Dairy Data

Utilising technology for decision making in pasture-based dairy farming

A report for

NUFFIELD AUSTRALIA FARMING SCHOLARS

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Executive Summary

It is easy to get caught up in the hype of digital agriculture. The possibilities that new technologies provide are set to revolutionise farming in ways that probably can't even be imagined at this point. Attending AgTech conferences with stall after stall of new start-up ventures offering shiny new sensors, data management and other digital farm services further re-enforces this excitement. The digital agriculture revolution provides the hope of smarter farming, increased yields with less inputs and a more sustainable farming future. The promises are vast, the practical realities are currently less so but still very real, provided the focus can be maintained on practical solutions which achieve valuable outcomes.

New technology and low-cost sensors now make it possible to monitor almost every aspect of grazing-based systems. From connected, virtually herded cow through to live readings on pasture biomass from automated robots. With almost anything now seemingly possible, it is more important to make the distinction between what data can be collected, and what data is actually needed.

Block calving, grazing-based dairy systems are inherently robust and simple in their success, relying on efficient systems-based management to deliver efficient, predictable results. If digital agriculture is to successfully engage farmers to move past this to more elite data driven decision making, it must do so without overly complicating the day-to-day operation or compromising these existing strengths.

The stark contrast between what is now technically possible, and the slow progression of technology uptake by much of the industry highlights a lack of proven, clear financial benefit or demonstrated integral link between technology and the success of farming systems. While some aspects of technology and data interrogation are already delivering financial gains for those with an interest and skill set to successfully utilise them, it is perhaps in other areas such as helping to meet ever increasing compliance demands, improved animal welfare outcomes and maintaining a social licence to farm that technology may have the biggest impact in the future.

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Foreword

The word 'Nuffield' has been in my vocabulary from a young age. My grandfather Kenneth Macdonald is a New Zealand Nuffield Scholar who travelled to the United Kingdom (UK) to compare dairy industries in 1971. While this in itself would be enough to cement Nuffield in my mind, it is further engraved in my identity by the fact that the contacts made during this UK Nuffield trip would eventually lead to my father, Alastair, meeting (and subsequently marrying) my Scottish mother, Lesley.

Despite being aware of Nuffield and the potentially life changing contacts and opportunities it can create, it took some time for me to decide I had a strong enough interest in a topic to apply. Family support was never lacking, with strong encouragement from both my father and grandfather and a knowledge my wife Shannon would support me as she has through every other aspect of our relationship.

The real emphasis for finally applying came from spending time away from the farm (and family) by attending a precision dairy technology conference in the Netherlands (generously supported by Dairy Australia). This not only gave me the time to write the application and gain further insights into the possibilities new technologies could bring to farming but showed that I could spend time away from the business and family without the world falling apart.

I have always been strongly interested in technology and enjoy incorporating it into our farming business and the potential ability to utilise technology to increase farm profitability was one of the key drivers for me returning to the family farm from a career as an environmental and Farm Mapping/GIS Consultant.

However, even for someone like myself who has some technology skills and a strong interest, it can still be difficult and frustrating to turn technology and especially data, into profitable outcomes. I strongly agree with the '*You can't manage what you don't measure'* mantra, but I am also more and more conscious of the potential danger of '*drowning in data'*.

My Nuffield travels lead me to Brazil for the Contemporary Scholars Conference, before embarking on our Global Focus Program tour to the USA, Czech Republic, Poland, Ukraine, Kenya and South Africa. During my personal studies I attended the 11th European Conference on Precision Agriculture (ECPA) in Edinburgh as well as the Forbes AgTech Summit in Salinas, California, and closer to home the Harvesting the Benefits of Digital Agriculture – Australian Farm Institute conference in Melbourne. During my personal studies I also travelled to the Midwestern United States (US), the UK, Ireland and to New Zealand to investigate my topic in greater detail.

This travel has reinforced that the AgTech revolution is definitely upon us. Surely with the advent of low-cost sensors, drones and big data, machine learning and internet of things (IoT) it will become easier than ever before to turn our data into valuable decisions?

Acknowledgments

First and foremost, I owe a huge thank you to my partner Shannon for her ongoing support during the completion of all scholarship requirements. She not only stepped up to help run our business in my absence, but also did an amazing job caring for our two children (Charlotte and Oliver). I cannot thank her enough for the sacrifices she has made, and I will endeavour to make the most of the ongoing experiences and opportunities that being part of the Nuffield family will no doubt continue to offer.

Secondly to my father and business partner Alastair, for not only his encouragement in applying but for his support in integrating Shannon and me into the business and for his extra work keeping the farms running smoothly in my absence.

To my mother and business funding partner Lesley, for her role in supporting and encouraging me during my schooling and extracurricular activities and for teaching me to touch-type at a young age which has served me well, especially in my interactions with technology.

My grandfather, Kenneth Macdonald has also been extremely supportive of my scholarship and deserves a special mention for inspiring me to apply.

My scholarship would of course not have been possible without the generous financial support of my investors, Bonlac Supply Company and the Sylvia and Charles Viertel Charitable Foundation. This support is greatly appreciated and valued.

And finally, to all those, too numerous to list, who gave up their valuable time to meet with me in my travels and share their opinions and experiences. I hope to be able to repay the favour should you ever find yourself in Tasmania.

Abbreviations

AHIS – Australian Herd Improvement Scheme

ECPA – European Conference in Precision Agriculture

GPS – Global Positioning System

IoT – Internet of Things

IoPT – Internet of Profitable Things

RGB – Red Green Blue

ROI – Return on Investment

UAVs – Unmanned Aerial Vehicles aka drones

UK – United Kingdom

US – United States of America

Objectives

Despite having a strong interest in technology and digital agriculture, the author has only invested in limited amounts of technology on farm, due largely to uncertainty about return on investment and practicality of use. While many products and services are available, deciphering which ones best suit the system now and into the future, and which will have profitable outcomes is not easy. While there has been a strong emphasis on data collection as a major focus of the farm business, ensuring timely and consistent collection of data and fully utilising this data to its best effect remains a challenge.

The pasture-based dairy industry presents challenges for data collection and technology use that typical housed systems may not. This results from the more extensive and diverse nature of the system and resulting communication, power source and other associated challenges.

With the AgTech revolution, the digital agriculture space is being flooded with new products and services promising to make farmers more profitable and efficient. While the potential of these advances is exciting, it is also daunting to determine where – or if – investment should be made.

Wanting to maximise the potential benefit of these advances, the following objectives were identified:

- Investigate technology, software and data collection tools currently being used by pasture-based farmers and the data/outcomes they provide.
- Investigate new technology on the horizon and its potential use and benefits.
- Understand how to best integrate data sources to allow live, up to date farm decisions.
- Understand what is required for farmers to make valuable decisions from data.

Chapter 1: Introduction

In Tasmania, where the temperate climate favours perennial ryegrass, dairy feeding systems are strongly pasture focused with 50% of farms feeding less than one tonne of grain concentrate per cow per year (Dairy Australia, 2015). Tasmanian feeding systems and calving patterns (primarily block calving) closely resemble that of New Zealand farms (Mounsey, 2015). This distinction is important because it determines the operational system that the farms are running and hence the particular data sources and technologies that may be most beneficial to farming operations. For example, technologies that are common place in other countries such as robotic milking and individual cow monitoring have not yet become common in pasture-based systems (Eastwood, 2017).

Digital agriculture is rapidly evolving with new technologies and analysis capabilities promoting exciting opportunities for agriculture. While farmers were previously limited to relatively simple PC-based farm software packages, web-based software is now readily available and terms such as drones, big data, internet of things (IoT), machine learning and artificial intelligence are common place. These technologies offer promises of automated tasks, improved animal welfare, smaller environmental footprints, easier ability to meet safety and compliance obligations and ultimately, improved profitability (Eastwood, 2017).

