) and animal health applications, the common underlying assumption is that changes in the location and/or behaviour of stock could be detected in a timely manner to provide an early warning system. The key R&D requirement is understanding the variation in animal location & behaviour and evaluating if anomalies reliably indicate the event of interest. It is unlikely to require actual quantification of traits, but rather detection of a deviation from the ‘normal’. A constant monitoring system would then need to be developed if the data acquisition and analysis processes were sound. Any requirement to adjust the location/behaviour information based on the state of the environment could also be provided by in-built sensors or by integration with other vegetation or environmental sensing.

Animal association applications would utilise the radio-transmitter on the same system. The underlying assumption would be that contact between two animals within a certain distance and with a certain frequency is related to their pedigree or indicates conception. The R&D requirement is to determine the measurable frequency and proximity metrics that accurately define association between dam-offspring and/or sire-dam.

Stock auditing would only require the location monitoring capacity, integrated with farm management software.

7.3 Ability to autonomously control location and movement of stock

The above sections on pasture and animal monitoring describe underpinning technologies that in their own right offer significant benefits. The application of this technology will rely in part on the ability to manage stock around different parts of the paddock and property in a timely manner. The dairy industry often allocates pasture more precisely to optimise pasture utilisation as well as other complementary feeds, but this also comes at a cost of increased labour input, with animals in an intensive paddock rotation..

There are products on the market to automatically move electric fences in intensive systems. In Europe, Lely markets a robotic fencer that can be programmed to allocate pasture as required, but because it physically moves a hard-wired electric cable it is not readily applicable to large paddocks (larger than small dairy paddocks), paddocks with trees or very undulating landscapes.

The ability to remotely control the location and movement of stock without physical fences has been hypothesised since the early 1970s. In a recent review of virtual fences (VF) by Umstatter (2011), it was concluded that in order to reach the stage of a marketable product the most urgent issues are the limitation of energy supply to keep the system running, and development of a system which ensures safety and animal welfare. Australia and the USA are leaders in virtual fencing R&D.

This technology would enable pasture supply and demand to be matched at any spatial and temporal scale. However, this may also require changes in both infrastructure and management before these benefits can be realised. It may be that autonomous animal control would not be 100% effective and therefore may not be suitable when absolute control is required (eg a boundary fence adjacent to a road). Some animals may be unsuitable for these systems due to their behaviour and may need to be excluded from the herd.

CSIRO have developed a prototype autonomous animal control system and successfully demonstrated its use on herds of beef cattle (Bishop-Hurley *et al*. 2007, Ruiz-Mirazo *et al.* 2011). Tests have shown that, in less than one hour, cattle learn to associate an audio cue from their collars with, and avoid, the virtual boundary, and that animals are not unduly stressed by the method of control. Studies have also indicated that it may be possible to control an entire herd by fitting devices only to leader animals. The main technological challenges of power consumption and interfacing the devices with the animals are still to be resolved, but the solutions are likely to be similar to those for animal location and behaviour monitoring systems. These include more efficient storage and GPS solutions, solar and kinetic energy sources, duty cycling (turning the device off when not required), use of radio localisation in conjunction with GPS, and the use of integrated sensors to either track the animals or identify periods of activity when accurate location data is required. The difficulty of delivering the cues and controls in a reliable way over an extended period of time should also not be underestimated.

The majority of the work that has been done to date has focussed on the protection of environmentally sensitive areas and the exclusion of animals from riparian areas adjacent to a hard boundary such as an impassable river. Proof-of concept has been established, but work is still required to understand how animals would respond to this method of control under different production systems and in particular where multiple virtual fences lines or moving fence lines are involved. Furthermore, there has been only limited research into optimising cue and control devices, with researchers exploring the topic only long enough to find some that work.

Beyond precision livestock technologies to monitor soil, plant and animal characteristics, a capacity to remotely and autonomously manage livestock in the system offers a further suite of applications. It is unlikely to see a commercial product available within the next 5 years, however a strategic investment in the development of VF technology may be warranted.

7.4 Tailoring data requirements for end-users

7.4.1 Introduction

One of the key issues faced by producers is the management of data from the various sensors and systems that they may have in place across the property. In the case of livestock operations there is currently a range of software packages for farm management. These systems vary in complexity from basic herd and animal data recording systems through to more complex packages that integrate mapping and productivity monitoring.

In addition to existing data management and visualisation packages there will be an increase in the number of software systems as some of the new technologies reviewed in this report become commercially available. In some situations existing software packages might be used as the delivery platform for new sensing technologies however in many cases new standalone software is being developed.

The challenge for some producers is the ability to integrate data from a number of systems that currently do not (or will not in the future) talk to each other. Whilst some managers with high level analytical skills can undertake this exercise many find it frustrating and there is a strong feeling that data flows need to be integrated to optimise information delivery and decision making. One large producer has been directly quoted as saying “The challenge for agriculture is how do we get this right and how do we turn the seven data-management programs I currently have on my computer into one, with this satellite-fed data slotting straight in" (Matthew Monk – Sundown Pastoral in GRDC Ground Cover issue July/August 2010).

There is a clear need for simple data integration across a range of sensors and information systems. Whilst there have been some attempts at this (e.g. AgHub in New Zealand - www.aghub.co.nz) there remains no system that enables integration across the full range of programs used by producers.

7.4.2 Advanced data analysis

There is some interest amongst the agricultural community in applying the Business Intelligence protocols to the grazing system. Business Intelligence involves the integration of data flows from various systems, reducing this to useful information and delivering it to the right decision makers. It is more than simply sending key warnings (e.g. the water trough is low). The development of new sensing technologies reviewed in this report and integration with existing data streams (e.g. RFID individual animal recording) could open the grazing system to the analytical techniques developed in the Business Intelligence sector and potentially integrated with whole-of-supply-chain systems such as Livestock Data Link.

7.4.3 Data delivery and visualisation

Different end-users (eg producers and service providers) will have different requirements for how accessible the raw and processed data is, how it is presented, and how it is integrated with stand-alone and other commercial software. There is a growing interest amongst producers in accessing data through the web and particularly on mobile devices (Roberts and McIntosh, 2012).

Much of the data produced by the sensors systems discussed in this report has a spatial element (e.g. Spatial livestock monitoring and satellite data). In many cases the current data streams include a spatially enabled visualisation platform (e.g. Pastures From Space and Agtrix's display of Taggle Ear Tag data). It would seem reasonable that any efforts to integrate data streams should also include a spatial platform to enable data display and visualisation. There has been some preliminary scoping work undertaken by the CRC for Spatial Information into the development of a spatially enabled data integrating interface for agricultural production systems.

Effort is required across all areas to understand how to integrate data flows from different precision livestock technologies, application-specific analysis and presentation requirements across different end-users, and how third-party software providers can capture and integrate different information.

8. Case Studies - Economic Evaluation

The purpose of the case study evaluations was to provide a snapshot of the potential impact that information and data provided by precision technology could have on key decision areas for managing southern Australian sheep and beef enterprises. Table 7 below presents a summary of the key decision areas and corresponding technologies evaluated for each case study area.

