PASTURE MONITORING FROM SPACE

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Introduction

On-farm pasture cover is a key variable in profitable dairy farm management, and feed budgeting is used on about 20% of New Zealand dairy farms. 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. Currently, many farmers use visual assessment, rising plate meters (RPM) or electronic probes to obtain pasture cover estimates. Rising plate meters give reliable estimates of pasture cover when at least 50 readings per paddock are taken in paddocks where average herbage mass is between 1000- 4000 kg DM/ha (Lile *et al*., 2001). All are time-consuming processes, however, that rapidly become monotonous when done with the frequency needed to make really effective management decisions. Farmers, consultants and technicians would all welcome an accurate technique that could be delivered in ‘real time’ with minimal human intervention.

Remote sensing from aircraft or satellites has now been shown to be a feasible way of monitoring vegetation in a range of environments. Ten years ago at Dexcel we showed that digital video imagery from aircraft was capable of detecting differences in pasture cover at ‘break’ level within paddocks. In Western Australia sheep and cropping farmers are currently part of the Commonwealth Scientific and Industrial Research Organisation’s (CSIRO) “Pastures from Space” (PfS) programme with satellite-based pasture growth rate information delivered via a farmer-friendly tool “Pasture Watch”. For more information see the following websites: http://www.pasturesfromspace.csiro.au and http://www.fairport.com.au/PastureWatch

In 2002, Fonterra formed a partnership with CSIRO to investigate the potential use of this technology in New Zealand dairy farming. The expected outcome is a service that provides New Zealand farmers with ‘real time’ information on the quantity and quality of their pastures on a paddock basis.

Principles of pasture monitoring from satellite

Different materials have different spectral reflectance characteristics and these differences can be used to construct an index that is correlated with the amount of pasture cover. The Normalised Difference Vegetation Index (NDVI) is constructed from the near infra-red (NIR) and red (R) parts of the spectrum and is defined as NDVI= (NIR-R)/(NIR + R).

Green leaves have higher reflectance in the NIR than the R part of the range, whereas dead leaves have less. Consequently, a high NDVI is associated with high green, dense pasture covers.

The basis of the research is to use a series of pasture height measurements taken with a rising plate meter (RPM), and the NDVI (from the satellite information) for that area, and from these data sets build an equation to predict pasture height from NDVI. Using this equation the RPM height across an entire paddock, farm or region can be calculated – either as an average, or for each pixel (about 5 sq. metres). Height data can be converted to pasture cover (kg DM/ha) using standardized equations developed by Thomson *et al*. (2001). Pasture cover can then be used in Feedplan (Blackwell, 2002) to forecast feed budgets. Both RPM and calibrated visual assessments can account for 80-90% of the variation in pasture cover, and the error from these two methods in several studies is about 400 kg DM/ha. To be useful to New Zealand farmers satellite imagery will need to match or exceed these levels of accuracy.

The project covered here is a joint venture between Fonterra, Dairy InSight, Meat & Wool New Zealand, Dexcel, AgResearch and CSIRO with farmer participation and is jointly funded by the first three organisations. The project started in June 2005 and this paper outlines the methods used to collect data to validate the technology on New Zealand dairy farms and to identify the challenges to be overcome before the technology becomes a commercial reality.

Pasture cover

Procedure

Eight farms of flat contour in the Waikato region within the footprint of one satellite image (60 x 50 km) were chosen for the initial validation. There are 6 commercial farms, one Fonterra farm and the Dexcel Scott farm. Interest in the project and collection of regular farm cover estimates determined selection of these farms. On each farm, ten to 12 monitor paddocks with a minimum width of 60 m were set up with sampling grids.

When a clear (minimal cloud cover) satellite image (see Figure 1) is obtained, CSIRO map the ground coordinates of each farm on to the image. The ground sampling team is told that a farm is clear and farmers are alerted as soon as possible. Field measurements of pasture cover for comparison with the satellite estimates and for the calibration of the satellite imagery are collected by Dexcel. At each clear farm, five monitor paddocks are selected to achieve as wide a range of pasture cover as possible and sampled according to an agreed protocol based on measurements with a rising plate meter and with a proper understanding of spatial variability in biomass within and between paddocks in each farm. A series of transects are plated across the marked grid with a rising plate meter, recording the average RPM height at regular, defined intervals. The sampling path is recorded with a global positioning unit (GPS). Conversion of RPM data to biomass is carried out using the equations published by Dexcel, which represent the industry standard for monitoring pastures in New Zealand.

