TECHNOLOGIES FOR MEASURING GRASS/CROPS

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Introduction

On-farm pasture cover is a key variable in profitable dairy farm management, and formal feed budgeting is used on about 20% of New Zealand dairy farms (Clark *et al.* 2006.). As farms have grown in size, larger teams of people with a range of skills and experience are being employed but many farms struggle to assess pasture cover on a regular basis. This task is particularly difficult to schedule during spring due to the demands of calving, however this is a critical time of the year for feed budgeting as poor pasture allocation during this period can have long-lasting consequences throughout the season. More accurate and timely information on pasture cover would allow cows to be better fed throughout the year by optimising decisions on rotation lengths, supplementary feeding, nitrogen fertiliser use and conservation. Research from Australia (Fulkerson *et al*., 2005) reported that it was possible to improve pasture use with an improvement in production by more than 10%, even in well managed pasture, if accurate measurement of pasture mass could be achieved.

The most accurate method of measuring pasture cover is to cut, weigh and dry all the material present – not something that is feasible on a dairy farm. Therefore, a number of different methods are used to estimate pasture cover. With any technique there are errors, the extent of which depends on the individual tool being used, and their relative importance must be assessed in relation to the decisions being made. All methods of pasture measurement require calibration. The more accurate the calibration, the more accurate the pasture cover estimation.

Traditionally, pasture cover has been estimated by visual assessment, rising plate meters (RPM) or electronic probes. The plate meter gives a reliable estimate of pasture cover when at least 50 readings per paddock are taken in paddocks ranging from 1000 to 3500 kg DM/ha and appropriate calibrations are used (Lile *et al*. 2001). All the above methods are skilled, time consuming processes that rapidly become monotonous when done with the frequency needed to make effective management decisions. The frequency of pasture assessment required can be farm specific; however, it is recommended that during the peak growing season, pasture cover be assessed at least every 7-10 days.

In recent years, some new products have emerged on the market, that address the time constraints. They include tools that can be towed (C-DAX Rapid Pasture Meter) or attached to (Automatic Pasture Reader) an all terrain vehicle (ATV) or utility/car. While these reduce the labour required and the between-operator variability of manual methods, they still require staff to complete the task. In some instances pasture measurement can be incorporated into other farming practices e.g. collecting the cows for milking, setting up break fences or weed control. However, this may involve only a subset of paddocks on the farm. When obtaining pasture cover for all paddocks on the farm, vehicle mounted tools are most efficient on farms with gateways at the front and back of every paddock. Farmers, consultants and technicians would welcome an accurate technique that could be delivered in 'real time' with minimal human intervention. Thus, remote sensing from satellites has been investigated as a means of monitoring both the quantity and quality of vegetation in a range of environments (Clark *et al.* 2006).

While there has been considerable effort spent on measuring pasture cover there has been less effort directed to the measurement of pasture quality. Currently, there are no commercially available tools to estimate any of the parameters of pasture quality in paddock, in real-time. All quality parameters, including metabolisable energy, crude protein, water-soluble carbohydrates and fibre can be measured on dried samples by Near-Infrared Reflectance Spectroscopy (NIRS) or 'wet' chemistry. There are several laboratories in New Zealand that provide this service, however, the analysis may take days to complete and report by which time the pasture has been consumed. Moreover, the value of this information for on-farm decision making is yet to be determined. A component of the dairy industry believes that if you manage 'quantity' correctly, quality will look after itself. Pasture quality becomes an issue when pre and post-grazing targets are not achieved, which is common on many dairy farms throughout New Zealand. Quality sensors are used in arable and horticultural industries. Recent work has assessed the usefulness of both proximal (hand-held and quad bike-mounted) and remote (satellite) sensors for the dairy sector.

This paper outlines the attributes of the new and emerging pasture measurement tools and describes how they might be incorporated into dairy farm systems in the future. All the tools described above provide alternative data sources for the range in feed budgeting software packages that are currently available.

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Assessment methods

Rapid Pasture Meter

The rapid pasture meter concept was originally developed by Massey University's, New Zealand Centre for Precision Agriculture, to provide a fast and reliable method of measuring and mapping pasture cover (Lawrence *et al*., 2007). A number of measurement concepts were considered but it was felt that the simple idea of a series of interrupted light beams used to create an accurate profile of the pasture would be as accurate as alternative methods. In addition the light beam concept suffers from fewer environmental problems in terms of measuring pasture under different weather/moisture conditions and could be produced at lower cost than many of the alternatives. After further development the Rapid Pasture Meter, now produced by C-Dax Systems Ltd, was commercialised.