Table 7. *Key decision area and corresponding technologies evaluated for each case study area for the economic evaluation*

Pathway	**Feed Based Outcomes**		**Animal Based Outcomes**	
Key on farm decision point currently limiting productivity growth.	*Pasture Growth* What type and rate of fertilisers/conditioners do I need to apply to my pastures to optimise fertiliser use efficiency? (kg pasture DM grown per unit cost of fertiliser input)	*Pasture Utilisation* How do I decide which stock get what paddocks, when and for how long to optimise pasture utilisation? (kg animal output per unit of pasture consumed)	*Per Head Animal Production* How do I ensure per head animal production targets are met at lowest cost while preserving animal welfare?	
What information/data that is currently not available in a sufficiently timely and/or cost effective form would assist producers to make better decisions in this key area?	Information about the underlying variability in soil fertility within paddocks and across a farm. **Soil Fertility**	Information about the current quantity and quality of feed available within paddocks across the farm. Growth rate would also be useful. **Feed Allocation**	Real time data to alert producer to any animal health issues that are impacting on animal welfare and animal production. **Animal Health Monitoring**	Real time data to alert producer of trigger points when animal growth rates/CS begin to decline. **Animal Production Monitoring**
How frequently would this information/data be required?	Once every four years.	On demand.	On demand.	On demand.
What are the benefits of improved decision making that this information/data could provide?	Increased outputs of pasture DM per unit cost of fertiliser input at either the paddock or whole farm scale – decreased cost of production and increased productivity.	Improved allocation of feed between growth and maintenance resulting in decreased cost of production and increased productivity.	Decreased production losses from sub-clinical animal health issues. Decreased deaths from major diseases such as bloat/ ryegrass toxicity. Overall improvement in animal welfare, decrease in cost of production and increase in productivity.	Increased production per head due to increased ability to make timely decisions regarding supplementation, joining, weaning, feed allocation and sale times – decreased cost of production and increased productivity.
What technology is most likely to be able	Zonal variable rate analysis using integrated	Range of calibrated sensors applicable, from hand-held,	Intra-ruminal devices and/or livestock behaviour & location	Walk-over weighing systems for liveweight

Pathway	Feed Based Outcomes		Animal Based Outcomes	
to deliver this information most efficiently and effectively within the next five years?	soil, plant & animal spatial data sets	vehicle, airborne and satellite platforms.	monitoring.	monitoring. Body condition score monitoring with imaging and laser scanners. Intra-ruminal devices for rumen optimisation.
Does this technology have the potential to deliver benefits in other areas of the farm?	Direct application for feed allocation, pasture yield mapping and feed prediction	Direct application for soil fertility, pasture yield mapping and feed prediction Useful for interpretation of livestock monitoring technologies	Intra-ruminal devices applicable for optimising nutrition and animal production outcomes. Location/behaviour directly applicable to stock auditing and security, animal association, and animal health applications. Required for pasture yield mapping.	Intra-ruminal devices for animal health monitoring

8.1 Methodology

Enterprise spreadsheet models were used to represent the ‘with’ and ‘without’ technology scenarios for each of the key decision areas and corresponding technologies evaluated. The results have been presented as a change in the gross margin in moving from a ‘without’ technology scenario to a fully implemented ‘with’ technology scenario. In practice most producers, depending on the nature of the technology being implemented, would implement the technology over several years.

In addition to gross margins, the growth in Total Factor Productivity (TFP) due to the application of precision technology in each key decision area has been calculated. TFP compares total outputs relative to the total inputs used in production of the output(s). TFP growth has been calculated as a ratio of the TFP index of the without technology scenario to the scenario where application of the technology has been fully implemented. TFP growth may reflect either an increase in output volume relative to the level of resources used, and/or a reduction in inputs required to achieve a particular level of output. Indexes were calculated using the Fisher procedure where the Fisher index is defined as the geometric mean of the ratio of Laspeyres and Paasche input and output quantity indices (ABARES, 2011). Note that with the exception of the feed allocation and animal production monitoring case studies where the same base farms were used, it is inappropriate to directly compare TFP growth figures between case studies as base case study farms are different and the indexes are not transitive (ABARES, 2011).

Note that the capital cost of purchasing and implementing the technology on farm was not considered in the case study analyses, due in part to the current high cost of some technologies which is likely to decline rapidly with time, and in some cases the difficulty in quantifying the costs of technologies where they are not currently commercially available.

While cost of the actual technologies has not been considered, non-technology related on farm applications of use of the information/data provided by the technologies has been considered. In most cases this relates to changes in labour usage, enterprise costs such as animal health, and fertiliser expenses, and capital investments in lime/fertiliser and additional livestock.

Additional labour requirements or labour savings have been valued at $25 per hour, and the value of changes in enterprise costs are described in each section. Capital investments in fertiliser have been amortised over their useful life at a rate of 8 percent to generate an equivalent annuity for inclusion in the annual gross margin calculations. Capital investments in livestock to increase stocking rate have been accounted for as interest on additional capital invested at 8 percent. Capital values used were $5,000 and $1,200 for bulls and cows respectively and $1,000 and $180 for rams and ewes respectively.

Case studies for each key decision area have been based on actual farm data from the Department of Primary Industries’ Victorian Livestock Industry Farm Monitor Project. All sheep enterprises are based on a 1,000 ewe breeding flock and beef enterprises on a 500 cow breeding herd. Base case studies have then been modified where required to accurately represent likely scenarios for the ‘with’ and ‘without’ technology situations.

The assumptions used for each case study are described in each of the sections below. Selection of case studies has been based on locations and enterprise types where it was felt that the greatest benefit from application of relevant precision technologies in key decision areas was likely to apply. The base case studies for each key decision area are summarised in Table 8 below.

***Table 8**. Base case studies for each key decision area.*

	Soil Fertility	Feed Allocation	Animal Production Monitoring	Animal Health Monitoring
Sheep	Predominantly set stocked self replacing Xbred ewe flock grazing on granite country in NE Victoria.	Self replacing Xbred ewe flock rotationally grazed on high yielding pastures in south west Victoria.	Self replacing Xbred ewe flock rotationally grazed on high yielding pastures in south west Victoria.	Self replacing Xbred ewe flock rotationally grazed on high yielding pastures in south west Victoria.
Beef	Predominantly set stocked self replacing spring calving beef herd selling yearlings at 12-14months of age grazing on granite country in NE Victoria.	Self replacing spring calving beef herd rotationally grazed in south west Victoria selling yearlings at 12-14months of age .	Self replacing spring calving beef herd rotationally grazed in south west Victoria selling yearlings at 12-14months of age.	Self replacing spring calving beef herd grazing high clover based pastures in the Ovens Murray region of Victoria selling yearlings at 12-14months of age.

8.2 Case Study Results

8.2.1 Soil Fertility

It is considered that precision technology would be used to identify soil fertility zones within paddocks which are then subjected to soil sampling to identify the underlying soil fertility within each zone. Actual farm data on the within paddock variability in soil fertility from a sheep property in North East Victoria was used as the basis for this case study. Data collection involved the identification of three intra-paddock zones within a 9 hectare paddock with three soil samples subsequently taken from each zone (J. Shovelton, pers. comm). Soil samples were then assessed for pH, phosphorus, potassium and aluminium. The average values for each variable within the paddock, along with the degree of variability around the mean across the three zones is presented in the table below.

