A protocol for sampling pastures in hill country

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Abstract
To develop a protocol to guide pasture sampling for estimation of paddock pasture mass in hill country, a range of pasture sampling strategies, including random sampling, transects and stratification based on slope and aspect, were evaluated using simulations in a Geographical Information Systems computer environment. The accuracy and efficiency of each strategy was tested by sampling data obtained from intensive field measurements across several farms, regions and seasons. The number of measurements required to obtain an accurate estimate was related to the overall pasture mass and the topographic complexity of a paddock, with more variable paddocks requiring more samples. Random sampling from average slopes provided the best balance between simplicity and reliability. A draft protocol was developed from the simulations, in the form of a decision support tool, where visual determination of the topographic complexity of the paddock, along with the required accuracy, were used to guide the number of measurements recommended. The protocol was field tested and evaluated by groups of users for efficacy and ease of use. This sampling protocol will offer farmers, consultants and researchers an efficient, reliable and simple way to determine pasture mass in New Zealand hill country settings.

Keywords: hill country, feed budgeting, protocol pasture mass, slope

Introduction
Meat and wool production from grazing ruminants is a function of the quantity and quality of pasture intake, a factor strongly governed by allocation (Poppi *et al.* 1987). Operational and tactical decision making to optimise per animal and per hectare productivity requires pasture mass data for feed budgeting and determining feed allocation. Regular monitoring of pasture mass allows farmers to make early decisions to conserve or feed out supplements, to buy or sell stock and to more effectively manage the effect of climate variability.

A common practice on New Zealand dairy farms is a weekly farm walk to collect pasture mass data using calibrated tools, such as a "rising plate meter" (RPM), a "sward stick", a C-DAX Rapid Pasturemeter (Lawrence *et al.* 2007; from here referred to as "C-Dax") or FeedReader (AgHub, Ultrasonic Feed Reader developed by the Department of Primary Industries Australia, 2001). These data enable farmers to understand the feed available for short-term feed budgeting and effective pasture utilisation. On flat land, pastures tend to be relatively uniform and easy to access compared to hill country. Research has tested the validity of tools for estimating pasture mass and sampling methods, particularly for pastures on dairy farms with small paddocks that have little variation in terrain (Stockdale & Kelly 1984; Piggot 1986, 1989; L'Huillier & Thompson 1988; Lile *et al.* 2001; Thomson *et al.* 2001). In contrast, quantifying feed availability for hill country farms is practically challenging and time consuming. In addition, there is far greater variability in pasture mass within and between paddocks due to the range in slope, aspect, altitude, soil fertility, pasture species and stock classes (Gillingham 1973; Ledgard *et al.* 1982).

Given the effects of the physical factors on pasture production (Gillingham 1973; Radcliffe *et al.* 1976; Radcliffe & Lefever 1981; Radcliffe 1982), hill country research has developed calibration equations to estimate pasture mass from pasture height using tools such as the RPM or capacitance pasture meter (Webby & Pengelly 1986; Litherland *et al.* 2008). Progress has been made towards pasture mass estimation via remote sensing (Kawamura *et al.* 2012), but for the present and near future, manual measurement remains the only realistic option for most farmers. Devices such as the C-Dax are restricted to areas with vehicle access, while other devices require skilled and physically fit operators (e.g., RPM, sward stick and capacitance pasture meter).

The objective of this project was to develop a pasture measurement protocol, suitable for use with a manual measurement device on hill country sheep and beef pastures. The approach was to first measure the entire surface of paddocks intensively and determine the total amount of pasture available, and then to use these data to model the number and type of sampling sites needed to estimate the amount available, according to the terrain and different levels of accuracy. A decision tree

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was developed to optimise the locations and minimum number of measurements to estimate herbage mass at the paddock scale to the required accuracy.

Methods

Protocol development

Paddocks were measured with two manual measurement devices and all measurements geo-referenced. A C-Dax towed behind a quad bike was used where safe and practical (approximate slope <20°), though this was dependent on traction when the soil and pasture were moist. C-Dax readings were taken along parallel transects with 5-10 m between transects and 1-2 m between point measurements along each transect. Paddocks on steeper terrain were measured using a RPM following a 10 m grid spacing, coupled with GPS. Both instruments measure pasture height in millimetres which can be transformed to pasture mass. The C-Dax estimates the average height of the sward electronically. The RPM compresses a small area of pasture and estimates compressed sward height, which is dependent on pasture density and rigidity of the pasture components. Calibration of the RPM was based on the work of Litherland *et al.* (2008).

