Evaluation of the Forage-disk Method in Mixed-grass Rangelands of Kansas

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Abstract

The forage disk meter, a double sampling device used to predict forage biomass, has been used extensively on improved pastures, but its use on rangelands has not been investigated thoroughly. Efficiency of the forage disk meter was investigated in predicting yields of forage biomass on different range sites in western Kansas. Using least squares regression methods, resting heights (forage bulk) and dry matter yields were used to calibrate the disk meter for each site and sampling date. Highly significant regressions ($P<0.0001$) were obtained on all the shortgrass sites, where several factors that had unfavorable effects on the regression relationship between forage bulk and forage biomass were not apparent. These factors, although not quantified, included accumulation of litter, microrelief, lodged vegetation, and presence of broadleaf species. Regression coefficients (b) and intercepts (a) varied between sites and dates, thus the forage disk meter should be calibrated for every range site. If a forage disk meter is calibrated for a specific range site, regression coefficients and intercepts might not differ from year to year if grazing pressure and species composition are temporally consistent, which implies that recalibration might be unnecessary. The forage disk meter was useful as a double sampling device on range sites dominated by shortgrasses, but its use was limited on areas dominated by annual forbs or midgrasses.

Key Words: double sampling methods, forage production, vegetation structure, disk meter, dry matter yields, forage bulk

Estimates of standing crop (forage biomass) and other forage attributes aid in understanding plant-animal interactions on rangeland. Forage biomass estimates may be applied to investigations of forage production, carrying capacity, and the effectiveness of grazing management strategies. Harvesting of plots (clipping) often is used to estimate forage biomass. This method is considered to be the most objective and accurate, but clipping of plots is labor and time intensive, destroys a portion of the stand being sampled, and requires numerous samples for reliable estimates of forage biomass. Other methods to estimate the weight of aboveground plant material have been developed and these include double sampling techniques. Double sampling techniques measure forage attributes and attempt to correlate these with clipped yields. Examples of forage attributes measured in double sampling techniques include pasture height, percentage ground cover, the product of height and cover, and forage bulk or bulk density (Alexander et al. 1962, Evans and Jones 1958, Michalk and Herbert 1977, Shrivastava et al. 1969, Whitney 1974).

Forage bulk (Bransby et al. 1977) or bulk density (Alexander et al. 1962) has been used successfully as a predictor of forage biomass. Forage bulk or bulk density can be visualized as the volume of compressed forage beneath a plate of known weight (Bransby et al. 1977). The "compressibility" of the forage is a function of forage attributes such as plant height and density. To measure forage bulk, devices such as cardboard boxes, cardboard squares, plywood squares, and disk meters are dropped onto the forage from a predetermined height (Alexander et al. 1962, Baker et al. 1981, Bransby et al. 1977, Michalk and Herbert 1977, Santillan et al. 1979, Shrivastava et al. 1969, Vartha and Matches 1977). Investigators have found that the regression relationship between forage bulk and forage biomass usually varies, especially between species of grasses (Castle 1976), between seasons or harvests (Bransby et al. 1977, Castle 1976, Powell 1974, Shrivastava et al. 1969) and between different types of pasture and time of day (Earle and McGowan 1979). However, the regression relationship sometimes remains relatively constant, especially over the winter season (Earle and McGowan 1979, Michell 1982, Powell 1974). When the regression relationship varied, separate calibrations of the disk meter have been suggested for each sampling area and date. Separate regression equations would be necessary each time forage biomass is predicted. However, for sampling locations and dates where the regression relationship is constant, calibrations may be pooled and a single calibration relationship may be used, allowing many stands to be sampled with precision and in less time.

In the past, the forage disk meter has been used successfully to predict forage biomass on improved pastures, whereas its use on native rangelands has not been investigated thoroughly. In this study, we investigated the efficiency of the forage disk in predicting yields of forage biomass on different range sites in western Kansas.

Methods and Materials

The disk of the forage meter was constructed of clear, acrylic plastic 0.5 cm (0.20 in.) thick, with a diameter of 50 cm and an area of 0.2 m^2 in a manner similar to that described by Sharrow (1984). A 3.8-cm diameter hole was drilled through the center of the disk and the center of a square plate of like material (15.5 cm^2), which was glued to the disk as an added support for the handle. The handle, constructed of PVC tubing, was 19.5 cm long and 3.8 cm (o.d.) in diameter. The handle was inserted into the 3.8-cm diameter hole formed by the disk and the square support and then glued flush with the bottom edge. Sharrow (1984) used a meter stick to control the descent of the disk. We used a cylindrical wooden rod because the meter stick was unwieldy. The wooden rod (1.5 m long and 3.0 cm o.d.), graduated in mm, allowed the forage disk meter to descend freely. The disk meter weighed 1.26 kg and the weight:-area ratio was 6.3 kg m^{-2}.

