Rising plate meters and a capacitance probe estimate the biomass of chicory and plantain monocultures with similar accuracy as for ryegrass-based pasture

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Abstract
It is useful to gain an estimate of herbage biomass when feed budgeting. However, none of the tools that are available to estimate biomass (e.g., the rising plate meter (RPM) or capacitance probe (CP)) have been tested on popular forage herbs, such as chicory or plantain. We tested the hypothesis that RPM and CP could be used to estimate biomass of first year pure chicory and plantain swards with accuracy at least as great as for ryegrass-based pasture. In two summer experiments at different locations in the Waikato, RPM, CP and uncompressed sward height (SH) readings were taken throughout regrowth within 0.2 m² quadrats in chicory and plantain swards, and ryegrass-based pasture. The herbage was then cut to ground level and oven-dried to estimate biomass. Linear equations relating biomass to mean readings were generated for each method, both within each experiment and as pooled datasets. In ryegrass-based pasture, the correlation coefficients (R^2) were 0.73, 0.43 and 0.51 for RPM, CP and SH, respectively. For chicory swards, the pooled correlation coefficients (R^2) were 0.73, 0.73 and 0.81 for RPM, CP and SH, respectively, while for plantain swards the R^2 were 0.70, 0.59 and 0.68 for RPM, CP and SH, respectively. This led to the conclusion that the RPM was a suitable tool for the estimation of biomass in pure chicory or plantain swards as it had similar accuracy to calibration equations for ryegrass-based pasture.

Farmers, at least in the Waikato, can estimate first year chicory or plantain biomass through the summer and autumn period using the following equations:

Chicory biomass (kg DM/ha) = 86 × RPM reading + 235, or = 0.64 × CP reading + 437, or = 94 × SH - 190.

Plantain biomass (kg DM/ha) = 94 × RPM reading + 455.

Keywords: rising plate meter (RPM), capacitance probe (CP), chicory, plantain

Introduction
Chicory (*Cichorium intybus* L.) and plantain (*Plantago lanceolata* L.) are becoming popular feed sources for New Zealand farmers during dry summer months. Chicory and plantain have root structures that enable them to access moisture that ryegrass cannot (Rumball 1986; Stewart 1996) and, therefore, have the potential to grow large amounts of high quality feed during dry periods (Glassey *et al.* 2013; Minneé *et al.* 2013; Rollo *et al*. 1998). Currently, there is no suitable and quick method for farmers to estimate the herbage biomass of these two herbs. It is important to estimate herbage mass of paddocks to manage the feeding allowance of cows in a way that maximises the utilisation of feed offered by reducing wastage or over-grazing (Clark *et al*. 2006; Macdonald & Penno 1998). Researchers use the cut and oven-dry method which delivers accurate results, but is labour and time intensive, making it an impractical method for most farmers.

Over the last 30 years, rising plate meters (RPM) and capacitance probes (CP) and sward height (SH) have been developed and used to estimate herbage biomass (L'Huillier & Thomson 1988; Stockdale & Kelly 1984). These instruments have been used to measure pure grass swards/mixed pastures (L'Huillier & Thomson 1988; O'Donovan *et al*. 2002) and legumes (Serrano *et al.* 2011) with varying degrees of success (Table 1). Calibration equations for pasture mass estimations can often vary as they are affected by factors such as density of the sward, dead material (Currie *et al.* 1973; L'Huillier & Thomson 1988) and herbage moisture content (Jones & Haydock 1970; Serrano *et al*. 2011). Although chicory and plantain have different canopy architecture to ryegrass, there is no reason to suggest the RPM, CP and SH will not be capable of estimating chicory and plantain biomass in their first year of growth. First year crops in this study were defined as those sown in spring, with measurements taken during the first year post-sowing. Chicory plants that have been vernalised during the winter develop large, woody reproductive stems the following spring/summer (Clark *et al*. 1990). It is likely that these reproductive stems would greatly influence the calibration equations, depending on the proportion of leaf and stem in each sward.

We tested whether RPM, CP and uncompressed SH could be used to estimate biomass of first year

Table 1 Previous research using rising plate meters (RPM), capacitance probes (CP) and sward height (SH) to estimate herbage biomass.

