A review of herbage mass estimation techniques appropriate for Northern Ireland, and suggested developments to improve adoption and accuracy of grassland management assessments.

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1.0 Introduction

Although the Northern Ireland dairy industry continues to evolve, one of the main themes of the past 20 years has been the increase in concentrate input and milk output per cow. This intensification creates a number of new challenges for dairy farms, principally how to economically achieve the high nutrient intakes required by the high yielding dairy cow. Despite wildly fluctuating market prices for cereals and fertilisers during the past 10 years, grazed grass remains the cheapest feed available in Northern Ireland. However, this economic advantage is based on the assumption that high yields of this forage can be produced, and that the resulting high quality feed is efficiently utilised by the grazing animal. Provided it can be utilised efficiently, the inclusion of grazed grass in dairy cow diets offers an opportunity to reduce the costs of milk production, or certainly reduce the reliance on conserved forages and purchased concentrates.

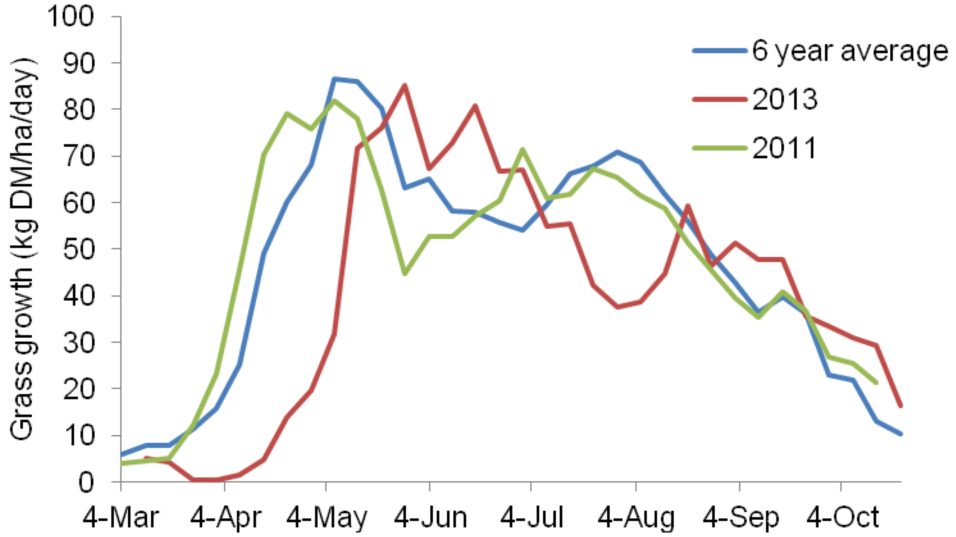


Figure 1. Average weekly grass growth throughout 2011 and 2013, in comparison to the average grass growth over the past six years (source: GrassCheck).

Whilst there are clear advantages to optimising the intake of grazed grass, achieving this is challenging, and particularly in terms of providing a constant supply of high quality feed. Grass growth can be variable, and although there are typical periods of rapid growth (April/May) and slow growth (February and October) there can be considerable variation between months and also between years. For instance, grass growth data recorded in Northern Ireland has shown growth rates ranging from 70 to 5 kg DM/ha/day during mid-April in recent years (2013 and 2011, respectively). This variation in growth is highlighted within Figure 1, with grass growth for 2013 and 2011 shown in comparison with the average grass growth over the past six years (2007-2012).

This variation provides grassland managers with a constant challenge, and it is a key grassland management requirement to recognise whenever differences are occurring between grass supply and grass demand, and take the required action. Whilst extreme surpluses or deficits of grass supply are easily identified, the recovery from this situation will incur a significant cost, and it is likely that animal and sward performance will be adversely affected. To minimise the impact of grass surpluses and deficits, decisions need to be taken at a much earlier stage, and thus there is a requirement for grassland managers to be able to continually quantify grass supply during the season. Whilst there are sources of regional grass growth information published in the farming press (GrassCheck, NI; GrassWatch, ROI), ideally grassland managers should be able to quantify grass supply within their own grazing platform.

Whilst many farmers invest considerable amounts of time during the winter months closely monitoring forage intakes and silage stocks, this focus largely dissipates once the herd begins grazing in spring. Whilst animal performance at grass can be affected by a number of factors outside of the grassland managers control, most notably the weather, any input in terms of time spent monitoring grass performance could be well rewarded. These advantages include optimising grass quality, optimising quantity of grass grown, a reduced need for topping, maximising the efficient use of expensive fertilisers, potential to reduce the inputs of supplements and the potential to identify poorly performing fields and prioritise field works (drainage, soil fertility, soil structure, reseeding). Despite these clear incentives, very few farmers in Northern Ireland are actively and regularly assessing sward growth during the summer. There are a number of reasons for this lack of uptake, including the time involved and also a growing uncertainty about the methodology involved, both in terms of which technique to use and also the accuracy of these techniques.

The objective of this review is to establish the potential and accuracy of the methodologies that are currently applicable to Northern Ireland, with a particular focus on the relationship between compressed sward height and herbage mass, and to identify strategies that could be used to improve accuracy and adoption of grassland measurement technologies.

2.0 Range of methodologies currently available

There are a number of options available for quantifying the amount of herbage within a sward, and some of these are detailed in Table 1.

Table 1. A summary of the main methodologies currently available for measuring grass swards and subsequently for handling the data.

Quantify the amount of herbage	Handling the data
Sward height	Excel spreadsheets - farm cover
Sward stick	feed wedges
Wellington boot	
Ruler	Smartphone APP's
Herbage mass	Specialist computer packages
Rising plate meter	Grass consultant
Eye ball assessment	
Cut and weigh	
Capacitance/infrared/ultrasound	

In general terms, there are four aspects of measurement which are applicable across the individual methodologies, and these are:-

1. **Measurement of sward height**

The simplest measurement of the sward is height, and this can be taken by a range of equipment ranging from the calibrated Hill Farming Research Organisation (HFRO) sward stick to a simple assessment taken against the side of a wellington boot. Typically targets are provided for optimum sward heights pre- and post-grazing, and this measurement can be taken to check the achievement of these targets. The rising plate meter can also be used to measure sward height, and in this instance the measurement is 'compressed sward height.'

2. **Measurement of herbage mass**

The conversion of sward height (cm) to herbage mass (kg DM/ha) facilitates the calculation of additional details of herbage availability, with the estimation of average farm cover, grass intake, herbage allowance and grass growth all possible. This calculation also allows for different paddock sizes to be taken into account as the quantity of herbage is expressed on a per hectare basis.

3. **Measurement of available herbage or total herbage**

Quantifying the amount of herbage within a sward can be described in one of two ways, namely available herbage or total herbage. Total herbage is all the herbage above ground level and this is the terminology generally used in the UK and New Zealand. However, in other countries only the 'available herbage' is measured, as all herbage at the lower levels of the sward is assumed to be not available for the grazing animal. For example, within the Republic of Ireland available herbage is quantified as being above a sward height of 3.5 cm.

4. **Handling of data that is collected**

Whilst this review is principally about the methodologies involved in quantifying the amount of herbage within the sward, a crucial part of the process is the interpretation of the information collected, and the action that is subsequently taken. If a suitable system of data handling is not adopted, the time that has been spent collecting the data could be wasted. This aspect of the measurement process has developed rapidly in recent years, particularly as farmers are becoming increasingly conscious of computer packages and also technologies accessible through mobile devices such as smart phones and computer tablets.

2.1 Critique of methodologies

The approaches that are applicable to Northern Ireland can be defined as either measuring sward height or herbage mass.

Sward height -

Extended tiller height

Although the measurement of extended sward height can be achieved relatively cheaply (sward stick, wellington boot, ruler), other than the provision of information on the achievement of targets pre- and post-grazing this measurement has major limitations. The measurement of sward height on its own does not take into account the area of the field or the density of the sward. Furthermore, to get a representative measurement from the field a number of readings should be taken, and this can be a slow and laborious process. The conversion of sward height into herbage mass will add to the value of the measurement, and some authors have shown that herbage mass can be estimated as accurately from sward height measurements as from measurements taken with the rising plate meter (Virkajarvi *et al.*, 1999; Murphy *et* *al.,* 1995; Harmoney *et al.,* 1997). However, others suggest that sward height is not a useful indicator of forage availability (Sanderson *et al.,* 2001).

Compressed sward height (rising plate meter)

The measurement of compressed sward height using a rising plate meter allows the assessment of sward height and density to be carried out together. Furthermore, multiple readings can be taken across a field very quickly, providing a more accurate estimation of the 'average' sward height within that field/paddock. However, as above, the usefulness of compressed sward height on its own is limited.

Herbage mass -

Rising plate meter

The principle role of estimating the compressed height of a sward using the rising plate meter, is as a basis for the subsequent estimation of herbage mass. This is achieved by applying an equation to the sward height, which generally represents an estimation of sward density (kg DM per cm of sward height). The rising plate meter is a well recognised method of estimating herbage mass, and the concept has been used for over 30 years (Meijs *et al.,* 1982; Michell, 1982) and is used worldwide (Mould, 1990; Thomson *et al.,* 1997; Zhao *et al.,* 2007). The relationship between herbage mass and sward height differs between forage types (Harmoney *et al.,* 1997), but there is also evidence that within a grazed ryegrass sward, there is seasonal variation within the relationship (Powell, 1974; Barrett and Dale, 2005). Therefore, whilst there are those who use a single equation across a long grazing season (Vance *et al.,* 2012; Litherland, 2009) there are others who have used multiple 'seasonal' equations (L'Huillier and Thomson, 1988; Frame, 1993).

In addition to the potential effect of seasonality, there can be some variation between operators (Aiken and Bransby, 1992). This variation is linked to the sampling process, whereby the plate meter should be used randomly across the area, and when a measurement is taken, the equipment should be held straight at all times and not forced down into the sward abruptly. The accuracy of the methodology is also vulnerable to ground conditions, particularly in poached soils. Furthermore, other aspects of the sward will also have an effect on accuracy, for example when the sward changes from the vegetative to reproductive phase of growth (Douglas and Crawford, 1994) or when the sward is not standing straight (after heavy rain or when grass cover is high).

Cut and weigh

The physical cutting, weighing and drying of a sample of herbage from within the sward is often regarded as the definitive measurement of herbage mass. This technique is widely used within research studies (Barrett and Dale, 2005; Vance *et al.,* 2012; Ganche *et al.,* 2013; Tunon *et al.,* 2014), with the cutting being carried out within a strip or a square area. Although large strips (up to 10m long and 1m wide) can be harvested within a research environment, the cutting equipment required for this scale of cutting is not applicable to on farm use. The cutting of smaller areas can be achieved with battery operated hand held shears, and the area marked with either a meter long stick or a quadrat (e.g. 0.50 x 0.50 m). Once the area is identified, all the herbage within the area is removed, weighed and a sample is dried to determine its dry matter content. Herbage can be cut to ground level, or alternatively, cut to a pre-defined 'stubble height,' with the estimated herbage mass within this 'stubble' added onto the herbage mass that is cut and weighed. Based on the fresh weight, the dry matter and the area harvested, an estimate of the herbage mass (kg DM/ha) can be obtained.

Whilst the technique can provide an accurate estimate of the herbage mass present within an area, how representative that herbage mass estimate is to the field/paddock in general will depend largely on the selection of the site that is cut. Ideally the area cut should reflect the average herbage mass present within the field/paddock. Site selection is important as repeating this assessment multiple times within a single field will be very time consuming, and so it is likely that a field estimate will be based on the cutting of one or two areas within that field.

Due to the multiplication of the yield measured within the relatively small area that is cut, any errors will also be multiplied as this yield is transformed into a per hectare basis. A typical quadrat (0.5 x 0.5 m) represents 0.25 m^2, and the resulting yield from this will be multiplied by 40,000 to represent a hectare. Ensuring the site selected is representative of the average herbage mass and that it can be cut cleanly (not in an area that is excessively poached, or affected by dung/urine patches etc) is essential.

Although the majority of the equipment used in this methodology is available for on farm use, the assessment of dry matter is generally completed visually rather than placing the sample in an oven. Although typically fresh grass has a relatively narrow range of dry matter (16-20%), it can be more extreme during periods of very wet or dry weather. This estimate is a possible source of error. For example, if 440 g of herbage is harvested to ground level within a 0.25m^2 quadrat, this will provide a herbage mass estimate of 2,816 or 3,168 kg DM/ha depending on whether dry matter content is estimated as 16 or 18%, respectively. Furthermore, although the equipment involved (battery operated shears, quadrat, spring balance, sample bags) does not require a major investment, this equipment is bulky to carry around if multiple measurements are made within the grazing platform.

'Eye ball' assessment.

The visual assessment of herbage mass by a trained person has been used successfully (Stakelum, 1996; O'Donovan *et al.,* 1997, 2002; Lopez-Guerrero *et al.,* 2011). This methodology offers many advantages, as it requires no equipment and an assessment of a large area can be achieved relatively quickly. The difficulty with this technique is that as a subjective assessment of herbage mass by an individual, weekly measurements carried out by different personnel may not necessarily be that comparable. Furthermore, it is open to bias, and so there is a need for the operator to 'calibrate' their assessments on a regular basis during the season. Therefore, although the actual measurement by visual assessment involves little equipment and cost, the process of calibration merits the purchase of additional equipment, albeit not used on a weekly basis.