Seasonal calibration equations for both the C-Dax and the rising plate meter were also reported for dairy pastures in five regions of New Zealand (King *et al.* 2010). The two methods were used on different terrain with little overlap for practical reasons, so the measurements made by the two instruments were calibrated against each other on flat paddocks in Canterbury and the Manawatu ($R^2 = 0.882$, $P<0.001$), and against pasture mass in Canterbury with the C-Dax ($R^2 = 0.759$). Since the rising plate relies on gravity to slide up and down a rod, the frictional force between the rising plate and the rod may interfere with the readings at some angle, this was tested on a slope in Canterbury. Pasture mass estimated from harvested quadrats (n=36) was significantly related to RPM readings (P=0.024), but not affected by slope (P=0.413), and there was no significant interaction between slope and plate reading over the range of slopes from 0 to 20°. This was measured in July on one farm at an average pasture mass of 2878 ± 750 kg DM/ha, where individual quadrats varied from 1484-4420 kg DM/ha.

Data on pasture mass across a range of altitude, slope, aspect, pasture types and grazing regimes were collected from hill country pastures on five sheep and beef farms in Waikato, Manawatu and Canterbury. A total of 38 474 individual sward assessments were collected from a number of paddocks on different dates (Table 1). The farm in the Manawatu was studied in great detail. A total of 30 paddocks from 0.8 to 31.6 ha, were measured over 3 days in mid-November 2012. One paddock on the Waikato farm was sampled on three dates, one paddock was sampled on two dates and another was sampled only once. One Canterbury paddock was sampled on two dates, while two others were sampled once each. All the sward heights on the Waikato farm were estimated with a RPM as the terrain was not suitable for C-Dax measurement.

At least two observers recorded RPM readings at each farm, with one observer common to four of the five farms, another observer common to three farms and a total of nine observers. GPS readings were recorded at each sample site using a hand-held device alongside the RPM. One C-Dax unit was used on all farms and this recorded both location (GPS) and pasture height at each site. GPS readings were used to obtain GIS information to determine slope, aspect and altitude. ArcGIS 10.1 (ESRI, Redlands, California, USA) was used to display and analyse the spatial data related to the topography of the sites. The slope and aspect of each site was calculated from a 15 m spatial resolution Digital Elevation Model (DEM) of New Zealand (Landcare Research) using ArcGIS Spatial

Table 1 Region, date of observation, location and range of altitude on five farms, and the number of sites where pasture mass was estimated using the C-Dax or the RPM.

Farm	Date	Location		Altitude (m) a.s.l.	Number of measurements	
		°N	°E		C-Dax	Rising plate
Manawatu	Nov. 2012	-39.6473	175.8637	487 to 740	24767	1959
Waikato	June 2013	-38.2764	175.5749	338 to 494		333[A] and 472[B]
	Sept. 2013					274[A] and 503[C]
	Jan. 2014					384[A] and 530[B]
Canterbury	June 2013	-42.8539	173.1441	326 to 400	2827	262
	Sept. 2013				1492	231
Canterbury	Aug. 2013	-42.7363	172.7626	259 to 314	2631	633
Canterbury	Feb. 2014	-43.8849	170.9330	672 to 750	461	1881

[A]Paddock A, [B] Paddock B, [C] Paddock C

Analyst extension. Where the C-Dax and RPM had been used in conjunction, there was an uneven spatial density of data because the C-Dax could rapidly gather vast amounts of data. Spatial bias in the point data was removed by weighting point samples proportionally to their Dirichlet polygon area (Beardon 1983), and since the C-Dax recorded a greater density of points, these were given a smaller weighting than those from the RPM. Spatially balanced randomised sampling evenly disperses sample sites across the study area (Stevens & Olsen 2004). Confidence in the similarity of measurements by C-Dax and the RPM was bolstered by analysis of average pasture mass in neighbouring measurement sites with different methods, which showed a slope not significantly different from one and an intercept not significantly different from the origin.