The inventors of the Rapid Pasture Meter felt that it was also important to measure residual pasture levels in order to achieve better pasture utilisation i.e. monitor post grazing targets. The Rapid Pasture Meter has been designed to operate in this extremely difficult environment.

When the Rapid Pasture Meter was being developed, comparisons were made between intensive sampling within paddocks and taking a simple transect using a rising plate meter. While some transects were representative of the paddock it was found that errors of up to 60% could be introduced. This was not because the individual readings were incorrect; it was simply that the route taken by the operator was not representative of the whole paddock. A similar issue emerges when considering how many readings should be taken in order to make an accurate measurement of a variable pasture. A sufficient number of samples must be taken in order to reduce error. The pasture meter measures at approximately 200 times a second; at speeds of up to 20 km per hr this gives the distance between individual measurements as 0.028m. These measurements are recorded and can then be averaged over the paddock to give a pasture cover estimate. When the Rapid Pasture Meter is driven to cover the whole paddock for mapping purposes it should be driven in parallel passes similar to that used when spraying or spreading fertiliser. The data can then be analysed using geostatistics to generate a pasture map (Figure 1).

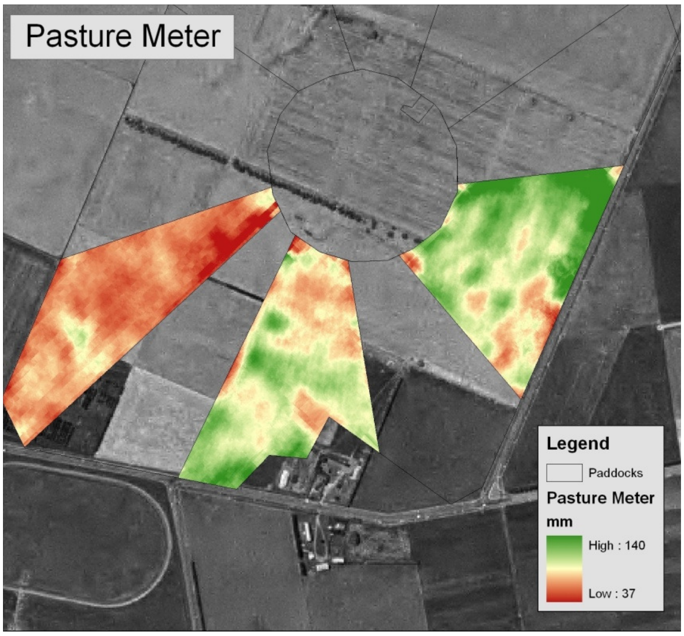

Figure 1. Pasture map 3 paddocks on the north block of the Lincoln University Dairy farm generated using the Rapid Pasture Meter and geostatistics

The Rapid Pasture Meter has been designed to be simple to operate. The height of pasture is measured and this is used to estimate dry matter (DM) through a series of calibration equations. Initial calibrations are preloaded but the operator can input their own data according to pasture type or time of year. As with all methods of measurement, calibration is essential, in this case a simple linear function is used. Initial calibration trials were completed by Massey University and the linear calibration performed very well in comparison to more complex alternatives.

AgResearch and DairyNZ are now developing a universal calibration equation for the Rapid Pasture Meter as part of a Pastoral 21 funded project. A series of calibration cuts have been taken over a 12 month period on dairy farms in Northland, Waikato, Taranaki, Canterbury and Southland. Preliminary annual equations have been developed for Canterbury and Southland however these require further validation before release to the industry. Very strong relationships between rising plate meter height and Rapid Pasture Meter height have been determined across the range of normal dairy pasture cover (Figure 2). Above 3500 kg DM/ha

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(22 clicks on the rising plate meter using the winter equation) the relationship weakens; however inherent errors with pasture estimation occur with both methods above this cover.

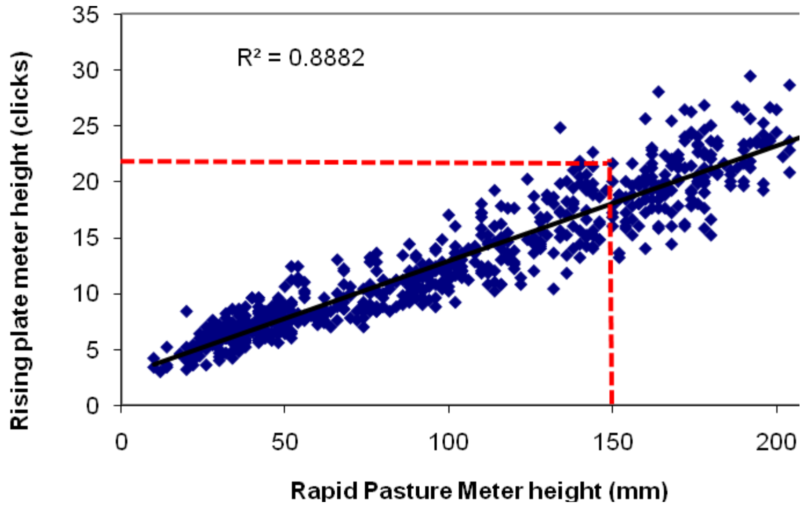

Figure 2. Relationship between rapid pasture meter height and rising plate meter height from calibration quadrats collected at Lincoln University Dairy Farm from November 2007 to January 2009