However, existing technology and digital agriculture uptake by Australian dairy farmers overall is low, with 7% reporting they do not collect any data at all, and the bulk of records kept by livestock farmers still paper-based (>50%) with the exception of finance records (Zhang, Baker, Jakku, & Llewellyn, 2017).

Given this current divide between existing uptake and the plethora of products and services that are currently (or will soon become) available to farmers, it is important to understand where farmers will achieve the greatest benefits. Digital agriculture has the potential to revolutionise farming, but for these benefits to be maximised careful consideration needs to be given to ensure solutions are targeted and outcome driven, and practical for individual farming situations.

With rapid advances in AgTech it is possible that everything from farming methods to food processing and marketing will be very different in 10-20 years. However, rather than speculating about the multitude of potential possibilities or the extensive research projects that are being undertaken, this report aims to focus more on the immediate commercial options available for farmers at the pre-farm gate level.

Chapters two, three and four focus on data collection and technology options for cow and paddock data. Chapters five and six discuss software and network options for collating this information and chapter seven attempts to summarise the key points for maximising decision making from data/technology.

For anyone particularly interested in this topic area, it is well worth reading fellow Nuffield Scholar Dr. Debbie McConnell's recent report on optimising the value of precision dairy technology in the UK.

Chapter 2: Cow Data

As herd numbers have grown, keeping track of individual cow information has become progressively difficult. Traditionally, keeping cow records up to date has been a labour intensive, monotonous task of entering data in a dairy office or home computer. High data loads usually coincide with the busiest times of year (mating, calving) meaning that data entry is often missed or back entered, making it unavailable for timely decisions. Currently, only around 35% of Australian dairy farms consistently record breeding and medical treatment information in electronic form (Zhang et al., 2017)).

Smart phones now enable every capable staff member to become a link in the chain of farm data collection and to record behaviour or events as it is observed. This, combined with cow wearables and other in shed cow monitoring, make it easier than ever before to manage cows as individuals, even in large commercial herds.

In-shed technologies

A wide range of in shed technologies are available with every major dairy manufacturer offering their individual solutions. Due to the large and diverse range of products, it is not within the scope of this report to review these. However, more information on the data/software implications will be discussed in chapter five and for those interested more information can be found on the Dairy Australia website (Dairy Australia, 2017)

Cow sensors

Advances in technology have allowed the creation of a wide range of cow wearable sensors. These can be leg, neck or ear mounted with some devices even placed in the rumen. They can be used to detect and monitor oestrus, mastitis, lameness, calving and onset of illness (Bewley, 2017) and facilitate the reality of the 'Connected Cow' (Figure 1).

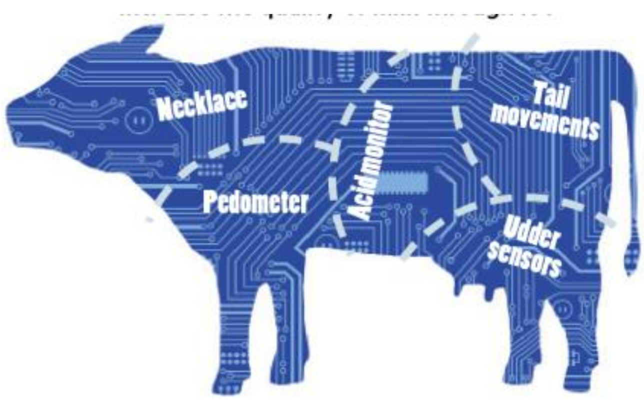

Figure 1: The Connected Cow (Fildes, 2017)

While they have been common in housed systems in Europe and the US for years, it is only recently that these wearables have started to occur more commonly in grazing-based farms. They are common with robotic milking installations and there have been numerous commercial early adopters in commercial farms which Dairy NZ estimates would represent 5-10% of the industry (Eastwood, 2018). Research groups are now looking at them in a commercial setting. For example, Lincoln University is currently trialling 100 collars on the Lincoln University Demonstration Farm (LUDF) (Pellows, 2018) and the Tasmanian Dairy Research Facility (TDRF) is also trialling an alternate brand (Hills, 2017).

Figure 2 : On Site at Lincoln University Dairy Research Farm to Discuss Cow Collar Technology (Author 2018)

Pasture-based farms where cows walk long distances from the dairy shed (rather than being housed in close quarters as in a barn system) caused some challenges for wearable providers when first released. Numerous farmers who were interviewed reported false oestrus alerts, issues with data backlogs and processing times (due to the whole herd arriving at the shed at the same time) and connectivity issues. However, these seem to be largely resolved in recent releases (although not in all cases) with improved algorithms focused on comparing behaviour within a herd to detect anomalies such as oestrus and health alerts rather than standard behaviours (which vary greatly between a housed and a grazing-based system).

Figure 3: Mobile receiver for Cow Manager system allowing relay of cow information when cows in a grazing situation are out of range of the dairy. (Author, Netherlands, 2016).

The ability of these devices to successfully detect oestrus has been verified by numerous studies (Sumon Shahriar et al., 2016). There are numerous companies offering solutions. Some of the more popular, based on the author's study, include SCR (SCR by Allflex, 2018), Cow Manager (Cow Manager, 2018) and MooMonitor+ (DairyMaster, 2018). An Industry Innovations Report provides an excellent comprehensive list of many of the available cow sensor devices (Horizon 2020 European Union Funding for Research and Innovation, 2016).

One of numerous newer players in the space include Dutch-based Connecterra (Connecterra, 2017). This company is embracing the machine/deep learning concept with a data science engine in their software to allow for a self-learning and potentially developing farm specific algorithms that learns from user feedback. Connecterra also offer a subscription-based sales contract for the devices which doesn't require the initial outlay of some of the other offerings.

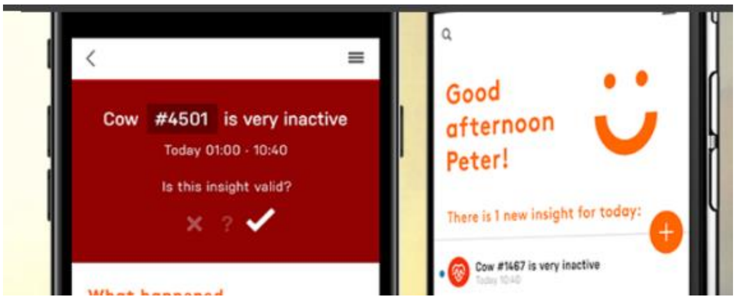

Figure 4: Example App interface from Connecterra software (Connecterra, 2017)

As another new option, Korean-based LiveCare (LiveCare, 2017), offer an orally ingested bio-capsule that claims to be able to detect diseases, oestrus, drinking behaviour and optimal calving time of the cow.

The cost of each solution varies but is generally approaching $200AU/cow. The lifespan of the devices also varies, with some designed as throw away devices with 2-7 year life spans and others offering replaceable batteries and potentially longer. Regardless of the exact design, these represent substantial investment with a reasonably short potential ROI timeline.

Moocall (Moocall Ltd, 2018), who are currently best known for their calving alert system, have recently entered the heat detection space with their Moocall Heat product. This wearable product is applied not to the cows, but to vasectomised herd bulls. This is a novel use of this technology and potentially has a good fit with seasonal mating herds.

The author found oestrus detection is the most common reason quoted for purchase of cow wearable devices and they are generally well trusted in this regard. When combined with automatic drafting, these devices are extremely useful in a year-round calving scenario where a small number of cows may need identifying, drafting and subsequently mated every day of the year. In these systems that are reliant on traditional heat detected methods, almost half of all heats are missed and up to 15% of cows are mated when not actually on heat (O'Connor, 2017). The benefits of wearables are even higher in a robotic system where there is little opportunity for human observation of in heat behaviour, or other visual heat detection aids.

