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SEED YIELD MODEL OF *HALOXYLON AMMODENDRON* (C.A. MEYER) BUNGE IN JUNGGAR BASIN, CHINA

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Abstract

The relationships between seed yield and plant growing conditions of 6 populations that were grown in typical habitats were studied in Junggar basin. Correlation analysis indicated that seed yield (M) had high and positive correlations with crown (C), basal diameter (D) and height (H). Path coefficient analysis showed that crown had the maximal and positive direct effect on seed yield, followed by height and diameter. Finally, Established seed yield prediction model is $M=178.572+3.470\times10^{-5}\times CH-1.106\times H-0.007\times C$ ($R=0.830$，$p<0.01$)

Introduction

Seed is the end product and also the beginning of plant sexual reproduction. It is the main carrier of plant spreading and going through the adverse environment. Simultaneously seeds have significant effect on plant population regeneration and plant distributing area expansion. So seeds hold the great significance in the study of Plant ecology and Evolutionary biology (Heydecker, 1972; Harper, 1977; Abrahamson, 1979; Solbrig, 1981; Bertin, 1982; Quinn & Hodgkinson, 1984; Hancock & Pritts, 1987; Allan, 1989). The number of seed yield reflects both the biological characteristics of species and approaches of plant to adapt to the environment. Also it implies the effect of environment to the process of plant sexual reproduction (Heydecker, 1972; Solbrig, 1981; Wilson, 1985). Seed yield has significant impact on whether there were enough seed which were distributed to forming soil seed bank, escaping from the adverse environment, reaching seedling establishment, adding offspring to the population. It is significantly important to the stability and development of populations. Meanwhile seed stage is the only phase in which sexual reproducing plant having mobility. It has significant effect on the distribution pattern of population, population dynamics and population management (Harper, 1977; Steven, 1991; Xie *et al*., 1998). The number of seed yield is affected by plant nutrition, life history strategy and the condition in the community succession (Harper, 1977). And it is different in some microhabitats (Harper, 1967; Heydecker, 1972; Abrahamson, 1979). Because seed yield is particularly important in production, the relationships between seed yield and related factors were studied deeply in agriculture and horticulture. However, little was done in the seed yield of wild plant (Dewey & Lu, 1959; Ma *et al*., 2001) and the studies aimed at the seed yield condition of dominant plant in arid desert region were extremely lackimg. *Haloxylon ammodendron*（C.A.Mey）Bunge is the dominant species in desert region of north-western china. In the present study the relationship between the morphological traits and seed yield of *Haloxylon ammodendron* has been studied.

Haloxylon Bunge is a shrub, belong to Chenopodiaceae. It is mainly distributed in the arid region of temperate and subtropical zone in Asian and African continent. Which are located in 25°～48°10′N，5°～110°30′E (McKee, 1993). Deserts dominated by *Haloxylon* Bunge are thought as '*Haloxylon* forest' in desert region and it is the most wildly distributed desert vegetation in Asian desert area (Editorial board of *Vegetation of China*, 1983). *Haloxylon* Bunge comprises of 11 species in the world (Anon., 1983). But only 2 species are reported from china, *H.* ammodendron (C.A.Mey) Bunge and *H. persicum* Bunge ex Boiss.et Buhse (Chenopodiaceae) (Hu, 1963). Under the natural selection through several generations *H. ammodendron* had great capabilities of drought resistance and saline tolerance, which resulted in wide distribution in various habitats. It occurs mainly in the land between fixed and semi-fixed sand dunes. And it was also found in the lower part of sand dunes, clay desert, gravel desert and saline land in Junggar Basin. The leaves of this species are very small and the green branches photosynthesis (Tobe *et al*., 2000). With the rapid development of Chinese economy and the speedy increasing of population, *H. ammodendron* served as livestock feed and firewood was wildly used in China (Fu & Jin, 1992). Due to its over exploitation the population of *H. ammodendron* degenerated. The Chinese government had identified it as protected plant of 3 levels (Anon.，1991).

Few researches have studied the seed yield of *H. ammodendron.* In the present study the relationship between the easily measured morphological traits of plant and seed yield has been investigated. It is aimed to establish prediction model of seed yield for individual of *H. ammodendron* and find a way to forecast seed yield easily, directly and accurately. This is significantly important for promoting the basic theoretical researches in population quantitative ecology of desert plant and the conversation practice of the desert ecosystem.

Study areas: Following 6 populations of *H. ammodendron* occurring in typical habitats along the edge of the Gurbantunggut Desert were studied for the seed yield (Fig. 1. & Table 1).