Automatic Pasture Reader (APR)

The Automatic Pasture Reader is the newest pasture measurement technology to enter the market. This unit is not commercially available in New Zealand yet, but has been advertised by Farmworks. More information is available at www.pasturereader.com.au. Developed in Australia, this unit uses sound technology, similar to that in fish finders, to measure pasture height. The unit and display are easily attached onto the front of an ATV or vehicle with a 12 volt power supply (Figure 3).

The developers claim that a 1 t DM/ha per year increase in pasture consumption, achieved through regular pasture monitoring, will result in a $20,000 saving ($200/ha) per year in supplements for an average Victorian dairy farm. Prototype machines used on Australian dairy farms resulted in less supplement required for the same production, more production with similar supplement intake, increased pasture quality on offer, more, higher quality silage being conserved and the ability to purchase cheaper cereal hay to feed with the higher quality pasture silage. All these benefits would be expected from regular pasture monitoring, however the Pasture Reader made this task easier to perform and, therefore, the job actually got done!

The average pasture measurement can be displayed as height (cm) and DM (kg DM/ha) or DM available per animal for that paddock.

Apparent advantages of the Pasture Reader, compared to existing measurement technologies, are

- It can either report total pasture available to ground level or available pasture above a set residual. This is achieved by either zeroing the unit on bare ground/concrete to get total pasture available or zeroing on a paddock with the desired post-graze residual to measure available pasture
- There are no moving parts and it can be mounted within the protection of bull bars on ATVs
- Permanently connected to the bike to be used as required
- Less between operator variability providing the machine is correctly zeroed.

Figure 3. Automatic Pasture Reader mounted to an ATV

Some issues to be aware of when using this equipment include

- The height of the bike needs to remain stable once the unit has been zeroed or the readings will be incorrect. Anything that changes the weight on the suspension e.g. weight or position of the rider, dogs jumping on the back of the bike and traversing hills, or turning at the end of runs will change the distance between the sensor and the ground and therefore affect the readings. The developers are currently working on a pause button to enable readings to be stopped if the rider is aware the suspension will temporarily change.

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- Calibrations for the machine are currently all based on Australian pastures
- None of the data available to date compare the yield predicted by the Pasture Reader with a yield estimated from an existing pasture measurement tool e.g. rising plate meter. All calibrations are based on cuts to ground level.

All we can say with this tool is 'watch this space'.

Remote sensing technologies

Remote sensing techniques, if successful, could provide regular estimates based on the whole paddock, delivered via the web, and in an electronic form ready for use by other decision support software. There are 2 possible remote sensing options for determining pasture cover being investigated – optical and synthetic aperture radar (SAR). Optical instruments (spectral satellites) measure reflected light from the pasture, with the extent of reflectance determined by biophysical characteristics at the leaf, whole plant and sward level (leaf pigments, morphology, photosynthetic processes, etc) and shadowing. Radar instruments respond to the bulk, shape, physical arrangement and electrical characteristics of the target. The optical and radar technologies should be seen as complimentary, measuring different aspects of the target, each with its own advantages and disadvantages.

Huge progress has been made in both forms of remote sensing technology over the past two decades. While radar technology has been around since WWII, imaging radars using the spacecraft/aircraft motion to synthesise very large antenna (SAR) are a development since the early 1980s in the civilian world. For both technologies, new satellites and sensors are going up almost on a weekly basis. These second generation instruments are a bit like moving from black and white to colour imagery. Earth observation is truly moving into the realm of operational commercial delivery and the choice of sensor, resolution and output will only continue to improve.

Spectral satellites (pastures from space®)

Different materials absorb or reflect light based on their biophysical characteristics. When the reflectance can be related to specific sensors or bands within sensors, useful indices can be developed that correlate with the material being observed. The Normalised Vegetation Index (NDVI) is the most widely used vegetation index for assessment of biomass and physiological state of plants. It is highly correlated with a range of biomass related variables such as green biomass, leaf area index, leaf cover, fraction of radiation intercepted or chlorophyll per unit of ground (Panuelas *et al.* 1998).

