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Measuring pasture mass and quality indices over time using remote and proximal sensors

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Abstract. *Traditionally pasture has been measured or evaluated in terms of a dry matter yield estimate, which has no reference to other important quality factors. The work in this paper measures pasture growth rates on different slopes and aspects and pasture quality through nitrogen N% and metabolizable energy and ME concentration. It is known that permanent pasture species vary greatly in terms of quality and nutritional value through different stages of maturity. Pasture quality decreases as grass tillers mature through to flowering. This study looks at the value of pasture on 14 sites, with different aspects, slopes and pasture species within Ohorea; a hill country sheep and beef station in the central North Island of New Zealand over a year. A field study was undertaken to examine the changes in pasture growth rate and quality. The purpose was to value the pasture in dollar terms calculated from a conversion factor based on animal carcass weight produced from an 845ha block over a twelve month period. The pasture produced, estimated from cage cuts on the 14 sites, varied in estimated value from NZ$0.11 to NZ$0.38kg^{-1} dry matter produced. The use of dry matter yield as the sole means of valuing pasture is flawed and a new index introduced based on a quality and quantity matrix is required.*

Keywords. *Dry Matter, Normalized Difference Vegetative Indices, Remote Sensing, Proximal Sensing*

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Introduction

In New Zealand, pasture measurements have been used to establish the mass of the dry matter either produced, available as animal feed, or cropped for silage and hay that is retained to be fed out in times of feed deficit or for sale (Gray *et al,* 2003).

In sheep and beef hill country farms, managing feed quality is not a simple undertaking because much of the land cannot be cultivated, meaning opportunities to grow supplemental feed are limited. Feed quality may be influenced by grazing management, additions of fertilizer, agricultural lime and over seeding with improved pasture species. Most farms graze stock all year round, with some supplementation with forage crops grown where possible. Hill country farms often have pasture growth deficits in winter and late summer where supplemental feeding or forage crops are needed. In spring and autumn, pastures tend to grow faster than the stock can eat and either supplementary stock are purchased and traded or a feed bank of low-quality feed from flowering annual grasses dominates (Chaves *et al,* 2006). Most farms carry insufficient stock numbers to prevent the flowering of annual grasses on hill country slopes; consequently pasture quality decreases as the grasses age because stems and flower heads have much lower nutritive value than leaf tillers as they contain higher concentrations of lignin and cellulose. The higher concentrations of lignin and cellulose also reduce animal feed uptake as the material takes longer to digest (Colman and Henry, 2002).

Yule *et al,* (2014) found that by using an ASD Fieldspec pro (formerly ASD Inc., now PANalytical, Boulder, Co.) hyperspectral proximal sensor that non-destructive in-field measurement of quality parameters is possible. They measured ME, organic matter digestibility (OMD), and crude protein (CP), estimated by total nitrogen analyzed multiplied by 6.35. All three parameters were estimated by iterative linear regression accurately $r^2 > 0.8$ (Pullanagari *et al,* 2012; 2013).

In this paper, pasture growth rates and %DM mass were measured over a 14 month period and CP was estimated from Normalized Difference Vegetative Indices (NDVI) as a measure of pasture quality using Landsat 8 satellite imagery. A pasture quality index in terms of a conversion ratio of pasture into carcass weight (CW) for the sheep and beef produced in the block established, and the value of pasture estimated in NZ$DMkg^{-1}. The block comprises 840 ha of land in summer moist hill country (1,300mm of rain per annum, 5 year average) between 260m and 780m in elevation. The farm has a good fertilizer history and Olsen P results of 22mgkg^{-1} are considered optimal for this class of farm.

Material and methods

Pasture measurement

Stock exclusion cages were laid out on 14 sites, which represented different slope and aspects, 3 cages of 0.5m^2 were placed at each site and cut for quality, at about 3cm height every few weeks to measure pasture growth rates (Lynch, 1966; Anon. 2008). The samples were dried at 60^o C in an oven to obtain dry matter. Pasture growth rates were measured over a twelve month period.

