GENETIC VARIABILITY IN EASTERN WHITE PINE FROM MICHIGAN: IMPLICATIONS FOR TAIWAN

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Pao-Chang Kuo
1971

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By

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AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Forestry

1971

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ABSTRACT

GENETIC VARIABILITY IN EASTERN WHITE PINE FROM MICHIGAN: IMPLICATIONS FOR TAIWAN

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A 9-year study included progeny tests of 123 seed-lots of native eastern white pine collected in 16 stands in 14 Michigan counties. Nine test plantations of the half-sib progenies were established in 1965 and 1966 in the western part of the Lower Peninsula, northeastern part of the Lower Peninsula and the Upper Peninsula; five plantations were measured for this study. The characters measured included mortality, height, white-pine weevil damage and numbers of trees with brown-tipped leaves.

Mortality since age 6 in three plantations was low; in two other plantations, mortality increased markedly from age 6 to 9. This phenomenon was mainly due to weed competition and/or poor site drainage. The height of test plantations was very much associated with length of growing season. Relative growth rate of two test plantations changed between ages 6 and 9 and there is reason to believe that warm-site test plantations will grow faster than cold-site plantations in the future.

In Lower Peninsula test plantations, trees grown from seed collected from the western part of the Lower Peninsula

grew 20 to 30 per cent faster than trees grown from seed collected in the Upper Peninsula. But in the Upper Peninsula plantation, trees of Lower Peninsula origin grew only slightly faster than Upper Peninsula origins. The differences in growth rate among the offspring of different trees within the stand were not significant. Stand-within-region and between-region differences were significant statistically in four plantations.

There were significant but small differences among seedlots in per cent of trees attacked by the white-pine weevil. The differences in white-pine weevil attack due to stand of origin were probably not significant.

A few seedlots contained a high per cent of trees with brown-tipped leaves. Most of the damage occurred in the offspring of trees in Grand Traverse and Lake counties, probably because these two counties were represented by many seedlots.

ACKNOWLEDGMENTS

The author wished to express his appreciation to Dr. J. W. Wright for suggesting the topic, providing experimental material, and for guidance in preparation of this manuscript. The author also wished to thank Mr. Walter L. Lemmien, Mr. M. W. Day, Mr. John N. Bright, and Mr. Y. N. Yao for assistance in measurement of trees.

The National Science Council, Republic of China, made this study possible by granting a one-year fellowship to the author.

I give grateful acknowledgment to my wife, Fenying, for her continuous encouragement and patient effort, while the author was away from her for one year undertaking graduate work at Michigan State University.

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Introduction

Eastern white pine (*Pinus strobus* L.) is the state tree of Michigan. It produces high-quality timber for construction use. Eastern white pine is the largest of northeastern conifers, producing trees of large diameter and height. Trees 40 inches in diameter and 150 feet tall were not unusual in Michigan. From the beginning of the logging industry in this country, the eastern white pine has been a most valuable species in its natural stands. As a result of overcutting of eastern white pine natural forest in the past, the timber resource of this species has become scarce, so the establishment of new forest becomes increasingly important to northeastern state forestry programs.

Eastern white pine is very easy to reproduce both naturally and artificially. It is also a pretty tree when used for ornamental purposes. It grows well on clay, loam, and sandy loam soils. It also flowers at an early age when 5 to 10 years old. It bears seed of high ability and survives well after outplanting.

Eastern white pine is a good tree but not perfect. Two serious pests damage it: white-pine weevil (*Pissodes strobi* Peck.) and white-pine blister rust (*Cronartium ribicola* Fisch. de Wald.). The white-pine weevil kills the terminal shoot, and thus affects ? or 3 years' growth. Bole crook and loss of stem length result from this injury. Eastern white pines are susceptible to white-pine blister rust from the seedling stage through maturity. Blister rust can cause high losses both in regeneration and in immature timber stands.

This paper describes the genetic variability at age 9 in eastern white pines of Michigan origin.

Past Work

The past work on tree improvement and breeding of eastern white pine has included range-wide geographic selection and half-sib progeny tests of Michigan parents and pest-resistance studies. Many efforts have been made in range-wide selections and little has been done in pest-resistance studies.

It is believed that seeds collected from different sources within a species' natural range can show different growth rates genetically among the ecotypes. The genetic variability can be used to improve the silvicultural operation by shortening forest rotation to a great extent.