Six sets of data were collected with the forage disk meter at 4 sites in western Kansas in 1984 and 1985. Sites were sampled during the months of August and September (Table 1). Site characteristics, locations, and data set codes in parentheses were: (1) grazed pasture, a shortgrass site dominated by buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) and blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) in northeastern Ellis County (R84 and R85); (2) grazed pasture, a midgrass site dominated by western wheatgrass (*Agropyron smithii* Rydb.) and Japanese brome (*Bromus japonicus* Thunb.) in northeastern Ellis County (R2); (3) grazed pasture, a shortgrass site dominated by buffalograss and blue grama in Rawlins County (G84 and G85); (4) ungrazed pasture, dominated by annual forbs and grasses in Rush County (T1).

Sites were sampled systematically. Line transects were spaced uniformly across each site and readings with the forage disk meter were taken at regular intervals along the transects. To measure forage bulk, the top of the handle of the disk meter was raised to a height of 1.0 m on the graduated measuring rod and released. For convenience and accuracy, resting heights of the disk were read from the measuring rod at the top of the disk's handle, then

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Manuscript accepted 31 March 1987.

Table 1. Regressions for six data sets collected with the forage disk meter on four sites in northwestern Kansas (n = number of data pairs, b = regression coefficients, SE = standard error, P = probability, a = intercept, r^2 = coefficient of determination, RSD = residual standard deviation).

Data set	Date	n	b±SE (kg ha^{-1} mm)	P (b=0)	a±SE kg ha^{-1})	P (a=0)	r^2	RSD (kg ha^{-1})
R2	Aug. 84	17	1.24± 9.71	0.9000	6771±1665	0.0010	0.001	1996
T1	Sep. 84	24	18.11± 5.39	0.0029	2112±420	0.0001	0.339	1174
R84	Aug. 84	17	41.37± 5.12	0.0001	659±229	0.0100	0.813	563
R85	Aug. 85	17	41.58± 5.33	0.0001	119±298	0.7000	0.802	464
G84	Aug. 84	33	17.98± 1.86	0.0001	761±180	0.0002	0.752	630
G85[1]	Aug. 85	46	33.37±10.67	0.0032	437±341	0.2062	0.839	766

[1]Third term: c±SE = 0.063±0.66.

adjusted accordingly. To eliminate the scale adjustments and improve the design, the scale on the rod should be zeroed at the height of the top of the disk's handle. After release, all plant material (including litter) beneath the disk meter was harvested using grass shears. Harvested plant material was bagged, exposed for 48 hours to a minimum temperature of 70° C, and weighed to the nearest gram.

The number of plots clipped for each site and sampling date ranged from 17 to 46 depending on a subjective assessment of site variability. Using least squares regression methods, the resting heights and forage weights from these clipped plots were used to calibrate the disk meter and develop the regression equations for each site and sampling date (Fig. 1). The mean yields of forage biomass estimated by the clipping and forage disk methods for each site and sampling date (Table 2) were obtained independently.

Table 2. Comparison between the mean yields of forage biomass (kg ha^{-1}) estimated by the clipping method and those predicted by the forage disk meter for the six data sets collected in northwestern Kansas (n = number of paired observations, SE = standard error, r = correlation coefficient).

Data set	n	Clipping±SE	Disk Meter±SE	r
R2	8	6814±1941	7161±222	−0.159
T1	12	3620±1029	2995±797	0.711
R84	8	1950±1123	2025±990	0.910
R85	8	2283±1044	2362±1292	0.948
G84	16	2070±2070	2208±1024	0.875
G85	23	2865±1839	2601±1631	0.933

Using random numbers, 2 subsamples were created from each of the 6 data sets. Each subsample consisted of half the paired observations in the data set. From the first subsample a regression equation was developed. The mean yield of forage biomass predicted by the forage disk meter was obtained by substituting the resting heights from the second subsample into this regression equation. The mean yield of forage biomass estimated by clipping was obtained independently from the forage weights in the second subsample. Individual yields of forage biomass obtained by the 2 methods were correlated (r, Table 2) to ascertain if the forage disk meter was a good predictor of forage biomass at each site. Coefficients of determination (r^2) were computed for each data set to assess the effect of forage bulk (disk resting height) in reducing the variation in forage biomass (Table 1). Intercepts (a) and regression coefficients (b) were tested for significance with 2-sided Student's t-tests. To satisfy the equal variance assumption of the simple linear regression model, the square root of forage weights was used for data set G85 (Neter et al. 1983). From observation of the scatter plots, data sets suspected of curvilinearity were fitted with polynomial regression models to investigate a possible quadratic relationship between forage bulk and forage biomass. Homogeneity of regression coefficients was tested by an analysis of covariance; regression coefficients were separated by the Tukey-Kramer test for multiple comparisons (Zar 1984). For data sets where the regression coefficients were not significantly different from one another, corresponding intercepts were tested for equality (t-test) to ascertain if the regression lines were coincidental (Zar 1984). The level of significance was set at 0.05.