Capacitance/infrared/ultrasound

Although the potential application of these technologies in quantifying herbage mass has been considered for some time (Neal and Neal 1973; 't Mannetje, 1978; Schut and Ketelaars, 2003; Flynn *et al.,* 2008; Fricke *et al.,* 2011; Serrano *et al.,* 2011), some of these technologies have only recently been integrated into commercially available equipment (C-Dax, Grassometer). One of the principle advantages of this equipment is that it can allow multiple readings to be taken across a large area relatively quickly, with the ability to mount the equipment onto vehicles or tow it behind vehicles. Due to the volume of readings, an accurate assessment of the 'average' herbage mass present within the field/paddock can be achieved. This equipment also records these data automatically, and the 'paperless' collection and processing of the data is a further advantage over the manual records required with the other methodologies.

The application of these techniques is also wider than just herbage mass estimation, with the techniques being used to assess crop N content, total sugar and mineral concentrations (N, P, K, S, Ca and Mg) (Schut *et al.,* 2005). The wider application of these techniques could help justify the financial investment, although most of these applications are still being tested and evaluated and not commercially available. Despite the potential accuracy offered by these techniques, it is likely that the financial costs involved will continue to be prohibitive, and limit their applicability to commercial farming systems.

Table 2 Summary of the main strengths and weaknesses of the main methodologies applicable to Northern Ireland to quantify herbage mass within a grazing sward.

Methodology	Strengths	Weaknesses
Rising plate meter	Takes account of sward density as well as height. Quick to take multiple readings across an area, which also encourages regular viewing across the breadth/width of each individual grazing paddock.	Cost of equipment. Evidence of seasonal variation in relationship between height and mass.
Eye ball assessment	Rapid assessment of a large area. Cheap and requires no equipment.	Potentially poor repeatability between different operators. There is a need to 'calibrate' periodically. Temptation to just glance over the fields from a distance. Very subjective measurement.
Cut and weigh	Repeatability of measurement between operators can be better than eye ball and rising plate meter. Can be useful to calibrate either plate meter or visual assessments.	Slow and labour intensive if multiple readings were taken in each grazing area. Accuracy influenced by site selection, herbage cutting and dry matter estimation. Any errors at any stage are multiplied significantly when converted to a per hectare basis. Equipment required is bulky.
Capacitance, Infrared, ultrasound	There is the potential to collect a large number of readings very quickly, hence producing a very accurate 'average' figure for that area. Data collected and interpreted electronically.	Very expensive equipment. Technology is still being piloted and evaluated in commercial situation, particularly in terms of assessing herbage quality.

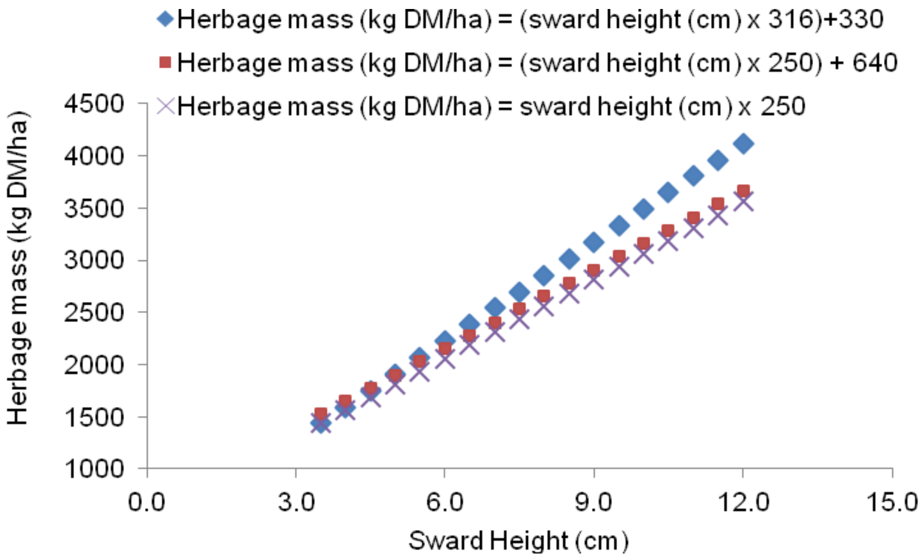
3.0 Analysis of data to establish relationship between sward height and herbage mass

The rising plate meter potentially represents the best option for measuring herbage mass within grazed swards. However, this methodology is reliant on a 'conversion equation' to relate the measured 'compressed sward height' into 'herbage mass.' As previously described, there are examples of seasonal variation and multiple equations are available. Figure 2 highlights the herbage mass (Y) calculated from sward height (x) using three different equations, namely:

1. Y= 316x + 330 (source: Jenquip, New Zealand)
2. Y = 250x + 640 (source: DairyCo)
3. Y = 250x (source; TEAGASC, 2011)

The equation from TEAGASC quantifies herbage mass above a residual sward height of 3.5 cm, so for comparison purposes the herbage mass within this residual was assumed as 1,436 kg DM/ha. This was added onto all values to ensure values represented total herbage cover above ground level.

Figure 2 The estimation of herbage mass from sward height using three different published equations.



Whilst the herbage mass produced by all three equations does not vary widely when sward height is low i.e. 4 cm (87 kg DM/ha), there is considerable variation when sward height increases. At a sward height of 10 cm, herbage mass varies by 429 kg DM/ha between the three equations. To identify how representative these equations are for grass swards in Northern Ireland, a number of datasets were identified which contained multiple observations of both sward height and herbage yield. These datasets were sourced from the GrassCheck plots (n = 4), and also from specific measurements taken on a regular basis throughout multiple grazing seasons at AFBI, Hillsborough (n = 3).

Grazing platform data

One of the challenges in achieving a representative relationship between sward height and herbage mass under grazing is including the variability associated with a grazing sward (trampling, selective grazing and inconsistent grazing residual). Whilst consistent measurements can be more easily achieved within a ‘simulated’ grazing environment (where the sward is cut and not grazed), the variability associated with grazing should be incorporated into the calibration dataset, as inevitably the plate meter will encounter this variability in practise. Furthermore, to achieve a good relationship, a range of sward heights need to be assessed within the typical grazing range, and to this end a set of data have been collected from Hillsborough grazing paddocks over three separate grazing seasons (2013, 2011 and 2009).

In 2013, five quadrats (0.50 x 0.50 cm) were assessed regularly throughout the grazing season, with 2 quadrats being representative of a sward immediately post-grazing, 2 quadrats immediately pre-grazing and 1 quadrat representative of a sward with a regrowth of 10-14 days. Once a suitable sward was identified, an area was selected and the quadrat placed on the ground. Sites were selected to ensure that the area was free from obstructions (stones, bare patches, dung patches) and included an area of herbage that was relatively consistent in height and density. Prior to cutting, 4 assessments of the height of the sward within the quadrat were taken using a rising plate meter. The herbage within the quadrat was then cut using battery operated shears, and all herbage was collected, weighed and a subsample taken to determine oven dry matter (dried in a 100^{o}C oven for 18 hours). Herbage mass was then calculated based on the fresh yield of herbage, the area of the quadrat and the oven dry matter.

These quadrats were cut to a consistent height above ground level, as achieving a total removal of herbage to ground level can lead to contamination of the sample, necessitating further processing of the sample by washing and cleaning. Therefore, to convert the herbage yield generated from the cut sample to represent the total herbage yield above ground level, a fixed ‘stubble’ herbage mass was added onto all the herbage yields. This ‘stubble’ yield (804 kg) was based on a stubble height of 1.5 cm converted to herbage mass using the equation : herbage mass = 316 x sward height + 330. The ‘stubble’ yield was included in all the data collected in 2013 and 2011, but was not necessary within the 2009 data as the sward was cut to ground level.

During 2013 a total of 100 data points were collated, with 126 and 244 data points collated in 2011 and 2009, respectively. A greater number of data points were collected in 2011 and 2009 due to an increased number of quadrats being harvested on a weekly basis. Over the three years of measurements a total of 17 data points were excluded from the analysis as they were identified as outliers. All data collected each year is presented in Appendices 1, 2 and 3, with the relationships between sward height and herbage mass within each year presented graphically in Appendices 8, 9 and 10. The overall relationship across the three years and the effect of seasonality are summarised in Table 3 and Appendix 15, with relationships for the data collected in early season (March – June) and late season (July – October) identified.

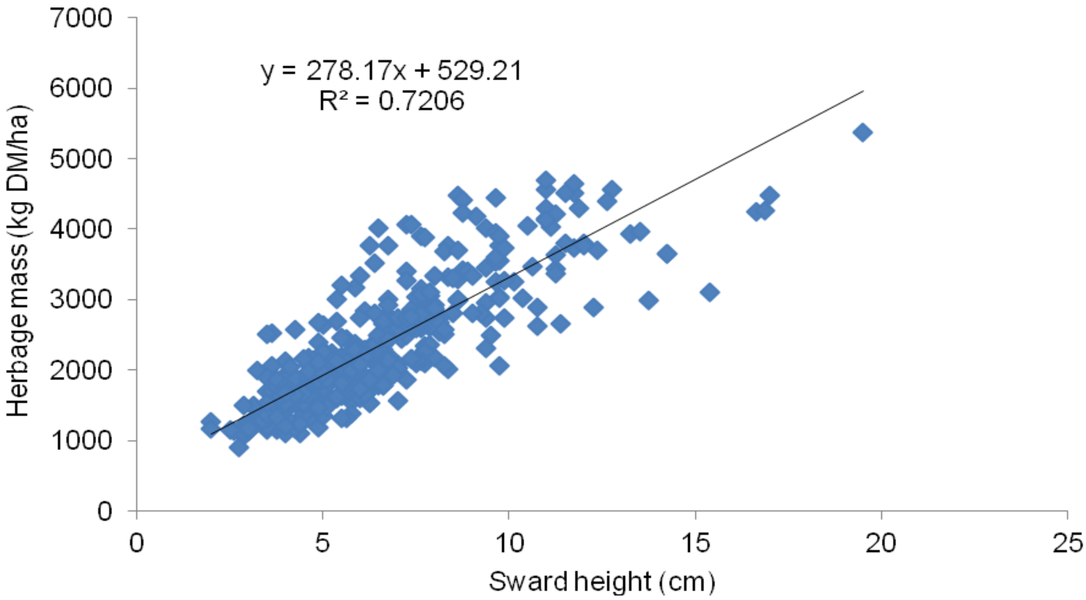
Table 3 Summary of relationships generated from detailed measurements of sward height and herbage mass taken from within grazing paddocks over three separate years.

	Source of data		
	Overall	Early season (March – June)	Late season (July – October)
Relationship#	Y = 278x + 529	Y = 287x + 489	Y = 266x + 591
r^2	0.72	0.76	0.66
Sward height (cm)	Herbage mass (kg DM/ha)		
4	1641	1637	1655
6	2197	2211	2187
8	2753	2785	2719
10	3309	3359	3251

Where Y = Herbage mass (kg DM/ha > ground level) and x = sward height (cm > ground level)

Although there is considerable variation within the dataset in terms of the herbage mass recorded at similar sward heights, the overall spread of the data is acceptable ($r^2 = 0.72$) (Figure 3). Overall, the seasonality effect within this dataset is minimal, with herbage mass estimates even at a sward height of 10 cm being very similar whether calculated based on the early or late season relationship (Table 3).

Figure 3 The estimation of herbage mass from sward height using data collected from grazing paddocks at Hillsborough over three different years



GrassCheck data

The GrassCheck project involves the cutting of three grass plots (5 m x 1.5 m) on a weekly basis, with the regrowth interval generally 21 days. For the past number of years, the sward height of all plots are measured prior to cutting and again post-cutting. These measurements are recorded with a rising plate meter, and in 2013, these measurements were repeated at four separate locations, namely Hillsborough, Downpatrick, and two sites at Antrim (Greenmount), Upper Croft and Right Croft. Sward height was assessed pre- and post-cutting by taking eight measurements across the plots. Herbage mass was calculated by cutting the herbage to 4 cm using a reciprocating knife bar mower, recording the fresh weight of herbage removed, and then drying a subsample of this herbage (dried in 100°C oven for 18 hours) to determine oven dry matter. Applying the oven dry matter and the area cut (width of mower x length of plot) to the weight of fresh herbage allows the calculation of herbage yield. This herbage yield relates to the herbage above the cutting height, so to adjust this value to represent total herbage yield above ground level, an equation was applied to the sward height post-cutting. This equation (herbage mass = sward height (cm) x 316 + 330) was applied to all readings taken throughout the year at all sites. All data collected from each site are presented in Appendices 4, 5, 6 and 7, and in total there are 327 data points comparing sward height and herbage mass across the sites. Nine data points were excluded from the final analysis as these data were identified as outliers.

The data from each individual location were assessed individually (Appendices 11, 12, 13 and 14), with a further analysis of seasonality carried out, with relationships generated for early (March – June) and late (July – October) season. All data from the four sites were then combined to produce a single overall relationship, and two further equations examining the effect of seasonality. These relationships are summarised in Table 4 and Appendix 16.

