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Factor Analysis of Differences in Biomass Accumulations between Male and Female *Populus Cathayana* Deedlings under Drought Stress

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Abstract

The main influential factor of biomass accumulations between male and female *Populus cathayana* seedlings is investigated from the point of factor analysis according to biomass of *P. cathayana* seedlings under drought stress as well as related morphological, physiological, and biochemical indicators. The results shows that biomass accumulations in male and female plants under drought stress are mainly associated with stem dry mass (SDM), root dry mass (RDM), height growth (HG), basal diameter (BD), total leaf number (TLN) and other morphologic changes, and have little relation with intrinsic water use efficiency (WUE). There is sex differences in the mode of biomass accumulation between male and female plants. Biomass accumulation in female plants depends on morphologic changes, followed by hormonal regulation, and finally physiological progress. However, biomass accumulation in male plants depends on morphologic changes (similar to female plants), followed by physiological progress, and finally hormonal regulation. Moreover, biomass accumulation in female plants on the morphologic aspects mainly depends on SDM, while is not relevant to TLN. However, male plants mainly depend on SDM, and have relationship with TLN. In sum, our study demonstrates that biomass accumulations in male and female *P. cathayana* seedlings under drought stress have different strategies.

Keywords: *Populus cathayana*, Biomass accumulation, Sexual differences, Factor analysis, Principal component

1. Introduction

Populus cathayana belongs to Salicaceae, Populus L. Sect. Tacamahaca Spach, and is wildly distributed in the north, northwest and southwest areas in our country (Zhao & Gong, 1991; Yang et al., 1996). As the common forestation species used in China, *P. cathayana* has some features, such as strong adaptability, easy to multiplication, fast growth, etc. Thus, it is wildly used in ecological management, environmental improvement, woodworking, and so on. Because of long-term evolution and adaptation, there have been significant differences in growth and development, reproductive characteristic and biomass distribution between male and female *P. cathayana*. It has been reported that male and female *P. cathayana* seedlings have significant differences in the response to stress environments. Male plants have higher resistance and accumulate more biomass under the circumstances of drought and strong ultraviolet radiation compared with female plants (Xu et al., 2008a; Xu et al., 2008b; Xu et al., 2010). Liu Xia also studies in man-made forest of *P. cathayana* and finds that the average height growth (HG), basal diameter (BD) and stem volume in male plants more than 2400 m height above sea level are higher than that of female plants, showing significant growth vigor (Liu, 2003).

However, the above studies reveal the differences under stress environments between male and female plants just from the aspects of morphology, physiology, biochemistry, and biomass accumulation. There has not been reported the causal analysis of such phenomenon. Therefore, in our report, based on biomass of male and female *Populus cathayana* seedlings under drought stress as well as related morphological, physiological, and biochemical indicators, the main mechanism for the differences formation is revealed with investigating the main influential factor of biomass accumulations between male and female seedlings from the point of factor analysis, which may provide a theoretical basis for forestry production and practice.

2. Data Sources and Analysis

2.1 Data Sources

The data are sourced from Different Physioecological Response between Males and Females of *Populus cathayana Rehd.* to Drought Stress (Xu, 2008). Two factors completely random design is used in this study: each male and female P. cathayana cutting seedlings for 40 plants, in which 20 plants grow in moist environment, and the other 20 plants grow in drought conditions. The whole test was performed from May 2006 to Sep. 2006 (Xu, 2008).

2.2 Datasheet Construction

12 factors which may be relevant with biomass accumulation are chosen. They are HG, BD, total leaf number (TLN), total leaf area (TLA), stem dry mass (SDM), root dry mass (RDM), leaf dry mass (LDM), photosynthesis rate (Pn), transpiration rate (E), intrinsic water use efficiency (WUE_i), abscisic acid (ABA), and stable carbon isotope composition (δ 13C). Table 1 shows statistical datasheet.

