ESTIMATING SPATIAL VARIATION IN ANNUAL PASTURE YIELD

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ABSTRACT

Yield mapping is a potentially valuable tool for precision management of pastures. However it is difficult to map annual yields of grazed pastures, which are harvested many times through the year, usually by grazing animals rather than by machine. Although pasture herbage mass can be mapped using tools such as the C-Dax Pasture Meter, this involves mapping the entire paddock repeatedly to measure annual pasture yields, a significant additional workload. For yield mapping to contribute to decision making, techniques are needed to allow selected strategic mapping events to be used to estimate the within-paddock variability of annual pasture yields.

Pasture herbage mass in kg DM/ha was mapped using the C-Dax Pasture Meter, pre- and post-grazing associated with most grazings, for 12 months on a rotationally grazed, irrigated ryegrass and white clover dairy pasture in Canterbury, New Zealand. Post-grazing pasture cover maps were subtracted from pre-grazing cover maps to obtain maps of pasture intake by cows for each grazing. The intake maps at each grazing event were added together to obtain a map of total pasture intake for the year. The yield variation present in individual pre-grazing maps was compared with the total annual variation in intake by cows, to identify individual maps that give a good estimate of the total annual yield variation.

On this property (an irrigated dairy farm in Canterbury, New Zealand), the variation in total annual pasture intake could be estimated by collecting a single map of pre-grazing pasture cover between December and early April, or ideally January – March. This timing is expected to be appropriate for other similar farms in the same climatic zone. Further work is ongoing to validate this timing with data from a second year of measurements.

Keywords: yield map, pasture, grazing, spatial variation

INTRODUCTION

Yield mapping is a valuable tool for precision management of arable crops. Crop yields are measured once, at harvest, automatically by the harvesting machinery, and may be used to inform a wide range of activities. A yield map can identify areas of a field that have low yields for any reason, allowing the cause of these low yields to be investigated further (Stafford et al. 1996). It can indicate the relative uptake of nutrients such as P and K in different parts of a field, and therefore guide variable rate application of nutrients to replace these (Godwin et al. 2003). It can allow calculation of maps of the economic return from different areas of a field (Blackmore 2000). This allows returns to be improved by either applying higher inputs to areas of a field that can respond economically to them, or reducing inputs to areas that have a lower yield potential to ensure the cost of inputs is lower than the value of the yield (Robertson et al. 2007).

Yield mapping is just one tool in a large toolbox of techniques that is used in precision agriculture. However it is a crucial tool as it quantifies the end result, the crop yield.

Intensive pastoral agriculture systems also exist in many areas of the world, with pastoral dairy farming being a key example. In New Zealand, the primary feed during lactation is pasture (often supplemented with other feeds). In 2012-13, New Zealand dairy herds averaged 401 cows, with some farms having cows numbering in the thousands (LIC and DairyNZ 2013). Pasture production ranges from 9 to 20 tDM/ha (DairyNZ 2010). Dairy farming is currently a highly attractive option financially for irrigable land in New Zealand, for instance an analysis by the ANZ Bank showed dairy to have an average potential return of NZ$2,380/ha (range $2,000 - $6,000), compared with $2,000 (range $1,000 - $2,500) for arable and processed crops, and $700 - $900 for alternative pastoral land uses such as sheep and beef farming (Bagrie, Williams, and Croy 2013).

Intensive pastoral dairy farming occurs on the same land that can be used for intensive arable production, dairy pastures are susceptible to essentially the same constraints on yield as arable crops are, and profitability of the system is comparable. There is considerable potential to apply the precision agriculture techniques that are being used successfully in the arable sector to intensive dairy farming to increase productivity of pastures and to assist management decisions e.g. fertiliser and regrassing decisions. This requires a cost-effective method for mapping pasture yields.

An arable crop is harvested at one time and the yield of product can be mapped using the harvesting machinery. However a grazed pasture is harvested many times through the year, and is harvested by a large number of animals rather than a single machine. Therefore, a different approach is needed to map annual pasture yields.

It is possible to map the standing herbage mass in a pasture at a point in time, such as just before grazing, using tools such as the C-Dax pasture meter (C-Dax 2014) to measure pasture height, which is correlated with pasture mass. However this does not directly measure the harvested yield, as cows will only graze a portion of the above ground pasture. The harvested yield from a single grazing can be calculated as the difference between the residual herbage after grazing and the pre-grazing yield map. To obtain a map of harvested yield the paddock must be mapped twice, before and after grazing.