In June (2005) a joint venture project between Fonterra, Dairy InSight (now DairyNZ Inc.), Meat & Wool New Zealand, Dexcel (now DairyNZ Ltd), AgResearch, CSIRO and participating farmers commenced on 8 farms in the Waikato region (Clark *et al.* 2006, Mata *et al.* 2007).

In intensively managed dairy systems, with extremes in biomass from pre-grazed to post-grazed paddocks, NDVI loses sensitivity at high leaf area index levels (Steyn-Ross *et al.* 1998) or with high chlorophyll content (Gitelson *et al.* 1996) and can also be influenced by the proportion of bare ground or dead litter relative to green biomass at low post-grazing residual levels. These factors can also vary depending on seasonal conditions and farming practices. Consequently since early 2008 the vegetation index used to develop the Pastures from Space tool in New Zealand has also included the 'green' and 'short wave infrared' (SWIR) bands of the SPOT satellites. In this way, the developers aim to better account for exposed soil and litter (SWIR band, Nagler *et al.* 2000) and the changing proportions of leaf chlorophyll as pastures mature in late spring and early summer (green band, Gitelson *et al.* 1996).

Encouraging results from this project (Mata *et al.* 2007) resulted in a submission to the Foundation of Research, Science and Technology for a 3-year programme of work to complete the work in the Waikato and extend the development into Canterbury. The current project is funded by FoRST (Government), Fonterra and DairyNZ Inc, through the Pastoral 21 initiative.

Procedure

Ten farms in the Canterbury region within the footprint of one SPOT satellite image (60x50 km, www.spotimage.fr) were chosen to test whether the algorithm (equation converting the vegetation index to pasture cover) developed for Waikato dairy farms would accurately predict pasture mass in Canterbury. The farms were chosen to represent the variability in irrigation practices, soil types and time since conversion observed in Canterbury. The Lincoln University Dairy farm is located in the north east corner of the image which then extends west as far as Te Pirita and South below the Rakaia River to Seafield (Figure 4).

When a clear (minimal cloud cover) satellite image (Figure 4) is obtained, CSIRO map the ground coordinates of each farm onto the image. Field measurements of pasture cover for comparison with the satellite estimates and for the calibration of the satellite imagery are collected by DairyNZ and AgResearch staff. Five paddocks are selected on each farm to achieve as wide a range of pasture cover as possible and sampled according to the agreed protocol based on measurements with the rising plate meter. A series of transects are plated across a 60 x 60 m marked grid which is placed in the selected paddocks. The sampling path is recorded with a global positioning unit (GPS). Conversion of rising plate meter data to biomass is carried out using equations published by DairyNZ, which represent the industry standard for

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monitoring pastures in New Zealand. In Canterbury the winter equation (kg DM/ha = hgt (clicks) x 140 + 500) is used throughout the season.

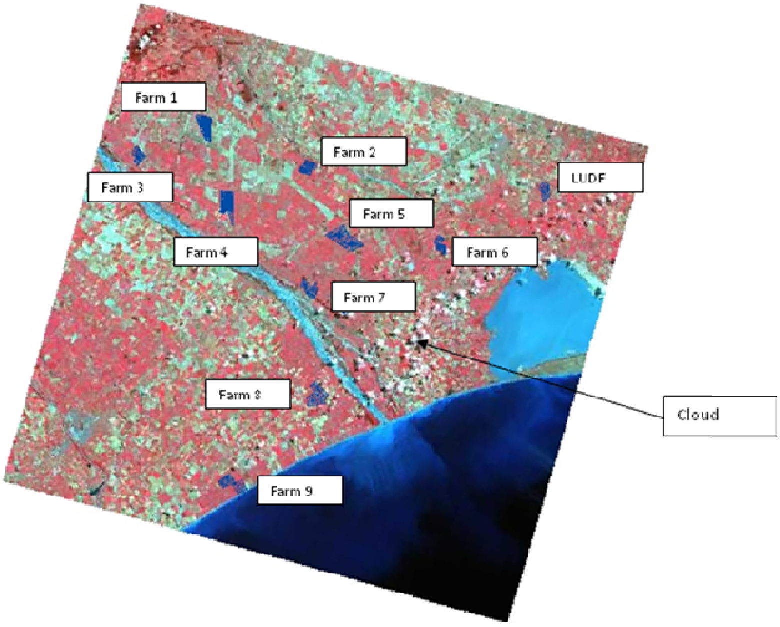

Figure 4. Spot satellite image of Canterbury showing location of the monitor farms