Soil Fertility Indicator	Paddock Average	Zonal Variability Around the Mean
pH	4.3	+/- 0.1 (2%)
Phosphorus (Olsen)	18.4	+1.9 (10%) to -3.7 (20%)
Potassium (Colwell)	147	+30 (21%) to – 58 (39%)
Aluminium % of Cations	16.7	+7.7(46%) to – 5.9 (35%)

With a current carrying capacity of 12 DSE per hectare, based on the average soil fertility data in the table above the recommendation would be to apply 2.5 tonne of lime per hectare at $60 per tonne spread as a capital application across the whole area. P is considered adequate and K is acceptable.

Using the soil fertility data from zonal soil sampling, the following recommendations would apply.

<u>Zone 1</u>

- No P, K or lime required.

<u>Zone 2</u>

- 2.5 tonnes per hectare of lime as a capital application.

<u>Zone 3</u>

- 2.5 tonnes per hectare of lime as a capital application.
- 60 kg per hectare of K at $1.30 per kg as a capital application for two consecutive years.
- 1.5 kg K per DSE for sheep and 2.0 kg K per DSE for cattle maintenance application.
- 0.6 kg P per DSE at $450 per tonne maintenance application.

The potential carrying capacity of the paddock is estimated to be 16 DSE per hectare. With the capital applications of lime and K it is estimated that this potential stocking rate would be reached after three years (40 % in each of years 1 and 2 and 20% in year 3), and maintained thereafter. Zonal soil samples would continue to be taken every four years to monitor soil fertility levels. Capital applications of lime and potassium have been amortised over a 15 year period to provide equivalent annuity costings for gross margin calculations.

For the purposes of this analysis, it has been assumed that the same degree of within paddock variability would be likely to exist across a whole sheep property. Cattle are known to exhibit less pronounced camping behaviour than sheep, therefore for the beef case study it has been assumed that only 80% of the within paddock variability observed on the exclusively sheep grazed area would occur on a cattle property. The results of the case study analysis are presented below:

Scenario	GM/DSE	GM/Ha	TFP Growth
Sheep enterprise			
Without Zonal Fert. Application	$34.30	$412	
With Zonal Fert. Application	$31.04	$497	
Net Benefit of Technology	**-$3.26**	**$85**	**26 %**
Beef Enterprise			
Without Zonal Fert. Application	$29.24	$374	
With Zonal Fert. Application	$24.27	$388	
Net Benefit of Technology	**-$4.97**	**$14**	**13 %**

8.2.2 Feed allocation

The benefits of improved producer knowledge regarding real time pasture availability, growth rate and quality would be to more efficiently allocate available energy between maintenance and growth of livestock. Combining knowledge of per head feed requirements for both maintenance and meeting target growth rates with the amount and quality of food on offer would then enable producers to more accurately calculate feed budgets and more effectively utilise supplements.

Given the lack of data available regarding the level of efficiency with which producers are currently able to allocate available feed between maintenance and growth to meet production targets, it is difficult to accurately define and subsequently quantify the potential gains that could be made with improved producer knowledge and technology in this area. However for the purpose of this case study we have estimated that producers are probably on average achieving 40% of the optimum level in terms of efficient allocation of feed between growth and maintenance during key times of the year (R. Manning pers. comm.). It is further estimated that with improved knowledge generated from precision technology, producers could potentially increase feed allocation efficiency to around 60% (R. Manning pers. comm.). For the case study farms it has been assumed that this magnitude of gains in the ability of producers to allocate feed between maintenance and growth could manifest in an increase from current average turnoff weights to the levels already being achieved by the top performers based on data from the Victorian Farm Monitor Project. This translates to production increases of 12 and 7.5 percent for the sheep and beef enterprise case studies respectively.

Results of the case study analysis are presented below:

Scenario	GM/DSE	GM/Ha	TFP Growth
Sheep Enterprise			
Without technology	$40.01	$776	
With technology	$44.94	$872	
Net Benefit of Technology	**$4.93**	**$96**	**11.1%**
Beef Enterprise			
Without technology	$25.18	$358	
With technology	$28.85	$410	
Net Benefit of Technology	**$3.67**	**$52**	**9.6%**

Note: Results exclude capital costs of purchasing and establishing new technology on farm.

8.2.3 Animal health monitoring

The issue of animal health and welfare is a significant one for both beef and sheep producers in southern Australia. According to a 2006 MLA study, the economic cost of endemic disease on the annual profitability of southern Australian sheep and cattle producers was estimated to be around 1.1 billion and 122 million dollars respectively (Sackett *et al*. 2006).

The use of precision technology has been identified as a potential means of reducing many of the losses that would otherwise occur on farms during high risk disease scenarios by providing an early alert to producers regarding the incidence of many animal diseases prior to the appearance of sub-clinical symptoms. To illustrate the potential saving from the use of precision technologies for this purpose, the issue of bloat in cattle and perennial ryegrass toxicity in sheep have been examined as case studies.

8.2.3.1 *Bloat in cattle*

The incidence of bloat most often occurs in high rainfall areas where white clover forms a significant part of the feedbase, and in areas where lucerne is commonly grown. According to Sackett *et al*. (2006) the southern Australian regions identified as being at high risk for bloat included the statistical divisions of Northern and Hunter in New South Wales, Ovens-Murray in Victoria; and Perth, South West and Lower Great Southern in Western Australia. All other areas were considered to be at low risk.

As such, the base enterprise for this case study is represented by a self-replacing spring calving beef enterprise selling yearling steers and heifers at 12-14 months of age at 400 and 370 kg LW respectively, based in the Ovens-Murray region of Victoria.

The 'with' technology scenario involves the provision of a pressure alert as an early warning sign of the incidence of bloat in a herd. Two 'without' technology scenarios have been considered: One involves the use of anti-bloat rumensin capsules which are administered to 50% of young growing stock, and the other scenario is where no preventative action is taken.

In defining the assumptions for the 'without' technology scenarios it was considered that the report by Sackett *et al*. 2006 understated the likely deaths from the incidence of bloat and over stated the likely per head production losses. Their assumptions were therefore modified for this report and are shown below:

Scenario	Additional % average annual deaths	Additional Monitoring required (hrs/yr)	Weight losses due to bloat
No treatment	6%	40	Growing steers – 22kg Growing heifers – 20kg
No treatment with pressure alert	3%	20	Growing steers – 22kg Growing heifers – 20kg
Treatment (capsules)	2%	23	Growing steers – 11kg Growing heifers – 10kg
Treatment with pressure alert	1%	7	Growing steers – 11kg Growing heifers – 10kg

Anti-bloat capsules are known to have a growth promoting affect in the order of additional per head growth of around 8kg (Sackett *et al*., 2006). It was estimated that the value of this additional growth would effectively cover the cost of the capsule and the labour for administration.

It was considered that the benefits of an early warning alert to producers would come in the form of reduced deaths that would otherwise have occurred, and in reduced labour requirements for monitoring of stock during the first 5 days of moving them onto a high risk pasture. Weight losses were halved across all growing stock with the use of capsules due to half of the stock being administered with anti-bloat capsules.

