Seed Source Trials of Eastern White Pine

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EXTENSIVE NURSERY TESTS and limited field trials of a large number of collections of eastern white pine (*Pinus strobus* L.) seed at the Harvard Forest in Petersham, Massachusetts, provide information on the early development of this species as related to locality of seed collection, the tree from which the collection was made, and seed weight.

The objectives of the study were twofold: (1) a provenance or seed source test to determine the extent of intraspecific variation of both local and distant sources by means of growing them together under uniform environmental conditions, and (2) an investigation of the possibility of identifying fast-growing strains in the nursery on the basis of their performance over a one- or two-year period.

The series of tests were initiated by Dr. P. R. Gast for the Maria Moors Cabot Foundation for Botanical Research, Harvard University, in 1937. Over a four-year period, two major nursery trials and several supplementary tests of white pine seed sources were carried on. The planning and execution of the experiments was done under the supervision of Dr. Gast to whom credit for the results obtained is due. One of the present authors (Spurr) was research assistant on the project from 1940 to 1942 and was responsible for much of the detail work and analysis of data.

The first nursery test involved the test of 86 collections from selected mother trees in the immediate vicinity of Petersham, while the second contained 94 seed sources from both local and distant localities. The Doe Valley nursery, containing the first test plants, was established in 1938 with seed from 1937 collections; while the Nichewaug nursery with the second was established in 1939 with seed collected in 1938 from New England, New York, Ontario, Michigan, Minnesota, and Virginia.

The supplementary tests included two series of pot cultures designed primarily to test the effect of various growth substances on selected seed sources, and a three-year test of the effect of seed weight on the early development of other selected sources.

In 1941 and 1942, individuals from 21 sources from each nursery were planted in field trials of approximately one acre each. These plantings were measured for the first time after the 1954 growing season by Frank Whitmore and assistants provided by the Cabot Foundation. At that time, Dr. Pauley, with the permission of Dr. Gast, made available existing data on the series of trials for final analysis and publication.

Experimental Design

The basic plan of all the trials was to plant

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seed of known weight and known seed source outside in the early spring. Each experiment was planned in accordance with a statistical design, balanced incomplete blocks being used for the two nursery and the two field trials. In the nursery, samples of the tops were cut following each of the first two growing seasons and their dry weights determined. In the field trials, stem diameter and amount of weevil damage was determined 13 years after establishment.

Statistical design. In the nursery trials, seed of a given origin were broadcast uniformly over a 1-foot section of a carefully prepared nursery bed 4 feet wide. In each nursery two series of balanced incomplete randomized blocks were used, the two experiments being laid down together in a checkerboard pattern. In the field trials the planting unit consisted of 16 trees planted in a square with a five-foot spacing between trees. Each of the two field trials consisted of a single series of incomplete randomized blocks.

The method of incomplete randomized blocks applied to field experimentation has been described by Yates (1936a, 1936b), while the modification adopted in the present experiments was developed by Youden (1937, 1940). This modification permits the construction of complete blocks of replicates without sacrificing the advantages of incomplete blocks. Furthermore, the blocks are sufficiently small that the field layout can be limited and site variation can thus be held to a minimum considering the number of varieties being tested.

The experimental design permits each variety to be replicated a number of times in such a manner that it grows once and once only in the same plot with every other variety. In determining the corrected yield, the total yield of each variety times the number of times it is replicated is compared to the total yield of the blocks in which that variety occurs. The resulting difference divided by the number of varieties represents the deviation of the yield of that variety from the mean of all varieties. If this deviation, therefore, is applied to the overall mean, the resultant value is the mean yield of the variety corrected for differences due to the variation in soil fertility between the blocks. Following the correction of variety means, the data were subjected to analysis of variance following usual techniques. The standard t test was used to test for significant differences between individual seed sources and groups of seed sources within the larger trials.