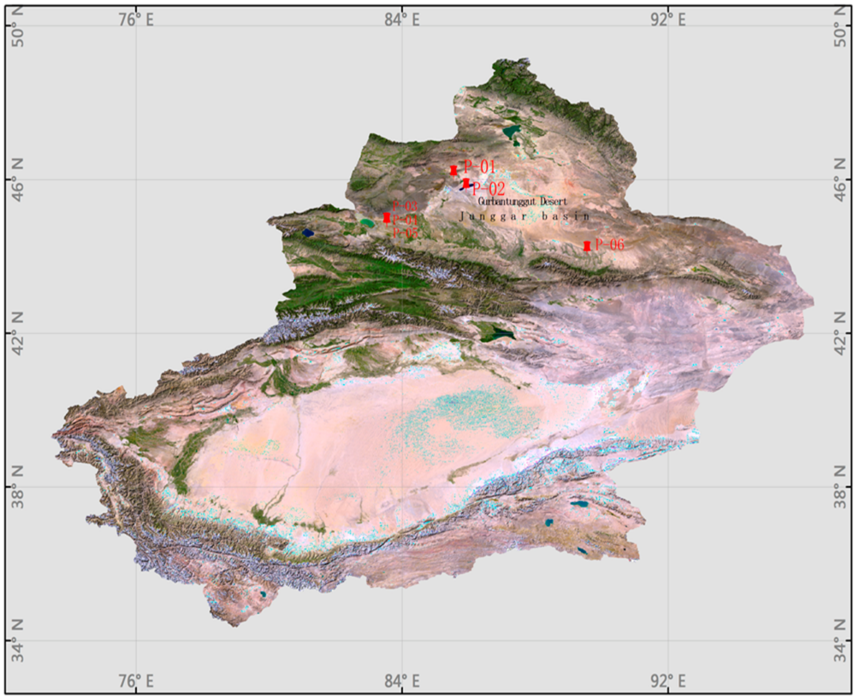

Fig. 1. The location of the studied *H. ammodendron* populations.

Table 1. Habitat characteristics of *H. ammodendron* populations.

Plot	Location	Altitude (m)	Soil properties				
			Soil layers (cm)	pH value	Conductance (ms/cm)	Organics (g/kg)	Total salt (g/kg)
P-01	46°10.012′N 85°33.087′E	419	0-10	8.90	0.095	4.294	0.755
			10-20	9.03	0.077	2.910	0.700
			20-30	9.04	0.083	2.341	0.750
			>30	8.95	0.108	2.836	0.800
P-02	45°50.460′N 85°55.593′E	252	0-10	9.37	7.940	6.699	25.350
			10-20	8.98	6.820	3.855	23.330
			20-44	8.66	2.480	3.064	9.550
			44-68	8.68	3.240	4.324	13.150
			>68	8.57	1.590	2.543	5.850
P-03	44°56.588′N 83°32.268′E	231	0-17	8.67	1.430	11.266	4.525
			17-27	8.06	2.900	6.818	10.050
			27-57	7.73	5.680	10.120	20.950
			57-90	8.57	0.634	2.196	2.350
			90-97	8.24	0.891	2.026	3.250
			>97	8.22	0.923	2.017	3.175
P-04	44°56.737′N 83°32.368′E	219	0-10	7.16	15.150	46.236	42.050
			10-20	7.35	9.100	11.832	37.500
			20-34	7.45	8.040	9.477	31.550
			34-69	7.69	4.350	3.591	17.975
			69-72	7.77	3.780	3.779	13.850
			72-86	7.85	3.160	3.076	11.600
			>86	7.85	3.560	2.693	13.250
P-05	44°56.224′N 83°32.553′E	208	0-10	9.57	2.090	10.672	9.150
			10-20	8.12	1.770	10.511	6.875
			20-37	7.9	1.258	13.545	4.975
			37-40	7.68	1.254	60.597	4.825
			>40	8.03	0.930	9.815	3.775
P-06	44°11.803′N 89°33.632′E	648	0-30	8.53	0.123	1.510	0.060
			30-60	7.81	0.705	4.500	0.310
			>60	8.63	1.340	7.890	0.500

Population 01 and 02 (P-01, 02) is located in the northwestern margin of Junggar Basin. This area has a mean annual precipitation of 96.4mm, an extreme maximum precipitation of 117.8mm, and an extreme minimum precipitation of 56mm. It annual evaporation of 3016.4mm, 31.3 times of rainfall in the same period. The January mean air temperature is -15.8°C. The July mean air temperature is 27.8°C. It exhibits an extreme maximum air temperature of 43.8°C and minimum air temperature of -40.2°C. The accumulated mean annual frost-free period is 225 days.

