Technical Note

A Nondestructive Method to Estimate Standing Crop of Purple Threeawn and Blue Grama

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Abstract

We used multiple regression analysis to develop models to predict standing crop of purple threeawn (*Aristida purpurea* Nutt.) and blue grama (*Bouteloua gracilis* [H.B.K.] Griffiths) nondestructively. Data were collected for 3 yr on the Texas Tech University Native Rangeland, Lubbock, TX, USA. Independent variables included plant length and area measurements (basal area and cross-sectional area at a 7.5-cm plant height and at 50% of total plant height). One hundred randomly selected plants of each species were measured in June 2008; 50 plants of each species were measured in June 2009 and 2010. Coefficients of determination exceeded 0.91 for both species in all 3 yr of measurement. For both species and years, cross-sectional area at 7.5 cm was the most important single predictor variable. For each species, models differed among years. Our regression models were successful at predicting mid- to late-season standing crop of purple threeawn and blue grama grass and provide an effective method for nondestructive monitoring of these species. This approach should be applicable to similar morphotypes of these species.

Resumen

Usamos un análisis de regresión múltiple para desarrollar modelos no destructivos para predecir la producción de purple threeawn (*Aristida purpurea* Nutt.) y blue grama (*Bouteloua gracilis* [H.B.K.] Griffiths). Los datos fueron recolectados durante 3 años en el pastizal nativo de Texas Tech University, Lubbock TX, USA. Variables independientes incluyeron longitud de la planta, y mediciones de área (área basal y área de la sección transversal a 7.5 cm de la altura de la planta, área de la sección transversal al 50% del total de la longitud de la planta). Cien plantas de cada especie fueron seleccionadas aleatoriamente y medidas en junio de 2008; 50 plantas de cada especie fueron medidas en junio de 2009 y 2010. Los coeficientes de determinación excedieron 0.91 para ambas especies durante los tres años que se llevaron a cabo las mediciones. Para ambas especies y años, el área transversal a la altura de 7.5 cm fue la variable única de predicción más importante. Para cada especie, los modelos fueron diferentes entre años. Nuestros modelos de regresión fueron exitosos en la predicción de la biomasa en la etapa media a tardía de crecimiento de de los pastos purple threeawn y blue grama y proporcionan un método efectivo no destructivo para el monitoreo de estas especies. Esta metodología debería ser aplicable para morfo tipos similares de estas especies.

Key Words: *Aristida purpurea*, biomass estimation, *Bouteloua gracilis*, regression

INTRODUCTION

A commonly accepted method for collecting biomass data is to harvest and weigh plants destructively. As an alternative method to clipping, biomass can be estimated from morphological characteristics that are highly correlated to it such as basal area, plant height, and canopy volume (Guevara et al. 2002; Flombaum and Sala 2007; Nafus et al. 2009) or with the use of reflectance measurements recorded radiometrically or cover estimates recorded photographically (Byrne et al. 2011). We used multiple regression models to predict biomass from plant measurements that are simple and practical to measure in the field. Similar models have been used to estimate the biomass of trees and shrubs (Ludwig et al. 1975; Whisenant and Burzlaff 1978).

For this study, purple threeawn (*Aristida purpurea* Nutt.), and blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths) were target plants. These species are common in our study area and widespread throughout the Great Plains (Stubbendieck et al. 2003). Purple threeawn is a bunchgrass with narrow leaves and tightly compacted tillers. Although blue grama is a bunchgrass in our study area (i.e., it does not have the sodgrass form common in heavily grazed settings), many of our larger plants had nevertheless fragmented into smaller units; in addition, blue grama's tillers are not nearly as tightly compacted as the tillers of purple threeawn. These species provided an opportunity to assess the effect of these growth-form differences on biomass prediction.