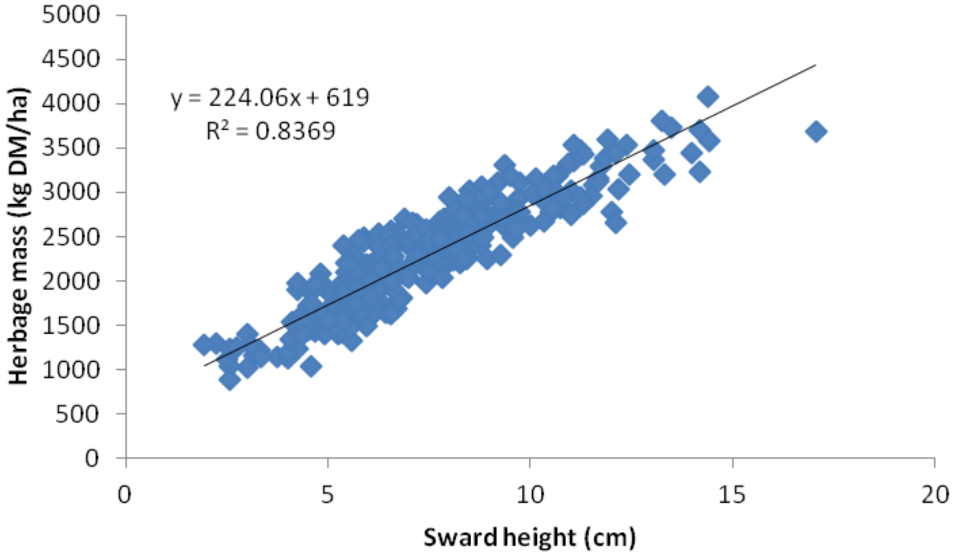
Table 4 Summary of relationships from the data collected at four different sites during the same year under simulated grazing management, including overall relationship and the relationships in early and late season.

	Source of data		
	Overall	Early season (March – June)	Late season (July – October)
Relationship#	Y = 224x + 619	Y = 233x + 480	Y = 228x + 634
r^2	0.84	0.90	0.68
Sward height (cm)	Herbage mass (kg DM/ha)		
4	1515	1412	1546
6	1963	1878	2002
8	2411	2344	2458
10	2859	2810	2914

Where Y = Herbage mass (kg DM/ha > ground level) and x = sward height (cm > ground level)

The overall relationship from the four sites is shown in Figure 4, and the data is relatively consistent across a wide range of sward heights, with an r^2 of 0.84. Furthermore, there is little evidence of any real effect of seasonality, with estimates of herbage mass being very similar throughout the range of sward heights presented in Table 4.

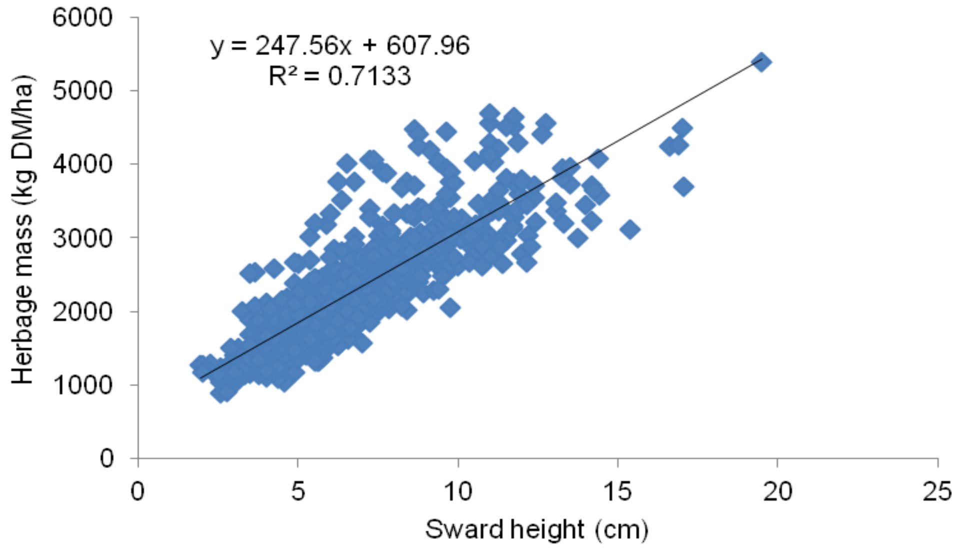
Figure 4 The estimation of herbage mass from sward height using data collected from 'simulated' grazing plots, cut in a regular three weekly cycle at four locations within the same year.



Combined analysis of sward height and herbage mass from all data

Following collation and quality control of the datasets from both the cutting plots and the grazing swards, the data were combined to examine the overall relationship between sward height and herbage mass. The overall relationship from the combined dataset is shown in Figure 5. The combined data produced a good spread of data within the typical 'grazing' range of 4.0 – 11.0 cm, with an r^2 of 0.71.

Figure 5 The relationship between herbage mass and sward height using data collected from grazing paddocks over three years (n=3) and from 'simulated' grazing plots within the same year (n=4).



Comparing the relationships derived from both sets of data to the overall relationships, it is apparent that the data collected from the grazing paddocks had a lower r^2 value than the data from the cut 'simulated grazing' plots within GrassCheck, however both datasets resulted in good relationships ($r^2 > 0.72$). The constancy of cutting and also the removal of the variability associated with grazed swards are likely to have contributed to the consistency observed in the 'simulated' grazing data. These relationships and the effect of applying the three different equations to a range of sward heights are summarised in Table 5 and Appendix 17. In comparison to the relationship identified from the cut plots, the grazing sward data results in a much higher estimation of herbage mass as sward height increases, being 451 kg DM/ha higher at a sward height of 10 cm.

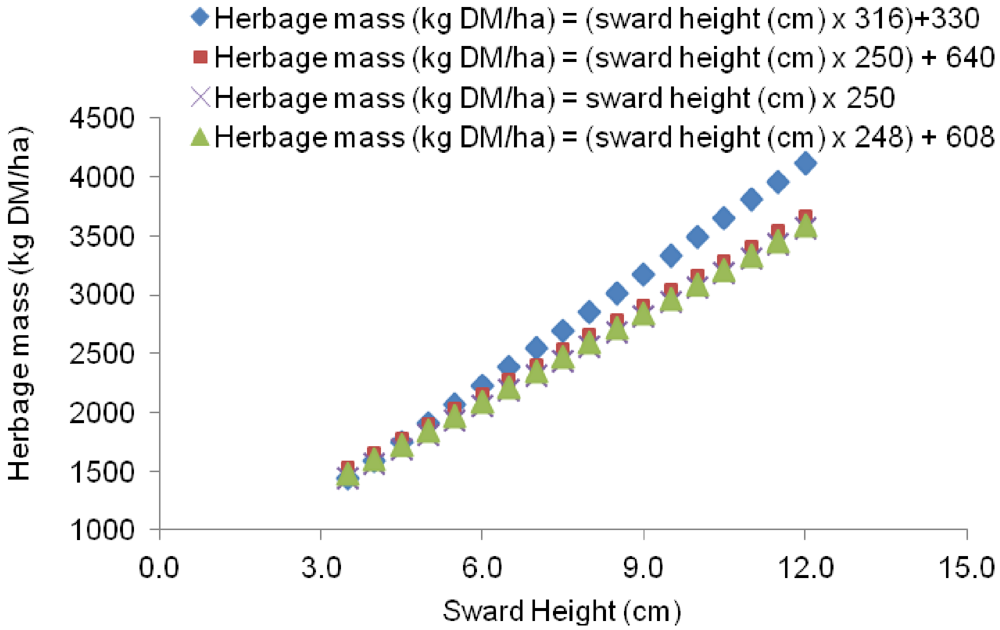
Table 5 The relationship between herbage mass and sward height generated from two separate sets of data, and also a combination of all the data.

	Source of data		
	Grazing paddocks	'Simulated' grazing plots	All sources combined
Relationship#	Y = 278x + 529	Y = 224x + 619	Y = 248x + 608
r^2	0.72	0.84	0.71
Sward height (cm)	Herbage mass (kg DM/ha)		
4	1642	1515	1598
6	2198	1963	2093
8	2755	2412	2588
10	3311	2860	3084
12	3867	3308	3579

Where Y = Herbage mass (kg DM/ha > ground level) and x = sward height (cm > ground level)

Figure 6 highlights the three published equations that were compared previously in Figure 2, and compares these to the new equation generated from the combined datasets. Two of the published equations are in close agreement with the Hillsborough data, with very small differences in herbage mass throughout a wide range of sward heights.

Figure 6 A comparison of three published regression equations to convert compressed sward height to herbage mass with the equation derived from Northern Ireland data (green triangles)



The comparison of the equations highlights that one equation appears to be over estimating the quantity of herbage mass present within the sward as sward height increases. This over estimation is in excess of 300 kg DM/ha when sward height reaches 10 cm. The consistency of three of the equations, including the relationship derived from the current data suggests that the latter produces a good estimate of herbage mass.

Effect on regression equation of having intercept at zero.

Whilst there is some rationale for forcing the regression equation to have its intercept at zero i.e. there is zero herbage mass whenever sward height is zero, this will ultimately alter the resulting equation. For example, the equation generated from the combined datasets (HM = sward height x 248 + 608), is simplified to :- Herbage mass = sward height x 326. However, the r^2 for the later equation is poorer at 0.63. The effect of this alternative equation on the herbage mass generated from a range of sward heights is defined in Table 6, with the effect that at low sward heights (<6cm) herbage mass is reduced, yet at higher sward heights (>8cm) herbage mass is increased, in comparison to herbage mass estimated from the first equation. Although at a sward height of 8cm the difference between the equations is minimal (+/- 20 kg DM/ha), at a sward height of 4 and 12 cm, there is approximately 300 kg DM/ha difference in the estimated herbage mass.

Table 6. The relationship between herbage mass and sward height generated from all data combined and presented after either forcing the intercept through zero or not.

	All sources of data combined	
	Normal equation	Equation with intercept fixed at zero
Relationship#	Y = 248x + 608	Y = 326x
r^2	0.71	0.63
Sward height (cm)	Herbage mass (kg DM/ha)	
4	1598	1304
6	2093	1956
8	2588	2608
10	3084	3260
12	3579	3912

Where Y = Herbage mass (kg DM/ha > ground level) and x = sward height (cm > ground level)

The amendment of the equation to include an intercept of zero did not improve the accuracy of the herbage mass estimates. The disparity in the herbage mass estimates at the extremes of the range required for grazing management would not allow accurate assessments of pre- and post-grazing herbage mass, with the reliability of the relationship also reduced, as highlighted by the r^2. In summary, whilst it may appear logical to assume the relationship between herbage mass and sward height should have an intercept of zero, applying this to the relationship reduced its accuracy. Furthermore, of the published equations currently in use within the UK, a number of them include a fixed constant, and thus will not produce a herbage mass of zero from a sward height of zero.

Summary and recommendations.

A large dataset was collated over a number of years (based on two methodologies) where both sward height and herbage mass were recorded. The combined dataset was analysed and the relationship identified was relatively consistent ($r^2 = 0.71$), and this relationship was very similar to two other published relationships. Any influence of seasonality on the relationship was assessed, and the lack of any major effects would suggest that multiple equations will not add any further accuracy to herbage mass estimation compared to a single equation. Therefore, it is proposed that a single equation be used to convert compressed sward height into herbage mass above ground level, with this equation being :-

Herbage mass (kg DM/ha) = ((sward height (cm) x 248) + 608)

4.0 Recommendations to improve adoption of grassland measurement techniques in NI

This report has highlighted a number of the issues in relation to the challenges associated with the methodologies available for quantifying herbage mass within grazed swards, and also documented Northern Ireland data which demonstrates the relationship between sward height and herbage mass. Despite some published equations indicating a need to adjust the conversion of sward height to herbage mass during the season, there was no evidence of a seasonality effect found within these data. Therefore, based on this validated relationship between sward height and herbage mass, the rising plate meter can be advocated as one of the main methods for measuring herbage mass within Northern Ireland. In addition, provided the grassland manager is suitably trained and regular 'calibration checks' are carried out, visually estimating herbage mass is also a possible option.

Regardless of the methodology ultimately used, the data handling aspect of the process should be considered. There are now grassland management packages available which can be used to interrogate the raw field data, with feed wedges and individual paddock performances available instantly. There is also the ability within some packages to simulate changes in grass growth and assess what effect that an increase or decrease in growth over the next week will have on grass supply over that period of time. Whilst these packages are clearly a useful development, they are directed towards an advanced grassland manager, as many of these require very detailed inputs of supplementation, livestock numbers etc, to operate to their potential. This level of detail is required on farms where grazed grass is not only supplying close to 100% of the animals diet during the summer, but sufficient forage must also be conserved for winter feeding from within this same total area. However, this level of detail is not required by many farmers within Northern Ireland, and many farmers that are interested in starting to monitor sward performance could be discouraged by the complexity of these packages.

Therefore, potentially there is an opportunity for the production of a simple computer based package which will allow the herbage mass data collected from individual paddocks on a farm to be collated and by including a few additional figures (grass intake, rotation length, target grazing residual, stocking rate) produce a feed wedge for that grazing platform. A simple spreadsheet that would enable the creation of a feed wedge could be hosted on the internet, for example the Rural Portal, and this would allow the grassland manager at an instant to identify:-

Are pre- and post-grazing targets being achieved?
What area is required per day to meet the herds grass intake requirements?
What paddock should be grazed next?
Is grass supply across the grazing platform on target (average farm cover)?
Is grass supply immediately ahead of the herd on target?
Are there any grass supply issues going to arise in around 10 days (herbage mass on paddocks due for grazing at that time)?