The earliest study on eastern white pine genetics was initiated by P. R. Gast at Harvard University, Petersham, Massachusetts, in 1937. His work later was analysed and published by Pauley et al in 1955. Gast grew offspring of 159 eastern white pine trees from several parts of New England for a ?-year period in two experimental nurseries. Forty-two of the half-sib progenies were tested for 13 years in field plantings. Trees from local seeds grew best. Heavy weevil injury precluded exact assessment of growth difference.

Funk (1965 and 1970), Fowler and Heimburger (1970), King and Nienstaedt (1969), Santamour (1960), Sluder (1963), Wright et.al,(1963), and Wright (1970) are some of the contributors to a range-wide seed source study of eastern white pine initiated by the Northeastern Forest Experiment Station, U. S. Forest Service in 1955. Data from northern Lake States plantations indicated that no one seed source or group of sources grew consistently better in the nursery or in field plantings. The source x plantation interaction was not directly proportional to either geographic or climatic changes. King and Neinstaedt thought the mean January temperature of the seed source could be a very useful guide in selecting sources for further testing in Minnesota and Wisconsin. Total height at age 7 was significantly correlated with mean January temperature and length of frost-free period of place of origin in the Turkey Point plantation, Ontario, Canada.

Genotype x environment interaction occurred in most experiments involving plantations in the northern and southern parts of the Lake States and contain one or two major examples of interaction, as when a series of southern seedlots grew well at southern test localities but suffered serious winter injury at northern sites. A 10-year result on provenance test of southern Appalachian origin of eastern white pine in northern Iowa indicated that the northern Georgia trees are still the tallest. The same test in Illinois and Indiana plantations shows trees from Tennessee are about twice as tall as those from Maine. Iowa is near the northern limit for superiority of southern Appalachian seed source.

Similar results were obtained in southern Michigan plantings, where trees from Tennessee and Georgia grew faster than trees grown from seeds collected in Michigan. They will produce sawlogs 5 to 10 years quicker than ordinary trees. Although southern Appalachian trees can survive north of Clare, Michigan, they suffer winter injury and growth gradually slows down.

Trees from the southern Appalachian states have grown well in all the central state plantations. This consistently superior performance indicated a truly good prospect for planting eastern white pine from southern Appalachian provenances in the central states. These results at least justify further trials, using additional southern Appalachian seeds in larger plantations.

A report (Wright et .al,, 1970) on 6-year results of half-sib progeny tests of eastern white pine of Michigan origin indicated that there was a strong correlation between height growth at age 2 and that at age 6 from seed. Trees from the West Central Lower Peninsula grew 15 percent taller than trees from the Northeastern Lower Peninsula. It was a 6-year result of this study.

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The number of branches per whorl is also related to eastern white pine seed source. The taller seed origins of Georgia, Tennessee and North Carolina are less branched. The fastest growing trees were from regions with long frost-free periods in southern and central states (Funk, 1970).

The white-pine weevil is a native insect that dwells throughout the range of eastern white pine in natural stands and plantations. It attacks trees one to many times, usually after they reach heights of 5 feet. The crook or fork deformations that result from the attack greatly reduce the value of the lumber. The susceptibility of eastern white pine to the white-pine weevil attack now has degraded the species to the role of a second-rate, or even weed tree in some parts of the region. In Michigan, for instance, eastern white pine has not been planted widely because of the white-pine weevil. Unless these problems can be solved, it will be difficult to expand to a large planting program of the species.

In 1952, the Northeastern Forest Experiment Station undertook a series of studies designed to explore the possibilities of developing strains of eastern white pine that would be resistant to the white-pine weevil (Wright and Gabriel, 1959). One of these studies, unreplicated, indicated that trees from Ontario were weevilled less than trees from New York. No data showing difference in inherent resistance to weevilling among local strains of eastern whi

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white pine were obtained. Garrett (in press) reported on white-pine weevil damage in a heavily infested range-wide provenance test of eastern white pine in New Hampshire. His between-origin differences were significant statistically but not large. Attacks were 75 percent as common in the most resistant origins as in the entire plantation. But Wright (1957) stated that western white pine (*Pinus monticola* D. Don) seems to furnish a reliable source of weevil resistance for certain areas at the present time.

Objectives

My study was meant to determine:

1. Whether or not trees of eastern white pine from different regions of Michigan grew at different rates;
2. Genetic differences in growth rate among the offspring of different trees in the same stand and of different stands in the same region;
3. Genetic differences in other traits; and
4. To provide material and data for the genetic improvement of eastern white pine.

