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Interrelationship of vegetative characters in black saxaul (*Haloxylon aphyllum*)

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Abstract
Black saxaul (*Haloxylon aphyllum*) is one of the best options for rehabilitating drought affected desert lands. The species is remarkably adapted to the central dry environment of Iran and a major source of raising pasture productivity of the areas. Progenies of 25 randomly selected black saxaul trees from four populations of the species were studied in a randomized complete block design with three replications. Path analysis was used to study interrelationship of four vegetative characters, plant height, crown diameter, number of lateral branches, and collar diameter. There were substantial differences of the vegetative characters observed between the studied progeny families, implying enough variability to be used in the correlation coefficient estimating and partitioning. Correlation coefficient values varied from 0.202 to 0.935, all statistically significant for all combinations of the studied characters. Path analysis revealed that among the independent characters, crown diameter had the strongest direct effect (0.725) on plant height. Lateral branch numbers showed the lowest and trivial negative direct effect (-0.025) on the dependent variable. Collar diameter showed the strongest positive total indirect effect (0.673) on plant height. It can be summarized that direct and indirect effects of crown diameter and collar diameter mainly positively affect plant height respectively.

Keywords: Black saxaul; Correlation coefficient; Path analysis; Vegetative characters

Introduction
Establishing drought tolerant plant species is of great concern in arid regions of the world. Where soil moisture is not high and precipitation is insufficient for growing other water demanding plant species. Particularly in the regions with the shifting sand dunes, utilizing drought tolerant trees and shrubs species are more useful approach to fix the sand dunes as well as providing adequate fodder for the desert wild habitants. Vigorous plants with a high number of lateral branches would provide major objectives, shifting sand dune fixation and wild life fodder. There are a great number of plant species, which are regarded as drought tolerant, the most competitive being those that can be established, grow and survive well for a long period of time in the dry areas. Furthermore, when it comes to fodder production those with the most herbage production in such stressful environments are the most successful species. Last half a century experiences of sand dune fixation in Iran showed that black saxaul (*Haloxylon aphyllum*) of Chenopodiaceae is one of the best options within drought tolerant plant species for rehabilitating drought affected desert lands in the center part of the country to achieve the mentioned objectives. The species is one of the dominant plants in the continental deserts of the Asian Irano-Turanian region (Pyankov *et al.*, 1999). The species is remarkably adapted to the central desert woodland environment of Iran and a major source of raising pasture productivity of the areas. It ranges in size from a large shrub to a small tree. Traditionally it is used as livestock feed and firewood. It is also artificially planted on a large scale in the afforestation of arid areas of the country. Being highly drought resistant, it has played an important role in fixation of the sand dunes. There are scattered studies done on genetic variation and potential of the existing

H. aphyllum populations for basic and applied purposes (e.g. Pyankov *et al.,* 1999, Mirzaie-Nodoushan *et al.,* 2001, 2002 and 2009; Mirzaie-Nodoushan and Asadi-Corom, 2002). There is some information of the interrelationship between the vegetative and morphologic characters of the species for other ecologic conditions such as Yazd and Semnan provinces of the country (Salar *et al*., 2005; Mirhosseini *et al*., 2007). It would be useful to investigate the subject on the data collected on the species in Yazd conditions as well. Four morphologic characters were studied because they play the basic role for fixing the shifting sand dunes and provide required fodder for the wild life habitants.

This research was performed to study randomly selected plants within four *H. aphyllum* populations for their vegetative growth characteristics and interrelationship between the vegetative characters. Since shifting sand dune fixation is one of the most important objectives of the administrators for rehabilitating the drought prone areas, taller trees and shrubs with the most number of branches and larger collar diameter would be more effective and appropriate trees and shrubs within an even aged group of a tree species. Therefore, within plant population genetic variation may be characterized and used to screen the most suitable genotypes and to achieve the goals. For the shifting sand dune fixation, tall trees and shrubs with stronger collar structure and higher number of lateral branches are more suitable plants to meet the requirements. What is the nature of the possible interactions between the mentioned characters is what we were interested to study.

