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Correlations among Morphological Characteristics of *Panax quinquefolium* Plants Grown in British Columbia, Canada

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Abstract

Correlations between various morphological characteristics of *Panax quinquefolium* plants grown in Lytton, British Columbia, Canada were assessed for 1-through 4-year old plants. Root dry weight, the dependent variable, was found to be strongly related to leaf dry weight, leaf length and root length for 1-and 2-year old plants during the middle of the growing season. For 1- and 2-year old plants at the end of the growing season, root dry weight was found to be related to leaf dry weight, leaf length and stem dry weight. For 3 and 4-year old plants, root dry weight was found to be related to leaf dry weight, leaf length and stem dry weight. For 3- and 4-year old plants, root dry weight was found to be related to leaf dry weight. For practical considerations, this latter relationship provides a simple method for selecting superior plants from which seed can be harvested.

Introduction

In recent years, the cultivation of American ginseng (*Panax quinquefolium* L.) has spread to locations well beyond the native range of the species in North America.[1] In 1982, commercial cultivation commenced in the Province of British Columbia, Canada. Since then, this new production area in western Canada has expanded annually.

In North America, American ginseng crops are maintained for four years and then harvested. Areas are expanded by planting the seeds from 3- and 4-year old plants. However, as yet, no breeding programs exist in North America[1] for selecting plants with superior growth characteristics.

Recent Korean research suggests that the aboveground morphological characteristics of *Panax ginseng* can be used as a basis for selecting plants with superior roots, the economically important part of the plant. Choi *et al.*[2] found that root dry weight in *P. ginseng* is correlated with a number of morphological characteristics. For 3- and 4-year old plants, root dry weight was particularly strongly correlated with leaf and stem dry weight, and diameter of the root. As yet, no comparable data for *P. quinquefolium* have been reported.

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This study represents a first attempt to provide American ginseng producers with a simple method for selecting superior plants based on aboveground morphological characteristics. The purpose is to describ the relationships among various morphological characteristics of American ginseng, and ultimately, to identify one or two easily observable indicators of plants with large roots. A subsidiary aim is to determine whether such indicators are constant across age groups and throughout the growing season.

Experimental Procedure

Research was conducted on a large commercial ginseng farm located at Lytton, British Columbia, Canada (50°17′ N, 121° 34′ W). Plants were grown using modern North American techniques employing raised soil beds covered with straw mulch. Shade was provided by black polypropylene fabric.

Plant growth measurements were made for 1-through 4-year old plants over three growing seasons: (a) 1- and 2-year old plants were sampled in 1984, (b) 1-, 2-, and 3-year old plants in 1985, and (c) 1- through 4-year old plants were sampled in 1986. Between April and September of each year, nineplant variables were measured at approximately weekly intervals. For this, 5 randomly selected American ginseng plants were removed from the field. Initial measurements were made and the plants were dissected. After this, individual plant components were dried at 70°C for 72h. The following measurements were made: (a) roo length was measured, (b) the number of stems were counted, (c) stem length (of the tallest stem in multi-stemmed individuals) was measured from bud to prongs, (d) leaf length of the longest, central leaflet was measured, (e) peduncle length in 3- and 4-year old plants was measured from prong to infructescence, and (f) root dry weight, stem dry weight, leaf dry weight and seed dry weight (3- and 4-year old plants) were measured. These measurements are tabulated in Table 1.

The data were divided into three groups based on changes in the nature of the root:total biomass ratios over the growing season (Fig. 1). From Fig. 1, it is evident that initially, root:total biomass values are high. This ratio falls as shoots begin to elongate. The data representing this early period are eliminated from further

Table 1. Measurements ot morphological characteristics and abbreviations used

Morphological Characteristic	Abbreviation
Root Length	RL
Stem Length	STL
Leaf Length	LL
Peduncle Length	PL
Number of Stems	#ST
Stem Dry Weight	STW
Leaf Dry Weight	LW
Seed Dry Weight	SW
Root Dry Weight	RW