Materials and Methods

This is a report on 9-year results of a half-sib progeny test conducted by the Michigan Agricultural Experiment Station. The study contains 123 individual-tree seedlots of native eastern white pine trees in 16 stands, from 14 Michigan counties (Figure 1 and Table 1). Open-

Figure 1.--Location of eastern white pine seed collection (circles); test plantations (A=ALLEGAN, CH=CHATHAM, CR=CRAWFORD, D=DUNBAR, K=KELLOGG, L=L'ANSE, R=RUSS); natural lower range (heavy dashed line); proposed geographical regions (U.P., Northeast, Grand Traverse, Western L.P. indicated by light dashed line).

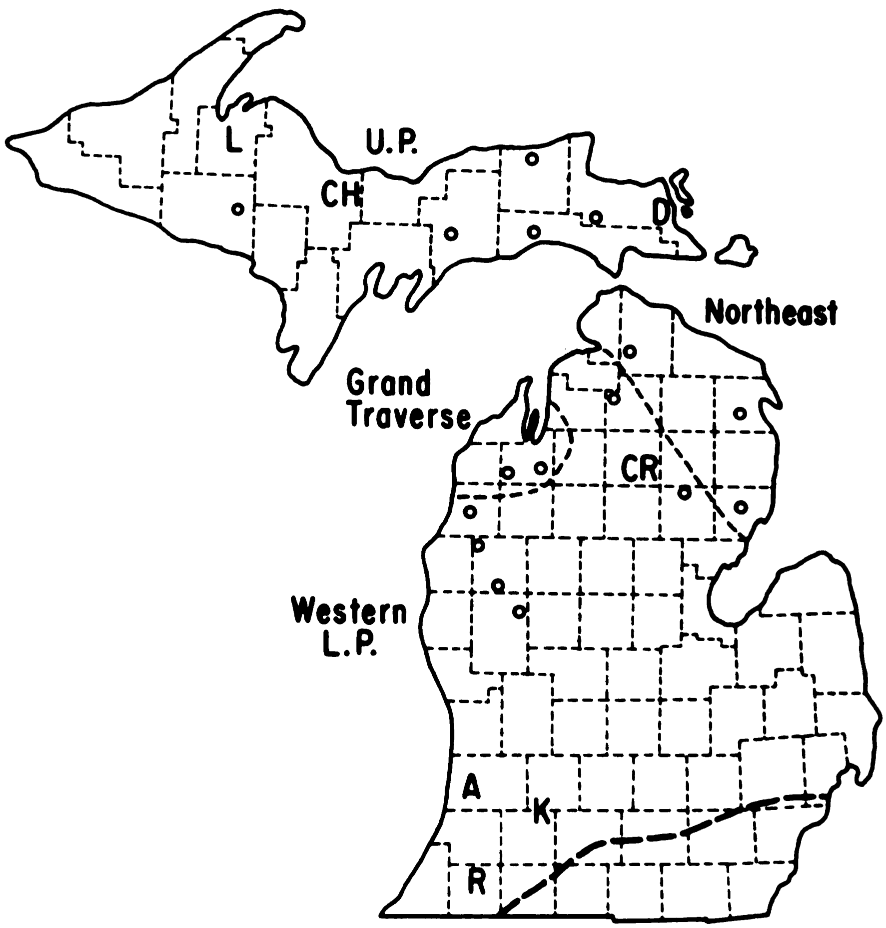
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Table 1.--Geography and climate of seed origin

Seed origin region and county	North lat.		West long.		Elevation	Average mean temp. Jan.	Average mean temp. July	Length frost-free season	Annual prec.
	°	'	°	'	Feet	- - ° F.- -		Days	Ins.
Upper Peninsula									
Iron	46	4	88	3	1,360	12.0	65.0	80	30
Luce	46	40	85	40	886	19.5	63.0	140	30
Schoolcraft	46	5	86	15	645	18.9	66.7	110	30
Mackinac	46	2	85	36	846	18.7	65.7	130	30
Chippewa	46	2	85	6	846	15.5	65.0	120	30
Average						16.9	65.1	116	30
Northeastern Lower Peninsula									
Cheboygan	45	19	84	40	610	19.0	67.0	100	31
Iosco	44	23	83	38	905	21.0	68.0	130	28
Alpena	45	0	84	38	689	20.7	67.0	120	28
Average						20.3	67.5	116	29
Grand Traverse County in Western Lower Peninsula									
Stand I	44	36	85	29	1,080	22.0	69.9	120	31
Stand II	44	33	85	55	1,080	22.0	69.9	120	31
Average						22.0	69.9	120	31
Western Lower Peninsula									
Otsego	45	10	84	27	925	18.5	67.0	70	31
Ogemaw	44	24	84	0	995	19.0	67.2	100	29
Lake I	43	50	85	44	830	20.0	68.8	100	32
Lake II	44	10	85	54	830	20.0	68.8	100	32
Manistee	44	16	86	2	585	22.0	69.7	120	31
Newaygo	43	44	85	55	770	22.0	70.1	120	32
Average						20.3	68.6	105	31

