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Multivariate Analysis of Seedling Survival and Establishment and their Related Growth Attributes in *Hammada elegans*

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Abstract. *Hammada elegans* is a widely distributed shrub in arid rangelands. It has a potential for reseeding. Identification of reliable and easy to measure growth attributes will help in monitoring seedling survival and establishment in reseeding projects. The aim of this study is to identify seedling growth attribute(s) that can be used to predict survival and establishment of *H. elegans* using simple correlation, factor analysis and path-coefficient analysis. Survival and establishment were highly and significantly correlated with most growth attributes. It was therefore difficult to identify any single attribute that has the greatest influence on survival and establishment using this approach. Factor analysis classified growth attributes into three groups of factors. Factor one accounted for 59% of variation and included survival and growth attributes measured post rainy seasons. Factor two included growth attributes during the rainy season while factor three included establishment only. This indicated that survival was associated with growth attributes measured post raining season while establishment was independent of the attributes studied using this approach. Path-coefficient analysis revealed a major direct effect of root depth and shoot weight on survival. There were also considerable indirect effects of shoot height and shoot weight on establishment. It is therefore concluded that growth measurements after the rainy season are good indicators of survival but further work is needed to identify predictors of establishment.

Introduction

Hammada elegans (Bge.) Botsch. is a widely distributed shrub in areas east of Pakistan and west of Libya, with greater diversity in Southern Iraq and Northern Saudi Arabia [1, p.387, 2, pp.l65-169]. *H. elegans* has been reported in many diverse habitat ranging from coastal plains and near salt marches to rocky hills and shallow to deep sandy soils [2, p.387, 3, p.237,4]. Several researchers have considered *H. elegans* as a promising range plant species for range reseeding programs because of its forage value, mainly for camels and for its environmental value as an effective sand stabilizing species [4, 5, 6]. Nevertheless, there is no data available on seedling establishment and survival except for a limited information on seed germination and seedling growth [4, 5].

This paper is part of a project to study seedling survival and establishment in *H. elegans* [7]. The objective of this study is to understand the growth attributes affecting seedling survival and establishment of *H. elegans* seedlings using multivariate analysis procedures. Multivariate procedures, such as factor analysis and multiple regression analysis, are used to explain the inter-correlations among a set of characters. They could also be used to select a group of few important characters among the original large set of characters [8, pp.1-21]. Path-coefficient analysis, standardized multiple regression, is a precise and accurate method for partitioning correlation coefficients into direct and indirect effects. These methods have been successfully used by plant breeders to identify characters affecting yield [9-13].

The present study applies three different statistical approaches, simple correlation, factor analysis and path-coefficient analysis, to study inter-relationships among growth characters related to seedling survival and establishment to identify the characters that affect seedling survival and establishment most. Results of this study will be helpful to researchers trying to understand seedling survival and establishment and to plant breeders working to select for improved seedling establishment of *H. elegans.*

Materials and Methods

The study was conducted on data obtained from a study on the effects of amount and distribution of rainfall on seedling survival and establishment of *H. elegans* [7]. A total of 720 tubes (15×50 cm) filled with soil were used in that experiment. Each tube contained three plants. Plants from three different populations, Riyadh, Qassim and Aljouf, were grown for 90 days under three moisture levels, equivalent to 100, 200 and 400 mm of rain and two patterns of distribution of rainfall, 7 and 14 days interval. Plants then were allowed to grow for 60 days on the residual moisture in the tubes [7]. The following measurements were taken for analysis: 1) Stem growth rate during the wet period, 2) Root growth rate during the wet period, 3) Stem growth rate during the dry period, 4) Root growth rate during the dry period, 5) Plant height at the end of the experiment, 6) Root depth at the end of the experiment, 7) Top dry weight, 8) Root dry weight, 9) Seedling survival (% seedlings remaining at the end of the experiment) and 10) Seedling establishment (% seedlings with roots equal or greater than 45 cm.). Means across populations and treatments were used in the statistical analysis in this study to represent the effect of the growth parameters on seedling survival and establishment (Table 1).

