2001

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Estimating Forage Mass with a Commercial Capacitance Meter, Rising Plate Meter, and Pasture Ruler

Matt A. Sanderson,* C. Alan Rotz, Stanley W. Fultz, and Edward B. Rayburn

ABSTRACT

Accurate assessment of forage mass in pastures is key to budgeting forage in grazing systems. Our objective was to determine the accuracy of an electronic capacitance meter, a rising plate meter, and a pasture ruler in measuring forage mass and to determine the cost of measurement inaccuracy. Forage mass was estimated in grazed pastures on farms in Pennsylvania, Maryland, and West Virginia in 1998 and 1999. Forage mass estimated by each method was compared with forage mass estimated by hand-clipped samples. None of these indirect methods were accurate or precise, and error levels ranged from 26 to 33% of the mean forage mass measured on the pastures. The computer model DAFOSYM (Dairy Forage System Model) was used to simulate farm performance and the resulting effects of inaccuracies in estimating forage mass on pasture. A representative grazing dairy farm was developed, and the costs and returns from low-input and conventional managements were calculated. Different scenarios were then simulated, including under- or overestimating forage yield on pastures by 10 or 20%. All scenarios simulated resulted in lower returns compared with the optimum farm, with decreases in net return ranging from \$8 to \$198 ha^{-1} yr^{-1}. Underestimating forage mass resulted in less hay and silage being harvested, more pasture being consumed, and more forage purchased compared with the optimum scenario. The opposite occurred for overestimation of forage mass. Our results indicate that achieving greater accuracy (to within 10% of actual pasture yield) in estimating pasture yields will improve forage budgeting and increase net returns.

Accurate budgeting of forage in grazing systems requires frequent assessment of forage mass in pastures. The standard method of assessing forage mass is to clip and weigh the forage. This method requires great effort and expense to collect enough samples to accurately represent a pasture, and farmers are not willing to make this effort in day-to-day management of pastures. Researchers commonly use double-sampling techniques to increase the precision of pasture sampling, and thus reduce labor and dollar expense (Frame, 1993). During the past 70 yr, many methods have been evaluated from simple rulers to sophisticated electronic meters (Lucas and Thomson, 1994). Some methods have been adapted for commercial use, including the electronic capacitance meter, rising plate meter, and simple pasture ruler.

The electronic capacitance meter relies on differences in dielectric constants between air and herbage. The meter measures the capacitance of the air–herbage mixture (Curie et al., 1987) and responds mainly to the surface area of the foliage (Vickery and Nicol, 1982). The rising plate meter integrates sward height and density into one measure, often called bulk height or bulk density (Michalk and Herbert, 1977). Pasture rulers rely on a positive relationship between forage yield and canopy height.

Commercially available meters come with factory calibrations; however, the accuracy and precision of these equations have not been evaluated for Northeast pasture conditions. Many studies of double-sampling techniques have shown that these techniques require frequent calibration and that *universal* equations for estimating pasture mass may be unreliable (Frame, 1993).

The level of error in measuring forage mass varies widely; however, Rayburn and Rayburn (1998) and Unruh and Fick (1998), working in pastures of the northeast USA, obtained calibration errors with plate meters of about 10% of pasture yields. They concluded that this level of error is acceptable for farm use. It is not known, however, what the economic consequences are of this level of error on a whole-farm basis. Farm data are not available to determine the level of inaccuracy that is economically acceptable. This type of research is expensive to conduct.

Whole-farm simulation models provide an alternative method to estimate economic consequences. The computer simulation model DAFOSYM (Dairy Forage System Model) is a whole-farm model where crop production, feed use, return of manure nutrients back to the land, production costs, income, and net return or profit of representative farms are simulated over many years of weather (Rotz et al., 1989; Rotz et al., 1999). Growth and development of alfalfa (*Medicago sativa* L.), grass, corn (*Zea mays* L.), and other crops are predicted on a daily time step from soil and weather conditions. Functions from the GRASIM (Grazing Simulation Model) model developed and validated by Mohtar et al. (1997a,b) are used to simulate pasture production. This mechanistic model simulates photosynthetic rate and carbohydrate production as a function of solar radiation level,

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Published in Agron. J. 93:1281–1286 (2001).

Abbreviations: DM, dry matter; SEP, standard error of prediction.

daylength, ambient temperature, atmospheric CO_2 level, and crop leaf area. The DAFOSYM model has been verified and used to evaluate many different dairy production systems with various options in manure handling, forage conservation, and animal feeding, including grazing (Rotz et al., 1999; Soder and Rotz, 2001). The model thus provides a tool for estimating the economic costs of inaccuracy in forage measurement on pastures.