A range of measurement strategies including sampling along transects, random sampling and stratified random sampling were tested by computer simulation. Each potential sampling approach was tested using the original point data, because interpolated data do not preserve the true variability of pasture across the paddock. Sampling approaches were appraised by applying each technique to the field datasets via computer simulation and comparing the resulting estimates against the actual paddock means. Computer simulations were repeated one thousand times per paddock, yielding a heuristic distribution of error at varying sample sizes. A draft protocol was developed based on the visually determinable paddock attributes and the relationship between the required numbers of measurements for an accurate sample.

Field evaluation

The draft protocol was validated on two Canterbury foothills farms (Farms A and B) not previously studied. One topographically heterogeneous paddock was chosen from each farm. At Farm A on the 30th of June 2015, pasture height was established from 2362 RPM readings, taken along 18 parallel transects spanning the paddock length. Estimates of average pasture length were made at 17, 38 and 87 sample sites per paddock, where pasture length at each sample site comprised the average of ten RPM readings taken in a 1 m radius around a single point location. The paddock estimates obtained using this protocol were compared to an estimate of the average obtained from 2 diagonal transects, from corner to corner of the paddock, with approximately 100 RPM readings per transect.

At Farm B, on the 15th of September 2015, a paddock was characterised using RPM readings along 18 transects across the paddock. Estimates of pasture length were made at 17, 38 and 87 sample sites per paddock, where pasture length was again taken as the average of ten RPM readings at each site in a 1 m radius around one point.

User evaluation

Potential users were asked to evaluate the protocol at two workshops of farmers and rural professionals. The first were staff of Taratahi Agricultural Training Centre in April 2015 at Glenside farm near Gladstone, Wairarapa. Subsequently, the Taumarunui Sustainable Land Management group members used the protocol at Otunui in May 2015. The participants were diverse, ranging in age and experience with pasture assessment and used their current technology, a mix of visual appraisal, RPM and sward stick to estimate pasture mass. They then critiqued the protocol for clarity before using it to collect objective data. No attempt was made to estimate the available pasture using harvested quadrats.

Results

Protocol development

An example outcome of computer simulation results is shown for one paddock in Table 2 where the intensively gathered data suggested an average pasture mass value of 2521 kg DM/ha. Similar comparisons were evident from other paddocks too numerous to report here. As sample size increased from five to 500, the standard deviation from the simulated sampling decreased from more than 400 kg DM/ha to less than 40 kg DM/ha. Simulated sampling of 100 points along transects

Table 2 Sample size, minimum, mean and maximum pasture mass (kg DM/ha) estimated by sampling random points from the original data, and the difference (Difference) between pasture mass estimated from random sampling and the mean calculated from the original intensively recorded data (2521 kg DM/ha).

Sample size	Minimum	Mean	Maximum	Std Dev	Difference
5	1385	2458	3703	427	-63
20	1937	2514	3258	201	-7
50	2222	2505	2934	132	-16
150	2348	2519	2741	72	-2
500	2421	2525	2628	38	+4

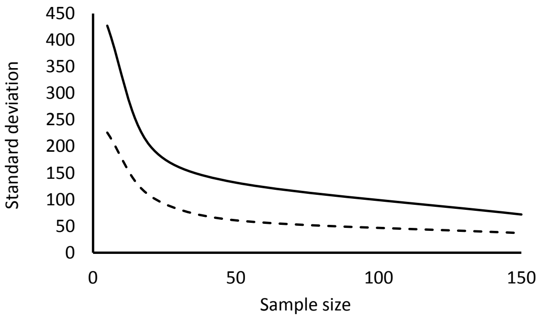

Figure 1 The effect of simulated sample size on the standard deviation of average pasture mass as sample size increases for random samples (solid line) and stratified random samples (dashed line).

exhibited much greater variation in the estimated mean than random sampling shown in Table 2 (2392 ± 290 kg DM/ha). Stratified random sampling simulations across the same paddock shown in Table 2 gave smaller errors at a similar sample size (Figure 1). The most important attribute for a paddock revealed by the analysis was whether herbage mass was greater or less than 2000 kg DM/ha. The second most important paddock attribute was the number of slope classes present. A greater number of samples were needed to achieve the same accuracy, in a paddock with more than two slope classes without stratification.

