J. Bamboo and Rattan, Vol. 1, No. 1, pp. 11–21 (2001)

Factor analysis of growth parameters in *Dendrocalamus strictus* seedlings: An exploratory approach

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Abstract—A study on *Dendrocalamus strictus* seedlings was conducted to identify the underlying factors in growth parameters, and then to analyse factor scores obtained through factor analysis to test the variation among groups of different number of culms per clump. Six-month-old seedlings (clumps) of *Dendrocalamus strictus* with four groups (based on two, three, four and five or more culms per clump) were sampled and different growth parameters (height of culms, basal culm diameter, number of leaves, number of rhizome sub-units and fresh and dry weight of culms, leaves, rhizome and roots) were measured. A three-factor model accounted for 72 percent of the total variation present in the data was extracted. The first factor, having high positive loadings on fresh and dry weight of rhizome and dry weight of roots, was called the 'below ground mass factor'. The second factor had high positive loadings on height of culms and basal culm diameter and was called the 'above ground growth factor'. The second factor was significantly different and divided the groups in two homogenous sub-groups. The third factor (photosynthetic) had high positive loading on the number of leaves and did not vary significantly within the group of number of culms per clump. Factor analysis provided a statistical tool for grouping the 12 correlated growth parameters into three uncorrelated factors. Analysis of factor scores allowed independent assessment of the number of culms per clump.

Key words: Bamboo; culms; *Dendrocalamus strictus*; factor analysis; growth parameters.

INTRODUCTION

Bamboo is a versatile multipurpose forest produce playing a vital role in the industrial and domestic economics of the world. A complete bamboo plant consists of three morphological structures — the aerial part (culms), and two under ground parts (rhizome and roots) [1]. *Dendrocalamus strictus* is one of the most important bamboo species. It is widely distributed in India in semi-dry and dry zone along

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analysis, the correlation matrix from a large number of correlated variables can be decomposed into the variance attributed to the underlying factors and the variance unique to each variable [10]. Factor analysis can reveal relationships not previously suspected and allow interpretations that would not ordinarily result from univariate analysis [11].

The present study has been undertaken with the following objectives/hypothesis:

(i) How are the different growth parameters of bamboo seedlings related?

(ii) Do the four groups of number of culms/clump have significant differences for the growth parameters under study?

(iii) Is it possible to construct a function $f(X_1, \ldots, X_n)$ of the variables that in some sense captures most of the sample differences present in the groups?

EXPERIMENTAL MATERIAL AND METHODS

The experiment was laid out in the month of March in the nursery of the Plant Physiology Discipline, Botany Division, Forest Research Institute (F.R.I.), Dehradun (altitude — 610 m, latitude — 30°N, longitude — 78°E), India. The seeds of *Dendrocalamus strictus* (Roxb.) were obtained from the Seed Testing Laboratory of the Institute. After germination in a germination chamber, all seedlings were transplanted in poly-bags filled with soil pH = 6.22; available N, P and K = 0.0081%, 0.0080% and 0.0096%, respectively), coarse sand and farmyard manure (FYM) [pH = 7.39; N, P and K = 0.0500%, 0.0167% and 0.0433%] in the ratio of 2 : 1 : 1. These poly bags were kept in natural conditions in the nursery. The range of max. temp., min. temp., relative humidity and rainfall during the experiment (March to August) was 23°–34.6°C, 9.5°–22.7°C, 71–94% and 64.4–828.7 mm, respectively. After six months, seedlings were divided into four groups based on number of culms per clump (group 1 — two, group 2 — three, group 3 — four and group 4 — five or more culms per clump). Twenty poly-bags of each group were selected randomly and thereafter, the soil was removed from the seedlings carefully by washing with water and different growth parameters like height of culms, basal culm diameter, number of leaves, number of rhizome sub-units, and fresh and dry weight of culms (without leaves), leaves, rhizome, and roots were measured. The mean and standard error of all these parameters are given in Table 1.

Factor analysis

Simple linear correlation between the growth parameters was calculated to identify significant biological interrelationships (Table 2). Factor analysis was performed using SPSS [12]. Because the growth parameters (variables) had different measurement units, the analysis was performed on the correlation matrix (Table 2), rather than the variance co-variance matrix to estimate the effects of different measurement units in the determination of factor loading [7, 11].