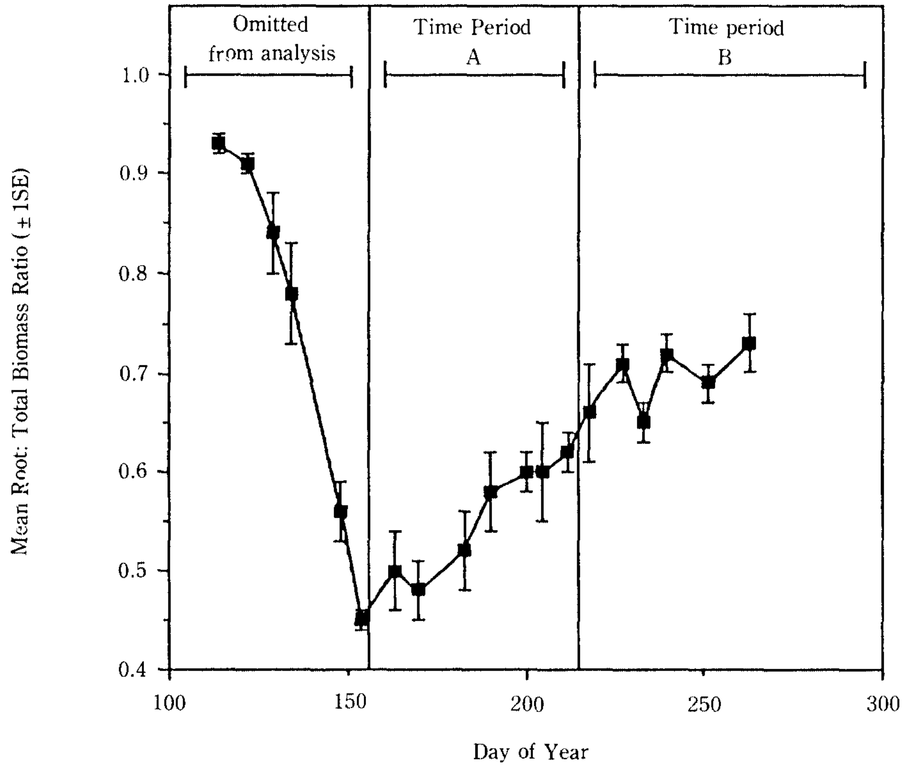

Fig. 1. Categorization of growing season data based on the root:total biomass ratio. Data from the early growing season were omitted from the analysis. Data from the mid-growing season period are labelled 'A' and data from the late growing season period are labelled 'B'. The data displayed are for the 3-year old plants sampled in 1985.

analysis. The middle part of the growing season was characterized by a linear increase in root:total biomass ratio and reflects the most active part of the season. Data from this period are labelled 'A' throughout this paper. The late growing season reflects a period where the root:total biomass ratio plateaus. These later data are labelled 'B' throughout this paper.

Preliminary analyses of individual plant age groups in each sample year illustrated similar growing season trends in the root:total biomass ratio. Data for 1- and 2-year old plants were pooled, as were the data for the 3- and 4-year old plants. The resultant data groups are:

(a) 1-2A: 1- and 2-year old plant data from the mid-growing season period,
(b) 1-2B: 1- and 2-year old plant data from the late growing season period,
(c) 3-4A: 3- and 4-year old plant data from the mid-growing season period, and
(d) 3-4B: 3- and 4-year old plant data from the late growing season period.

To conform to the assumption of normality, the root dry weight, stem dry weight, leaf dry weight and seed dry weight data were subjected to a natural logarithmic transformation prior to analysis.[3]. A correlation program was used to produce correlation matrices for the 1- and 2-year old plant data. Another procedure was utilized with the 3- and 4-year old plant data as this age group contained partially missing cases (peduncles and seeds had been removed late in the growing season for future planting purposes). The proceudre produces correlation matrices using incomplete cases.[4] A stepwise multiple regression procedure at the $p = 0.05$ significance level was performed on each data group to determine which morphological characteristics are most associated with root dry weight. The seed dry weight and peduncle length variables were omitted from this final analysis so that most cases were complete.

Results

For all data, both correlation and multiple stepwise regression procedures were performed. For the sake of brevity and clarity, variable names are abbreviated for the presentation of the correlation results and are presented in Table 1. The correlation matrices for the 1- and 2-year old plants, and 3- and 4-year old plants in the mid- and late growing season periods are presented in Table 2. Multiple stepwise regression results for these groups are given in Table 3.

Correlation Analyses

The results of the correlation analyses of 1- and 2-year old plants are similar in the middle and late growing season periods. Significant positive correlations ($p = 0.01$) were found among all variables. Stem length is most strongly associated with leaf length, leaf dry weight and root dry weight. Leaf length is most strongly correlated with stem length. Both leaf length and stem dry weight are correlated with leaf dry weight and root dry weight. Leaf dry weight was highly associated with stem length, leaf length, stem dry weight, and especially root dry weight. Correlation coefficient values involving root dry weight were high with stem length, leaf length and stem dry weight, and were highest with leaf dry weight.