2.3 Data Analysis

After the data is standardized, covariance matrixes between the various factors are separately calculated in male and female plants; covariance matrixe $\Sigma = LL' + \Psi$ is deducted with factor model: $X - \mu = LF + \varepsilon$ and $\Sigma = E(X-\mu)(X-\mu)'$; Variable variance is broken down into load and its transposed cross products as well as variance of special factor; characteristic root and characteristic vector of covariance matrixes are calculated by principal component method in order to determine the variance of principal component and coefficients of indicator variable of various principal components; The number of public factors is decided based on the relative importance of each factor; reasonable explanation is endued with transforming combined with public factors, and the variables are objectively divided into groups according to factor value (Zhang, 2002; Yu & He, 2003; Lu, 2008). All the data are analyzed by SPSS software.

3. Results and Analysis

3.1 Results of Bartlett Test of Sphericity and Kaiser-Meyer-Olkin (KMO) Test

Bartlett test of sphericity and KMO test can be used to check whether there is closer correlation among each factor so as to determine whether it is applicable for factor analysis. In this study, the value of KMO test is 0.792, according to the standard proposed by statistician Kaiser, this value exceeds 0.6, and it is applicable for factor analysis (Zhang, 1999; Zhang, 2002). Besides, Chi-square value of Bartlett test is 383.56, and concomitant probability ratio is 0.000, which is less than the significance level 0.05. Thus, null hypothesis of this test is rejected, and it is considered that the data is also applicable for factor analysis.

3.2 Characteristic Value of Principal Components and Contribution Rate of Cumulative Variances

The passed data is performed with factor extraction by principal components analysis (PCA). Its advantage is that the first PCA axis is located in the direction as much as possible to obtain the variance along this ordination axis, and then find the second PCA axis. Continued based on such mode, finally variances relatively concentrate in the fewer axes so as to explain the index (Yang & Lu, 1981; Xu et al., 2005). Table 2 shows variance contribution rate and cumulative variance contribution rate of various principal components.

Table 2 shows that characteristic roots of principal components 1, 2 and 3 of female plants are separately 6.13, 2.42 and 1.65, occupy 51.08%, 20.17% and 13.76% of the entire variable, and the first 3 principal components integrate 88.01% of the entire information; characteristic roots of principal components 1, 2 and 3 of male plants are separately 7.47, 2.01 and 1.10, cover 62.24%, 16.77% and 9.13% of the entire variable, and the first 3 principal components integrate 88.14% of the entire information. Therefore, only the first 3 principal components can be chosen in order to reduce principal components, and the deleted principal components are considered as interference information.

3.3 Factor Load Matrix of Principal Components

In order to place the principal components in the pace which is most conducive to the analysis and benefits naming and explaining the public factor, factor mode is performed rotation transformation using Varimax, which can cause that each factor with maximum load have minimum number of variables so as to explain the factor. Table 3 shows the load matrix of male and female plants after rotating. Scatterplot of 12 related indicators in coordinate axis constituted by principal component 1 and 2 is shown in Figure 1.

Combined with Table 3 and Figure 1, it is shown that male and female plants have the differences in the related indicators of principal component of 1, 2 and 3: principal component 1 of female plants have absolutely larger correlation coefficient in HG, BD, TLN, SDM, RDM and LDM, while principal component 1 of male plants also has a close relationship with TLA and Pn in addition to the above six morphologic indicators; principal component 2 of female plants has a close relationship with TLA and ABA, while principal component 2 of male plants is closely related with E; principal component 3 of female plants has a greater correlation with Pn and E, while principal component 3 of male plants is closely related with ABA. Moreover, principal component1, 2 and 3 of male and female plants has less correlation with WUE and δ^{13}C.

Because principal component 1 has close relationships with HG, BD, TLN, TLA, SDM, RDM and LDM, principal component 1 can be named as form factor. However, principal component 2 and 3 varies at different gender. Principal component 2 of female plants has a relationship with ABA and TLA, and principal component 3 is associated with Pn and E. Therefore, Principal component 2 and 3 can be separately named as hormone factor and physiology factor. Principal component 2 of male plants has a relationship with E and principal component 3 is associated with ABA. Thus characteristic reflected by principal component 2 and 3 of male plants are just opposite with that of female plants, which are separately named as physiology factor and hormone factor.

