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Estimating Twig Production of Four *Atriplex* species Using Shrub Measurements

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Abstract. *Atriplex* spp. received considerable attention for its adaptation as browse shrubs in arid and saline range regions. The relationships beween shrub production parameters (current year growth, CYG, and allowable grazing foliage, AFG) and shrub dimensions (height, compact circumference and radius) were investigated for 4 *Atriplex* spp. Shrubs investigated were *Atriplex halimus, At. nummularia, At. canscens* and *At polycarpa*. Simple correlations revealed that compact circumference seems to have the highest proportion efficiency to estimate production parameters for most species. Multiple correlations showed that polynomial regression equations could be used to predict production parameters of *At. canscens* and *At. polycarpa*, while log-log equations were AGF could be expressed with quadratic equation and CYG with polynomial equation. The applicability of such equations varied according to many factors i.e. species, agroclimate, browsing pressure ... etc.

Introduction

Atriplex spp. are valuable shrubs for browse and adapted to saline and arid range regions. These species are very useful source of protein and mainly utilized for grazing by sheep and goats. Browse biomass is commonly recognized as one of the most difficult of all vegetation components to measure [1]. Estimating current production and utilization of shrub species possessed difficult problems for range managers. Shrubs are often large plants which are difficult to harvest [2]. They frequently exhibit intermittent growth during the current season that is often difficult to distinguish from that produced during previous growing seasons. Even so, knowledge of production is important as production directly influences the grazing capacity [3], forage available to herbivores [1], and estimation of their utilization [4].

Rapid and non destructive methods are needed to make biomass estimates in order to avoid the labor and expenses required to clip and weigh large shrubs and also to preserve the ecosystem [5]. Regression methods have been widely used to estimate total biomass, current annual production, and utilization in shrubs while reducing sample costs.

Shrub variables such as height, crown diameter, (height X circumference), crown volume, and current annual stem diameter and length were used to predict production parameters of different species or plant parts within species [6-11]. Few studies dealt with more than one shrub species [1, 3, 5, 12].

Byrant *et al.* [1] evaluated the use of various regression functions for the prediction of biomass from crown volume for several browse species. He found that log-log function yields best results with some species and quadratic function with other species under study. Haughes *et al.* [3] obtained the same results. Bently *et al.* [12] expressed their data on a log-log scale between the dependent and independent variables. Rittenhouse and Seneva [13] suggested the use of the exponential form for estimating big sagebrush production.

The objectives of this study were to (1) determine the relations between shrub dimensions (height, compact circumference and radius) and forage production parameters of four *Atriplex* spp shrubs (current year growth, CYG, and allowable grazing foliage, AGF), (2) evaluate the use of various regression functions for the prediction of (CYG) and (AGF) of various *Atriplex* spp, and (3) develop reasonable predicting equations to determine (CYG) and (AGF).

Materials and Methods

In February, 1989, shrub seedlings of four *Atriplex* species were established at King Saud University Desert Research Station at Al-Ghutghut, located 50 km. west of Riyadh. Four *Atriplex* species were studied: *Atriplex halimus, At. nummularia* Lindly, *At. canscens* James, and *At. polycarpa.* Wats. The soil at the study site was Torripsamments, sandy loam, deep, calcareous, 0-3% slope, permeability 1-5 cm/hr, salinity 0.8 to 3.8 mmohs/cm. The climate condition is subtropical hyper arid type. Average annual rainfall is about 100 mm/yr.

Seedlings were cultivated in rows three meters apart, while the distance between the successive plants in each row was two meters. Plants were fertilized annually in spring season with 100 g of ammonium sulfate for each. Plants were supplementary irrigated with saline water (about 5000 ppm). When shrubs were well established, 108 individual plants of each species were chosen at random as material for the study, except in case of *At. nummularia,* 72 individuals were chosen for its limited availability. Plants were subjected to three different defoliation intensities representing the more expected allowable grazing foliage (AGF), nearly equal 25%, 50%, and 75% of the current year growth (CYG) corresponding to light, medium and heavy grazing intensities, respectively. One third of each species plants represented one defoliation intensity.

