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Predication of Biomass of Three Perennial Range Grasses Using Dimensional Analysis

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Abstract: Biomass of key range plants is one of the most commonly measured attributes in range inventory programs that is a base for most range management decisions. This study was done to estimate biomass of three grasses (Agropyron cristatum, Bromus tomentellus and Stipa barbata) using dimension analysis. So plant biomass was measured through harvesting method. Plants height, basal diameter and canopy diameter were recorded in the field as dimensional parameters. Pearson correlation coefficients were used to assess relationships of dimensional variables with biomass. The variables were then evaluated for predicting biomass by using best subset and stepwise regression approaches. Results showed that there was significant relation between biomass and dimensional parameters. The results clearly showed that dimensional analysis is an appropriate method for estimation grasses biomass. So we can say that the dimensional parameters are good predictors of biomass and all parameters are not the same in terms of explanatory power. In this study plant height was the best predicator of the biomass in single species models and multispecies model. Basal diameter added medium predictive value when height was already in the model. Only in multispecies model, canopy diameter remained in the model and its explanatory power was relatively acceptable.

Key words: Biomass · Agropyron cristatum · Bromus tomentellus · Stipa barbata · Regression · Dimensional analysis

INTRODUCTION

Proper rangeland management has always been centered on exact documentation of all the existing resource status within a management unit, so that collected information can be used to develop high quality short and long-term land use plans; and eventually play a positive role in improving the country livestock industry [1]. Grazing by animals, both domestic livestock and wildlife, remains a primary land use on rangelands. Therefore, many rangeland inventory and monitoring programs must focus on obtaining information that can be interpreted to ensure productive and sustainable forage consumption within the management unit. So one of the main factors that should be concerned in range management, is stocking rate. Stocking rate is a fundamental component of rangeland management decision in terms of rangeland vegetation, domestic livestock, wildlife and economic responses [1] because it is an important management tool that connects standing crop and utilization level that key species can tolerate [2].

Biomass is one of the most commonly measured attributes in range management programs. So biomass is regarded as the most important indicator of ecological and management processes in the vegetation. Biomass provides a valuable tool to make short-term stocking rate adjustments according to the amount of forage reserves and residual biomass [3].

Biomass refers to the weight of plant material within a given area. Other general terms, such as 'yield' or 'production', are sometimes used interchangeably with biomass. Production term most of the time reflects current year's growth and includes all green organs of stem, flowering branches, flowers, seeds and fruits.

The production measurement methods have been developed since the early 19th century but much more efforts and studies have been devoted to developing methods to estimate production. So some new techniques were developed or traditional ones were adjusted somehow. It is obvious that techniques with high accuracy and precision are acceptable.

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Different methods have been developed to measure the grasses production, each with its own advantages and disadvantages.

For herbaceous plants and grasses because of grow beginning from the ground, the total above-ground plant biomass on the site at a particular point in time considered as production [1]. Biomass can be determined using either direct or indirect sampling methods. Direct methods involve techniques that weigh or estimate the actual biomass of plants in quadrats. Clip and weight from quadrats of a known size is the most straightforward direct approach to determine biomass. Clip and weight is a method that is time consuming, destructive and laborious [4, 5]. In most of the studies, indirect methods may be selected over direct methods to determine biomass because they are non-destructive and usually less time consuming. Indirect methods are based on developing a relationship between plant weight and an easier-to-measure attribute such as plant height, rainfall, or cover.

One of the indirect methods is based on using many different attributes describing plant dimensions to determine plant biomass that is known as dimensional analysis. Dimensional analysis is conducted to establish the regression relationship, with biomass as the dependent variable [6, 7]. Many studies founded indirect methods practical, simple and convenient for estimating the plant's production [8, 9]. Cover and its property due to the ease and speed of measurement can be appropriate criteria for estimating standing crop (biomass) in many herbaceous species especially grasses [10, 11]. Paton *et al*. [12] presented that there are different regression models for different shrub species. They examined the relationships between 22 shrub species production with canopy cover, plant height, crown large diameter, crown small diameter and crown volume. Some studies on grass species showed that basal area and its combination with plant height are good predicator variable for biomass [13]. Some studies reported the same regression relationships for different grass species but different relationships for shrub species [3, 14-16].