Nursery trials. The Doe Valley test was established in 1938 using seed collected in 1937. It was located on level glacio-fluvial outwash sand (Merrimack series) in southern Athol near the Petersham town line. The seed was collected from selected mother trees in five stands in the Harvard Forest and adjacent territory. Unfortunately, most of these trees were blown down in the 1938 hurricane. Two series of seed source trials were established, occupying the largest part of 19 nursery beds each 50 feet long and 4 feet wide. One series consisted of 57 varieties, each replicated 8 times; and the other of 31 varieties, each replicated 6 times. Top samples cut at the ground line were taken following each of the first two growing seasons. The better plants of 21 sources were selected for field planting after the fourth season.

The Nichewaug nursery was established in 1939 using seed collected in 1938. It was located on a level piece of glacial moraine (Charlton fine sandy loam) adjacent to the village of Petersham. Considerable effort was expended harrowing and fertilizing the tract to obtain as uniform site conditions as possible. The seed sources used represented 25 collections from Massachusetts, 27 from New Hampshire, 17 from New York, 21 from Ontario, 3 from Michigan, 9 from Minnesota, and 2 from Virginia.[1] Eight seed sources, previously tested in the Doe Valley nursery, were included in the Nichewaug tests, and ten seed sources were replicated in both series of the Nichewaug trials. Most of the collections were from a single mother tree but nine stand collections were included. Two series of seed source trials, each consisting of 57 varieties replicated 8 times each, were established in a block of 21 nursery beds, each 50 by 4 feet in size. Growth was better than in the Doe Valley nursery. Top samples were cut at the ground line following each of the first two growing seasons. Selected varieties were planted in the field trials after the third season in the seedbeds.

Supplementary trials. In addition to the seed source tests in the nursery, a number of supplementary tests yielded information on some of the same seed sources and thus provided an opportunity to test the effect of different growing conditions on the relative growth of the different sources.

In two series of pot cultures (1940 and 1941) designed to investigate the effect of growth substances on the development of white pine seedlings,[2] ten of the seed lots that had previously been used in the Doe Valley trials were grown in washed quartz sand subirrigated with mineral nutrient solution.

In another experiment, 100 seeds of each of ten lots that had previously been used in the Nichewaug test were weighed individually and grown under controlled conditions (Spurr, 1944). Of these, one-third were grown in washed quartz sand in a hydroponicum subirrigated with mineral nutrient solution, while the others were grown in an artificial soil made up of equal parts of soil from the Nichewaug nursery, sand, and humus. In this test, records were kept for each individual seedling rather than for each lot as in previous experiments. After the conclusion of this three-year experiment, 12 trees of one seed source were left in the artificial soil bed for an additional five growing seasons to provide some idea of the lasting effect of seed weight upon growth.

Field trials. In May 1942, two plantations were established with seedling stock from the Doe Valley and Nichewaug nurseries. These plantings are situated on glacial till soil (Gloucester sandy loam) near the Quabbin Reservoir in the town of Hardwick, about one mile south of the Petersham town line.

Each plantation is approximately one acre in extent. The South Field was planted with 3-year-old seedling stock from the Nichewaug nursery, and the North Field with 4-year seedlings from the Doe Valley nursery. Each field was planted to 21 seed sources, each replicated 5 times. Each randomized incomplete block contained 5 seed sources, and each seed source was represented by sixteen trees in a square with a 5-foot spacing between trees. Extra plants were heeled in between regularly assigned points. Many lived, however, producing plots which had extra trees in 1955. Positions of blocks and of plots within blocks were randomly selected.

Planting was done in tilled strips plowed with a rotary tiller at 5-foot intervals in both directions. Each strip was plowed three times to a depth of eight inches in a strip 20 inches wide. The actual planting was done by digging holes about 16 inches in diameter and 12 to 14 inches in depth into which the seedlings were carefully placed. Roots were kept spread as the soil was added and gently tamped down.