In March, 1991, each individual plant was measured to the nearest centimeter for (1) average height of plant (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 (w1) and crown width at right angles to w1 (w2), so, radius = (w1+w2)/4, representing (X_3). Height and radius related directly to the crown volume. Compact circumference was measured to overcome the variation in crowded foliage of the crown in different plants. These dimensions (X_1, X_2 and X_3) were taken as independent variables.

For production estimates, clipped foliage samples were oven dried at 60°C for approximately 48 hours, and weighed to the nearest 0.1 g. The (CYG)'s of shrubs from each species were estimated according to the dry weight of (AGF)'s. Both (AGF) and (CYG) were taken as dependent variables (Y_a and Y_c), respectively.

The set of independent variables (X_1, X_2 and X_3) for each *Atriplex* species to be employed separately in different models were examined by Rp^2 and Cp criteria as mentioned in Neter *et al.* [14]. The criterion Rp^2 examines the coefficient of determination R^2 values in order to select one or several subsets of X variables. The 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 correlations between dependent variables (AGF or CYG) and each of the independent variables (height, compact circumference or radius) were conducted [15, 16]. Multiple correlations were also investigated between dependent variables and subset of independent variables (X_1, X_2 and X_3).

Different regression models were evaluated for suitable predictive equations. The investigated regression models included linear, ($y=a+b1\ X_1 + b2\ X_2 + b3\ X_3$) quadratic ($y^2=a + b1\ X^2_1 + b2\ X^2_2 = b3\ X^2_3$), square root transformation ($y^{1/2}=ab1\ X^{1/2}1 + b2\ X^{1/2}2 + b3\ X^{1/2}3$), semi-log ($y=a + b1\ logX_1 + b2\ logX_2 + b3\ logX_3$), log-log ($logy=a + b1\ logX1 + b2\ logX2 + b3\ logX_3$) and polynomial ($y=a+b1\ X_1 + b2\ X_2 + b3\ X_3 + b4\ X^2_1 + b5\ X_1 X_2 + b6\ X^2_2 + b7\ X_1 X_3 + b8\ X_2 X_3 + b9\ X^2_3$) functions, where y= (AGF or CYG), X_1= height, X_2= compact circumference and X_3=radius. Regression coefficients and the best predictive equations were derived for different treatments.

Results and Discussion

Height, compact circumference and radius parameters were chosen from number of parameters for their expected high relationship with the foliage production and their reasonable measurements. These measurements are criteria for volume determination. Rp and Cp criteria were taken as selective procedures for the examination of all possible regression [14]. Table 1 shows that the use of the subset (height, X_1, compact circumference, X_2, radius, X_3) in the regression models appears to be reasonable for all Atriplex species. This subset has the highest R_p^2 and low Cp that is near to p value (p= parameter number). The subset (X_1 and X_2) has R_p^2 almost close to that of subset (X_1, X_2 and X_3) and low Cp also, but it is preferred to take the subset (X_1, X_2 and X_3) as radius independent variable is considered essential parameter related to the crown volume. The height seems to be the most efficient parameter for predicting (AGF) and (CYG) of all shrub species. The subset (X_1) has higher (Rp) and lower Cp values than those of (X_2) and (X_3) subsets.

Simple correlations between both dependent variables (AGF or CYG) and any of the independent variables (X_1, X_2 or X_3) for all shrub species were highly significant at 0.0005 level. Although the correlations were highly significant, a number of their values seems to be low. Correlation coefficient values ranged from 0.35 for the correlation between (CYG) and height in case of *At. canscens* to 0.66 for the correlation between (AGF) and compact circumference of the same plant. Correlation coefficient values between (AGF) and any of the independent variables (X_1, X_2 or X_3) were higher than those between (CYG) and any of the independent variables for all species, except the case of *At. halimus* for compact circumference and radius.

