Technical Note

Comparison of Comparative Yield and Stubble Height for Estimating Herbage Standing Crop in Annual Rangelands

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Abstract

We compared calibration equations for estimating herbage standing crop (HSC) from comparative yield (CY) rank or stubble height (SH) to determine 1) if CY rank is a better estimator than SH of standing crop, 2) if addition of SH to CY rank will improve the estimation of standing crop, 3) if there is a seasonal effect on CY rank or SH, and 4) if botanical composition influences the prediction of HSC from CY. The results of this study indicate that CY is a slightly better predictor of HSC than is SH. Addition of SH to CY did not improve the prediction of HSC. Models that predict HSC from CY in summer were weaker than models for winter, early spring, and late spring. Thus the CY method can be used with confidence throughout the year. The presence of filaree (*Erodium cicutarium* L.) in winter and early spring resulted in steeper calibration equations than were present in nonfilaree quadrats.

Resumen

Comparamos ecuaciones de calibración para estimar la biomasa en pie (HSC) a partir de los método de rendimiento comparativo por clases (CY) o la altura del rastrojo (SH) para determinar: (1) si el rendimiento comparativo por clases (CY) es un mejor estimador de la biomasa que la altura del rastrojo (SH); (2) si la adición de la altura del rastrojo SH a el rendimiento comparativo por clases mejoraría la estimación de la biomasa y (3) si hay un efecto estacional sobre el rendimiento comparativo por clase (CY) o la altura del rastrojo (SH) y (4) si la composición botánica influye la predicción de la biomasa (HSC) a partir del rendimiento comparativo por clases (CY). Los resultados de este estudio indican que CY es un estimador de la biomasa ligeramente mejor que la SH. La adición de la SH a CY no mejoró la predicción de HSC. Los modelos que predicen la HSC a partir de CY en verano fueron mas débiles que los modelos para invierno, inicios de primavera y finales de primavera, por lo tanto, el método de CY puede ser usado con confianza a lo largo del año. La presencia de "Filaree" (*Erodium cicutarium* L.) en invierno e inicio de primavera resultó en ecuaciones de calibración mas precisas que las obtenidas de los cuadrantes sin "Filaree."

Key Words: double sampling, filaree, monitoring, residual dry matter

INTRODUCTION

Many local, state, and federal agencies and other organizations rely on University of California Cooperative Extension (UCCE) recommendations in the selection of vegetation monitoring methods. Monitoring programs within these agencies, businesses, and citizens' groups are intended to improve the sustainability of annual rangeland plant communities by protecting soil, maintaining productivity, and protecting or increasing species diversity. Consequently, it is crucial that UCCE be confident in the methods that it recommends. UCCE recommends the comparative yield (CY) method for rapid surveys of residual dry matter (RDM) over large areas (Frost et al. 1990; Bartolome et al. 2002). RDM is the old plant material left standing or on the ground before the beginning of the new growing season. The CY method is also widely used for rapid monitoring of herbage standing crop (HSC) (Parkes 2001; Cóser et al. 2003; Dexter 2003; Jama et al. 2003).

The CY method is used to estimate pasture standing crop in which the yields of randomly sampled quadrats are ranked with respect to a set of reference quadrats preselected to provide a scale, which is available for reference throughout sampling (Haydock and Shaw 1975; Bureau of Land Management 1996). A number of quadrats are both ranked and harvested to create a calibration equation for transforming CY ranks into dry weights. Usually, a linear relationship is used to convert CY rank to an estimate of dry weight. Friedel et al. (1988) compared linear and quadratic models for estimating pasture dry weight from CY rank on arid Australian rangelands and

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concluded that linear models of untransformed data were preferable.

UCCE has conducted numerous training sessions for students and rangeland management professionals so that they could use the CY method for rapid inventory of RDM over large areas. Because UCCE recommends assessment of RDM near the end of the dry season, most training has occurred in the summer or fall on dry vegetation, which is mostly grass because many common forbs have shattered. During the dry season it is common for trainees to rapidly become proficient at this method, commonly attaining $r^2 > 0.89$ for their calibration equations. In recent years the CY method has increasingly been used during the growing season to estimate HSC of green forage. Additionally, some observers were using stubble height (SH) to predict HSC throughout the year.