Our objectives were to (i) evaluate an electronic capacitance meter, a rising plate meter, and a pasture stick for accuracy and precision in estimating forage mass on pasture and (ii) estimate the economic consequences of inaccurate measurements of forage mass.

MATERIALS AND METHODS

Forage Mass Measurement

We evaluated an electronic capacitance meter (Alistair George Manufacturing, Waihi Beach, New Zealand[1]), a rising plate meter (B.M. Butler Computing, Palmerston North, New Zealand), and a pasture ruler. The capacitance meter is a single-probe electronic device with data collection, storage, and calculation capabilities. The theory and operation of the single-probe meter is explained by Vickery and Nicol (1982). The capacitance meter senses an area of 100 mm diam. by 400 mm tall (according to the manufacturer) and automatically calculates forage mass according to proprietary equations stored in the computer module. The rising plate meter has a disk with a diameter of 362 mm (0.1 m^2) and mass of 0.315 kg. It is based on the Ellinbank pasture meter (Earle and MacGowan, 1979) and manually records pasture height in 5-mm increments with a counter. The pasture ruler, available from local Extension and Natural Resources Conservation Service advisors, is a meter rule with pasture management information inscribed on the sides. It has a table that relates forage height to estimated yield in kilograms of dry matter (DM) per hectare per centimeter of height based on information from Gerrish and Roberts (1999).

We evaluated the measurement tools on cool season grass–legume pastures on a dairy farm in Franklin County, Pennsylvania; on two dairy farms in Frederick County, Maryland; and on an experimental farm in Monongalia County, West Virginia. The pastures on each farm were grazed on a 3- to 5-wk rotation by dairy cows (*Bos taurus*) (Pennsylvania and Maryland) or beef cattle (West Virginia). Stocking density at each grazing on the dairy farms was 100 to 150 cows ha^{-1}. Stocking density at the experimental farm in West Virginia ranged from 25 to 100 cows ha^{-1}, with grazing stays of 1 to 4 d per paddock. Pastures on the Pennsylvania farm were more than 30 yr old and consisted of tall fescue (*Festuca arundinacea* Schreb.), Kentucky bluegrass (*Poa pratensis* L.), and white clover (*Trifolium repens* L.). One Maryland pasture was planted in fall 1998 to perennial ryegrass (*Lolium perenne* L.). The other Maryland pasture was an old permanent pasture consisting of Kentucky bluegrass, orchardgrass (*Dactylis glomerata* L.), white clover, and tall fescue. In West Virginia, pastures were predominately orchardgrass and white clover. Sward heights at each location ranged from 7 to 30 cm.

Three pastures were sampled on the Pennsylvania farm before grazing on six dates during August through October 1998. In 1999, five pastures were sampled on 16 dates from April through October. In Maryland, pastures on the two farms were sampled on two dates in August 1998 and on 10 dates during April through October 1999. In West Virginia, 21 pastures were sampled over several dates from July through November 1998.

On each sampling date and farm, the capacitance meter, rising plate meter, and ruler were used to estimate forage mass according to the manufacturers' instructions. These instructions recommended collecting a minimum of 30 readings per pasture. We established a set of five transects in a zigzag pattern on each pasture and collected six measurements per transect (30 total) with each tool. We then clipped three 0.1-m^2 quadrats per transect (15 total). One person took all measurements in Maryland and West Virginia. In Pennsylvania, there were different operators on some dates. Herbage was clipped to ground level with battery-powered shears that were 100 mm wide and then placed in a paper bag and frozen until the sample was processed. The frozen samples were separated into green and dead material and then dried at 55°C for 48 h. Soil and other foreign material were discarded during the separation process.

Pasture means of green and total (green + dead) DM yields (n = 15) were regressed on pasture means of forage mass (n = 30) estimated by each method (Webby and Pengelly, 1986). Three equations to estimate forage mass from rising plate meter readings were provided by the manufacturer:

$$Y = 158(\text{rising plate meter reading}) \quad [1]$$

$$Y = 158(\text{rising plate meter reading}) + 200 \quad [2]$$

$$Y = 158(\text{rising plate meter reading}) + 1000 \quad [3]$$

where Y is the herbage yield (kg ha^{-1}).

