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Prediction of *Salsola vermiculata* Foliage Production for Different Grazing Intensities

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Abstract. *Salsola vermiculata* is considered as one of promising indigenous fodder shrub with high relative palatabilty. Productivity parameters of this shrub are an important factor to determine its potential and carrying capacity for different grazing intensity. There are relationships between productivity parameters and shrub measurements. Height, compact circumference and radius seem to be the most parameters, which affect the productivity. Simple and multiple correlations between productivity parameters and shrub measurements for various defoliation intensity treatments were significant. Compact circumference has the highest efficiency to predict productivity.

The relation between productivity and shrub measurements, as related to site condition, could be best expressed with quadratic equations for medium and light defoliation treatments. Semi-log equations could be used for heavy defoliation treatment. Linear model for most treatments had (R^2) values lower than those for the best models with small difference.

Introduction

Estimating plant production is important in range management as it influences directly the grazing capacity of the range [1]. Production information has its value for range managers to estimate forage availability, utilization and productivity for herbivores [2-4, pp 55-59]. Browse biomass is commonly recognized as one of the most difficult of all vegetation components to be measured [5]. Estimates of shrub production, however, have been more laborious and less reliable than that for herbaceous production [1].

A wide array of shrub sampling techniques have been reported. Attempts to measure shrub browse production have centered on a few basic techniques, including tagged twig methods, ocular estimates, and clip and weight methods. Regression methods have been widely used to estimate total biomass, current annual production, and utilization in shrubs while reducing sampling costs [6]. Regression techniques are then employed to predict leaf or shoot biomass. These techniques facilitate more efficient and accurate analyses [3,7-10]. These relationships vary among areas, sites, species and individual plants [11]. In addition, browse intensity often affects the accuracy of these determination techniques [12 and 13].

Revegetation with promising and highly relative palatable shrubs could improve range condition, and decrease the variance between spring and autumn productivity. *Salsola vermiculata* is considered one of the important indigenous shrubs, that have high relative palatability. It has nearly disappeared from many sites due to overgrazing and its high relative palatability.

The objectives of this research were to (i) determine the relationships between *S. vermiculata* measurements (height, compact circumference and radius), and current year growth (CYG) and the weight of allowable grazing foliage (AGF), (ii) use of various regression models for developing predictive equations of (CYG) and (AGF) production, and (iii) determine the effect of different defoliation intensity treatments on the previous relationships and the predictive equations.

Materials and Methods

The experiment was conducted on El Myzahemia experiment station, Center for Desert Studies, located 50 km west of Riyadh, Saudi Arabia. The soil of the experimental site was Torripsamment soils. It has deep soil profile, sandy to sandy loam texture, calcareous, very low content of organic matter, alkaline reaction with electrical conductivity ranging from 0.8 to 3.8 m.mohs, and gypsum content from 2.7 to 3.5%.

Shrub seedlings of *S. vermiculata* were cultivated during February 1989 in rows two meters apart, while the distance between the successive plants in each row was 1.5 meter. Plants were fertilized annually in spring season with about 50 g of ammonium sulfate for each. Plants were supplementary irrigated with saline water (about 5000 ppm), in summer and autumn every two months.

Three defoliation intensities treatments were subjected after shrub establishing. The three defoliation treatments represented the three allowable grazing foliage (AGF) intensities of about 25%, 50%, and 75% of the current year growth (CYG), which could be considered as light, medium and heavy grazing intensities, respectively. In April 1991, thirty-six shrubs were taken at random for each defoliation intensity treatment for shrub measurements.

Each individual plant was measured to the nearest centimeter for 1] average height of shrub (X_1), 2) compact circumference measured by surrounding a measuring tape around the compact crown in its widest area (X_2), and 3) radius mean calculated from the measurements of maximum crown width (W_1) and crown width at right angles to W_1 (W_2), so, radius = $(W_1 + W_2)/4$, represented (X_3). These measurements X_1, X_2 and X_3 were taken as independent variables.

Fresh materials of AGF were cut according to their percentage of CYG for different defoliation treatments as mentioned before. Clipped foliage samples were oven dried at 60°C for approximately 48 hours, and weighed to the nearest 0.1 g. The CYG of shrubs was estimated according to the dry weight of AGF. Both AGF and CYG were taken as dependent variables (Ya and Yc), respectively.