However, in a seasonal block calving system (as are most common in grazing-based systems) the benefits are less obvious. Under these systems operators generally only need to identify, draft and mate animals for six weeks each year. Staying focused with simple protocol-based systems for this shorter period is achievable and farms can often reach excellent mating results equal to, or better, than those utilising wearable technology. Comparing farm to farm is, however, difficult as each farm will have different breeding strategies and focus and different limiting factors. It is perhaps more relevant to compare improvements in mating performance that any individual property may achieve from utilising wearable technology, and in this regard most adopters report improved mating results (probably in part due to detection of silent heats which traditional methods struggle to identify). However, for these benefits to be realised operators need to trust the technology and not ignore alerts as false alarms. Some studies have found that farmers effectively ignore health alerts from similar systems two thirds of the time (Bewley, 2017).

While heat detection is the primary purpose for many purchasing cow wearables, it is perhaps individual health and behaviour monitoring that they offer the greatest potential benefit. Identifying cows as they become sick (rather than once clear clinical signs are already visible) has strong implications for improved treatment outcomes and reduced antibiotic usage. Showing a clear financial ROI from these outcomes may still not be clear but it is the potential for increased animal welfare outcomes that may drive many to invest in the future.

Figure 5 : Saber Automatic Heat Detection and Drafting Setup in Northern Ireland. One of a kind technology in the district offering lower investment cost than collars for heat detection, but with more limited function (no animal health/monitoring).

Researchers also believe that future wearables utilising new algorithms may create an ability to monitor individual pasture intake of animals (Hills, 2017). This could have implications for improved breeding outcomes by allowing selection of animals based on grazing efficiency.

Virtual fencing and GPS cows

Advances in battery life and solar integration mean that relatively cost-effective GPS units for individual cows are now a reality. In its simplest form, a GPS unit could be put on cows within a herd to automatically monitor paddocks grazed for farm auditing records ("proof of placement" for cows). Alternatively, GPS units can be combined with other technology to allow virtual herding (https://agersens.com/eshepherd/) control of every individual cow in the herd. While GPS collars use is still largely confined to research trials and university-based

'Smart Farm' installations, if proven successful in commercial settings this may represent a significant change in how livestock are monitored and managed in grazing systems.

Summary

Despite this available technology it still seems that it is difficult to demonstrate profitable outcomes from so called 'precision dairy' management. In fact, the opening address at a precision dairy conference (Conference on Precision Dairy Farming June 2016) stated that well managed protocol-based blanket management systems were still outperforming precision management on a profit basis in most instances. An example was dry cow treatment, whereby studies comparing selective dry cow therapy (based on individual cow records) versus blanket dry cow treatment failed to show a profitable outcome from the precision approach.

Profit is undoubtedly an essential part of a successful and sustainable business, but other factors are also becoming increasingly paramount. In the dry-cow example the precision approach did result in less antibiotic treatment. In the cow wearable space and even robotic milking space the key drivers for early adopters appear not to be profit, but animal welfare considerations.

The author concludes that cow wearables are most suitable for housed systems (with year-round calving) but their effectiveness and popularity in grazing situations is increasing.

Ultimately, there is little data to support a clear financial ROI for this technology in block calving grazing-based farms, but other factors such as potential improved animal welfare outcomes and social licence should be considered.

Accuracy of these devices is likely to continually improve as algorithms are refined.

Chapter 3: Pasture Measurement

Pasture measurement

Why measure pasture?

A perennial ryegrass, or ryegrass/clover mix, forms the dominant feedbase of Tasmanian and most temperate grazing focused dairy regions throughout the world. For pasture-based systems, nothing correlates as strongly with profit as the ability of a farmer to maximise home grown feed (Flight, 2017).

For many systems, ryegrass (or resulting stored supplement in the form of hay or silage) may make up over 90% of the diet and therefore, understanding how grass growth is varying throughout the year and how much feed is on hand at key times can be extremely important.

Industry bodies in Australia, New Zealand and Ireland all promote the benefits of regular pasture measurement and monitoring. In fact, recent modelling work has compared the difference between a set grazing rotation with paddock selection, based solely on days since last grazed ("low knowledge") against a more considered paddock selection where the farmer would estimate or measure the cover and base grazing decisions accordingly ("good knowledge"). Modelled results suggest a substantially increased profit of NZ$385/ha (Beukes, McCarthy, Wims, & Romera, 2018)

Figure 6: Impressive crowd attending the Tegasc Open Day at Moore Park, Ireland where a strong focus was placed on pasture management and measurement (Author, 2017)

To date, there are no automated measurements for leaf stage available, but many farmers subsequently rely on kgDM/ha readings (through multiple methods described in following sections) to help identify paddock grazing order, total available feed and an indication of appropriate leaf stage/grazing height.

Therefore, with these well-established grazing rules, measuring quantity of pasture available at individual paddock level to optimise quality and feed intake for cows, and at a farm level to monitor the total feed inventory (especially at key times of the year) should be of high priority. So why do only one in five farmers at best actually do it?

Barriers to pasture measurement

Anecdotal, and survey information from most pasture focused dairy regions around the world, all indicate that at best only 20% of farmers regularly measure and record pastures (e.g. Hall, 2018 and Eastwood, 2018). In the UK it is estimated to be as low as 10% (McConnell, 2017).

In fact, many profitable farmers do not undertake regular pasture measurement but instead rely on monitoring of rotation length (ensuring cows only graze the appropriate portion of the farm each day to allow sufficient time for 2.5-3 leaves to grow between grazing). This method usually involves eyeballing paddocks, or ad hoc pasture measurements (DM or leaf stage) to determine paddock grazing order and therefore would fall somewhere between the two knowledge scenarios modelled by Dairy NZ (low knowledge – good knowledge).

The extent to which a rotation length technique alone is effective depends on the skill and experience of the operator, uniformity and predictability of growth rates (and leaf emergence rates) and the availability of low cost, high quality supplements to fill any feed gaps.

In theory, a farmer more closely monitoring and measuring the situation should be able to identify feed shortages earlier, correct with a smaller amount of supplement because they maintain target pre-grazing levels and therefore optimise pasture production. With better sensor and monitoring data the Dairy NZ modelled 'Perfect Knowledge' scenario (whereby the farmer consistently balances the daily energy requirement of the cow with the herbage mass available) should be attainable. If achievable, this level of decision making was modelled to add a further NZ$155/ha/year profit (Beukes et al., 2018)

The theory says one thing, but in practice the simplicity of focusing on correct daily pasture allocations (rotation) makes it a popular and robust system. Many traditional pasture measurement techniques are time consuming and give variable results making farmers wary of decision making on this basis. Collating and interpreting the data has also historically been potentially confusing and reliant on the farmer having additional training.

To increase the value of measuring pasture the industry requires fast, consistent, repeatable methods and accompanying software that is easy to integrate and supports farmers in the decision-making process. Some are already available and not being widely utilised, while others are just becoming accessible.

Pasture measurement devices

Some pasture experts who have spent entire careers monitoring and measuring pasture believe it is virtually impossible to measure pasture (through any method other than complete physical destructive sampling and analysis) to accuracy greater than 300kgDM/ha (Anonymous, 2018) and that people are subsequently kidding themselves if they think they can! Even with new technologies on the horizon this may well remain true, and highlights that it is not necessarily the absolute accuracy of the methods that is most important but perhaps the frequency with which methods are undertaken and the ability to turn those measurements into timely farm decisions.