Whilst the uptake of sward measurement techniques and also the accessibility of appropriate data handling packages will be important factors in improving grassland management within Northern Ireland, a renewed focus on G.R.A.S.S involves 5 main areas :-

Good infrastructure

Realistic targets

Assessing swards regularly

Soil nutrition and health

Silage production

Good infrastructure

Regardless of the efforts employed to monitor grassland performance during the grazing season, irregular sized fields that are poorly serviced with water and laneways will greatly restrict the potential of a grazing platform. Challenging weather conditions are almost inevitable at some stage during the grazing season, and therefore good laneway access, multiple entry/exit points and multiple water access points will ultimately influence how easily some of the well established ‘wet weather’ grazing strategies can be utilised. Back fencing, grazing square blocks and even ‘on/off’ grazing are all strategies that are well proven to reduce the risks of poaching and yet achieve reasonable intakes of grazed grass. Recent evidence in ROI suggests that restricting access to grazing for 3 hours after each milking can achieve similar milk yields to grazing full time, with the animals grazing for short bouts grazing for 98% of the time they spent in the field (Kennedy *et al.*, 2011). The challenge of managing grass supplies within a grazing platform is also greatly increased if there is a large variation in field sizes. It is much easier to identify surpluses and deficits and also easier to correct them if the grazing area is divided into smaller, reasonably sized grazing areas. Large fields that require grazing over a prolonged period of time (4-7 days), increases the risks of poaching and also cows will inevitably back graze the fresh regrowth, impacting on grass supply for the next rotation.

Realistic targets

When setting targets for the potential performance of the grazing herd, it is important to put these targets into context. Many targets for grazing management originate from countries that operate almost exclusively systems whereby grazed grass forms a large proportion of the annual forage requirement, and as a consequence grazing seasons are long, milk yields per cow are modest and concentrate supplementation is kept to a minimum.

However, the typical dairy system in Northern Ireland is somewhat different, including generally much higher levels of supplementary feeding, greater variability in grazing conditions and higher yielding dairy cows. Recognised targets for pre- and post-grazing herbage mass are 3,000 – 3,300 kg DM/ha and 1,600 – 1,800 kg DM/ha, respectively. Reducing pre- and post-grazing targets below these levels can improve pasture utilisation, but is likely to result in a reduction in animal performance (Ganche *et al.*, 2011, Dale *et al.*, 2011). These targets represent a balance between animal performance and pasture utilisation. Furthermore, the area within the grazing platform is a major limiting factor on many farms, and in order to graze low grass covers, generally a lower stocking rate is required than is feasible on many farms in Northern Ireland.

Within a grazing system, there is much debate about the milk yield that can be supported by grazed grass (after accounting for the energy required for the maintenance of the cow). This is often regarded as 'Maintenance Plus' and it is well recognised that this value varies during the grazing period, with approximately 25 kg/cow/day reported from grazed grass in late May, with this value declining to approximately 14 kg/cow/day by mid September (Ferris *et al.,* 2007; Mayne *et al.,* 1991). However, other recent evidence would suggest that the 'Maintenance Plus' could be considerably lower than this (Purcell *et al.,* 2014; Dale *et al.,* 2014), with anecdotal evidence suggesting that these Maintenance Plus targets are not being achieved on commercial dairy farms in Northern Ireland. This is obviously influenced by many factors associated with grazed grass (availability, quality, weather conditions, grazing conditions) and the animal (stage of lactation, current yield, level of supplements). However, in general there is enough evidence to suggest that the theoretical potential of grazed grass is becoming increasingly difficult to achieve, with Table 7 summarising recent data from NI, highlighting appropriate targets for the milk production potential of grazed grass when used to define concentrate supplementation levels.

Table 7. Milk sustained from grazed grass during the grazing season (taken from Purcell *et al.,* 2014)

	May/June	July	August	September
Milk yield (litres/cow/day)	21.0	18.0	14.0	11.5

Making best use of grazed grass is not always about maximising its inclusion in the diet, but optimising it. Appropriate supplementation is important to optimise herd and farm performance and involves both quick intervention to include more supplements when circumstances necessitate, but equally prompt removal of these expensive supplements to optimise the intake of grazed grass. Supplementation of grazing cows is generally in the form of conserved forages (grass silage, whole crop wheat silage or maize silage) or concentrates. Whilst there is some evidence that offering forage supplements over a short period of time (2 to 3 hours daily) has the potential to improve total dry matter intakes compared to grazed grass only (Morrison *et al.,* 2007), this 'buffer feeding' with grass silage did not result in any improvements in animal performance. Furthermore, there is other work to suggest that offering a greater quantity of grass silage to grazing cows (offered overnight) had no benefit compared to grazed grass only (Ferris *et al.,* 2008; Purcell *et al.,* 2014a). All these studies highlight that the results are largely affected by the grazing conditions encountered and the quality of the conserved forages. Therefore, in situations whereby grass availability is not limiting, there may well be little performance benefit from the supplementation of forages to grazing dairy cows, and in fact the detrimental impact of feeding these supplements on grazing behaviour could well be a disadvantage of their inclusion. There is evidence that cows will graze slower and graze for less time, increasing the challenge of achieving high levels of grass utilisation as the cows will be more unsettled and more selective (Kennedy *et al.,* 2011).

Concentrates represent the major cost involved in milk production in Northern Ireland, and as such they must be utilised efficiently. As concentrates are generally offered through the parlour twice daily there is an upper limit to the daily concentrate intake that is possible if cows are grazing full time, and cows in Northern Ireland have been offered 8 to 10 kg concentrates/cow/day (Dale *et al.,* 2011, 2011a; Jiao *et al.,* 2014) through the parlour, with evidence that at levels up to 8 kg/day there is no detrimental impact on rumen function (Johnston *et al.,* 2014). Therefore, for high yielding cows (>40 litres in May) high levels of supplementation can be offered in addition to grazed grass, although this is reliant on concentrates being allocated on an individual cow basis in the parlour. When establishing concentrate levels, one option is to allocate concentrates at a fixed rate i.e. kg concentrate per litre of milk, and this is generally applied to the yield above that assumed to be provided from grazed grass. Recent evidence would suggest that a concentrate feed rate of 0.45 kg concentrate per litre is appropriate for use in Northern Ireland (Dale *et al.,* 2014), with no production benefits achieved from further increases in feed rate.

Assess swards regularly

The key to grazing management is to make the right decision at the right time, and this is reliant on the collection of timely and accurate information. Grass growth can fluctuate widely and it is influenced by a number of factors including the time of year, temperature, and availability of water and other nutrients. Therefore it is vital that during the main grazing season (April – September) the grazing area is walked frequently. Furthermore, it is vital that once an issue is identified that corrective action is also taken in a timely manner. Making small changes can overcome surpluses and deficits in grass supply if they are identified early, whereas the later a decision is taken the greater impact the surplus or deficit is likely to have, both on the performance of the sward and animal. By assessing swards regularly it is also possible to build up a picture of the performance of each field, which can be important when identifying areas for rejuvenation, draining etc.

Soil nutrition and health

The nutritional and structural condition of the soil is a key component of an efficient agricultural system. The detrimental effects of poor drainage (Ball *et al.*, 2013) or compaction (ADAS, 1984) on forage yields are well recognised, and there are useful practical indicators that should be used to help identify the presence and extent of these issues (CAFRE, 2013). In terms of soil nutrition, an appropriate soil pH for grassland is around 6.2 (DEFRA, 2010), and this is important as at low soil pH the availability/ mineralisation of soil nutrients and the efficiency of utilisation of applied nutrients is reduced (Gibbons *et al.,* 2014). Maintaining soil nutrients within optimal ranges is also important, as deficiencies and indeed surpluses of one nutrient can adversely influence the utilisation of another. The key nutrients are phosphorus, potassium and sulphur. A regular soil sample should be taken (one year in five) from all grassland to ensure nutrient levels remain optimal, as this has been emphasised as important within high quality roughage production (Reijneveld *et al.*, 2014).

Silage production

Although there are some milk production systems where there is less emphasis on the quality of winter feed (ROI, NZ), within Northern Ireland the winter period (October – February) is a crucial part of the annual milk production cycle. In comparison to medium or poor quality grass silage, the production of high quality silage will result in improved animal performance and a reduced requirement for supplementary feed (Keady *et al.*, 2013). Rising fuel costs have seen a dramatic rise in contractor charges for silage harvesting, and in an attempt to reduce these costs, there has been an increasing tendency to allow grass to 'bulk-up' prior to harvest, thus maximising the yield per hectare. This is based on the fact that contractors charge per area, thus there is a belief that these high yields are 'diluting' the costs of harvesting. However, the winter forage that is produced as a result of this is likely to be medium quality, and not only will this therefore require higher levels of supplementary feeding, but also be more difficult to nutritionally balance within the animals diet.

Table 8. The concentrate feed level required to supplement a poor, medium and high quality grass silage to meet the requirements of a dairy cow producing 30 litres/day.

Silage quality	Metabolisable Energy (MJ/kg DM)	Crude protein (% DM)	Concentrate required to support 30 litres/cow/day (kg/cow/day)
Poor	10.9	8.0	14
Medium	11.4	13.1	12
Good	12.3	15.8	11

However, in reality there is considerable variation in silage quality produced on NI dairy farms, and indeed this variation can be made more extreme during seasons when ensiling conditions are more difficult (Park *et al.*, 2013). However, as highlighted in Table 8, the true costs of producing poor quality forages are only realised when it is included in the diet of a high yielding dairy cow.

OVERALL SUMMARY

Whilst grazed grass remains the cheapest feedstuff for milk production, achieving high levels of animal and sward performance requires attention to detail throughout the season to ensure the quality and quantity of grass that is constantly available is optimised. The only way to achieve this is by understanding and measuring grass growth continually, so that frequent and timely decisions can be made. Whilst a wide range of methodologies for measuring grass swards were included in this review, the key factor is that regular assessments are made by a small number of individuals, ideally by one individual. This allows these operators to become familiar with the grazing platform, and will aid in the interpretation of the data as they will see growth surges or growth deficits during the collection of the data. In addition, as grassland measurement becomes increasingly computerised, hopefully this will aid the speed of collection and interpretation, which are widely considered two of the main barriers to adoption. This review highlights that the plate meter can be a reliable methodology for measuring herbage mass, and highlights five key areas that could ultimately improve milk output from G.R.A.S.S.

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Appendix 1 Sward height and herbage mass data collected from grazing paddocks at Hillsborough during 2013.

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
05/03/13	3.6	1410
05/03/13	3.1	1478
05/03/13	7.1	2441
05/03/13	9.8	3043
05/03/13	8.8	3418
07/05/13	7.0	1572
07/05/13	3.9	1231
07/05/13	9.4	2962
07/05/13	11.8	3737
07/05/13	14.3	3655
15/05/13	4.6	2175
15/05/13	3.1	1279
15/05/13	6.1	2839
15/05/13	11.3	3440
15/05/13	12.8	4562
22/05/13	4.9	1177
22/05/13	2.9	1074
22/05/13	6.6	2494
22/05/13	16.6	4240
22/05/13	12.4	3704
30/05/13	7.6	2181
30/05/13	6.3	2160
30/05/13	6.9	2144
30/05/13	16.9	4261
30/05/13	15.4	3110
05/06/13	7.8	2101
05/06/13	6.6	2484
05/06/13	9.8	3764
05/06/13	17.0	4484
05/06/13	11.3	3364
19/06/13	5.9	1749
19/06/13	4.8	2149
19/06/13	9.8	3547
19/06/13	9.4	3450
19/06/13	8.1	2539
26/06/13	4.6	1461
26/06/13	5.8	1545
26/06/13	7.3	1858
26/06/13	19.5	5379
26/06/13	13.3	3938
03/07/13	4.4	1690
03/07/13	4.3	1844
03/07/13	7.8	2339
03/07/13	8.0	2177
03/07/13	9.9	2734
18/07/13	7.0	2074
18/07/13	5.9	1908
18/07/13	7.5	2919
18/07/13	12.3	2887
18/07/13	9.4	2741

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
24/07/13	5.6	1880
24/07/13	4.6	1935
24/07/13	7.8	2282
24/07/13	11.4	2656
24/07/13	10.8	2621
31/07/13	5.6	2065
31/07/13	4.3	1594
31/07/13	7.9	2365
31/07/13	8.1	2733
31/07/13	8.3	2503
07/08/13	4.8	1764
07/08/13	4.8	1600
07/08/13	7.8	2252
07/08/13	10.8	2880
07/08/13	9.5	2484
14/08/13	3.5	1689
14/08/13	3.5	1260
14/08/13	7.9	2602
14/08/13	7.0	1971
14/08/13	9.8	2054
21/08/13	5.8	1377
21/08/13	4.4	1094
21/08/13	9.4	2305
21/08/13	13.8	2994
21/08/13	14.3	3650
28/08/13	5.3	1571
28/08/13	3.8	1157
28/08/13	8.4	2019
28/08/13	11.5	3807
28/08/13	13.5	3956
04/09/13	2.0	1272
04/09/13	2.9	1221
04/09/13	9.6	3260
04/09/13	12.0	3791
04/09/13	11.0	4154
11/09/13	3.6	2527
11/09/13	4.3	2574
11/09/13	4.0	1924
11/09/13	10.1	3255
11/09/13	12.0	3760
15/10/13	5.3	2250
15/10/13	3.3	2000
15/10/13	5.0	2648
15/10/13	9.9	3274
15/10/13	10.4	3028

* Sward height measured >ground level
**Herbage mass measured >1.5 cm. A further 804 kg DM/ha is added to represent herbage mass > ground level

Appendix 2 Sward height and herbage mass data collected from grazing paddocks at Hillsborough during 2011.