Dependent and independent data for the previous three intensity treatments were extrapolated for the fourth treatment (mixed intensity treatment), to give the most probable expected grazing intensity irrespective to the degree of grazing.

The set of independent variables X_1, X_2 and X_3 to be employed in the models were examined by R_p^2 and Cp criteria [14, pp 417-429]. R_p^2 criterion calls for an examination of the coefficient of multiple determination R^2 in order to select one or several subsets of X variables. Cp criterion is concerned with the total mean square error of the n (number of observations) fitted values for each of the various subset regression models.

Simple and multiple correlations between dependent variables AGF and CYG and independent variables (height, compact circumference and radius) were determined [15, pp 311-335 and pp 139-200]. Several regression equations included linear ($y = a + b_1X_1 + b_2X_2 + b_3X_3$), quadratic ($y = a + b_1X^21 + b_2X^22 + b_3X^23$), square root transformation ($Y = a + b_1X^{1/2}1 + b_2X^{1/2}2 + b_3X^{1/3}3$), semi-log ($y = a + b1 \log X_1 + b_2 \log X_2 + b_3 \log X_3$) and log-log ($\log y = a + b1 \log X_1 + b_2 \log X_2 + b_3 \log X_3$) functions, where y = (AGF) or (CYG), X_1 = height, X_2 = compact circumference and X_3 = radius. Regression coefficients and the best predicting equations were derived for different treatments.

Results and Discussion

Examination of all-possible-regressions selection procedures using R_p^2 and Cp criteria [14] revealed that the use of the subset (X_1, X_2 and X_3) in the regression model appears to be reasonable, for all the different defoliation intensity treatments (Table 1). This subset has the highest Rp and low Cp, which is near to the P value (P

Table 1. Coefficient of determination (R^2) and Cp values for regression models of four grazing intensities of *S. vermiculata*

	Grazing intensity									
Variable in model	Heavy AGF, CYG		Medium AGF, CYG		Light AGF, CYG		Mixed AGF		CYG	
	R^2	Cp	R^2	Cp	R^2	Cp	R^2	Cp	R^2	Cp
X_1	0.29	3.5	0.18	13.1	0.12	7.8	0.16	23.9	0.14	10.2
X_2	0.29	3.4	0.40	1.1	0.28	0.6	0.31	1.7	0.19	4.3
X_3	0.21	7.5	0.24	10.1	0.13	7.6	0.18	20.6	0.09	16.5
X_1X_2	0.34	2.9	0.42	2.0	0.29	2.0	0.32	2.0	0.21	2.9
X_1X_3	0.29	5.4	0.28	9.5	0.16	8.2	0.21	18.5	0.15	11.3
X_2X_3	0.29	5.4	0.40	3.0	0.28	2.5	0.31	3.5	0.19	6.3
X1X2X3	0.36	4.0	0.42	4.0	0.30	4.0	0.32	4.0	0.22	4.0

X_1 = plant height, X_2 = C. circumference and X_3 = radius.

= parameters number). This criterion showed that the subset (X_1 and X_2) also has R_p^2 almost close to that of subset (X_1, X_2 and X_3) and low Cp.

Simple correlations between both AGF or CYG and any of independent parameters (height, compact circumference, or radius) for various defoliation intensity treatments were highly significant, except for light intensity, which was 0.35 for height and 0.36 for radius (Table 2). For this exception the correlation was significant only at 5% level. The correlations coefficient values were relatively low in spite of their high significance may be for irregularities in shape of shrub individuals. Bryant [5] found that some plants showed great variability in weight among individual plants, possibly due to the lack of uniformity in either growth on the degree to which they were browsed. Bentley [17] visually adjusted for irregularities in crown width and height of green leaf manzanita.

Highest simple correlations were achieved with compact circumference in all defoliation intensity treatments. Both height and circumference had the same value of correlation (0.54) in heavy defoliation treatment.