Feedback from the industry workshop indicated that the use of an alert to producers regarding the incidence of a disease outbreak/issue in livestock would provide greater confidence to increase the intensity of livestock management, thus an increase of 5 percent in annual stocking rate has been assumed for the alert scenarios.

The results of the case study analysis are presented below.

Scenario	GM/DSE	GM/Ha	TFP Growth
Capsules	$24.63	$262	
Capsules with Pressure Alert	$24.92	$276	
Net Benefit of Pressure Alert	**$0.29**	**$14**	**4.3%**
No treatment	$22.77	$242	
No Treatment with Pressure Alert	$23.56	$261	
Net Benefit of Pressure Alert	**$0.79**	**$19**	**6.8%**

Note: Results exclude capital costs of purchasing and establishing new technology on farm.

8.2.3.2 *Perennial ryegrass toxicity in sheep*

According to an MLA report into the economic assessment of the impact of perennial ryegrass toxicity on the productivity and profitability of sheep and cattle enterprises, approximately 26.5 million sheep (25% of the national flock) are at risk, the majority of which run in the temperate south eastern part of Australia (Sackett & Francis, 2006). Of these 26.5 million, 12.4 million are considered to have a high risk of ryegrass toxicity in any one year.

Ryegrass staggers in sheep is observed nearly every year in some regions. The south west region of Victoria is considered to be a high risk area, and as such the base enterprise for this case study is a self replacing Xbred ewe enterprise based in this region. The 'with' technology scenario involves the provision of an intra-ruminal or implantable device to producers as an early warning sign of the incidence of toxicity in a flock.

The 'without' technology scenario assumptions are based on those used in the Sackett and Francis (2006) study noted above for a prime lamb enterprise in a high risk scenario. These assumptions, along with those for the 'with' alert scenario are provided below:

Key Impact Variables	Without Alert	With Alert
Deaths (%)		
- Weaners	4%	2%
- Adults	7%	4%
Reduced fertility (%)	18%	9%
Decreased LW/Hd		
- Weaners	1kg	0.25kg
- Adults	2kg	0.5kg
Extra Labour (days)	14	10
Extra Supp Feed/hd	10kg	12kg

Given the lack of actual data on the likely impact an alert would have on these variables conservative estimates have been made. As noted with the bloat case study, producers at the project industry workshop indicated that an animal health alert system would give them greater confidence to increase the intensity of their systems, thus an increase of 5% in stocking rate has been assumed in the 'with' alert scenario.

The early alert would involve moving affected stock onto a low endophyte pasture and supplementary feeding until the risk passes. Given that stock would be removed from high risk pastures earlier the resulting extra supplementary feed costs with the alert are higher.

Results of the case study analysis are provided below.

Scenario	GM/DSE	GM/Ha	TFP Growth
Without Alert	$28.22	$522	
With Alert	$33.07	$640	
Net Benefit of Alert	**$4.85**	**$118**	**13.5%**

Note: Results exclude capital costs of purchasing and establishing new technology on farm.

8.2.4 Animal production monitoring

Improvements in the ability of producers to easily and consistently monitor the weights and condition scores (CS) of livestock could potentially involve gains in terms of fertility, more efficient use of supplementary feed, increased turnoff weights through better allocation of feed and improved timing of turnoff. Ideally precision technology would be used to provide producers with an alert when livestock reach a critical CS or live weight where pre-determined management strategies are required. This may involve a trigger for average sale weights, minimum condition scores or growth rate changes.

The key assumptions for the case study are presented below:

- 25% increase in supplementary feed use efficiency with technology.
- 10% increase in ewe fertility with technology.

The results of the case study analysis are presented below.

Scenario	GM/DSE	GM/Ha	TFP Growth
Sheep			
Without technology	$40.01	$776	
With technology	$43.75	$857	
Net Benefit of Technology	**$3.74**	**$81**	**9.6%**
Beef			
Without technology	$25.18	$358	
With technology	$27.28	$387	
Net Benefit of Technology	**$2.10**	**$29**	**4.1%**

Note: Results exclude capital costs of purchasing and establishing new technology on farm.

9. Recommendations for R&D investments

Given the significant benefit possible, and the potential technological solutions available, the following recommendations for R&D investment are made to MLA (note that these recommendations are fully detailed in the following section). In addition one strategic recommendation is made below:

1. High priority
   D. **Soil fertility –** The development of zone-based variable rate applications by understanding how integrated soil, plant and animal spatial datasets can best be integrated and interpreted to predict soil constraints to production.
   E. **Pasture biomass –** The establishment of a regionally-based R,D&E program that simultaneously calibrates and validates a range of vehicle, airborne and satellite technologies to quantify pasture biomass, develops systems to integrate the data with farm management software, and demonstrates tangible applications in a commercial setting.
   F. **Animal location and behaviour** – An investment in the development of a number of applications utilising technology to monitor the location and behaviour of animals, in particular improved feed allocation (matching animal demand with feed supply), early detection of animal health, sire-dam and dam-offspring associations, and stock auditing and security. A program of work is required to deploy these technologies and establish relationships between the location/behaviour metrics and the events of

interest in order to deliver an integrated solution capable of real-time data acquisition, analysis and interpretation.

2. Medium priority
   C. **Individual animal production monitoring**
      A.1. Animal liveweight – An investment is recommended to establish agreed data-handling processes for commercially available weighing systems (particularly walk-over-weighing) that enable producers to capture the full potential from the technology in not only mob-based but also individual animal management. This should include data infrastructure that captures information remotely and makes it readily available to producers in near real-time with appropriate integration with decision support systems.
      A.2 Body condition score – The current MLA investment into an imaging system for measuring p8 fat and muscularity should be supported so that its potential accuracy and reliability in on-farm conditions can be evaluated. However an investment is recommended into laser scanner technology because it actually quantifies the structure of the animal, and is less likely to be subject to errors associated with field conditions.
   D. **Animal health and rumen function –** The current MLA investment into the intra-ruminal device for measuring methane needs to be fully supported, and if successful in terms of the platform technology, then it should be extended to include key rumen health (eg pH, temp) and nutritional (eg VFA) parameters. A watching brief should also be kept on commercial developments to see if issues related to device longevity can be overcome. The investment recommendation above in animal location/behaviour applications should also focus on early detection of animal health issues.

3. Low priority
   E. Pasture quality - A relatively small investment is recommended to establish proof-of-concept in NIRS/Hyperspectral spectroscopy to estimate pasture quality parameters and to determine the potential accuracy of the information relevant for improved feed allocation, animal management and plant nutrient status.
   F. Weed management – A small proof-of-concept study is recommended to examine the potential of NIRS/Hyperspectral spectroscopy to detect green weeds in green pasture swards, and to determine its capacity to quantify percentage weed infestation.
   G. Pasture yield mapping – Because of the need for estimates of actual pasture productivity at the sub-paddock scale, taking into account animal intake, any investment should be delayed until other investments are concluded and the capacity to estimate pasture biomass and animal intake is known.
   H. Feed prediction – A more thorough review is recommended to understand the forecast/prediction requirements for key decision points in production systems, the capacity of current forecasts, and build a strategy for ongoing R&D and delivery. A watching brief is required on advances in the climate forecast models as these are continually improving and will underpin an ability to forward-prediction feed availability and quality.

