An Evaluation of Beta Attenuation for Estimating Aboveground Biomass in a Tallgrass Prairie

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Abstract

The attenuation of beta particles by vegetation was evaluated as a nondestructive method for estimating aboveground biomass in tallgrass prairie in northeast Kansas. Regression equations using the sum of beta attenuation measurements for each of 5 height classes within the vegetation and mean midday leaf water potential as the independent variables were used to predict live and total biomass. Live and total biomass were better predicted on burned (r^2=.91 and .88, respectively) than unburned sites (r^2=.71 and .70, respectively). Greater variability in the relationship between beta attenuation and biomass in unburned prairie was a result of the large and variable amount of dead biomass on unburned sites. Dead biomass was poorly predicted by beta attenuation (r^2=.24 - .49). Beta attenuation predicted biomass in burned tallgrass prairie within ±5% of harvest values until late season vegetative senescence. In unburned prairie, predictions were poorer, but the technique could still be useful if the required accuracy need be only ±25%.

Measurement of aboveground biomass by clipping and weighing the vegetation is labor intensive and destroys the plot for subsequent measurements for at least a year. These disadvantages prompted the development of several nondestructive techniques [see Tucker (1980) for review]. Due to the success of Teare et al. (1966), Mitchell (1972), and Johnson et al. (1976) with the beta attenuation technique in herbaceous vegetation, we evaluated beta attenuation as a nondestructive method for estimating aboveground biomass in a tallgrass prairie. This evaluation was accomplished by deriving regression equations from calibration plots and testing their predictive value.

Material and Methods

Research was conducted on the Konza Prairie Research Natural Area (KPRNA) near Manhattan, Kans. The vegetation is characteristic of bluestem prairie (Bailey 1980). Sites burned annually (late April) or left unburned were used in this study. None of the sites have been grazed recently, nor had the unburned sites been burned for 5 years. The soil at the study sites is a moderately deep Reading silt loam (Typic Argiudolls; Jantz et al. 1975).

The apparatus constructed to measure beta attenuation consisted of 4 parts: a beta particle source, a Geiger-Mueller (GM) tube, a scaler, and a mounting frame. The beta source consisted of 10 capsules (1-cm diameter) containing 10 microcuries of strontium^{90} each. A side-window GM tube was placed 50 cm from the source. The GM tube was connected to a Ludlum model 2000 scaler to record the number of beta particles received by the GM tube. The beta source, GM tube, and scaler were mounted on a rigid frame with a moving section that held the GM tube at a fixed horizontal distance from the beta source, but permitted the tube and source to be moved vertically. Five vertical positions, representing 5 height classes were used in this study (0–10, 10–20, 20–30, 30–40, and 40–50 cm). This height stratification allowed the integration of the density of vegetation over the height of the stand (Teare et al. 1966). Further details on the construction and operation of the frame are available from L.C. Hulbert (Director, Konza Prairie Research Natural Area).

Twenty 20×50-cm plots, systematically located along 50-m transects, were sampled in burned and unburned tallgrass prairie at 2-week intervals from late-May to mid-September (1983). Four beta attenuation measurements were taken at 5-cm intervals at each of the 5 heights in each plot (total = 20/plot). Vegetation in each plot was clipped at ground level, sorted into live and dead biomass, oven-dried, and weighed. After the 20 plots were clipped, additional beta attenuation measurements were made at 40 points along an adjacent transect. These data were used to test the accuracy of the predictive equation developed from the clipped plot data. Also, during the 1982 and 1983 growing seasons, a comparison of predicted biomass values with clipped plot data was made in nearby sites which had either shallower or deeper soils.