Results

Significant linear regression relationships between forage biomass and forage bulk were established for all data sets except R2 (P = 0.90; Table 1). For data sets R(84 and 85) curvilinearity was suspected but polynomial regression models were not adequate because the quadratic effect coefficients did not differ significantly from zero (P>0.10). For data set R2 only 0.1% of the total variation in forage biomass was explained by forage bulk. A significant linear regression relationship was established for data set T1, but only 33.9% of the total variation in forage biomass was explained by forage bulk (Table 1). Site R2 was grazed lightly for many years and site T1 was ungrazed for at least 15 years prior to sampling. High accumulations of litter, large variations in microrelief, lodged vegetation, and abundance of broadleaf species were factors present on site R2. Litter accumulation was low on site T1 but kochia (*Kochia scoparia* (L.) Schrad.), an annual forb, was abundant. Because kochia plants were mature at the time of sampling, dry matter content of the forage was high and compressibility was low.

Residual variation (RSD, Table 1) was less for the remaining 4 data sets and r^2 values were all greater than 0.75. The grazing histories of sites R(84 and 85) and G(84 and 85) differed from those of sites R2 and T1. Site R (84 and 85) surrounded a windmill and stock watering tank and had been grazed heavily and uniformly by cattle and black-tailed prairie dogs *(Cynomys ludovicianus)* for many years. Site G(84 and 85) had been grazed moderately for many years, including 1984, but it was ungrazed during the growing season in 1985. Both sites were dominated by buffalograss and blue grama; but western wheatgrass, Japanese brome, and red triple-awn *(Aristida longiseta* Steud. var. *longiseta)* were common on site G(84 and 85). Consequently, in species composition and forage height, the stands on site G(84 and 85) appeared more heterogenous than stands on site R(84 and 85). The increased heterogeneity probably contributed to the higher residual variations observed for site G(84 and 85). Modest accumulations of litter, little variation in microrelief, vegetation free from lodging, and low abundance of broadleaf species were factors shared by these 2 sites.

Yields of Forage Biomass

To use the forage disk meter with confidence in predicting yields of forage biomass, the forage yields predicted by the forage disk meter should correlate well with forage yields estimated by clipping. Individual yields of forage biomass estimated by clipping and those predicted by the forage disk meter were correlated in Table 2. For data set R2, the forage disk meter was poor in predicting yield of forage biomass (r = −0.159) because it could not predict accurately the yields of forage biomass for resting heights obtained in the

