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Biomass estimation for native perennial grasses in the plain of Mendoza, Argentina

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Plant allometric relationships were studied at the end of the 1999–2000 growing season for eight grasses. Logarithmic regressions were developed relating above-ground biomass to dimensional measurements or to tiller density. Basal diameters (the longest and the greatest perpendicular to the first) and plant height (defined as that reached by vegetative tillers) were recorded on individual plants of tussock grasses. The number of tillers per 1 m^2 plot was counted for a rhizomatous grass. Our study proved that regression models including basal area or a combination of basal area and height as independent variables gave a good fit to the biomass data for tussock grasses. Density of tillers proved to be a good predictor of biomass for a rhizomatous species. A validation test using 20% of the data not used for estimating the regression equations indicated that these models made accurate prediction of grass biomass. Further work is needed to prove if there are year-to-year differences between models.

Keywords: grasses; allometric relations; basal area; plant height; tiller number; above-ground biomass; model validation

Introduction

Biomass estimation of forage plants is an important problem in range research and is crucial for evaluating their production and utilization (Johnson *et al.*, 1988). Estimation of biomass by direct measurement of plant weight has been carried out over a period of 7 years in the Mendoza plain. Harvesting occurred at the end of the growing season (April–May) giving the maximum standing crop. Based on this information, the rain-use efficiency factor and the rangeland carrying capacity were calculated (Guevara *et al.*, 1997).

Direct measurements of plant weight by harvesting biomass is destructive and expensive (Reese *et al.*, 1980). Plant destruction in an important risk particularly in the Mendoza plain ecosystems where the mean density of several preferred grasses such as *Digitaria californica* (Benth.) Henr. and *Pappophorum philippianum* Roseng. is as low as 0·34 and 0·23 plants m^{-2}, respectively. Also, the destructive technique is inappropriate in several experiments in which harvest is an undesirable treatment.

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Further studies are needed in the Mendoza plain for adjusting the carrying-capacity estimations. The application of regression equations based on allometric relationships instead of the harvest technique could result in lower sampling cost or higher precision due to relatively greater sampling efficiency (Reese *et al.*, 1980).

Dimensional analysis has been used to estimate plant biomass in the Mendoza plain. Regression equations relating dry weight to plant dimensions were developed for trees and shrubs (Braun *et al.*, 1978; Passera, 1983; Passera & Borsetto, 1989). Biomass equations for three grasses were estimated using visual estimates of canopy cover (Guevara & Tanquilevich, 1976). Ocular estimates have the disadvantage of varying between observers as well as over time for a single observer, introducing unknown, but potentially substantial, error into the plant dimension estimates (Risser, 1984; Andariese & Covington, 1986). We postulated that using some combination of plant basal area and plant height measurements or the number of tiller count might overcome the visual estimation problems. Allometric equations have been developed to estimate grass biomass in other countries of the world by Andariese & Covington (1986), Johnson *et al.* (1988) and Assaeed (1997), among many others.

The objectives of this paper were: (1) to develop regression equations relating above-ground biomass to plant dimensions for eight native perennial grasses in the plain of Mendoza; and (2) to check the validity of these equations in predicting biomass.

Study area and methods

This study was conducted at El Divisadero Cattle and Range Experiment Station (33° 45′S, 67° 41′W, elev. 520 m) in the north central Mendoza plain, mid-west Argentina (Fig. 1). Detailed description of the biogeographic characteristics of the study area is given by Guevara *et al.* (1997).

The eight species used for estimating regression equations were: *Aristida mendocina* Phil., *A. inversa* Haeck., *Chloris castilloniana* Lillo and Parodi, *Digitaria californica*, *Panicum urvilleanum* Kunth, *Pappophorum philippianum*, *Setaria leucopila* (Scrib. & Merr.) Schum., and *Sporobolus cryptandrus* (Torr.) A. Gray. They are the most common warm-season perennial grasses in the Mendoza plain. *Panicum urvilleanum* is a rhizomatous species and the others are tussock grasses.