The data used to generate the correlation relationships compares the biomass estimates along the transects with NDVI from pixels superimposed on the transects using geographical Information systems (GIS) software (ArcGIS 9.1, ESRI).

The satellite images are acquired using the SPOT 4 and SPOT 5 satellites of the Spot constellation. Within a few hours of image acquisition, the data are downloaded to a base station in Toulouse, France and a quick-look image is posted on a dedicated web site (http://sirius.spotimage.fr/).

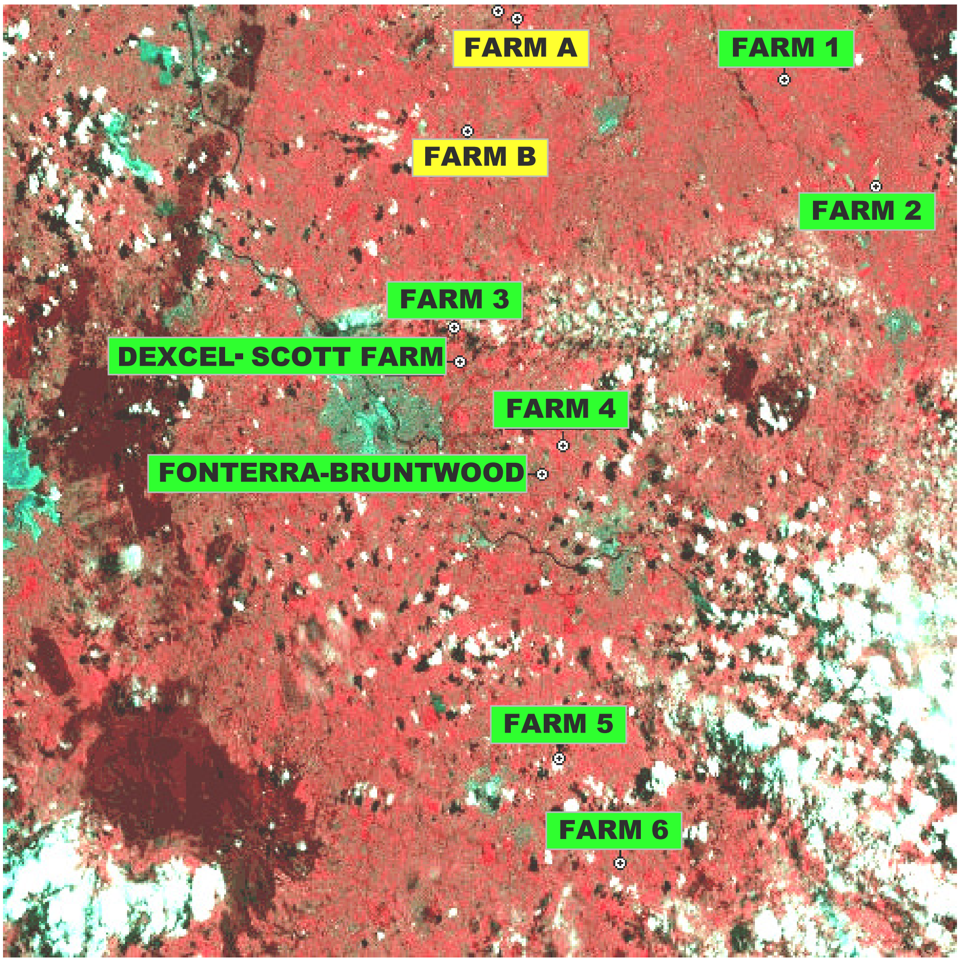

Figure 1: SPOT satellite image of the Waikato showing cloud cover, clear areas and location of monitor farms

Challenges

The first nine months of this trial have identified some important challenges. Very frequent and widespread cloud cover over the Waikato has meant that many fewer images than predicted have been available for further analysis. It is also evident that while some farms will have cloud free images, others on the same day can be "clouded in". Normal farm practices such as mechanical operations (eg topping, irrigation, effluent spreading, fertiliser application), pugged pastures, calf grazing and sudden changes in pasture management decisions will always create challenges in the collection of ground data. However, improvements in the understanding and implementation of the sampling protocols as the season progressed resulted in cleaner data and a lower incidence of failed relationships in the month of November. Analysis of the remaining images is necessary to determine if this trend is maintained.

