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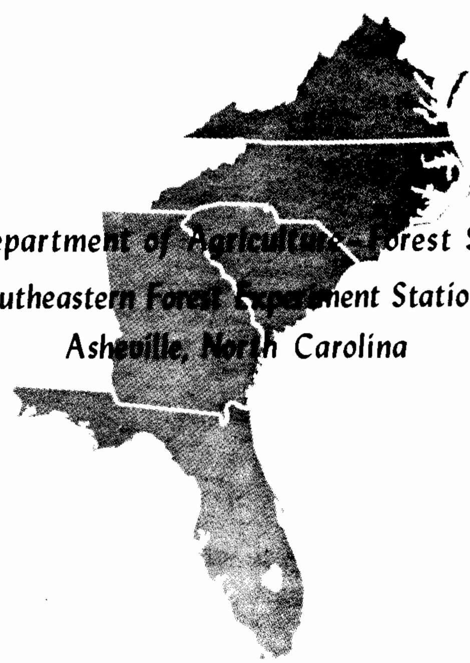

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INTRODUCTION

Precocious flowering in forest trees offers important advantages for genetic and physiological research. Early flowering permits tree breeders to accelerate their programs by substantially reducing the generation interval. The small size of such trees facilitates controlled pollinations and cone collections. Small, experimental material is also better suited to the study of flower, cone, and seed development. For these reasons, precocious flowering in the genus *Pinus* has received considerable attention and has been noted in many species (Righter 1939; Mergen and Cutting 1957; Fielding 1960; Mergen 1961; Greene and Porterfield 1963; Gerhold 1966; Rudolph 1966; Heimburger and Fowler 1969; Smith and Konar 1969). This study presents quantitative data on the frequency of early flowering in a Virginia pine plantation and the relationship of reproductive and vegetative growth for the initial 6 years.

METHODS

The plantation observed in this study comprises a one-parent progeny test designed to evaluate the heritability of natural pruning in Virginia pine. Thirty parent trees were selected as 15 pairs, each pair representing a well-pruned and poorly pruned tree from the same stand. Other characteristics (diameter, height, and surrounding basal area) were similar. Seed collected in the fall of 1963 were planted in a nursery bed, and the seedlings were outplanted at 8- by 8-ft. spacing in the spring of 1965. The planting design consisted of completely random single-tree plots with 10 trees from each parent. Survival of the 300 study trees was 98.7 percent after 5 years in the field. The outplanting site is comprised of Virginia Piedmont Nason and Tatum soils with moderate slope. This area was in cultivation 30 or so years ago and was subsequently occupied by a young, open-grown stand of Virginia and shortleaf pine (*Pinus echinata* Mill.). Prior to the present planting, it was cleared, windrowed, and disked.

RESULTS AND DISCUSSION

The plantation means of tree height, stem diameter, and flower production for the years 1965-70 are listed in table 1.

Table 1.--Means of vegetative and reproductive measurements of the Virginia pine plantation

Year	Vegetative (December)			Reproductive (April)	
	Height	Stem diameter[1]	D.b.h.	Male catkin clusters	Female flowers
	Feet	- - Inches - -		- - Number - -	
1965	0.67	--	--	0	0
1966	1.76	--	--	0	.003
1967	3.37	0.70	--	0	.05
1968	5.57	1.27	--	([2])	4.05
1969	8.35	2.09	1.01	22.98	9.20
1970	--	--	--	149.11	22.76

[1]Measured 1.0 ft. above ground.
[2]Three study trees produced male catkins, but number of catkin clusters per tree was not recorded.

The percentage of trees with female flowers (megasporangiate strobili) was 0 at age 1, 0.3 at age 2, 4 at age 3, 66 at age 4, 81 at age 5, and 94 at age 6. The average number of female flowers per tree increased from 0.003 in 1966 to 22.8 in 1970. The plantation produced about 15,500 flowers per acre in 1970. If 75 percent survival of flowers and 25 sound seed per cone is assumed, it is reasonable to estimate that 300,000 sound seeds per acre could be produced in the fall of 1971.