The results of the 3- an 4-year old plant data are also similar for the mid- and late growing season periods. The correlation coefficients from the later period, however, have generally lower values. Root length showed little association with the other variables. For the mid-growing season data, stem length was positively associated with stem dry weight, leaf length, leaf dry weight, and to a lesser extent, with peduncle length, root dry weight and seed dry weight. At the $p = 0.05$ significance level it was negatively associated with number of stems. For the late growing season data, stem length showed strong positive associations with stem dry weight, leaf dry weight, leaf length, and to a lesser extent with root dry weight and peduncle length. Leaf length was correlated with all variables except the number of stems, and for late growing season period, root length. Peduncle length was positively associated with all variables except root length, and for the late growing season data, stem number. The number of stems showed negative correlations with most variables, although the only statistically significant associations were with stem length and peduncle length for the mid-growing season data. Stem dry weight was positively correlated with all variables except root length and the number of stems. Leaf dry weight exhibited an identical pattern, except for a weak association with root length for the mid-growing season data. Seed dry weight was positively associated with leaf length, peduncle length, stem dry weight and leaf dry weight for the late growing season data. For the

Table 2. Correlation coefficients among morphological characteristics of 1- and 2-year old plants and 3- and 4-year old plants for mid- (A) and late (B) growing season periods

Plant Data Group		Correlation	Matrices							
1-2A	RL	1.0000								
	STL	0.5919**	1.0000							
	LL	0.6045**	0.9258**	1.0000						
	STW	0.4142**	0.7874**	0.7984**	1.000					
	LW	0.4754**	0.8177**	0.8674**	0.8952**	1.0000				
	RW	0.5523**	0.8275**	0.8647**	0.8216**	0.9001**	1.0000			
		RL	STL	LL	STW	LW	RW			
1-2B	RL	1.0000								
	STL	0.7308**	1.0000							
	LL	0.7282**	0.8989**	1.0000						
	STW	0.4397**	0.6487**	0.5880**	1.0000					
	LW	0.5639**	0.7487**	0.7804**	0.7913**	1.0000				
	RW	0.6133**	0.8127**	0.8504**	0.7687**	0.9369**	1.0000			
		RL	STL	LL	STW	LW	RW			
3-4A	RL	1.0000								
	STL	0.0507	1.0000							
	LL	0.2275*	0.6962**	1.0000						
	PL	0.1374	0.5675**	0.6956**	1.0000					
	#ST	-0.1211	-0.2267*	-0.1352	-0.3198**	1.0000				
	STW	0.1484	0.7558**	0.8128**	0.5966**	-0.0329	1.0000			
	LW	0.2393*	0.5974**	0.8316**	0.6118**	0.0165	0.9452**	1.0000		
	SW	0.1772	0.5185**	0.7160**	0.6306**	-0.1722	0.7817**	0.8145**	1.0000	
	RW	0.2832*	0.5235**	0.7729**	0.6410**	-0.0239	0.8703**	0.9272**	0.8466**	1.0000
		RL	STL	LL	Pl	#ST	STW	LW	SW	RW
3-4 B	RL	1.0000								
	STL	0.1003	1.0000							
	LL	0.1556	0.7603**	1.0000						
	PL	0.2093	0.4865**	0.6201**	1.0000					
	#ST	-0.3551	-0.0325	-0.0961	-0.2299	1.0000				
	STW	0.1390	0.8945**	0.8298**	0.6072**	0.0725	1.0000			
	LW	0.1285	0.7656**	0.8329**	0.6003**	0.1008	0.9440**	1.0000		
	SW	-0.0573	0.3044	0.5471**	0.3698*	-0.1089	0.4380*	0.5685**	1.0000	
	RW	0.1582	0.6687**	0.7008**	0.5752**	0.0498	0.7940**	0.7994**	0.3074	1.0000
		RL	STL	LL	PI	#ST	STW	LW	SW	RW

Significance Levels: *ρ = 0.05 **p = 0.01

Table 3. Results of the stepwise multiple regression on morphological characteristics of 1- and 2-year old plants and 3- and 4-year old plants for mid- (A) and late (B) growing season periods