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STUDY AREA

Research was conducted at a native rangeland site on the Texas Tech University campus located in the northwest portion of Lubbock, TX, USA (lat 33°36′14.78″N, long 101°53′50.44″W) at 992-m elevation. Soils are Acuff-Urban land complex (fine–loamy, mixed, superactive, thermic aridic paleustolls), Amarillo-Urban land complex (fine–loamy, mixed, superactive, thermic aridic paleustalfs), and Midessa fine sandy loam (fine–loamy, mixed, superactive, thermic aridic calciustepts) (Natural Resources Conservation Service [NRCS] 2008). The Amarillo-Urban land complex occupies the greatest area (42%) followed by the Acuff-Urban land complex (37%) (NRCS 2008). The Amarillo complex is characterized by 0–36 cm of fine sandy loam, and 36–203 cm of sandy clay loam. These soils generally consist of loamy eolian deposits and become sandier as they approach playa lakes. Acuff soils have a neutral brown loam surface (0–30 cm) horizon underlain by 40 cm of mildly alkaline reddish brown sandy clay loam. Mean annual rainfall is 47.5 cm with peak rainfall months of June (7.6 cm) and September (6.5 cm) (National Oceanic and Atmosphere Administration [NOAA] 2008). Mean monthly air temperatures range from an average daily maximum of 33°C in July to an average daily minimum of –6°C in January (NOAA 2008). Vegetation is typical of shortgrass plains common in the southern Great Plains. Species common to the site are mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*), blue grama, buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.), purple threeawn, silver bluestem (*Bothriochloa saccharoides* [Sw.] Rydb.), Arizona cottontop (*Digitaria californica* [Benth.] Henr.), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray) and various forbs. Cattle had not grazed the study area for 5 yr prior to our sampling.

METHODS

Grass Biomass and Morphological Measurements

We collected field data in late June 2008, 2009 and 2010 in order to estimate standing crop in mid–late July, a period that is often used to set late-season stocking rates; additionally, summer burning is often practiced at this time, and biomass responses to summer burning may be of interest to land managers. Target plants of blue grama and purple threeawn were randomly selected from the population of plants without regard to initial size. In 2008, 2009, and 2010, blue grama basal areas ranged from 2.95 to 98.92 cm^2 (mean=31.86 cm^2); 8.99–88.92 cm^2 (mean=49.41 cm^2); and 0.51–195.87 cm^2 (mean=39.40 cm^2), respectively. For purple threeawn basal areas ranged from 1.68 to 55.79 cm^2 (mean=16.02 cm^2); 5.43–45.40 cm^2 (mean=18.80 cm^2); and 0.77–92.37 cm^2 (mean of 17.47 cm^2), respectively. Diameter was measured to the nearest 0.01 mm with digital calipers. Plant length (i.e., the maximum of length of the longest leaf or tallest tiller) was measured from mineral soil with a ruler to the nearest 0.1 cm. We measured basal width, basal length, diameter at 7.5-cm plant height, and plant length and diameter at 50% of the plant length. Diameter at 7.5-cm plant height and diameter at 50% of plant length were measured after compressing plant material into a firm bundle. After measurements, plants were clipped at 1 cm above ground, dried at 60°C for 48 h, and weighed to the nearest 0.01 g. A total of 100 plants of each species were measured in 2008; in 2009 and 2010, 50 plants of each species were measured. Predictive models were developed for each year and species.

Statistical Analysis

Diameter measurements were converted to area and variables were used in multiple regression to predict dry weight of target plants. Our dependent variable was plant biomass; explanatory variables were basal area, area at 7.5 cm plant height, plant length and area at 50% plant length. Preliminary graphic analysis suggested that for both species relationships between dry weight and area measurements were approximately linear but that the relationship between dry weight and plant length was curvilinear; this latter relationship was accounted for by regressing dry weight on the square of plant length. Variable selection was based on MAXR improvement (we retained variables only if they were significant at $P=0.05$) and on AIC_c (SAS 2003); both methods selected the same variables for both species. Errors were assumed to be independent and normally distributed, with homogeneous variances. Residual plots suggested approximate compliance with these assumptions.

RESULTS

Correlation Analyses

For both species, dry weight and area at a 7.5-cm height were highly correlated ($r > 0.90$, $P < 0.001$) in all years. Correlations between dry weight and other area measurements varied among years. For example, correlation coefficients between blue grama dry weight and basal area ranged from $r=0.72$ ($P < 0.001$) in 2009 to $r=0.90$ ($P < 0.001$) in 2010; for purple threeawn, these coefficients ranged from $r=0.82$ ($P < 0.001$) in 2010 to $r=0.90$ ($P < 0.001$) in 2008. Plant length showed a lower correlation with dry weight than area measurements; for blue grama, these coefficients ranged from $r=0.56$ ($P < 0.001$) in 2009 to $r=0.76$ ($P < 0.001$) in 2008, and for purple threeawn, these coefficients ranged from $r=0.36$ ($P < 0.01$) in 2010 to $r=0.73$ ($P < 0.001$) in 2009.

Multiple Regression

The explanatory variables we measured explained at least 91% of the variation in dry weight for each species in each year (Table 1). The upper bound of the condition index for each of these models indicated little multicollinearity.