4. Strategic investment priority
   Autonomous control of livestock - Beyond monitoring technologies, we also make a case for a strategic investment in technology to autonomously control livestock. The development of a business case with market research is required to focus further work and to detail the steps required to get the current state of technology to a commercial product. This will then inform further R&D requirements in both the underpinning technology and the animal behaviour domain. It is anticipated that most R&D effort initially will be required to understand better how animals respond to different cues and controls in different circumstances, the consistency with which animals respond, and the implications for individual and mob/herd-based management.

More detailed information on these R&D recommendations is provided below:

Detailed R&D recommendations and approaches

HIGH PRIORITY

1. Soil fertility

Priority – HIGH

Nature of R&D – Algorithm & application development

Gap/Opportunity

Numerous studies and programs have demonstrated that in the medium to high rainfall zones large increases in productivity can be achieved by correcting soil nutritional deficiencies/acidity problems etc. The current method of assessing soil nutrient status is through the manual collection of soil samples but the time involved in collecting the samples and the cost of the analyses are limitations to extensive sampling. There is a need to develop a method for identifying spatial variation of soil nutrient status and soil pH either through direct measurement or through proxy means.

The direct measurement of soil nutrients *in situ* using on-the-go sensors remains an ongoing challenge with few suitable tools available for deployment in pastures. There appears to be a reasonable amount of research going into this field from the cropping industries although the transfer of these technologies to non-arable pastures where un-cultivated soil may damage any probes remains an issue. A key challenge remains in sensing green weed species amongst desirable green swards.

A more immediate solution to the problem would be the development of zone based variable rate application. There are a range of tools to measure spatial variability in soil, plant, animal and climate characteristics but a spatial informatics R&D approach is required to understand how these best be used to define variable rate zones

R&D objectives

- To develop an understanding of the spatial and temporal variability of soil nutrients in grazing systems and associated spatial datasets.
- To understand which spatial datasets reliably indicate soil constraints to production, how they are best integrated, and the impact of other potential constraints.

- Validation of the economic value of site specific fertiliser management in pastures.
- To develop clear guidelines for soil sampling/testing and subsequent site specific fertiliser applications

R&D approaches

- Need to address specific regions/soil types in turn, collating spatial soil, plant, animal and climate datasets to establish relationships with soil constraints to production.
- This investigation should consider the minimum data sets required for accurate development of zones, and the use of more 'sophisticated' spatial informatics techniques to establish the relationships.
- The outcome should be a clear process for producers to understand their optimum strategy to apply fertiliser according to requirements

Timeframe – 5 years. Requires extensive field research across regions. Program should include the establishment of field sites, 3 years of field research, and a final "harvest" year.

Risk of failure – Medium (due largely to complexity of factors influencing soil health/fertility)

Size of investment – Large ($500-750k pa) – dependent on how many regions conducted simultaneously, but likely to require significant science capacity, technical support and operating

Key partners – CRC for Spatial Information, CSIRO, UNE, CSU, State Dept Agriculture, PA consultants and service providers, fertiliser manufacturers.

Opportunities for RDC co-investment – AWI, GRDC

2. Pasture monitoring - biomass

Priority – HIGH

Nature of R&D – Algorithm development & sensor testing

Gap/Opportunity

Efficient utilization of feed for specific management objectives depends upon allocating the appropriate quality and quantity of feed to different classes of stock in a timely manner. Accurate feed allocation to meet production targets has the potential to improve not only pasture production but also to improve feed utilization. Visual assessments of feed quantity and quality are invariably subjective and objective measurements would rarely be taken on farm due to labour constraints.

There is a need to establish techniques to quantitatively estimate pasture biomass as it underpins a range of applications including feed allocation, soil fertility, pasture yield mapping, and feed prediction. There are a range of technologies currently at or close to market, including vehicle, airborne and satellite platforms. There is unlikely to be one single technology that meets the needs of all systems and user requirements. Fundamentally they all require calibration across seasons, pasture types and regions.

R&D objectives

- To simultaneously calibrate and validate a number of technologies to quantify pasture biomass, and make those calibrations available to industry.
- To develop systems to integrate the real-time biomass data into supporting farm management software, and demonstrate applications of the information in a commercial setting.

R&D approaches

- The recommendation is to design a regionally-based R&D program that simultaneously calibrates & validates several technologies to pasture biomass.
- Regions can be defined based on an initial spatial analysis of agro-climatic data and experience in other regions/countries, and the sampling protocol set up to establish how geographically disperse calibrations can be used.
- Consideration should be given to integration of this project with the national pasture variety trials.
- A component of this research should be conducted on commercial farms to demonstrate the different technological options and specific applications in a commercial setting, with a focus on improved feed allocation and defining soil fertility zones.
- Requires a component of work to ensure systems are in place to integrate the biomass data into supporting farm management software.

Timeframe – 3-4 years per 'region' to capture within and between year variation. Staggered roll-out to other regions.

Risk of failure – Low

Size of investment – Large ($500-750k pa) – dependent on how many regions conducted simultaneously, but likely to require significant science capacity, technical support and operating. Could be structured as an overarching science leader to co-ordinate regional activities.

Key partners – CSIRO, UNE, State Departments of Agric, CRC for Spatial Information, State Commercial technology providers.

Opportunities for RDC co-investment – DA, AWI

3. Animal location and behaviour

Priority – HIGH

Nature of R&D – Technology, algorithm and application development

Gap/Opportunity

An underpinning capacity to monitor the location and behaviour of animals enables several applications including improved feed allocation, early detection of animal health, sire-dam and dam-offspring associations, and stock auditing and security. The value proposition for investing in the location and behaviour technology is its capacity to yield these multiple benefits in one integrated solution.

An investment is warranted in (1) developing and delivering tangible applications from those technologies which are currently commercially available or near to market through on property testing and evaluation, and (2) the development of a research tool that integrates location with behavioural sensors such as accelerometers, magnetometers, audio (including ultrasonics), optical sensors, pressure sensors and radio-transmission to determine which sensors best relate to the behaviours of interest to deliver the range of potential benefits described above. The learning outcomes of the investment in the integrated research tool should flow directly to the commercial systems. The limitations of the commercially available sensors discovered in (1) should directly inform the development of the research tool (2).

The key requirement is to understand the natural variation that occurs in the location and behaviour metrics and establish relationships between them and specific events of interest (trends and/or deviations). For real-time monitoring applications there is a requirement for on-line data processing and interrogation systems.