A total of six images were captured and data collected between August 2008 and March 2009. Due to delays in digitising the farms and mustering a fully competent sampling team only the last 4 images involved field measurements by the technical team. For the images collected on 14th August 2008 and 21st October 2008 farmer cover estimates collected within 3 days of the satellite image were acquired for comparison. For images collected on 12 January, 8th February, 1st March and 15th March all ground data acquisition on a minimum of 5 farms was completed within 4 days of image acquisition minimising error increments from additional pasture growth between image and ground measurements and management activities. In addition to the 5 detailed grids collected from each farm, average pasture cover data was estimated from at least 20 paddocks on each farm using farmer best practice farm walking procedures. This involved walking a diagonal track with the rising plate meter across each paddock, incorporating at least 2/3rds of the length of the paddock. Ideally these tracks would be from corner to corner in each paddock; however the size of many of the paddocks and farm layout meant that this was not possible in the time available on each farm. This highlights the difficulty in using the rising plate meter to provide accurate estimates of pasture cover in large paddocks typical of Canterbury dairy farms. On the last sampling in March the Rapid Pasture Meter was also used to measure pasture height and predict pasture cover. The farmer best practice dataset was used to assess the accuracy of the satellite predictions derived using the data from the grids. Analysis of these results is ongoing.

Initial results from the 2009 images are encouraging. While it is likely that some modification to the Waikato algorithm will be required to more accurately (as determined by comparison with the rising plate meter) predict pasture cover under irrigated Canterbury conditions the results to date show good alignment in paddock rank from highest to lowest pasture cover between the two methods of estimation (Figure 5). Pasture cover range (the difference between maximum and minimum pasture cover) for both field observed and satellite predicted pasture covers were shown to have a major effect on the ability to rank paddocks accurately in the Waikato in 2007 i.e. the smaller the difference between the highest and lowest cover paddock the more difficult it was to rank paddocks accurately. For many farmers the ability to rank pastures would be a step up from their current situation where farm walks are not done on a regular basis. However, for those who already routinely monitor their pastures it is expected that the satellite technology will need to be as good as, if not better than, their current methods to warrant change. Alternatively, if the new technology can offer additional benefits or cost/time savings adoption is more likely to occur.

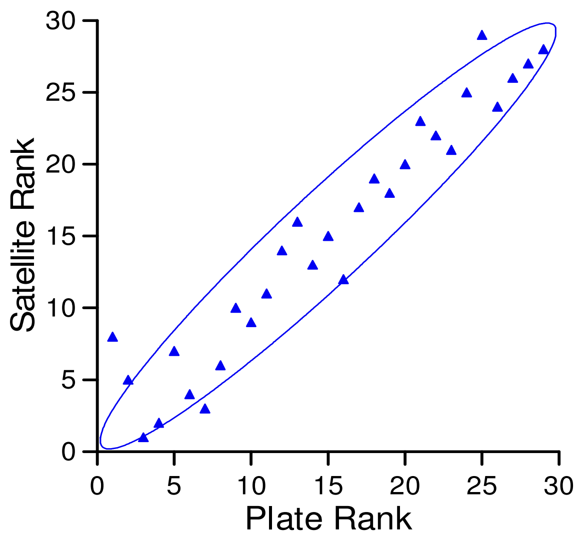

Figure 5. Relationship between plate meter rank of individual paddock pasture cover and satellite estimated paddock cover rank for Farm 2 data collected 3 March 2009. (Kendall Tau co-efficient = 0.84)

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The Australian experience

In Western Australia (WA) pasture utilisation, a key driver of profitability is low; generally between 20 and 30% (Michael *et al.* 1997), as farmers manage the risk associated with seasonal variability in the start and finish of the green phase of growth by adopting conservative stocking rates. Attempts to improve pasture utilisation have failed due to the low adoption of pasture measurement techniques, despite strong push by industry bodies to train producers in monitoring practices. The universal issues of lack of time, labour units or a clear understanding of potential benefits (in an extensive grazing system) have limited the adoption of monitoring practices essential for strategic and tactical decision making at the paddock and farm level.

Economic analysis of producers who have adopted the Pastures from Space PGR tool (www.pasturesfromspace.csiro.au) has shown increased productivity (stocking rate up by 1 to 4 dry sheep equivalents per hectare) and profitability (increased gross margin profit between $21 and $63/ winter grazed hectare) compared to their own performance prior to adopting PGR. Producers related these improved economic indicators to greater confidence and timeliness in decision making, based on sound pasture data (Gherardi *et al*. 2004, Clark *et al.* 2006).