pollinated seed was collected in 1960 from average trees because a limited number of mother trees were available. The seeds were given a 10-day cold-water stratification treatment and sowed in the University research nursery, East Lansing, Michigan, in the spring of 1962, using a 5-replicated, randomized complete block design. Each plot was a 4-foot row containing about 50 seedlings; the rows were 1 foot apart. The seedlings were transplanted to the State of Michigan's Southern Michigan Nursery near Brighton the following spring. Again, a 5-replicated, randomized complete block was used. The transplants were lined out in 24-tree rows 4 feet long and 1 foot apart.

Nine test plantations with 1-2 or 1-3 stock were established in 1965 and 1966 in the Southern Lower Peninsula (ALLEGAN, KELLOGG and RUSS[1]), the Northern Lower Peninsula

[1]To avoid confusion, names of test plantations or of regions where trees were tested are capitalized, and names of seed collection localities are in lower case.

(CHARLEVOIX, BUCKLEY and CRAWFORD), and in the Upper Peninsula (CHATHAM, DUNBAR and L'ANSE). Among these, five plantations were measured for this study. Each test plantation follows a randomized block design with 4-tree plots and 8 8-foot spacing. The number of replicates per plantation varied from 7 to 10. Most planting sites were sprayed with amino-triazole and simazine to maintain a weed-free condition for the first year. One site on a light sandy soil with little weed competition received no weed control.

The data for each character in each plantation were subjected to an analysis of variance, using plot means as items, followed by a breakdown of variance components into portions due to stands, parent-within stands, stand-within regions, and stand-between regions. There were 15 degrees of freedom for stand-within region, 2 for stand-between region, 48 to 83 for parent-within stand, and 163 to 631 for error.

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Table 2.--Location of test plantations

MSFG	Name of Plantation	County	North Lat. °	'	West Long. °	'	Elevation Feet
1-65	ALLEGAN	Allegan	43	32	85	51	629
2-65	KELLOGG	Kalamazoo	42	17	85	36	945
14-65	RUSS	Cass	42	0	85	56	780
14-66	CRAWFORD	Crawford	44	31	84	45	1,190
21-66	DUNBAR	Chippewa	46	19	84	14	600

Table 3.--Site conditions in test plantations[1]

Name of Plantation	Mean Temperature			Ann. Prec.	Length Frost-Free Season	Soil
	Jan.	July	Ann.			
	° F.	° F.	° F.	Ins.	Days	
ALLEGAN	26.5	72.6	49	33	155	Sandy
KELLOGG	24.9	72.7	48	35	155	Sandy loam
RUSS	26.3	73.7	49	36	160	Sandy loam
CRAWFORD	19.5	69.9	44	30	100	Sandy loam
DUNBAR	15.5	64.5	40	30	140	Sandy loam

[1]Climate data: 30-year average (1931-1960), source U. S. Weather Bureau, Michigan State University, East Lansing, Michigan.

Results

Mortality.--Mortality did not differ significantly among seed sources, but did among plantations, as shown in the following tabulation:

Age (from seed) of Mortality Count	Mortality Rate in Plantation at				
	ALLEGAN	KELLOGG	RUSS	CRAWFORD	DUNBAR
Years	Percent				
6	9	6	20	12	17
9	11	8	21	25	28

The relatively high mortality at the RUSS Forest was probably due to inadequate weed control the first year after planting. Chemical weed control was renewed the second year, with the result that most of the survivors were able to become well established.

Weed control at the CRAWFORD plantation was adequate the first year after planting, but the simazine then decomposed and left the planting strips free for the invasion of weeds, especially of sweet clover. Much of the mortality occurred in parts of the plantation covered with sweet clover, which was still troublesome at age 9.

Similarly, weed control was effective in most of the DUNBAR plantation, but not in poorly drained patches covered with sedges. Early mortality was very high in these sedge patches and the few survivors died between ages 6 and 9.