Traditional methods

All the traditional measurement methods effectively rely on a 'farm walk' of some description whereby each paddock is walked by one or multiple operators and readings manually recorded. One of the most beneficial aspects of this is the farm walk itself, which allows social interaction with multiple operators and discussion and observation of other farm topics simultaneously. As one farm consultant working across 59 farms noted, 'It is the eyes on the ground that are most important, not necessarily the accuracy of the readings' (Anonymous, 2018).

The Grasslands LLC farms visited by the author in Missouri, US, had a similar philosophy, with completion of regular farm regular walks by the management team seen as essential to the operation, and trained eyes seen as the most accurate and consistent form of pasture measurement (Figure 7).

Figure 7: Joining the Grasslands LLC Farm Management Team in Missouri, US on a regular farm walk recording visual estimates of pasture covers (Author, 2017)

Traditional methods include measurement by eye, pasture cut and weigh and readings using a rising plate meter.

Figure 8: A pasture measurement kit including quadrat, clippers and weigh scale with conversion chart viewed on farm in Northern Ireland (Author, 2017)

New rising plate meters

The grasshopper rising plate meter (TrueNorth Technologies, 2018) is one example of a modern take on the rising plate meter, which incorporates a new unique low maintenance design and GPS integration, allowing for auto paddock recognition and even the ability to map a farm. A smartphone App allows syncing of records and makes recording paddock records a paper free task.

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Figure 9: The Grasshopper viewed by the author on display at Moore Park, Ireland

CDAX pasture sled

In recent years, the CDAX pasture sled has become a popular tool for measuring grass on larger farms with many farmers finding them a consistent and valuable tool. Some consultants have even developed pasture measurement businesses utilising them to monitor multiple properties. Dairy Australia provides a good overview of this technology on its webpage (Dairy Australia, 2018). CDAX is owned by Ravensdown Ltd and is linked to its Smart Maps web-based software which is currently transitioning to Hawkeye (see software section below).

Jenquip rapid plate meter

This tool in an alternate option for those considering the CDAX pasture sled and can be mounted on any tow ball equipped vehicle (Jenquip, 2018). Design wise it is more similar to a rising plate meter than a CDAX and uses mechanical measurements of how much the plastic skid rises in relation to the measurement wheel which sets the ground reference height as well as determining when readings are taken (number of revolutions). The data from the meter is transferred via Bluetooth to a dedicated App which can then link to some of the most popular software packages (including FarmIQ and Agrinet).

Figure 10: Viewing the Jenquip rapid plate meter on trial in Cork, Ireland (Source: Author 2017)

Satellite imagery

Pastures from space has been providing pasture measurement services from satellite data for a number of years (CSIRO, 2018). There has, however, been limited uptake of this service in the dairy sector due to limitations with frequency of images (confounded by cloud cover) and resolution of available imagery (generally >30m/pixel).

Recently, LIC has launched an updated platform aimed at the dairy sector known as Satellite Pasture and Cover Evaluation or SPACE service (LIC, 2018). This utilises the Planet Labs constellation of over 88 Dove Satellites (the largest constellation ever to reach orbit when launched) to image the entire planet every day (Planet Labs Inc., 2018). As images are available daily it means that even in cloudy weather images can still be acquired at close to weekly intervals. Images are also at 3m resolution which is not only good enough to determine an average reading for each individual paddock but can also show how covers vary within a paddock and across the farm. LIC has released a paid service for the Canterbury region and has begun trialling the service in the Waikato. The paid service subscription costs are detailed below in Figure 11.

Farm size (ha)	Price (per annum)
<100	$2000
100-150	$2250
151-200	$2500
201-300	$2750
301-400	$3000
401+	$3000 + $1.00/ha

Figure 11: Current LIC SPACE pricing NZ$ (LIC, 2018)

This technology is currently based on using algorithms to convert an NDVI reading to an estimate of pasture biomass. It is important to remember that this is not a physical measurement of biomass, but an attempt to correlate how much green light is reflected from the sward with how much biomass is present. How accurate this can be at higher pasture covers (above 3000kgDM/ha) and in varying situations (rainfed vs irrigated vs different pasture cultivars etc) is yet to be determined in the commercial setting but there is very strong interest from farmers in New Zealand.

Hyperspectral data

Hyperspectral data collected by small piloted aircraft has shown great promise for mapping nutrient concentrations and pasture quality in the New Zealand hill country (Hyperceptions, 2017). This has great potential to aid in variable rate fertiliser applications and other precision applications. Hyperspectral imagery may also eventually allow cost effective regular pasture monitoring (including quality, accurate biomass and nutrient status). Further work is needed to better understand the data these sensors collect and further refining algorithms. This combined with the likely future availability of lower cost hyperspectral sensors may make regular hyperspectral data collection for dairy farms an eventual reality.

Pasture measurement robot

Ravensdown have been developing a C-Dax robotic pasture measurement unit which utilises similar technology to their current trailed units but mounted on a semi-autonomous robotic platform. At the time of writing the robots hadn't been commercially released but the current design is made to operate almost continuously, returning by itself to a set charging station before continuing to follow its set measurement path (Barlow, 2018). Its designers believe the unit mounted with different payloads could potentially serve multiple purposes on farm with options such as weed control, or even cow fetching not being ruled out. The pasture measurement unit has been designed to retail for less than the cost of a traditional quad bike (Barlow, 2018) which is a significant reduction in cost for an automated platform compared to established platforms (eg. Clearpath Robotics, 2018).

Figure 12: CDAX Robotic Pasture Measurement Robot Prototype

In summary, measuring and monitoring pasture is important for monitoring changes in grass growth and maximising grass grown. Farmers have access to efficient and reasonably accurate techniques now, but still only 20% at best measure grass.

Traditional techniques still have their place and measuring regularly may be more important than measuring accurately. New techniques may allow for pastures to be monitored remotely but it is still important to be viewing what is happening on the ground. New techniques are not always more accurate, but generally take less effort.

Software developments need to focus on helping farmers make management decisions from pasture data. If farmers do not trust the data, they will not make decisions from it.

New technology incorporating integration of plant, animal and climate sensors may eventually allow farmers to have consistently ‘perfect knowledge’ for pasture management, but it is not available yet.

Chapter 4: Drones

Drones or Unmanned Aerial Vehicles (UAVs) are being heavily promoted as an essential tool in modern day agriculture. The market is well supplied with a plethora of different brands, models and capabilities. The most common design for consumer use is a quad copter model with four rotors, but six and eight rotor varieties are also available (providing greater stability, carrying capacity and flight redundancy). Battery life has improved substantially in recent years and numerous models now promote >30min flight times. For even greater flight times and coverage, fixed wing options like the Sentera PHX UAV (Sentera, 2018) can fly for almost an hour and survey 700 acres in one flight.

Figure 13: Sentera PHX UAV viewed at the Sentera Head Office Minneapolis (Author, 2017)

Very capable and easy to fly products like the DJI Mavic Pro drone (retailing for around $1,500AU) can now enable almost any farmer who can work a smart phone (or has children who can) to get an aerial view of the farm. Even the standard RGB imagery from these base models can provide interesting insights and capabilities.

One New Zealand farmer interviewed relies heavily on regular RGB imagery over winter to monitor break sizes and remaining area of fodder beet crop as well as a constant inventory of remaining baleage. Another Tasmanian dairy farmer has made novel use of the DJI Phantoms 'Follow Me' function which allows it to lock on to and follow a moving object. At milking time, the farmer fetches the cows to the lane in a traditional manner but then locks his drone onto the last cow in the herd, the one that every herd has who always arrives at the dairy last. The drone then follows at a safe distance and height while the farmer can bypass the cows and get to the dairy where he can start milking, the drone controller and display sitting next to him as he cups up the cows (see flight regulations section below).