The fact that different subsets of variables were selected in 2008, 2009, and 2010 indicates that there was no single model that applied under all growing conditions encountered during this study. For example, plant length was not included in the best model for blue grama in 2009 and basal area was not included in the model for 2010. Similarly, basal area was not included in the best model for purple threeawn in 2008 and area at 50% plant height was not included in the 2010 model.

However, models for blue grama for each year included area at 7.5-cm height and area at 50% of plant height (with adjusted coefficients of determination of 0.89, 0.88, and 0.90 for 2008, 2009, and 2010, respectively). Blue grama models that included

Table 1. Regression coefficients (SE) and adjusted R^2 for models that predict blue grama or purple threeawn standing crop (g) in 2008 (n=100), 2009 (n=50) and 2010 (n=50) at the Texas Tech University, Native Rangeland, Lubbock, TX, USA. All variables are significant at $P < 0.05$; all models were identical with MAXR and with AIC_c variable selection methods.

		Predictor variables				
Year	Intercept	Basal area (cm^2)	Area at 7.5-cm plant height (cm^2)	Area at 50% of plant height (cm^2)	Square of plant length (cm)	Adj. R^2
Blue grama						
2008	−2.872 (0.735)	0.063 (0.014)	2.469 (0.492)	4.880 (1.210)	0.003 (0.0008)	0.916
2009	−1.139 (1.034)	0.123 (0.023)	2.500 (0.290)	5.024 (1.008)	–	0.922
2010	−3.294 (0.911)	–	1.667 (0.238)	14.289 (2.692)	0.002 (0.0003)	0.934
Purple threeawn						
2008	−7.312 (1.517)	–	2.710 (0.260)	5.273 (0.983)	0.005 (0.0006)	0.964
2009	−9.584 (2.137)	0.314 (0.119)	2.526 (0.425)	8.502 (1.434)	0.005 (0.0009)	0.961
2010	−2.536 (1.074)	0.089 (0.029)	3.132 (0.161)	–	0.002 (0.0005)	0.964

only these two variables differed ($F_{6,191}$=4.2, P=0.0005). In addition, regression surfaces were not parallel ($F_{4,191}$=5.8, P=0.0002): The relationship between dry weight and area at 7.5 cm differed ($F_{1,144}$=9.8, $P < 0.0001$) among the 3 yr, as did the relationship between dry weight and area at 50% ($F_{1,144}$=5.4, $P < 0.0054$) (Fig. 1).

Likewise, models for purple threeawn for each year included area at 7.5-cm plant height and plant length (with adjusted coefficients of determination of 0.95, 0.93, and 0.96 for 2008–2010, respectively). When we compared purple threeawn models with these two variables across years, models differed ($F_{6,190}$=10.9, $P < 0.0001$) and regression surfaces were not parallel ($F_{4,190}$=4.16, P=0.003). Although the relationship between dry weight and area at 7.5-cm plant height differed ($F_{2,190}$=6.25, P=0.002) among years, the relationship between dry weight and plant length was similar ($F_{2,190}$=0.76, P=0.471) among years (Fig. 2).

DISCUSSION

Although aboveground biomass of grasses is composed of several structural components (leaves, stems, seed heads), leaves made up the majority of aboveground plant weight in our shortgrass species. Plant length (e.g., Williamson et al. 1987; Guevara et al. 2002) and basal area (e.g., Williamson et al. 1987; Andariese and Covington 1986; Assaeed 1997; Guevara et al. 2002; Nafus et al. 2009) have generally been found useful for predicting standing crop of grasses. Therefore, we expected that our models (which included several measures of plant length and area) would be successful at predicting standing crop of our target species. Given that area at 50% plant height and area at a 7.5-cm height explained > 88% of the variation in plant weight regardless of year, our models are, in one sense, robust to differences in growing conditions for both species. However, we also found that variables that were important predictors of standing crop varied across years for both species. Furthermore, when we modeled only those variables that were selected for all 3 yr, models for each species differed across years.

These differences are likely explained in part by growing conditions throughout the duration of our study (Fig. 3). Attributing specific effects of growing conditions on our models is beyond the scope of this study. However, some speculations can be offered. Our plant measurements were collected in June; plant morphology at this time was affected by rainfall in the