3.4 Factor Bias

Scatterplot constructed by the score date of factor 1 and 2 could reflect the individual bias in the two factors. Figure 2 shows the scatterplot obtained by the score date from factor 1 (form factor) and factor 2 of male and female plants.

From Figure 2, it is shown that there is a significant difference in factor bias between male and female plants: majority of male plants distribute in 1 and 4 quadrants as contrasted with the female plants, while female plants mainly distribute in 2 and 3 quadrants, suggesting that male plants is more inclined to factor 1. Because factor 1 reflects external morphologic changes of the plants, we can have a conclusion that male plants have a higher ability to keep external morphologic changes compared with female plants under drought stress, and then promote more biomass accumulations.

4. Discussions

On the view of the data analysis, biomass accumulations of male and female plants under drought stress are mainly relevant with SDM, RDM, HG, BD, TLN, and other morphologic changes, followed by hormone and physiology progress, and has less relationship with WUEi. Besides, there are differences in the order of correlation factors between male and female plants. Biomass accumulation of female plants mainly depends on morphologic changes, followed by hormonal regulation, and finally physiology progress, while biomass accumulation of male plants mainly depends on morphologic changes, followed by physiology progress, and finally hormonal regulation. According to the view of Pan Ruichi and his colleagues, under physical environment (non-stress environment), morphologic changes of the plants depends on physiology progress, and physiology progress depends on hormonal regulation, displaying that the decision law morphology-physiology-hormone) (Pan, 2004). Because the decision order of male *P. cathayana* under drought stress is coincidence with this law, while the decision order of female *P. cathayana* changes, it is supposed that male *P. cathayana* under drought stress still keep normal growth and development, and then have higher drought adaptation compared with female plants. This deduction has been proved in the study of sea buckthorn by Li Chunyang et al. (2004) and the study of *P. cathayana* by Xu Xiao et al. (2008).

Moreover, although biomass accumulations of both male and female plants have relationships with morphologic changes, there are significant differences in the order of various morphologic changes, which based on correlation coefficient between female plants and morphologicindex relative with biomass accumulation, and they are SDM, RDM, HG, BD, LDM and TLN. While as for male plants, they are RDM, SDM, HG, LDM, TLN, TLA and BD (Table 1 and Figure 1). These results suggest that biomass accumulations of female plants under droughty stress mainly depend on SDM in morphology, and have no relationship with TLA. While biomass accumulations of male plants mainly depend on RDM and have relationship with TLA. It is demonstrated that there are different strategies in biomass accumulations of male and female plants.

In summary, although lots of papers have reported that male plants under drought stress have higher HG, BD, TLN, TLA, Pn, stomatal conductance compared with female plants, and then have higher biomass (Xu et al., 2007). No much attention has been paid to the main differences in biomass accumulation between male and female plants. Compared with the previous studies, in our study, the main differences in biomass accumulation between male and female plants and its basic reason are investigated from multiple ecological factors indexes by principal components factor extraction method, which may provide new ideas for the related studies.

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Table 1. Eco-physiological factors data of male and female *Populus cathayana* under drought stress