Flight regulations

In Australia, drone flight (or Remotely Piloted Aircraft – RPA) is governed by the Civil Aviation Safety Authority (CASA). Due to the explosion in drone usage (from backyard operators through to commercial start-ups) CASA has introduced extra levels of legislation specific to different classes and use of drones. The rules differ slightly whether you are flying recreationally (not for financial gain) or flying commercially.

At the time of writing, and within the commercial category, there is a <2kg (excluded) category and a >2kg category. Most drones that a farmer may purchase for basic operation would fall under this weight class, while operators requiring higher payloads (such as high-end photography) and utilising larger platforms would fall into the >2kg category. Once in the >2kg commercial category operators are also required to gain a remote pilot licence (RePL) and an RPA operator certificate (ReOC) which is a substantial investment in training and resources.

Some general rules apply across all categories (except for in some cases where licenced operators may have approval to fly outside standard operating conditions) and can be viewed on the CASA website (CASA, 2018). Importantly, all these rules still apply even if a farmer is flying over their own land.

The rule that has the greatest implications for farmers who might want to operate a drone is *'you must only fly during the day and keep your drone within visual line-of sight'* (CASA, 2018). This means that the scenario described above whereby the farmer used their drone to bring the cows to the dairy is not permitted because the drone is not maintained in line of sight.

Automated drone use

The maximum operational flight time for most lower cost quadcopters is still around 30-45 minutes (other than petrol hybrids) which place limitations on tasks the drones can realistically perform. Some companies have produced autonomous drone base stations with enclosed platforms (See Figure 14) from which the drone can appear and launch, complete its pre-programmed mission before returning to the base station where a new fully charged battery is automatically swapped out. This sort of technology would mean that almost continual operation would be technically possible.


Figure 14: Autonomic drone platform by Cattlewatch (CattleWatch, 2017)

This type of system could allow almost completely autonomous drone use on farm. In its most basic form, it could result in a series of photos of infrastructure being automatically sent to a farmer to review daily. However, with different payloads and specific software and algorithms there are numerous other data collection or farm tasks that the drones could be doing. However, this sort of operation is not currently permitted in Australia under CASA regulations.

Another option for extended drone use is that of tethered drones (Rise Above Drones, 2018). Tethered drones utilise a lightweight power transfer cable that permanently connects the drone to a ground-based power source. This allows the drone to operate for as long as required at distances of up to 100m from the power source. If paired with a waterproof drone and power source, this could potentially allow 24/7 monitoring of a small area (subject to flight regulations). If paired with a thermal camera, this technology could have a place monitoring cows at point of calving in a paddock-based setting where fixed ground-based cameras (commonly used in housed systems) may not be suitable.

Waterproof drones

Other than battery life, the durability of the drone to be able to operate in adverse weather conditions (both rain and wind) is another factor limiting practicality on farm. There is little point relying on a drone if it can only do it when it's not raining. Some waterproof drones are available, most commonly targeted at the drone fishing or surf life-saving industries where the ability to land on the water is paramount.

Drones with NDVI

In agriculture, the most publicised use of drones is probably for crop scouting or NDVI (Normalised Difference Vegetation Index) data collection. Pairing drones with small, lightweight NIR (Near Infrared) sensors expands drone functionality past qualitative assessment (e.g. with an RGB image) and allows quantitative assessment of within or between field variation. Numerous companies now offer end-to-end workflow solutions with simple to fly, NDVI capable drones and powerful data processing and analysis.

As with everything, it is important to remember that you get what you pay for. Also, NDVI is effectively just a measure of how much green light is reflected from the plant. It is not a physical measurement. There are some very in-expensive NDVI products and services available that provide little more useful information than a standard RGB image. In these scenarios, basing fertiliser or other decisions on this information could be costly. However, an operator with a quality sensor, professional workflow and a proper understanding of the limitation of the data could provide useful information for a farming enterprise.

Measuring pasture with drones

Drones have the potential to provide indication of pasture biomass in the same way that the LIC SPACE program is functioning. However, there are pros and cons of this technique against using a satellite image. The major benefit of a drone is that it can be deployed (weather permitting) to capture data when it is needed and can collect information on cloudy days. It can also collect information at substantially higher resolution (1-5cm vs 3m).

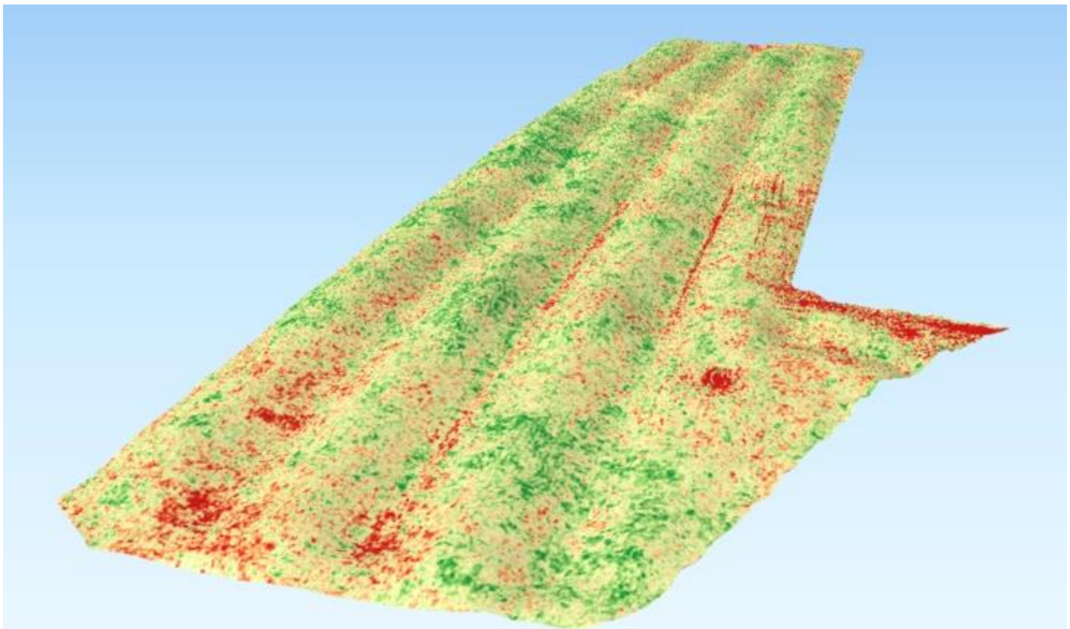

Figure 15: 3d model of pasture variation in a Tasmanian dairy paddock obtained using a drone mounted NIR camera (Source: Author).

The downside of drone imagery is the post processing required, and difficulties with collecting comparable imagery. To collect a similar image to that of a satellite, a drone must collect hundreds of individual images and then have these ‘stitched’ together to produce a mosaic image. This post processing is becoming much easier with integrated workflows from software providers. However, to allow comparison of imagery, an incident light sensor is normally required to monitor changes in ambient light conditions and processing must account for these variations.

This is all technically possible but is not a simple process for accuracy and has not been fully automated in most drone imagery processing. This, combined with the regulations around drone flying which limit the financial viability of running a drone monitoring service, is perhaps why there are currently no commercially available pasture monitoring drone services (known to the author) operating (despite some start-ups in this space).

Where drones may be able to supersede satellite imagery in this regard, is with novel payloads or integration of other sensors not suitable for satellite operation.

In summary, drone/UAV regulations still apply when flying over an operators' own property. Drones have many potential uses on farm, but their practicality is currently limited by battery life, flight regulations (line of sight and daylight hours) and ability to fly in all weather conditions.

NDVI based products and services should be considered carefully and their limitations understood.

