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Calibration of Pasture Forage Mass to Plate Meter Compressed Height is a Second-order Response with a Zero Intercept

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Plate meters are used to estimate pasture forage mass (FM; lb dry matter/acre) by measuring meter-compressed forage height (CHt; inches) and multiplying that value by a forage density (FD; lb dry matter/acre/inch) coefficient. Since FD has a linear relation to CHt (Eq. 1) and FM equals FD times CHt (Eq. 2 and 3) the FM calibration model is second order with no intercept (Eq. 4).

$$FD = a + b\ CHt \quad [1]$$

$$FM = FD\ CHt \quad [2]$$

$$FM = (a + b\ CHt)\ CHt \quad [3]$$

$$FM = a\ CHt + b\ CHt^2 \quad [4]$$

To test this hypothesis, 20 rotationally stocked pastures at five sites in the Alleghany Plateau (three) and Appalachian Ridge and Valley (two) of West Virginia were used to calibrate a plate meter. Sites differed in species composition: Grant, tall fescue (*Schedonorus arundinaceus*; previously known as *Festuca arundinacea*); Terra Alta, orchardgrass (*Dactylis glomerata*) and white clover (*Trifolium repens*); WVU1 and WVU2, orchardgrass, tall fescue, Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), and white clover; Pendleton, smooth bromegrass (*Bromus inermis*). Pastures were sampled over 3 years pre-grazing (93), post-grazing (96), and in mid-regrowth (11) for a total of 200 sampling events across the grazing season (2 May–2 December). Pastures were walked in a zig-zag manner with paired CHt and FM samples taken at regular intervals, ensuring that 15 samples were taken uniformly across the pasture. A falling plate meter (Rayburn and Rayburn, 1998) was used to measure CHt. This meter is an 18-inch square, 0.22-inch thick piece of acrylic plastic, weighing 2 lb 15 oz. Pasture CHt was measured by placing the plate on the pasture and reading its height above the ground once the canopy supported its weight. Within the area measured for CHt, a 1–sq ft area was clipped at ground level. Clipped samples were oven dried at 131°F for 48 h, weighed and FM calculated.

The 15 CHt and FM samples were used to calculate FD present on the day of sampling by linear regression with zero intercept

Core Ideas

- Forage density has a linear relation to pasture height.
- The regression of forage density to pasture height is a measure of plant morphology within the sward.
- Forage mass is the product of forage density and pasture height resulting in a second-order relation with zero intercept.
- The form of the second-order relation of forage mass to pasture height can be diminishing return, linear, or exponential, depending on the distribution of forage density within the pasture.

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Abbreviations: CHt, compressed forage height; FD, forage density; FM, forage mass.

Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

	Column 1	Column 2	
Length			
0.304	foot, ft	meter, m	3.28
2.54	inch	centimeter, cm (10–2 m)	0.394
Area			
0.405	acre	hectare, ha	2.47
Mass			
0.454	pound, lb	kilogram, kg	2.205

as recommended by Ferraro et al. (2012). Within sites and across sampling dates, FD values were regressed against CHt as in Eq. 1. Then FM was calculated algebraically as in Eq. 2. Also, FM was calibrated directly to CHt as a first-order regression and as second-order regressions with and without an intercept. Each of the 200 CHt, FM, and FD data points are the mean of 15 CHt or FM values or the regression slope (FD) of 15 FM vs. CHt samples. The precision of the regressions was evaluated using regression coefficient SE and the SD of residuals about the regression (SD_{reg}). A small SD_{reg} shows high precision; a large value, low precision. Statistical analysis was conducted using NCSS10 software (NCSS, LLC. Kaysville, UT) with statistical significance at $P \leq 0.05$.

The FD vs. CHt regressions differed between sites, other than the WVU1 and WVU2, which did not differ and so were pooled (WVU1&2) (Table 1: A1–A4). When FM was calculated as the product of FD time CHt, Eq. set B (Table 1: B1–B4) was produced. When FM was regressed against CHt the intercepts were significant (Table 2: C1–C4). When FM was regressed against CHt and CHt^2, none of the intercept values were significantly different from zero (Table 2: D1–D4). When FM was regressed against CHt and CHt^2 with the intercept set to zero (Table 2: E1–E4), the respective regression coefficient SE decreased greatly and SD_{reg} values did not change appreciably and were similar to the SD_{reg} of FM calculated as the product of FD and CHt (Table 1: B1–B4).

To calculate a second-order relation, calibration samples need to be taken across the range of CHt that can occur in the pasture with pre- and post-grazing sampling. If only pre-grazing samples are used, a linear relation with a positive intercept will often occur, as as shown for the Grant site (Fig. 1).

Different responses for FD vs. CHt are the result of the pasture species composition and growth habit of the dominant plants. Cool-season grasses have one of two growth habits: short-shoot, nonjointing aftermath growth, as found in orchardgrass and tall fescue; or long-shoot, jointing aftermath growth, as found in smooth bromegrass. During regrowth, the growing points in short-shoot grasses do not rise above the soil surface but instead form tiller bases of encircling leaf sheaths, presenting high FD in the lower canopy. Sites containing fescue and orchardgrass had typical pasture canopy structure as described by Hodgson (1990),

Table 1. Plate-meter calibration regressions for forage density (FD) vs. forage compressed height (CHt) and forage mass (FM) expressed as the product of the FD regression times CHt for four locations.