Male catkins (microsporangiate strobili) were not observed on any plantation tree until 1968, when 1 percent of the trees produced pollen. By 1969 (age 5), 51 percent of the trees had male catkins, and 92 percent of the trees were producing pollen by 1970. The 1970 average of 149 catkin clusters per tree was surprising. Generally, pollen production lags considerably behind female flower initiation and may be limiting in young plantations.

Regression analysis was used in this study to relate the 5-year measurements of height and diameter with reproductive development. The simple correlation coefficients of all vegetative and reproductive variables are presented in table 2.

The additive effects of certain significant independent variables when the number of female flowers per tree in 1970 was used as the dependent variable in stepwise multiple regression are noted in table 3. In

Table 2.--Correlation matrix of variables from the Virginia pine plantation[1 2]

	66 Ht.	67 Ht.	68 Ht.	69 Ht.	67 SD	68 SD	69 SD	69 D.b.h.	69 M	70 M	68 F	69 F	70 F
65 Ht.	0.844	0.724	0.622	0.517	0.729	0.528	0.516	0.546	0.229	0.357	0.218	0.283	0.257
66 Ht.		.867	.774	.656	.856	.695	.673	.667	.308	.458	.285	.340	.330
67 Ht.			.886	.781	.865	.775	.765	.782	.306	.493	.206	.274	.279
68 Ht.				.917	.818	.783	.816	.877	.279	.475	.214	.259	.275
69 Ht.					.727	.746	.796	.893	.224	.388	.153	.202	.209
67 SD						.848	.822	.782	.340	.510	.286	.358	.365
68 SD							.844	.790	.282	.455	.220	.313	.314
69 SD								.848	.266	.480	.207	.299	.317
69 D.b.h.									.265	.463	.181	.240	.280
69 M										.676	.250	.236	.239
70 M											.254	.245	.289
68 F												.684	.710
69 F													.661

[1]65-69 Ht. = tree height; 67-69 SD = stem diameter at 1.0 ft. above ground; 69 D.b.h. = stem diameter at 4.5 ft. above ground; 69-70 M = number of male catkin clusters per tree; 68-70 F = number of female flowers per tree.

[2]r values greater than 0.113 are significant at 0.05 level of probability.

Table 3.--Stepwise regression analysis of vegetative and reproductive variables measured in the Virginia pine plantation

Step number	Dependent variables							
	1970 female flowers				1970 male catkin clusters			
	Independent variable added	d.f.	R^2	Regression F value	Independent variable added	d.f.	R^2	Regression F value
1	1968 female flowers	1/294	0.504	298.18**	1969 male catkins	1/294	0.457	247.54**
2	1969 female flowers	2/293	.561	187.4 **	1969 stem diameter	2/293	.554	182.5 **
3	1969 stem diameter	3/292	.576	132.5 **	1967 height	3/292	.565	126.2 **

**Significant at 0.01 level of probability.

the regression analysis, previous flower production in 1968 and 1969 were the most important variables, and together they had an R^2 value of 0.561. The 1969 stem diameter entered third, bringing the R^2 value to 0.576.

With the 1970 male catkin as the dependent variable, the 1969 male catkin production was the strongest independent variable, followed by 1969 stem diameter and 1967 height (table 3). Again, previous reproductive growth was more important than vegetative growth: 1969 male catkins had an R^2 value of 0.457 and the two vegetative variables--1969 stem diameter and 1967 height--increased the R^2 value by only 0.108.