Table 1.
Means and standard errors of growth parameters of bamboo, *Dendrocalamus strictus* seedlings for number of culms per clump

Group (culms per clump)	Parameter											
	HOC (cm)	BDC (mm)	FWC (g)	DWC (g)	NOL	FWL (g)	DWL (g)	NORSU	FWRZ (g)	DWRZ (g)	FWRT (g)	DWRT (g)
1 (Two)	87.78 (8.07)	3.71 (0.26)	12.85 (1.69)	5.82 (0.84)	18.38 (1.31)	8.04 (0.72)	3.16 (0.28)	6.2 (0.45)	12.12 (1.38)	3.00 (0.33)	8.61 (1.07)	1.44 (0.19)
2 (Three)	84.86 (5.21)	3.42 (0.12)	18.78 (1.32)	7.76 (0.59)	16.50 (1.00)	9.73 (0.68)	3.65 (0.27)	7.4 (0.41)	13.45 (1.16)	3.01 (0.29)	11.18 (1.03)	1.91 (0.18)
3 (Four)	65.85 (4.22)	3.18 (0.25)	15.49 (1.61)	6.45 (0.71)	15.46 (1.75)	7.88 (0.63)	3.14 (0.26)	9.47 (0.56)	13.52 (1.50)	3.71 (0.51)	8.82 (1.18)	1.54 (0.21)
4 (Five or more)	57.63 (3.87)	2.83 (0.18)	14.75 (1.42)	6.29 (0.72)	13.42 (1.13)	8.77 (0.64)	3.27 (0.30)	10.33 (0.54)	13.48 (1.39)	3.35 (0.44)	8.47 (0.98)	1.51 (0.15)

HOC = height of culms BDC = basal diameter of culm, FWC = fresh weight of colums, DWC = dry weight of culms, NOL = number of leaves, FWL = fresh weight of leaves, DWL = dry weight of leaves, NORSU = number of rhizome sub-units, FWRZ = fresh weight of rhizome, DWRZ = dry weight of rhizome, FWRT = fresh weight of root and DWRT = dry weight of roots.

* Values in parentheses are standard errors.

Table 2.
Correlation coefficients between growth parameters of the four groups

	HOC	BDC	FWC	DWC	NOL	FWL	DWL	NORSU	FWRZ	DWRZ	FWRT	DWRT
						Group 1↓						
HOC		0.386	0.625*	0.692*	0.317	0.425	0.606*	0.212	0.217	0.058	0.205	0.088
BDC	−0.225		0.592*	0.516*	0.045	0.510*	0.452*	0.173	0.055	0.329	0.598*	0.486*
FWC	0.423	0.146		0.974*	0.477*	0.700*	0.863*	0.436	0.349	0.397	0.527*	0.448*
DWC	0.476*	0.085	0.919*		0.510*	0.699*	0.867*	0.441*	0.402	0.398	0.420	0.328
NOL	−0.271	−0.120	−0.326	−0.061		0.322	0.524*	0.071	0.257	0.241	0.259	0.114
FWL	−0.284	0.280	0.409	0.504*	0.352		0.878*	0.330	0.478*	0.651*	0.592*	0.598*
DWL	0.120	−0.024	0.543*	0.708*	0.451*	0.740*		0.262	0.558*	0.594*	0.499*	0.476*
NORSU	0.165	−0.318	0.227	0.155	−0.227	−0.074	0.064		−0.014	−0.145	−0.225	−0.295
FWRZ	−0.288	−0.110	0.144	0.122	0.364	0.358	0.235	0.498*		0.728*	0.287	0.311
DWRZ	−0.145	0.074	0.392	0.423	0.288	0.425	0.346	0.275	0.854*		0.656*	0.666*
FWRT	0.029	0.158	0.574*	0.644*	0.324	0.709*	0.879*	0.211	0.420	0.513*		0.956*
DWRT	0.121	0.068	0.544*	0.670*	0.414	0.707*	0.929*	0.229	0.387	0.445*	0.966*	
						Group 2↑						

Table 2.
(Continued)