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
18/04/11	2.8	901
18/04/11	4.1	1268
18/04/11	7.6	2134
18/04/11	4.0	1100
18/04/11	7.0	2020
18/04/11	7.5	2087
18/04/11	6.6	2294
11/05/11	4.6	1323
11/05/11	8.1	2665
11/05/11	8.3	2066
11/05/11	8.6	3287
11/05/11	9.3	2813
11/05/11	9.6	3534
19/05/11	4.5	1693
19/05/11	4.0	2120
19/05/11	6.5	4014
19/05/11	9.6	4445
19/05/11	11.8	4512
19/05/11	11.0	4553
26/05/11	5.6	2439
26/05/11	3.6	2066
26/05/11	4.6	2070
26/05/11	6.6	2719
26/05/11	8.4	3767
26/05/11	8.6	4480
26/05/11	11.1	4022
02/06/11	3.6	1690
02/06/11	6.4	2807
02/06/11	5.4	3008
02/06/11	4.0	1826
02/06/11	5.9	3174
02/06/11	6.0	3328
02/06/11	9.4	4019
16/06/11	4.1	1959
16/06/11	6.8	3010
16/06/11	5.4	1985
16/06/11	6.3	3757
16/06/11	7.3	3401
16/06/11	7.3	4066
16/06/11	11.0	4297

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
23/06/11	4.1	1922
23/06/11	4.9	2389
23/06/11	5.4	2690
23/06/11	6.0	2736
23/06/11	9.6	3946
23/06/11	9.1	4186
23/06/11	9.8	3894
30/06/11	5.9	2370
30/06/11	5.1	2226
30/06/11	5.0	2252
30/06/11	6.8	3767
30/06/11	12.6	4402
30/06/11	10.5	4042
30/06/11	11.8	4639
06/07/11	4.4	1463
06/07/11	5.6	1315
06/07/11	4.8	1593
06/07/11	4.5	2157
06/07/11	5.5	3200
06/07/11	11.5	4505
06/07/11	8.3	3683
22/07/11	4.3	1886
22/07/11	7.5	3035
22/07/11	5.0	2063
22/07/11	7.3	3273
22/07/11	7.6	3894
28/07/11	2.6	1128
28/07/11	3.5	1154
28/07/11	4.9	2030
28/07/11	8.3	2574
28/07/11	6.6	2663
28/07/11	11.9	4296
28/07/11	11.3	4216
04/08/11	6.3	1708
04/08/11	4.3	1174
04/08/11	7.5	2140
04/08/11	4.6	1876
04/08/11	7.1	2711
04/08/11	10.6	3463
04/08/11	8.9	3394

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
11/08/11	6.5	1779
11/08/11	3.6	1446
11/08/11	3.8	1765
11/08/11	7.3	2485
11/08/11	9.0	2811
11/08/11	7.4	2862
11/08/11	9.6	3594
18/08/11	5.5	1963
18/08/11	3.8	1388
18/08/11	5.5	2196
18/08/11	9.9	3736
18/08/11	8.4	3323
18/08/11	11.0	4693
18/08/11	7.6	3158
25/08/11	4.1	2039
25/08/11	3.5	2510
25/08/11	7.4	4060
25/08/11	7.8	3882
25/08/11	8.8	4411
25/08/11	8.8	4237
01/09/11	4.9	2665
01/09/11	3.0	1253
01/09/11	6.0	2308
01/09/11	8.6	3706
01/09/11	11.0	4130
14/09/11	5.5	2000
14/09/11	5.0	1348
14/09/11	5.1	1476
14/09/11	5.1	1844
14/09/11	7.6	2582
14/09/11	6.8	2142
14/09/11	6.0	2223
28/10/11	2.9	1098
28/10/11	3.8	1601
28/10/11	3.5	1888
28/10/11	3.1	1497
28/10/11	5.8	1973
28/10/11	6.4	3518
28/10/11	5.9	2147

* Sward height measured >ground level

** Herbage mass measured >1.5cm. A further 804 kg DM/ha is added to represent herbage mass > ground level

Appendix 3 Sward height and herbage mass data collected from grazing paddocks at Hillsborough during 2009.

Date	Sward height (cm)*	Herbage mass (kg DM/ha)
11-Apr	3.0	1133
11-Apr	3.0	1186
11-Apr	4.4	1239
11-Apr	4.0	1586
11-Apr	4.4	1586
11-Apr	4.6	1644
11-Apr	5.6	1647
11-Apr	5.6	2056
11-Apr	7.1	2550
11-Apr	7.0	2594
11-Apr	7.6	2700
17-Apr	3.5	1328
17-Apr	3.8	1344
17-Apr	4.5	1372
17-Apr	4.0	1433
17-Apr	4.0	1467
17-Apr	4.0	1478
17-Apr	3.9	1569
17-Apr	5.5	1628
17-Apr	5.0	1656
17-Apr	4.5	1689
17-Apr	4.6	1706
17-Apr	5.6	2050
17-Apr	6.4	2236
17-Apr	6.3	2328
17-Apr	7.9	2950
24-Apr	3.5	1300
24-Apr	3.5	1344
24-Apr	4.0	1472
24-Apr	4.3	1528
24-Apr	4.0	1533
24-Apr	4.5	1561
24-Apr	6.0	1589
24-Apr	4.0	1594
24-Apr	5.0	1956
24-Apr	5.6	2006
24-Apr	6.0	2172
24-Apr	6.4	2175
24-Apr	6.3	2194
24-Apr	6.4	2272
24-Apr	7.5	2594
24-Apr	7.4	2611
1-May	3.0	1222
1-May	4.5	1500
1-May	4.0	1550
1-May	5.9	2192
1-May	5.9	2217
1-May	6.1	2258
1-May	6.5	2331
1-May	6.6	2414
1-May	6.8	2564
1-May	7.0	2667
8-May	3.5	1258
8-May	4.0	1550
8-May	4.0	1556
8-May	4.0	1556
8-May	4.6	1608
8-May	4.8	1906
8-May	5.5	1936
8-May	5.5	1997
8-May	5.8	2164
8-May	5.9	2192
8-May	7.0	2581
8-May	9.0	3331

Date	Sward height (cm)*	Herbage mass (kg DM/ha)
15-May	3.5	1222
15-May	3.5	1389
15-May	4.0	1464
15-May	3.1	1478
15-May	4.0	1500
15-May	3.8	1522
15-May	4.5	1656
15-May	5.1	1772
15-May	4.8	1864
15-May	5.0	1911
15-May	5.9	2133
15-May	6.5	2497
15-May	7.3	2642
15-May	7.3	2664
22-May	3.5	1272
22-May	3.5	1517
22-May	4.1	1517
22-May	4.0	1528
22-May	4.0	1528
22-May	4.0	1528
22-May	6.3	1539
22-May	4.3	1550
22-May	3.9	1594
22-May	5.0	1747
22-May	5.0	1794
22-May	5.5	1819
22-May	6.1	2189
22-May	6.4	2219
22-May	7.3	2661
22-May	7.9	3056
29-May	3.5	1206
29-May	3.5	1339
29-May	4.0	1517
29-May	4.0	1539
29-May	4.0	1561
29-May	4.5	1572
29-May	4.8	1803
29-May	5.3	1878
29-May	5.9	2219
29-May	5.8	2283
29-May	6.5	2492
29-May	6.9	2550
29-May	6.8	2561
29-May	6.9	2700
5-Jun	4.0	1433
5-Jun	5.4	1600
5-Jun	5.0	1689
5-Jun	6.1	1711
5-Jun	6.5	1800
5-Jun	6.6	2361
5-Jun	8.6	2994
12-Jun	2.5	1156
12-Jun	3.5	1433
12-Jun	3.5	1433
12-Jun	3.5	1433
12-Jun	3.5	1472
12-Jun	3.9	1472
12-Jun	4.0	1489

Date	Sward height (cm)*	Herbage mass (kg DM/ha)
12-Jun	4.5	1539
12-Jun	4.0	1542
12-Jun	3.9	1561
12-Jun	4.4	1639
12-Jun	5.1	1850
12-Jun	5.3	1861
12-Jun	5.0	1867
12-Jun	5.8	2278
19-Jun	3.5	1294
19-Jun	3.5	1433
19-Jun	3.5	1439
19-Jun	3.5	1442
19-Jun	4.0	1544
19-Jun	4.0	1642
19-Jun	5.6	1806
19-Jun	6.3	2219
19-Jun	6.1	2225
19-Jun	6.1	2272
19-Jun	5.9	2281
19-Jun	6.4	2283
19-Jun	6.1	2300
19-Jun	5.9	2306
19-Jun	6.4	2358
19-Jun	6.6	2694
26-Jun	4.4	1239
26-Jun	3.5	1442
26-Jun	3.1	1478
26-Jun	4.0	1586
26-Jun	4.6	1644
26-Jun	4.5	1656
26-Jun	4.0	1692
26-Jun	5.9	2278
26-Jun	7.3	2642
26-Jun	7.6	3078
26-Jun	7.9	3100
26-Jun	8.0	3333
3-Jul	4.0	1194
3-Jul	6.1	1639
3-Jul	4.0	1756
3-Jul	6.6	1783
3-Jul	5.0	1794
3-Jul	6.0	1794
3-Jul	7.4	2167
3-Jul	5.5	2456
3-Jul	6.5	2492
3-Jul	8.0	2839
3-Jul	8.6	2994
3-Jul	7.9	3056
10-Jul	3.0	1133
10-Jul	3.0	1186
10-Jul	3.4	1275
10-Jul	4.0	1528
10-Jul	6.3	1539
10-Jul	5.0	1747
10-Jul	5.5	1819

Date	Sward height (cm)*	Herbage mass (kg DM/ha)
10-Jul	5.6	2056
10-Jul	6.1	2189
10-Jul	6.8	2417
10-Jul	7.1	2550
10-Jul	7.0	2594
10-Jul	7.3	2661
10-Jul	7.6	2700
17-Jul	3.0	1172
17-Jul	3.5	1358
17-Jul	4.3	1639
17-Jul	4.9	1811
17-Jul	3.8	1861
17-Jul	4.9	1861
17-Jul	4.6	1972
17-Jul	6.0	1981
17-Jul	5.5	2036
17-Jul	5.6	2111
17-Jul	5.4	2125
17-Jul	7.0	2722
4-Sep	2.9	1506
11-Sep	4.0	1194
11-Sep	4.9	1472
11-Sep	6.1	1639
11-Sep	4.0	1756
11-Sep	6.6	1783
11-Sep	6.0	1794
11-Sep	7.4	2167
11-Sep	5.5	2456
11-Sep	8.5	2800
11-Sep	8.0	2839
11-Sep	8.0	2922
18-Sep	5.5	1322
18-Sep	3.8	1336
18-Sep	3.5	1533
18-Sep	6.0	1722
18-Sep	5.1	1867
18-Sep	5.0	1961
18-Sep	5.9	1972
18-Sep	5.8	1992
18-Sep	6.5	2000
18-Sep	4.9	2106
18-Sep	7.6	2786
18-Sep	8.6	3003
18-Sep	9.8	3025
25-Sep	4.0	1692
25-Sep	7.0	2736
25-Sep	8.0	2872
25-Sep	7.6	3078
25-Sep	7.9	3100
25-Sep	8.0	3333
25-Sep	11.3	3639
28-Sep	2.0	1167
28-Sep	5.4	1611
28-Sep	3.9	1633
28-Sep	4.0	1667
28-Sep	6.3	1861
28-Sep	6.9	1922
28-Sep	6.0	2083
28-Sep	7.3	2733
28-Sep	7.4	2750
28-Sep	6.8	2917
28-Sep	8.5	3306

Appendix 4 Sward height and herbage mass data collected from ‘simulated’ grazing plots cut at three weekly intervals during 2013 in Garden Field at Hillsborough.