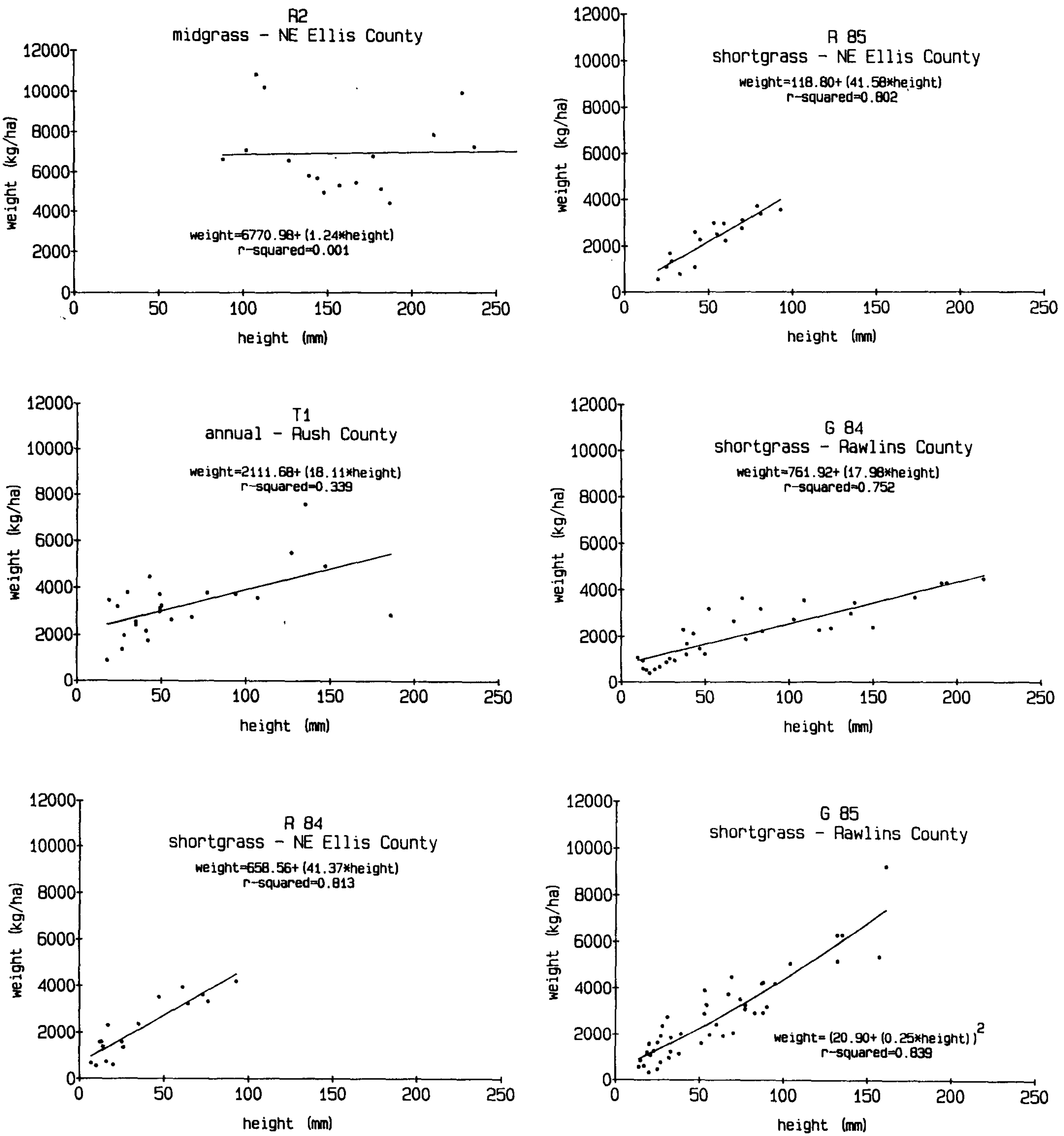

Fig. 1. *Regression relationships between forage biomass (weight) and disk height (height) for 6 data sets obtained with the forage disk meter in northwestern Kansas: (a) R2, (b) T1, (c) R(84), (d) R(85), (e) G(84), (f) G(85).*

second subsample. For the remaining 5 data sets, correlation coefficients ranged from 0.711 to 0.948, suggesting that the forage disk meter predicted yields of forage biomass fairly well for these range sites. However, the forage disk meter was a better predictor of forage yields on the sites dominated by shortgrasses (R84 and 85; G84 and 85) than the site dominated by annual forbs and grasses (T1). In this study the forage disk meter predicted yields of forage biomass with greater accuracy on range sites with low accumulations of litter, little variation in microrelief, vegetation free from lodging, and low abundance of broadleaf species.

Frequency of Calibration of the Forage Disk Meter

For a pooled regression line to be used for the 4 different sites (6 data sets) sampled in this study, regression coefficients and intercepts must be statistically homogeneous among all sites. Regression coefficients were not homogeneous among sites (analysis of covariance; $P<0.001$); therefore a pooled regression line could not be used for all 4 of the sites. However, regression coefficients for the data sets T1 and G84, and data sets R(84 and 85), did not differ significantly ($P>0.99$; Tukey-Kramer). regression intercepts differed significantly ($P<0.0005$) for the data sets T1 and G84, but they were not significantly different ($P=0.12$) for the data sets R(84 and 85). Grazing pressure was heavy and uniform on site R(84 and 85) and species composition and forage height were similar in 1984 and 1985. A pooled regression line could be used to describe the relationship between forage bulk and forage biomass for site R(84 and 85) only.

Intercepts varied between sites and on the same site in successive years (Table 1). Factors responsible for this variation were probably varying litter depths and dry matter contents of the forage. Litter depths and dry matter contents on the sites at the times of sampling were documented but not measured. Highest litter accumulations were observed on site R2 and the intercept for site R2 was the largest. Resting heights of the disk were high on site T1 because of the high content of dry matter and low compressibility of the mature kochia stands. Consequently, the intercept for site T1 was high also. Little litter accumulation was observed on the shortgrass sites G(84 and 85) and R(84 and 85); for data sets R85 and G85, the intercepts did not differ significantly from O (P = 0.70 & 0.21). Corresponding intercepts were low on these shortgrass sites compared to intercepts on the midgrass site R2 or the annual site T1. Because intercepts varied among most of the data sets, the forage disk meter probably should be calibrated for every range site. However, when grazing pressure and species composition do not change from year to year on a range site (R84 and 85 in this study), regression coefficients and intercepts might not vary and recalibraton might be unnecessary.