The equations were developed in New Zealand on perennial ryegrass–white clover pastures. We were not able to determine the equations for the capacitance meter because they were proprietary information. For the pasture ruler, we chose the factors of 110 and 154 kg DM ha^{-1} cm^{-1} forage height. These were the midpoints of values recommended for tall fescue–legume pastures of good and excellent sward density, respectively (Gerrish and Roberts, 1999).

Accuracy and precision of each method were evaluated by regression procedures (PROC REG; SAS Inst., 1998). If a method was perfect (i.e., the estimated yield was the same as the measured yield), then regression of measured yield on estimated yield would result in a straight line with an intercept of zero, a slope of 1, and zero error. For each regression, the estimated standard error of prediction (SEP) was calculated under the assumption that the variables were multivariate normal (SAS Inst., 1998).

Economic Analysis

The computer model DAFOSYM (Rotz et al., 1989) was used to model the economic consequences of inaccuracies in measuring forage mass on pasture. The biological and physical processes on a dairy farm are integrated in DAFOSYM. Crop production, feed use, and the return of manure nutrients back to the land are simulated over many years of weather. Forage losses and nutritive changes; the timing of field operations; and the use of machinery, fuel, and labor are among the many factors tracked by the model to predict performance and resource use for representative dairy farms. Simulated performance is used to predict the costs, income, and net return or profit. All production and economic information are determined for each simulated year.

Seven scenarios were modeled for representative low-input and conventional grazing dairy farms. The representative farms were based on actual management and production information from dairy farms in the Northeast. Assumptions for the

[1] Mention of a trademark does not imply endorsement.

low-input farm were 125 holstein cows and 100 replacement animals grazed on orchardgrass pasture in a management-intensive rotational stocking system for the grazing season (April to October). The herd was supplemented with grass silage, hay, and corn grain to meet its nutrient needs. Excess pasture in the spring and summer was harvested as bale silage or hay. This was a seasonal herd with a spring calving cycle; all cows were dry during the winter months, and peak milk production occurred in late spring. Milk production was 5900 kg cow^{-1} yr^{-1}, with a culling rate of 25%.

Seven scenarios were modeled for the low-input grazing farm:

1. Optimal management and performance conditions for the farm. Forage on pasture was measured accurately and budgeted optimally, so an economically optimum balance of pasture utilization and conservation of excess forage on pasture was used.
2. Constant 10% underestimate in forage production for each month. There was more forage available than estimated; consequently, the paddocks were sized too large, and some conservable forage was lost.
3. Constant 10% overestimate in forage production for each month. There was less forage available on pasture than estimated; consequently the paddocks were sized too small, the animals were short on pasture forage, and more feed was conserved and fed than was necessary.
4. Constant 20% underestimate in forage production.
5. Constant 20% overestimate in forage production.
6. A 10% underestimate of forage in April through June and 10% overestimate in summer.
7. A 10% overestimate of forage in April through June and 10% underestimate in summer.

Assumptions for the conventional farm were 85 holstein cows and 60 replacement animals with 20.2, 40.5, and 20.2 ha of alfalfa, corn, and orchardgrass pasture, respectively. The herd grazed the pasture in a management-intensive rotational stocking system during April through October. First and third cuttings of alfalfa were harvested as chopped silage while second cutting was harvested as dry hay. Most of the corn was harvested and stored as silage, but in good growing years, some of the corn was custom-harvested as dry grain. All silage was stored in tower silos. The herd was fed rations consisting of available silages, grain, and protein supplements blended to meet requirements. Milk production was 9000 kg cow^{-1} yr^{-1}, and the culling rate was 30%. This was a conventional year-round calving herd that was housed in a free-stall barn when not on pasture. Excess forage was not harvested from the pastures.

Seven scenarios were modeled for the conventional grazing farm:

1. Optimal management and performance conditions for the farm. Forage on pasture was measured accurately and budgeted optimally, minimizing the need for conserved forage use.
2. Constant 10% underestimate in forage production for each month. The excess pasture forage provided to animals was wasted.
3. Allocation of 10% less forage from pasture in the ration, causing animals to consume more conserved forage.
4. Allocation of 10% more forage from pasture in the ration than was available, causing a shortage of pasture forage at the end of the rotation cycle and a need for conserved forage feeding.
5. Constant 20% underestimate in forage production.
6. Allocation of 20% less forage from pasture in the ration.
7. Allocation of 20% more forage from pasture in the ration.