It was originally intended to use both diameter and height as units in the 1954-55 measurements. Severe tip damage by the white pine weevil (*Pissodes strobi*), however, had so deformed the trees that height was eliminated as a usable measure. The number of weevilings per stem, therefore, was substituted. Diameters were taken

[1]Collections were made by the Cabot Foundation, New Hampshire Forestry and Recreation Department, New York State College of Forestry, Ontario Department of Lands and Forests, University of Michigan, University of Minnesota, and Tennessee Valley Authority.

[2]Gast, P. R., and S. H. Spurr. 1942. Adenine, B_1 and nicotinic acid and the growth of white pine seedlings. Unpub. ms. 19 pp.

TABLE 1. Effect of seed weight on first and second year top weight for seed from Petersham mother trees, Doe Valley Nursery.

Seed source	Year	Seed size class I	II	III	IV	V
		Dry weight (mg.)				
52 (Wilders)	rdw[1]	15.3	14.9	14.1	13.3	------
	1938	101.5	93.2	85.3	82.3	------
	1939	533	538	406	481	------
10 (S.C. II-XI)	rdw	15.1	14.2	12.9	12.2	------
	1938	96.5	87.1	83.3	79.6	------
	1939	404	397	400	354	------
50 (Wilders)	rdw	13.6	12.9	11.7	10.9	------
	1938	73.9	65.6	64.9	58.0	
	1939	307	299	296	300	------
20 (T.S. V-VI)	rdw	11.6	10.5	10.2	9.5	9.0
	1938	78.0	71.7	67.8	63.3	62.5
	1939	365	335	303	302	333
54 (Wilders)	rdw	9.8	9.4	8.4	8.1	5.5
	1938	62.7	57.9	55.5	47.6	46.2
	1939	300	265	255	204	227
11 (S.C. II-XI)	rdw	8.4	7.9	7.2	7.1	------
	1938	54.5	52.0	46.1	51.9	------
	1939	291	299	187	199	------

[1]Reserve dry weight, or average dry weight of the seed less average dry weight of the seed coat.

to the nearest 0.5 centimeter at a height of 19.5 inches from the ground.

Seed Weight

In any effort to estimate growth of seedlings, the effect of seed weight must be taken into account. Large seed will produce large seedlings, small seed will produce small seedlings, and differences in inherent growth rate may well be masked by the effects of initial seed weight.

Gast (1937) and Mitchell (1934, 1937) have demonstrated that at any time during the first growing season, the size of the seedling is closely related to the weight of the seed and even more closely related to the "reserve dry weight" or "rdw," which is defined as the dry weight of the seed less the dry weight of its seedcoat. Furthermore, this relationship remains the same regardless of nutrient conditions. For example, if seed A is 10 percent heavier than seed B from the same tree, the plant resulting from seed A will be correspondingly heavier than that from seed B under any nutrient condition at any given time during the first growing season.

The effect of seed weight on the early development of eastern white pine was studied in detail over a 3-year period in one of the supplementary trials and the results have been published (Spurr, 1944). It was found that heavy seed germinated better, germinated earlier, and survived in a higher proportion than did light seed of the same source. Shoot weight at the end of the first year was closely correlated to seed weight. As the plants grew older, however, the effect of seed weight on shoot weight diminished, but was still highly significant at the end of the third year. This relationship was the same for all ten seed origins. Furthermore, the effect of seed weight on shoot weight was the same whether the plants were grown in a sand culture of high fertility or in a soil bed of moderate fer-

TABLE 2. Effect of seed weight on first and second year top weight for seed of all sources, Nichewaug Nursery.

Size class	No. of sources	Seed weight: Seed coat	Seed weight: rdw	Seed weight: Total	1939 (1 year)	1940 (2 years)
		Dry weight (mg.)				
Large	11	8.01	13.55	21.56	84.1	497
Medium large	20	7.74	12.24	19.98	75.5	465
Medium	33	6.93	10.69	17.62	67.7	434
Medium small	35	6.36	9.53	15.89	60.9	383
Small	15	5.67	8.00	13.67	50.0	314

tility. The effect of seed weight was independent of soil fertility and of seed source.