Correlation square can be used to estimate the proportion in the dependent variable (AGF or CYG) that is attributed to variation in the independent variables (height, compact circumference, and radius). Compact circumference seems to have the highest proportion efficiency to estimate dependent variables (AGF and CYG), except for (AGF) weight of *At. halimus*, where height had the highest proportion (35%). Height variable had the same proportion efficiency (37%) like that of compact circumference to estimate (AGF) of *At. nummularia*. Height variable had the lowest proportion efficiency to estimate dependent variables of *At. canscens* and *At. polycarpa*. while radius had the lowest proportion to estimate *At. nummularia*.

Techniques used for predicting browse yield have included linear regressions of crown volume and the weight of plants. Crown volume requires at least two measurements of the plant in addition to weight, and is well suited because the combination of measurements is usually better than any single measurement [17]. Bentley *et al.* [12] had dealt with volume-weight relationship for more than one shrub species.

Multiple correlation (R^2) values of predictive equations, derived using different correlation models are presented in Table 3.

All correlations between dependent variables (AGF or CYG) and independent variables (height, circumference and radius) were highly significant at 0.001 level for

Table 1. Coefficient of determination (R^2) and Cp values for all possible regression models of four Atriplex species.

Species	Depen. vari.	P	X_1 2	X_2 2	X_3 2	X_1X_2 3	X_1X_3 3	X_2X_3 3	$X_1X_2X_3$ 4
At. halimus	Y_a	R^2	0.35	0.23	0.21	0.36	0.36	0.24	0.36
		cp	1.9	20.9	25.3	2.2	2.3	21.8	4.0
	Y_c	R^2	0.33	0.31	0.26	0.37	0.35	0.34	0.37
		cp	6.0	10.5	18.4	2.5	5.7	7.5	4.0
At. nummularia	Y_a	R^2	0.37	0.37	0.23	0.49	0.40	0.39	0.49
		cp	14.9	15.3	34.1	2.0	13	15	4.0
	Y_c	R^2	0.20	0.18	0.17	0.25	0.23	0.22	0.26
		cp	5.3	7.6	8.2	3.0	4.8	5.1	4.0
At. canscens	Y_a	R^2	0.44	0.25	0.20	0.45	0.44	0.28	0.46
		cp	3.3	39.4	49.4	2.1	4.3	35.1	4.0
	Y_c	R^2	0.18	0.12	0.12	0.20	0.19	0.15	0.21
		cp	3.4	10.9	11.2	2.1	4.3	9.0	4.0
At. polycarpa	Y_a	R^2	0.37	0.27	0.23	0.39	0.38	0.30	0.39
		cp	3.9	20.6	27.4	2.6	3.5	18.0	4.0
	Y_c	R^2	0.27	0.22	0.22	0.30	0.28	0.26	0.31
		cp	6.3	12.7	13.3	2.4	5.4	9.1	4.0

(X_1) = Plant height, (X_2) = Comp. circumference, (X_3) = Radius
Y_a = AGF = Available grazing foliage
Y_c = CYG = Current year growth.

Table 2. Simple correlation between (AGF,CYG) and independent variables (X_1, X_2 and X_3)

Species	No. of obser.	Depen. vari.	Correlation coeff. r_yx_1	r_yx_2	r_yx_3
At. halimus	108	AGF	0.59	0.45	0.48
		CYG	0.51	0.58	0.55
At. nummularia	72	AGF	0.61	0.61	0.48
		CYG	0.42	0.45	0.41
At. canscens	108	AGF	0.44	0.66	0.50
		CYG	0.35	0.43	0.35
At. polycarpa	108	AGF	0.48	0.61	0.52
		CYG	0.47	0.52	0.48

All correlation coefficients were significant at 1% level.