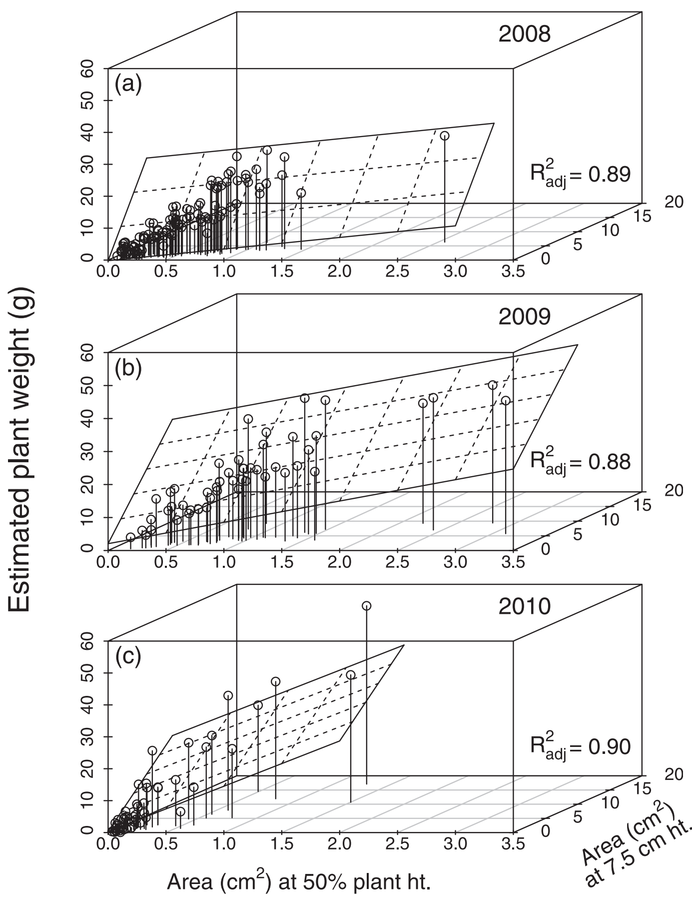

Figure 1. Predicted standing crop (g) of blue grama in 2008, 2009, and 2010 as a function of area (cm^2) at 50% plant height and area (cm^2) at 7.5 cm height. Regression models differ ($F_{6,191}$=4.2, P=0.0005) among years; regression surface are not parallel ($F_{4,191}$=5.8, P=0.0002) among years; and regression planes among years are not parallel along the area at 50% plant height axis ($F_{1,144}$=5.4, $P < 0.0054$) or the area at 7.5-cm height axis ($F_{1,144}$=9.8, $P < 0.0001$).

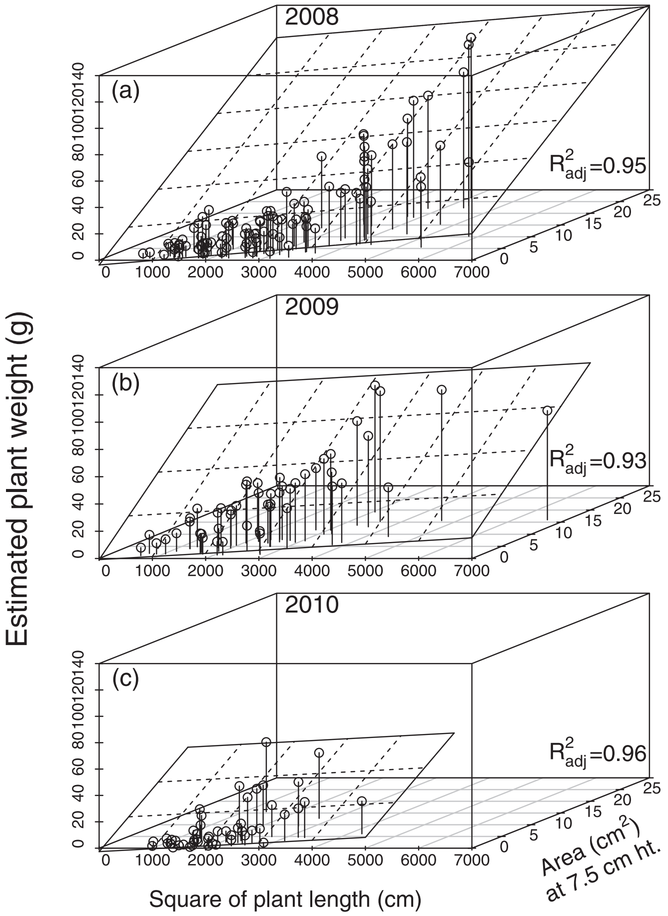

Figure 2. Predicted standing crop (g) of purple threeawn in 2008, 2009, and 2010 as a function of the square of plant length (cm) and area (cm^2) at 7.5-cm height. Regression models differ ($F_{6,190}$=10.9, $P<0.0001$) among years; regression surface are not parallel ($F_{4,190}$=4.16, P=0.003) among years; and regression planes among years are not parallel along the area at 7.5-cm height axis ($F_{2,190}$=6.25, P=0.002); however, there was no evidence that planes differed in slope ($F_{2,190}$=0.7665, P=0.471) along the plant-length axis.