Correlation analysis is the first step to quantify the interaction between the target characters. Path analysis is widely used by researchers in many other plant species to evaluate interrelationship of various characters (e.g. Espahbodi *et al.,* 2008, Aliyu, 2006). In fact understanding the nature of interrelationship between the characters is very crucial and important for any plant breeding efforts. This knowledge would enable breeders to know how the selection pressure exerted by the breeders on one trait would cause changes in other related traits; furthermore, the direction and magnitude of such changes would be clarified.

Materials and methods

Seed was collected on 25 randomly selected black saxaul (*H. aphyllum*) trees from four populations of the species in four central provinces of the country. The seeds were sown in plastic pots and grown for four months to make sure they would stand the harsh conditions of their natural habitat in which they were going to be established. Eighteen seedlings of each 25 genotypes (25 progeny families) were divided to the rows of three replications with 5 m intervals between the rows and plants within the rows. In other words, 450 seedlings were planted in an experimental field located in Yazd, a desert margin province of Iran (Figure 1), based on a randomized complete block design with three replications. Plant height, crown diameter, number of lateral branches, and collar diameter were recorded during the fifth year of the experiment. Conventional analysis of variance revealed strong heritable genetic variability, which is published elsewhere (Mirzaie-Nodoushan *et al.,* 2009). Since wide ranges of the mentioned characters were observed on the studied genotypes, their interrelationship was investigated by path analysis. Path analysis can be used to estimate direct and indirect contributions between the standardized predictor and criterion variables (Sokal and Rohlf, 1995). Pearson correlation coefficient was estimated between all combinations of the characters. A Q-basic program called Path2, written by the first author was used to perform path analysis on the estimated correlation coefficients for estimating the direct and indirect influences of collar and crown diameter, and number of lateral branches on plant height of the species. Path coefficients (PC) were obtained by solving simultaneous equations. Indirect path coefficients were determined by multiplying appropriate r correlation coefficients and PC values (Chaturvedi and Pandey, 2004).

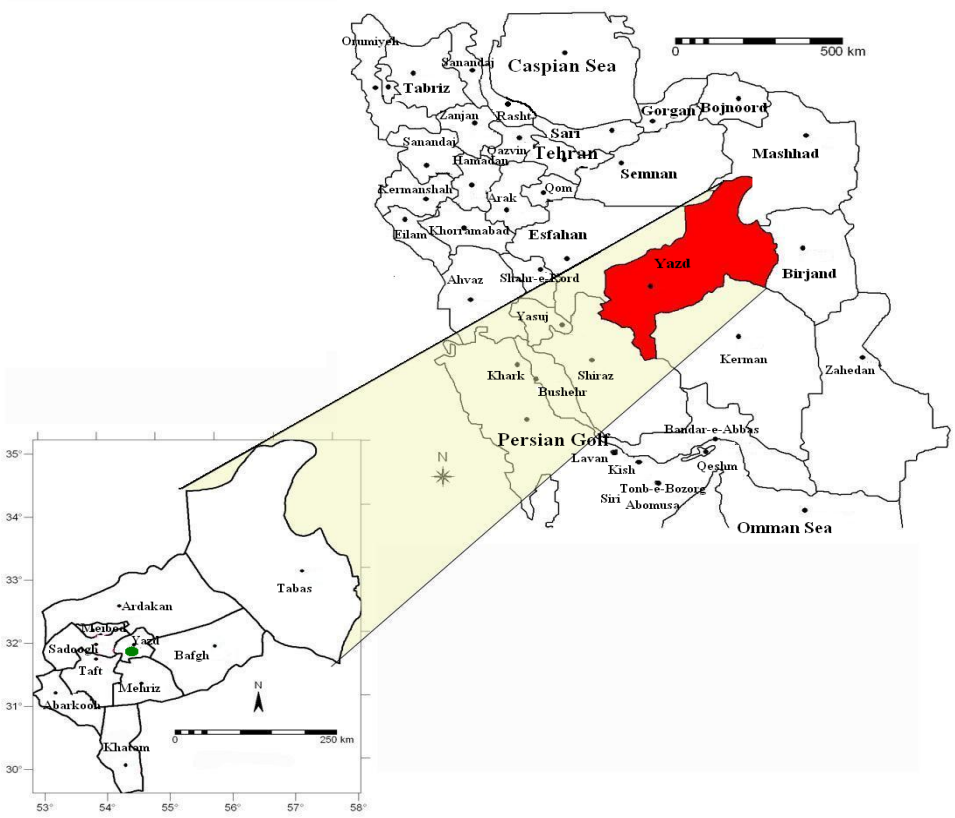

Figure. 1- Map of Yazd province, located in center part of Islamic Republic of Iran, showing the location of the field test site.