Discussion

Bransby et al. (1977) used a disk meter on tall fescue (*Festuca arundinacea* Schreb.) pastures grazed by yearling steers and obtained correlation coefficients (r) ranging from 0.79 to 0.94 for bulk-height and dry matter yield. For several different grasses, Santillan et al. (1979) used a disk meter and reported correlation coefficients of 0.79 to 0.99 between settling height and dry matter yield, with most exceeding 0.92. Sharrow (1984) used a disk meter on grass-subclover and oat field pasture types and obtained coefficients of determination (r^2) between 0.70 and 0.91 for either forage bulk or sward height and sward phytomass yield. The magnitude of correlation between forage bulk-height and forage biomass yields obtained in those studies was attained in this study only for data sets R(84 and 85) and G(84 and 85), these range sites being dominated by shortgrasses. Poorer regression relationships between forage bulk and forage biomass have been attributed to several factors, including microrelief (Earle and McGowan 1979, Powell 1974, Santillan et al. 1979, Sharrow 1984), trampling of forage by livestock and accumulations of litter (Vartha and Matches 1977), lodging of vegetation (Michalk and Herbert 1977), and presence of broadleaf species (Bakhuis 1960). Bakhuis (1960) stated that the weight/length ratios differ between dicots and monocots, which produces undesirable effects on measurements of forage bulk (measured as sward density × length) as well as the correlation between forage bulk and dry matter yield. This was especially problematic in stands where dicot composition exceeded 10%. As noted, the poor correlation between forage bulk (disk resting height) and forage biomass observed for range sites R2 and T1 was attributed to some or all of the above factors. On fields composed of 90% or more grasses, Bakhuis (1960) obtained higher correlations, as we did on the shortgrass range sites R(84 and 85) and G(84 and 85).

Curvilinear regression relationships between forage bulk-height and dry matter yields were reported by Baker et al. (1981) and Bransby et al. (1977), especially for high disk meter readings (>200 mm). Curvilinear relationships in Baker et al. (1981) were thought to be related to high dry matter yields (>4,500 kg ha^{-1} dry forage) obtained on hay swards, yields usually being higher than those obtained in pasture experiments. Curvilinearity was suspected in this study only for the data sets R(84 and 85) at high disk meter readings, but as noted, polynomial regression models were not appropriate. Estimated yields of forage biomass did not exceed 4,500 kg ha^{-1} dry forage for these data sets. Curvilinearity at high disk meter readings was not suspected for the data sets R2 and T1, although estimated yields of forage biomass exceeded 4,500 kg ha^{-1} dry forage. Linear regressions were appropriate for the range sites in this study, but the use of polynomial regressions for range sites with yields of forage biomass exceeding 4,500 kg ha^{-1} dry forage should not be overlooked.

Estimates of forage biomass on a range site will be influenced by factors other than forage bulk (disk resting height), including litter depth, microrelief, dry matter content of forage, and possibly others. Multiple regression models with stepwise regression analyses would be appropriate in describing the relationship between forage and bulk and forage biomass for some range sites. However, measuring these additional factors will increase the calibration time for the forage disk meter, detracting from its use as a double sampling device.

Baker et al. (1981) obtained nonsignificant regression coefficients and significantly different regression intercepts for calibrations of hay swards. Recalibration of the disk meter was not necessary when moving from sward to sward in their study if the proper intercept value for each sward was known and used. They suggested that both regression coefficients and intercepts were influenced by the species composition of swards; and for swards with different species, determinations of new intercept values and recalibration of the disk meter may be required. Earle and McGowan (1979), Santillan et al. (1978), and Shrivastava et al. (1969) reported that devices used to estimate forage bulk-height should be calibrated for each site and sampling date because the regression relationship varies with botanical composition and time of sampling. Species composition of stands sampled in our study differed and both regression coefficients and intercepts were significantly different among the range sites. However, on one range site R(84 and 85) recalibration of the disk meter from year to year was not necessary, probably because grazing intensity and amount of forage available on the site remained relatively constant from year to year. On range sties where such occurs, the forage disk meter can be used effectively as a double sampling device to predict yields of forage biomass.

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