The future in New Zealand

In the next 12 months an additional nine images will be collected in Canterbury during the period August 2009 to April 2010. This will enable further testing of the Waikato algorithm and if necessary sufficient data to develop a Canterbury specific algorithm. Additional work will be undertaken in the Waikato to collect data on autumn saved pastures that have currently been excluded due to the difficulty in accurately estimating pasture covers above 3500 kg DM/ha with the rising plate meter. The third component of the project over the next 12 months will be to engage with potential commercial partners to develop a business case for commercial delivery of PfS cover estimates to dairy farmers by 2012.

Radar

While the scientific literature has examples of radar being used to monitor crops and forests, few examples occur with a focus on pasture. Two key characteristics of radar are potentially very advantageous for routine pasture monitoring. First, in theory, it responds more directly to the field pasture bulk when compared to optical methods. Secondly, radar “sees” through cloud and light rain, and can operate at night or day, making the scheduling and acquisition of regular imagery simpler. On the downside, radar images appear ‘noisy’ as a result of the method of imaging used, so the imagery is not as crisp as an equivalent optical image. To overcome this, the radar imagery needs to be averaged over an area to provide robust estimates of pasture cover. It is also in general more difficult to interpret than optical imagery as a large number of factors could influence the radar return.

One objective of the Pastoral 21 programme is to evaluate synthetic aperture radar (SAR) technology for pasture monitoring. This required access to imagery from Germany's TerraSAR-X satellite instrument as part of the international science team researching applications for the DLR (German Space Agency). Since February 2008, 21 TerraSAR-X images of the Lincoln University Dairy Farm have been acquired. Nearly all were taken during the milking season - mostly in the 2008/09 season. The images are timed to be as close as possible to the weekly (Tuesday) farm walk, where a transect across each paddock, using a rising plate meter, is used to estimate the pasture cover for each paddock.

Images have been taken with a variety of different transmit/receive polarisation and incident angle parameters to find out which combinations, if any, are sensitive to pasture cover. The aim is to confirm that radar imagery is sensitive to pasture cover, and then focus on characterising the impact of other factors such as moisture, soil, pasture species, slope and aspect to refine the pasture cover estimate.

Initial results from this work are promising and as can be seen in Figure 6, within a typical image, visual differences can be seen between paddocks relating well to cover. While relative differences within one image are clear, estimating absolute cover from a new image is more difficult as the return for the whole image can bias up or down depending on prevailing conditions. Understanding and correcting this is the focus of the current work. At this stage cover can be estimated from a new image to approximately 10% on a whole paddock basis when compared to the rising plate meter results.

If the research provides a robust means of estimating cover using SAR imagery, then it seems natural that this technology should be integrated with the Pastures from Space project which is based on optical remote sensing technology. Depending on the relative accuracies of the different techniques, the cost of purchasing and processing imagery, and satellite orbit constraints, a mixture of imagery could be used along with weather information, climate and grass growth models to provide farmers with cover estimates, or at least paddock rankings on a regular basis. Information would be delivered via the WEB, most likely on a subscription basis. At this stage the relative performance of radar technology for this application is unknown. However, even if inferior, radar could have a role where cloud or orbit constraints would otherwise result in significant gaps in the satellite coverage.

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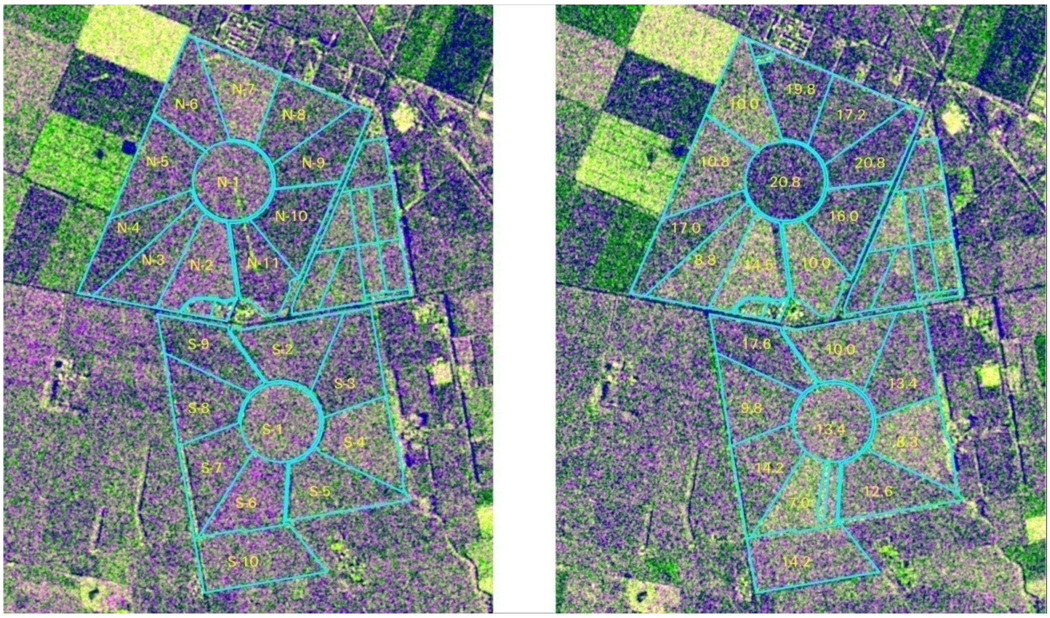