Results

Mean values of the recorded characters on the studied genotypes are presented in Table 1. There were substantial differences of the vegetative characters observed between the studied progeny families. Mean values of the progeny seedlings on collar diameter, lateral branch numbers, crown diameter and plant height varied quite enough to be used in correlation coefficient analysis (Table 1).

Correlation coefficient values were also noticeable (Table 2). The coefficient values varied from 0.202 to 0.935, all statistically significant for all pair combinations of the studied characters.

Table 1- General mean values of the vegetative characters recorded on progenies of 25 single mother plants of *Haloxylon aphyllum*, during the fifth year of growth.

Genotype	Collar Diameter (cm)	Lateral Branches (No.)	Crown Diameter (cm)	Plant Height (cm)
H1	2.6	2.7	89	91
H2	4.1	2.3	146	131
H3	4.1	2.9	147	130
H4	3.8	2.9	119	95
H5	5.7	3.0	180	167
H6	4.6	3.2	181	127
H7	3.2	2.6	119	91
H8	5.1	2.8	137	111
H9	4.2	3.0	147	124
H10	2.1	2.7	77	68

Continued Table 1- General mean values of the vegetative characters recorded on progenies of 25 single mother plants of *Haloxylon aphyllum*, during the fifth year of growth.

Genotype	Collar Diameter (cm)	Lateral Branches (No.)	Crown Diameter (cm)	Plant Height (cm)
H11	7.0	3.1	216	192
H12	4.5	3.3	164	136
H13	3.6	2.8	116	111
H14	2.4	3.3	81	81
H15	3.8	3.0	140	118
H16	7.5	3.4	272	195
H17	2.5	2.7	76	79
H18	3.6	3.3	118	122
H19	7.9	2.7	361	303
H20	5.9	3.2	238	203
H21	2.9	2.7	94	110
H22	4.0	3.1	148	142
H23	7.1	3.2	242	274
H24	3.1	3.5	105	94
H25	2.8	3.0	93	83
Minimum	2.1	2.3	76	68
Maximum	7.9	3.5	361	303

Table 2- Phenotypic correlation coefficients between all pair combinations of the vegetative characters recorded on the progenies of 25 single trees of *H. aphyllum.*

Characters	Collar Diameter	Lateral Branches	Crown Diameter	Plant Height
Collar Diameter	1.00			
Lateral Branches	0.202*	1.00		
Crown Diameter	0.935**	0.254**	1.00	
Plant Height	0.901**	0.205*	0.932**	1.00

Significance of the main effects and their interaction are indicated as *=P<0.05 and **=P<0.01

Table 3- Direct and indirect path coefficients between dependent variable, plant height, and independent variables, collar diameter, number of lateral branches and crown diameter of the studied progenies on *Haloxylon aphyllum*.

Independent variables	Phenotypic correlation with plant height	Direct effect of the independent variables	Total indirect effects	Indirect effects of independent variables on plant height		
				Collar diameter	Lateral branches	Crown diameter
Collar diameter	0.901	0.228	0.673	-	-0.005	0.678
Lateral branches	0.205	-0.025	0.230	0.046	-	0.184
Crown diameter	0.932	0.725	0.207	0.213	-0.006	-
Residual = 0.124						

A diagram describing the path analysis of the data regarding plant height and its correlated characters is presented in the Figure 2. The diagram indicates direct and indirect pathways of influences of independent variables, collar diameter, Lateral branch numbers, and crown diameter on the dependent variable, plant height