Thirty-five plots including a variable number of *P. urvilleanum* tillers and approximately 30 plants of each of the tussock grasses were selected. These plants were protected from livestock grazing during the growing season. Plants were randomly selected so that they represented the range of variability in plant size observed in the field. Two performance attributes were recorded on each tussock grass individual: basal diameter and plant height to the nearest 1 mm and 1 cm, respectively. Two basal diameters for each plant were measured (the longest and the greatest perpendicular to the first) and averaged. The average basal diameter for each plant was recorded in the field. Plant height was defined as the height reached by vegetative tillers; reproductive tillers whose height surpassed those of the previous ones were not considered because their contribution to biomass is negligible (Cavagnaro *et al.*, 1983). The number of tillers per 1 m^2 plot was counted for *P. urvilleanum*. Phenological observations were made in connection with measurement of plant parameters.

Basal area was derived from the basal diameter of each individual plant. Individual plants of tussock grasses and all tillers of *P. urvilleanum* were handclipped at ground level, oven-dried at 70°C to a constant weight and weighted to the nearest 0·1 g.

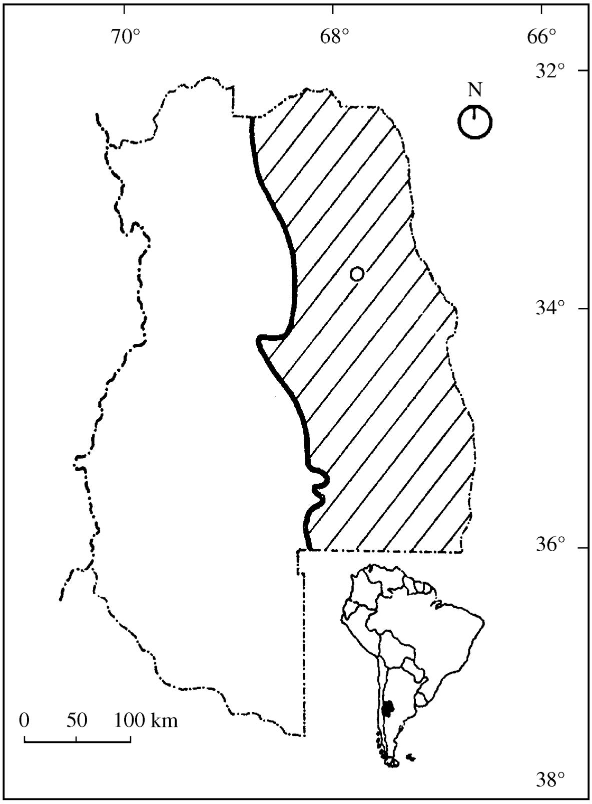

Figure 1. Location of the arid Mendoza plain and the study site. (▨) Mendoza plain; (○) EI Divisadero Cattle and Range Experiment Station.

Data were collected at the end of the 1999–2000 growing season. All grasses were dried-up. Reproductive phases for each species are indicated in Table 1.

A portion of the collected plants ($\sim$80%), called the estimation data set, was randomly selected from all harvested plants and used to estimate the model coefficients. For biomass estimation, simple and multiple regression equations were fitted to the data. Basal area (X_1) and height (X_2) were regressed on biomass (Y) for tussock grasses. Number of tillers (X_3) was regressed on plant dry weight for the rhizomatous species. Heterogeneity of variance and nonlinearity were removed by transforming ($\log_{10}$) the independent and the dependent variables. Goodness of fit of models including the same number of independent variables was measured by the coefficient of determination (R^2). Comparisons between models including one (X_1 or X_2) or two independent variables (X_1 and X_2) were made through the test statistic $F = (RSS_0 - RSS_1/1)\ (RSS_1/n - 3)^{-1}$, where RSS_0 and RSS_1 are the residual sum of squares at model with one and two independent variables, respectively (Weisberg, 1980). We tested the null hypothesis (NH) against the alternative hypothesis (AH): NH: $Y = a + b\ X_1 + e_i$; AH: $Y = a + b\ X_1 + c\ X_2 + e_i$.