All variables were checked for normality with procedure Univariate using SAS [14]. Pearson correlation coefficients were calculated over all treatments among all biological traits evaluated in the study to obtain the degree of association among traits. The principal component analysis was obtained using the procedure FACTOR.

The data then were standardized to a mean = 0 and Std = 1 using the procedure STANDARD. The output data were used in a multiple regression analysis to obtain the standardized partial regression coefficients (SPRC), which represent the direct effect of each trait on seedling survival and establishment [15]. SPRC were then used to estimate the indirect effects in the Path Coefficient Analysis.

Table 1. Means of growth attributes and seedling survival and establishment of *H. elegans* seedlings included in the study

Attribute	Mean	Attribute	Mean
Top growth rate (wet period)	0.41 mm/day	Root length	345.75 mm
Root growth rate (wet period)	2.17 mm/day	Shoot weight	0.19 g/plant
Top growth rate (dry period)	0.75 mm/day	Root weigh	0.21 g/plant
Root growth rate (dry period)	1.82 mm/day	Seeding survival	23.89%
Shoot length	98.4 mm	Seedling establishment	6.08%

Results and Discussion

1. Simple correlation

Significant correlation coefficients were observed between all growth attributes and both seedling survival and establishment (Table 2). Stem and root growth rates during the dry period, plant height, root depth and top and root weights had the highest correlation coefficients with seedling survival and establishment ($P<0.01$). There were very significant correlations among all growth attributes except between stem and root growth rates during the wet and dry periods (Table 2). This could be attributed to the patterns of growth for shoot and roots during the wet and dry periods in which *H. elegans* seedlings convert more growth towards roots during early growth stages to develop a root system that could support the top growth during the dry period (Table 1). This is common in desert plants to insure survival [16, 17].

Table 2. Simple correlation coefficients among growth attributes and seedling survival and establishment

	Top Growth Rate (wet period)	Root Growth Rate (wet period)	Top Growth Rate (dry period)	Root Growth Rate (dry period)	Seedling Height	Root Depth	Top Dry Weight	Root Dry Weight	Survival
Root Growth Rate (wet period)	0.653**	-	-	-	-	-	-	-	-
Top Growth Rate (dry period)	0.051	0.135*	-	-	-	-	-	-	-
Root Growth Rate (dry period)	0.098	0086	0.876**	-	-	-	-	-	-
Seedling Height	0.250*	0175	0.765**	0.760**	-	-	-	-	-
Root Depth	0.210*	0221*	0.737**	0.806**	0.905**	-	-	-	-
Top Dry Weight	0.279**	0.224*	0.726**	0.748**	.0955**	0.886**	-	-	-
Root Dry Weight	0.250*	0.219*	0.668**	0.648**	0/808**	0.775**	0.807**	-	-
Survival	0.252*	0.213*	0.587**	0.558**	0.734**	0.768**	0773**	0.694**	-
Establishment	0.299*	0265*	0.549**	0.556**	0.700**	0.664**	0.702**	0.625**	0.682**

* Significant at $P < 0.05$
** Significant at $P < 0.01$

Results of correlation coefficients did not help in the identification of traits contributing most to seedling survival and establishment because of the high correlation among the growth attributes measured in this study. Gomez and Gomez [18, p.358] stated that it is difficult to determine which character is more important to the dependent variable from a number of correlations involving many related characters. The same conclusion was reached by other researchers trying to identify traits affecting yield in agricultural crops [9-13].

2. Factor analysis

Factor analysis is a multivariate procedure used to simplify a large set of characters into few factors affecting the dependent variable. The magnitude of the influence of a factor is the factor loading for that character. Factor loading greater than 0.5 are usually considered important to the factor [8, p. 45-60]. In this study factor analysis has revealed that growth attributes of *H. elegans* seedling could be distinguished into three factors (Table 3).