Grasses are the dominant vegetation in many habitats, including grassland, salt-marsh, high lands and semi-steppes. They also occur as a smaller part of the vegetation in almost every other terrestrial habitat such as steppes and deserts. In both cases, grasses most of the time considered as key and palatable species. Although there are some studies on measuring rangeland plants production [17, 18] and its relationship with different plant attributes such as canopy cover [19] but there is not much information in relation to the production of grasses in rangelands and the relationships between native grasses biomass and dimensional variables are poorly documented.

Regard to the importance of grass species in rangeland vegetation composition and their significant roles in the rangeland management, health and hydrology, it seems important to develop such regression relationships for determining grasses biomass. In this study, different attributes including canopy cover, plant height, average crown diameter and basal area as describing plant dimensions are used to determine plant biomass. Therefore our objective was to develop regression relationships between Stipa barbata, Bromus tomentellus and Agropyron cristatum biomass and foregoing dimensional variables to assess the possibility of providing applicable statistical models as indirect method of determining grasses biomass.

MATERIALS AND METHODS

Study Area: Study area is part of Khooshaab-Rizaab range management plan which is located in 68 km NW of Shahroud county and 6 Km SW of Shaahkooh-e-sofla village (54°21'36"E- 36°31'12"N and 54°23'24" E-36°31'48"N). The mean elevation is about 2900 m asl. The study site receives between 650 and 750 mm of annual precipitation that mostly occurs as snow. The annual mean temperature is varying between 2 and 6°C. The shallow area soils are of coarse texture (loam and sandy loam entisols), with gravels and rocks. The dominant vegetation structure is grassland-shrubland with sparse Juniper and the area considered as good rangeland of the region. The three selected grass species for sampling are Agropyron cristatum, Bromus tomentellus and Stipa barbata that are considered as main grass species in the region.

Data Collection: Part of the rangeland with area about 5 hectares was selected for sampling. This part was protected from grazing for 3 years so that the possibility of finding ungrazed species was maximum. Data were collected at the end of the 2013 growing season (early June). Data were collect using 10 transects. The distance between transects was determined randomly. The transects were laid out along main slope in the region. A prominent distant landmark such as a large tree, rocky point, etc., were used as the transect bearing point. Sixty observations points on each transect were randomly selected (six plant along each transect). At each observation point, the plant of the interested species (just mature species) nearest the point was sampled to determine the plant biomass, height to the nearest 2.5 cm, average crown diameter (i.e. mean of small and large diameter) and basal area. If a sufficient number of plants is not encountered along the transect, its length was extended. To measure vegetation biomass, clip and weigh method was used. Before harvesting plants, their height, canopy cover, average crown diameter and basal area were measured with ruler in the field. The plants were then clipped to within 2.5 cm of the ground. All old leaves and stems of previous year's growth were removed. The clippings were dried until a final dried weight is achieved. The dried samples were then weighed using a digital scale (0.01g). Therefore, the final weight is considered as biomass weight.

Statistical Analyses: The correlation coefficient between the amount of biomass and the dimensional parameters were tested for significance. The correlation coefficient test was done to assess co-linearity between variables. For studying the relationship between biomass and dimensional parameters, regression models were fitted to the data. The general regression model was:

$$Y = \beta_o + \beta_1 X_H + \beta_2 X_B + \beta_3 X_C + \varepsilon$$

where:

Y = Biomass (g);
β_o = intercept;
β_i = coefficients;
X_H, X_B, *and* X_C = Height, Basal diameter and Canopy diameter (cm);
ε = random errors.

Comparisons between models including one, two or three independent variables were made through the best subset regression. The best regression model was introduced through stepwise regression considering the amount of biomass as the dependent variable and canopy cover, plant height, canopy large and small diameters, as independent variables. Regression models were evaluated using the coefficient of determination (R^2) and Mallows' C_p criteria. The R^2 statistics measure the goodness of fit of a regression model. The C_p gives an index of bias in fitted response introduced by not including an important independent variable in the model. Good models have C_p values near to or less than the number of variables in the model [20]. All statistical analyses were performed using Minitab version 16.2.4 (Minitab Inc., State College, Pennsylvania).