Results and discussion

Image and ground data acquisition

A total of 13 data collections were carried out between mid August 2005 and early May 2006, but only those fully analysed up to November are presented (Table 1). In general all ground data acquisition were completed within 4 days of image acquisition, ensuring minimal error increments from additional pasture growth between image and ground measurements. Delays in initiating data collection in general were associated with delays in the satellite 'quick looks' being displayed on the SPOT website. The satellite angle of view was set at ±30º, to maximize the opportunities for regular acquisitions, which in general provided a look at the Waikato region every 2-4 days. A smaller angle would result in less coverage when the satellite path is not directly overhead of the area of interest.

Initial teething problems in scheduling satellite acquisitions and ground sampling teams resulted in only one image per month being acquired for the first 3 months of the trial. Better predictions of satellite availability and understanding of the operational practices of the satellite managers allowed better scheduling of human resources, aiming to avoid unnecessary 'stand-by' periods and the need for weekend sampling where possible.

NDVI and pasture cover correlations

Table 1 presents the proportion of variation (R^2) in RPM pasture cover explained by satellite NDVI for a total of 34 correlations for individual farms from August-November 2005. On initial analysis, eight are classed as 'Very Good' (R^2>0.85), 12 as 'Good' (0.7>R^2<0.85), four as 'Moderate' (0.45>R^2<0.7) and 10 as 'Poor' (R^2< 0.45).

Of the 10 poor relationships, eight occurred in the first 3 months of the project when some teething problems were identified with the implementation of the sampling procedures. The incidence of poor relationships in the last four images indicates that some of these issues were resolved. On 5 occasions the poor relationships were due to one paddock outlier, exclusion of this paddock from analysis improved the relationship significantly (R^2>0.80 in all but one farm where R^2=0.67). It is important to determine if management practices can also be associated with these specific paddocks, which may further explain the variation in these results.

Failed relationships included paddocks where the range in either biomass or NDVI was too narrow (see Figure 2, NDVI wedge graph). For example, in August one property showed a pasture cover range of 2600 kg DM/ha (2600 - 5200). The lowest value was about 900 kg higher than the average minimum measured in the other five farms sampled in August. The upper range was also greater than would be expected for the time of year and likely to be associated with conserved forage rather than paddocks within a normal grazing rotation. At this stage our intention is to treat higher biomass data from conservation or silage paddocks separately to the data from paddocks in a grazing rotation, if they can be identified. In two cases in November, one of the five paddocks in a farm was affected by cloud. Excluding these paddocks resulted in strong relationships for the remaining data (Figure 3).

Table 2 summarises the range of NDVI in each month on each farm. Sixteen out of thirty-six farms show NDVI ranges below 10 and of these, three in the month of August had an NDVI range below 3. Such narrow NDVI ranges are not sufficient to allow a proper comparison of satellite and ground data. Table 2 also summarises the range of pasture covers measured in each month on each farm. At the upper level, two farms had pasture cover ranges greater than 2500 kg DM/ha while at the lower end, five farms had ranges lower than 600 kg DM/ha.

Additionally, the average NDVI for all paddocks in each farm was calculated to get a better understanding of the potential full range in NDVI and their distribution in relation to the sampled paddocks. A sample graph is presented in Figure 2 as a) an NDVI map for a farm showing the five sampled paddocks and b) the 'NDVI farm wedge' with sampled paddocks. Although the paddock with maximum NDVI of 80 was sampled the lowest sampled NDVI was only 75, whereas the minimum paddock at this time had an NDVI of < 60. Sampling of more paddocks covering the full range of NDVI will allow a better test of the satellite imagery.