The relationship between a single grazing yield map and annual yield for pastures is not known. Climate varies between seasons, as do irrigation, fertiliser applications and animal management. For instance, an area of well-drained soil may be highly productive in wet months but then less productive in the dry summer, so the within paddock variability may differ through the year. The extent to which the variation at one grazing event in a single season can be used for management decisions is not known. Mapping pasture is additional to standard farm operations, and with current technologies is time consuming. Based on the experience of the authors, using a quad-bike mounted sensor to map before and after every grazing on all paddocks of a commercial dairy farm for a year would require approximately half an FTE plus equipment and fuel costs. Furthermore this work must occur at specific times dictated by the grazing rotation, which may be logistically challenging. A cost-effective method is needed to estimate the variation in annual yields from a grazed pasture, to allow precision agriculture techniques from the arable sector that require an estimation of annual yield variation to be applied to grazed pastures. This paper presents the development of an initial methodology.

METHOD

Data collection

The study was conducted on the Lincoln University Dairy Farm (43° 38’40”S, 172° 26’33”E) located near Lincoln, Canterbury, New Zealand. The study site was a 160 hectare irrigated milking platform, rotationally grazed with ryegrass and white clover pasture.

Pasture herbage mass was mapped, pre- and post-grazing, for most grazings from the 1st October 2012 to the 14th October 2013 on 6 paddocks (Figure 1) selected with a range of irrigation systems, soil types and other potential causes of yield variation.

Pasture herbage mass was mapped using a C-Dax Pasture Meter XC1 manufactured by C-Dax Ltd, New Zealand. The Pasture Meter was pulled by a four wheeled motorcycle at speeds up to 20 kph depending on terrain and ground conditions with a measurement logged every second. Paddock coverage was achieved by navigating a continuous track spaced no more than 15 metres apart. The paddocks were mapped as close as possible to grazing.

Production of maps

Using the raster package for R (Hijmans 2014; R. Core Team 2013) a 25 m by 25 m grid was imposed on the herbage mass data, the mean of each grid cell calculated and pasture cover in kg DM/ha was determined from the measurements of pasture heights using calibration equations (C-Dax 2014). Post-grazing pasture cover maps were subtracted from pre-grazing cover maps to obtain maps of

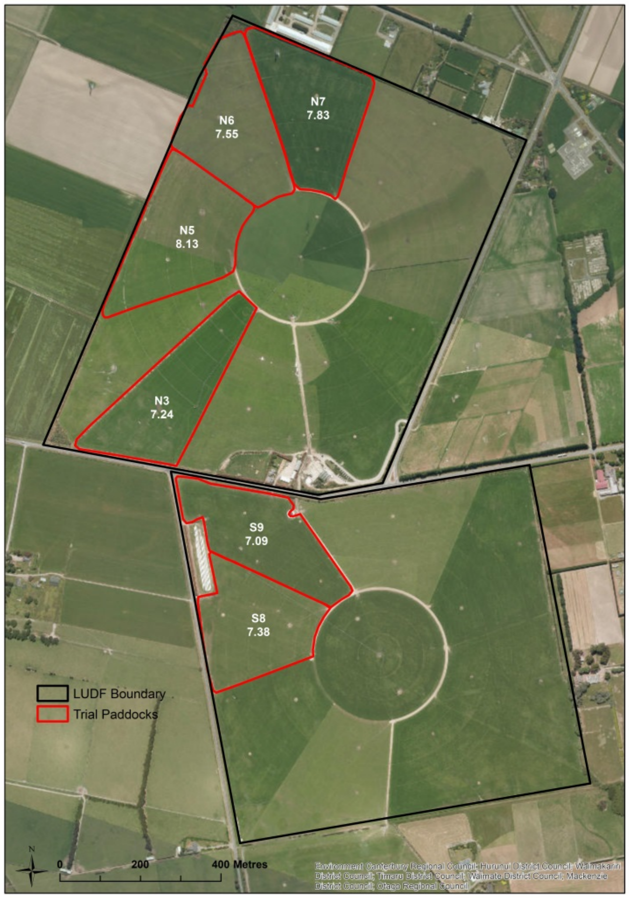

Figure 1. Lincoln University Dairy Farm (LUDF), New Zealand, with location and size (hectares) of the 6 paddocks yield mapped.

pasture intake by cows for each grazing. The intake maps at each grazing event were added together to obtain a map of total pasture intake for the year.