RESULTS

The results of descriptive statistics of different dimensional parameters and biomass are summarized in Table 1. Stipa barbata had the highest height and canopy diameter. The highest basal area was belonging to Bromus tomentellus. As expected, the highest biomass is related to Stipa barbata because of its large dimensions. This statistical summary of measured variables is reflection of the inherited differences among the three species. Large standard deviations and coefficients of variations were observed mostly in individual plant biomass of all three species. Such high variations are usually to be expected in natural vegetation [21] suggesting a need for more observations. However, all other measured variables have relatively low to moderate variability (Table 1).

The correlations between the analyzed parameters in this study are shown in Table 2. Observed correlations between all of the measured parameters were significant ($p<0.05$). The highest correlation between biomass and other variables was related to the height (Table 2). There is some relationship between the biomass and canopy diameter, but it's a weak one in comparison to other variables. The results suggest that all three variables are not good predicators for biomass although they have the same pattern in the three species. So we can expect that height and basal area to be good predicators for biomass and canopy diameter omitted from the models. In multispecies case, the correlations between biomass

Table 1: Summary of measured variables for Agropyron crystatum, Bromus tomentellus and Stipa barbata.

	Agropyron crystatum			Bromus tomentellus			Stipa barbata		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Biomass	34.02	18.77	55.19	14.30	9.75	68.19	22.55	14.46	64.13
Height	54.65	14.76	27.00	54.25	13.89	25.61	71.60	16.91	23.62
Canopy diameter	32.85	7.75	23.61	26.12	10.69	29.93	41.933	7.595	18.11
Basal diameter	21.900	7.532	34.39	33.93	10.16	40.93	23.817	7.177	30.13

Table 2: Pearson correlation between biomass and height, canopy diameter and basal area for Agropyron crystatum, Bromus tomentellus and Stipa barbata

Variables	Species	Pearson correlation
Height	Agropyron crystatum	0.924
	Bromus tomentellus	0.902
	Stipa barbata	0.902
	Multispecies	0.667
Canopy diameter	Agropyron crystatum	0.735
	Bromus tomentellus	0.784
	Stipa barbata	0.823
	Multispecies	0.529
Basal diameter	Agropyron crystatum	0.714
	Bromus tomentellus	0.809
	Stipa barbata	0.902
	Multispecies	0.532

Table 3: The results of best subset regression for selecting the best predicators

	Agropyron crystatum					Bromus tomentellus					Stipa barbata					Multispecies				
Variables	Height	Canopy diameter	Basal diameter	C_p	R^2	Height	Canopy diameter	Basal diameter	C_p	R^2	Height	Canopy diameter	Basal diameter	C_p	R^2	Height	Canopy diameter	Basal diameter	C_p	R^2
1	x			7.2	85.4	x			4.2	81.3	x			6.3	81.3	x			8.0	44.5
1		x		12.8	54.0			x	5.7	65.4			x	6.3	81.3			x	61.6	28.3
2	x	x		7.2	85.6	x	x		4.1	82.7	x	x		5.9	83.8	x		x	6.9	45.4
2	x	x		7.2	85.6	x		x	4.2	81.5		x	x	6.1	83.0	x	x		8.1	45.0
3	x	x	x	7.3	85.6	x	x	x	4.1	82.7	x	x	x	5.9	84.1	x	x	x	4.0	46.9

and dimensional parameters had generally decreased reflecting high differences between three species dimensions. In this case, it's difficult to decide which variables will remain in the models because the correlations between biomass and dimensional parameters are relatively close (Table 1). In other word we can expect that all three dimensional parameters stay in the models.

The results of best subset regression showed that one variable is not generally enough for predicating biomass and multivariate regression will have better explanatory power (Table 3). As it can be seen, between all three variables, height had the highest R^2 and the lowest C_p that is representative of explanatory power of the variable (Table 3). So height can be considered as the best predicator of biomass. There is an exception about stipa barbata. In this species, height and basal area act the same in one variable mode (the same R^2 and C_p). In the two variables case for Agropyron crystatum, there is no change in R^2 and C_p. This is the case for three variables too. For Bromus tomentellus, by adding the second variable, R^2 has increased and C_p is decreased that show that the two variables mode is better than one variable mode. In this regard, canopy cover is better predicator because of its higher R^2 and the lower C_p. For stipa barbata also adding the second variable will improve explanatory power of the model. In this case, canopy cover is better predicator too, because it has higher R^2 and lower C_p in comparison to basal area. For all three species adding the third variable had no substantial effect on the models. In three variables mode, for Agropyron crystatum, R^2 didn't change but C_p is increased slightly. For Bromus tomentellus, adding the third variable changed neither R^2 nor C_p. For stipa barbata, by adding the third variable, R^2 is increased slightly but there is no change in C_p. For multispecies case, in one variable mode, height is the best predicator of biomass. In two variables mode, adding basal diameter can improve explanatory power of the model although it didn't changed R^2 but decreased C_p. The three variables mode is the best one. In this mode, R^2 slightly increased but C_p substantially decreased.