preceding months of the current growing season as well as by rainfall in the preceding fall (Cable 1975). Plant length is relatively dynamic and responsive to growing conditions compared to changes in basal area. For blue grama, plant length was important in predicting biomass when the preceding fall had above-normal rainfall or when the preceding winter and spring had above-normal rainfall (although fall 2008 had above-average precipitation [Fig. 3], nearly 16 cm of rainfall occurred during a single precipitation event in September, and the remainder of the year was below average; it is reasonable to suggest that, with respect to growing conditions experienced by plants, fall 2008 was at best average with respect to rainfall, if not perhaps below average). In contrast, plant length was not important in predicting blue grama plant weight when preceding fall, winter and spring months were dry.

Our data represent responses of blue grama and purple threeawn in a nongrazed pasture; further, our pasture had not experienced livestock grazing for 5 yr prior to our data collection. Effects of grazing on plant morphotypes is well-

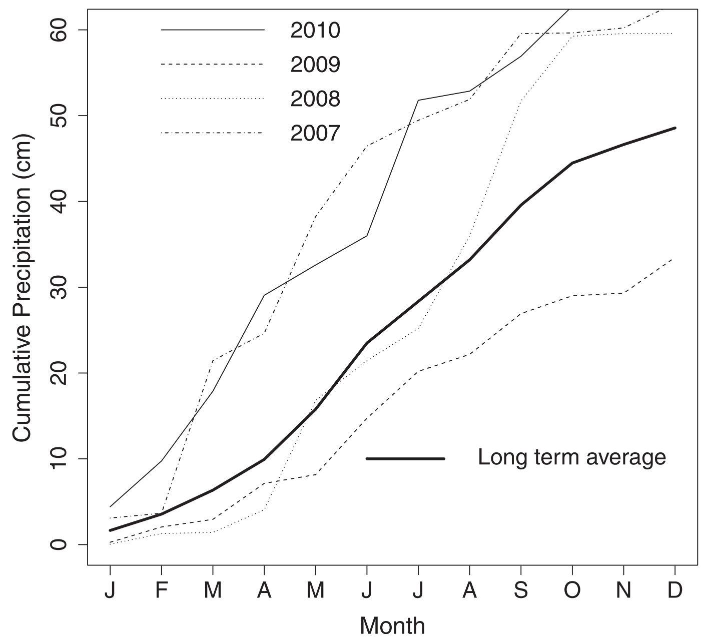

Figure 3. Cumulative monthly precipitation (cm) in 2007, 2008, 2009, and 2010 (and long-term average) at the Native Rangeland study area, Texas Tech University, Lubbock, TX, USA (west Texas mesonet data).

documented for numerous species, including blue grama (e.g., Briske and Richards [1995] and citations therein). However, morphology of our plants was similar to morphology for these species that we observed in other areas of the southern Great Plains (e.g., Rideout-Hanzak et al. 2011) that were properly grazed. It is unlikely that lack of recent grazing had any measurable effect on our results. Our models should be applicable as long as our measurements can be recorded (e.g., plants should be tall enough that area at a 7.5-cm plant height can be recorded); thus, our approach should be applicable for predicting mid- to late-season standing crop of these species. However, if overgrazing has converted blue grama to the sod-forming morphotype, then our approach would not be applicable because our variables could not be measured.

IMPLICATIONS

Many morphometric features of herbaceous plants change in response to changing patterns and amounts of rainfall (e.g., Weaver and Albertson 1936; Gibbens and Beck 1988; Shackelford 2004). Thus, although changes in basal area and plant length in response to timing and amount of rainfall are complex and species specific, it is reasonable to expect that the relationship between our morphometric variables and standing crop would vary among years. The practical implication is that regression equations should be re-estimated for each growing season, a recommendation made by Williamson et al. (1987) and Johnson et al. (1988) as well. However, even though we recommend re-estimating equations each year, our results suggest that for these species the morphometric features we used should be generally useful—i.e., our models suggest that area at 7.5-cm height is useful to predict biomass, although its regression coefficient should be estimated each year. Our measurements are relatively easy to collect; they require no specialized equipment, minimal training, and little time. However, these measurements would likely not be effective for grasses of different growth forms; sod formers such as buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.) and tall grasses such as big bluestem (*Andropogon gerardii* Vitman) will require other morphometric measurements.

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