Species/ Method	Location	Reference	Period	Equation[a]	R^2	n	Standard error
Grass/legume mix							
CP (Single Probe Meter)	Australia	Stockdale & Kelly 1984	Short term		0.97[b]	8	502
CP (Pasture Probe)	New Zealand	L'Huillier&Thompson 1988	Full season		0.84		410
			Winter/early spring	9.9 × CP + 600			
			Late spring/early summer	9.5 × CP + 1200			
			Mid summer	13.6 × CP + 1240			
			Early autumn	12.7 × CP + 1020			
			Late autumn	10.4 × CP + 990			
CP (GrassMaster II)	Portugal	Serrano *et al.* 2011	Short term		0.87		578
CP (GrassMaster II)	New Zealand	Litherland *et al.* 2008	Full season	0.72 × CP + 129	0.58	693	
CP (Pasture Probe)	New Zealand	Piggot 1986	Winter/spring		0.84		
RPM	Australia	Stockdale & Kelly 1984	Short term		0.97[b]	8	495
RPM	New Zealand	L'Huillier & Thompson 1988	Full season		0.86	220	390
			Winter/early spring	125 × RPM + 640			
			Late spring/early summer	130 × RPM + 990			
			Mid summer	165 × RPM + 1460			
			Early autumn	159 × RPM + 1180			
			Late autumn	157 × RPM + 970			
RPM	New Zealand	Roche 2007	Winter	149.1 × RPM + 785.1[c]	0.75	457	805
RPM	New Zealand	Roche *et al.* 2005	Winter	156.7 × RPM + 945.4	0.69	315	1073
RPM (Ellinbank)	New Zealand	Piggot 1986	Winter/spring		0.82		
RPM	New Zealand	Roche *et al.* 2010	Winter/early spring	142.3 × RPM + 646.8[c]	0.79	552	775
RPM	New Zealand	Litherland *et al.* 2008	Full season	151 × RPM + 1034	0.52	2279	
RPM	New Zealand	Nobilly *et al.* 2013	Full season	133 × RPM + 150	0.76	288	
RPM	New Zealand	Nobilly *et al.* 2013	Full season	137 × RPM + 35	0.84	288	
SH	New Zealand	L'Huillier &Thompson 1988	Full season		0.81		415
			Winter/early spring	120 × SH + 590			
			Late spring/early summer	70 × SH + 1340			
			Mid summer	172 × SH + 1340			
			Early autumn	195 × SH + 610			
			Late autumn	300 × SH + 400			
SH	New Zealand	Piggot 1986	Winter/spring	190 × SH + 1460[de]	0.82		
SH	New Zealand	Litherland *et al.* 2008	Full season	186 × SH + 756	0.44	2528	
Grass monoculture							
CP (Pasture Wand)	Ireland	O'Donovan *et al.* 2002	Spring, summer, autumn		0.76		442
CP (GrassMaster II)	Portugal	Serrano *et al.* 2011	Short term		0.90		555
RPM	Ireland	O'Donovan *et al.* 2002	Spring, summer, autumn		0.88		318
Legume monoculture							
CP (GrassMaster II)	Portugal	Serrano *et al.* 2011	Short term		0.48		771

[a] Where CP = calculated value from the capacitance probe (pre-cut corrected meter reading minus post-cut corrected meter reading); RPM = RPM reading in half cm; SH = uncompressed sward height in cm.
[b] Multiple R^2
[c] Multiplier converted from cm in journal paper to RPM height (half cm)
[d] Average of monthly equations taken
[e] Pre-grazing equation

pure chicory and plantain swards at a similar level of accuracy to that obtainable by using a RPM for ryegrass-based pasture. Calibration cuts were taken in chicory and plantain swards, and in ryegrass-based pasture during two summer experiments in the Waikato.

Materials and Methods

Samples were taken from two locations in the Waikato. The first dataset was collected between January and April 2012 on a chicory sward on a commercial dairy farm in Pirongia (37°59′S, 175°13′E), while the second was collected at DairyNZ's Scott farm located near Hamilton (37°47′S, 175°19′E) between January and April 2013. The first dataset was used to calibrate the RPM and CP measurements against standing dry matter (DM) of an unirrigated chicory sward, while the second calibrated the RPM, CP and uncompressed SH measurements against standing DM of irrigated chicory and plantain swards, and unirrigated ryegrass-based pasture. All chicory and plantain swards were spring-sown (October), three months before sampling began. The ryegrass-based pastures were all well-established swards, 2 years old or older.