Discussion

The observed differences between the studied progeny families would be essential for studying interrelationship of the traits. In other words, the differences implied enough variability to be used in the correlation coefficient estimating and partitioning. Mean values of the five-year old progeny seedlings on collar diameter varied from 2.1 to 7.9 cm, a difference of 276%, which is remarkable. The mean values of the seedlings on lateral branch numbers varied from 2.3 to 3.5 (52 % difference). Crown diameter and plant height were of more importance for the administrators of the dry areas. Crown diameter mean values varied from 76 to 361 cm and plant height from 68 to 303 cm (Table 1), differences of 375% and 346% respectively. Taller and larger crown give rise to more suitable barriers for shifting sand dunes as far as this problem is concerned. These also would end to a higher capacity for supplying fodder for the domestic and wild animal habitants. Long distances between the locations sampled and mother trees selected for seed collection assured enough genetic variation to be sampled for the study.

Correlation coefficient values justified the path analysis to be done for partitioning the total correlation coefficients to direct and indirect coefficients. The important point was the positive values for the total phenotypic correlation coefficients. As far as plant height is concerned as a dependent character, based on the total phenotypic correlation coefficients, increment in the other three studied characters would end to increment of plant height.

The path analysis diagram (Fig. 2) indicated direct and indirect pathways of influences of independent variables, collar diameter, Lateral branch numbers, and crown diameter on the dependent variable, plant height. Path analysis revealed that among the independent characters, crown diameter had the strongest direct effect (0.725) on plant height (Table 3). In contrast, lateral branch numbers showed the lowest and negative direct effect (-0.025) on the dependent variable, plant height. Although the negative direct effect value of this character was trivial, but it was in contrast to its total phenotypic correlation with plant height (0.205). Crown and collar diameters revealed trivial negative indirect effects on plant height through lateral branches, -0.006 and –0.005 respectively. These would imply that lateral branched would affect negatively the dependent variable, either directly by itself or indirectly by other characters. Collar diameter showed the strongest positive indirect effect on plant height through crown diameter (0.678). This was decreased to the value of 0.673 total indirect effects by its negative indirect effect through lateral branch number (-0.005). In fact it can be summarized that direct and indirect effects of crown diameter and collar diameter mainly positively affected plant height. In other words, collar diameter mainly affected the dependent character directly but crown diameter mainly affected the character indirectly. Although there are some negative direct and indirect effects of the studied independent characters on reducing the dependent variable, but they are trivial and not noticeable. The residual of the model was 0.124. Comparing to the estimated direct and indirect effects this value of the residual is not substantial. It is noticeable that the higher the number of the studied character in such studies the lesser residual would be expected to be left in the model, unless the most suitable characters are involved in the study. Such a low residual value implied the appropriateness of the selected characters for investigating the dependent variable.

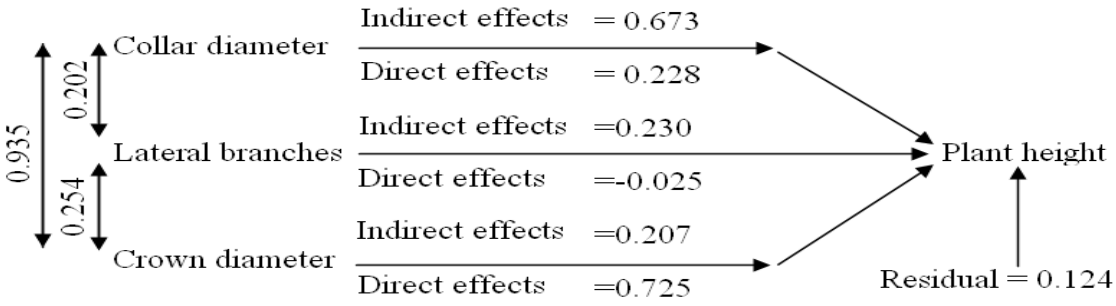

Figure 2- Path diagram showing interrelationship among the dependent variable, plant height, and the independent variables collar diameter, number of lateral branches and crown diameter. Double-headed arrows represent phenotypic correlation coefficients and unidirectional arrows represent direct path coefficients.

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