Although range managers have extensive experience estimating RDM in the fall using the CY method, we were uncertain of the quality of predictions when CY was used to predict HSC during the growing season. We were concerned that substantial differences in height, density, and growth habit of several species within a quadrat might increase observer error during the ranking process. Additionally we were concerned that SH ignores the contribution of sward density to standing crop. To effectively monitor standing crop across large areas methods must be effective regardless of seasonal conditions and different observers should be able to achieve consistent results. Therefore we compared the calibration equations for several observers during 2 years and 4 seasons to test the following hypotheses: 1) CY rank is a better predictor of HSC than is SH, 2) incorporation of SH with CY will improve the prediction of HSC, 3) there is a seasonal effect on the prediction of HSC from CY or SH, and 4) species composition influences the prediction of HSC from CY.

METHODS

During a rapid survey of HSC and botanical composition in annual rangeland pastures, 16 observers double-sampled 15 quadrats (0.09 m^2) using CY rank (Haycock and Shaw 1975) and SH as estimators of standing crop. On each observation day only 2 to 5 of the 16 observers were available to sample. The daily observers double-sampled the same quadrats. A different set of 15 randomly distributed quadrats was used on each observation day during 4 seasonal sampling periods (late spring, summer, winter, and early spring) and over 2 years, which resulted in 24 different sets of 15 quadrats each. During winter (January) the sward was a mixture of dry residue (litter) from the previous growing season and newly germinated annual grasses and forbs. In early spring (late February and March) the sward was dominated by the current season's crop of vegetative annual plants. In late spring (April and May) HSC was dominated by flowering annual grasses and forbs. The July and August summer vegetation was mostly dry annual grasses.

This study was conducted on 4 annual rangeland pastures (20 to 25 ha each) at the University of California Sierra Foothill Research and Extension Center 28 km northeast of Marysville, California. Two of the pastures were cleared of most blue oak (*Quercus douglasii* H. & A.) and interior live oak (*Quercus wislizenii* A. DC.) trees and other woody vegetation except in the riparian corridors. The other 2 pastures were a mosaic of open grassland and oak–woodland patches. The slope in each pasture ranged from 0% to more than 60%. The soils in these pastures are complexes of the Auburn (loamy, oxidic, mixed, thermic Ruptic-Lithic Xerochrepts), Sobrante (fine-loamy, mixed, thermic Mollic Haploxeralfs), and Timbuctoo Series (fine, mixed, thermic Typic Rhodoxeralfs).

In addition to the oak trees other woody species included wedgeleaf ceanothus (*Ceanothus cuneatus* [Hook.] Nutt.), whiteleaf manzanita (*Arctostaphylos viscida* Parry), and poison oak (*Toxicodendron diversilobum* Torr. & Gray) in the uplands and figs (*Ficus carica* L.), willow (*Salix* spp.), and interior live oak in the riparian corridors. Understory vegetation was composed largely of annual grasses and forbs. Annual grasses included soft chess brome (*Bromus hordeaceus* L. ssp. *hordeaceus*), rip-gut brome (*Bromus diandrus* Roth), annual ryegrass (*Lolium multiflorum* Lam.), wild oats (*Avena fatua* L.), annual fescue (*Vulpia myuros* [L.] K. C. Gmel.), foxtail barley (*Hordeum murinum* L. ssp. *leporinum*), and medusahead (*Taeniatherum caput-medusae* Nevskii). Dominant annual forbs included red-stem filaree (*Erodium cicutarium* L.), rose clover (*Trifolium hirtum* All.), and subterranean clover (*Trifolium subterraneum* L.).

To use the CY method, 5 quadrats (0.09 m^2 each) were placed in the sward at the beginning of an observation session. Quadrat 1 was placed where sward weight was low but greater than 0. Quadrat 5 was placed on the highest standing crop, and Quadrat 3 was placed on a standing crop halfway between Quadrats 1 and 5. Likewise Quadrat 2 was halfway between Quadrats 1 and 3 and Quadrat 4 was halfway between Quadrats 3 and 5. This resulted in 5 ranks of increasing weight. During training the observers viewed these 5 quadrats so that they could recognize ranks 1–5. Quadrats in the area of interest were then ranked as the observer walked along a transect. At the end of the day, CY rank was determined, SH was measured, and botanical composition was estimated for 15 randomly distributed plots before they were clipped. The dry weights from these 15 plots were regressed on the CY rank and SH to form linear conversion equations for CY and SH. Botanical composition was determined by estimating cover (percentages) of litter, bare ground, rocks, grass, legumes, filaree, and other forbs in the 0.09-m^2 quadrat.

Data were analyzed using a mixed model with season, CY, SH, and cover type as potential fixed effects, and date and observer as random effects. The interactions between CY or SH with date and observer were also included as random effects where warranted to account for random effects of dates and observers in the slopes of the calibrations. Random effects were kept in models only if they were significant by a likelihood ratio test as described in Pinheiro and Bates (2000). Homogeneity of variance and normality of residuals and random effects were assessed graphically with trellis plots (Pinheiro and Bates 2000), and serial correlation of residuals was tested for lags 1–5 using autocorrelation function plots with 99% confidence intervals. HSC was transformed by square root to obtain normality and homogeneity of variance among levels of CY.