	Group 3↓											
	HOC	BDC	FWC	DWC	NOL	FWL	DWL	NORSU	FWRZ	DWRZ	FWRT	DWRT
HOC		0.584*	0.641*	0.631*	−0.128	0.199	0.095	0.468*	0.418	0.342	0.152	0.154
BDC	−0.225		0.900*	0.936*	0.151	0.548*	0.671*	0.707*	0.659*	0.435	0.524*	0.558*
FWC	0.511*	0.146		0.971*	0.127	0.673*	0.638*	0.825*	0.801*	0.745*	0.638*	0.610*
DWC	0.485*	0.085	0.935*		0.194	0.660*	0.681*	0.823*	0.768*	0.741*	0.577*	0.589*
NOL	−0.424	−0.120	−0.354	−0.295		0.286	0.260	0.076	−0.063	−0.053	−0.141	−0.196
FWL	0.062	0.280	0.819*	0.797*	−0.047		0.780*	0.491*	0.598*	0.572*	0.464*	0.413
DWL	0.125	−0.024	0.857*	0.848*	−0.120	0.915*		0.539*	0.580*	0.617*	0.475*	0.488*
NORSU	0.036	−0.318	0.500*	0.500*	−0.092	0.657*	0.550*		0.625*	0.549*	0.514*	0.529*
FWRZ	0.261	−0.110	0.611*	0.684*	−0.270	0.707*	0.549*	0.726*		0.930*	0.902*	0.904*
DWRZ	0.150	0.074	0.660*	0.789*	−0.226	0.777*	0.686*	0.606*	0.914*		0.842*	0.912*
FWRT	0.215	0.158	0.417	0.392	−0.411	0.437	0.264	0.449	0.506*	0.361		0.943*
DWRT	0.140	0.068	0.548*	0.577*	−0.269	0.609*	0.541*	0.431	0.624*	0.607*	0.844*	
	Group 4↑											

* Significant at 0.05 probability level.

The principal component analysis was used as the method of factor extractions and all the factors were subjected to an orthogonal rotation using the Varimax rotation with Kaiser Normalization method [12]. A Varimax rotation with Kaiser Normalization redistributes the variance of each variable so that each variable loads highly on only one factor with non-zero loading on other factors [10]. Growth variables used were height of culms, basal culm diameter, number of leaves, number of rhizome sub-units and fresh and dry weight of culms, leaves, rhizome and roots.

Univariate analysis

Factor scores are linear transformation of the original variables and are estimated of values for the unobserved factors [11]. Rotated factor scores from each observation were computed using SPSS and analysed by analysis of variance using a completely randomised block design.

RESULTS

The range of variation among groups was apparent in most of the growth parameters of clump, especially height of culms (57.63–87.79 cm), basal culm diameter (2.84–3.71 mm), fresh weight of culms (12.85–18.78 g) and number of rhizome sub-units (6.20–10.33) as depicted in Table 1. This variation may be due to different number of culms per clump and an indicator of different physiological behavior of the groups.

Thirty-three, twenty-four, forty-seven and thirty-two out of a total of sixty-six correlations between variables of each group were found significant in group 1, 2, 3 and 4, respectively (Table 2). In general, the dry weight of culms and roots was positively correlated with many growth parameters. The number of rhizome sub-units was negatively correlated with nearly all growth parameters except number of leaves for group 1, whereas it was positively correlated with all growth parameters for group 3 and group 4 (Table 2). The values of correlation coefficients among many variables in all four groups indicate that they can be grouped into homogenous sets of variables based on underlying factor patterns.

Eigenvalues for the first three factors were >1 and when added, accounted for 72.3% of the total variation in the growth parameters (Table 3). Communalities estimated the portion of variance in each variable that was explained by the factor model. The three-factor model explained >80% of the variance in dry weight of leaves and culms; >75.0% of the variance in fresh weight of culms, fresh weight of leaves, number of leaves and dry weight of rhizome and >70.0% of the variance in height of culms, fresh weight of rhizome and dry weight of roots (Table 3). However, the three-factor model explained only 59.0% of the variance in basal diameter of culms and number of rhizome sub-units. The comparatively low communalities for basal diameter and number of rhizome sub-units indicate that a significant portion of the variance of these variables remained unexplained.

Table 3.
Rotated factor loadings and communalities of a three factor model of growth parameters of bamboo, *Dendrocalamus strictus*

Growth parameter	Component			Communalities
	1	2	3	
HOC	0.083	0.829	0.139	0.714
BDC	0.297	0.697	−0.134	0.592
FWC	0.757	0.444	0.110	0.782
DWC	0.755	0.450	0.212	0.818
NOL	−0.006	0.035	0.868	0.755
FWL	0.774	0.129	0.384	0.763
DWL	0.771	0.192	0.444	0.829
NORSU	0.489	−0.513	−0.297	0.591
FWRZ	0.829	−0.123	−0.072	0.707
DWRZ	0.856	−0.073	−0.118	0.752
FWRT	0.759	0.292	−0.111	0.674
DWRT	0.808	0.203	−0.081	0.701
Proportion of total S^2	44.3	17.0	11.0	

Less importance should be ascribed to variables with low than to those with high communalities while interpreting the variable associations represented by a factor.