A decision making protocol developed from the modelling process is outlined in Figure 2. The user estimates whether more than 2000 kg DM/ha is present, then observes the terrain and decides how many classes of slope are present in the pasture according to Table 3 from Lynn *et al.* (2009). Finally a decision on how accurate an estimate of pasture available is needed for the intended purpose, and with the aid of Figure 2, the user determines how many points to sample. For example, more than 2000 kg DM/ha, more than two slope classes, to be measured with 80% accuracy and within 200 kg of the true value. The decision tree (Figure 2) suggests the user should measure 17 points across such a paddock. At each point the measurement device was used to take ten measurements but only the average was recorded, so in this example the observer would make 170 measurements in total but record 17 mean values. Alternatively, in a pasture with more than 2000 kg DM/ha and more than two classes of slope, for 90% accuracy of estimating herbage mass within 150 kg of the true value, 38 sample sites would be required.

Field evaluation

Appropriate seasonal regression coefficients (Litherland *et al.* 2008) were used to transform RPM measurements obtained using the protocol to kg DM available per hectare (Table 4). The pasture examined at Farm A using the draft protocol was estimated to have a pasture mass of 3052 (± 709) kg DM/ha based on the mean of 87 measurement sites. The contour across much of the paddock was relatively gentle and it was also measured using the C-Dax which estimated 3046 kg DM/ha. Intensive measurements across the remainder of the pasture with the RPM estimated 3112 (± 755) kg DM/ha. Furthermore, taking 194 RPM measurements on two diagonal transects across the whole paddock estimated 3023 kg DM/ha. Clearly this paddock had just over 3000 kg DM /ha whatever measurement method was used, and 38 plate measurements was sufficient to characterise this.

At Farm B, the protocol with 87 measurement sites estimated 3839 (± 810) kg DM/ha. This pasture was not suitable for the C-Dax and the terrain had two slope classes. When two diagonal transects (n=194) across the paddock were used to characterise the entire pasture using the RPM, slightly more pasture was available (4010 ± 860 kg DM/ha).

User evaluation

The paddock assessed on the Wairarapa farm was dominated by large hill faces, with smaller areas of ridges, flats and toe-slopes. Visual estimates of DM were consistently lower 1610 kg (± 214), than those estimated using manual techniques in a manner guided

Table 3 Slope classes of terrain (Lynn *et al.* 2009).

Slope	Slope angle	Description	Typical examples
A	0 - 3°	Flat to gently undulating	Flats, terraces
B	4 - 7 °	Undulating	Terraces, fans
C	8 - 15°	Rolling	Downlands, fans
D	16 - 20°	Strongly rolling	Downlands, hill country
E	21 - 25°	Moderately steep	Hill country
F	26 - 35°	Steep	Hill country and steeplands
G	>35°	Very steep	Steeplands and cliffs

Table 4 Data collected on two Canterbury foothills farms using the number of samples suggested by the protocol. The values provided are average pasture mass (kg DM/ha) estimates based on the RPM and (±) the standard deviation between sites.

n	Farm A	Farm B
17	2770 ± 782	3676 ± 591
38	3109 ± 683	3925 ± 594
87	3052 ± 709	3839 ± 810

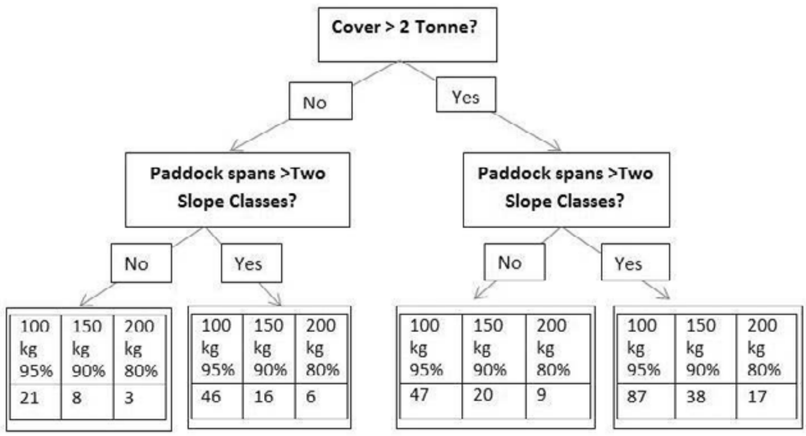

Figure 2 Decision matrix from the draft protocol. The first decision is based on a visual estimate of pasture mass (2 tonne = 2000 kg DM/ha), the second on the number of slope classes (Table 3) and the third on the accuracy and precision required. The final number of measurements to take across the paddock are shown in the last row.