The remaining 20% of the collected plants of each species, called the prediction data set, was used to measure the prediction accuracy of the model (Snee, 1977). To validate each regression model, it was applied to this data set to predict biomass. Standard error of estimate (SEE) was calculated separately for the estimation data and the prediction data for each model. To check the model validity, the SEE for the prediction data was compared with the SEE of the equation.

Table 1. *Phenological phases in the reproductive development of grasses at the end of the 1999–2000 growing season in the Mendoza plain*

	Phenological phases				
Species	Green fruits	Ripe fruits	Green and ripe fruits and dispersing seeds	Ripe fruits and dispersing seeds	No reproductive organs
	(percent of observed plants)				
Aristida inversa	—	9·1	—	90·9	—
Aristida mendocina	—	26·7	—	73·3	—
Chloris castilloniana	7·2	10·7	—	60·7	21·4
Digitaria californica	—	40·6	—	40·6	18·8
Panicum urvilleanum	—	—	—	—	100·0
Pappophorum philippianum	—	42·3	—	34·6	23·1
Setaria leucopila	—	36·5	4·5	54·5	4·5
Sporobolus cryptandrus	5·0	57·5	15·0	22·5	—

Results and discussion

Measured plant parameters showed differences among the eight grasses (Table 2). Individual plant weight for tussock grasses showed the largest coefficients of variation. In contrast, weight of individual tillers of *P. urvilleanum* exhibited a relatively moderate variation. Moderate variation was also observed in basal diameters of the tussock grasses. Height of the latter species showed the lowest variation. Similar variation patterns were found for weight, basal diameter and height for three perennial grasses in Saudi Arabia rangelands (Assaeed, 1997).

The final regression equations and statistics for both estimation and prediction data sets are shown in Table 3. All models exhibited *F*-ratios significant at $p < 0{\cdot}001$.

When height was regressed on plant biomass, the coefficients of determination (R^2) were substantially lower than those for equations including basal area as independent variable. Consequently, models including height as independent variable are not shown.

Adjusted R^2 and SEE for equations including basal area as the independent variable ranged from 0·65 to 0·83 and from 0·186 to 0·282, respectively. These adjusted R^2 values are comparable with those obtained by Andariese & Covington (1986) for grasses in Northern Arizona. On the contrary, basal area explained only 24% and 58% of the variability in the observed values of biomass for *Stipagrostis drarii* (Täckh.) De Winter and *Lasiurus sindicus* Henr., respectively (Assaeed, 1997). The log–log relationship between biomass and canopy cover provided adjusted R^2 of 0·87 for *Digitaria californica* (Guevara & Tanquilevich, 1976), comparable with that obtained in the present study when basal area was included as independent variable.

For *Aristida inversa* and *A. mendocina* and according to the *F*-test, the null hypothesis was accepted, i.e. models including basal area as independent variable fit the data significantly better ($p < 0{\cdot}05$) than those including basal area and height as predictors of biomass. In contrast, for the other tussock grasses, *F*-test provided very strong evidence against NH and in favour of AH. Thus, models that include two independent variables (basal area and height) fit the data significantly better than the reduced models. Conversely, Andariese & Covington (1986) and Assaeed (1997) found that the inclusion of basal diameter and height in the models added little to the R^2 values obtained when basal diameter was used as the independent variable. Another combination of variables (basal and canopy diameters) or the inclusion of three variables (height, basal and canopy diameters) was needed for satisfactory biomass estimation (Assaeed, 1997).