<u>R&D objectives</u>

- To develop an integrated program of work that captures and interprets animal location and behaviour information to derive applied applications for stock location and security purposes, improved feed allocation, early detection of animal health issues, and animal association applications.
- To understand the variation in location & behaviour that naturally occurs within and between animals in different conditions in order to understand what deviation represents a specific event of interest.
- To develop data handling processes that detect anomalies and reliably indicate events requiring further investigation (eg theft, health, welfare)

<u>R&D approaches</u>

- Effort is required to deploy the latest technology in a demonstration setting, but as a research objective to build relationships between the metrics and specific physiological and management scenarios. An understanding needs to be established as to how the metrics vary in space and time, between animals and management regimes, and how trends and anomalies in behaviour can be detected to signify key physiological events such as animal health or feed availability/quality constraints.
- A two-tiered approach is feasible: (1) deployment of commercially available location technology on commercial and demonstration farms to test basic feasibility and accuracy and develop tangible applications such as stock auditing, landscape utilisation and security, and (2) an R&D investment on an integrated location/behaviour technology that understands the physiological implications of the metrics and develops more sophisticated applications of feed allocation and animal state (eg health, welfare).
- A multi-disciplinary approach is likely to be required that merges an understanding of animal behaviour and animal and plant physiology, with the data availability, analysis and interpretation.

- Demonstration of this capability to industry is an important component of this work, including the capacity to see and interrogate real-time information in the context of specific applications. A strong producer and service provider input is recommended to understand the potential value in the information and influence product design and delivery (including how to package and present the information, and how to integrate it with decision support systems and farm management software).
- Significant opportunities exist to leverage off current investments at Armidale NSW (Australian Centre for Broadband Innovation), Townsville QLD (QLD Smart State Digital Homestead project), and the MLA investment in Northern Australia "On-property benefits of Precision Livestock Management (PLM) technologies and applications". Opportunities exist for co-investment in the Wool and Dairy sectors.

Timeframe – 3-5+ Years

Risk of failure – Low - Medium

Size of investment – Large. (1) Demonstration and evaluation of current or near to market technologies could be staged and scaled according to the number of regions to be targeted. A basic program establishing 3-5 sites would cost $500k pa. (2) Development and evaluation of the integrated research tool for detection of a range of key behaviours would require substantial scientific and technical support with an estimated cost of $500-750k pa.

Key partners – CSIRO, UNE, private commercial technologists

Opportunities for RDC co-investment – AWI, GRDC, DA, (private commercial funding could also be considered)

MEDIUM PRIORITY

4. Liveweight monitoring

Priority – MEDIUM

Nature of R&D – Algorithm development

Gap/Opportunity

Monitoring weights and body condition is important in managing reproductive performance and animal growth rates. Conception rates in the case of sheep and the period between calving and cycling in cattle are closely related to stock condition. Understanding whether or not animals are in a positive or negative energy balance early enough to intervene with supplementary feeding and/or increased allocation of feed can have significant effects on reproductive performance of stock. In the case of growing animals, growth targets are important in relation to achieving critical mating weights and target sale weights.

Manual weighing requires stock to be brought from paddocks to yards and is a limitation to regular stock monitoring. Technology is currently being developed through public and private investment for automatic and remote weighing of livestock and no further investment by MLA on the technology per se is warranted. However investment is required to establish agreed data-handling processes that enable producers to capture the full potential from the technology in not only mob-based but also individual animal management.

R&D objectives

- To develop clear standard operating procedures for how to analyse individual weights over time to generate accurate individual animal data with known errors.
- To ensure there is a data infrastructure that captures information remotely and makes it readily available to producer in near real-time.
- To integrate data/information with decision support systems such as BeefSpecs, and ensure optimal presentation/visualisation for ease of interpretation and adoption.
- Demonstration on commercial farms and clear establishment and visibility of applications and benefits.

R&D approaches

- Utilise commercially-available technology on commercial farms where possible.
- Run concurrent trials with cattle in both southern and northern regions, and sheep. Leverage off current installations. Try to standardise methodologies to ensure comparison and broad-scale applicability.
- Consider the use of more sophisticated data processing and statistical techniques to retain individual animal data rather than coarse filtering techniques that remove large volumes of data.
- Ensure outcomes can be applied independent of any particular commercial product, and data can be integrated into decision support and farm management software.

Timeframe – 2-3 years

Risk of failure – Low

Size of investment – Medium ($200-$300k pa for 2-3 years)

Key partners – Sheep CRC, State Departments of Agric, CSIRO, Commercial technology providers, USQ, CRC for Remote Economic Participation

Opportunities for RDC co-investment – AWI, Sheep CRC

5. Body condition score

Priority – MEDIUM

Nature of R&D – Technology and algorithm development

Gap/Opportunity

In addition to monitoring weights, body condition score is important in managing reproductive performance and animal growth rates. However manual assessment of body condition requires stock to be brought from paddocks to yards and is prone to the subjective nature of the assessments.

With sheep, the presence of wool makes direct measurement difficult and there is no immediately technological solution available other than it being modelled from other parameters such as liveweight.

For cattle, imaging technology is currently being evaluated for measurement of P8 fat and muscularity and this needs to be assessed for its accuracy (is it accurate enough to improve tactical management decisions) and its reliability in field conditions (other studies suggest digital and 3D imaging is prone to errors caused by lighting, photo angles and changes in cow posture which may make it difficult to extend these technologies from saleyard to in-paddock/remote applications).

There is significant potential to use a laser scanner system because these actually quantify the structure of the animal, and is less likely to be subject to such errors.

R&D objectives

- To conclude the evaluation of an imaging system to quantify body condition score, documenting its potential accuracy and reliability.
- To assess a laser scanning system to quantify body condition score, and document its potential accuracy and reliability in on-farm conditions.

R&D approaches

- Requires relationships to be established between reference methods and technology metrics, and then validated on independent datasets.
- Reliability in different conditions needs to be assessed.
- Both technologies could be tested concurrently to allow a direct comparison in both southern and northern beef systems, and lower the cost associated with collecting the reference body condition scores.
- If successful, the technology should be integrated with real-time remote monitoring systems (egg liveweight) and integrated with farm management and decision support software.

Timeframe – 2-3 years

Risk of failure – Low-Medium

Size of investment – Medium ($200k - $300k pa for 2-3 years)

Key partners – State Depts Agriculture, Sheep CRC, CSIRO, USQ, UTS

Opportunities for RDC co-investment – AWI, DA

6. Animal health and rumen function

Priority – MEDIUM

Nature of R&D – Technology and algorithm development

Gap/Opportunity

Responses to animal health management are either preventative (such as vaccination) or reactive when there are clinical indications of disease. There are many situations where subclinical diseases impact on performance or where they are a precursor to clinical symptoms. Early intervention in these situations can have a significant impact on performance, profitability and welfare.

Current methods of disease detection depend on the appearance of clinical symptoms or sometimes, changes in behaviour. There is a need for constant real-time monitoring of altered metabolic state, temperature anomalies or behavioural characteristics that might indicate disease processes initially on a herd/flock basis but with the potential to monitor individual high value stock.

There are several intra-ruminal devices commercially available for livestock (eg for rumen temperature, pH, pressure) but the key technical constraint is longevity - reportedly accurate for up to 40-50 days. There is also a significant effort between collaborating Australian RDCs, including MLA, into the development of a rumen bolus for measuring methane led by CSIRO.

A key knowledge gap in implementing these devices is understanding the biological significance of the signal – that is, what change in a parameter(s) actually signifies a physiological event requiring intervention. Further effort is required to understand how specific applications can be extracted from these data streams given the potential variability of the information.