Comparison of maps

Two different statistics were used to measure the degree of pattern matching between pre-grazing cover or consumed pasture mass at different times during the year, and the total pasture intake map – rank correlation (RC) and median absolute difference (MAD).

Calculating the rank correlation (RC) statistic:

This statistic determines whether the “high” yield areas in one map correspond to the “high” yield areas in another, and vice versa. It does not consider the magnitude of the differences between these areas.

1) For each paddock (either pre-mass or consumed yields) and grazing event the grid cell means were ordered from highest to lowest, and each cell was assigned a rank depending on its position on the ordered list.

2) The above process was repeated for the total pasture intake map.

3) The ranks from the total consumed yield map were correlated against the ranks of the equivalent cells (in terms of map position) from the pre-mass yield maps.

4) The correlation obtained from 3) is the rank correlation between the total consumed yield map and the pre-grazing yield map. A rank correlation of 1 is indicative of a perfect match of patterns while an RC of 0 would be indicative of no relationship between the patterns of the two maps.

The RC is a "goodness of fit" statistic, with high values being indicative of good pattern matching and low values of poor pattern matching.

Calculating the median absolute difference (MAD) statistic:

This statistic quantifies the magnitude of the differences in relative yield between the same areas on each individual grazing map and the total pasture intake map.

Because our focus is on matching yield patterns, we standardised the cell means of all maps prior to the calculation of the MAD statistic. This avoided miss-match caused by intrinsic difference between the total yield and date specific pre-graze/consumed yields.

For each grazing event on each paddock for both pre-grazing and consumed (i.e. pre minus post) yields:

1) With $\boldsymbol{M_{jk}}$ as the set of all grid cell means (either pre-grazing or consumed yields) from paddock j at grazing event k, and m_{ijk} as the ith individual grid cell mean from $\boldsymbol{M_{jk}}$, standardised grid cell means: s_{ijk} , were calculated using the following equation for $i = 1,2,3, \ldots N_j$:

$$s_{ijk} = \frac{m_{ijk} - \min(\boldsymbol{M_{jk}})}{\max(\boldsymbol{M_{jk}}) - \min(\boldsymbol{M_{jk}})}$$

The resulting set of standardised cell values, $\boldsymbol{S_{jk}}$, fall in a range from 0 (for the cell with the lowest yield) to 1(for the cell with the highest yield).

2) The above process was applied to produce a set of standardised cell values: $\boldsymbol{T}_{jk}$ from the total yield map.

3) With the cells matched by grid location within the paddock, the absolute difference of the standardised pre-grazing and total grid cell means was calculated:

$$\boldsymbol{D}_{jk} = |\boldsymbol{S}_{jk} - \boldsymbol{T}_{jk}|$$

A close agreement of the yield patterns of the pre-grazing and total yield maps would tend to produce low values in $\boldsymbol{D}_{jk}$ and poor matching would produce high values.

4) The median of the set of matched absolute differences gives the median absolute difference (MAD) statistic:

$$\text{MAD}_{jk} = \text{median}(\boldsymbol{D}_{jk})$$

The MAD is a "lack of fit" statistic because MAD tends to zero with a perfect match and increases with reduction in the agreement between patterns.

RESULTS

An example of the pasture cover maps generated pre- and post-grazing, and the resultant map of harvested yield derived by subtracting the post-grazing map from the pre-grazing map is presented in Figure 2. Although the position on the colour scale is different, there is a general correlation between the pre-grazing cover map A and the harvested yield map C, with the same areas being either low or high in each map. The pre-grazing map was collected on 4 April 2013, and the post-grazing on 8 April 2013. The total consumed pasture measured for the same paddock, derived from adding together all maps of consumed pasture yield is shown in Figure 3.

These maps were generated for each of the six paddocks. A total of 9, 11, 8, 8, 13 and 14 grazing events were recorded for paddocks N3, N5, N6, N7, S8 and S9 respectively, a total of 63 grazing events. The differences in the number between paddocks are due partly to different pasture growth rates and partly due to missing measurements due to practical difficulties coordinating such measurements with grazing on a working commercial farm.