We chose the 10% level because this has been considered by others as an acceptable error rate for farm use (Rayburn and Rayburn, 1998; Unruh and Fick, 1998). We chose the 20% level to determine the effect of an unacceptably high rate of error.

RESULTS AND DISCUSSION

Performance of Pasture Measurement Tools

The three indirect methods for measuring forage mass on pasture were not accurate or precise. The slope of the regression line was <1 ($P < 0.05$), and the r^2 was low (Table 1). The capacitance meter and pasture ruler were highly inaccurate in estimating green or total herbage mass. The SEP, as a percentage of the mean forage mass on pasture, ranged from 26% for the rising plate meter to 33% for the capacitance meter. Error rates were much greater than the 10% level considered ac-

Table 1. Statistics for regression of measured and estimated green or total dry matter (DM) yield on estimated yields.

Item	Mean forage mass on pasture	No. of pasture means	Regression statistics				
			Intercept	Slope	SE of slope	r^2	RMSE†
	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}
		Alistair pasture gauge					
Green DM	1597	82	901	0.34	0.09	0.14	535
Total DM	2562	103	1534	0.51	0.10	0.19	762
		Pasture ruler					
Green DM (110 factor)‡	1519	89	876	0.34	0.10	0.11	500
Green DM (154 factor)	1519	89	876	0.24	0.07	0.11	500
Total DM (110 factor)	2500	89	1434	0.57	0.14	0.16	690
Total DM (154 factor)	2500	89	1434	0.41	0.10	0.16	690
		Rising plate meter					
Green DM [Eq. 1]§	1551	105	278	0.48	0.07	0.31	447
Green DM [Eq. 2]	1551	105	−206	0.48	0.07	0.31	447
Green DM [Eq. 3]	1551	105	181	0.48	0.07	0.31	447
Total DM [Eq. 1]	2554	123	1195	0.56	0.08	0.31	653
Total DM [Eq. 2]	2554	123	637	0.56	0.08	0.31	653
Total DM [Eq. 3]	2554	123	1084	0.56	0.08	0.31	653

† RMSE, root mean square error.
‡ 110 factor, 110 kg DM cm^{-1} canopy height; 154 factor, 154 kg DM cm^{-1} canopy height. Factors taken from Gerrish and Roberts (1999).
§ Eq. 1, 158 (rising plate meter reading); Eq. 2, 158 (rising plate meter reading) + 200; Eq. 3, 158 (rising plate meter reading) + 1000. From manufacturer.

Table 2. Estimated production, costs, and net returns for the low-input grass farm (125 cows plus replacements on 81 ha of pasture producing 5900 kg milk cow^{-1} $year^{-1}$).

Production or cost parameter	Scenarios† 1	2	3	4	5	6	7
	Mg DM‡						
Hay production	121	113	125	104	128	113	125
Silage production	205	185	220	200	231	202	202
Grazed forage consumed	316	325	299	330	283	313	310
Hay sold (purchased)	44	21	53	12	54	28	45
Corn grain purchased	253	248	257	243	260	249	257
Supplement purchased	30	30	31	32	32	30	31
	$						
Total feed cost	95 791	95 030	97 231	94 730	98 555	96 038	96 296
Total manure cost	4 728	4 763	4 702	4 809	4 681	4 735	4 725
Facilities cost	90 521	90 521	90 521	90 521	90 521	90 521	90 521
Milk and animal sales income	261 357	261 357	261 357	261 357	261 357	261 357	261 357
Income from feed sales	8 487	6 965	9 088	4 994	9 141	7 695	8 463
Return to management	78 804	78 009	77 992	76 291	76 742	77 759	78 179
Difference from Scenario 1		−795	−812	−2 513	−2 062	−1 045	−625
Per ha of pasture per year		−10	−10	−31	−25	−13	−8
Per cow per year		−6.40	−6.50	−20.00	−16.50	−8.40	−5.00

† Scenarios: 1, forage on pasture was measured accurately and budgeted optimally; 2, constant 10% underestimate in forage production for each month; 3, constant 10% overestimate in forage production; 4, constant 20% underestimate in forage production; 5, constant 20% overestimate in forage production; 6, 10% underestimate of forage in spring (April–June) and 10% overestimate in summer; 7, 10% overestimate of forage in spring and 10% underestimate in summer.
‡ DM, dry matter.

ceptable by others. Researchers in Scotland also reported a poor relationship between yield estimated with a rising plate meter using New Zealand equations and measured yield (Dowdeswell, 1998).