Two to four times during a daily sampling period, 10 replications of beta attenuation were measured at each height class in an area devoid of vegetation. These measurements were used to correct vegetation measurements for daily and seasonal differences in absolute humidity and electronic drift. Attenuation was calculated using the following equation:

$$\text{Beta Attenuation} = 1 - \frac{T^{veg}_{ht_x}}{T^{air}_{ht_x}}$$

where $T^{veg}_{ht_x}$ is the number of beta particles transmitted through the vegetation (in 6 sec.) at a given height (ht_x) and $T^{air}_{ht_x}$ is the number of beta particles transmitted through the air. Leaf water potential (Ψ_{leaf}) was measured concurrently with beta attenuation hourly on a clear day late in the 1982 growing season to determine if diurnal variations in the water relations of the vegetation influenced beta attenuation. Measurements of Ψ_{leaf} were made with a Scholander-type pressure chamber on 5–7 fully expanded leaves of big bluestem *(Andropogon gerardii* Vitman), the dominant species in the study area. Additionally, midday Ψ_{leaf} (1500 hr CDT) was measured for 5–7 big bluestem leaves each week throughout the 1983 growing season to examine the relationship between seasonal variation in Ψ_{leaf} and beta attenuation.

Regression equations were developed with total, live and dead biomass as the dependent variables and the sum of the beta attenuation measurements for each of the 5 height classes (Σatt) and the mean midday Ψ_{leaf} preceding the sampling date ($\bar{x}\ \Psi_{leaf}$) as independent variables. Data transformations and model fitting followed the techniques described by Neter and Wasserman (1974).

Results and Discussion

The relationship between aboveground biomass and Σatt was exponential as reported by Teare et al. (1966) and Mitchell (1972). Because of heteroscedasticity of variance in data sets from burned and unburned sites, a log/log transformation was necessary to meet the assumptions of a linear model (ln(x+1); Zar 1974). Several combinations of the height class variables were used but Σatt produced the highest coefficient of determination.

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Two aspects of the relationship between the moisture content of the vegetation and beta attenuation were evaluated: diurnal and seasonal changes in leaf water potential. When the diurnal course of Ψ_{leaf} and beta attenuation were monitored concurrently (Fig. 1)

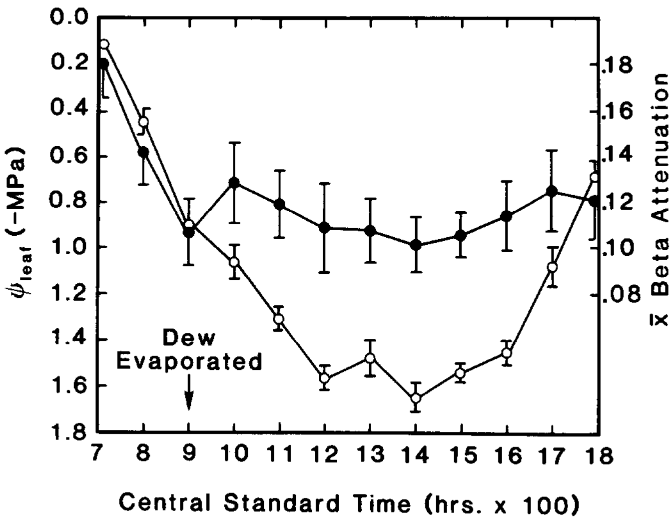

Fig. 1. *Diurnal course of leaf water potential (Ψ_{leaf} - open symbols) and beta attenuation (closed symbols) at 30 cm in tallgrass prairie burned in the spring. Measurements of Ψ_{leaf} were made on big bluestem leaves located approximately 30 cm above the soil surface on 2 September 1982. Vertical bars represent ±1 standard error of the mean (n=10 beta readings, 5-7 Ψ_{leaf} measurements).*

a significant positive correlation was found after dew evaporation (r=0.85, p<0.05). However, the magnitude of this diurnal variation in Ψ_{leaf} resulted in less than a 4% variation in beta attenuation. In contrast, dew on the vegetation caused as much as a 10% error in attenuation. On a seasonal basis, a mid-season drought resulted in a much greater decrease in midday Ψ_{leaf} in big bluestem (–0.5 MPa to –6.6 MPa) than the diurnal change and consequently, the quantity $\bar{x}$ Ψ_{leaf} was also a significant independent variable for both sites. During a summer with normal precipitation in tallgrass prairie, $\bar{x}$ Ψ_{leaf} in *A. gerardii* varies little throughout the season (Knapp 1984) and probably would not have a substantial influence on the relationship between beta attenuation and biomass.