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
15/04/13	3.0	1025
15/04/13	3.9	1157
15/04/13	3.3	1224
22/04/13	4.6	1046
22/04/13	3.2	1156
22/04/13	3.8	1143
29/04/13	4.9	1462
29/04/13	4.5	1444
29/04/13	4.2	1352
03/05/13	5.9	1744
03/05/13	5.8	1863
03/05/13	5.9	1896
13/05/13	11.7	3158
13/05/13	9.6	2898
20/05/13	9.7	2708
20/05/13	10.7	3186
20/05/13	8.5	2569
24/05/13	11.3	3474
24/05/13	11.3	3435
24/05/13	13.5	3734
03/06/13	11.1	3356
03/06/13	11.1	3527
03/06/13	11.6	3082
07/06/13	9.8	2941
07/06/13	10.1	3155
07/06/13	8.9	2628
24/06/13	8.1	2634
24/06/13	8.8	3068
24/06/13	7.9	2700
01/07/13	9.2	3108
01/07/13	9.4	3308
01/07/13	10.6	3182
08/07/13	7.2	2640
08/07/13	6.9	2433
08/07/13	8.0	2940
11/07/13	6.9	2699
11/07/13	6.6	2563
11/07/13	5.9	2493
22/07/13	5.7	2104
22/07/13	5.9	2182

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
22/07/13	4.8	2090
29/07/13	5.4	2200
29/07/13	5.4	2398
29/07/13	5.7	2268
05/08/13	5.7	2193
05/08/13	6.3	2236
05/08/13	6.6	2162
12/08/13	4.6	1877
12/08/13	5.2	1678
12/08/13	4.7	1938
19/08/13	6.3	2540
19/08/13	6.4	2348
19/08/13	6.1	2188
23/08/13	5.4	2094
23/08/13	5.5	2030
23/08/13	5.7	2081
02/09/13	7.9	2260
02/09/13	6.6	2390
02/09/13	7.6	2460
09/09/13	5.6	2294
09/09/13	6.7	2529
09/09/13	5.9	2152
13/09/13	6.1	2202
13/09/13	5.9	2447
13/09/13	5.8	2099
23/09/13	6.4	2366
23/09/13	6.1	2014
23/09/13	6.6	2037
30/09/13	5.7	2020
30/09/13	6.4	1971
30/09/13	6.1	1885
07/10/13	6.3	1772
07/10/13	6.7	1690
07/10/13	6.9	2071
14/10/13	5.2	1576
14/10/13	6.1	1726
14/10/13	6.0	1568
21/10/13	4.5	1509
21/10/13	5.3	1462
21/10/13	5.8	1642

* Sward height measured >ground level

** Sward height post-cutting is measured and a 'stubble' mass is then calculated and added onto cut yield

Appendix 5 Sward height and herbage mass data collected from 'simulated' grazing plots cut at three weekly intervals during 2013 in Right Croft at Greenmount.

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
15/04/13	2.6	1041
15/04/13	2.5	1110
15/04/13	2.6	887
22/04/13	5.3	1770
22/04/13	4.7	1690
22/04/13	5.1	1476
29/04/13	6.8	1808
29/04/13	5.1	1594
29/04/13	5.3	1399
03/05/13	7.4	1971
03/05/13	6.1	1636
03/05/13	5.6	1768
13/05/13	11.9	3598
13/05/13	8.8	2904
13/05/13	8.8	2540
20/05/13	10.5	2880
20/05/13	8.4	2758
24/05/13	11.8	3287
24/05/13	10.4	2864
24/05/13	9.3	2622
03/06/13	8.9	2604
10/06/13	8.5	3018
10/06/13	9.3	2744
10/06/13	8.3	2476
17/06/13	9.8	3115
17/06/13	10.8	2818
17/06/13	8.6	2560
24/06/13	9.5	3185
24/06/13	9.2	3096
24/06/13	8.8	2825
01/07/13	10.0	2622
01/07/13	7.7	2209
01/07/13	7.2	2233
08/07/13	8.8	2762
08/07/13	7.5	2414
08/07/13	7.1	2160
11/07/13	5.8	2467
11/07/13	7.1	2359
11/07/13	5.9	2117

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
22/07/13	7.5	2423
22/07/13	6.5	2285
22/07/13	6.6	2065
29/07/13	5.8	2115
29/07/13	6.3	2031
29/07/13	5.6	1806
05/08/13	6.3	2379
05/08/13	7.8	2668
05/08/13	7.6	2485
12/08/13	8.8	2393
12/08/13	7.4	2325
12/08/13	8.0	2238
19/08/13	8.8	2897
19/08/13	9.2	2742
19/08/13	8.3	2735
23/08/13	5.9	2004
23/08/13	5.8	2069
23/08/13	5.7	2117
02/09/13	8.8	2737
02/09/13	7.0	2463
02/09/13	7.3	2336
09/09/13	4.3	1899
09/09/13	4.3	1970
09/09/13	5.0	1869
16/09/13	7.4	2272
16/09/13	7.5	2398
16/09/13	7.3	2368
23/09/13	6.3	1982
23/09/13	6.4	1649
23/09/13	5.6	1698
30/09/13	6.8	1774
30/09/13	5.7	1749
30/09/13	6.0	1738
07/10/13	4.7	1425
07/10/13	5.3	1420
07/10/13	4.9	1402
14/10/13	5.7	1834
14/10/13	6.2	1882
14/10/13	5.6	1709
21/10/13	3.0	1407
21/10/13	3.1	1276
21/10/13	2.6	1241

* Sward height measured >ground level

** Sward height post-cutting is measured and a 'stubble' mass is then calculated and added onto cut yield

Appendix 6 Sward height and herbage mass data collected from 'simulated' grazing plots cut at three weekly intervals during 2013 in Upper Croft at Greenmount.

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
15/04/13	4.2	1310
15/04/13	4.0	1130
22/04/13	6.0	1778
22/04/13	5.8	1781
22/04/13	5.2	1480
29/04/13	4.8	1590
29/04/13	5.3	1878
29/04/13	5.2	1631
03/05/13	6.6	1679
03/05/13	5.7	1824
03/05/13	5.6	1691
13/05/13	8.8	2946
13/05/13	8.5	2366
13/05/13	8.1	2460
20/05/13	8.2	2816
20/05/13	8.9	2247
24/05/13	11.5	2965
24/05/13	10.5	2771
24/05/13	10.6	2811
03/06/13	8.0	2625
03/06/13	9.3	2291
03/06/13	8.4	2273
10/06/13	9.3	2804
10/06/13	8.8	2713
10/06/13	11.0	2743
17/06/13	10.1	2988
17/06/13	10.7	2992
17/06/13	11.8	3384
24/06/13	9.0	3021
24/06/13	10.1	2973
24/06/13	9.3	2705
01/07/13	8.5	2656
01/07/13	8.5	2619
01/07/13	8.5	2524
08/07/13	7.8	2552
08/07/13	7.4	2299
08/07/13	7.1	2655
11/07/13	7.6	2492
11/07/13	7.8	2611
11/07/13	6.2	2108
22/07/13	6.6	1984
22/07/13	5.5	2202
22/07/13	6.3	2252

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
29/07/13	5.4	1870
29/07/13	6.2	1640
29/07/13	6.1	2105
05/08/13	7.2	2522
05/08/13	8.3	2726
05/08/13	6.5	2521
12/08/13	8.4	2935
12/08/13	7.8	2566
12/08/13	7.8	2369
19/08/13	9.3	2884
19/08/13	11.0	3021
19/08/13	8.8	2486
23/08/13	7.8	2331
23/08/13	8.4	2249
23/08/13	6.7	2398
02/09/13	7.8	2518
02/09/13	7.4	2575
02/09/13	7.9	2181
09/09/13	7.6	2090
09/09/13	7.5	2466
09/09/13	7.4	2135
16/09/13	10.3	3029
16/09/13	10.3	2669
16/09/13	9.6	2492
23/09/13	8.1	2241
23/09/13	7.0	2040
23/09/13	6.5	2031
30/09/13	7.8	2204
30/09/13	7.8	2036
30/09/13	8.3	2209
07/10/13	6.5	1648
07/10/13	6.8	1797
07/10/13	5.6	1319
14/10/13	6.7	2202
14/10/13	5.8	1884
14/10/13	6.3	1887
21/10/13	4.3	1233
21/10/13	4.8	1562
21/10/13	3.3	1138

* Sward height measured >ground level
** Sward height post-cutting is measured and a 'stubble' mass is then calculated and added onto cut yield

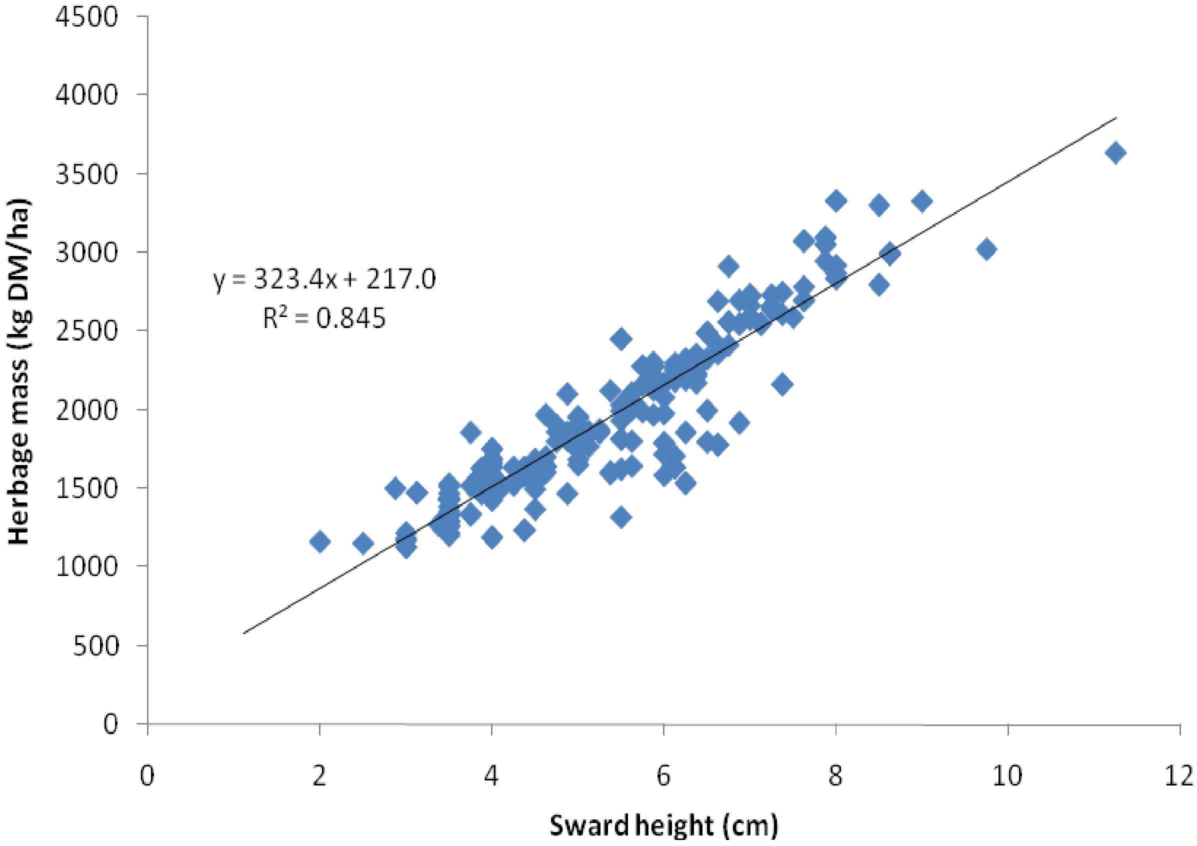
Appendix 7 Sward height and herbage mass data collected from 'simulated' grazing plots cut at three weekly intervals during 2013 in Downpatrick.

Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
15/04/13	2.8	1257
15/04/13	2.3	1291
15/04/13	1.9	1274
22/04/13	4.5	1578
22/04/13	4.6	1495
22/04/13	4.0	1186
29/04/13	5.3	1767
29/04/13	4.6	1467
29/04/13	4.1	1348
03/05/13	6.6	1895
03/05/13	6.6	1626
03/05/13	5.4	1647
13/05/13	13.1	3369
13/05/13	10.9	3326
13/05/13	10.9	2943
20/05/13	13.1	3478
20/05/13	11.7	3128
20/05/13	12.4	3208
24/05/13	13.3	3814
24/05/13	14.4	3581
24/05/13	12.4	3539
03/06/13	11.3	2945
03/06/13	12.1	3443
03/06/13	12.2	3029
10/06/13	13.3	3198
10/06/13	14.0	3445
10/06/13	14.2	3232
17/06/13	14.4	4083
17/06/13	17.1	3687
17/06/13	14.2	3703
24/06/13	12.0	2780
24/06/13	9.8	2704
24/06/13	12.1	2663
01/07/13	11.3	2875
01/07/13	9.6	2589
01/07/13	8.3	2341
08/07/13	9.8	2773
08/07/13	8.2	2358
08/07/13	7.2	2269
11/07/13	7.5	2115
11/07/13	6.6	1989
11/07/13	6.0	2006