Growth Rate.--Rate of height growth varied with age of tree and among plantations. At 6 years, the KELLOGG and ALLEGAN plantations were the tallest (Table 4). At 9 years, the height rank of the five plantations showed a somewhat different order. KELLOGG still remained tallest, but the RUSS plantation had surpassed the ALLEGAN plantation.

Height growth rate of the plantations was probably correlated with length of growing season and soil type (Tables 3 and 4). The KELLOGG, RUSS and ALLEGAN plantations were fastest growing and had the longest growing seasons. The slower growth at ALLEGAN than at RUSS or KELLOGG was undoubtedly due to the low moisture-holding capacity of the sandy soil at ALLEGAN.

The largest genetic height differences at age 9 were associated with region of origin of the seed. In the LOWER PENINSULA plantations, trees raised from seed collected in the Lower (southern) Peninsula were 9 to 35% taller than trees grown from seed collected in the Upper Peninsula (Table 4). Even in the DUNBAR (UPPER PENINSULA) plantation, some Lower Peninsula origins grew faster than Upper Peninsula origins, but by a smaller amount.

The Lower Peninsula was divided somewhat arbitrarily into three regions--Northeastern, Grand Traverse County and Western (exclusive of Grand Traverse County) on the basis of the 9-year height data. At most test plantations, trees grown from seed collected in these regions differed from each other. At all except the CRAWFORD plantation, trees

Table 4.--Relative height of 9-year-old eastern white pine grown from seed collected in 14 Michigan counties and tested at 5 locations in Michigan

County of Origin	Relative Height when Planted at				
	ALLEGAN	KELLOGG	RUSS	CRAWFORD	DUNBAR
	- - - - Percent of Plantation Mean - - - - -				
Upper Peninsula					
Iron	90	95	75	91	88
Luce	87	88	81	102	--
Schoolcraft	77	86	82	90	109
Mackinac	95	96	77	80	90
Chippewa	89	89	62	81	--
Average	86	91	79	89	96
Northeastern Lower Peninsula					
Cheboygan	97	93	98	104	89
Iosco	108	100	107	111	97
Alpena	101	111	105	119	92
Average	103	102	103	113	96
Grand Traverse County in Western Lower Peninsula					
Stand I	110	105	106	97	100
Stand II	105	89	94	99	97
Average	109	100	103	98	99
Western Lower Peninsula (Exclusive of Grand Traverse County)					
Otsego	105	108	111	99	--
Ogemaw	117	111	119	97	122
Lake I	108	104	115	107	100
Lake II	111	110	112	114	96
Manistee	114	107	113	101	105
Newaygo	113	109	110	111	97
Average	111	108	114	106	104
Actual Mean Height, Centimeters					
At age 6	50	60	46	41	45
At age 9	124	172	159	76	103

grown from seed collected in the western part of the Lower Peninsula exhibited the fastest growth.

As Table 5 shows, the differences among regions of origin were statistically significant (1% level) in each of the five plantations. The greatest part of the significance was probably due to differences between Upper and Lower Peninsula. Only at RUSS and KELLOGG were there moderately sharp differences among the three Lower Peninsula regions of origin.

I subjected the 9-year height data for each plantation to analysis of variance to determine the significant of differences among the offspring of different parents within the same stand, among the offspring of different stands in the same region, and among the offspring of different regions. The F values from those analyses of variance are presented in Table 5.

The differences of height of offspring of the different stands in the same region were significant statistically at four plantations (Table 5). However, the F values were not large. In the RUSS, ALLEGAN and CRAWFORD plantations, most of the significance within region was due to the large differences among trees grown from seed collected in the Upper Peninsula. The fastest growing trees were from the western Lower Peninsula. Only in the DUNBAR plantation were there significant differences among offspring of different western Lower Peninsula stands.

Table 5.--F values for height growth in five test plantations

Source of Variance	Test Plantation				
	ALLEGAN	KELLOGG	RUSS	CRAWFORD	DUNBAR
Stand					
Within Region	1.5	0.6	2.6**	2.4**	3.5**
Between Region	46.5**	21.4**	33.8**	15.8**	8.5**
Parent Within Region	1.9	2.7**	0.8	0.9	0.7
Replicate	11.9**	14.7**	0.2	11.3**	16.2**

**Significant at 1 percent level.

The seedlots of this study were obtained from stands distributed over two different peninsulas--Upper and Lower. These are separated by the Straits of Mackinac between Lakes Huron and Michigan. The Lower Peninsula is characterized by higher annual mean temperatures, also by longer frost-free season. In annual precipitation, there is little difference between the Lower and Upper Peninsulas (Tables 1 and 6). The genetic differences in growth rate of eastern white pine from Michigan's two peninsulas is probably associated with the temperature differences. Although there are large climatic differences within the Lower Peninsula, they do not correspond with the regions of origin as defined in Table 4.