Pasture estimates with drones is possible but there are currently limitations to its accuracy and practicality.

Chapter 5: Software

Software has progressed greatly in recent years and web-based programs are now the norm. The days of software licenced to individual computers and battling with how to manage multiple licences, access points and syncing data between computers should be history.

Smart phones put the power of data collection into the hand of any trustworthy operator allowing for data to be recorded as it happens. Most providers now accommodate off-line data collection with automatic sync when data becomes available. While many areas in Australia still struggle with functional data connection (Zhang et al., 2017), this is gradually improving as the larger providers slowly improve current black spots and enterprising companies like WiSky (Wi-Sky, 2018) help the more remote communities get connected.

Cow/herd software

The recent developments by DataGene in Australia incorporating the integration of the Australian Dairy Herd Improvement Scheme (ADHIS) with a central data repository represents a significant step forward for cow records for Australian farmers. This helps move towards a more centralised system like that of LIC in New Zealand and has already resulted in the release of tools such as the HerdData App and the Herd Test Dashboard (Datagene Ltd, 2017). The essence of their tools and the DataGene service itself is that data is entered once and can then be accessed in a variety of ways.

The value of this pooled information at an industry level for genetic and production gains is immense, and at the farm level, the better visualisation and identification of cow characteristics should substantially aid in farmer decision making around breeding and culling. A well-designed central repository should allow for the creation of numerous tools and valuable outputs at all levels in future years.

Pasture Software

Measuring pasture is only of real use when it is recorded and used in the farm decision making process. Software should aim to aid in this decision process and displaying key pieces of information valuable in these decisions. There are numerous pasture software packages being used globally and potential users should complete research regarding which package best suits their needs. Some more common packages encountered as part of the research include:

EXCEL

Excel spreadsheets are still commonly used by farmers to collect and analyse pasture data. This is especially true for larger farms, or corporate groups where the flexibility of EXCEL to create custom feed wedges and outputs particular to the individual operation is of value. Some very complex and powerful spreadsheets for this purpose have been developed.

Agrinet

An Irish, web-based software with accompanying App used to track milk production as well as pasture and paddock information (Irish Farm Computers Ltd, 2017). The greatest strength of this software is its ability to compare multiple farms and share information amongst users. This could be as simple as multiple farms owned by a single entity, or whole farm discussion groups where every member can see key milk and pasture production records. The strength of this feature is that it not only encourages farm comparisons but encourages pasture measurement itself. Numerous discussion groups in Ireland have regular pasture assessment and entry as a condition of continued involvement in the group.

Minda Land and Feed

This is the standard, and most commonly used program by New Zealand farmers to upload their pasture information. As part of LICs suite of packages, it offers a relatively simple program for tracking pasture cover. The LIC SPACE data will also automatically upload to this service for those that have an active subscription. It requires an LIC account so unlikely to be suitable for operations outside New Zealand.

Ravensdown Hawkeye

Hawkeye replaces Ravensdowns previous Smart Maps interface and has been rebuilt from the ground up. Built with strong integration of proof of placement fertiliser spreading (and ordering) this powerful software is aimed at helping farmers achieve environmental compliance and has a strong mapping interface. Integration of the CDAX suite of pasture measurement devices allows for pasture data to be easily recorded and monitored.

Pasture.io.

This recent Tasmanian developed software has a strong focus on balancing cow diets to maximise production and allows tracking of the farms ‘live’ feed wedge (Pasture.io, 2018). Works in conjunction with other modules such as Milk.io and has been expanded to an integrated pasture monitoring/measuring component (utilising satellite and modelled data).

Integrated software

Web based software is extremely convenient. It allows accessing data from anywhere in the world. However, the more software packages used, the more complicated it becomes with the need to maintain multiple logins (and passwords). Integrated software packages offer the potential to simplify this process and are becoming very common for other agricultural industries with cropping leading the way with all-encompassing software from climate information to variable rate tractor maps (Farmers Edge Inc, 2016). Livestock farmers have generally not embraced this level of precision agriculture for pasture (England, 2017) and therefore do not typically have the same workflow of data that precision cropping farms have.

When discussing software options with data-engaged farmers, the most common item on the wish list is a '*digital dashboard*'. A single location where all the key performance indicators most important to the farm operation can be viewed. Some commercial software providers are now providing dashboards in their software (e.g. Minda Land and Feed, FarmIQ, Agrigate) while other early adopters are choosing to invest in custom solutions for their businesses.

FarmIQ

Probably the best dairy relevant entry to this integrated software marked observed by the author is New Zealand based Farm IQ (FarmIQ, 2017). One of its biggest strengths is it also communicates with other software providers such as financial services (CashManager and Xero) and the FARMAX feed budgeting tool (FARMAX, 2018). This is an essential step in the success of the software and means they can leverage on the strengths of pre-existing software leaders rather than trying to replicate a similar (and most likely sub-standard) product.

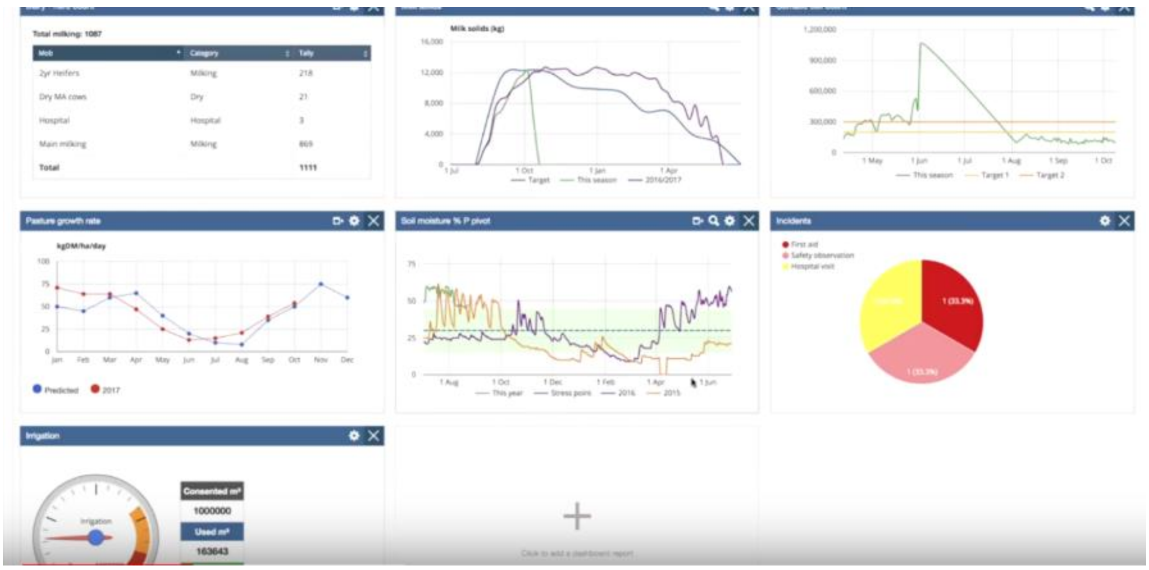

Figure 16: Customised Farm Dashboard from FarmIQ software (FarmIQ, 2017)

One FarmIQ employee refered to the software as a ‘BEAST’ due to how much is going on behind the scenes to make it work. The other telling comment was how many users request updates or changes that are often specific to their enterprise or decision process, and therefore difficult, if not impossible to accommodate.

Custom integrated platforms

The Australian dairy industry runs a diverse range of systems (feeding, calving etc) and subsequently, different ways of managing, and different Key Performance Indicators (KPIs). For this reason, a single, all accommodating software and analysis interface will be extremely difficult to create. If commercial products do not offer the ideal solution it may be better to invest in custom solutions specific to an operator’s needs.