Table 2. *Measured plant parameters for eight perennial grasses in the Mendoza plain*

Species	Weight (g)			Basal diameter (cm)			Height (cm)		
	Mean	S.D.	CV	Mean	S.D.	CV	Mean	S.D.	CV
Aristida inversa	23·05	19·12	82·95	6·37	4·16	65·31	30·34	6·66	21·95
Aristida mendocina	28·10	20·39	72·56	7·13	3·96	55·54	29·33	6·31	21·51
Chloris castilloniana	18·37	17·52	95·37	5·09	2·19	43·03	24·36	7·66	31·44
Digitaria californica	12·52	9·92	79·23	4·10	2·19	53·41	31·56	8·49	26·90
Panicum urvilleanum	0·69	0·25	36·23	—	—	—	—	—	—
Pappophorum philippianum	10·69	7·96	74·46	3·55	1·43	40·28	26·25	6·33	24·11
Setaria leucopila	18·68	15·63	83·67	3·64	1·46	40·11	32·19	8·84	27·46
Sporobolus cryptandrus	5·53	6·28	113·56	3·09	2·23	72·17	27·00	9·07	33·59

Table 3. *Regression equations of log transformed plant basal area in* cm^2 (X_1), *plant height in cm* (X_2) *or number of tillers* m^{-2} (X_3) *on plant dry weight (g) for eight perennial grasses, and comparison of estimation and prediction data statistics*

Species	Independent variable	Regression coefficient			Data statistics			
					Estimation			Prediction
		a	*b*	*c*	*n*	Adjusted R^2	SEE	SEE
Aristida inversa	X_1	0·356	0·635			0·79	0·206	0·408
	X_1 X_2	0·238	0·629	0·086	22	0·77	0·211	0·410
Aristida mendocina	X_1	0·293	0·679			0·65	0·282	0·385
	X_1 X_2	−0·955	0·572	0·963	22	0·66	0·279	0·299
Chloris castilloniana	X_1	−0·140	0·979			0·76	0·236	0·320
	X_1 X_2	−2·008	0·623	1·685	22	0·92	0·140	0·214
Digitaria californica	X_1	0·107	0·807			0·82	0·252	0·250
	X_1 X_2	−2·437	0·497	1·912	25	0·88	0·204	0·121
Panicum urvilleanum	X_3	−0·469	1·219		30	0·91	0·145	0·132
Pappophorum philippianum	X_1	0·164	0·797			0·83	0·186	0·304
	X_1 X_2	−1·410	0·663	1·204	24	0·90	0·142	0·199
Setaria leucopila	X_1	0·229	0·931			0·74	0·214	0·192
	X_1 X_2	−1·075	0·778	0·971	22	0·81	0·187	0·159
Sporobolus cryptandrus	X_1	0·068	0·656			0·72	0·249	0·414
	X_1 X_2	−1·547	0·534	1·211	25	0·92	0·137	0·264

For *P. urvilleanum*, the number of tillers per m^2 accounted for 91% of plant biomass variation. Thus, tiller density proved to be a good predictor of plant dry weight for this rhizomatous grass.

For each of the best models, the SEE calculated for the prediction data set was in close agreement with the SEE of the regression equation (Table 2), indicating that the models made accurate predictions of independent data (Snee, 1977).

Our study proved that regression models including plant basal area or a combination of basal area and plant height gave a good fit to the biomass for the tussock grasses of the Mendoza plain. On the other hand, density of tillers proved to be a good predictor of biomass for the rhizomatous grass. These models made accurate prediction of grass biomass. For determining production per unit area is needed to measure the plant parameters considered in this study at individual plant level within the required number of sample plots.

Ideally, our regression equations estimated using data from one growing season would be valid for evaluating grass production at the end of all growing seasons. However, Johnson *et al.* (1988) showed that there were substantial year-to-year differences between equations, which indicate the necessity for developing new models each year. Further work is needed to prove if their results are applicable to the grasses considered in our study and if this were the case to identify variables that explain the interannual differences between models.

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