The results of stepwise regression and best subset regression analyses were consistent. For Agropyron crystatum just plant height remained in the model, so canopy diameter and basal area were omitted (Table 4). For Bromus tomentellus and Stipa Barbata, height and basal area for both species remained in the model and canopy cover was omitted (Table 4). Since canopy boundaries of grasses are delimited and change easily with the wind. So the canopy diameter measurements are somewhat subjective. Therefore most probably the basal diameter and height would be enough for the biomass estimation of the both species. For multispecies model, all three dimensional remained in the model and the R^2 of the model is relatively lower than single species models (Table 4).

Table 4: Regression intercepts, coefficients and R^2 of plant basal diameter (X_B), plant height (X_H) and canopy diameter (X_C) models to solve for the current year's biomass (g)

		Coefficients			
Species	Intercept	X_H	X_B	X_C	R^2
Agropyron crystatum	- 30.2	1.18	-	-	85.4
Bromus tomentellus	- 18.5	0.515	0.187	-	82.7
Stipa barbata	- 28.2	0.398	0.934	-	83.8
Multispecies	- 13.0	0.723	0.396	- 0.450	46.9

The results obtained in this study clearly showed that dimensional analysis is an appropriate method for estimation grasses biomass. So we can say that the dimensional parameters are good predictors of biomass and all parameters are not the same in terms of explanatory power. In this study plant height was the best predicator of biomass in single species models and multispecies model. Basal diameter added medium predictive value when height was already in the model. Only in multispecies model, canopy diameter remained in the model and its explanatory power was relatively acceptable.

DISCUSSION

Biomass is one of the most commonly measured attributes that is time consuming and laborious to collect, but easy to interpret. Biomass is regarded as an important indicator of ecological and management processes in the vegetation. Dimension measurements of biomass are non-destructive methods and require little training and time to apply. They are, therefore, less expensive, making them a preferred choice in estimating rangeland production. Therefore dimensional analyses to determine biomass have recently attracted increasingly attentions. The present results showed that it's possible to use height, basal diameter and canopy diameter as dimensional variables to predict biomass of Agropyron crystatum, Bromus tomentellus and stipa barbata. These results are consistent with previous work for grasses [13, 22, 23]. The results also showed that height and basal diameter are the main predicator of biomass and supports the concept of height–weight relationship that the most weight of grasses concentrated in basal parts of plant. There was little improvement in predictive strength when adding canopy diameter to single-species models that already contained basal diameter and height.

For Agropyron crystatum, only height was enough to predicate biomass. For Bromus tomentellus and stipa barbata, height and basal diameter were sufficient to measure plant biomass. However, for multispecies mode, all three dimension measurements i.e. basal diameter, height and canopy diameter may be required for satisfactory results.

Theoretically, such equations that relate some plant growth attributes to biomass for one season would be generalize for all seasons and grazing histories. Usually such equations are site specific and may not perform in other locations. Especially for multispecies model this might not always be the case.that generalizes across species and it may not perform as well in other locations. There are substantial year-to-year variations in the prediction equation of grasses biomass [24]. Further, factors such as location, grazing history and phenological growth stages may influence canopy structure of grasses and should be considered [25, 26].

CONCLUSION

Grazing by animals, both domestic livestock and wildlife, remains a primary land use on rangelands. Therefore, many rangeland inventory and monitoring programs must focus on obtaining information that can be interpreted to ensure productive and sustainable forage consumption within the management unit. So one of the main factors that should be concerned in range management, is stocking rate. Stocking rate is a fundamental component of rangeland management decision in terms of rangeland vegetation, domestic livestock, wildlife and economic responses.

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