In a related study carried on at the Harvard Forest, Wright (1945) studied seed size from various portions of the cone in various parts of the tree. He found that the largest seed developed in the base of the cones on the largest cones of the tree. He found no obvious correlation between seed or cone size and the age, diameter, or growth rate of the parent.

The present paper presents data that antecedes the studies previously published and, in fact, provided the basis for their planning.

In preparing the seed for the Doe Valley trial, a seed sorting device was designed by Dr. Gast. The seed was placed in a vertical column and was subjected from below to an air blast. As the velocity of the air flow was increased, the seed rose higher in the column with the lower density seed being at the top. By drawing off successive fractions of the seed as the air velocity was increased, it was possible to sort large quantities of seed into approximate seed size classes.

The seed from six local origins was thus sorted into four to five weight classes, and each class was treated as a separate lot in the Doe Valley nursery. As Table 1 shows, the mean seed weight of each successive class was greater than that previously drawn off. Later, however, it was found by weighing several thousand individual seed on a micro-balance that the variance of seed weights within each class was great. While class I invariably had a higher mean weight than class II, the spread in individual seed weights within each class was several times greater than the differences between the means.

Notwithstanding, the Doe Valley data show a high degree of correlation between the mean reserve dry weight of the class and the dry weight of the tops at the end of the first year. After the second season, the relationship is still apparent, but the degree of correlation is much lower. The lesser correlation in subsequent years confirms on a larger scale the results obtained from the more precise small-scale tests.

In Table 1, the seed sources are arranged in order of decreasing seed weight. An inspection shows that seed from tree 20 was definitely faster-growing than seed from tree 50 inasmuch as its seed weight in each class is smaller but its corresponding top weights after one and two growing seasons are in each case larger.

Since the detailed study had shown that the effects of seed weight were independent of seed source, it was possible to sort the data from the Nichewaug nursery to demonstrate the effect of seed weight on early shoot weight on a large scale. All the sources were sorted into five broad seed-size classes, and the corresponding top weights were computed (Table 2). The plants from the 11 heaviest seed sources averaged 497 mg. top dry weight at the end of the second season as compared to only 314 for the 15 lightest sources.

In the seed weight study, it had been found that a significant degree of correlation between seed weight and top weight was still apparent at the end of the third growing season, but that the effect was lessening from year to year. Twelve plants from a single seed origin (No. 10) were left in the artificial soils bed for an additional 5 years. At the end of eight growing seasons, these plants were measured, and the basal diameter, total height, and volume related to the actual weight of the individual seed from which they grew. No correlation was found, the effects of initial seed weight on growth having been apparently wiped out by variation in inherent growth capacity and by competition between the plants even though the site conditions were uniform. Omitting one badly-overtopped tree, the correlation coefficient between seed weight and 8-year volume was -0.204, a statistically non-significant value. Actually, the largest tree was the product of the smallest seed, and there was some indication that with a larger sample and wider spacing, the smaller seeds might be shown to produce larger trees.

Even though the effect of seed weight seems not to be very persistent, its importance for the first two years is evident. To determine growth differences between different seed sources, it is obviously necessary to take into account differing original seed weights. In the Doe Valley and Nichewaug nursery trials, this was done by computing an overall regression of seedling dry weight on reserve dry weight for each nursery at the end of each growing season. The following regression were obtained at the end of the first season:

$$\text{Doe Valley } Y = 17.21 - 4.78 \text{ rdw}$$
$$\text{Nichewaug } Y = 11.99 - 5.15 \text{ rdw}$$

where Y is the mean top weight of an oven-dried sample in milligrams, and *rdw* is the mean dry seed weight less the mean dry seed coat weight of a sample of seed taken from the seed source collection at the time of sowing.

From these and similar regressions, it is possible to adjust all yield values to a common reserve dry weight, thus correcting growth from the effects of differing seed weights.