Coefficient of determination can be used to estimate the proportion in the dependent variable CYG or AGF that is attributed to variation in the independent

Table 2. Simple correlation between (AGF, CYG) and independent variables shrub dimensions

Grazing intens.	No. of observ.	Dependent variables	r_yx_1	r_yx_2	r_yx_3
Heavy	36	AGF, CYG	0.54**	0.54**	0.46**
Medium	36	AGF, CYG	0.41	0.63	0.49
Light	36	AGF, CYG	0.35	0.53	0.36
Mixed	108	AGF	0.40	0.55	0.43
		CYG	0.38	0.43	0.31

X_1 = height, X_2 = c. circumference and X_3 = radius
ryx = correlation coefficient
* = significant at 5% level
** = significant at 1% level

variable (height, circumference or radius). Accordingly, variation in shrub weight parameters under heavy treatment can be attributed to variation in height and circumference, each contributes by 29%. The variation for medium treatment may be affected up to 40%, 24% by circumference and radius, respectively, while for light treatment, circumference was the most effective parameter with 28%.

Irrespective to the degree of grazing, where the range is not under control, and there is uneven distribution of shrub grazing from heavy to light, mixed defoliation treatment revealed that the correlations between AGF and any of independent variables X_1, X_2 and X_3 (0.40, 0.55 and 0.43), respectively, were higher than the correlation between CYG and those independent variables (0.38, 0.43 and 0.31), respectively. The differences of correlations between the two dependent variables AGF and CYG were higher for circumference and radius than that for height. Rittenhouse and Sneva [18] also noted good results in estimating big sagebrush with one variable. Cook [19] preferred two or more plant measurements than one single measurement.

Multiple correlation (R^2) values of predicting equations, derived using different correlation models (Table 3), revealed that all correlations between AGF or CYG and independent variables for different defoliation treatments were highly significant, except square root, semi-log and log-log models for light intensity defoliation treatment. The R^2 values of predictive equations varied from 0.19 in semi-log subset for CYG of mixed defoliation to 0.53 in quadratic subset for medium defoliation treatment.

The relation between AGF or CYG and independent variables could be best expressed with quadratic regression equations for medium and light defoliation

Table 3. Coefficient of determination (R^2) for different models based on regression AGF, CYG on 3 shrub dimensions of *S. vermiculata*

Grazing intensity	No. of observ.	Depend. variable	Linear	Quadratic	Sq. root	Semi-log	Log-log
Heavy	36	AGF,CYG	0.36	0.35	0.35	0.37	0.35
Medium	36	AGF,CYG	0.40	0.53	0.41	0.35	0.39
Light	36	AGF,CYG	0.29	0.33	0.28	0.27	0.25
Mixed	108	AGF	0.32	0.30	0.32	0.30	0.30
		CYG	0.22	0.24	0.21	0.19	0.20

intensity treatments. AGF or CYG weights of heavy defoliation treatment were best predicted with semi-log equations. For mixed defoliation treatment, AGF weight could be predicted well with either a linear or square-root, while CYG weight was best expressed with quadratic equation. The log-log model proved least reliable in predicting plant production for all treatments.

In general, the linear model for most treatments had R^2 values lower than those for the best models with small difference. For this, the linear regression equations could be taken as a good predictor of AGF and CYG for most treatments. For mixed treatments, there was no difference between R^2 values of linear model and the best model (square root) for AGF parameter, while R^2 value for CYG increased from linear model (0.22) to (0.24) for the best model (quadratic). The increase of R^2 values from linear to the best models for heavy (semi-log) and light (quadratic) defoliation treatments were 0.01 and 0.04, respectively. The difference was high for medium defoliation treatment and increased from linear (0.40) to quadratic (0.53). Ruyle [20] used three models to predict snowberry utilization and found the accuracy of the models varied with grazing intensities.

Reliable linear regression equations and their alternatives, which have high R^2 values, to predict AGF and CYG are shown in (Table 4). Regression equation may predict browse production with high precision, but equations generally apply only to specific situations [6]. Forage production varies within and among species, among years, with age of plants, season of the year, and with sites. Hughes [1] pointed that the equations developed must be used carefully and tested, due to the possible effects of weather and animal consumption on forage production, although they found range site had no effect on the regression equations for any of the species measured

Table 4. Equations and R^2 values from regression analysis models to predict allowable grazing foliage and current year growth of *S. vermiculata*