Measurements

Measurements for both sampling periods were taken during the summer after sowing in spring. Ten quadrat calibration cuts were taken weekly over a 3-month period that covered a range of biomass, both pre- and post-grazing. Before the quadrat (0.2 m²) was placed on the ground, two uncompressed SH measurements were taken using a ruler, followed by one RPM reading using a Farmworks Plate Meter™ (Farmworks Precision; Feilding, New Zealand). The SH measurements were taken on two randomly selected leaves within the quadrat area, measuring from ground to the uppermost point of the leaf as it lay undisturbed in the sward. The RPM reading was taken before the CP unlike a previous study (L'Huillier & Thomson 1988) as it was noted the CP would crush the chicory and plantain leaves. Pre-grazing chicory and plantain swards have a thick, tangled canopy that the CP collapsed when placed to ground level, whereas the RPM was held aloft by the canopy.

To avoid the risk of the steel quadrat interfering with the CP measurements, four small wooden pegs were placed at the four corners and the quadrat was removed while the CP measurements were taken using the GrassMaster II™ (Novel Ways Ltd, Hamilton, New Zealand). Firstly, a "clear air" reading was taken by holding the CP at chest height, parallel to the ground. This number was stored in the device while nine herbage readings were taken in a grid formation and averaged. All herbage within the quadrat was then cut to ground level with hand shears (chicory and plantain) or battery powered hand pieces (ryegrass-based pasture). After the herbage was cut, a further air reading and series of nine ground readings were made where the herbage had been cut. The pre- and post-air readings were automatically subtracted from the averaged pre- and post-cut quadrat readings respectively, to provide pre- and post-cut corrected meter readings (CMR). The post-cut CMR reading was then subtracted from the pre-cut CMR reading, effectively removing the capacitance value of the soil, which was variable due to changing soil moisture and temperature. Previous research (L'Huillier & Thomson 1988; Serrano *et al*. 2011; Stockdale & Kelly 1984) did not measure and remove the ground reading. This measurement was introduced in this study to provide a more accurate and consistent reading. Moreover, the new model of the CP used requires a bare soil reading before herbage measurements can begin. Herbage samples were placed on ice for transporting to the laboratory, where they were washed and oven-dried at 95˚C for 2 days, and then weighed to estimate total DM mass.

Climate

Climate data from NIWA are presented in Table 2. The chicory and plantain swards in Hamilton also received an additional 50 mm of irrigation, split into two 25 mm applications, one in late January 2013 and the second in mid-February. The 2013 months were drier and warmer than the average while the 2012 months were wetter and cooler than average. The year 2013 was memorable for severe drought conditions.

Statistical analysis

Simple regression analyses were conducted on the data to derive an equation for each of the three data sets. The closeness of fit of the calibration equation to actual data points was calculated and used as a measure of

Table 2 Total monthly rainfall (mm) and mean temperature (°C) for January, February and March 2012 and 2013, and the 30 year average (1981–2010).

		2012	2013[b]	Average[b]
Rainfall (mm)	January	111.0[a]	7.2	79.0
	February	171.2[a]	20.0	70.0
	March	107.0[a]	23.6	79.7
	Total	389.2	50.8	228.7
Mean temperature (°C)	January	16.4[b]	19.0	18.4
	February	16.9[b]	18.9	18.8
	March	15.1[b]	19.1	17.1
	Average[c]	16.1	19.0	18.1

[a] Data collected at Ngahinapouri (11 km north of Pirongia) by NIWA
[b] Data collected at Ruakura (5 km west of Scott Farm) by NIWA
[c] Average calculated using figures from the table

accuracy (standard error) and R^2 was used as a measure of correlation. Significance was tested to the 5% level ($P<0.05$).