Table 1: Summary of the proportion of variation (R^2) in pasture cover explained by satellite normalised vegetation difference index at six sampling dates on eight farms

Farm No.	Aug-05	Sep-05	Oct-05	10 Nov-05	24 Nov-05	28 Nov-05
1	0.05	0.86	0.19 (0.90)	0.98	0.70	ns
2	0.51	0.02	ns	0.28	0.96	ns
3	0.75	0.76	0.02	0.07 (0.88)	0.78	0.82
4	0.71	0.22 (0.97)	0.86	0.89	0.83	ns
5	0.02 (0.82)	ns	ns	0.84[#]	0.75	0.78
6	0.02 (0.80)	ns	0.78	0.81	ns	ns
7	ns	ns	0.01	0.48	0.85[#]	ns
8	ns	ns	0.5	0.89	ns	0.97

ns = not sampled. [#]Paddocks cloud affected and excluded from correlation. Bracketed figures are where one outlier paddock is removed.

Table 2: Summary of the range for pasture cover (kg DM/ha) and normalised vegetation difference index (in brackets) at six sampling dates on eight farms

Farm No.	Aug-05	Sep-05	Oct-05	10 Nov-05	24 Nov-05	28 Nov-05
1	2539 (1)	1553 (15)	627 (6)	1347 (18)	488 (8)	ns
2	3355 (4)	1286 (20)	800 (-)	670 (8)	1099 (6)	ns
3	1649 (12)	1310 (7)	1304 (6)	1176 (10)	729 (17)	845 (7)
4	1118 (15)	1043 (8)	801 (13)	1152 (13)	512 (9)	ns
5	1650 (8)	ns	ns	1461 (12)	750 (17)	669 (10)
6	1007 (3)	ns	526 (15)	621 (14)	ns	ns
7	ns	ns	485 (14)	386 (18)	920 (11)	ns
8	ns	ns	1022 (26)	1048 (11)	ns	929 (11)

ns = not sampled.

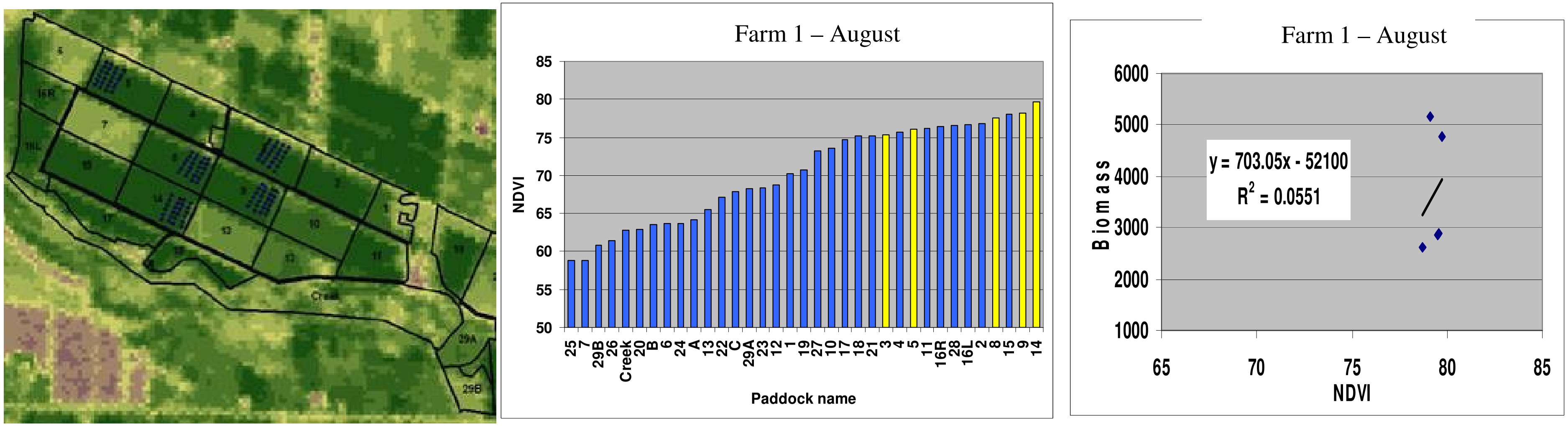

Figure 2: Failed relationship between NDVI and pasture cover where the low biomass and NDVI range is not sampled (NDVI wedge graph) and the higher biomass levels are within the recognised saturation point of NDVI (biomass > 3500-4000 kg DM/ha)