The relative importance of past reproductive performance on the production of male and female flowers (table 2) indicates some inherent control of flowering. Analysis of variance of the 30 half-sib families for all variables indicated significant differences for all variables measured except the 1969 female flowers. The differences between families were used to compute the heritability of reproductive traits by the equation

$$h^2 = \frac{4\ \sigma_F^2}{\sigma_F^2 + \sigma_W^2} \quad \text{(Becker 1967, p. 9)}$$

where σ_F^2 = mean square between families minus mean square within families divided by number of progeny per family, and

σ_W^2 = mean square within families.

Heritability estimates for female flowering were 0.59 in 1968 and 0.65 in 1970. For male flowering, the heritability estimates were 0.48 in 1969 and 0.44 in 1970. These heritabilities indicate a large amount of additive genetic variation in reproductive development at early ages. In contrast, Varnell et al. (1967) estimated heritability of fruitfulness in slash pine (*Pinus elliottii* Engelm.) at 0.13. The nonsignificant family difference in female flower production in 1969 is unexplained, but it may reflect a relatively large difference among families to some environmental effect during the period of flower initiation in 1968.

The age at which the trees first began producing flowers was a strong factor in the flower production for 1970. Mean flower production in 1970 was 42 for trees that began producing flowers at age 3, 29 for those that began at age 4, 11 for those that began at age 5, and 8 for those that began at age 6. Some exceptions to this trend occurred when trees decreased in production from one year to the next, but the general pattern was that the trees that flowered most precociously were also the most prolific.

As considerable energy is required for reproductive development (Fielding 1960), it is possible that heavy flowering could cause a reduction in vegetative growth. In this study, flowering trees were significantly taller than nonproducers in 3 of the 4 years of flower production (table 4). When the trees were stratified into six height

Table 4.--Height growth of flowering and nonflowering trees in the Virginia pine plantation

Year	Mean height		F ratio	Level of significance
	Flowering	Nonflowering		
	- - -Feet - - -			
1966-67	2.05	1.75	4.80	0.01
1967-68	3.45	3.21	7.12	.01
1968-69	5.63	5.19	7.07	.01
1969-70	8.35	8.26	.04	NS

classes, the tallest trees at age 6 had more male and more female flowers (table 5). This finding agrees with that of Schmidtling (1969). Thus, it appears that taller trees have more flowers and that, up to age 6, flower production does not seriously reduce height growth. The more subtle question of the vegetative height growth of the tallest trees without any male or female flowers remains unanswered.

Table 5.--Mean number of male and female flowers in 1970 for six height classes in the Virginia pine plantation

Height class (feet)	Trees	Plantation mean	
		Female flowers	Male catkin clusters
	- - - - - - - Number - - - - - - -		
10.1 and larger	25	34.4	266.6
9.1-10.0	59	24.5	196.4
8.1- 9.0	89	23.7	167.0
7.1- 8.0	88	22.3	97.5
6.1- 7.0	25	11.1	62.3
6.0 or less	10	8.0	88.9

From the observations in this Virginia pine plantation, it is evident that insufficient production of either male or female strobili is not a factor hindering early selection of second-generation progeny for further crossing and seed production. The major problem now must be the reliability of juvenile-adult correlation of desired characteristics. This correlation can only come with time as present-day stands continue to grow. It seems reasonable, however, to make selections now when the progeny reach the age of adequate seed production--at 5 or 6 years. Parents can be retained and remeasured. If the correlations hold reasonably well, a breeding cycle of 5 years should allow for rapid genetic gain.

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Ninety-four percent of the trees in a Virginia pine (*Pinus virginiana* Mill.) plantation produced female flowers at 6 years of age, and 92 percent of the trees produced male flowers. The average number of female flowers per tree was 23; the average number of male catkin clusters was 149. Flower production at age 6 was much more closely related to past flower production than to height or diameter growth. Heritability estimates of female flower production from the half-sib families were 0.59 and 0.65 for the years 1968 and 1970. Estimates of male flowering heritability were 0.48 and 0.44 for 1969 and 1970. Flower production did not appear to be detrimental to juvenile height growth, as the flowering trees were significantly taller during 3 of the 4 years of flower production.

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