Table 3. Coefficient of determination (R^2) values based on regressions of AGF and CYG on shrub dimensions

	Depen. varia	*At. halimus*	*At. nummul.*	*At. canscens*	*At. polycarpa*
No. of observ.		108	72	108	108
Linear	AGF	0.36	0.49	0.46	0.39
	CYG	0.37	0.26	0.21	0.31
Quadratic	AGF	0.23	0.51	0.44	0.34
	CYG	0.27	0.32	0.19	0.27
Sq. root	AGF	0.42	0.46	0.46	0.39
	CYG	0.45	0.24	0.22	0.32
Semi-log	AGF	0.34	0.46	0.39	0.39
	CYG	0.32	0.24	0.18	0.29
Log-Log	AGF	0.48	0.44	0.42	0.38
	CYG	0.49	0.23	0.20	0.32
Polynom.	AGF	0.40	0.50	0.49	0.40
	CYG	0.39	0.36	0.23	0.34

all *Atriplex* species. R^2 value of predictive equation varied from 0.19 for quadratic, model to estimate (CYG) of *At. canscens,* to 0.51 for quadratic model also to estimate (AGF) of *At. nummularia.*

The relation between dependent variable (AGF or CYG) and independent variables (X_1, X_2 and X_3) could be best expressed with log-log regression equations for *At. halimus* shrub, while it was polynomial for both *At. canscens* and *At. polycarpa.* Quadratic regression equation had the highest (R^2) value to predict (AGF) weight of *At. nummularia,* and polynomial regression equation was the best equation to predict (CYG) for this shrub. The semi-log model proved least reliable in predicting plant production for all species.

The difference between (R^2) values of linear regression model and the best regression model for predicting (AGF) or (CYG) was small in case of *At. canscens* and *At. polycarpa,* where polynomial model was the best model for predicting both dependent variables. The difference of (R^2) values was also small (0.02) to predict (AGF) of *At. nummularia.* The highest differences of (R^2) values appeared for *At. halimus* as it increased from (0.36 and 0.37) for linear regression model to (0.48 and 0.49) for log-log regression model to predict (AGF) and (CYG), respectively. The (R^2) values for predicting (CYG) of *At. nummularia* increased from 0.26 for linear regression model to 0.36 for polynomial regression model. Hughes *et al.* [3] found the log-log and quadratic models, in particular, work best for several South Texas species.

Equations presented in Table 4, are the linear regression equations and the best model regression equations for the predicting of shrub allowable grazing foliage (AGF) and current year growth (CYG) for different species under study, using the three dimensions (height, compact circumference and radius) of the shrub. However, any of these predicting equations should be used carefully as they could be affected by many factors. Hughes *et al.* [3] suggested that the equations developed must be used carefully and tested, due to the possible effect of weather and animal consumption on forage production. Several authors had emphasized the effect of site, browsing pressure, over story canopy, and years on the relationship between foliage weight and shrub measurements [3, 4, 11, 18-22]. The correlation between edible biomass of different browse plants and crown volume was affected by the quadratic or log-log equations dependent upon the species [1]. They also showed that great variability in weight especially among the older plants, possibly due to the lack of uniformity in either growth or the degree to which they were browsed.

Table 4. Equations and R^2 values from regression analyses for linear and best models predicting allowable grazing foliage and current year growth of four Atriplex spp.