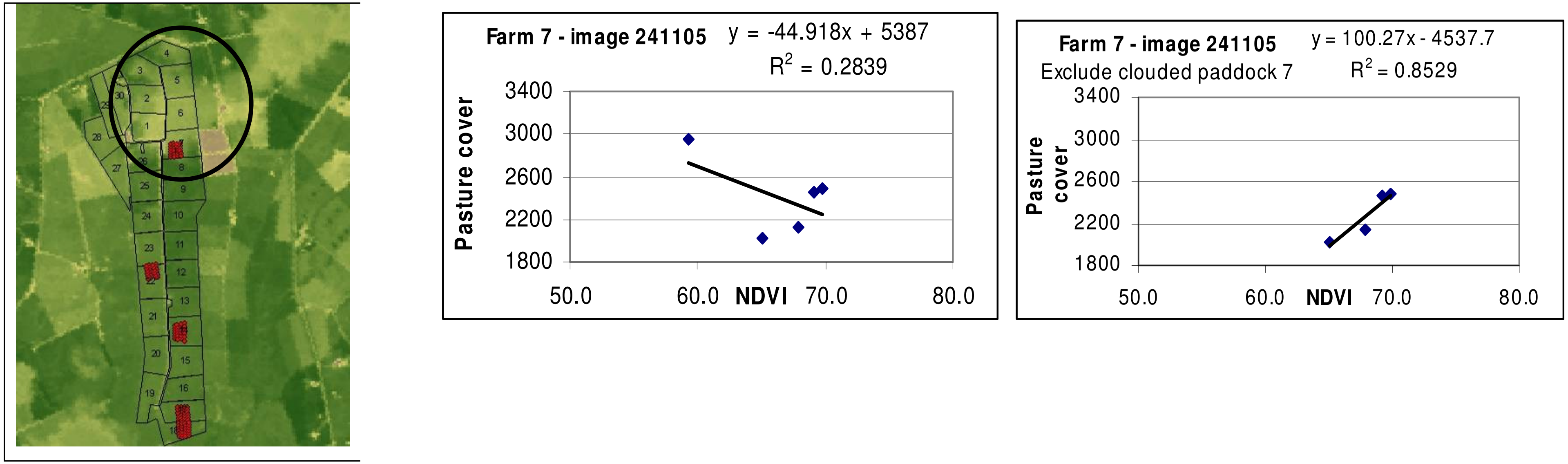

Figure 3: Cloud interference lowered the NDVI measured in paddock 7 of farm 7, significantly affecting the relationship. Exclusion of paddock 7 from analysis led to a very good relationship between pasture cover and NVDI.

Pasture quality

Pasture quality in summer and autumn, is a key driver of animal performance. Soon pasture quality may be measured directly in the paddock using satellite imagery containing either many spectral bands (hyperspectral) or less likely a few multi spectral bands. Our research challenge is to be able to measure paddock pasture quality quickly and accurately so that it can be use to calibrate satellite imagery. Cosgrove *et al.*, (1998) showed that for a uniform May dairy pasture twelve, 0.09 m^2 quadrats cut to normal grazing height were required to estimate paddock ME to within 0.5 MJME/kg DM. Clearly, collecting large numbers of pasture samples for subsequent laboratory analysis is tedious, expensive and slow. A device is needed that can accurately measure pasture quality directly in the field. This device could then be used to calibrate current and future satellite images for pasture quality.

Near infra red reflectance (NIR) has long been used successfully to measure pasture quality on dried and ground pasture samples (Corson *et al.*, 1999). However, in fresh grass a greater proportion of the light is reflected from the surface due to the waxy leaf coating, and less light passes into the leaf. A lesser but still significant problem is that water is highly absorptive and this “shadows” some of the spectral signatures of other chemicals in wet forage. In addition changes in the leaf angle following growth and grazing can affect reflectance (Schut & Ketelaars, 2003).

Preliminary analyses using hand-held hyperspectral reflectance devices (using sunlight) in Australia shows promise (Edirisinghe *et al.,* 2004) in the prediction of pasture digestibility (R^2 >0.9) and nitrogen content (R^2 >0.87). Overseas researchers have some promising results in the measurement of quality in the paddock using hyperspectral reflectance from a device with its own light source (Schut & Ketelaars, 2003).