Grazing intens.	No. of observ.	Depend. variable	Model	Predective equations	R^2
Heavy	36	AGF	Linear	$Ya = 22.4 + 0.76\,X1 + 0.28\,X2 - 0.98\,X3$	0.36
			semi-log	$Ya = -96.6 + 28.7 \log X1 + 24.6 \log X2 - 19.9 \log X3$	0.37
		CYG	Linear	$Yc = 30.1 + 1.04\,X1 + 0.38\,X2 - 1.37\,X3$	0.36
			semi-log	$Ya = -130 + 39.3 \log X1 + 3301 \log X2 - 27.7 \log X3$	0.37
Medium	36	AGF	Linear	$Ya = 10.3 + 0.61\,X1 + 0.40\,X2 - 0.12\,X3$	0.40
			quad.	$Ya = -1663 + 1.57\,X1 + 0.63\,X^22 - 3.7\,X^23$	0.53
		CYG	Linear	$Yc = -20.5 + 1.21\,X1 + 0.98\,X2 + 0.24\,X3$	0.40
			quad.	$Yc = -665 + 6.27\,X^21 + 2.53\,X^22 - 14.8\,X^23$	0.53
Light	36	AGF	Linear	$Ya = 23.7 + 0.25\,X1 + 0.29\,X2 - 0.13\,X3$	0.29
			quad.	$Ya = 596 + 0.2\,X2 + 0.17\,X^22 + 1079\,X^23$	0.33
		CYG	Linear	$Yc = -95.2 + 0.97\,X1 + 1.15\,X2 - 0.52\,X3$	0.29
			quad.	$Yc = -9630 + 3.1\,X^21 + 2.64\,X^22 + 28.6\,X^23$	0.33
Mixed	108	AGF	Linear	$Ya = -16.7 + 0.28\,X1 + 0.33\,X2 - 0.07\,X3$	0.32
			sq. root	$Ya = 4.69 + 0.02\,\sqrt{X1} + 0.02\,\sqrt{X2} + 0.13\,\sqrt{X3}$	0.32
		CYG	Linear	$Yc = 14.4 + 2.1\,X1 + 1.1\,X2 - 2.45\,X3$	0.22
			quad.	$Yc = -782.5 + 8.05\,X^21 + 2.41\,X^22 - 16.7\,X^23$	0.24

** All models in the table were significant at 0.01 level of probability.

in their studies. In contrast, Lyon [21] found that the precision of regression equations varied with range site for serviceberry plant.

Browsing intensity often affects the accuracy of regression techniques and equations [12 and 13]. Many studies revealed that it should be warned that frequent checks may be necessary to assure application of the most appropriate equation [7,9,11,12 and 22].

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التوقع بالإنتاجية الرعوية لشجيرات الروثة تحت معدلات الرعي المختلفة

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ملخص البحث. تعتبر الروثة أحدى الشجيرات الرعوية المحلية المهددة بالانقراض ذات الاستساغة النسبية العالية والتوقع بالإنتاجية النباتية السنوية والكمية المسموح برعيها تحت ظروف الرعي المختلفة مهم لتقدير الحمولة الرعوية.

تهدف هذه الدراسة إلى التوقع بالإنتاجية الخضرية للسنة الجارية ووزن الجزء الأخضر المسموح برعيه تحت ظروف الرعي المختلفة (خفيف ـ متوسط ـ جائر) عن طريق قياسات حجم التاج الخضري ذات العلاقة القوية مع الإنتاجية (ارتفاع الشجيرة ـ محيط الشجيرة المضغوط، نصف قطر التاج).

أظهرت النتائج أن معاملات الارتباط والانحدار البسيط المتعدد المدروسة بين محددات الإنتاجية والقياسات المرتبطة بحجم شجيرة الروثة تحت معدلات الرعي المختلفة، وجود ارتباطات معنوية عالية بين كل من الإنتاجية الخضرية للسنة الجارية والجزء المسموح به للرعي مع القياسات المدروسة، كذلك بينت النتائج أن محيط التاج الخضري المضغوط له التأثير الأكبر في توقع الإنتاجية.

وكانت أفضل المعادلات التي يمكن استخدامها للتوقع بإنتاجية الروثة تحت ظروف التجربة هي المعادلات التربيعية لكل من الضغط الرعوي والمتوسط والخفيف ومعادلات الشبه لوغاريتيمة للضغط الرعوي الجائر.