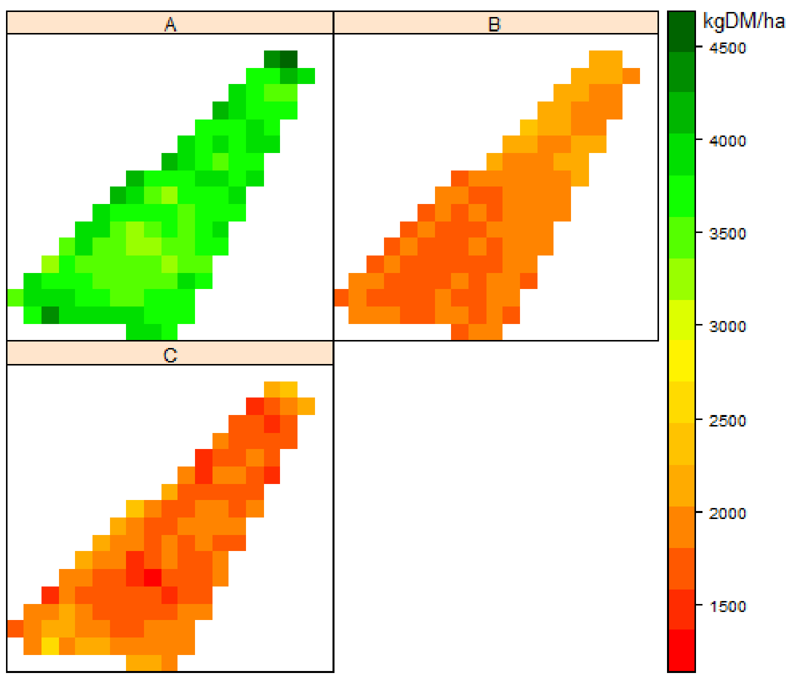

Figure 2. Pre (A) and post-grazing (B) pasture covers, and consumed (C) pasture (kg DM/ha), at one grazing event on paddock N3.

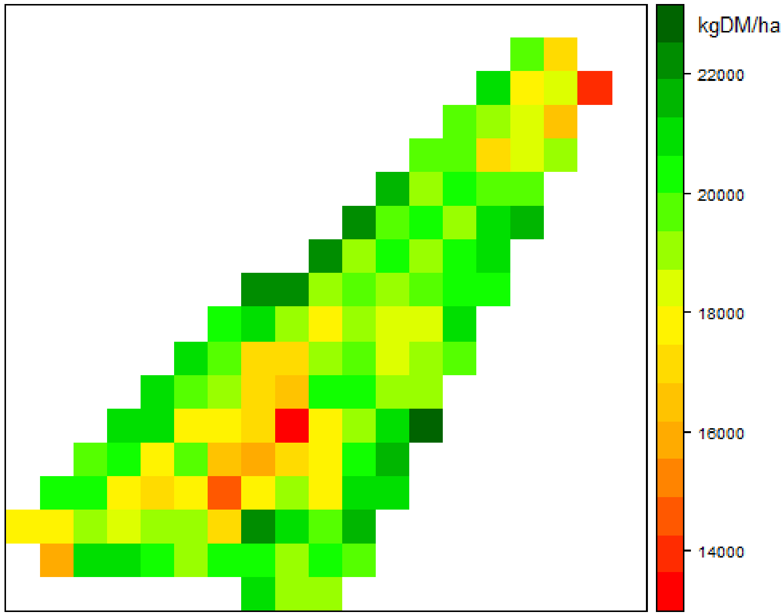

Figure 2. Total pasture intake (kgDM/ha) for the entire measurement period of paddock N3.

The RC and MAD statistics were plotted against the time of sampling to create the plots shown in Figures 4 to 6. The individual points represent individual grazing dates. The lines show the median and quantiles of the respective statistics calculated at 14 day intervals with the window of data in which the statistics were calculated extending 14 days either side of the day on which the mean/median was calculated. The red triangles shown on the graphs show the centre of the window over which the medians were calculated.

The RC of the maps of pasture intake for each grazing (i.e., pre-grazing pasture cover minus post-grazing pasture cover) as compared with the total pasture intake for that paddock are presented (Figure 4). The pasture maps collected during September – October (i.e., early-mid spring) showed the lowest correlation with the total intake map. For the remainder of the year the maps had a RC of around 0.6, with some variation.