	Site	Regression	R^2	SD_{reg}†	No. of paired samples
FD vs. CHt					
A1	Grant	FD = 1244 − 76 CHt			
		SE‡ 97 22	0.27	252	35
A2	Pendleton	FD = 171 + 28 CHt			
		SE 31 7	0.47	67	21
A3	Terra Alta	FD = 732 − 60 CHt			
		SE 56 12	0.35	168	51
A4	WVU1&2	FD = 726 − 42 CHt			
		SE 25 5	0.41	115	93
FM calculated as product of above FD and CHt					
B1	Grant	$FM = 1244\,CHt - 76\,CHt^2$	NA	850	35
B2	Pendleton	$FM = 171\,CHt + 28\,CHt^2$	NA	332	21
B3	Terra Alta	$FM = 732\,CHt - 60\,CHt^2$	NA	576	51
B4	WVU1&2	$FM = 726\,CHt - 42\,CHt^2$	NA	364	93

†SD_{reg}, standard deviation about the regression.

‡SE, standard error.

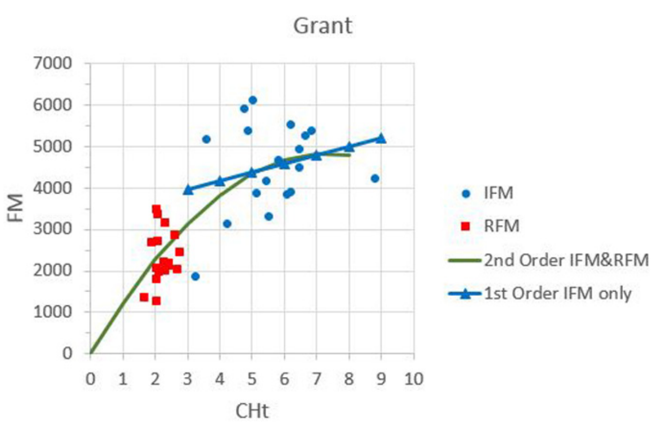

Fig. 1. Sampling both pre-grazing initial forage mass (IFM) and post-grazing residual forage mass (RFM) provides a range of plate meter compressed height (CHt) and forage mass (FM) giving a second order regression through the intercept. Sampling only IFM gives a linear regression with an intercept.

Table 2. Plate meter calibrations for forage mass (FM) expressed as the first-order regression of FM vs. forage compressed height (CHt) and the second-order regression of FM vs. CHt and CHt^2 with and without intercept terms for four locations.

	Site	Regression	R^2	SD_{reg}†	No. of paired samples
FM regression against CHt					
C1	Grant	FM = 1320 + 539 CHt			
		SE‡ 363 82	0.57	943	35
C2	Pendleton	FM = −448 + 428 CHt			
		SE 172 37	0.88	368	21
C3	Terra Alta	FM = 1063 + 177 CHt			
		SE 191 40	0.29	567	51
C4	WVU1&2	FM = 838 + 297 CHt			
		SE 82 18	0.76	382	93
FM regression against CHt and CHt^2 with intercept					
D1	Grant	FM = − 629 + 1629 CHt − 122 CHt^2			
		SE 778 401 44	0.65	860	35
D2	Pendleton	FM = 502 − 140 CHt + 64 CHt^2			
		SE 462 262 29	0.90	336	21
D3	Terra Alta	FM = 676 + 373 CHt − 20 CHt^2			
		SE 493 233 24	0.30	569	51
D4	WVU1&2	FM = 281 + 576 CHt − 27 CHt^2			
		SE 177 81 8	0.79	360	93
FM regression against CHt and CHt^2 without intercept					
E1	Grant	FM = 1317 CHt − 90 CHt^2			
		SE 111 19	0.95	856	35
E2	Pendleton	FM = 136 CHt + 34 CHt^2			
		SE 62 10	0.96	338	21
E3	Terra Alta	FM = 683 CHt − 50 CHt^2			
		SE 59 9	0.92	574	51
E4	WVU1&2	FM = 700 CHt − 38 CHt^2			
		SE 23 3	0.97	363	93

†SD_{reg}, standard deviation about the regression.

‡SE, standard error.

with FD high in the lower canopy, decreasing with height and giving a negative FD vs. CHt relation. The inclusion of short-statured species such as bluegrass increases FD in the lower canopy. Long-shoot grasses have new growth emerging near the soil surface, and as tillers grow, the growing point rises above the soil surface (joints), moving the stem and leaves higher into the canopy, adding FM as the height increases. This results in a positive FD vs. CHt relation.

At four sites, FM vs. CHt had a diminishing-return form; at the Pendleton site it was exponential. The diminishing-return form occurs when pastures have a negative FD vs. CHt slope (Table 1: A1, A3, A4), expected since most pastures have greater density lower in the canopy (Hodgson, 1990). The exponential form occurs when pasture have a positive FD vs. CHt slope (Table 1: A2), as found in the nearly pure smooth bromegrass pasture at the Pendleton site. The FM vs. CHt relation can also be linear with zero intercept. For example, a site has a FD vs. CHt intercept of 452 and slope of 0.0 (FD is constant at all levels of CHt):

$$FD = 452 + 0.0\ CHt$$

$$FM = FD\ CHt$$

$$FM = (452 + 0.0\ CHt)\ CHt$$

$$FM = 452\ CHt + 0.0\ CHt^2$$

$$FM = 452\ CHt$$

This brief supports the hypothesis that the calibration model for FM vs. CHt is second-order with no intercept and shows that this relation results in different curve forms that are dependent on the FD structure in the pasture.

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