Results

The linear calibration equations created during this experiment for chicory, plantain and ryegrass-based pasture are presented in Table 3 with all individual data points used to create each graph depicted in Figure 1. In chicory swards the R^2 for all tested estimation methods were similar within each dataset, with an R^2 of 0.79–0.81 obtained for all three methods in Hamilton, while in Pirongia the R^2 ranged from 0.63 to 0.65 for the RPM and CP. This resulted in an R^2 of 0.73 for both the RPM and CP when both datasets were pooled. In the plantain sward in Hamilton, the R^2 ranged from 0.70 (RPM) to 0.59 (CP), while in ryegrass-based pasture the R^2 ranged from 0.73 (RPM) to 0.43 (CP).

Discussion

Data from the current study support the hypothesis that the biomass of chicory and plantain can be estimated with tools that are already used on New Zealand farms to estimate pasture mass. In New Zealand, the RPM is an accepted method of yield estimation for pasture (L'Huillier & Thomson 1988). For yield estimation methods to be considered acceptable for first year chicory or plantain swards, the accuracy of these methods must be similar to, or greater than that for ryegrass-based pasture.

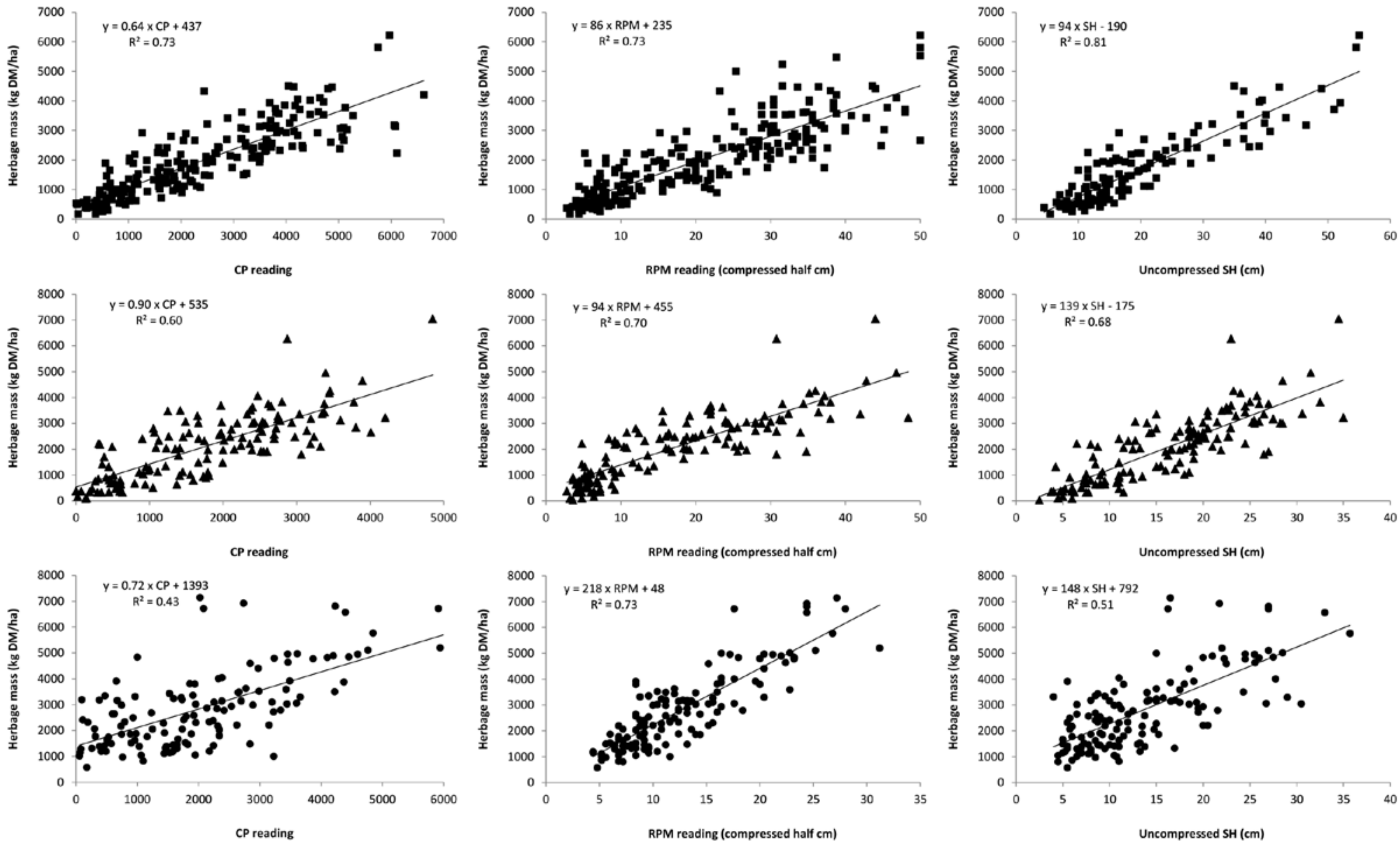
When data from the chicory swards at both sites were pooled, the R^2 values for the RPM and CP were 0.73, which was the same as the value for the ryegrass based pasture. This indicates that both methods were acceptable. Interestingly, the R^2 of the Pirongia dataset collected on a commercial dairy farm was lower than that collected from the experimental sward on the DairyNZ research farm (0.63–0.65 vs 0.79, respectively). Plant density in pure chicory swards can vary dramatically, with some areas containing high plant numbers and other areas much lower numbers. This may indicate that there is greater variability in crops on commercial dairy farms than in research crops which are managed much more intensively. Conversely, the plant density of the experimental sward may have declined less over time, reducing the variability in the dataset. Unfortunately, the plant densities of both swards were measured only once during the measurement period, so it is not possible to draw any conclusions regarding the source of variability. The plant density of the commercial farm sward was 103 ± 9 plants/m^2 when measured in early January while the plant density of the research sward was 120 ± 35 plants/m^2 in mid-April. This provides some indication of the swards in which our equations may be relevant.