The differences due to region of origin were much greater in LOWER PENINSULA plantations than in the DUNBAR plantation in the UPPER PENINSULA. Apparently the offspring of the Lower Peninsula trees suffered from cold weather when planted in the UPPER PENINSULA.

Natural selection in the Lower Peninsula favored trees which were fast growing and adapted to the warm climate conditions found there. In the Upper Peninsula, natural selection favored hardy trees, apparently at the expense of fast growth.

Yao et.al.,(in press) reported on a half-sib progeny test of Michigan natural red pine including 272 individual trees and four plantations in Upper and Lower Peninsulas.

Table 6.--Site condition of Michigan regions

Region	Annual Mean Temperature	Frost-Free Season	Soil
	°F.	Days	
Upper Peninsula	39 to 42	90 to 140	Rock knobs, acid sands to silt loam, low agricultural value, best land use in forestry and recreation
Northeastern Lower Peninsula	42 to 44	100 to 150	Rolling to hilly, poorly drained sandy loam, most hardwood forest, originally good soil but poor topography for farming
Grand Traverse County	45 to 46	100 to 160	Level to rolling well-drained soils formed from limy sands and loamy sands; a considerable acreage is devoted to cherry orchards
Western Lower Peninsula (Exclusive of Grand Traverse County)	42 to 47	90 to 150	Soil is similar to that in Northeastern Lower Peninsula, the original forest was largely hardwoods

At 10 years of age, the Lower Peninsula origins surpassed the Upper Peninsula origins by 10 percent in the LOWER PENINSULA plantations. Lower Peninsula origins surpassed the Upper Peninsula origins by only 3 percent in the UPPER PENINSULA plantations. Apparently the cold weather in the Upper Peninsula affected the Lower Peninsula origins badly.

White-Pine Weevil.--For the past 15 years, there has been interest in development of a strain of eastern white pine resistant to the white-pine weevil. Some progeny and provenance tests are being exposed to weevil attack, but there are no definite data on genetic differences in susceptibility (Wright, 1970).

I conducted analyses of variance for seedlots, disregarding stands and regions. The differences in white-pine weevil attack among seedlots were significant at the 5 percent level at ALLEGAN and at the 1 percent level in the KELLOGG and CRAWFORD plantations. They were not significant in the RUSS plantation. The F values for white-pine weevil attack for Michigan eastern white pine in three plantations are shown as following tabulation:

Source of	Test Plantation			
Variance	ALLEGAN	KELLOGG	RUSS	CRAWFORD
Seedlot	1.3*	1.8**	0.32	3.2**
Replicate	8.4**	6.8**	0.00	20.2**

As I inspected the data, the differences of white-pine weevil attack due to stand of origin are probably not significant. Probably there were significant differences in white-pine weevil attack between regions of origin in RUSS and CRAWFORD plantations.

Seedlots from Upper Peninsula showed less weevilling than those from the Lower Peninsula except in the KELLOGG plantation, where the western Lower Peninsula seedlots showed the least white-pine weevil damage. Among Lower Peninsula seedlots, the western ones were weevilled less than north-eastern ones. The ALLEGAN plantation contained more white-pine weevil damage than any of the other four test plantations. There was no white-pine weevil damage in the DUNBAR plantation.

Table 7.--Percentage of trees with white-pine weevil in eastern white pine in three Michigan Regions

Region	Trees with White-Pine Weevil at				
	ALLEGAN	KELLOGG	RUSS	CRAWFORD	DUNBAR
	- - - - - - - - -	- -	Percent	- - - - -	- - - - - - -
Upper Peninsula	29	7	8	9	0
Northeastern Lower Peninsula	32	8	21	21	0
Western Lower Peninsula	29	5	19	11	0
Plantation Average	29	6	17	12	0

Brown-Tipped Leaves.--In almost all test plantations, the leaf tips of eastern white pine from some seed origins appeared brown in color. The brown color covered one-third to all the leaf area. The real reason for this damage is not yet known. Since it happened on the current leaves, it could not be winter injury. And it can be considered as some kind of damage caused by site adaptability due to genetic variation in some stands. This character was worthwhile to note because the differences in numbers of trees with brown-tipped leaves were significant in three test plantations.