Procedure

We have used a device with its own light source to allow sampling on both sunny and cloudy days. Our objective was to determine whether this field NIR device could be used to assess New Zealand pasture quality (OMD, organic matter digestibility) directly on the growing pasture, or failing that, by a fast off-paddock measurement on simply processed, “field wet” grass samples.

At completion of this study we will have collected pasture samples at monthly intervals for 8 months resulting in a dataset of 400 samples. At each sampling date we cut 7 quadrats (0.2 m^2) from one paddock on each of 5 dairy and 2 sheep and beef farms. Each quadrat was scanned in triplicate *in situ by* NIR at three heights, along with the appropriate reference spectra. Total NIR scanning time was of the order 3 minutes, but once the optimum scanning position(s) have been determined, it likely this time could be considerably shortened to a few seconds. This study used a NIR diode array spectrophotometer with its own light source (400-1700 nm, 152 diodes, providing spectra with 5 nm intervals) and a 10 cm diameter sensing zone. This device has been used successfully previously in New Zealand to measure pasture minerals on "field wet" pasture grasses following minimal processing.

After scanning, the quadrats were cut to approximately 1 cm in height. This pasture was measured for morphological composition (dead matter, green leaf, reproductive stem, legume and weed), NIR scanned wet after processing, then dried and ground for the standard FeedTech determination of quality. The remainder of the pasture was cut to ground level, washed, dried and both samples were combined to calculate pasture cover. These data will be analysed to determine the optimal vertical scanning position for pasture quality estimation. The relationship between field reflectance and OMD will be determined.

Results

Table 3: Morphological composition, crude protein, metabolisable energy of pasture collected monthly from five Waikato dairy farms to March 2006

			Percentage of dry matter			
Month	**Dead**	**Green leaf**	**Clover**	**Weeds**	**Crude protein**	**Metabolisable Energy (MJME/kgDM)**
Oct	14	70	6	8	20	10.8
Nov	19	58	7	6	18	10.6
Jan	22	48	18	11	21	9.7
Feb	28	53	10	5	19	9.3
Mar	48	38	9	4	_	_

The Australian Experience

In Western Australia (WA) pasture utilization, 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 rights.

Attempts to improve pasture utilization have failed due to the low adoption of pasture measurement techniques, despite many attempts by industry bodies to educate producers on these techniques. Producers with limited time availability soon lost the confidence to accurately estimate pasture cover, partly due to the extent of within and between paddock variability in pasture cover and growth rate and the time requirements to assess pastures across the whole farm (Sneddon *et al.* 2000).

Pastures from Space (PfS) provides quantitative, accurate, timely, spatial and low cost pasture monitoring solutions that assist producers with strategic and tactical decision making at the paddock and farm level. Two products have been developed by the PfS project with evaluation and refinements to the technology facilitated by the collaboration of producer groups across the southwest of WA (Gherardi *et al.* 2004). Pasture growth rate (PGR, kg DM/ha/day), uses satellite information (NDVI, 1 pixel = 6.25 ha) and climate data (minimum and maximum temperature, rainfall, evapo-transportation and solar radiation) to generate a weekly PGR spatial map from which paddock or farm statistics can be calculated. Feed-on-Offer (kg DM/ha) delivers pasture covers at a higher resolution (between 0.01 and 0.06 ha).

On farm use

Since 2004 PGR has been commercialised through Fairport Technologies International and delivered to individuals through the internet using a farmer-friendly software package Pasture Watch® (Wiese et al. 2004). This combination of ready access, weekly updates during the growing season and easy to use software for interpretation of the data results in a powerful tool which has been shown over the last 2 years to deliver significant gains in productivity and profitability (Table 4).

Producers that have used the PfS technology have demonstrated increased adoption of improved management skills, leading to increased productivity and utilization. Economic analysis showed increases in stocking (SR) of between 1 and 4 dry sheep equivalents (DSE)/winter grazing ha (wgha) associated with increased gross margin profits of between \$21 and \$63 per wgha compared to performance prior to using the PfS data. Subsequent surveys of these producers showed that these improvements in profitability were the result of greater confidence in decision-making provided by the PfS data driving productivity while managing risk at key decision times (Gherardi *et al.* 2004).