Surface temperature and normalized difference vegetative indices (NDVI) were obtained from Landsat 8 imagery (NASA) and processed using ENVI 5.2 (Excelis Visual Information Solutions, Denver Co.) and ArcGIS 10.3 (ESRI, Redlands Ca.). There were 9 images of Ohorea downloaded which were clear of cloud from which surface information could be obtained over the twelve month period the cuts were taken.

Proximal NDVI measurements were recorded using a Rapidscan (Holland Scientific, Lincoln Ne.). Nitrogen measurements were taken on the dried cut samples using an ASD FieldSpec® pro (PANalytical ASD Spectral devices, Boulder Co.) (Pullanagari *et al* 2012; 2013). The New Zealand

Centre for Precision Agriculture (NZCPA) has calibrated 10,000 dried pasture samples including 1,200 from Ohorea to calibrate the ASD Fieldspec to laboratory wet chemistry and have obtained an $r^2 > 0.96$ for nitrogen, which is within the laboratory error of 6%. The work was carried out to compare proximal and remote NDVI readings, compare the NDVI ratios with the plant nitrogen concentration and examine the changes to these ratios across a range of growth conditions. Pasture cuts were also compared to readings taken with a rising plate meter (50 readings per site) carried out in accordance with Anon, (2008) for calibration purposes.

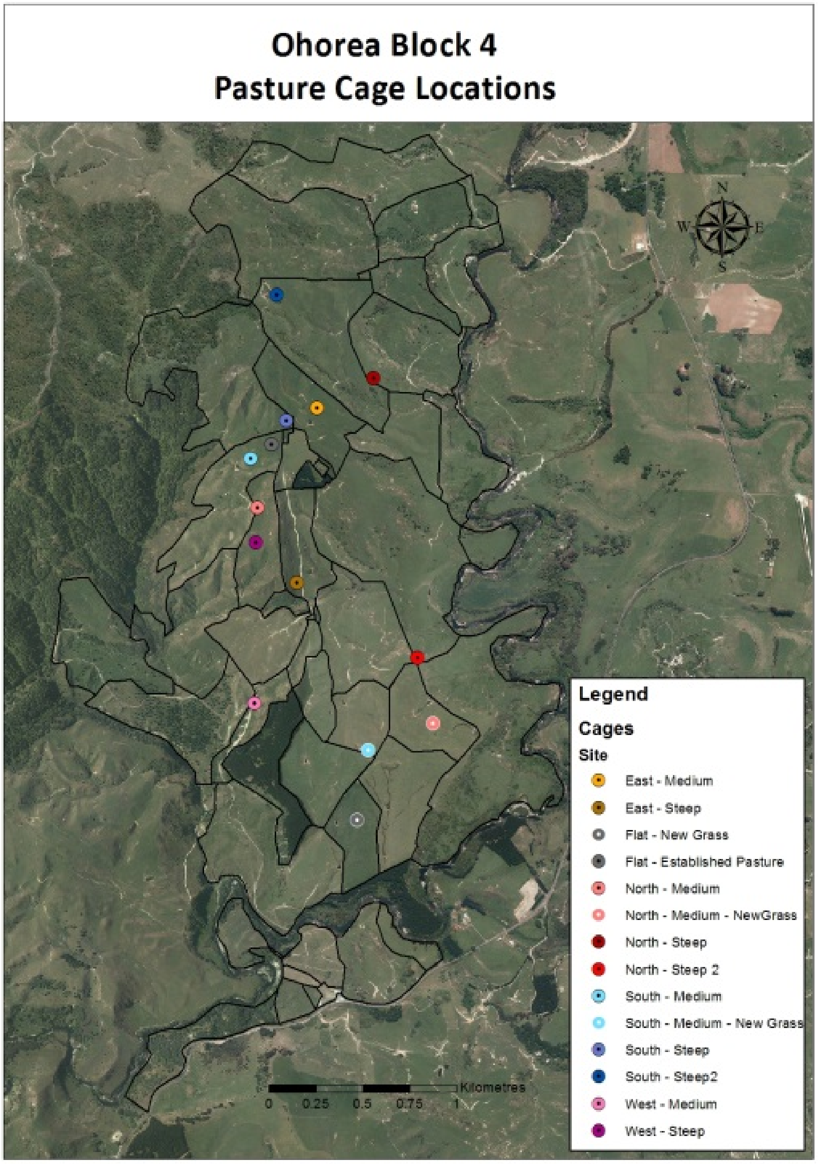

Fig 1. Location of pasture cages on Ohorea Station.