Species	n	Dep. var.		Equations*	R
At. halimus	108	AGF	Linear	$Y_a = -3.89 + 0.75 X_1 + 0.04 X_2 + 0.31 X_3$	0.36
			Log-Log	$\log Ya = -0.22 + 0.64 \log X_1 + 0.23 \log X_2 + 0.141 X_3$	0.48
		CYG	Linear	$Y_c = -83.5 + 1.2 X_1 + 0.85 X_2 + 1.55 X_3$	0.37
			Log-Log	$\log Y_c = -1.4 + 0.51 \log X_1 + 0.62 \log X_2 + 0.32 \log X_3$	0.49
At. nummul.	72	AGF	Linear	$Y_a = 1.35 + 0.52 X_1 + 0.27 X_2 + 0.05 X_3$	0.49
			Quadr.	$Y = 282 + 0.47 X^2_1 + 0.19 X^2_2 + 0.09 X^2_3$	0.51
		CYG	Linear	$Y_c = -28.5 + 1.07 X_1 + 0.64 X_2 + 1.72 X_3.$	0.26
			polynom.	$Y_c = 0.33 + 0.7 X_1 + 0.42 X_2 + 0.76 X_3 + 0.44 X^2_1 + 0.22 X_1X_2 + 0.06 X^2_2 + 0.8 X_1X_3 + 0.12 X_2X_3 + 0.52 X^2_3.$	0.36
At. canscens	108	AGF	Linear	$Y_a = -19.3 + 0.34 X_1 + 0.48 X_2 + 0.20 X_3$	0.46
			polynom.	$Y_a = 28.3 + 0.33 X_1 - 0.16 X_2 - 0.89 X_3 - 0.004 X^21 + 0.01 X_1X_2 + 0.001 X^2_2 - 0.04 X_1X_3 - 0.02 X_2X_3 + 0.01 X^2_3$	0.49
		CYG	Linear	$Y_c = -62.5 + 1.42 X_1 + 0.92 X_2 + 0.85 X_3$	0.21
			polynom.	$Y_c = -538 - 0.33 X_1 - 0.95 X_2 + 12.2 X_3 - 0.02 X^2_1 + 0.05 X_1X_2 + 0.004 X^2_2 - 0.04 X_1X_3 - 0.06 X_2X_3 - 0.06 X^2_3$	0.23
At. polycarba	108	AGF	Linear	$Y_a = -7.57 + 0.16 X_1 + 0.21 X_2 + 0.25 X_3$	0.39
			polynom.	$Y_a = 2.2 + 0.04 X_1 - 0.35 X_2 + 1.2 X_3 - 0.003 X_1X_2 + 0.02 X_1X_3 - 0.001 X_2X_3 - 0.034 X^2_3$	0.40
		CYG	Linear	$Y_c = -35.4 + 1.16 X_1 + 0.67 X_2 + 0.91 X_3$	0.31
			polynom.	$Y_c = -74.3 + 3.3 X_1 - 1.6 X_2 + 7.4 X_3 - 0.03 X^2_1 + 0.05 X_1X_2 - 0.003 X^22 - 0.12 X_1X_3 + 0.002 X_2X_3 - 0.02 X^2_3$	0.34

*All models were significant at 0.005% level of probability.

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تقدير الإنتاجية الخضرية لأربعة أنواع من شجيرات القطف باستخدام قياسات النمو

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ملخص البحث. تعتبر أنواع القطف من الشجيرات ذات الإنتاجية الرعوية المقبولة تحت ظروف الجفاف والملوحة. والتوقع بالإنتاجية الرعوية لهذه الشجيرات قبل موسم الرعي مهم لتقدير الطاقة الكامنة للرعي، كما أن الحمولة الرعوية لها علاقة قوية بقياسات النمو الخضري للشجيرات، خاصة ارتفاع الشجيرة والمحيط المضغوط ونصف قطر التاج الخضري.

وتهدف هذه الدراسة إلى التوقع بالإنتاجية الخضرية للسنة الجارية والكمية المسموح بها للرعي دون التأثير على قوة الشجيرة لأربعة أنواع من القطف هي (القطف الملحي ـ القطف الأمريكي ـ قطف البولي كاربا ـ القطف الأسترالي).

وبمعالجة النتائج إحصائيًا، أظهرت معاملات الارتباط والانحدار البسيطة والمتعددة بين محددات الإنتاجية والقياسات المرتبطة بحجم الشجيرة، وجود معاملات ارتباط معنوية بين كل من الإنتاج الخضري للسنة الجارية والكمية المسموح بها للرعي مع قياسات النمو لجميع الأنواع، كما تبين أن محيط التاج الخضري المضغوط له الأثر الأكبر في توقع الإنتاجية لمعظم الأنواع.

وبدراسة معاملات الارتباط المتعدد للمعادلات الرياضية المختلفة، وجد أن المعادلات المتعددة الحدود Polynomial هي أفضل المعادلات لتقدير محددات الإنتاجية لكل من القطف الأمريكي وقطف البولي كاربا، وأن المعادلات اللوغاريتمية Log-Log هي الأفضل للقطف الملحي، أما القطف الاسترالي فإن المعادلة متعددة الحدود هي أفضل معادلة لتقدير الكمية المسموح بها للرعي، بينما المعادلة التربيعية Quadratic كانت الأفضل لتقدير الإنتاج الخضري للسنة الجارية.