Table 3 Calibration equations and accuracy of regression analysis for chicory, plantain and ryegrass-based pasture.

Species/Method[a]	Location	n	Summer/Autumn Period	Equation[b]	R^2	SD	Significance[c]
Chicory							
CP	Hamilton	134	2013	y = 0.74 × CP + 364	0.79	551	***
CP	Pirongia	85	2012	y = 0.59 × CP + 419	0.65	637	***
CP	Pirongia+Hamilton[d]	219	2012, 2013	y = 0.64 × CP + 437	0.73	611	***
RPM	Hamilton	135	2013	y = 92 × RPM + 224	0.79	546	***
RPM	Pirongia	109	2012	y = 87 × RPM + 97	0.63	774	***
RPM	Pirongia+Hamilton[d]	244	2012, 2013	y = 86 × RPM + 235	0.73	664	***
SH	Hamilton	134	2013	y = 94 × SH -190	0.81	520	***
Plantain							
CP	Hamilton	132	2013	y = 0.90 × CP + 535	0.59	809	***
RPM	Hamilton	135	2013	y = 94 × RPM + 455	0.70	711	***
SH	Hamilton	135	2013	y = 139 × SH - 175	0.68	734	***
Ryegrass-based pasture							
CP	Hamilton	125	2013	y = 0.72 × CP + 1393	0.43	1132	***
RPM	Hamilton	135	2013	y = 218 × RPM + 48	0.73	772	***
SH	Hamilton	135	2013	y = 148 × SH + 792	0.51	1042	***

[a] RPM, rising plate meter; CP, capacitance probe; SH, uncompressed sward height.
[b] Where CP = calculated value from the capacitance probe (pre-cut corrected meter reading minus post-cut corrected meter reading); RPM = RPM reading in half cm; SH = uncompressed sward height in cm.
[c] ***, P<0.001.
[d] The combined dataset from both sites was used to create the regression equations depicted in Figure 1.

Figure 1 Regression equations using all data (Hamilton and Pirongia) for pure chicory (■) and plantain (▲) swards, and ryegrass-based pasture (●) for the capacitance probe (CP), rising plate meter (RPM) and uncompressed sward height (SH).