The quantity and quality of the pasture were assessed in terms of conversion ratios to Kilograms carcass weight. This was undertaken by estimating ME, OMD and DM from the ASD calibrations from the 400 sampling sites at 80 locations, which had been sampled three times each over the 12 month period (Coleman and Henry, 2002).

Results

The results from the pasture cage cuts show a near three fold difference between the highest and lowest producing site, the new north medium and established north medium sites respectively, see table 2. The two lowest producing sites were the new north medium, which is a particularly dry site and new south medium, where the pasture has struggled to become established. The steeper sites produced between 9,000 and 11,000 kgDMha^{-1} over the 12 month period. The highest levels of production were the established flat and new north medium sites, producing 22,054 and 21,054kgDMha^{-1} respectively.

The seasonal pattern of pasture growth over the 14 sites shows peak spring production around early November for north and east facing slopes, with the peak for south and west facing slopes later, around December. Growth rates slow over the summer months. A much reduced peak, compared to spring, is evident for all sites in mid-autumn, growth then slows into the winter months.

The Rapidscan NDVI measurements were close to those obtained from processing the Landsat 8 imagery. Higher NDVI ratios generally indicate higher quality parameters in crops and pastures and are usually associated with higher concentrations of nitrogen within the plant tissue. However, at the extremes of the feed wedge the NDVI readings were inconsistent with nitrogen concentrations. The feed wedge is the level of pasture that is available for feed, the extremes are after grazing has ceased and stock have been moved to fresh pasture ready to feed. Taller grass produced high NDVI readings, but the nitrogen concentration was low, probably due to advanced maturity with reduced nitrogen concentration. Areas that had been grazed hard had high nitrogen concentrations in the remaining pasture but low NDVI ratios probably because there was incomplete pasture cover and some bare soil visible.

The estimated measurements of nitrogen were obtained from dry cuts analyzed by the Cropspec rapid scan using the algorithms developed from the complete data set from the 10,000 samples collected by the NZCPA are shown in Table 1.

Table1 Shows, site description, estimated N, crude protein and NDVI values for the 14 sites

	Aspect	Slope °	Average Predicted N	Average CP kg/DM	NDVI	% CP kgDM
East Steep	70	36	0.65	41.22	0.61	4.12
East Medium	70	18	0.91	58.00	0.70	5.80
North Steep 1	30	44	0.73	46.26	0.67	4.63
South Steep 2	190	32	0.53	33.69	0.60	3.37
South Steep 1	180	40	0.74	47.24	0.63	4.72
Flat Old Pasture	70	9	0.96	61.25	0.76	6.12
West Steep	280	29	0.62	39.34	0.63	3.93
North Medium	20	20	0.44	27.80	0.67	2.78
South Medium New Grass	200	17	1.30	82.82	0.55	8.28
Flat New Grass	130	4	1.31	82.94	0.78	8.29
West Medium	260	23	0.42	26.75	0.83	2.68
South Medium	220	13	0.48	30.59	0.71	3.06
North Medium New Grass	360	13	0.92	58.34	0.83	5.83
North Steep 2	360	30	0.22	13.81	0.68	1.38

The pasture cut growth rates were measured and taken as the average between consecutive cuts, the growth rates from the 14 sites are shown in Table 2.

Table 2 shows estimated pasture production in kgDMha^{-1} growth rates, average pasture covers and conversion ratio kgDM to kgCW.