The number of trees with brown-tipped leaves was converted to percentages for all the data for 16 seedlots which had been planted at ALLEGAN and KELLOGG are presented in Table 8. The 16 seedlots were from a single stand.

It is interesting to note that most seedlots had no damage. Great damage occurred only in few seedlots. As Table 8 shows, the heavily damaged seedlots in one plantation were also heavily damaged in another plantation.

In three plantations, there was a total of 181 damage counts. Of these, 121 occurred in only six seedlots from two counties: Grand Traverse and Lake located in western Lower Peninsula.

Table 8.--Differences among half-sib progenies from Grand Traverse Stand No. 1 in percentage of trees having brown current-year's needles

Plantation	Percent of Trees Affected in Progeny No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
ALLEGAN	24	14	8	3	4	0	0	0	0	3	0	0	0	0	0	0
KELLOGG	30	24	13	11	4	11	8	8	4	0	3	0	3	0	0	0

Applicability to Michigan

Before we present any facts for Michigan use, it is important to know what we could learn from the Michigan half-sib progeny test of eastern white pine.

Considering Michigan is only a small part of the total forest range of the eastern white pine in the eastern United States, it is safe to say that there was a genetic variability noticed in Michigan eastern white pine selected from its state-wide range stands. The growth of eastern white pine can be expected to be 20-30 percent greater for the trees from northeastern and western Lower Peninsula stands than for trees from Upper Peninsula seed. This 20-30 percent gain can result in a rotation period three-fourths as long as the rotation period for trees from slower growing origins. Therefore, Michigan tree growers will be wise to select eastern white pine from the northeastern and western Lower Peninsula origins if they want a shorter rotation period. The fast-growing offspring from this particular region were mostly from Alpena, Ogemaw, Lake and Newaygo counties. All parents in these counties produced offspring which for the past 9 years had fast growth rate desired by tree growers. Tree growers may be very selective and choose parental trees which are superior phenotypically. But these superior trees may or may not produce offspring with growth rate greater than the 20-30 percent as mentioned.

Height growth rate has been considered as the most important factor in genetic improvement of trees. For high-quality-timber growers, straightness of trunk and growth rate are equally important. Eastern white pine is a good timber tree in addition to being of good form. It can, as mentioned, grow faster than the average rate if seed is collected from the northeastern and western Lower Peninsulas. So its benefits vary with the objective of its planting.

Referring back to the high-growth trees of northeastern and western Lower Peninsula origins, the tree grower may wonder how these trees will perform in the next 10 to 20 years or longer. It is difficult, of course, to answer this question with the experimental information available presently. But, as far as the 9-year study results of this paper are concerned, we probably have good reason to predict that the genetic behavior of the fastest growing origins will continue this same trend. This prediction is based on a strong correlation growth rate indicated in the study existing between the 3-, 6-, and 9-year trees. Therefore, the 9-year trees may reflect their future growth pattern to a great extent. If, in fact, this is not the case, at least we can conclude from this study that the fastest seed origin of eastern white pine can continue its growth rate up to 10 years period.

The eastern white pine has shown its greatest growth rate in the southern Appalachian origins within its entire range. Can Michigan grow the eastern white pine of the southern Appalachian origin? The answer to this question is optimistic due to results from a KELLOGG and RUSS plantations located in southern Michigan, which showed excellent performance after 14 years of study. But how far north in Michigan can it grow? The forest geneticist can not be able to answer this question because no test plantations similar to that at KELLOGG and RUSS have been established in northern Michigan. Since most forest area of Michigan is in the north, this is an important question to be answered.

The Michigan range-wide test plantations of eastern white pine have been established over a relatively wide area in the Lower and Upper Peninsulas of Michigan. This study is useful to the Michigan tree grower, informing him as to where he can collect the seed of fast-growing origins and where these can grow. In fact, this study provides immediate information for current Michigan forestry needs. Whereas the entire range-wide test of eastern white pine does not have the applicability to the Michigan reforestation program as does the Michigan state-wide selection studies, perhaps in the long run the entire range-wide study on eastern white pine will contribute great genetic improvement to southern Michigan and other states. It is the author's recommendation to establish few more test plantations of southern Appalachian origin of eastern white pine in Michigan's Northern Lower Peninsula and Upper Peninsula. Thereby valuable information as to racial adaptability of eastern white pine can be obtained in next 10 years from these test plantations. This information can tell Michigan tree growers how far north southern Appalachian origins of eastern white pine can grow normally. Another idea which will be meaningful to Michigan tree growers is to collect eastern white pine seed from stands located in southern Michigan and test it over this state; by doing this, possibly greater growth rate of trees can be selected from the warmer region.