Seedling Trials

In the two nursery trials, a total of 159 seed sources were tested over a two-year period. Of these, 148 were seed collected from single open pollinated mother trees, and 11 were mixed lots from a single stand. Geographically, 67 of the collections were from the town of Petersham, 13 were from other parts of Massachusetts, and 79 were from distant localities. From the standpoint of different nutrient levels, 15 seed sources were used in two separate trails; 4 were used in three trials, and 4 also in four trials.

The various trials are summarized in Table 3, together with the summary of the analyses of variance. Although adjustments for seed size were utilized in both the nursery trials, analyses of variance were run only for the first year of the Doe Valley trial.

Several basic conclusions can be drawn from this summary. First, the various seed sources differed significantly[3] in growth both on an unadjusted and on an adjusted (for seed weight differences) basis. There can be no question but that growth differences exist for eastern white pine between collections from single mother trees in a given locality and from mother trees in different localities. Where the analysis of variance is applied to unadjusted values, this significant variation is due in part to inherent growth capacity and in part to variation

[3]In this paper, significance is used in its statistical sense; non-significance denoting probabilities that differences noted are not due to chance are less than 1 out of 20, significance denoting probabilities greater than 1 out of 20, and high significance denoting probabilities greater than 1 out of 100.

TABLE 3. Summary of analyses of variance and seed source trials.

Experiment	Series and year	Seed size adj.[1]	Degrees of freedom	No. of collections	Mean yield[2]	Variance ratio (F)[3]	Std. error[4]
Doe Valley	H38	No	432	57	76.1 mg.	27.40 h.s.	3.3
	K38	No	180	31	71.5	17.05 h.s.	4.4
	H38	Yes	432	57	65.4 mg.	2.43	4.2
	K38	Yes	180	31	61.9	7.68 h.s.	4.5
Nichewaug	H39	No	420	57	407	17.13 h.s.	4.7
	K39	No	170	31	360	6.49 h.s.	7.2
	H39	No	453	57	68.8	105.03 h.s.	1.4
	K39	No	427	57	63.6	51.48 h.s.	2.0
	H40	No	451	57	421	9.79 h.s.	5.3
	K40	No	433	57	412	8.08 h.s	5.3
Pot cultures	40	No	159	8	84.0	24.73 h.s.	2.8
	40	Yes	159	8	----	12.35 h.s.	1.1
	41	No	------	7	121.3	----	----
	41	Yes	27	7	----	3.61 sig.	6.6
Seed weight	41	No	199	10	76.9	18.80 h.s.	5.6
	41	Yes	199	10	76.9	3.11 h.s.	4.2
North field	55	No	101	21	9.02 cm.	1.76 sig.	6.6
South field	55	No	91	21	8.07	1.76 sig.	7.5

[1]*Yes* indicates values adjusted to single *rdw*, or expressed on growth ratio basis.

[2]Mean top dry weight (*mg.*). Field trial yields are mean diameter (*cm.*), 19.5 inches from the ground.

[3]Ratio of variance between collections to error variance. *h.s.*, highly significant; *sig.*, significant.

[4]Expressed as a percent of the overall mean.

in seed weight between the different collections. The significant results obtained from adjusted values, though of a lower order than obtained from unadjusted values, demonstrate that inherent differences in growth rate do exist independently of seed weight variation.

In the trials that were carried more than one year, significance decreased with time. This fact does not necessarily indicate that variance between seed sources decreased, but rather that unexplained variance increased so that the resulting variance ratio (F) decreased with time. None the less, highly significant variation in mean top dry weights of the different seed sources was found after the second growing season in both the Doe Valley and Nichewaug nurseries.