Plant Data Group	Dependent Variable	Independent variables entered into the regression equation at the 0.05 significance level.	Independent variables not entered into the regression equation at the 0.05 significance level	Partial	r^2	Significance Level
1-2 A	Root Dry Weight	Leaf Dry Weight		0.9001	0.8101	0.0000
		Leaf Length		0.3875	0.8387	0.0000
		Root Length		0.1864	0.8443	0.0091
			Stem Length	0.0999		0.1657
			Stem Dry Weight	0.0635		0.3790
1-2B	Root Dry Weight	Leaf Dry Weight		0.9369	0.8778	0.0000
		Leaf Length		0.5453	0.9141	0.0000
		Stem Dry Weight		0.2036	0.9177	0.0270
			Root Length	-0.0222		0.8126
			Stem Length	-0.0637		0.4953
3-4 A	Root Dry Weight	Leaf Dry Weight		0.9124	0.8325	0.0000
			Root Length	0.1877		0.1313
			Stem Length	-0.1470		0.2387
			Leaf Length	-0.1151		0.3574
			Stem Dry Weight	-0.0496		0.6927
3-4 B	Root Dry Weight	Leaf Dry Weight		-0.7994	0.6390	0.0000
			Root Length	0.0931		0.4645
			Stem Length	0.1466		0.2477
			Leaf Length	0.1053		0.4078
			Stem Dry Weight	0.1989		0.1152

mid-growing season data, it was also correlated with stem length and root dry weight. Root dry weight was positively correlated for mid-growing season data with every variable except the number of stems. In the late growing season period it was not associated with root length, number of stems and seed dry weight.

Regression Analyses

The results of the regression analysis of 1- and 2-year old plants for the mid-growing season period differ only slightly from those of the same age group for the late growing season period. Three variables were entered into the regression equation for the midgrowing season data at the $p = 0.05$ significance level. Approximately 81% of the variance in root dry weight was attributable to variation in leaf dry weight. Variation in leaf length and root length explained a further 3% and 0.6% of the variation in root dry weight, respectively. For the late growing season data, variation in leaf dry weight was associated with approximately 88% of root dry weight variation, while a further 4% and 0.4% were attributable to variation in leaf length and stem dry weight, respectively.

The results for the 3- and 4-year old plants from mid- and late growing season periods are also quite similar. Only leaf dry weight was entered into the regression equation at the $p = 0.05$ significance level. Leaf dry weight variation was associated with approximately 83% of the variance in root dry weight for the mid-growing season data, and 64% of the root dry weight variation in the late growing season period.

Discussion

The correlation results for 1- to 2-year old plants of American ginseng are similar to those reported for *P. ginseng*. Choi *et al.*[2] found significant positive associations among the characteristics common to their study as well as the present one in 1-year old *P .ginseng* plants. Their results for 2-year old plants differed from those of the present study in that *P. ginseng* root length was not associated with any other variables. As in the present analysis, root dry weight was most highly correlated with leaf dry weight.

In the 3- and 4-year old plants, similarities between both *Panax* species are again noticeable. Choi *et al.*[2] reported correlation coefficients similar to those produced here among comparable traits in *P. ginseng* except that root length was associated with leaf length, leaf dry weight, stem dry weight, root length, and in 3-year old plants, stem length.

The results of this study indicate that there are strong correlations among morphological characteristics in American ginseng. These may vary in degree of association with plant age, and to a lesser extent with growing season stage. Generally, however, the trends are consistent.

Conclusions

Root dry weight is the principle concern for commerical ginseng producers as the root is the economically important components of the ginseng plant. In North America, it is preferred that plants reach at least 4 years of age before the roots are harvested. Hence, years of invisible root growth occur. Inference of this growth from aboveground growth is desired. The results of this study identify several aboveground morphological characteristics as indicators of root weight. At all plant age and growing season stages examined, root dry weight was positively correlated with stem length, stem dry weight, leaf length and leaf dry weight. As might be expected, plants with high aboveground biomass tend to produce greater root material. This confirms the selection criteria used in the past to select plants of superior root weight from wild populations.

Although several aboveground variables are associated with root dry weight, the regression results indicate that leaf dry weidght is by far the most important single indicator of root growth. Leaf dry weight, while not easily measured, is well associated with the amount of aboveground leaf foliage.

The results of this study must be interpreted with a cautionary note. Planting densities in North America are usually high. Intraspecific competition undoubtedly has a strong impact on plant growth. Despite this, the correlation results and the root-growth indicators identified here are quite similar to those identified for *P. ginseng.* Hence, it is suggested that information generated for one species may translate into practical information for the other.

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