The RC of the pre-grazing pasture cover maps as compared with the total intake map is shown in Figure 5. The RC is generally higher than in Figure 4, showing the pre-grazing pasture cover maps alone to be a better predictor of the total intake map than the maps of pasture consumed at each grazing. The RC is highest (around 0.7) from January through to mid-April, i.e., from mid-summer to early autumn. The lowest correlation is again in September – October.

Comparison of the pre-grazing pasture cover maps to the total intake map using the alternative MAD statistic, where a lower value represents a better correlation is shown in Figure 6. The poorest correlation was seen in August – October, and the best correlation in December – January and in late March – early April. The results are more variable than in Figure 5.

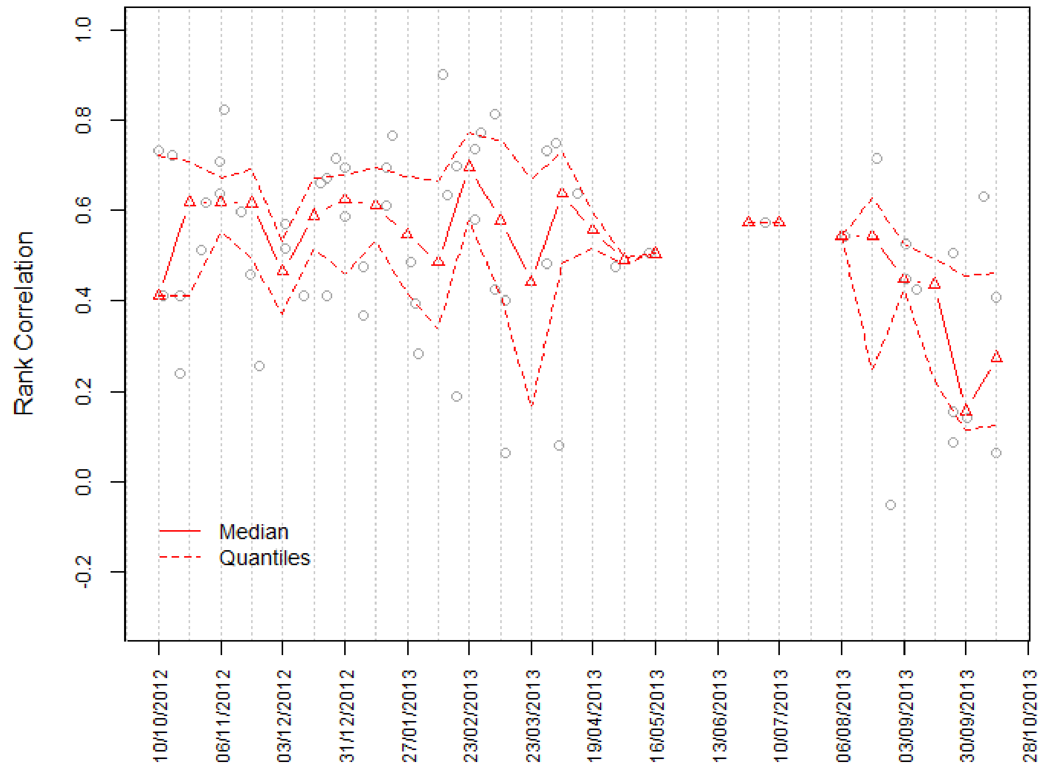

Figure 4. Rank correlation between pixels on maps of pasture intake at each grazing and the total annual dry matter intake map