The regression equations with Σatt and $\bar{x}$ Ψ_{leaf} as independent variables used to predict biomass had coefficients of determination of 0.91 and 0.88 for live and total biomass in burned prairie and 0.71 and 0.70 for live and total biomass in unburned prairie. Not including $\bar{x}$ Ψ_{leaf} in the model reduced the coefficients to 0.87, 0.77, 0.53 and 0.58, respectively. The variances associated with biomass estimates from clipped plots and beta attenuation were equal (95% confidence intervals were ±10 and ±15% of the means in burned and unburned prairie, respectively). For the beta attenuation technique to be successful, we decided that predicted values should be within the confidence limits of the harvest plot values and not significantly different when compared with Student's *t*-test. A comparison of predicted and actual biomass values for the 1983 growing season (Fig. 2) indicated that beta attenuation adequately predicted live and total biomass in the burned site (p<0.05 and predicted values usually within ±5% of harvest values) with the exception of the late season value when the proportion of dead biomass was high. Beta attenuation was not as accurate in unburned tallgrass prairie (predicted values often as much as 25% different from harvest values) due to the large amount of dead biomass (3–6 times the live component) which was poorly predicted by beta attenuation (r^2=0.24–0.49 during the growing and dormant seasons). These low coefficients of determination may be explained by the low moisture content of dead biomass. Furthermore, the only significant difference between predicted and mea-

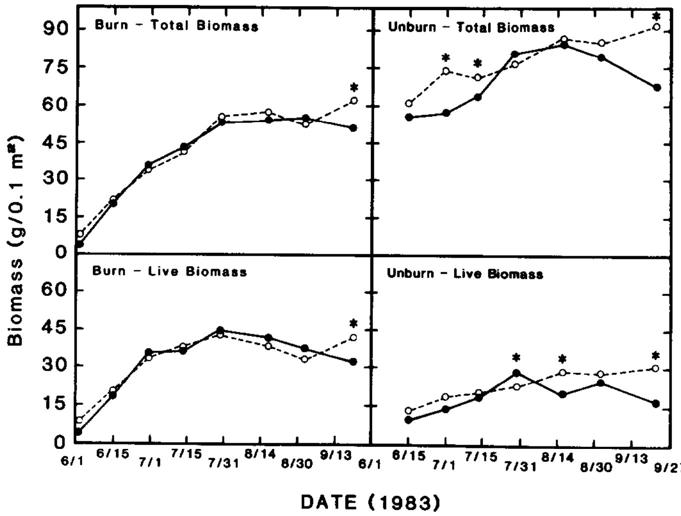

Fig. 2. *Seasonal course of actual (closed symbols) and predicted (open symbols) aboveground biomass in burned and unburned tallgrass prairie during the 1983 growing season. Asterisks denote when actual and predicted values are significantly different (t-test, p<.05).*

sured values in burned prairie occurred when the proportion of dead biomass increased to about 35% of the total near the end of the growing season. Errors in predicting biomass due to dead biomass have also been reported with other nondestructive techniques (Campbell et al. 1962, Boutton and Tieszen 1983).

Use of the equations developed in 1983 to predict biomass at other sites from 1982 and 1983 was not entirely successful. Predicted biomass at mid-season (1983) was underestimated by about 14% on a burned site with a shallow soil and, on a deeper soil than that used for the calibration, was overestimated by 10 and 24% for live and total biomass, respectively. Greater water stress at the site with a shallow soil and differences in species composition at both sites may have contributed to the errors in these predictions. Thus, for the beta attenuation method to be useful, separate calibrations for each site are warranted (Teare et al. 1966). Similarly, biomass predicted for the 1982 growing season using the 1983 calibration data was overestimated by about 25%, possibly because the 1982 growing season was more mesic than 1983.

In conclusion, beta attenuation predicted aboveground biomass in tallgrass prairie within ±5% of harvest values when dead biomass did not constitute a major portion of the total. If sequential, nondestructive estimates of aboveground biomass are desired, this method is applicable on burned and probably mowed and grazed tallgrass prairie. If reduced accuracy is acceptable (±25%), then this method may also be useful in undisturbed tallgrass prairie. The addition of relatively simple midday Ψ_{leaf} measurements at the site may increase the accuracy of estimates in drought years or in ecosystems where water stress is common.

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