Applicability to Taiwan

In Taiwan, a very intensive forest tree improvement program has been undertaken since 1964. The main objective of this work is to improve Taiwan's reforestation program through the selection of fast-growing species or strains of species from their native population or foreign countries. Since this work was begun not very long ago, little has been accomplished in the reforestation of Taiwan.

It is understandable that the selection of fast-growing tree species can be achieved only through a long period of experimentation in the field. It is possible to obtain reliable information and hopeful results when the selection range is wide enough. Compared with other forestry research, the tree improvement studies take longer and require more funds. Until now, we have not yet started large geographic selections of either native species or foreign trees. We will be soon ready to start such a program of geographical selections. Taiwan tree breeders now, in principle, understand how such a program can be executed.

It is believed that there will be many problems encountered in such a study as we proceed.

As one Taiwan tree breeder, what can I contribute to the Taiwan tree improvement program after I obtain advanced training? And, how will Taiwan tree breeders benefit from such advanced knowledge that I may bring back to Taiwan? In fact, I feel Taiwan tree breeders are very interested in learning of any new findings concerning tree improvement and breeding. From this paper, I hopefully will benefit the Taiwan forester and tree grower in two important areas.

First, it has been proven that improved genetic variability in fast-growing trees such as the eastern white pine can be obtained from a small-range selection from Michigan origin. There is good indication that through range-selection fast-growing trees may be selected from Taiwan[2] trees: Taiwan red pine (Pinus taiwanensis Hay.), China fir (Cunninghamia lanceolata Hook.), Taiwan red cypress (Chamaecyparis formosensis Matsum.), and some Taiwan hardwood species.

Secondly, I may contribute to the seed origin study in terms of half-sib progeny tests on Taiwan trees through my advanced training. Thus, this includes the approach in experiment design, establishment of test plantation, and measurement and analysis of the research data.

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[2] Taiwan is one-fourth of Michigan in size.

Concerning the first area, Taiwan tree breeders have greatly benefited by tree breeding experts of the United States: Dr. K. K. Ching, Dr. C. W. Wang, and Dr. J. W. Wright. The experts have been to Taiwan and have consulted with Taiwan foresters on tree improvement and breeding programs during the past seven years. But their advice has not yet been fully utilized in tree selection programs in Taiwan. The Taiwan forest budget has a limited amount of funds that may be used to support a long-run experimental project which may have doubtful results. It is my impression that the selection of fast-growing trees in a long-run project but good results are possible, such results come only if a high-quality program of research is undertaken. I feel this way from my experience and studies connected with Michigan State Forest Genetic Programs. The Michigan State Forest Genetic Program is quite convincing to any one who has seen its positive results. As I was convinced of the merits of this program, I may be in a better position to advise Taiwan foresters of this program than many non-native experts. Besides advising other foresters, I will apply these methods on Taiwan trees on Taiwan land through my university research projects. This work may serve as a demonstration model to Taiwan foresters who are interested in such a program. This example may be used to convince Taiwan foresters of the possibility of selecting faster growing trees from their small nature ranges, in addition to its application to Taiwan forestry. This idea will convince Taiwan foresters that money spent on tree improvement studies will pay off and are worthwhile. Such programs would be a reliable asset to future Taiwan reforestation programs.

Concerning this second area, I would believe that I am benefitted from the work I have done. So is Taiwan, as Taiwan is in need of an improved reforestation program. The quality of tree breeding and improvement work depends very much on the quality of the researchers themselves. Regarding this experiment, it is very important to explain the high-quality experimental work undertaken in the Michigan Forest Genetic Project. From my experience of writing this thesis, I wish to explain that good research in tree improvement is dependent upon good planning and adequate measurement and analysis until the final result is known.

Taiwan is not interested in fast-growing eastern white pine as it will not adapt to the subtropical climate conditions. But we can apply the same research method to Taiwan tree species on Taiwan land.

As a teacher at the National Taiwan University, I am very happy to share the knowledge I have acquired during my studies in the United States. Finally, I am very glad to benefit my nation by these studies as a researcher and also hope to benefit my students as well.

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