Table 3. Factor analysis of growth attributes, seedling survival and establishment

Source	Factor 1	Factor 2	Factor 3	Communalities
Top Growth Rate (wet period)	0.472	0.7	-0.238	0.818
Root Growth Rate (wet period)	0.345	0.772	-0.282	0.775
Top Growth Rate (dry period)	0.587	-0.617	0.019	0.756
Root Growth Rate (dry period)	0.555	-0.685	-0.167	0.805
Seedling Height	0.880	0.073	-0.124	0.795
Root Depth	0.806	-0.085	-0.300	0.746
Top Dry Weight	0.891	0.045	-0.420	0.798
Root Dry Weight	0.677	-0.044	0.108	0.472
Survival	0.464	0.259	0.801	0.924
Establishment	0.796	0.194	0.282	0.751
Variance	4.502	2.0106	1.003	7.611

The most important factor, factor one explained 59% of the variations among characters in the study. It contained stem and root growth rates during the dry period, plant height, root depth, top and root weights and seedling survival. All the characters explained by factor one were measured during the dry period (Table 3). Factor two, on the other hand, accounted for characters measured during the wet period and included stem and root growth rates during the wet period. About 28% of variance was explained by factor two (Table 3). Factor three included only seedling establishment and accounted for only 13% of the variance. In this study, no character had loading higher than 0.5 on more than one factor (Table 3). This result indicated that seedling survival is associated with seedling growth attributes during the dry period while seedling establishment appeared independent of all characters studied.

3. Path-coefficient analysis

Results of path coefficient analysis have revealed that there were large direct effects on seedling survival from root depth (0.76) and top weight (0.77). Stem growth rate during the dry period also showed considerable direct contribution to seedling survival (0.39) (Table 4). The indirect effects of these traits on seedling survival were, also the highest among all variables. Plant height did not have any positive contribution to seedling survival. This could be attributed to the fact that the weak seedlings of *H. elegans* lost portions of their top growth to survive [7].

Path coefficients for seedling establishment were generally low. This result agrees with the result of factor analysis in that the contribution of the measured characters on seedling establishment were limited. Considerable direct effects on seedling establishment were observed only from plant height (0.26) and shoot weight (0.23) (Table 5). Indirect contribution of all traits were, also low. Root depth, which was highly correlated with seedling establishment ($r = 0.66$), had considerable indirect effect on plant height and top weight. This result indicates that plant height, which is easy to measure, could be used as an indicator of seedling establishment. The same conclusion has been reached by Clor *et al.* [19].

From the results of all tests we conclude that measurements of growth parameters during the dry season are better indicators of seedling survival than those measured during the wet season. While seedling establishment could not be associated to any of the studied traits. Path coefficient analysis has shown that plant height could be the best indicator of seedling establishment but further work is needed to identify good predictors of establishment.

Table 4. Path coefficients for direct (on diagonal and underlined) and indirect effects (off diagonal) of growth attributes on seedling survival of *H. elegans*

Attributes	Direct Effect	Indirect Effect								Correlation Coefficient
		Top Growth Rate (wet period)	Root Growth Rate (wet period)	Top Growth Rate (dry period)	Root Growth Rate (dry period)	Seedling Height	Root Depth	Top Dry Weight	Root Dry Weight	
Top Growth Rate (wet period)	0.1400	-	-0.0855	0.0201	-0.0511	-0.1750	0.1586	0.2140	0.0308	0.2520*
Root Growth Rate (wet period)	-0.1309	0.0914	-	-0.0532	-0.0488	-0.1230	0.1669	0.1718	0.0270	0.2121*
Top Growth Rate (dry period)	0.3942	0.0071	-0.0177	-	-0.4564	-0.5360	0.5566	0.5569	0.0823	0.5876**
Root Growth Rate (dry period)	-0.5210	0.0137	-0.0113	0.3453	-	-0.5320	0.6087	0.5738	0.0799	0.5572**
Seedling Height	-0.7000	0.0350	-0.0229	0.3016	-0.3960	-	0.6835	0.7326	0.0996	0.7334**
Root Depth	0.7552	0.0294	-0.0289	0.2905	-0.4199	-0.6340	-	0.6797	0.0955	0.7680**
Top Dry Weight	0.7672	0.0391	-0.0293	0.2862	-0.3897	-0.6690	0.6691	-	0.0955	0.7734**
Root Dry Weight	0.1233	0.0350	-0.0287	0.2623	-0.3376	-0.5660	0.5853	0.6191	-	0.6941**