Another notable difference between the chicory equations from the two datasets was that the slope of the linear equation generated from the Pirongia sward was shallower than the experimental sward in Hamilton for both the RPM and CP. This could be due to a difference in plant dry matter percentage (DM%) and/or change in plant morphology brought about through different climate conditions (i.e., soil moisture content and ambient temperature). Previous research (Litherland *et al.* 2008) indicated the use of plant DM% in regression equations on sheep and beef grazed pastures significantly improved the estimate of change in herbage mass with both a CP and RPM. In the case of this study, substantially different rainfall was observed between the two datasets, with 389 mm recorded in 2012 in Pirongia and only 51 mm (plus 50 mm of irrigation) in 2013 in Hamilton. Furthermore, chicory plant dry weight can increase exponentially with thermal time (°C.day) (Powell *et al.* 2007) and the average temperature during this study was 16.1°C and 19.0°C for the three months of 2012 and 2013, respectively. Thus heightened DM growth for 2013 vs 2012 was likely, supporting the steeper slope of the 2013 regression equation. Both rainfalls and temperatures are fairly extreme, and may have affected the plant DM%, altering the rate at which DM yield increased with plant height and volume.

In the experimental chicory sward, the uncompressed SH method produced an R^2 of 0.81, indicating that it may be an acceptable method of yield estimation. One potential problem with using height to estimate mass, however, is that it fails to take into account the density of the sward (Fulkerson & Donaghy 2001). Therefore, chicory swards of varying density could vary in biomass and yet have a similar height. In a range of sward conditions uncompressed SH may, therefore, be less accurate than either the RPM or CP. Or it may simply be that more than two SH measurements are required to better account for the variability within the swards; this requires further investigation. The coefficient of variation for the SH method, which does not take into account plant density, was higher than the RPM, which does take into account density in its measurements.

In the plantain sward none of the tested methods had an R^2 greater than 0.73; however, the RPM with an R^2 of 0.70 could be considered acceptable, given the R^2 in previous research has been below 0.70 (Table 1). This plantain sward had a plant density in mid April of 180 ± 50 plants/m^2, again providing some indication of the swards in which the equation may be relevant.

The 2013 drought in the Waikato affected the size of the dataset and therefore the quality, as during data collection, it became difficult to gain readings from the CP on the dry soils and the minimal surrounding herbage mass. The CP is programmed to detect differences between the air and the ground (Serrano *et al*. 2011). When the difference did not meet the default threshold set internally by the manufacturer (when CMR<700) no reading could be taken. Consequently, this reduced the size of the data set for the ryegrass-based pasture by 10 data points and influenced the accuracy of the linear regression. In a previous study (Neal & Neal 1973), short dry pastures were also identified as a limitation to the CP. Under non-drought conditions, where pastures remain green, existing CPs can estimate herbage mass of ryegrass well (O'Donovan *et al.* 2002; Serrano *et al.* 2011; Stockdale & Kelly 1984), with standard deviation (SD) ranging from 440 to 555 and R^2>0.75 (Table 1). Since this experiment was undertaken, further commercial development of the CP has resolved the issue where the CP struggled to take measurements in dry conditions.

There was greater variability of yields at the higher end for all yield estimate methods of chicory and plantain (Figure 1). The majority of samples were taken at lower yields and the variability there was smaller than the higher yield end. An increased number of samples at the higher yield end would strengthen the regression equation, and should be a focus of future research. There was also large variation in yields at similar points of measure, perhaps due to the varying nature of plant density in the swards. This is one reason why a minimum number of measurements per paddock (e.g. 50) are recommended.

The equations developed in this study (Table 3) for chicory and plantain were created using swards from paddocks on two individual farms, for which they proved accurate; however additional data are required to ensure their relevance on swards in different environments where soils and climate can vary markedly. These equations allow farmers to better estimate herbage biomass. However, if post-grazing residuals on the chicory and plantain swards are consistently lower or higher than expected, it may be that the biomass is being over- or under-estimated. Therefore, the daily area should be increased when over-grazed or decreased when under-grazed. This is more likely to occur at greater herbage yields where there was often greater variability.

Conclusion

The RPM was a suitable tool for the estimation of biomass in pure chicory or plantain swards as it had similar accuracy to similarly developed calibration equations for ryegrass-based pasture. The CP and uncompressed SH methods also estimated chicory biomass with similar accuracy to the RPM.

Farmers, at least in the Waikato, can estimate first year chicory or plantain biomass through the summer and autumn period using the following equations:

Chicory biomass (kg DM/ha) = 86 × RPM reading + 235, or = 0.64 × CP reading + 437, or = 94 × SH - 190.

Plantain biomass (kg DM/ha) = 94 × RPM reading + 455.

Further investigation is required to ensure these equations are valid over a range of first year sward conditions in different environments.

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