P-01 occurred in gravel desert of hilly slopes. This region was denudated by the northwest wind perennially and the hills and deserts were has a mean staggered. Natural vegetations are rare and the water table is extremely deep here. P-02 is located in Lacustrine sedimentary area with the Manas lake drying up. This area is belongs to the Urho basin, and has a high water table. Before 1970s, water can be found about 1m under the ground and about 2m now (Anon., 1999).

Population 03, 04 and 05 (P-03, 04, 05) were placed in the Ganjiahu national reserve in the southwestern margin of Junggar Basin. This area has a mean annual precipitation of 150mm and the precipitation ranged between 97.2 and 180mm. It has a mean annual evaporation of 2000mm, 13 times of rainfall. The January mean air temperature is -19.2°C. The July mean air temperature is 26.2°C. It has an extreme maximum air temperature of 43.7°C and an extreme minimum air temperature of -42.1°C and the accumulated mean annual frost-free period is 180 days (Xu & Han, 1996).
There are the largest and the most completely protected vegetation of *H. ammodendron* in the world under almost original conditions. Here, *H. ammodendron* has various habitats and the growing status is significantly different in these habitats. P-03, 04 and 05 were chosen to investigate the seed yield.

P-03: The soil is sticky and compact. It is bad for the water and gas to permeate. So it is adverse for plant growth. Therefore, the plants are small and thick here.

P-04: There is a crunchy salt crust on the surface of the soil and under that soft sandy loam is present. As the salt crust has high salt content, *H. ammodendron* is regenerated poorly, plants are tall and thin.

P-05: The terrain is flat. The soil is thick and has a fine texture. The water condition is good and plants are tall (Anon., 2000).

Population 06 located in southeastern margin of Junggar Basin. This area has a mean annual precipitation of 176mm. And it has a mean annual evaporation of 2141mm, 12 times of rainfall. The annual mean air temperature is 4.7°C. It has an extreme maximum air temperature of 43°C and an extreme minimum air temperature of -42.6°C and the accumulated mean annual frost-free period is 156 days. The water table is about 3mm and it slightly changed with seasonal variation. The soil is aeolian (Liu *et al*., 2010).

Material and Methods

Investigation of seed yield: As the fruited plant can be tall or small in nature, 8-12 plants have been selected using the methods of uniform distribution in the size range of plant individuals. 12, 8, 12, 11, 12, 12 plants have been marked separately in P-01, 02, 03, 04, 05, 06. The crown, height, basal diameter and seed yield per plant were investigated. The plants were covered entirely with nylon net of 1mm mesh in October 2008 (Fig. 2). It was necessary to strengthen the junction of the stem and nylon net to avoid the seed disappearing. After the seed maturing and fall in March 2009, they were collected and took back by plant individually. Because the seed weight is similar with the weight of dry branches, it is hard to separate them. Wind separation and dustpan screening were done firstly and handpicking was used finally to obtain seeds only.

Multivariate statistical analysis: Seed yield model is the key to study the quantitative relationship between seed yield and the crown, height, diameter. Because the traits do not only directly affect the yield, they also affect the yield indirectly by affecting other traits in negative or positive manners. As a trait has helpful effect on a trait for yield, it can affect some other or all traits negatively (Walton, 1980). For that reason, it is clear that a correlation coefficient which measures the simple linear relationship between two traits is not enough. So path coefficient analysis was chosen in this study. Path coefficient analysis is a statistical technique of partitioning the correlation coefficients into its direct and indirect effects, so that direct and indirect contribution of different morphological traits to seed yield should be estimated. Dewey & Lu (1959) were determined path coefficients.

Results

Correlation analysis: Highly positive correlations were found between seed yield per plant and all the characteristics in every population: 0.693* for crown, 0.588 for diameter and 0.513 for height in P-01; 0.722* for crown, 0.673* for height and 0.593 for diameter in P-02; 0.880** for height, 0.771** for diameter and 0.742** for crown in P-03; 0.630* for diameter, 0.499 for crown and 0.490 for height in P-04; 0.669** for crown, 0.621* for height and 0.564* for diameter in P-05; 0.655** for height, 0.648* for crown and 0.495 for diameter in P-06. Additionally, for the 6 populations calculated as an entirety, significant and positive correlations were observed between seed yield per plant and crown (r=0.672**), diameter (r=0.562**), height (r=0.324**). Simultaneously, strong and significance correlations were determined among crown, height and diameter at 0.01 probability level, except for 0.684* for crown and height, 0.439 for diameter and height in P-01, 0.682* for crown and diameter in P-02 (Table 3).

