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民勤荒漠绿洲过渡带优势植物地上和地下生物量的估测模型

魏小平[1]　赵长明[1]　王根轩[2,1*]　陈宝明[1]　程栋梁[1]
（1 兰州大学，干旱与草地农业生态教育部重点实验室，兰州　730000）
（2 浙江大学生命科学学院，植物生理与生物化学国家重点实验室，杭州　310029）

摘　要　荒漠优势物种生物量的定量测量是荒漠土壤管理的重要依据。为精确估计民勤典型绿洲-荒漠过渡带中优势物种生物量，我们用随机选取的 82 个 10 m×10 m 的样方进行优势物种调查。结果显示试验地物种结构简单，而且总盖度仅为 16.12%。选取 5 种荒漠优势物种（白刺（*Nitraria tangutorum*）、沙拐枣（*Calligonum mongolicum*）、梭梭（*Haloxylon ammodendron*）、沙蓬（*Agriophyllum squarrosum*）和盐生草（*Halogeton arachnoideus*）），利用全挖法测定其地上和地下生物量。用测定生物量 80%的数据分析每一种植物地上和地下干、鲜生物量与其自身的形态参数地径、高度和冠幅之间的相关关系，再利用线性回归分析方法，以相关性显著的形态参数为自变量确定了预测试验地每一优势物种最适宜的地上及地下干、鲜生物量的回归模型。研究结果证实包括地茎（除白刺）和盖度为自变量的回归方程和 5 种优势荒漠植物的生物量拟合度很好，用测定生物量 20%的数据对所有模型进行检验，证实所有生物量的估测模型能够精确预测优势荒漠物种生物量。
关键词　植物　生物量　荒漠　过渡带　绿洲

ESTIMATION OF ABOVE- AND BELOW-GROUND BIOMASS OF DOMINANT DESERT PLANT SPECIES IN AN OASIS-DESERT ECOTONE OF MINQIN，CHINA

WEI Xiao-Ping[1]　ZHAO Chang-Ming[1]　WANG Gen-Xuan[2,1*]　CHEN Bao-Ming[1] and CHENG Dong-Liang[1]
（1 *Key Laboratory of Arid and Grassland Agroecology at Lanzhou University*，*Ministry of Education*，*Lanzhou* 730000，China）
（2 *State Key Laboratory of Plant Physiology and Biochemistry*，*College of Life Sciences*，*Zhejiang University*，*Hangzhou* 310029，China）

Abstract　Most desert soil management decisions are based on quantitative measurements of the biomass of the dominant plant species. The biomass of the dominant plant species in a typical oasis-desert ecotone（ODE）of Minqin was measured in 82 plots（10 m×10 m）. The results showed that the distribution and total cover was approximately 16.12%. Above- and below-ground biomass of five dominant desert species（*Nitraria tangutorum*，*Calligonuum mongolicum*，*Haloxylon ammodendron*，*Agriophyllum squarrosum* and *Halogeton arachnoideu*）was measured by excavation. Linear regressions were used to analyze the relationships among all the biomass components for each plant（fresh and dry weight of above- and below-ground biomass）and the basal diameter，total height and canopy cover. Best fit models were constructed for each species using 80% of the data. Our results showed that basal diameter（excluding *N. tangutorum*）and canopy cover were the best predictors of biomass for all five desert plant species. A validation test using the other 20% of the data not used for estimating the regression equations indicated that these equations made accurate predictions of desert plant species biomass.
Key words　Plant，Biomass，Desert，Ecotone，Oasis

Minqin oasis lies between Badain Jaran Desert and Tengger Desert. In recent years，it has been greatly threatened by desertification and became a typical location with shrinkage of vegetation of many other oases lying along the desert fringes of Northwest China（Ma *et al*., 2003）. However，the oasis-desert ecotone（ODE）has been first faced the threat of desertification which is vulnerable. So it is an important study area for managing de-