The calibrations for the rising plate meter were developed in New Zealand on ryegrass–white clover pastures. We were not able to determine the calibrations for the capacitance meter because they were proprietary information; however, the instrument was developed in New Zealand. Several previous studies have indicated that universal prediction equations were not useful because of variations in pastures, management, and climate (Frame, 1993). Nearly all studies indicate that frequent recalibration of indirect methods is necessary. Earle and MacGowan (1979), reporting on the Ellinbank pasture meter (basically the model design for the rising plate meter), stated that separate calibrations were required for different types of pastures and that the meter was not suited for comparing production of pastures that differ in species composition.

The SEP of forage mass in Table 1 includes the error associated with hand-clipping the forage samples and the error in taking capacitance meter, rising plate meter, or pasture ruler readings. Both of these errors can be reduced by increasing the number of observations on pastures (Fulkerson and Slack, 1993). Increasing the number of indirect measurements would have increased the precision of these estimates, but it would not have improved the accuracy of the estimates because the underlying calibration relationship was not appropriate for northeastern USA pastures.

Murphy et al. (1995) tested a commercially available capacitance meter (Pasture Probe, Design Electronics, Palmerston North, New Zealand) on bluegrass–white clover pastures in Vermont and reported a coefficient of variation of 29%. The relationship between measured and actual yields, however, was much better ($Y = -314 + 0.9x$; $r^2 = 0.42$) than we obtained for the capacitance meter used in our study. Harmoney et al. (1997) reported r^2 of 0.08 and error rates of 717 kg ha^{-1} for regressions of sward height (measured by ruler) on clipped yield of tall fescue pastures in Iowa. Relationships were better with a rising plate meter ($r^2 = 0.85$, error = 290 kg ha^{-1}). Studies reporting calibration relationships with the rising plate meter in Australia and New Zealand reported r^2 of 0.6 to 0.8 and error rates of 240 to 830 kg ha^{-1} on perennial ryegrass–white clover pastures (Michell, 1982; Piggott, 1986).

Reasons for poor regression relationships between the direct and indirect measurements include uneven ground (e.g., dips and holes) in pastures, trampling of vegetation by livestock, lodging of vegetation, heterogeneity of species composition, and observer bias (Aiken and Bransby, 1992; Karl and Nicholson, 1987). These conditions cause variability in both the indirect and direct measure. Additionally, the capacitance meter has a sensing area of 100 mm diam. by 400 mm tall; thus, herbage taller than 400 mm would not be sensed and measured. There were dates during our study when forage was taller than this height, which could have contributed to error.

In earlier models of electronic capacitance meters, separating dead from green material did not affect regression relationships indicating that dead material had little influence on meter readings. Research with temperate and tropical grasses in Australia showed that an electronic capacitance meter did not differentiate between green and dead plant material; but, dead material could contribute to variation of estimates about the regression line (Curie et al., 1973). Neal et al. (1976) noted that separation of dead litter probably was not necessary but that litter affects variability of yield. The proportion of dead material in pastures at the Pennsylvania farm ranged from >60% in the spring to 20% in the fall (data not shown).

Economic Consequences of Measurement Errors

In this section, we discuss the economic consequences of error in estimating forage mass on pasture. As previously discussed, error rates in our study ranged from 26 to 33% of the mean forage mass on pasture (Table 1). Sources of error in estimating forage mass in our study were (i) variation in pasture composition; (ii) hand-clipping of herbage; (iii) capacitance meter, rising plate meter, and ruler variation; and (iv) errors in separating and weighing green and dead material.

Low-Input Grazing Farm

Underestimating forage mass on pasture by 10 or 20% resulted in less hay and more grass silage being harvested, more pasture forage consumed, and less forage sold compared with the base farm (Table 2, Scenarios 2 and 4). The opposite occurred for overestimation of forage mass (Table 2, Scenarios 3 and 5). Feed costs increased when forage mass on pasture was overestimated, but this was partly offset by an increase in forage sold. On the other hand, feed costs decreased when pasture forage mass was underestimated, but this was entirely offset by the reduced amount of forage sold. Underestimating forage mass in the spring followed by overestimating yields in the summer (Table 2, Scenario 6) reduced net returns more than the opposite scenario (Table 2, Scenario 7). This indicates that accurate forage mass estimates are critical during the spring flush of pasture growth.