Overall year	Pasture Produced	Average cover (kgDMha^{-1})	Ratio kgDM/kgcW
East Steep	11,790	1,310	18.00
East Medium	11,649	1,294	20.00
North Steep 1	10,994	1,222	22.75
South Steep 2	9,500	1,056	17.75
South Steep 1	10,679	1,187	16.00
Old Flat	21,045	2,338	14.00
West Steep	9,614	1,068	21.00
North Medium	8,539	949	28.00
South Medium New	8,650	961	22.25
Flat New Grass	14,933	1,659	16.50
West Medium	12,382	1,376	19.25
South Medium	15,475	1,719	18.00
North Medium New	22,054	2,450	15.75
North Steep 2	9,887	1,099	27.00

There was an inverse correlation between surface temperature and NDVI in summer and winter, whereas in spring and autumn NDVI were generally high at all locations. In summer when water stress is apparent the areas which had high NDVI were the coolest, whereas the warmer areas had higher NDVI in winter. Where water stress is not evident then there is a positive correlation between surface temperature and NDVI see Figure 4 (Grafton and Yule, 2015).

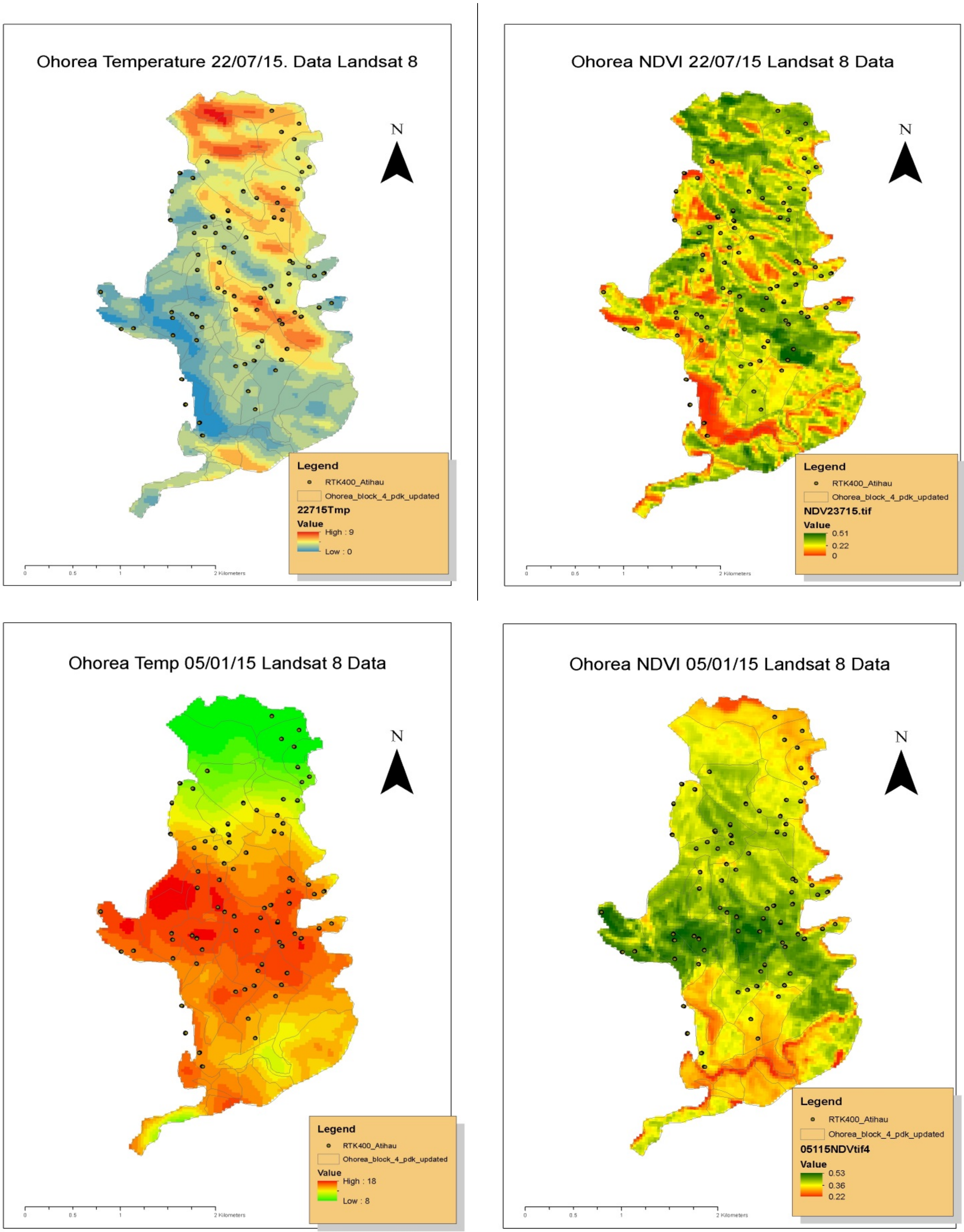

Fig 4: Shows NDVI in summer 5 January and winter 22 July (*left side*). Shows surface temperatures, same dates (*right side*) winter 0° – 8°C; summer 8° - 16°C. The marked areas are where additional soil, pasture samples and pasture spectral readings have been undertaken four at each of 80 sites, four times, autumn, winter, spring and summer.

Pasture Value

The values used to measure pasture value were based on the New Zealand meat schedule in July 2015, see Table 1.

Table 1 Shows value of meat product farm gate NZ$kg^{-1} carcass weight.

	Ckg^{-1} CW	NZ$kg^{-1} CW
Lamb price	0.547	5.47
Mutton all grades	0.309	3.09
Steer & Heifer	0.595	5.95
Bull	0.507	5.07
Cow	0.404	4.04

The stocking carrying capacity of block 4 at Ohorea Station is around 9.5 stock units per hectare, see Table 4. Each stock unit requires around 540kgDM of quality pasture per annum for maintenance. On top quality pastures a conversion factor of 12kgDM to 1kgCW of lamb can be achieved; however, pastures vary in quality depending on tiller maturity, species and soil moisture content and fertility (Burke *et al* 2000; Coleman and Henry, 2002; Jarvis *et al* 2002; Waghorn and Clark, 2004; Chaves *et al* 2006; Gillingham *et al* 2007). These factors are also affected by slope and aspect. The amount of dry matter eaten in comparison to the total dry matter grown also varies considerably; for this study 70% of dry matter was considered to have been consumed by the stock on the block.