Figure 6. Radar image for the Lincoln University Dairy Farm with different dates (25th February (left; showing the paddock names) and 18 March (right; grass length in half cms (clicks)), polarisation (HH and HV) and view angles

Initial results from remote sensing technologies have been encouraging. Integration of remote sensing technologies with pasture growth simulation models, to cover periods when images may not be available, is now a feasible option.

Pasture quality

Metabolisable energy and crude protein are usually the focus in considering pasture quality. In New Zealand focus has historically been on the energy component of pasture, in the knowledge that the crude protein content of pasture is always in excess of cow requirements. In the future, however, the need will be to balance increasing intensification of farming systems with high performance cows, increasing input costs, profitability and environmental outcomes. Knowledge of crude protein content of pastures is likely to be of increasing importance as the dietary proportion of high energy, low protein forages increases and nitrate leaching caps are enforced by regional councils. The term pasture quality can mean different things to different people as energy, fibre, protein, sugars, vitamins and minerals all contribute to ‘quality’. For most dairy farmers, metabolisable energy is the most important parameter. Quality is driven by pasture species composition, the ratio of green matter to dead matter, stem to leaf, reproductive state of the plant and climatic conditions. As systems intensify and supplements are fed, the relative importance of components of the diet changes. For example, optimising effective fibre intake of a diet which includes pasture requires knowledge of quality parameters.

In dairy pastures consistently grazed to a pasture residual of 1500-1700kg DM (7-8 Clicks of RPM), there will be only a limited decline in quality through late spring and early summer as pastures 'harden off' (Figure 7). Pasture quality will, however, drop significantly if the amount of dead matter, stem, weed and seed head is allowed to accumulate. Increasing temperatures and higher or inconsistent residuals can drive pasture quality down. For many systems maintaining quality is a real challenge.

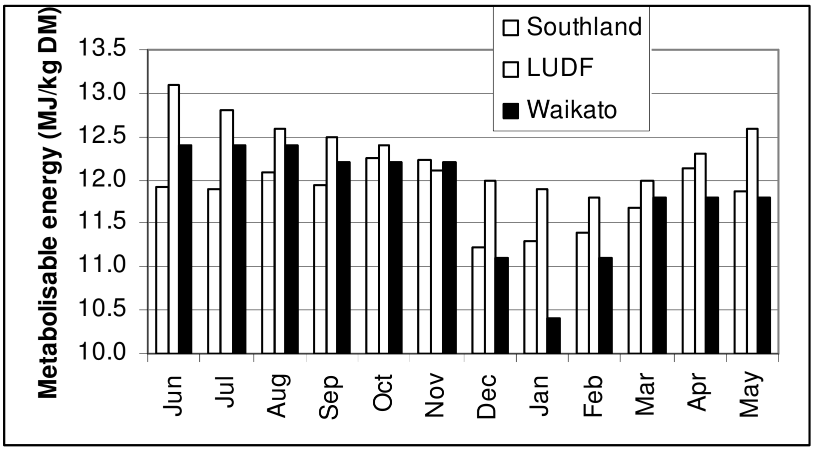

Figure 7. LUDF (2004-2007) (□) Southland (2007-2009) (□) and Waikato (RED trial control 2001-2007) (■) monthly metabolisable energy per kilogram dry matter

Currently pasture quality assessment can only be carried out in the laboratory. For quality to be a key driver of tactical decision-making, timely, accurate and inexpensive methods which assess standing pasture are required. A few indirect methods for quality measurement exist, either on the farm (visual, botanical composition, green herbage mass, Q-Graze) or in the laboratory (Near Infrared Reflectance Spectroscopy or 'wet' chemistry). The opportunities to incorporate pasture quality parameters in daily decision-making require sensors that measure the standing quality of pasture. The Pastoral 21 Feeds programme is evaluating two potential sensors:

1. The Crop Circle ACS470 sensor (Holland Scientific) uses an active light source and measures three channels in the NIR (Near Infrared) and VIS (visible) range and measures

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crop reflectance, biomass and nitrogen status. It is currently a tool for arable farmers in North America and Europe to use the sensor maps for the targeted application of nitrogen, growth regulators and fungicides.