Conventional Grazing Farm

Underestimating forage mass on pasture by 10 or 20% and not harvesting the excess as silage or hay resulted in \$1900 to \$4000 less in net return compared with the base farm (Table 3). Departures in net return from the base farm were less when pasture measurement errors were simulated by changes in forage allocation than for other scenarios. Regardless, all error scenarios resulted in lower net returns compared with the base farm.

Rougoor et al. (1999), in a survey of dairies in the Netherlands, concluded that inaccurate forage budgeting on pasture increased feed costs and that mistakes in sizing paddocks could not be compensated for later in the rotation. Previous research showed that calibrated plate meters had an error rate of 10% of the pasture yield (Rayburn and Rayburn, 1998; Unruh and Fick, 1998). Assuming a producer would spend about 1 h d^{-1} measuring forage mass before and after moving cows, then the labor cost (at \$6 h^{-1}) for monitoring forage mass would be \$1045 (180 d $\times$ 1 h d^{-1} $\times$ \$6 h^{-1}). Except for one instance in our study (Table 2, Scenario 6), the reduction in net return was <\$1000 yr^{-1} for error levels of 10%. Thus, an investment in labor for measurement of forage mass can only be justified if the error in yield estimation is no greater than 10%. In most instances, as the error level increased above 10%, the loss in net return was greater than the labor cost required to regularly monitor forage mass. Thus, the error levels we obtained with the capacitance meter, rising plate meter, and ruler were not only statistically inaccurate, but also economically unacceptable. Regular pasture monitoring, however, can provide other benefits, such as identifying pastures that need improvement and tracking pasture condition, that were not accounted for in our model analysis. Given the inherent spatial and temporal variability of pastures, it may be difficult for a producer to achieve an error level of ≤10%. On-farm research in the northeast USA, however, has shown that calibration errors with a rising plate meter can be reduced to about 10% (Rayburn and Rayburn, 1998; Unruh and Fick, 1998).

Table 3. Estimated production, costs, and net returns for the conventional farm (85 cows producing 9000 kg milk yr^{-1} plus replacements on 20.2, 20.2, and 40.5 ha of grass pasture, alfalfa, and corn, respectively).

Production or cost parameter	Scenarios† 1	2	3	4	5	6	7
	Mg DM‡						
Hay production	40	40	40	40	40	40	43
Silage production	146	146	146	146	146	146	122
Grain crop silage	204	204	204	204	204	204	204
Dry grain	125	125	125	125	125	125	125
Grazed forage consumed	159	144	159	154	130	157	141
Hay sold (purchased)	1.8	15	0.9	(3)	34	0	(11)
Corn grain purchased	74	70	72	72	68	71	72
Supplement purchased	32	32	32	32	32	32	32
	\$						
Total feed cost	97 470	98 461	97 482	97 773	99 550	97 495	98 804
Total manure cost	15 659	15 785	15 828	15 575	16 021	15 968	15 611
Facilities cost	98 529	98 529	98 529	98 529	98 529	98 529	98 529
Milk and animal sales income	253 923	253 923	253 923	253 923	253 923	253 923	253 923
Income from feed sales	3 646	2 863	3 619	3 286	2 053	3 594	2 919
Return to management	45 911	44 007	45 703	45 330	41 869	45 525	43 893
Difference from Scenario 1		−1 904	−208	−581	−4 042	−386	−2 018
Per ha of pasture		−94	−10	−29	−198	−19	−100
Per cow		−22.50	−2.40	−6.80	−47.60	−4.50	−23.70

† Scenarios: 1, forage on pasture was measured accurately and budgeted optimally, minimizing the need for conserved forage; 2, constant 10% underestimate in forage production; 3, allocation of 10% more forage from pasture in the rotation; 4, allocation of 10% less forage from pasture in the ration than was available, causing a shortage of pasture at the end of the rotation cycle and a need for conserved forage feeding; 5, constant 20% underestimate in forage production; 6, allocation of 20% more forage from pasture in the ration; 7, allocation of 20% less forage from pasture in the ration.

‡ DM, dry matter.

CONCLUSIONS

The tools for measuring forage mass on pasture that we evaluated were inaccurate and imprecise, with error levels of 26 to 33%. This indicates that at least region-specific calibrations are necessary for these tools (e.g., Rayburn et al., 2000). Economic analysis of error levels indicated that an error level of <10% is necessary to justify a farmer's investment in the labor and tools for measuring forage mass on pastures.

ACKNOWLEDGMENTS

This research contributes to the mission of the Northeast Pasture Research and Extension Consortium.

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