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* Author for correspondence　E-mail：wanggx@zju.edu.cn

sertification (Wang & Cui, 2004). In many ODEs, the vegetation had degraded with desertification. The desert plants curb desertification processes and improve the quality of the soil. Moreover, the biomass of desert species can serve as good indicators of desertification (Padrón & Návarro, 2004). Therefore, land managers and researchers call for reliable estimates of total plant or component weights to assess site productivity, food abundance, treatment effects, and fuel loading (Návar *et al.*, 2004). Present-day biomass estimation are required to estimate stocks and fluxes of carbon dioxide, within the earth-atmosphere system (Schimel *et al.*, 2000). To readily estimate biomass components non-destructive techniques are also necessary, which are rapid, relatively accurate, and have few training requirements. The estimation of the plant biomass for a desert ecosystem is a basic and necessary step to fully understand its dynamics and carry out an adequate management (Bai *et al.*, 2004).

Many different approaches have been used to study biomass. Percent cover is the most commonly used predictor of grass biomass. However, large coefficients of variation associated with low vegetation cover (Hatton *et al.*, 1986) made this method unreliable under sparse vegetation conditions in arid areas (Assaeed, 1997). Clutter *et al.* (1983) reported the one independent variable nonlinear, one independent variable linear, and multiple regression equations which were used for biomass estimation. However, most studies suggested that method of multiple line regression analyses is fitted well to predict biomass (Assaeed, 1997; Parresol, 1999; Návar *et al.*, 2002). So Multiple line regression was used to develop equations for predicting biomass in this paper.

In fact, desert vegetation was scattered spot patterns with simply species structure (von Hardenberg *et al.*, 2001). Therefore, total biomass can be obtained in desert ecosystem by determining biomass of individiul plant. At present, few studies of the biomass of desert species was conducted and most researches focused on above-ground biomass (Padrón & Navarro, 2004; Návar *et al.*, 2001; Guevara *et al.*, 2002; Zhao *et al.*, 2004). However, plant below-ground biomass often constitute a major part of the total biomass in arid areas. It is inadequate to understand the dynamics of ODE and desertification in arid desert in that only few studies were about the estimation of total biomass of desert plants (Wang & Li, 1994; Jia *et al.*, 2002).

The objectives of this study were: 1) to develop alometric equations for estimating above-ground and below-ground standing biomass at the individual species scales and 2) to check the use of simple morphology measurements as a reliable tool for predicting the biomass of arid plant species in the ODE of Minqin. The results may provide valuable information for management and restoration of the temperate oasis which was being degraded rapidly.

1 Material and methods

1.1 Study site

This study was conducted during the summer of 2002 at Minqin Integrated Desert Control Experimental Station (MIDCES)(38°34′ N, 102°58′ E) in the Northwestern of China, southern edge of the Badain Jaran Desert, with a total area of 1 200 hm^2. The Minqin oasis lies in the lower reaches of the Shiyanghe River watershed of eastern end of the Hexi Corridor. The central area except the southern is surrounded by the Badain Jaran Desert and adjacent to the Tengger Desert with mobile, semi-mobile, and static dunes, including large areas of sparsely vegetated desert rangeland. In our study area, the climate belongs to the fearfully arid continental monsoon climate region of the temperate zone with a windy winter and spring. Average annual temperature is 7.6 ℃. Mean precipitation is 110 mm, with most of it occurring from July to September while estimated potential evapotranspiration is about 2 604.3 mm. Zonal soil types in the area include gray-brown desert soil and gray desert soil. The mineralization degree of water quality is 8 – 10 $g \cdot L^{-1}$ and groundwater is buried at 17 m underground. Agricultural irrigation depends on groundwater. Grazing is forbidden at the study site.