Fig. 2. Sampling of seed yield per plant.

Path coefficient analysis: As the populations were grown in different habitats, the morphological traits were significantly different (Table 2). The trait which had the maximum direct effect on seed yield was diverse in different populations. P-01: crown was determined the maximal and positive direct effect on seed yield. Diameter and height had negative effect on seed yield. And they had high and positive indirect effect on seed yield through crown; P-02: it was similar with P-01; P-03: height was played the role of crown in P-01 and P-02; P-04: diameter was taken the place of crown in P-01 and P-02; P-05: crown and height were had positive direct effect on seed yield. Crown is higher than height. Diameter had negative effect on seed yield. And it had high and positive indirect effect on seed yield through crown and height; P-06: diameter had the maximum and negative direct effect on seed yield. Height and Crown had positive direct effect on seed yield and they also had positive indirect effect on seed yield through diameter. Additionally, for the 6 populations calculated as an entirety, crown was observed the maximum and positive effect on seed yield. Height and diameter had negative direct effect on seed yield. They had high and positive indirect effect on seed yield through crown (Table 4).

Table 2. Morphological traits of *H. ammodendron* populations in different habitats.

Plot	Population density (plant hm^{-2})	Mean crown (mean ± SD, cm^2)	Mean height (mean ± SD, cm)	Mean diameter (mean ± SD, cm)	1000 seed weight (mean ± SD, g)
P-01	2320 ± 955	9692.64 ± 10052.06	67.91 ± 34.05	3.59 ± 2.63	2.3931 ± 0.6026
P-02	568 ± 159	61879.59 ± 79621.91	198.27 ± 84.22	9.38 ± 8.43	1.7357 ± 0.2441
P-03	4843 ± 1491	7659.06 ± 12659.45	125.05 ± 55.68	3.85 ± 2.83	2.0902 ± 0.3371
P-04	2261 ± 1164	13904.50 ± 23512.89	162.58 ± 81.28	5.37 ± 5.09	1.6734 ± 0.3005
P-05	1739 ± 415	41124.01 ± 54963.84	240.34 ± 105.10	8.58 ± 6.34	1.4896 ± 0.2653
P-06	500 ± 165	37402.74 ± 27778.98	181.37 ± 70.38	5.76 ± 2.90	2.4420 ± 0.3901

Table 3. Correlation analyses of morphological traits and seed yield per plant.

Population	Character	Height(cm)	Diameter(cm)	Seed yield(g)
P-01	Crown (cm^{-2})	0.684*	0.939**	0.693*
	Height (cm)		0.439	0.513
	Diameter (cm)			0.588
P-02	Crown (cm^{-2})	0.925**	0.893**	0.722*
	Height (cm)		0.682*	0.673*
	Diameter (cm)			0.593
P-03	Crown (cm^{-2})	0.894**	0.895**	0.742**
	Height (cm)		0.939**	0.880**
	Diameter (cm)			0.771**
P-04	Crown (cm^{-2})	0.890**	0.962**	0.499
	Height (cm)		0.913**	0.490
	Diameter (cm)			0.630*
P-05	Crown (cm^{-2})	0.784**	0.867**	0.669**
	Height (cm)		0.855**	0.621*
	Diameter (cm)			0.564*
P-06	Crown (cm^{-2})	0.953**	0.930**	0.648*
	Height (cm)		0.940**	0.655**
	Diameter (cm)			0.495
Integration	Crown (cm^{-2})	0.743**	0.921**	0.672**
	Height (cm)		0.752**	0.324**
	Diameter (cm)			0.562**

*: Significant correlation at $p<0.05$; **: Significant correlation at $p<0.01$

Table 4. Path analysis of morphological traits to seed yield per plant.