PfS data provided a common language between the landowner and his family or employees improving communication on pasture management issues. The way in which the data are being used to make decisions varies across the farms studied, but some key widespread uses are:

- Stocking Rate – Producers use a flexible SR approach. Tactical adjustments to stocking rate were made throughout the season based on observed changes in PGR. While targeting increased pasture utilization this flexible SR approach has provided greater risk management if seasonal conditions become unfavourable by allowing confident decision-making 2-3 weeks earlier than usual.

- Compare Paddock Performances – Producers have compared DM production from the same paddocks between years and between paddocks within years. Feed deficit issues were identified from a) 1st year paddocks out of crop relative to established pastures and b) PGR responses to tactical N use, which produced increased feed production to make up the deficit. Spatial analysis of PGR variability within paddocks identified high and low PGR areas, which were then assessed for soil fertility and botanical composition (Table 4, Case study 3).
- Achieve Better Pasture Management – Monitoring PGR to estimate pasture cover and timing of pasture deferment resulted in better pasture establishment and greater annual production, along with associated agistment and feedlotting practices to manage risk. Total pasture production derived from weekly PGR was used to benchmark productivity a) within and between neighbouring properties, b) new pasture varieties (Table 4, Case study 1, 4 & 5). Feed budgets were used to determine fodder conservation needs.

Table 4: Summary of adoption and financial performance for five cases studied in 2003

Case	Management decisions-making	Impact	Gross Margin ($ gain)
1	Stock movements Break of season feedlotting Paddocks for silage Optimise fertiliser use	Increased stocking rate by 2 DSE/wgha in the last two years.	$23/wgha with little increase in risk
2	PGR data showed that SR matched to the 'worst years'	1 DSE/wgha increase in SR and use of a number of other strategies	$49/wgha equates to gross income increase of $87,220.
3	Calculated TDM for each paddock Some paddocks showed lower than expected production after autumn fertiliser	Rationalised fertilizer application Determined need for pasture renovation	$27/wgha saved by not applying additional fertiliser.
4	This farmer had been strip grazing wethers and young sheep over winter and spring using electric fencing for a number of years Extend the technique to one flock of ewes grazed in a single paddock from break of season to weaning	21% increase in pasture utilisation (61% v 40% for strip grazing v set stocking)	
5	Historical PGR data to determine potential SR Target SR set by deviation from normal date of break of season (1 week = 1 DSE) Determine the length of deferment of pasture paddocks using weekly PGR. Plot feed demand (kg DM/ha/d) vs. PGR to balance supply and demand Respond to deficits with N-fertilizer, supplements or agistment Benchmark TDM production between	Increased SR by 4 DSE/wgha from 12 to 16 DSE while optimizing production per head, micron and lambing percentage. Identified feed deficits from 1st year paddocks out of crop relative to established pastures and b) PGR responses to	$53 /wgha increase in gross margin from $314 to $367. Historical PGR used to assess value of land to lease.

paddocks and between years	tactical nitrogen use

DSE = Dry sheep equivalent, wgha = winter grazed hectare, SR = stocking rate.

Cases 1-4 from Gherardi *et al.* 2004, Case 5 from Wooldridge *et al.* 2005.

Conclusion

Commercial experience on Australian farms shows that significant gains in profitability can be made from both strategic decisions, e.g. matching stocking rate with feed supply, and tactical decisions, e.g. identifying which pastures will respond best to N fertiliser and optimising conservation decisions. New Zealand dairy farmers can expect to also improve decision making in these areas as well as in dairy specific decisions such as culling and drying off, starting and stopping supplement feeding and achieving the correct grazing residuals to ensure high ME at subsequent grazing.

There are still significant technical barriers before this technology can be delivered on to New Zealand dairy farms in a form that will simplify pasture management at low cost. But the gains in both profit and labour saving justify the research investment.

Over the next year we intend to collect as many satellite images as possible together with “ground truth”. Then a decision will be made about the feasibility of providing this data on a real time basis to dairy farmers, and if the answer is yes, how this is to be accomplished. Running concurrent with this project is an AgResearch project that is looking at ways of providing real time pasture quality data to dairy farmers.

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