1.2 Dominant plant species investigated

To obtain distribution of vegetation and accurately estimate the biomass, 82 sampling points with every 10 m × 10 m quadrates were randomly selected across the study area. In each quadrate, the number of species, breadth of canopy (length and width), total height, basal diameter and frequency of all standing plants were measured to calculate the importance value (relative density (%) + relative frequency (%) + relative cover (%)) of each species as a standard to determine dominant species. Shrubs belonged to a specific sampling quadrate if their stems were located within the quadrate, although parts of the shrub crown might have grown outside the quadrate. To calculate the importance value of species, it wasn't necessary to exactly locate the stem position. Therefore, it was decided to account as an individual plant depended on canopy areas inside quadrate. The species existed less than two sampling points in our result was excluded.

1.3 The biomass and average morphological characteris-

tics measurements

A portion of the collected plants (about 80%), called the estimation date set, was randomly selected from all harvested plants and used to estimate the equation coefficients (Guevara *et al*., 2002). The remaining 20% of the collected plants of each species, called the prediction data set, was used to measure the prediction accuracy of the equation (Snee, 1977). First, the dominant species we randomly selected were recorded and measured with basal diameter (*Nitraria tangutorum* is not measured basal diameter for cespitose species), total height, canopy cover and the height of sand mounds with *N. tangutorum* (in many regions, most of the enclosed sand mounds are vegetated with *N. tangutorum* brush). Second, to measure fine roots (roots ≤ 1 mm in diameter) biomass, soil was sampled in cores of 5 cm diameter and 50 cm depth from each rhizosphere of plant (we only sampled the upper 50 cm soils because over 80% of the fine roots are concentrated in this depth) (Jackson *et al*., 1996). And the cores were immediately put in sealed plastic bags and transported to the laboratory. The live roots were carefully separated from the soil by washing out of the samples with sieves. Then according to the volume proportion between soil cores and total root zone, the total small root biomass was calculated. Third, we clipped the aboveground biomass and recorded the fresh weight, and then all coarse roots (roots ≥ 1 mm in diameter) were dug up and washed and weighed. Finally, all samples of each component of each species were dried in an oven at 80℃ to a constant weight in order to determine the dry biomass.

2 Results

2.1 Vegetation composition in ODE

Table 1 shows importance values of individial species, which indicate not only vegetation structure but also few dominant species. Total 16 species representing are collected and identified, and the total cover is approximately 16.12% in study area (Table 1). It was found that the relatively dominant shrub species are *Nitraria tangutorum*, *Calligonum mongolicum* and *Haloxylon ammodendron*. The dominant herbaceous species are *Agriophyllum squarrosum* and *Halogeton arachnoideus* according to the importance value (Table 1). Furthermore, the dominant species were selected to conduct this research.

2.2 Morphological characteristics of dominant species

The measured morphological characteristics of the studied species are shown in Table 2. Among them *Haloxylon ammodendron* is a huge shrub with the basal diameter of 2.93 cm·plant^{-1}, total height of 221.59 cm·plant^{-1}, canopy cover of 0.35 m^2·plant^{-1} and mean above-ground weight of 1 876.36 g·plant^{-1}. *N. tangutorum* is an espitose shrub with the height of sand mounds of 27.72 cm·plant^{-1}, total height of 28.32 cm·plant^{-1}, canopy cover of 3.71 m^2·plant^{-1} and mean weight of 1 010.46 g·plant^{-1}. *C. mongolicum* is also a shrub with basal diameter of 0.99 cm·plant^{-1}, total height of 45.10 cm·plant^{-1}, canopy cover of 0.24 m^2·