Population	Character	Direct effect	Indirect effect via			Total
			Crown(cm^{-2})	Height(cm)	Diameter(cm)	
P-01	Crown (cm^{-2})	2.033	1	-0.251	-1.088	0.694
	Height (cm)	-0.367	1.391	1	-0.509	0.515
	Diameter (cm)	-1.159	1.909	-0.161	1	0.589
P-02	Crown (cm^{-2})	2.085	1	-0.672	-0.690	0.723
	Height (cm)	-0.727	1.929	1	-0.527	0.675
	Diameter (cm)	-0.773	1.862	-0.499	1	0.590
P-03	Crown (cm^{-2})	-0.112	1	1.227	-0.373	0.742
	Height (cm)	1.372	-0.100	1	-0.392	0.880
	Diameter (cm)	-0.417	-0.100	1.288	1	0.771
P-04	Crown (cm^{-2})	-1.383	1	-0.379	2.261	0.499
	Height (cm)	-0.426	-1.231	1	2.146	0.489
	Diameter (cm)	2.350	-1.330	-0.389	1	0.631
P-05	Crown (cm^{-2})	0.652	1	0.325	-0.308	0.669
	Height (cm)	0.414	0.511	1	-0.304	0.621
	Diameter (cm)	-0.355	0.565	0.354	1	0.564
P-06	Crown (cm^{-2})	0.727	1	1.084	-1.163	0.648

	Height (cm)	1.137	0.693	1	-1.175	0.655
	Diameter (cm)	-1.250	0.676	1.069	1	0.495
Integration	Crown (cm^2)	1.139	1	-0.266	-0.202	0.671
	Height (cm)	-0.358	0.846	1	-0.165	0.323
	Diameter (cm)	-0.219	1.049	-0.269	1	0.561

Model of seed yield: Based on the results of correlation and path coefficient analysis, the crown (C), height (H) and diameter (D) were found to have significant effect on seed yield (M). The influence of crown was higher than height and diameter. Introduced CH as a independent variable, Multiple stepwise regression analysis were conducted using C、H、D、CH as independent variables and M as dependent variable. The Regression equation is below:

$$M = 178.572+3.470\times10^{-5} \times CH - 1.106\times H - 0.007 \times C$$

The test of significance reveled that 178.572 , 3.470×10^{-5} , -1.106 , -0.007 and the equation were significant at 0.01 probability level. The Regression equation is best (r=0.830; r^2=0.688).

Discussion

Seed yield is a complex trait and is the result of many growth processes expressed in the yield components (Iannucci & Martiniello, 1998). Due to the importance of seed yield in agriculture production, related studies were conducted mainly in agronomy. They were concentrated in finding the species of high production through the study of the relationship between the seed yield and the yield components. The traits related the generative part of plant were considered more, such as pods per plant, number of seed per pod, number of fertile spikelets per panicle, panicle length, spikelet density, number of filled seeds, number of effect tillers per plant, 1000 seed weight (Sarawgi *et al*., 1997; Güler *et al*., 2001; Tahir *et al*., 2002; Machikowa *et al*., 2005; Hidayatullah *et al*., 2008; Arshad *et al*., 2010; Khan *et al*., 2010). Few studies were done on the plant morphological traits-height, crown and basal diameter, through they were valued in defining the best criteria for selection in biological and agronomic studies. In some investigations positive correlations between seed yield and height was observed but the height didn't have direct effect on seed yield in smooth bromegrass (*Bromus inermis* Leyss.) (Sekera & Serin, 2004). In the present study the relationship between seed yield and the morphological traits were investigated from the ecological view in order to find a simple and relatively accurate way to predict the seed yield of *H. ammodendron*. It made a foundation for the basic theoretical studies in restoration ecology of desert plant.

H. ammodendron is a shrub, mainly found in desert regions of north-western China (Fu & Jin, 1992). The seed of *H. ammodendron* is small and light and the number of seed per plant is huge. In the present study, the relationship between seed yield and easily measured morphological traits were studied. Significant and positive correlations were observed between seed yield per plant and crown, diameter and height, also crown was observed the maximum and positive effect on seed yield. Height and diameter had negative effect on seed yield. they had high and positive indirect effect on seed yield through crown. When the crown is more, the number of green branches photosynthesis will be more providing greater fixation of carbon, leading to more accumulation of dry matter. Simultaneously more height and diameter provided the ability of more plant bifurcations leading to more green branches. So the direct selection of crown is effective for increasing seed yield of *H. ammodendron* and the simply and easily using way to predict seed yield is provided here.

Conclusions

H. ammodendron (C.A.Mey) Bunge is the dominant Constructive species in the desert region of north-western china. Through the environment in this region is extremely harsh, this plant had adapted to the environment and formed good vegetation dominated by itself. The vegetation in this area is the ecological barrier of the native people living and the region's economic development. However, in recent decades the population of *H. ammodendron* was degenerating rapidly. Now it is extremely urgent to restore and expand the population of *H. ammodendron* for combating desertification. The results of present study increase our knowledge on the seed production of *H. ammodendron*. It is the first thing to study the life history of this plant. The present study makes the foundation of population Quantitative ecology and restoration ecology.

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