Sex	NO	HG (*cm*)	BD (*mm*)	TLN	TLA (cm^2)	SDM (*g*)	RDM (*g*)	LDM (*g*)	Pn (u1)	E (u2)	W (u3)	ABA (u4)	$\delta^{1}3C$ (‰)
F	1	44	5.13	7	81.51	2.83	1.63	0.39	13.10	4.38	52.61	0.27	-27.58
	2	44	5.21	3	26.83	3.29	1.80	0.18	10.80	3.64	57.14	0.43	-27.84
	3	40	4.95	6	37.04	2.61	2.02	0.30	12.64	3.88	60.83	0.57	-27.47
	4	75	7.1	23	97.22	6.42	5.15	6.11	14.70	3.88	71.99	0.36	-27.63
	5	26	3.61	7	47.99	1.38	0.89	0.34	4.45	1.44	58.17	0.52	-26.03
	6	24	3.68	4	25.06	1.32	0.55	0.18	13.06	3.92	53.00	0.55	-25.69
	7	14	3.6	6	28.63	0.63	0.34	0.18	8.12	2.98	57.51	0.35	-25.83
	8	20	3.21	3	28.19	0.96	1.46	0.21	11.66	2.85	83.29	0.53	-25.76
	9	17	2.51	4	18.41	0.75	0.28	0.20	10.32	3.42	57.02	0.86	-26.88
	10	39	4.17	13	270.65	2.07	1.50	1.97	11.66	2.85	83.29	0.89	-26.65
	11	26	4.11	14	333.65	2.45	2.03	2.45	14.42	4.33	56.73	1.09	-27.06
	12	33	3.79	11	236.06	2.39	1.10	1.71	10.32	3.42	57.02	0.81	-25.77
	13	33	3.9	10	227.93	1.60	1.72	1.60	12.32	2.91	85.44	1.32	-26.41
	14	28	3.62	13	236.17	2.05	0.83	1.64	12.12	3.94	56.11	0.95	-26.84
M	1	83	6.21	23	413.17	5.12	3.21	3.14	17.02	5.00	84.83	0.98	-26.94
	2	89	6.64	21	421.11	4.50	4.62	3.42	16.78	3.36	94.38	1.19	-26.81
	3	87	7.13	19	519.24	5.93	3.62	3.42	18.32	5.05	96.13	1.57	-27.24
	4	55	6.11	18	219.24	2.24	2.47	1.53	15.06	2.42	91.41	0.78	-26.83
	5	11	3.19	9	36.05	0.50	0.65	0.52	11.96	3.05	72.40	0.61	-25.92
	6	14	3.83	14	59.12	0.82	0.66	0.51	12.68	4.71	47.46	0.78	-26.20
	7	78	5.28	16	176.24	4.30	2.99	1.62	14.74	4.08	59.44	0.87	-26.11
	8	83	5.39	26	306.38	6.90	3.83	2.79	10.72	2.90	73.12	0.48	-26.33
	9	12	2.82	4	22.38	0.69	0.93	0.16	10.48	3.28	56.71	0.93	-26.71
	10	78	6.06	29	465.84	6.29	4.14	3.71	18.28	3.87	83.47	1.37	-26.66
	11	80	7.05	26	489.94	6.55	4.99	4.24	20.32	5.33	55.73	0.54	-26.91
	12	68	5.21	22	359.45	4.41	3.34	3.23	18.00	4.31	69.28	0.73	-25.35
	13	84	6.23	20	356.49	7.09	4.03	3.00	19.64	5.13	63.81	0.67	-25.55
	14	78	6.32	23	498.74	6.69	4.61	3.94	19.20	5.11	53.75	1.04	-25.96

The data are sourced from Different Physioecological Response between Males and Females of *Populus cathayana Rehd.* to Drought Stress (Xu, 2008). Note: u1:$molm^{-2}s^{-1}$, u2:$mmolm^{-2}s^{-1}$, u3:$mmolmmol^{-1}$, u4:$\mu gg^{-1}FW$.

Table 2. Total variance explained of male and female *P. cathayana* individuals

Component	Extraction Sums of Squared Loadings					
	Female			Male		
	Total	%of Variance	Cumulative (%)	Total	%of Variance	Cumulative (%)
1	6.13	51.08	51.08	7.47	62.24	62.24
2	2.42	20.17	71.25	2.01	16.77	79.01
3	1.65	13.76	85.01	1.10	9.13	88.14
4	0.82	6.81	91.83	0.54	4.47	92.61
5	0.55	4.56	96.38	0.33	2.72	95.33
6	0.20	1.63	98.01	0.22	1.80	97.13
7	0.12	0.98	99.00	0.17	1.45	98.58
8	0.06	0.52	99.52	0.10	0.80	99.38
9	0.03	0.28	99.80	0.04	0.34	99.72
10	0.02	0.13	99.92	0.03	0.22	99.95
11	0.01	0.06	99.98	0.01	0.05	100.00
12	0.00	0.02	100.00	0.00	0.00	100.00