Table 1 Analysis of dominant species in study area

Plant species	Species number per sample (Mean ± *SD*)	Frequency (%)	Coverage (%)	Importance value
Agriophyllum squarrosum	7.71 ± 7.60	30.3	0.956	70.841
Nitraria tangutorum	1.45 ± 2.17	7.06	9.049	69.703
Calligonum mongolicum	5.43 ± 8.06	26.4	2.501	66.307
Haloxylon ammodendron	1.34 ± 2.44	7.21	2.642	29.630
Halogeton arachnoideus	2.67 ± 3.63	10.20	0.212	23.503
Phragmites communis	1.11 ± 2.45	5.40	0.008	10.437
Sophora alopecuroides	0.65 ± 2.96	3.14	0.056	6.395
Limonium aureum	8.40 ± 5.08	2.49	0.012	4.864
Artemisia arenaria	0.44 ± 1.70	2.14	0.017	4.220
Thermopsis schischkinii	0.51 ± 2.32	2.08	0.010	4.058
Elaeagnus angustifolia	0.06 ± 0.36	0.30	0.488	3.599
Suaeda glauca	0.30 ± 1.95	1.48	0.012	2.926
Hedysarum scoparium	0.12 ± 0.46	0.59	0.122	1.897
Bassia dasyphylla	0.06 ± 0.29	0.30	0.001	0.583
Caragana microphylla	0.04 ± 0.19	0.18	0.037	0.571
Cirsium setosum	0.05 ± 0.27	0.24	0.001	0.466

The number of *N. tangutorum* is its espitose plant^{-1} and mean weight of 67.20 g•plant^{-1}. The rest of species, *A. squarrosum* and *Halogeton arachnoideus*, are herbaceous with slight weight of 5.28 g•plant^{-1} and 6.94 g•plant^{-1}, respectively.

2.3 Regression analysis

Plant biomass (above-ground dry biomass, below-ground fresh biomass, total fresh biomass, total dry biomass, respectively) were significantly correlated with plant basal diameter and canopy cover of *C. mongolicum*, *Haloxylon ammodendron*, *A. squarrosum* and *Halogeton arachnoideus* (including $p < 0.001$, $p < 0.01$, $p < 0.05$). Height of sand mounds and canopy cover of *N. tangutorum* were significantly correlated with plant biomass. Correlation coefficients between morphological characteristics (basal diameter, canopy cover and height of sand mounds) and plant biomass ranged from 0.492 to 0.967 in *C. mongolicum* (Table 3). These results suggest that plant biomass of the studied species was more closely related to plant basal diameter and canopy cover than total height.

According to the degree of correlation, height of sand mounds (*N. tangutorum*), basal diameter, and canopy cover were selected as individual plant parameters for multiple line regression equations of biomass. And based on the previous determined results, we obtained the equation for predicting the species biomass by using multiple line regression analyses method.

From the results in Table 3, we developed simple equation between the parameters with higher levels of significance and the biomass of dominant species (Table 4). To estimate biomass, simple and multiple regression equations were fitted to the data. Biomass ($Y_{1,2,3}$), the dependent variable, was regressed on basal diameter (X_1) and canopy cover (X_2) as the independent variables.

Biomass equations with two statistical parameters were fitted to the standing biomass. However, the variable, height of sand mounds, was excluded in

Table 2 Plant species and average morphological characteristics of dominant species

Species	Weight (g•plant^{-1})		Height of sand mounds (cm•plant^{-1})	Basal diameter (cm•plant^{-1})	Total height (cm•plant^{-1})	Canopy cover (m^2•plant^{-1})
	Above-ground	Below-ground				
Nitraria tangutorum	288.91 ± 320.66	721.55 ± 779.67	27.72 ± 21.29	–	28.32 ± 6.75	3.71 ± 4.69
Calligonum mongolicum	34.69 ± 17.37	32.51 ± 17.08	–	0.99 ± 0.47	45.10 ± 16.41	0.24 ± 0.13
Haloxylon ammodendron	1 876.36 ± 836.31	–	–	2.93 ± 1.04	221.59 ± 75.26	0.35 ± 0.21
Agriophyllum squarrosum	4.69 ± 2.29	0.59 ± 0.35	–	0.32 ± 0.08	18.78 ± 6.81	0.11 ± 0.06
Halogeton arachnoideus	6.24 ± 4.26	0.70 ± 0.49	–	0.35 ± 0.17	11.72 ± 3.75	0.09 ± 0.06

Data are presented as means ± *SD*

Table 3 Correlation coefficients between basal diameter, total height, canopy cover and height of sand mounds with *Nitraria tangutorum* and biomass of species