For example, one Irish farmer visited by the author (See Figure 17) has a very strong data focus on their business KPIs. These are developed in strong consultation with share farmers and staff members and updated each year. Using an in-house system developed utilising the farm accountant’s spreadsheet expertise, staff use Google Forms to record vital farm information and this is collated and analysed to assess performance. They are further developing this to an online dashboard which better tracks and displays these key criteria. Staff engagement and development is also a strong focus with monthly recommended book lists and audio books encouraged in the workplace.

Figure 17: The Author on farm in Ireland and inset the monthly recommended reading for farm staff

Corporate farms also commonly invest in custom software solutions specific to their needs, and the persisting popularity of the humble Excel spreadsheet, for use by farmers and consultants alike, highlights the extreme importance of flexibility and customisable outputs in any new solutions offered.

Where is the ROI for software developers?

Despite investment in precision farm management and sensor technology reaching $363M globally in 2016 (Fildes, 2017) visible via a seeming avalanche of Agtech start-ups, it is also important to remember the limited size of the current market for software developers in the temperate pasture based dairy sector.

While cow-based software is largely applicable to every dairy farm in the world, those integrating temperate pasture specific modules would only apply to approximately 15% of the overall market (International Dairy Federation, 2017). Remembering that 50% of Australian farmers are still using paper-based records and only 20% (at best) are choosing to measure pasture there is even less potential market return.

This is highlighted by the best examples of this software around the world resulting from government grants or similar subsidies. For example, the PastureBase Database controlled by Tegasc in Ireland (which integrates with the Agrinet platform) was developed through substantial investment from Tegasc because of recognised market failure in this area. Likewise, the FarmIQ software was the result of substantial investment by the sheep and beef sectors in New Zealand (New Zealand Government, 2017) before expanding to a dairy module. Perhaps this sort of additional investment is required to produce more user friendly and powerful software which will, in turn, increase uptake and the potential market share of software craving dairy farmers.

In summary, integrated software solutions offer the most promise for helping farmers make decisions from data yet creating integrated solutions that meet everyone's needs is difficult.

Custom solutions, specific to individual enterprise KPIs, are possible and may offer the best outcome in some situations.

Additional investment from Government or other programs may be required to maximise software power and effectiveness and resulting industry benefit where a market failure exists.

Chapter 6: Internet of Things (IoT)

The term Internet of Things (IoT) refers to connecting virtually every possible device to the internet where information can then be shared between devices or collated and displayed in some sort of electronic platform. In homes the IoT will include not only appliances (e.g. tv, fridge, washing machine, lamps etc) but also people, through phones and wearable devices. If this idea is applied to a connected pasture-based dairy farm the number of potentially connected devices is almost endless.

Many farms that have access to reliable internet infrastructure will already have the start of an IoT system in place (maybe without realising it). This could be as simple as a smartphone with a farm app, a soil moisture sensor with a web portal interface, or a web-based security camera. However, more complete integrated IoT systems remain rare outside of University based 'Smart Farm' type installations.

The author's vision of what a more complete system may look like in a reasonably basic form using technology currently available today, is shown in Figure 18. Through this sort of network of monitoring it should, in theory, be possible to make the right grazing and right feeding decision every time. At the very least, such a system should help an inexperienced operator to perform at an elite farm management level.

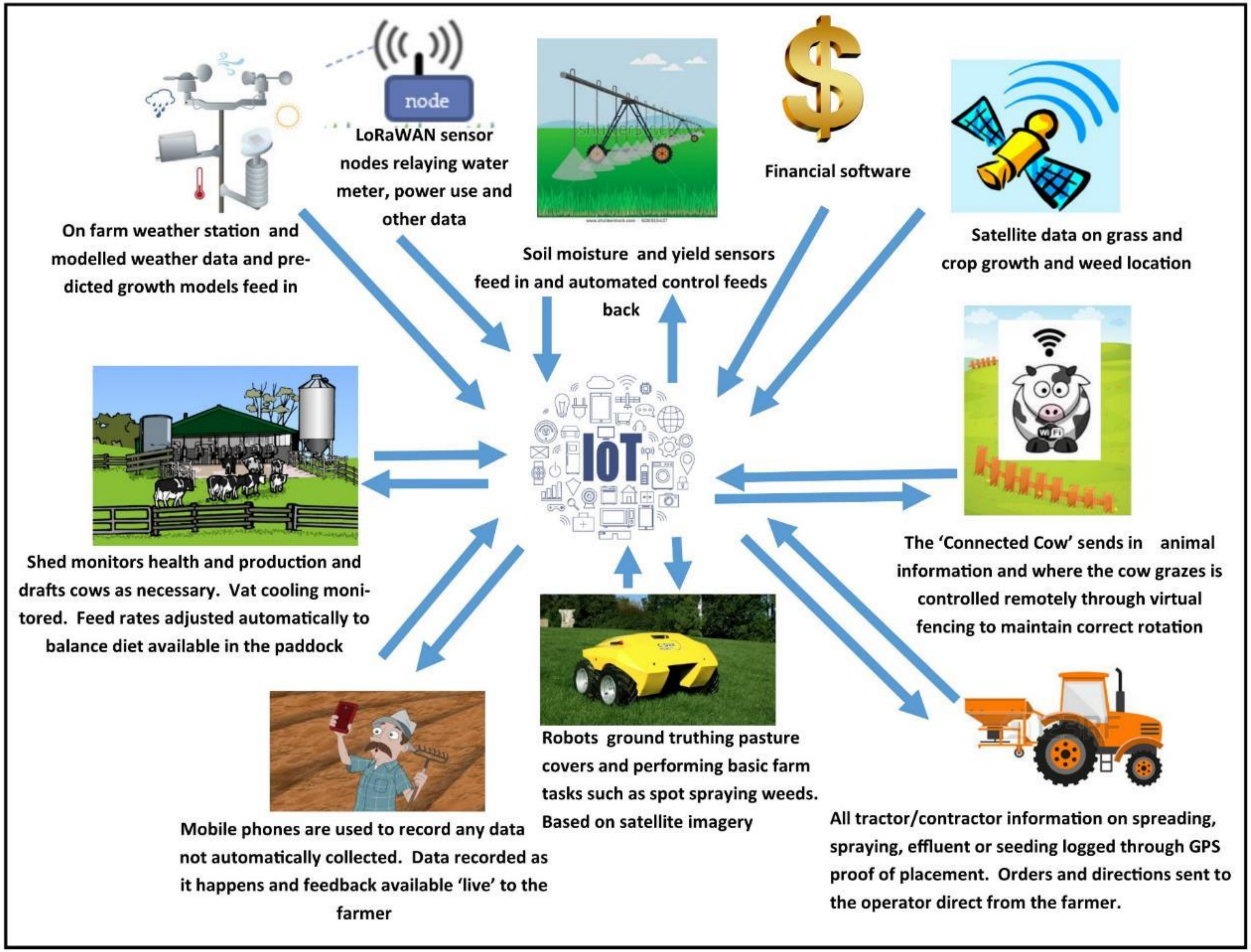

Figure 18: The authors vision of a Farm IoT Network

Getting data to the internet is the easiest part, with many devices already setup to communicate in this way (through WIFI, Bluetooth, 4g, Z-Wave, Zigbee etc.). The difficult part is enabling connections between (often propriety) devices and software and ultimately designing an interface that can analyse the data and provide valuable insights (customised to individual operations). This is where investment is most required and where the key lies to helping farmers make profitable decisions from data.

As one conference speaker noted (Harvesting the Benefits of Digital Agriculture – Australian Farm Institute, Melbourne 2017), it is perhaps better referred to IoT as IoPT, the "Internet of Profitable Things" to ensure focus is maintained on outcomes from this technology and not simply creating more data.