R&D recommendation

That a watching brief be kept on commercial development of intra-ruminal devices, however if the MLA (and other RDC) investment in the CSIRO et al. bolus proves successful in terms of the platform technology, it should be expanded to include key rumen health parameters such as pH and temperature, and consideration given to key nutritional parameters (eg VFAs).

If the accuracy and longevity of the devices are sound, the focus should be on understanding natural variation and what anomaly in the parameter(s) signifies a physiological event (as described below).

R&D objectives

- To establish the accuracy and reliability of intra-ruminal devices for measuring key rumen parameters.
- To understand the naturally occurring variation in rumen parameters, and what anomaly signifies a physiological event.
- To determine if anomalies can be reliably detected with known false negatives and positives to build a business case for disease detection.

- To develop data processing techniques for real-time anomaly detection.

R&D approaches

- Once developed, intra-ruminal devices need to be deployed in key classes of stock in sufficient numbers to allow baseline variation to be established (within & between animals, management, climate etc).
- Response of rumen parameters to a range of factors needs to be determined so that an event of interest can be detected reliably from other 'normal' events.
- Devices can be deployed in concurrent projects to capture background data.
- Should consider advanced informatics techniques such as anomaly detection in order to develop a system of on-line data processing.

Timeframe – 3-5 years

Risk of failure – High (given complexity of factors influencing rumen environment)

Size of investment – Medium - Large (no investment until platform technology available, and then requires extensive animal experimentation to understand response functions of rumen parameters. Should be deployed in other animal-based projects)

Key partners – CSIRO, AWI, Univ Sydney, commercial technologists

Opportunities for RDC co-investment –AWI, DA

LOW PRIORITY

7. Pasture monitoring - quality

Priority – LOW (Proof-of-concept)

Nature of R&D - Technology & Algorithm development

Gap/Opportunity

In the context of improved feed allocation, the key requirements for quality assessment of pasture are protein content and metabolisable energy. There is a strong theoretical basis for using hyperspectral/NIRS technology for estimating pasture quality on a range of platforms with greater accuracy than simple NDVI-type indices and there is some proof-of-concept in different vegetation types. A commercially-available business model is likely to be 5-10 years in the future given R&D requirements, current technology availability and cost, and satellite deployment. Analytical accuracy and reliability needs to be established.

R&D objectives

- To evaluate the potential accuracy and reliability of hyperspectral/NIRS spectroscopy *in situ* for estimating pasture quality parameters.

R&D approaches

- Initial investigation to establish proof-of-concept should be conducted with proximal sensor(s), with some spatial satellite and/or airborne remote sensing included at key times to explore if quality can he quantified from remote spatial platforms.
- A spectral analysis should be conducted to see if specific wavelengths can be selected for future implementation in simpler active optical sensors.

Timeframe – 18-24 months duration to capture seasonal variation and establish proof of concept only in selected pasture types (Postgraduate study – 3 years. Or science investment – 2 years)

Risk of failure – Medium

Size of investment – Small ($100k-200k pa) for proof-of-concept only. Could be set-up as a small component within the pasture biomass project.

Key partners – CSIRO, UNE, Massey University (New Zealand Centre for Precision Agriculture).

Opportunities for RDC co-investment – DA, AWI, GRDC

8. Weed management

Priority – LOW

Nature of R&D - Technology & algorithm development

Gap/Opportunity

Scattered pasture weeds may have little impact on productivity, but often these weeds have the potential to spread rapidly and have a significant effect on pasture productivity and impose significant long term control costs. The dilemma faced by producers is whether to spot spray or spray the whole paddock, with implications on amount of chemical used, cost and collateral damage to the underlying pasture.

Optical sensing systems for on-the-go spot spraying used in the grains and municipal applications are directly transferrable to pasture-based systems where the issue is the management of green weeds in fallows or senescent swards. There are currently no commercial systems available for automatically detecting and controlling green weeds in growing (green) pasture swards. Hyperspectral/NIRS and digital imaging technologies require proof of concept. The key success criteria will be the ability to differentiate the reflectance spectra of the weed species compared to the background sward.

It may be possible to use remote-sensed hyperspectral imagery to detect the presence and abundance (%) of different plant species, as an aid to early detection and to inform preferred management methods (eg spot spraying verses blanket application). This technique would also rely on being able to differentiate the spectral signature of the weed species in a timely manner. Some proof-of-concept has been established overseas but is required in our pasture systems

R&D objectives

- To determine the capacity for NIRS/hyperspectral signatures and proximal digital image analysis to detect green weeds in green pasture swards.
- To determine the potential accuracy of the technology in quantifying the percentage weed present.

R&D approaches

- The target weed species needs to be a priority industry threat, and tested across a range of pasture swards to ensure the spectral signature of the target weed species can be adequately distinguished from different backgrounds.
- For a higher success rate, a weed species that is likely to have a different spectral signature should be chosen (eg. a broadleaf weed in a grass/clover sward).
- For proof-of-concept, the project should involve *in situ* sensing with hand-held or vehicle-mounted proximal systems to control the field of view. Airborne and satellite platforms can be considered pending success with proximal sensors
- The study should include pasture ecology knowhow to better understand the physiological factors impacting on the ability to detect weeds and levels of infestation.

Timeframe – 18-24 months duration to capture seasonal variation and establish proof of concept only for key weed species in key pasture types.

Risk of failure – Medium-High

Size of investment – Small ($200k pa) for proof-of-concept only.

Key partners – USQ, CSIRO

Opportunities for RDC co-investment – AWI, GRDC, DA

9. Pasture yield mapping

Priority – LOW

Nature of R&D – Technology, Algorithm and Application development

Gap/Opportunity

Crop enterprises have the opportunity through yield monitors on their harvesters to map the productivity of their farms. No such tool exists for the grazing industries. Large differences in pasture production have been observed within and between paddocks. Knowing that these differences exist would provide the incentive to better understand why they occur and encourage the adoption of strategies to optimise production and utilisation per hectare.

Pasture biomass measurements record only what is in the paddock but not what has been eaten. There is a need for pasture yield maps at a sub-paddock scale that quantifies actual pasture productivity, taking into account animal intake.

R&D objectives

- To integrate measures of pasture biomass and animal intake to generate pasture yield maps at the sub-paddock scale.
- To demonstrate the use of pasture yield maps to identify underpinning constraints to production, and then opportunities for cost-effective amelioration.

R&D recommendation

That a specific investment only be made pending the success of both the pasture biomass monitoring and the estimation of intake from animal location and behaviour monitoring technology.

10. Feed prediction

Priority – LOW

Nature of R&D – Algorithm and application development

Gap/Opportunity

Climatic risk is the major risk faced by producers. The ability to predict future likely pasture growth with accuracy would provide producers with the ability to take pre-emptive decisions (particularly in poor years) but also to be able to fully capitalise on the opportunities offered by above average seasons. Tools such as the MLA's rainfall to pastures outlook tool provide some basis for decisions but are generic and do not relate to specific farms. All predictive tools suffer from confidence in their predictions. Studies suggest that current seasonal rainfall forecasts are not accurate enough to base farm management decisions on, but forecast skill (eg POAMA) is continually being improved and further investigation of its role will likely be warranted in the future.