Species biomass	Correlation coefficients			
	Sand mounds at height (cm)	Basal diameter (cm)	Total height (cm)	Canopy cover (cm^2)
Nitraria tangutorum				
Above-ground dry biomass, ADB (g)	0.711[a]	–	−0.002	0.868[a]
Below-ground fresh biomass, BFB (g)	0.810[a]	–	−0.099	0.918[a]
Total fresh biomass, TFB (g)	0.780[a]	–	−0.065	0.907[a]
Total dry biomass, TDB (g)	0.786[a]	–	−0.071	0.909[a]
Calligonuum mongolicum				
Above-ground dry biomass(g)	–	0.492[c]	0.033	0.949[a]
Below-ground fresh biomass(g)	–	0.488[c]	0.131	0.910[a]
Total fresh biomass(g)	–	0.437[c]	0.078	0.967[a]
Total dry biomass(g)	–	0.507[c]	0.051	0.922[a]
Haloxylon ammodendron				
Above-ground dry biomass(g)	–	0.790[a]	0.405	0.878[a]
Agriophyllum squarrosum				
Above-ground dry biomass(g)	–	0.851[a]	0.377[c]	0.704[a]
Total fresh biomass(g)	–	0.849[a]	0.291	0.639[a]
Total dry biomass(g)	–	0.853[a]	0.368[c]	0.694[a]
Halogeton arachnoideus				
Above-ground dry biomass(g)	–	0.791[a]	0.336[c]	0.883[a]
Total fresh biomass(g)	–	0.807[b]	0.339[c]	0.785[a]
Total dry biomass(g)	–	0.809[a]	0.315	0.888[a]

a, b and c represent significant correlation among variables at 0.001, 0.01 and 0.05, respectively

N. tangutorun biomass equations due to the significance of coefficients with $p > 0.05$ ($p = 0.644$) by multiple stepwise regressions of SPSS. Consequently, the multiple regressions equations of *N. tangutorun* including canopy cover as independent variable were shown. The R and p statistics were carried out to estimate the fitness of a regression equation (Table 4). In all regression equations, average R of the linear equation was 0.908. The p-values of the slop were less than 0.001. It was proved that plant canopy cover and basal diameter could be used to estimate the species biomass at the ODE in Minqin oasis.

To validate each regression equation, it was applied to the prediction data set to predict biomass. Among the equations, a better level of correlation between observed and predicted biomass was showed ($R > 0.932$, $p < 0.001$) in Table 4. For each of the best equations, the relationship of correlation between observed and predicted biomass was significant, indicating that the equations made accurate predictions of independent data.

Table 4 Regression equations of biomass and results of analysis

Species	Equations	Data statistics: Estimation R	N	F	P	Prediction R	P
Nitraria tangutorum							
ADB	$Y_1 = 68.878 + 0.005\,932\ X_2$	0.868	22	61.029	0.000	0.923	0.000
BFB	$Y_2 = 328.636 + 0.033\,781 X_2$	0.918	22	107.271	0.000	0.952	0.000
TFB	$Y_3 = 546.033 + 0.053\,14\ X_2$	0.907	22	92.606	0.000	0.983	0.000
TDB	$Y_4 = 224.909 + 0.021\,18\ X_2$	0.909	22	95.382	0.000	0.978	0.000
Calligonum mongolicum							
ADB	$Y_1 = -0.371 + 6.946X_1 + 0.011\,95X_2$	0.966	21	125.341	0.000	0.993	0.000
BFB	$Y_2 = -11.355 + 14.768X_1 + 0.022\,84X_2$	0.929	21	56.956	0.000	0.985	0.000
TFB	$Y_3 = -14.218 + 19.116X_1 + 0.053\,91X_2$	0.974	21	164.913	0.000	0.976	0.000
TDB	$Y_4 = -0.865 + 15.524X_1 + 0.022\,34X_2$	0.944	21	73.749	0.000	0.994	0.000
Haloxylon ammodendron							
ADB	$Y = 501.709 + 284.065X_1 + 0.24X_2$	0.903	22	41.885	0.000	0.917	0.000
Agriophyllum squarrosum							
ADB	$Y_1 = -3.348 + 20.230X_1 + 0.001\,453X_2$	0.906	33	69.004	0.000	0.954	0.000
TFB	$Y_2 = -8.422 + 69.941X_1 + 0.003\,591X_2$	0.881	33	52.199	0.000	0.947	0.000
TDB	$Y_3 = -3.870 + 23.298X_1 + 0.001\,571X_2$	0.904	33	67.045	0.000	0.968	0.000
Halogeton arachnoideus							
ADB	$Y_1 = -0.485 + 3.455X_1 + 0.006\,1X_2$	0.885	35	57.983	0.000	0.936	0.000
TFB	$Y_2 = -14.031 + 118.501X_1 + 0.025\,6X_2$	0.827	35	34.693	0.000	0.949	0.000
TDB	$Y_3 = -0.653 + 5.179X_1 + 0.006\,36X_2$	0.893	35	63.227	0.000	0.953	0.000