Three models were compared to address hypotheses 1–3. Model 1 had fixed effects for CY score, season, and CY * season, and random effects for observer, date, and CY * date. Model 2 had fixed effects for SH, season, and SH * season, and random effects for date and date * SH. Model 3 had fixed

Table 1. Characteristics of models used to calibrate comparative yield (CY) rank and stubble height (SH) to predict herbage mass per unit area in a 0.09-m^2 quadrat.

P values	Model 1	Model 2	Model 3
CY	0.0001	—	0.0001
SH	—	0.0001	0.0001
Season	0.0001	0.1557	0.0001
Season * CY	0.0005	—	0.0021
Season * SH	—	0.0003	—
Variance components[1]			
Observer	8.4	—	4.3
Date	20.4	24.9	19.8
Observer * CY	—	—	0.3
Date * CY	4.6	—	4.0
Date * SH	—	0.1	—
Confidence intervals[2] (kg · ha^{-1})			
97.5% quantile	716	512	693
2.5% quantile	3 409	3 602	3 399

[1]Variances are in kg · ha^{-1} because they are variances of herbage mass transformed by square root.
[2]Calculated about the mean of observed herbage mass per quadrat, which was 1 826 kg · ha^{-1}.

effects for season, CY, SH, and CY * season, and random effects for observer, CY * observer, date, and CY * date.

Because final models differed both in random and fixed effects, we compared 2 measures of model adequacy based on the cross-validation results: coefficient of variation (CV) and width of the 95% confidence interval (CI) for individual prediction at average predictor values. Cross-validation was obtained by holding out 1 randomly selected observation for each of the 66 combinations of date and observer, fitting the model, and saving the observed and predicted values for the 66 observations held out of the model fitting. This was repeated 100 times to obtain a set of 6 600 pairs of observed–predicted herbage mass for each model.

In order to test hypothesis 4, each of the 354 observations for which botanical composition was measured were classified as grass, filaree, grass–filaree mixes, or clover depending on the most abundant species. This categorical variable was added last to the model to determine if it was significant by sum of squares type III error.

RESULTS AND DISCUSSION

Based on cross-validation, model 1 had an adjusted R^2 of 0.80 and a root MSE of 64 kg · ha^{-1}, with a CV of 0.19. This model had significant season and season-by-CY terms (Table 1), which indicated that intercepts and slopes were different among seasons. Average herbage mass for the whole data set was 1 826 kg · ha^{-1}. Model 2, based on SH, had an adjusted R^2 of 0.76 and a root MSE of 78 kg · ha^{-1}, with a CV of 0.21. Model 3, which incorporated both CY and SH, also had an adjusted R^2 of 0.80 and a CV of 0.19; its root MSE was 63 kg · ha^{-1}.

Although the effect of SH was highly significant in model 3, the addition of SH measurements did not result in an increment of precision over model 1 of practical value. In fact, the CI width for an individual observation was greater for model 3 than for model 1 (2 706 vs. 2 693 kg · ha^{-1}). Each CY rank is a visual integration of height and density of herbage in the quadrat. Thus, CY and SH were highly correlated, because observers tend to give higher ranks to taller vegetation. Although collinearity between CY and SH makes it impossible to completely separate the effects of CY and SH on predicted HSC, each variable provided significant predictive power for HSC, but CY appeared to encompass all the practical information about herbage mass that SH was able to provide. Thus, if CY is used, it is not necessary to measure SH. However, a choice between CY and SH as alternatives requires a comparison of models 1 and 2. Model 1, based on visual estimations of CY, was clearly superior to model 2, which was based on SH measurements. Confidence interval width for model 2 was 3 090 kg · ha^{-1}, 15% wider than for model 1.

Table 2. Effects of season on calibrations of comparative yield (CY) rank and herbage mass. Results are based on model 1.

Parameter[1]	Seasons			
	Early spring	Late spring	Summer	Winter
Slope	7.9	11.0	4.3	6.5
95% CI slope[2]	(5.8, 10.0)	(9.1, 12.8)	(0.8, 7.9)	(4.4, 8.7)
Intercept	16.8	31.2	37.8	16.6
95% CI intercept	(12.2, 21.4)	(27.2, 35.1)	(31.3, 41.6)	(12.5, 20.8)
SE of prediction at average CY	2.11	1.96	3.58	2.22

[1]Slopes are in units of square root (kg · ha^{-1}) per unit yield score. Intercepts and standard errors (SE) are in square root (kg · ha^{-1}). SE of predictions were calculated at the average level of CY for each season.
[2]CI indicates confidence interval.