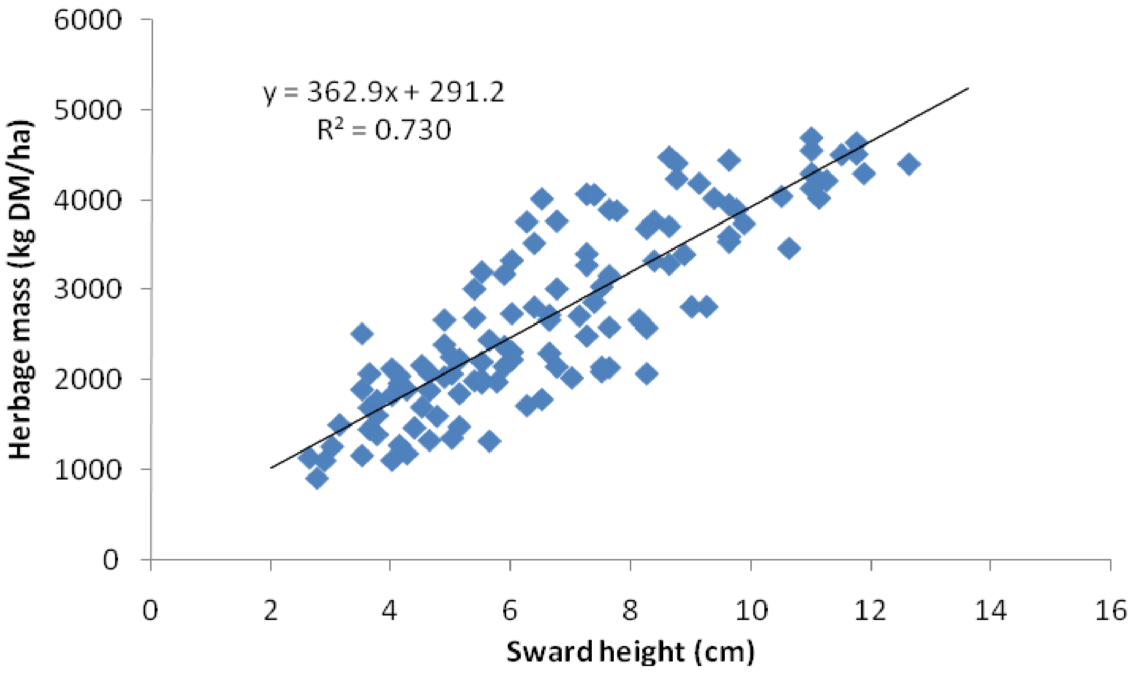
Date	Sward height (cm)*	Herbage mass (kg DM/ha)**
22/07/13	7.8	2479
22/07/13	6.6	2406
22/07/13	6.6	2278
29/07/13	6.1	2013
29/07/13	5.9	1704
29/07/13	4.6	1715
05/08/13	5.4	1784
05/08/13	5.5	1694
05/08/13	5.6	1776
12/08/13	6.3	2146
12/08/13	4.8	1990
12/08/13	5.1	1862
19/08/13	7.6	2282
19/08/13	8.3	2228
19/08/13	5.3	1925
22/08/13	5.1	1696
22/08/13	4.4	1548
22/08/13	4.6	1495
02/09/13	5.7	1907
02/09/13	5.9	1842
02/09/13	4.5	1713
09/09/13	5.3	1890
09/09/13	5.2	1705
09/09/13	4.3	1602
16/09/13	4.5	1569
16/09/13	4.1	1535
16/09/13	4.2	1508
23/09/13	5.1	1669
23/09/13	4.6	1752
23/09/13	4.4	1471
30/09/13	6.1	1806
30/09/13	5.8	1606
30/09/13	4.4	1536
07/10/13	5.9	1497
07/10/13	4.4	1408
07/10/13	4.7	1964
14/10/13	5.4	1868
14/10/13	5.7	1736
14/10/13	4.9	1632
21/10/13	5.6	1477
21/10/13	5.4	1554
21/10/13	5.0	1548

* Sward height measured >ground level
** Sward height post-cutting is measured and a 'stubble' mass is then calculated and added onto cut yield

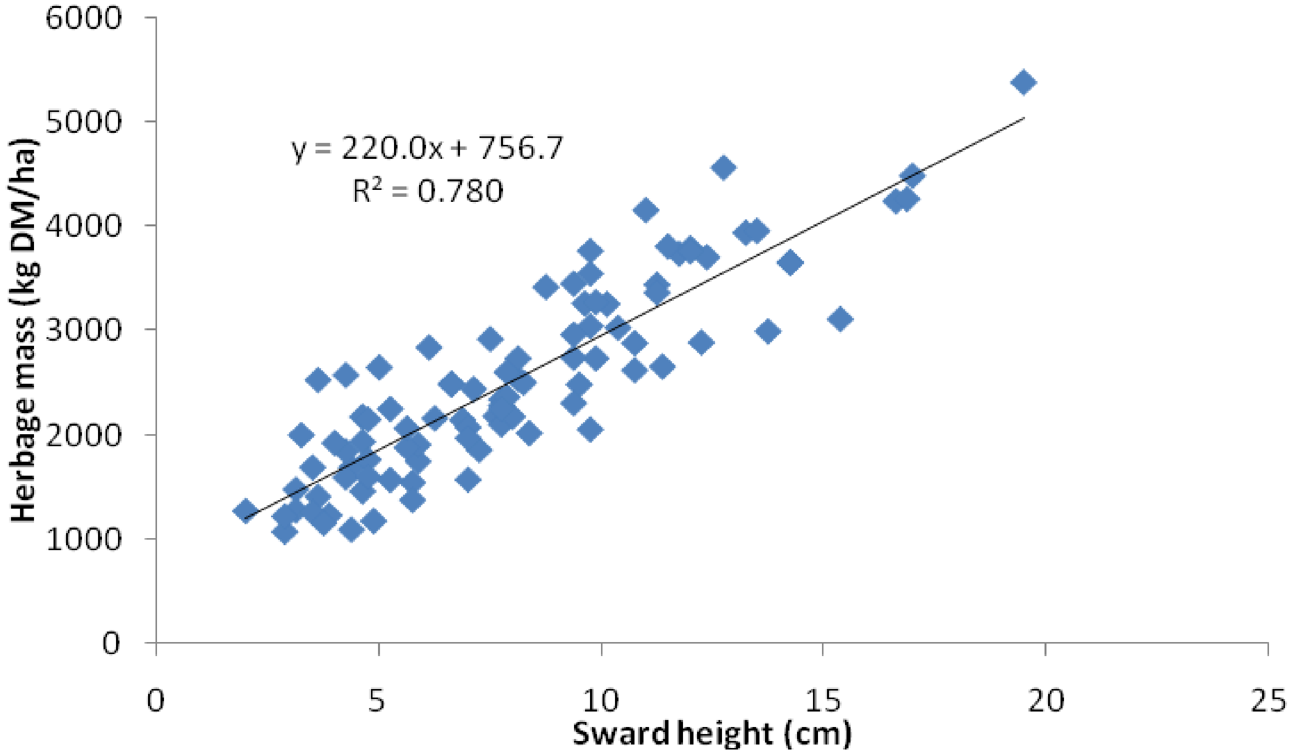
Appendix 8 Relationship between sward height and herbage mass recorded within the grazing paddocks at Hillsborough during 2009



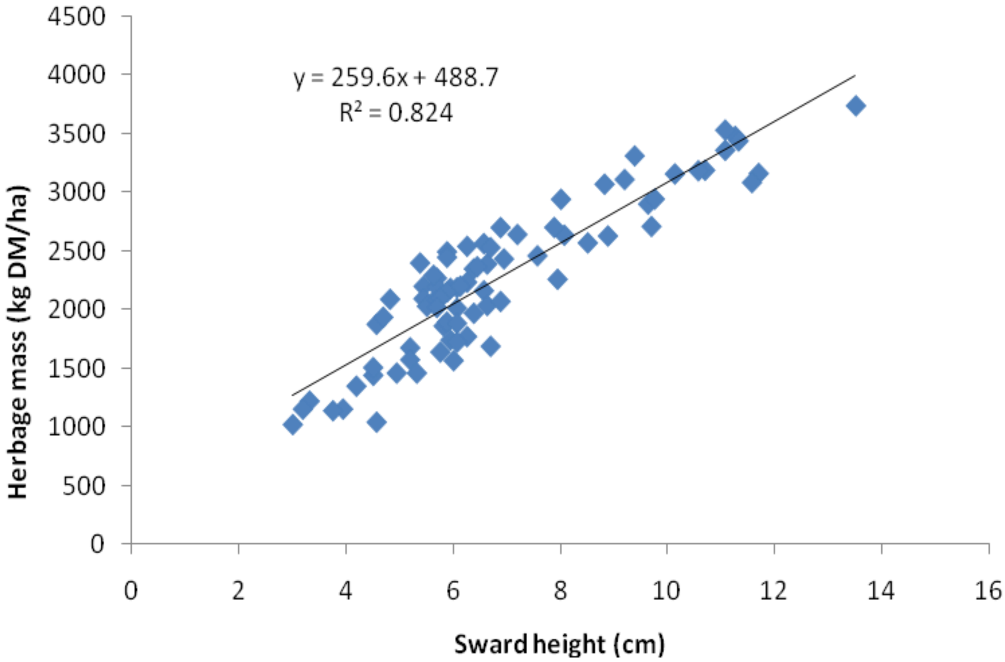
Appendix 9 Relationship between sward height and herbage mass recorded within the grazing paddocks at Hillsborough during 2011



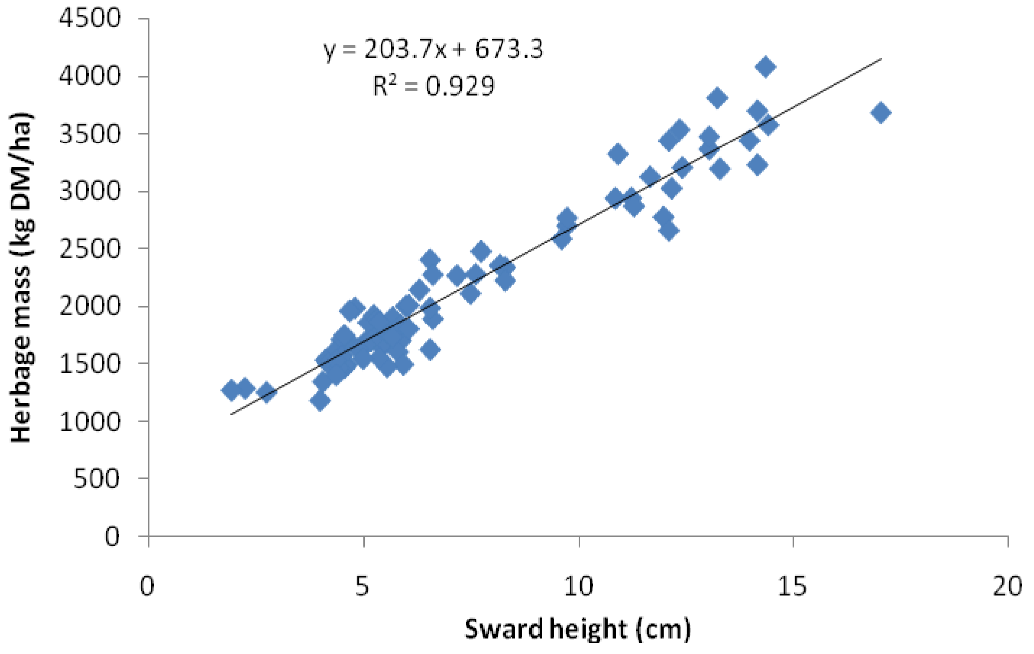
Appendix 10 Relationship between sward height and herbage mass recorded within the grazing paddocks at Hillsborough during 2013



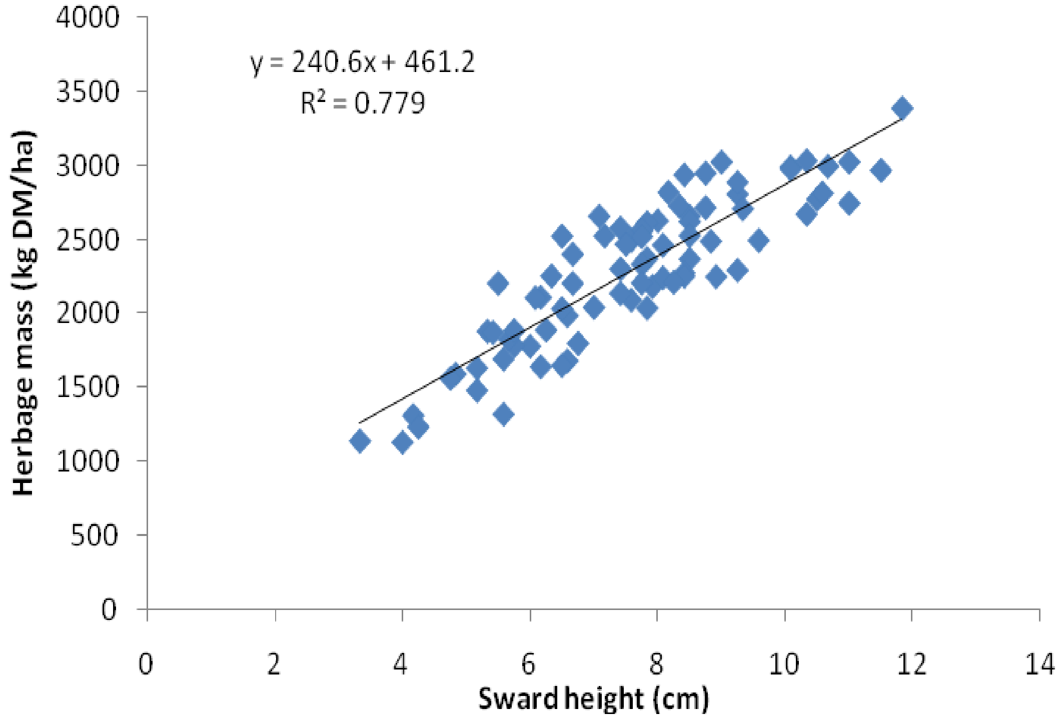
Appendix 11 Relationship between sward height and herbage mass recorded at the GrassCheck site at Hillsborough during 2013