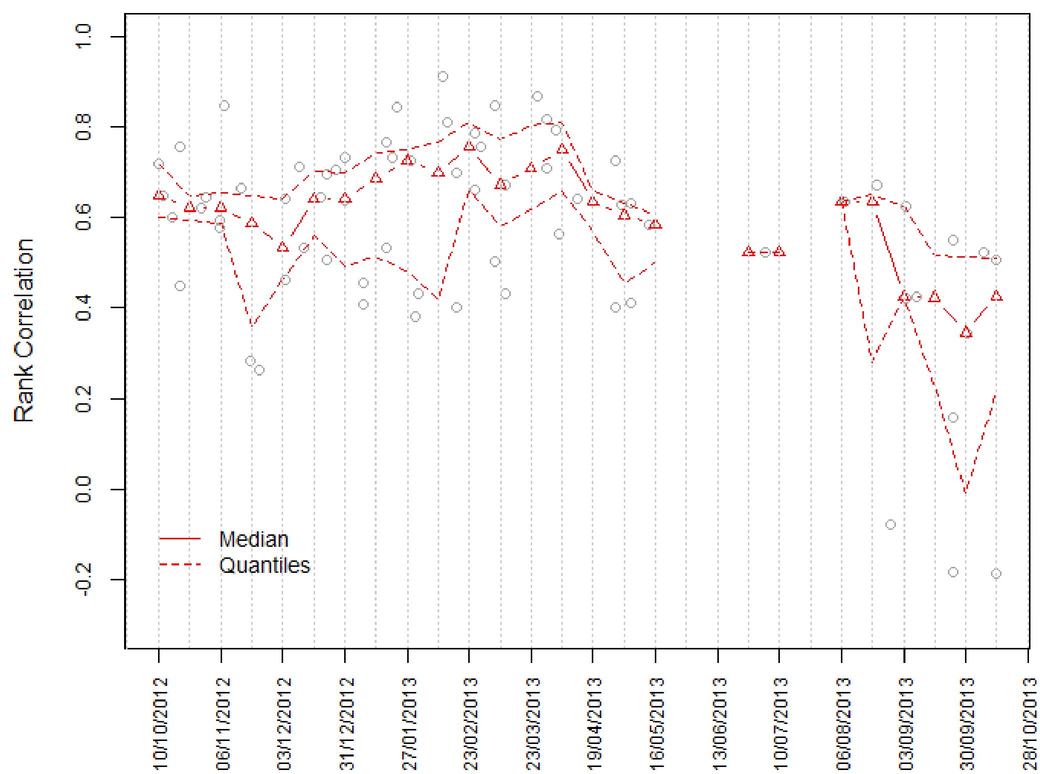

Figure 5. Rank correlation between pixels on each pre-grazing pasture cover map and the total annual dry matter intake map.

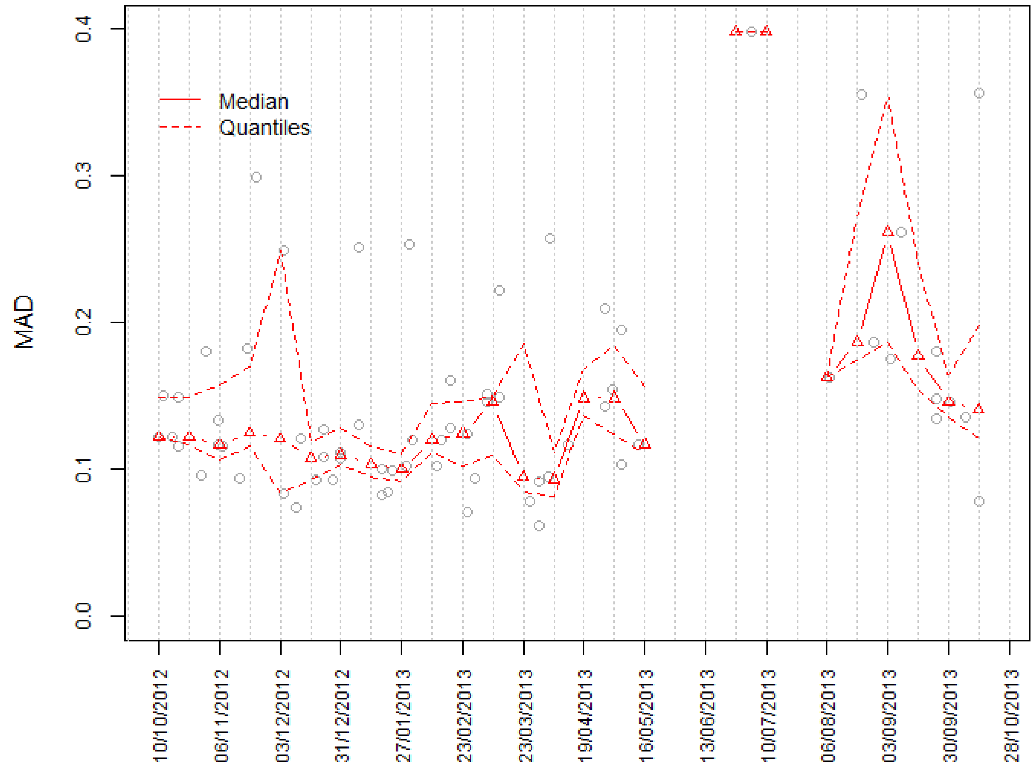

Figure 6. Median Absolute Difference between pixels on each pre-grazing map and the total annual dry matter intake map.