by the protocol 1824 kg (± 107). This was largely due to terracing and other micro-topographical features that lead to variation in pasture mass, which were not apparent until participants walked across the paddock. Two topographically variable paddocks were assessed at Otunui. In the first, visual assessments averaged 2380 (± 397) kg DM/ha while estimates guided by the protocol were lower, averaging 1983 (± 281) kg DM/ha. In the second paddock, which had two faces, visual estimates averaged 1300 (± 123) kg DM/ha, while estimates using the protocol were higher at 1423 (± 35) kg DM/ha.

Discussion

A draft protocol for measurement of pasture mass in hill country was developed based on the topographic complexity of a paddock, the overall pasture cover and required accuracy. The field evaluation showed close estimates using any method on Farm A, while on Farm B the protocol underestimated the amount of pasture available by up to 200 kg DM /ha. The average of the visual estimates of experienced practitioners and those made with the protocol were within 200 kg DM/ha of each other. However, individual users did estimate considerable differences between them (up to 400 kg DM/ha) and the smaller range of variation using measurement tools encouraged them to consider the protocol. Further work is needed to adapt and test this protocol, and in parallel the time and therefore cost of using it should also be evaluated.

User evaluation suggested that the protocol required the following additional components: 1) instructions on how to visually estimate pasture cover; 2) instructions to focus sample measurements on the average slope class for the paddock; 3) a guide to taking random samples. The process of validation undertaken with this user group demonstrated the protocol was easy to interpret and implement, but the subjective assessment of variability within a paddock was regarded as hard to quantify. Users estimated pasture mass more accurately when they used the protocol to inform sampling.

Provided users understand the accuracy and therefore the limitations of the protocol, it could be used to easily estimate available pasture in a number of paddocks and therefore gain some understanding of the forage available for the near future. The protocol offers greater consistency than visual assessments, even when the minimum number of samples were collected. This is consistent with previous research that demonstrated visual assessment requires regular calibration to be accurate (Piggot 1989), with the complication that in hill country the terrain also requires assessment. Preliminary results suggest that a RPM can be reliably used to estimate pasture mass on slopes up to 20°, though we acknowledge this should be examined in a variety of pastures and seasons with reproductive or dead material.

Further investigations using this draft protocol are warranted. Simulated sampling along transects gave large errors because randomly placed transects could sample areas of either particularly high or low pasture mass given the variation across the paddocks examined here. For this reason, simulations using stratified random sampling of high and low mass areas gave less variable results than random sampling (Figure 1), despite weighting records from the C-Dax and RPM according to their density. However, these sophisticated data collection and analysis techniques will be more useful for scientific purposes. Although stratified random sampling gave smaller errors, a larger number of random samples from average slopes provided the best balance between ease of data collection, simplicity of calculation and a robust protocol for extension to non-scientific users.

The protocol outlined here is a sampling method that needs to be combined with the wider suite of devices and tools for effective feed budgeting and pasture management. There is also scope for the protocol to be used in combination with visual estimation to reduce errors caused by seasonal changes in pasture. It could serve to calibrate paddock scale visual assessments, and might be used on a subset of paddocks when many paddocks are assessed. This protocol could also be used for farm-scale assessments as part of a double-sampling approach, with greater value derived from a faster but less precise method such as visual assessment, by combining it with a more intensive but more accurate method applied to a subset of paddocks (Ebrahimi *et al.* 2008). The protocol could be valuable on farms that have particular paddocks of greater importance, for example, a block used for intensive grazing of finishing stock. The greatest value of the protocol may be in motivating more hill country farmers to assess pasture mass and undertake feed budgeting by providing a simple method, which optimises accuracy and effort.

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