R&D objectives

- To understand the forecast/prediction requirements for key decision points in production systems, the capacity of current forecasts, and build a strategy for ongoing R&D and delivery.

R&D approaches

- A detailed review is required that describes how a predictive capacity can improve the timeliness and/or accuracy of key decision points in different production systems, and how current forecast skill aligns to these requirements. This should include identifying the requirements for both forecast accuracy and length of forward prediction. The review should ensure it considers the findings of recent studies, viz "Farming Systems R&D and Modelling for the Southern Feedbase" (Rogan *et al*. 2012), "Improving the Rainfall to Pasture Growth Outlook Tool – scoping study" (Platzen *et al*. 2011), and "Matching grazing decision points based on soil water and skill of seasonal forecasts" (Cullen and Johnson, 2012).
- Keep a watching brief on advances in forecast skill in the context of the above review.

- Consider how a data-model fusion approach of integrating higher level modelling systems with on-farm sensor data and maps of underlying spatial variability can be used to downscale the predictions to a sub-farm scale.

Timeframe – 12 months

Size of investment – Small (<$100k) (Review only)

Risk of failure – Low

Key partners – CSIRO/BOM

Opportunities for RDC co-investment – AWI, GRDC

STRATEGIC INVESTMENT PRIORITY

11. Autonomous control of livestock

Priority – MEDIUM

Nature of R&D – Technology, algorithm & application development

Gap/Opportunity

Beyond precision livestock technologies to **monitor** soil, plant and animal characteristics, a capacity to remotely and autonomously **manage** livestock in the system offers a further suite of applications, particularly for more precise matching of pasture supply with animal demand at any spatial and temporal scale. A capacity to remotely manage livestock offers potential benefits in many production systems, including (but not limited to) labour savings in extensive grazing systems, precision livestock management for improved feed allocation (spatial & temporal) in both extensive & intensive systems, and optimising sheep grazing management in large paddocks of mixed farming systems where farm layout is optimised for crop production often at the cost of being able to manage livestock optimally.

Although this remains somewhat of a visionary concept with a commercial product unlikely to be available in the next 5 years, Australia has been a global leader in development of the technology and has established an understanding of animal behaviour responses, welfare implications, and has demonstrated a capacity to autonomously control cattle in the field.

A strategic investment is required to continue the development of ‘virtual fencing’ technology. With the most recent advances in power management (energy harvesting and power consumption), and concurrent work in animal location and behaviour, some of the key technical constraints can be addressed leveraging off other investments. Further work is required to understand how animals respond to control measures in different applications, and how to optimise cues and controls.

The requirements for getting a product to market would be informed by development of a business case for southern Australia with market research conducted jointly with a commercial partner with expertise in product design and delivery.

R&D objectives

- To design the path to market for autonomous animal management technology.
- To develop an underpinning technology that can deliver long-term autonomous control for R&D and then commercialisation purposes
- To understand how animals respond to control measures in different applications, and how to optimise cues and controls.

R&D approaches

- The development of a business case with market research is required to focus further work (eg cattle or sheep) and to detail the steps required to get the current state of technology to a commercial product. This will then inform further R&D requirements in both the underpinning technology and the animal behaviour domain.
- It is anticipated that most effort will be required to understand better how animals respond to different cues and controls in different circumstances, the consistency with which animals respond, and the implications for individual and mob/herd-based management. This understanding will then inform further technology development requirements.

Timeframe – 3-5+ years

Risk of failure – High

Size of investment – Small ($100k) (Business case) then likely to be Medium-Large ($250-$500k pa) for on-going R&D and commercialisation

Key partners – CSIRO, Private commercialisation partner

Opportunities for RDC co-investment – AWI, GRDC, DA

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11. APPENDIX A. Project Oversight Committee

Committee membership:

Cameron Allen, MLA

Dr Warren Mason, RPC Solutions, Orange, NSW

Dr Angela Avery, DPI Victoria, Rutherglen, Vic

Dr Lewis Kahn, AIMS & UNE, Armidale, NSW

12. APPENDIX B. Technology Audit Questions

1. **Name of contact; affiliation etc**

2. **Technology name(s) – including brand name (if it has one) and other names it may be known as**

3. **What does it do? (this is the underlying technology – eg "measures pasture height using light beams")**

   a) Is it related to something biophysical (this is the systems-relevant measurable eg "pasture height is then related to biomass").
   b) How is this biophysical relationship inferred/established (eg "it is an empirical correlation with green biomass that requires calibration equations for each region/pasture species/season")
   c) How reliable & accurate is it? (any publications or technical bulletins to support it)

4. **Commercial availability – is it available now? how far away?**
   a) How is it packaged/delivered
      - Who is it delivered through?
      - Is it packaged with decision support software? if so, what software – name, key functions etc
   b) Level of adoption to date
   c) Are there any support structures available for adopters? (this might include technical support and support for applications of the technology)

5. **What level of skill is required to fully exploit technology's capability**

6. **What do <u>they</u> think its applications are in farming systems? Drill down to specifics –**
   a) What sectors/systems/regions?
   b) What management decisions are improved ? how?
   c) Any supporting evidence? (will probably need to ask them to forward documents through)

7. **Specific questions around key decisions .... do you see any application for improving...**
   (be flexible here with topics)
   a) Soil fertility, or nutrient use?
   b) Allocating pasture more accurately to stock demands?
   c) Weed management
   d) Damn-offspring association
   e) Stock security or predation
   f) Managing animals as individuals – e.g. liveweight, BCS
   g) Animal health or welfare, eg detecting metabolic diseases
   h) Risk management

8. **What are the future developments you see for this technology?**

13. APPENDIX C. – Industry Workshop

Airport Motel & Convention Centre, Melbourne

25th June 2012

Attendees:

Dr Dave Henry, CSIRO, Werribee, Vic	Project team
Dr Mark Trotter, UNE, Armidale, NSW	Project team
Jim Shovelton, MS&A, Euroa, Vic	Project team, Consultant, Producer
Charlie de Fegely, MS&A, Ararat, Vic	Project team, Consultant, Producer,
Dr Rod Manning, MS&A, Mansfield, Vic	Project team, Consultant, Producer
Lee Beattie, Beattie Consulting Hamilton, Vic	Project team, Consultant, Producer
Cameron Allen MLA	Program manager
Dr Warren Mason, RPC Solutions, Orange, NSW	Consultant
Dr Terry Longhurst, Strategic Science MLA, NSW	Program manager
Dr Angela Avery, Rutherglen, DPI Vic	Steering committee
Dr Lewis Kahn, AIMS, Armidale, NSW	Steering committee, Consultant
Mark Ritchie, Mansfield, Vic	Producer
Rob Martin, Euroa Vic	Producer
Brian Tiller, Crystal Springs SA	Producer
Josh Walter, Inverleigh Vic	Producer
Lachlan Ritchie, Warrnambool Vic	Producer
Matthew Monk, Armidale NSW	Producer
Dr John Webbware, Mckinnon Project, Werribee, Vic	Consultant