The rank correlations presented in Figure 4 and Figure 5 are directly compared to each other in Figure 7, to determine the level of agreement between the pre-grazing pasture cover and the consumed pasture mass measurement at any individual grazing. The values are correlated with an R^2 of 0.60.

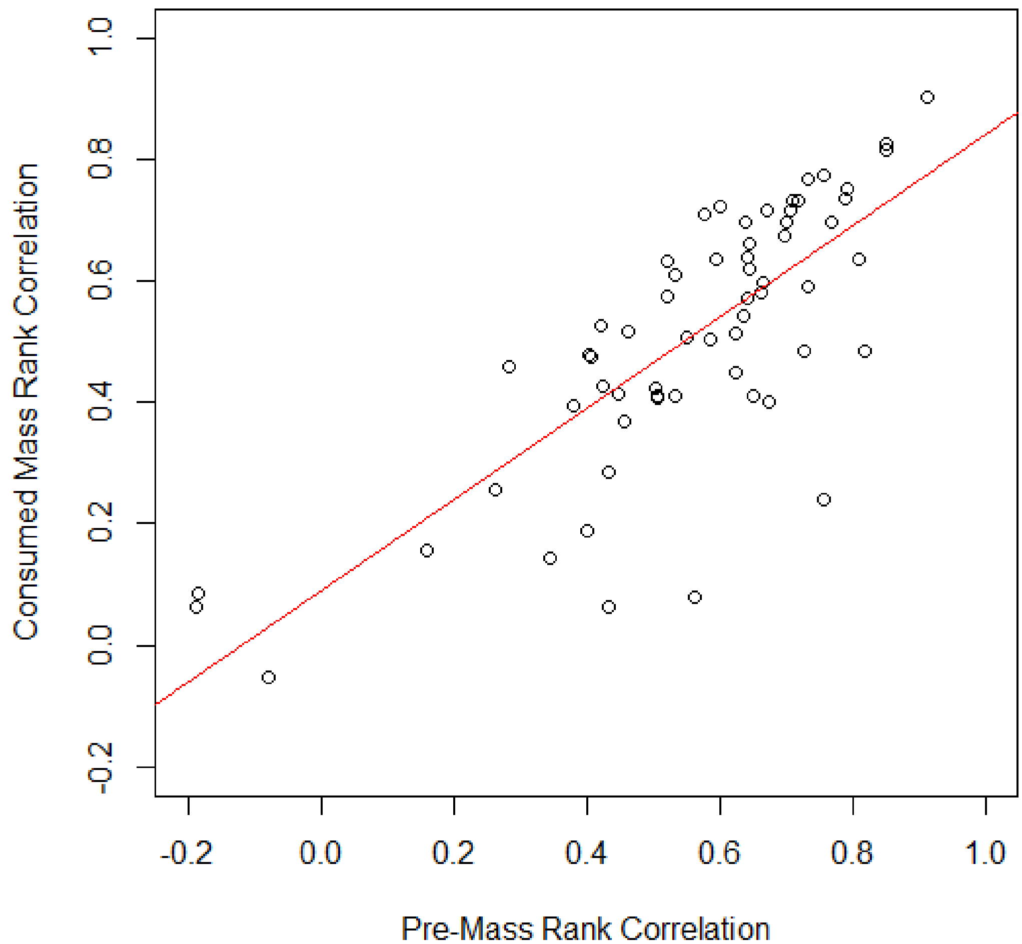

Figure 7. Correlation between the pre-grazing pasture cover RC and the consumed pasture mass RC statistic

DISCUSSION

A single pre-grazing yield map in the summer-autumn period correlated well with total estimated pasture intake.

The value of yield mapping will in practice be greatly affected by whether a single pre-grazing map can be used to inform management, or whether it is necessary to map the paddock both pre- and post-grazing and determine the actual pasture intake. Yield mapping with the C-Dax pasture meter took around 40 minutes for a seven hectare paddock, which would be reduced somewhat by wider run spacing. This makes it a practical operation to do occasionally, but not every grazing in a commercial environment.