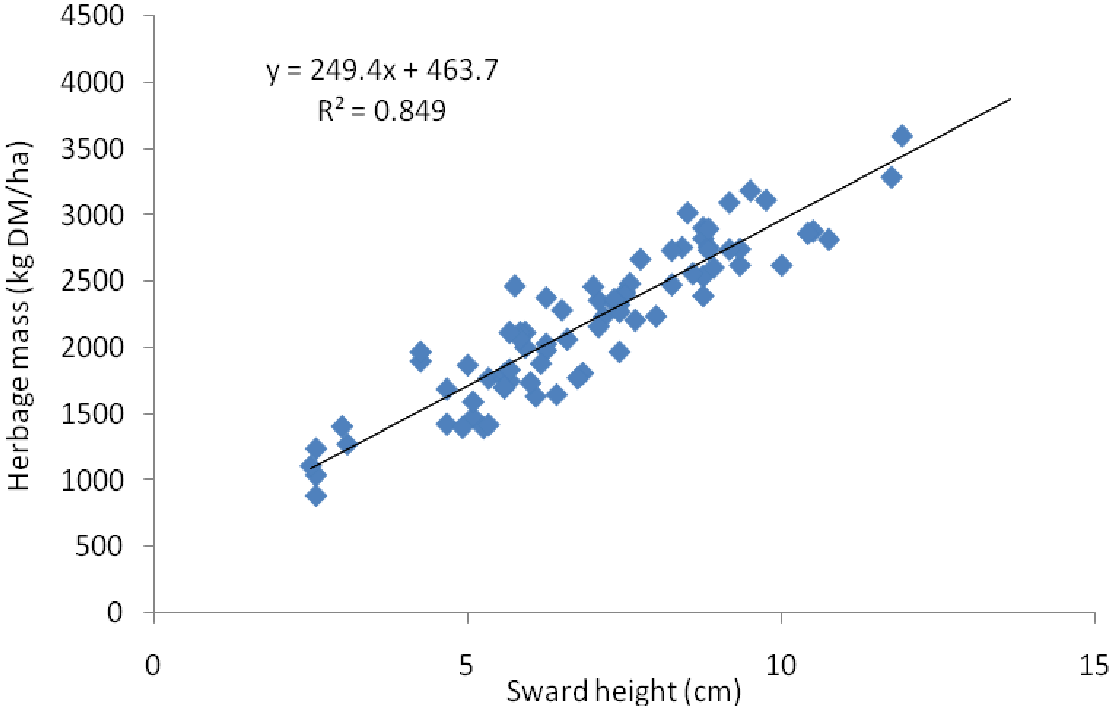
Appendix 12 Relationship between sward height and herbage mass recorded at the GrassCheck site at Downpatrick during 2013



Appendix 13 Relationship between sward height and herbage mass recorded at the GrassCheck site at Upper Croft, Antrim (Greenmount) during 2013

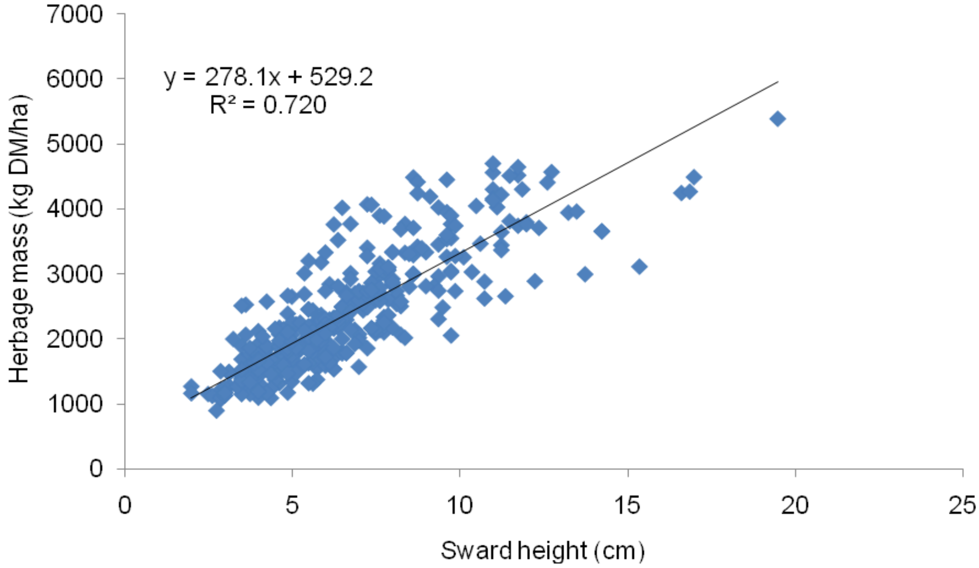


Appendix 14 Relationship between sward height and herbage mass recorded at the GrassCheck site at Right Croft, Antrim (Greenmount) during 2013

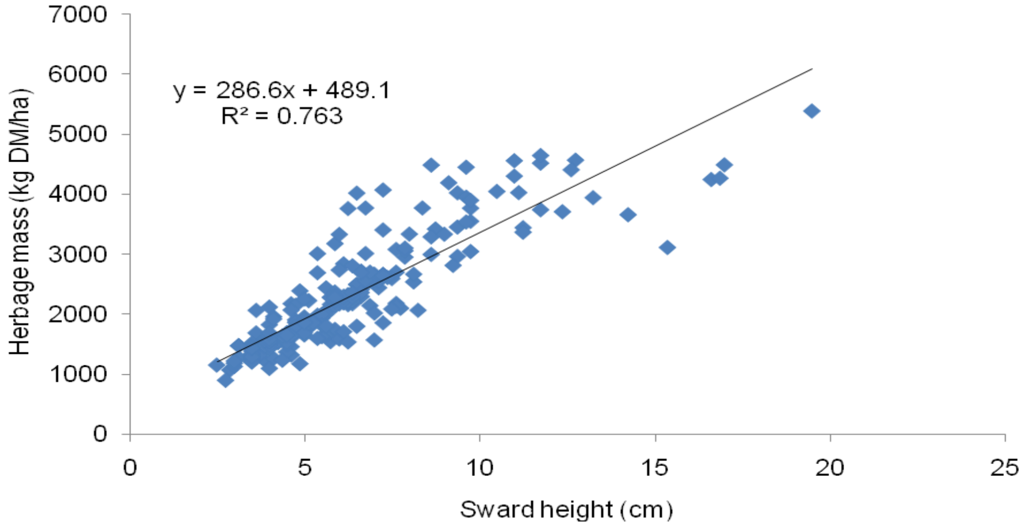


Appendix 15 Relationship between sward height and herbage mass recorded across all three years within the grazing paddocks at Hillsborough, including a. Overall relationships across the whole season, b. The relationship in early season (March – June) and c. The relationship in late season (July – October).

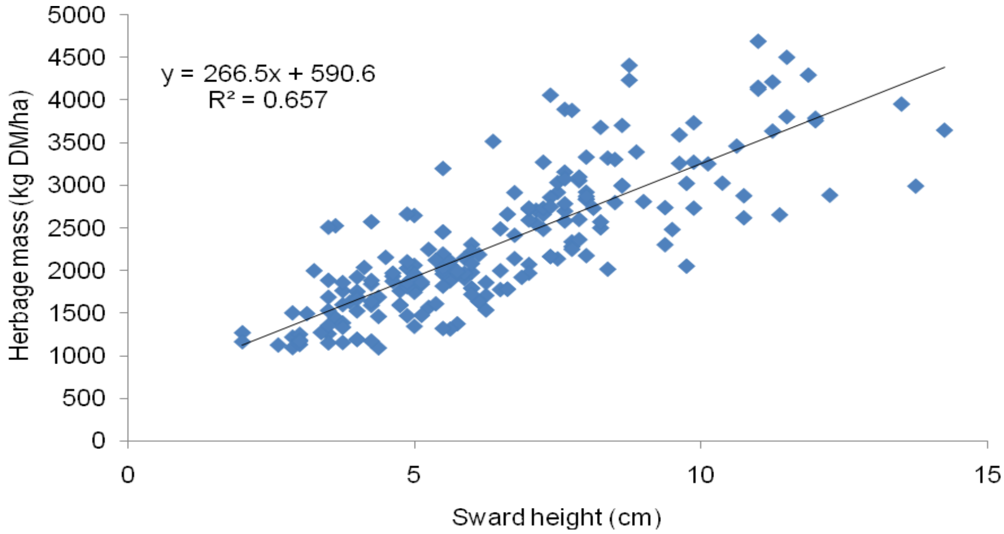
a



b

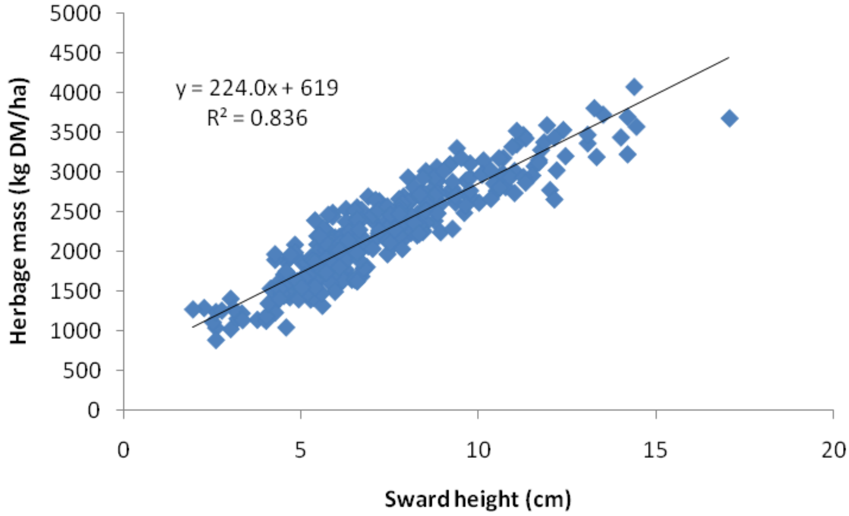


c

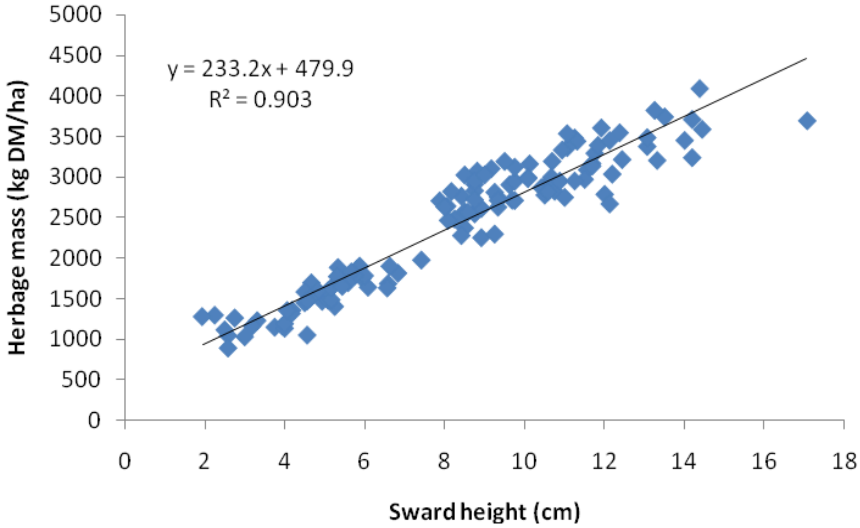


Appendix 16 Relationship between sward height and herbage mass recorded across all four sites within the GrassCheck project in 2013, including a. Overall relationships across the whole season, b. The relationship in early season (March – June) and c. The relationship in late season (July – October).

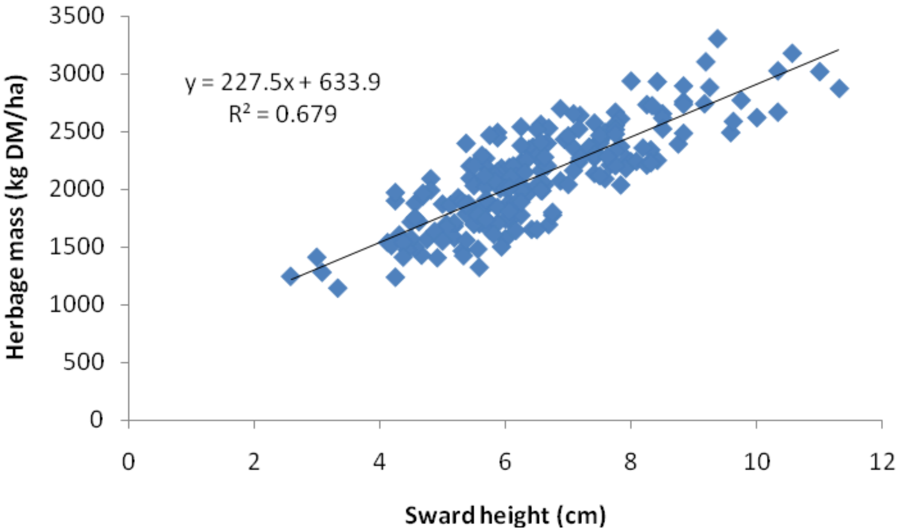
a



b



c



Appendix 17 Average relationship between sward height and herbage mass recorded over the whole season from all data combined. Data collected from the cut plots and the grazing paddocks are identified separately.