To summarise, a robust, completely integrated IoT farm network should allow farmers to make more accurate decisions more often. Creating this in practice is not easy and robustness, connectivity and integration of data sources remains an issue.

There is a need to focus on what data should be collected rather than what data can be collected. Consequently, build an IoT network gradually with most essential data sources first. A good start is making full use of mobile phones/devices to collect data when and where it happens.

Chapter 7: Making Decisions from Data

Start with doing compliance well

Data is often solely collected as part of farm compliance and licencing requirements. Compliance data collection is important and necessary, but substantial value is lost if done solely for this purpose, especially if data is back entered. Increasing regulation and compliance requirements can be the driving force for creation of powerful integrated software and technology solutions (i.e. New Zealand nutrient regulations driving development of Ravensdown Hawkeye). The acceptance that compliance records must be kept, and therefore kept accurate, live, and up to date, can help foster a data collection attitude within the workplace from which, not just compliance, but valuable information and resulting decision making can occur. Once this culture of strong data collection is in place it can be expanded to other aspects of key importance to your business.

Criteria for decisions from data

As the number of data sources available grows rapidly, the key criteria in ensuring good decisions are made from data remain largely the same as they have always been. Some key points are:

- Data should only be recorded if it can be translated into a meaningful action. Stay solution focused. How much data is needed? Don't look at what information can be recorded but what data will provide the most benefit to the business. What are the KPI's and how can data collection help reach them?
- Data should be collected regularly and accurately, remembering absolute accuracy may not be necessary providing trends can be identified.
- Systems for data collection must be robust and reliable. This includes both technology used, such as farm networks and sensors, along with any manual entry required by staff or farm operators.
- Limitations of potential data sources (i.e. accuracy) must be understood and considered.
- Data should be live and up to date so timely decisions can be made.
- A well-designed system should allow zero duplication of data entry – entered once only or recorded automatically through robust sensor options.
- Ultimately the data must be trusted (with reasonable common-sense checks in place)

Conclusion

Advances in technology undoubtedly offer the potential to better use data for more timely farm decisions. However, before making substantial investments in new technology it is very important to have a clear understanding of what is trying to be achieved, and to ensure the simpler and lower cost options that are available have first been exhausted. If poor cow health is a concern in a herd, is it better to invest in technology to detect when each cow becomes sick, or to address the reason and prevent the issue in the first place?

As an industry, the current utilisation of technology and interest in recording and utilising data is low. While Figure 19 below pertains to potential value from progressing knowledge of pasture measurement, the author would argue a similar pattern would hold true for knowledge in most aspects of farm businesses. In this regard, technology and data use at an industry level still lies somewhere between 'low' and 'good'. It is important to ensure the 'good knowledge' level is reached, utilising existing technology and data sources as well as sound farming principles and procedures before making substantial investments to make the jump to the 'perfect knowledge' level that many of the new technology offerings are attempting to provide.

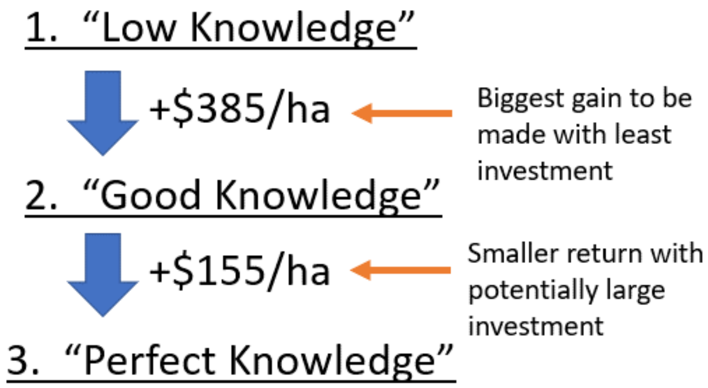

Figure 19: Potential value of Pasture Measurement (Adapted from DairyNZ, 2017)

This study initially had a vision of creating a fully integrated IoT dairy farm generating 'perfect knowledge' from autonomous data collection and guided decision making (See Figure 18). While this is still something that will most likely be gradually worked towards, the primary focus will return to ensuring the "good knowledge' level is being continuously reached in all aspects of the business and that data is used to help ensure key performance metrics (financial and social) are met.

Better engaging staff in both the development of these metrics and the value of data in achieving these metrics, as well as better utilising the smartphone at their fingertips to record data where and when it happens, will be a primary initial focus.

Recommendations

1. Have a clear understanding of the key performance metrics important to the business (financial and social) and understand what they are trying to achieve from collecting data before investing in technology. Explore simpler options first, have realistic expectations of what technology can deliver and understand limitations it may have.
2. The immense value of investing in comprehensive centralised data software solutions (such as LIC in NZ and PastureBase Ireland) should continue to be recognised by the Australian dairy industry. The resulting modelling, planning and research benefits are immense. A focus should be placed on building on the framework/principles developed by DataGene for cow data and expanding to pasture and other farm data and resources (i.e. better use of the SenseT platform).
3. Dairy training programs need to better integrate digital agriculture to both increase interest in agriculture as a career, and to help maximise the use and effectiveness of available technology on farm.
4. Agricultural software and technology developers need to be open to integration with other products and providers (open data standards) and providing customisable solutions.
5. Technology and software developers should consider the following:
    a. Farmers do not want:
        i. to see more raw data.
        ii. to have to log on to multiple apps and websites to access information.
        iii. to complicate their systems.
    b. Farmers do want:
        i. data summarised as valuable information in customisable dashboards from integrated data sources.
        ii. to receive exception (outside of normal operating) notifications (e.g. be told what is going wrong, not everything that's going right).
        iii. robust, simple and reliable solutions.

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Plain English Compendium Summary

Project Title:	**Dairy Data - Utilising Technology For Decision Making In Pasture Based Dairy Farming**
Nuffield Australia Project No.:	1701
Scholar:	Duncan Macdonald Macdonald Dairies 1659 Murchison Hwy Tasmania, Australia.
Phone:	+61 429 187 618
Email:	duncanandshannonmac@gmail.com
Objectives	• Investigate technology, software and data collection tools currently being used by pasture-based farmers and the data/outcomes they provide. • Investigate new technology on the horizon and its potential use and benefits. • Understand how to best integrate data sources to allow live, up to date farm decisions. • Understand what is required for farmers to make valuable decisions from data
Background	New technology and low-cost sensors now make it possible to monitor almost every aspect of grazing-based systems. From the connected, virtually herded cow through to live readings on pasture biomass from automated robots. With almost anything now seemingly possible, it is ever more important to make the distinction between what data can be collected, and what data is actually needed.
Research	In addition to a thorough literature review (as referenced in this report) the author attended the 11th European Conference on Precision Agriculture (ECPA) in Edinburgh, the Forbes AgTech Summit in Salinas, California the Harvesting the Benefits of Digital Agriculture – Australian Farm Institute conference in Melbourne. Additionally, farmers, researchers, software developments and providers were personally interviewed during travels to the Midwestern United States, the UK, Ireland and to New Zealand.
Outcomes	Block calving, grazing based dairy systems are inherently robust and simple in their success. If digital agriculture is to successfully engage farmers to move past this to more elite data driven decision making it must do so without overly complicating the day to day operation or compromising these existing strengths.
Implications	The stark contrast between what is now technically possible, and the slow progression of technology uptake by much of the industry highlights a lack of proven, clear financial benefit. It is perhaps in other areas such as helping to meet ever increasing compliance demands, improved animal welfare outcomes and maintaining a social licence to farm that technology may have the biggest impact in the future.
Publications	Presentation at the 2018 Nuffield National Conference, Melbourne, Victoria