2. The CROPSCAN, (CROPSCAN, Inc.) was also developed for arable farming systems. It has 16 bands and uses ambient light. It was developed to improve the assessments of various factors on plant health and yield. It does not give output continuously and is carried manually. When each reading is taken the unit needs to be held stationary for 10 seconds. This makes it unsuitable for use in extensive measurement or mapping, but it could still be used for calibrating other instruments.

The current evaluation process will determine the opportunities to use these existing sensors in pastoral systems. The sensors have both been used extensively in arable farming systems for assessing plant nitrogen content and automated precision application of nitrogen fertiliser. These sensors may have a future role in precision management of nitrogen in pastoral dairy systems, but calibration and validation are required.

Summary

Estimating pasture cover on dairy farms is an important part of the feed budgeting process, without which decision-making can be seen as just guesswork. The Lincoln University Dairy Farm, over the last 5 years, has demonstrated the benefits of pasture assessment for both day to day management (average pasture cover, surplus identification, supplementary feeding decisions etc.) and more strategic decision-making (identifying paddocks for renovation, assessing stocking rate vs. pasture supply curve etc.). The challenge for the dairy industry is to offer tools that enable the 70-80% of farmers, who currently don’t monitor their pasture routinely, to schedule this task into their regular activities.

There is now a variety of tools available and more under development, all of which have the ability to change the way pasture is assessed. The variation in farm size, terrain, staff number and ability suggests that the solution will not be a ‘one size fits all’ approach. It will be up to the individual to decide which tool or tools are most appropriate for them. Table 1 summarises the current and developing pasture assessment tools and ranks them on a number of criteria. All methods of pasture measurement require calibration. The more accurate the calibration, the more accurate the tool. However, the degree of accuracy required will depend on the end use of the information. For example, if the information is being used to rank the paddocks from highest to lowest to calculate which paddock to graze next, then the accuracy, relative to the actual cover present, is less important providing the tool ranks the paddocks accurately. By contrast if the information is being used for pasture allocation or making decisions around average pasture covers for drying-off then a higher degree of accuracy is required.

What the future holds for pasture assessment is easy to predict. The current tools will continue to improve as new versions are developed and integrated into existing software packages. The question is "will they be left to collect dust in the shed or office after the honeymoon period?" Therefore, the challenge for the New Zealand dairy industry is to convince producers of the economic, environmental and social benefits of adopting regular monitoring practices and to achieve the level of adoption necessary to maintain international competitiveness. For remote sensing technologies the challenge for the project team is to convince potential commercial providers that there is a viable business case and that farmers would engage such a service if it could be demonstrated that it was user-friendly, cost effective, reliable and accurate.

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Table 1. Evaluation rankings for current and developing pasture assessment techniques

	Plate meter	**Visual (calibrated)**	**Laneway Drive by**	**Sward Stick**	**Rapid pasture meter**	**Automatic Pasture Reader**	**Spectral Satellite**	**Radar**
Speed	✔	✔	✔ ✔ ✔	✔	✔ ✔	✔ ✔	?	?
Ease of use	✔ ✔	✔ ✔	✔ ✔ ✔	✔ ✔	✔ ✔ ✔	✔ ✔ ✔	?	?
Accuracy	✔ ✔	✔ ✔	✘	✔ ✔	✔ ✔	?	✔	✔
Ability to calibrate	✔ ✔	✔ ✔	✘	✔ ✔	✔ ✔	?	✔	✔
Representative of paddock	✔	✔	✘	✔	✔ ✔ ✔*	✔ ✔	✔ ✔ ✔	✔ ✔ ✔
Cost	✔	✔	NA	✔	✔ ✔	✔ ✔	?	?
Insensitivity to weather	✔	✔ ✔	✔ ✔	✔	✔ ✔ ✔	?	✔	✔ ✔
Consistency between operators	✔	✔	✔	✔ ✔	✔ ✔ ✔	✔ ✔ ✔	NA	NA
Portability	✔ ✔ ✔	✔ ✔ ✔	✘	✔ ✔ ✔	✔ ✔	✔ ✔	?	?
Pasture Friendly	✔ ✔	✔ ✔	✔ ✔	✔ ✔	✔	✔	✔ ✔ ✔	✔ ✔ ✔
Hazard Rating	✔	✔	✔ ✔ ✔	✔	✔ ✔	✔ ✔	NA	NA

✔ Low ✔ ✔ Medium ✔ ✔ ✔ High ✘ Not suitable ? currently unknown NA not applicable

*If used with GPS and mapping software