Table 3. Factor load matrix of male and female plants (after rotating)

Factors	Component					
	Female			Male		
	1	2	3	1	2	3
HG	0.909	-0.085	0.158	0.930	0.116	0.108
BD	0.876	-0.198	0.209	0.836	0.227	0.102
TLN	0.794	0.464	0.084	0.891	0.061	-0.027
TLA	0.157	0.951	0.131	0.877	0.285	0.234
SDM	0.939	-0.045	0.219	0.952	0.203	0.039
RDM	0.912	-0.044	0.205	0.975	0.077	0.067
LDM	0.871	0.298	0.144	0.925	0.245	0.115
Pn	0.328	0.174	0.902	0.648	0.507	0.168
E	0.160	0.047	0.903	0.309	0.916	0.099
WUE_i	0.159	0.180	-0.088	0.228	-0.256	0.294
ABA	-0.228	0.879	0.057	0.124	0.117	0.927
$\delta^{13}C$	-0.423	0.047	-0.293	-0.065	0.039	-0.227

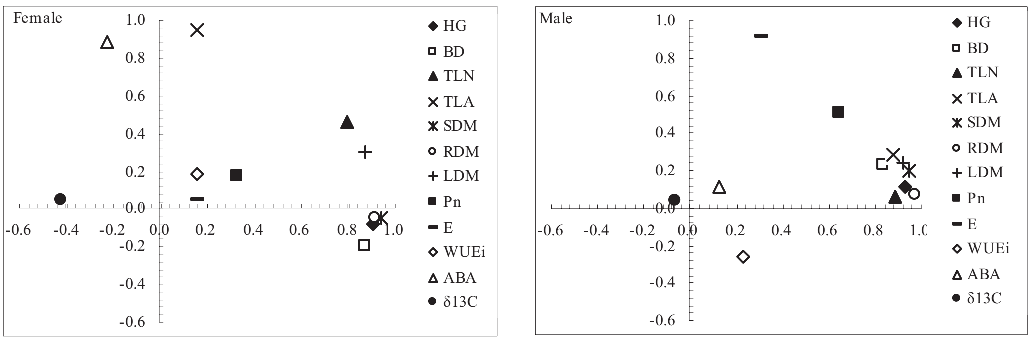

Figure 1. Factor scatter plot after male and female plants rotating

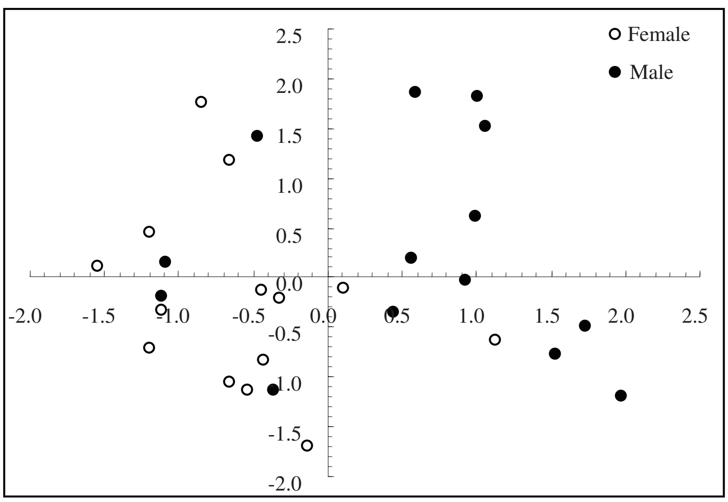

Figure 2. Scatter plot of factor score from male and female plants