Our hypothesis was that a map of pasture intake from each grazing (Figure 2c) would be the best predictor of the total annual intake (Figure 3). This is because the total annual intake map is a sum of the individual maps of pasture intake. We also hypothesized that the variation present in the pre-grazing pasture cover maps (Figure 2a) would be a reasonable estimate of the variation in pasture intake and thus would also allow the total annual pasture intake to be estimated.

As expected, there is a reasonable correlation between the pasture cover and pasture intake maps (Figure 7). However the results actually show that the variation present in the pre-grazing maps was consistently a better predictor than the intake maps of the variation present in the total annual intake map (Figure 4 *cf.* Figure 5). This was unexpected, as the total annual intake map is the sum of the individual intake maps, and is mathematically more distantly associated with the pre-grazing maps.

The reasons for this difference are not yet fully understood. It may be that variations in grazing residual cause variations in the map of pasture intake at that particular grazing that are evened out when all pasture intake maps are added together, but cause the individual intake maps to deviate from being an accurate representation of the total pasture intake. More work is required to understand this better.

This interim work suggests that a single pre-grazing map is just as good a predictor of total annual intake, in fact a better predictor, than a combination of a pre- and post-grazing map. This halves the amount of field measurement that would potentially have been required to generate a usable map, making pasture yield mapping considerably more practical and potentially more financially viable.

The variation present on the maps differed seasonally, as seen in Figures 5 and 6. However the variation seen in individual pre-grazing maps was well correlated with the total annual pasture intake during the summer months, particularly when quantified using the RC statistic (Figure 5). Late spring and summer is the period of highest growth rates in this environment, so these months contribute a high proportion of the total annual pasture intake, resulting in this strong correlation.

Taking the results of both methods of comparing variation into account (Figures 5 and 6), it appears that for this farm a reasonable estimate of the variation in annual pasture intake can be obtained from a single pre-grazing map collected during the period from December to early April, with January – March being the optimal time.

This farm is in a summer dry environment and relies heavily on irrigation to maintain pasture production during these summer months. The variation visible on the maps is strongly associated with different irrigation application methods. The north-east half of the paddock in Figure 3 is under a centre pivot irrigator, while the south-east half is under individual hand-shift sprinklers. Although the hand-shift system is well managed, with GPS-guided placement of sprinklers, the return interval between irrigation events is higher on this system than under the centre pivot and the uniformity of hand-shift sprinklers is also generally lower than centre pivot systems (Irrigation New Zealand 2007). These factors will reduce water use efficiency and ultimately pasture yields under the hand-shift system as compared with the centre pivot.

The pre-grazing map in Figure 2a shows an example of an early autumn map (4 April) that could be collected in order to estimate the variation in total annual pasture intake. A visual comparison with Figure 3 shows a strong correlation between the two maps, with the areas of high yield in Figure 2a also being the highest in Figure 3, and vice versa.

There are many different potential applications for yield mapping, and not all will require assessment of total annual pasture intake. It will often be desired to understand the yield variation in a particular season for instance, to understand the variation in a particular factor limiting pasture growth. However, where it is desirable to know the variation in total annual production, for instance for economic analysis, selection of paddocks for pasture renewal or total annual nutrient uptakes, it may be impractical to measure total production directly. This study shows that it is possible to estimate the variation in annual pasture intake on a paddock from a single pre-grazing pasture map taken at a strategic time of year, which for this particular farm is December to early April.

CONCLUSIONS

It is practical to collect pasture yield maps on dairy farms with a pasture meter towed behind an ATV, taking around 40 minutes for a 7 ha paddock using 10-15 m run spacings.

Directly measuring the variation in the total annual pasture intake is likely to be impractical in most circumstances, however there is potential to identify windows in the year when the variation in the field approximates the annual variation. In this case, annual variation could be estimated by collecting a single map of pre-grazing pasture cover between December and early April, or ideally January – March. This timing is expected to be appropriate for other irrigated farms in Canterbury, New Zealand.

Further work is ongoing to confirm this timing with a longer dataset, and additional work would be required to extend it to other environments. It is expected that the optimal timing in other environments would correspond to the period of peak pasture growth rates.

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