* Significant at $P < 0.05$
** Significant at $P < 0.01$

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Table 5. Path coefficients for direct (on diagonal and underlined) and indirect effects (off diagonal) of growth attributes on seedling establishment of *H. elegans* seedlings

Attribute	Direct Effect	Indirect Effect								Correlation Coefficient
		Top Growth Rate (wet period)	Root Growth Rate (wet period)	Top Growth Rate (dry period)	Root Growth Rate (dry period)	Seedling Height	Root Depth	Top Dry Weight	Root Dry Weight	
Top growth rate (wet period)	0.0766	-	0.0480	0.0011	0.0027	0.0644	0.0155	0.0644	0.0266	0.2992**
Root growth rate (wet period)	0.0735	0.0500	-	0.0028	0.0024	0.0451	0.0164	0.0517	0.0233	0.2651*
Top growth rate (dry period)	0.0208	0.0039	0.0099	-	0.0243	01970	0.0545	0.1676	0.0709	0.5489**
Root growth rate (dry period)	0.0277	0.0075	0.0063	0.0182	-	0.1957	0.0596	0.1726	0.0688	0.5565**
Seedling height	0.2575	0.0192	00129	0.0159	0.0211	-	0.0670	0.2204	0.0858	0.6997**
Root depth	0.0740	0.0161	0.0162	0.0135	0.0223	0.2330	-	0.2045	0.0823	0.6638**
Top dry weight	0.2308	0.0214	0.0165	0.0151	0.0207	0.2460	0.0656	-	0.0857	0.7016**
Root dry weight	0.1062	0.0192	0.0161	0.0139	0.0180	0.2080	0.0574	0.1863	-	0.6250**

* Significant at 0.05
** Significant at 0.01

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التحليل متعدد العوامل لتأسيس وبقاء بادرات الرمث *Hammada elegans* وصفات النمو المرتبطة بهما

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ملخص البحث. الرمث *Hammada elegans* نبات شجيري واسع الانتشار في المملكة العربية السعودية. ويعتبر من النباتات الواعدة في عملية إعادة زراعة المراعي المتدهورة كما أن له أهمية بيئية خاصة في تثبيت الكثبان الرملية. وقد أجريت هذه الدراسة للتعرف على صفات النمو ذات الدلالة القوية على بقاء وتأسيس بادرات الرمث باستخدام معامل الارتباط البسيط وتحليل العوامل وتحليل معامل المرور وذلك للمساعدة في متابعة برامج إعادة الاستزراع. تبين من النتائج أن البقاء والتأسيس ارتبطا معنوياً بمعظم صفات النمو المدروسة، وعلى هذا يصعب تحديد الصفة أو الصفات ذات التأثير الأقوى على البقاء والتأسيس. وعند استخدام تحليل العوامل أمكن تصنيف الصفات المدروسة إلى ثلاث مجموعات من العوامل. ضم العامل الأول نسبة بقاء البادرات وصفات النمو التي درست بعد نهاية موسم الأمطار وهي معدل نمو الساق والجذر وارتفاع البادرة وعمق الجذر ووزن الساق ووزن الجذر وقد فسر هذا العامل ٥٩% من مجمل التباين في الصفات المدروسة. واشتمل العامل الثاني على معدل نمو الساق والجذر أثناء موسم الأمطار بينما انفردت نسبة تأسيس البادرات كعامل ثالث مستقل. أما تحليل معامل المرور فقد أظهر أن هناك تأثيراً عالياً على البقاء من كل من صفات عمق الجذر ووزن الساق كما كان لمعدل نمو الساق تأثير جيد ومباشر في نسبة البقاء. وقد كان لارتفاع البادرة ووزن الساق تأثير مباشر ومعتدل على نسبة التأسيس. ويستنتج من هذه الدراسة أنه يمكن متابعة البادرات بدراسة صفات النمو بعد نهاية موسم الأمطار.