ADB, *BFD*, *TFB*, *TDB*: See Table 3 X_1: Basal diameter (cm) X_2: Canopy cover (cm^2) $Y_{1,2,3}$: Biomass (g)

3 Discussion

Monitoring the variance of biomass was an important work for ecosystems, especially, for degrading ODE in Minqin oasis. And it would be an easy work using biomass equation. In this paper, equations for estimating above-ground, below-ground and standing biomass were developed by five typical dominant species of ODE in Minqin oasis. Equations provided good statistics and therefore they are recommended to make preliminary estimates of biomass components.

Our results have proved that regression equations including plant basal diameter (excluding *N. tangutorum*) and plant canopy cover could give a good fit to the biomass for dominant desert plant species, as is shown in Table 3. The R and p-value of predicted variance in Table 4 can be used to compare and evaluate the prediction accuracy of the biomass equations. The results indicated the biomass was better correlated to the basal diameter (excluding *N. tangutorum*) and canopy cover than the total height, especially the canopy cover (Table 3). The height variables show less correlation with the biomass, which was corresponded with other results published before (Assaeed, 1997; Riegelhaupt *et al.*, 1990; Padrón & Navarro, 2004). However, some works showed plant height was a good fit to the biomass for the tussock grasses of the Mendoza plain (Guevara *et al.*, 2002). This could be due to: 1) the difference between the species of the studied biomass, and 2) the fact that the sample dimensions are different in both studies, which could have an effect on the final equations (Padrón & Navarro, 2004). In addition, we think plant would expand as possible as its canopy cover with basal diameter growing to absorb adequately light resource using limited water and nutrition in desert environment. Therefore, the biomass were highly correlated with the basal diameter (excluding *N*. *tangutorum*) and canopy cover. The total height was not significantly correlated with biomass of individual species. In general, the canopy cover was naturally more variable than the basal diameter since it to a greater extent was influenced by internal factors to stand growth such as stand density and competition from neighboring trees, and by external factors such as altitude, position on slope, climate variation, seasonal changes, wind damage and atmospheric pollution (Bi *et al*., 2004). Therefore, further researching are needed to confirm the validity of equations for predicting biomass on different sites.

In the present study, many relationships have been developed for predicting biomass (Hatton *et al*., 1986; Assaeed, 1997; Parresol, 1999; Návar *et al*., 2002; Bi *et al*., 2004), but little on desert plant species. In this paper, above- and below-ground biomass of dominant plant species can be estimated by regression equations, which show *R* coefficients above 90%. Equations allow for a fast estimation of the biomass of desert stand from relatively simple inventories. In our study area, vegetation displayed a mosaic of patches with sparsely distributed drought-tolerant shrubs and herbaceous species. Therefore, total biomass may be determined accurately and conveniently using predicting equations of individual species. Our equations provide valuable information for predicting biomass and the change of biomass in ODE.

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