Factor loadings are the simple correlations between the original growth parameters and the factors. The first factor accounted for 44.3% of the total variation in the growth variables and had high positive factor loadings on dry weight of rhizome, fresh weight of rhizome and dry weight of roots and low factor loadings for number of leaves and height of culms (Table 3). The first factor can be termed as 'below ground mass factor' because this factor represents the mass effect resulting from the accumulation of matter below the ground. There was no significant difference in 'below ground mass factor' scores among groups (Table 4). This indicated that below ground mass effect resulting from accumulated matter did not vary statistically for the four different groups. From Table 1, it is apparent that as the number of rhizome sub-units increased, the number of culms also increased. This implies that at the time of culm formation the rhizome divides into rhizome sub-units (multiplication units).

The second factor accounted for 17% of the total variation in the growth variables and had high positive factor loadings on height and basal diameter of culms and high negative factor loadings on fresh and dry weight of rhizome. The second factor can be termed as 'above ground growth factor'. Factor scores for this factor varied significantly between the four groups (Table 4). The further analysis for this factor reveals that there are two homogeneous groups, namely, group 4 and 3, and group 2 and 1 with values of −0.7864 and −0.3694, and 0.5416 and 0.6143, respectively based on the Schefe test. It clearly reflects that the number of culms per clump was not dependent on the accumulated matter (dry weight of rhizome). If the accumulated matter is the same and the number of culms per clump differs then

Table 4.
Analysis of variance and mean squares for the effect of number of culms per clump of bamboo, *Dendrocalamus strictus* on factor scores

Source of variation	df	Mean sum of squares		
		I	II	III
Between groups	3	1.479	7.128*	1.426
Error	76	0.974	0.672	0.977
Total	79			

*Significant at the 0.01 probability level.
I, II and III are first, second and third factors respectively.

it can be interpreted that the height and basal diameter of culms will be higher in clumps with lower number of culms (two and three culms per clump) than clumps with higher number of culms (four and five or more culms per clump). This phenomenon was also reported by Sun Tienren *et al.* for bamboo stands [13]. Further, it is reported that during luxuriant growth, the starch and other nutrients (accumulated matter) in rhizome were used [2].

The third factor accounted for 11.0% of the total variation in the growth variables and had high positive factor loadings on the number of leaves and high negative factor loadings on the fresh weight of roots and rhizome. The third factor can be termed the 'Photosynthetic factor'. There was no significant difference in the 'Photosynthetic factor' scores among groups (Table 4). This indicated that carbohydrate production due to the green mass for the different groups did not vary significantly. Hence by this study, it could be deduced that due to the number of culms, the green matter may not vary significantly, if the age of the clumps is the same.

DISCUSSION

Factor analysis was used to exploit the correlation structure present in a data set containing highly correlated growth variables (Table 2) in order to group the variables into a set of three uncorrelated factors for assessing the effect of number of culms per clump on growth parameters in bamboo (*Dendrocalamus strictus*). By performing analysis of variance on factor scores, it was possible to evaluate the changes in the performance of growth parameters with relation to number of culms per clump.

This method offered an advantage over the analysis and interpretation of each growth variable separately because many growth variables are correlated and rotated factors are orthogonal to each other. They provide an additional tool in identifying the independent effects of different factors, namely, environmental, physiological and genetic influences on growth performance.

Based on factor loadings and the analysis of factor scores, the number of culms per clump appeared to directly influence the height of culms and basal culm diameter and indirectly influence number of leaves, fresh and dry weight of rhizome by affecting the number of rhizome sub-units. Fresh and dry weight of culms, leaves and roots were not influenced. Thus, it can be concluded that the number of culms per clump influences the growth of clump. Ding *et al.* reported that growth of a new culm depends on the accumulated substance, which is due to the older culms stored in rhizome or transported directly to the growing shoot through the rhizome [14]. After its development, it also provides materials to the rhizome.

In view of the strong inter-correlations between the variables, a lesser number of variables may be sufficient to describe the differences among the number of culms per clump. In the present study, 12 variables were analysed and the results suggested that only five variables (height and basal diameter of culms, fresh and dry weight of rhizome, and leaf number) were sufficient to describe the number of culms in bamboo seedlings.

Factor analysis has been useful in this study and can suggest which of the variables need to be measured and which could safely be omitted. The application of the analysis may suggest how the economics of labour etc. in measuring a large number of variables could be saved by measuring a few of the variables and giving the same information as the totality of the variables.

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