Table 4 shows stock units for each class of animal supported on the farm(Cornforth and Sinclair, 1984).

Sheep	Stock Units	Beef Cattle	Stock Units
Ewes	1.0	M.A. Cows	5.5
Hoggets	0.7	Heifers 2.5Yr	5.5
Wethers	0.7	Heifers 1.5Yr	4.4
Rams	0.8	Heifers Weaner	3.5
		Bulls Weaner	4.5
		Steers Weaner	4.5
		Steers 1.5Yr	5.0
		Steers 2.5Yr	5.5
		Bull Beef 1.5Yr +	5.5
		Bulls Breeding	5.5

The conversion ratios from dry matter to carcass weight were estimated from the crude protein as established by the spectral reflectance from the dried samples of the average of the cuts taken at each site (Burke *et al* 2000) see Table 5.

The value of each kgDM produced is estimated from the conversion ratios to carcass weight at the prices shown in Table 1; these are shown in Table 6.

Table 6 shows site description and average value of DM produced in terms of carcass value when converted

Sites	Aspect	Description	Slope °	Lamb	Mutton	Steer	Bull
North Steep	30	Steep	44	0.24	0.14	0.26	0.22
North Steep 2	360	Steep 2	30	0.20	0.11	0.11	0.19
South Steep 2	190	Steep 2	32	0.31	0.17	0.34	0.29
South Steep 1	180	Steep	40	0.34	0.19	0.37	0.32
West Steep	280	Steep	29	0.26	0.15	0.28	0.24
East Steep	70	Steep	36	0.30	0.17	0.33	0.28
North Medium	20	Medium	20	0.20	0.11	0.21	0.18
South Medium	220	Medium	13	0.30	0.17	0.33	0.28
West Medium	260	Medium	23	0.28	0.16	0.31	0.26
East Medium	70	Medium	18	0.27	0.15	0.30	0.25
North Medium New	360	Medium	13	0.25	0.14	0.27	0.23
South Medium New	200	Medium	17	0.35	0.20	0.38	0.32
Old Flat	70	Flat	9	0.33	0.19	0.36	0.31
New Flat	130	Flat	4	0.39	0.22	0.43	0.36

Discussion

Mixed species pastures are the production base for hill country sheep and beef farming in New Zealand. Only flat and gently rolling hillsides are cultivatable and it is these areas where pasture can be renewed and fertilizing and weed control are easily undertaken. These areas tend to produce the highest quality pastures when these areas have been managed accordingly.