Overall, SH did not contribute to the precision of estimates. SH may be helpful for those observers that estimate CY rank less consistently but not for observers that are more consistent. In agreement with Laca et al. (1989) visual ranking of yield can achieve greater precision than direct measures such as height or pressure plate, but it requires well-trained and consistent observers. Additional measures such as SH would be beneficial if they can be performed quickly and if observers are not sure of their level of accuracy for ranking CY.

Calibration of CY varied over seasons (Table 2). This result was expected because training quadrats were selected based on the range of herbage mass at the time of sampling. The differences in herbage mass distribution over seasons resulted in differences in both slopes and intercepts. Late spring exhibited the greatest slope, whereas summer had the smallest slope and largest intercept. In the summer, vegetation was dry and had already received most of the seasonal grazing demand. Observers found it harder to estimate yield under summer conditions, as indicated by the greater variation of estimated parameters and estimated herbage mass. The inclusion of SH did not improve the calibrations in any of the seasons. To estimate average amount of herbage over large areas, as in management surveys, accurate observers have little to gain from incorporating SH measurements.

Botanical composition of quadrats, determined in the winter and early spring, did affect the calibrations (Table 3). Quadrats were clustered using Ward's method resulting in grass, clover, filaree, and mixed filaree–grass clusters. Addition of terms for

Table 3. Effects of botanical composition on calibrations of comparative yield (CY) rank and herbage mass. Results are based on model 1 augmented by adding terms for cover type and interaction between cover type and CY.

	Seasons			
Parameter[1]	Clover	Grass	Grass/filaree	Filaree
Slope	5.2	6.6	10.5	10.3
95% CI slope	(1.5, 8.9)	(4.5, 8.7)	(7.9, 13.1)	(8.1, 12.6)
Intercept	28.0	23.0	15.4	13.8
95% CI intercept	(20.6, 35.3)	(18.1, 28.0)	(10.6, 20.2)	(9.5, 18.0)
SE of prediction at average CY	2.86	2.91	2.22	2.02

[1]Slopes are in units of square root (kg/ha) per unit yield score. Intercepts and SE's are in square root (kg/ha). SE of predictions were calculated at the average level of CY for each cover type; degrees of freedom for the error term = 308.

cluster and cluster by CY into model 1 indicated that both terms were significant. Clover and grass calibrations had smaller slopes and larger intercepts than did calibrations where filaree was an important component of the vegetation. Filaree has a decumbent growth habit and a greater bulk density than do grasses and clover. These characteristics are deceptive and can cause observers to underestimate the rank of quadrats containing large amounts of filaree resulting in calibration equations with steeper slopes. Although this result suggests the need for separate calibration equations for filaree-dominated and nonfilaree quadrats, training observers to recognize the added weight effect of filaree prior to conducting vegetation surveys should reduce the need for separate calibration equations.

Several methods of rapidly estimating HSC have been tested in annual rangelands. Tadmor et al. (1975) found that it took extensive training and experience for 2 observers to estimate HSC in a double-sampling procedure that calibrated weight estimates with clipped weights. Capacitance meters, sward rulers, and rising plate meters have also been tried in annual rangelands and other pasture types but perform poorly when botanical composition is not uniform, dry vegetation is present, or the soil surface is uneven (Neal et al. 1976; Karl and Nicholson 1987; Murphy et al. 1995; Sanderson et al. 2001; Martin et al. 2005). The results reported in this study, where quadrats of mixed species composition during green and dry seasons were ranked across pastures with an uneven soil surface, were achieved with less than 2 hours of training at the beginning of each day.

MANAGEMENT IMPLICATIONS

The results of this study demonstrate that the CY method, which visually integrates height and density, is a strong predictor of HSC across green and dry seasons in the diverse mixture of grasses, filaree, and clover encountered in this study. This is an improvement over other rapid HSC estimation techniques such as weight estimation, capacitance meters, sward rulers, and rising plate meters. Although SH was also a good predictor of HSC, it was slightly weaker than CY and it generally takes longer to average several SH measures in a quadrat than to rank CY. Therefore, based on this study, CY is the preferred method for rapid surveys of standing crop over large areas of annual rangeland. Because filaree is frequently present in significant amounts observers should be trained to recognize its added weight effect before starting vegetation surveys. Based on the results of this study it is clear that the CY method will produce reliable information on HSC during the annual rangeland growing season as well as during the dry season.

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