On steeper terrain where cultivation is not possible, species composition can only be influenced by grazing management, paddock subdivision, over-sowing desired species; weed control and fertilizer inputs. There are an infinite variety of microclimates on hill country and moisture is the most common limiting factor. In these environments, the best-adapted species dominates each niche, which is usually a low-fertility annual grass or weed species (Yule *et al* 2014).

The standard measurement of pasture production and value is dry matter production. However, the areas which often produce the largest amounts of dry matter also tend to produce dry matter that contains more, crude protein, has higher levels of metabolizable energy and is more digestible. While these factors are known to be significant, they are given no importance in farm management production systems (Gray *et al* 2003).

This study found that the value of dry matter produced on the 14 sites varied between; $0.11 to $0.38 $kgDM^{-1}$ over the 14 month period. Steeper sites had lower NDVI and predicted nitrogen values than more gentle slopes. In the southern hemisphere the sun is in the northern sky and areas with a northerly aspect tend to dry out quicker than those with a southern aspect. When areas dry out weed and species better suited to moisture deficit, such as tropical C4 grasses and California thistle *Cirsium arvense* establish. These species have lower nutritional value than the desired species (Burke *et al* 2000; Waghorn and Clark 2004; Chaves *et al* 2006). In areas which can be cultivated, pasture renewal is undertaken and these new pastures consist of high value commercial perennial rye grass *Lolium perenne* and white clover *Trifolium repens* cultivars. The areas which are on flat to medium ground that can be cultivated, sown, fertilized and weed sprayed by vehicle have the highest value. There are smaller differences between easterly and westerly aspects, it is possible that easterly faces remain cooler than westerly faces as they receive solar radiation from a lower starting temperature and may, therefore, be less prone to moisture deficit, especially if shaded through topography after the sun's zenith.

A stock unit requires around 540kg dry matter per annum for maintenance, additional dry matter is needed to condition stock (Coleman and Henry, 2002). The amount of feed eaten is always a percentage of what is grown. On sheep and beef farms 80% of pasture eaten is considered good. The percentage of pasture eaten is governed by subdivision and the availability of capital stock, finishing stock and trading stock. Subdivision as it controls field size and stocking level so that grass is eaten evenly and down to a level that promotes tiller growth, usually by grazing cattle and following with sheep. In spring and autumn grass flushes occur, which result in wild annual grasses flowering, more prevalent in spring than autumn. The capital stock, especially cows with calves and ewes with lambs are preferentially grazed on the improved flatter pastures, with perennial rye grass and clover as these have higher metabolizable energy and crude protein levels, the aim is to prevent flowering of rye grass if possible. Bulls, rams and steers, often trading stock usually graze the steeper slopes when and where grass flowering is taking place.

The digestibility of feed is the key to fattening stock, higher crude protein from young tillers and clover legumes enables stock to gain condition faster (Burke *et al* 2000). Flowering grasses and tropical grasses have high levels of lignin and cellulose which are not easily digestible which limit the quantity of feed that can be eaten, especially by younger animals which prevents animals gaining condition (Chaves *et al* 2006).

It is logical that the dry matter value should be included in any farm management measurement system, however it likely that farmers already use their esoteric knowledge to judge ephemeral changes in pasture value when considering which class of stock is to feed in each production zone.

Conclusion

There needs to be a qualitative and quantitative index or matrix, for measuring pasture as dry matter varies considerably in terms of value in terms of carcass weight produced from each class of land. In this study there were 14 sites on 12 classes of land, which were measured for quantity and quality over 14 months.

There was considerable variation in pasture production in both quantity and quality, which supports the concept of introducing an index approach to monitoring dry matter.

A dollar value in terms of production may be a useful alternative to DM produced as the means of measuring agricultural production systems.

This study suggests that this is viable and could be introduced to improve farm management practices. The information could assist in decisions in regard to retiring pasture, fertilizer application requirements and searching for higher and better land use solutions.

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