In all cases, however, the error variance attributable in part to the variation in growing conditions within the individual trials and in part to genotypic variation within a given collection resulted in standard errors of from 1.1 to 7.2 percent of the mean yield. In the most precise nursery trial (Nichewaug, 1939), where site and growing conditions were most uniform, a difference of approximately 3 milligrams in mean top weight between two seed sources was necessary to establish significance by the *t* test. In the least precise trial (Doe Valley, 1939), where fertility differences in the nursery had affected second-year development, a difference of approximately 70 milligrams was similarly necessary. The former value is 5 percent of the mean yield while the latter is 18 percent of the mean yield. The large-scale nursery trials, therefore, are precise enough to classify a given seed source as faster-growing than another given source only when the two seed sources vary by 5-18 percent depending upon the precision of the test. Smaller differences would of course be sufficient for demonstrating significance beween groups of seed sources.

In the supplementary tests, the standard error values are comparable to those obtained from the nursery trials. The number of seedlings of each source grown in the supplementary tests varied from 10 to 100, however, while the comparable numbers in the nursery ranged from 500 to 2000. It is evident, therefore, that the pot cultures and carefully-prepared artificial soils bed gave greater precision in the testing of the various seed sources. Even better results could be expected with more replications in the supplementary trials.

Coming to the individual trials, the Doe Valley nursery provides information on the growth of seed sources from various local stands in and near the Harvard Forest (Table 4). The three younger stands (designated by Compartments) had seeded in on abandoned fields on glacial till soils (Gloucester fine sandy loam), while the two older stands had come in on sandy outwash soils which had never been farmed. Although individual seed sources varied in their growth rates to a highly significant degree on both an unadjusted and adjusted basis in this trial, there is no evidence that this variation is correlated with the forest stands, its age, or the underlying soil type. In other words, there is no evidence of ecotypic variation in the Petersham white pine. We may, however, conclude that genetic diversity does exist in the Petersham white pine, but that such diversity is randomly distributed in what is apparently a single undifferentiated population of the species. This is to be expected for no barriers to cross-pollination are known to exist.

A different situation is encountered when other localities are considered as in the Nichewaug experiment. In Table 5, the seed sources are grouped by states or provinces. The Massachusetts sources are subdivided into Petersham and other; the New Hampshire sources into southern, central, and northern groups; and the Ontario sources into peninsular or southern collections, Ottawa valley or northeastern collections, and central and western collections.

On the unadjusted mean top dry weight basis, the Virginia seed sources produced the largest seedlings during the first growing season, while the southern and central New Hampshire seedlings were the largest after the second season. No geographical trend is apparent from the unadjusted data.

When the adjustments for variation in initial seed weights have been made, however, a well-defined geographical pattern emerges. The local Petersham sources produced the largest 1-year plants while the other Massachusetts sources and the penin-

TABLE 4. Doe Valley seed source trials. Top weights after first and second growing seasons.

Locality	Age	No. of sources	Top dry weight (mg.) Unadjusted 1938	Unadjusted 1939	Adjusted 1938	Adjusted 1939
Tom Swamp V and VI	55	9	81.7	378	66.7	343
Wilder's Woodlot	55	19	73.4	373	63.9	373
Slab City II and XI	60	12	64.3	309	64.7	353
Tom Swamp IX	90	10	89.5	465	68.4	382
Tom Swamp IV	150	10	71.9	340	64.1	348
Others[1]		3	77.6	374	65.6	352

[1]Townsend and Carver, Massachusetts.

TABLE 5. Nichewaug nursery seed source trials. Average dry weights of tops in milligrams for first two years' growth. (*1939-1940*)

Locality	No. of sources State	Area	Unadjusted mean dry weight 1939	1940	Adjusted mean dry weight 1939	1940
Massachusetts	25		61.7	406	64.7	444
Petersham		14	65.3	427	66.6	435
Other		11	57.1	379	62.3	456
New Hampshire	27		71.2	458	64.4	424
South		11	71.7	470	64.7	430
Central		6	70.8	472	65.2	441
North		10	70.8	436	63.7	406
New York	17		64.9	395	64.4	409
Ontario	21		61.8	404	60.8	421
Peninsular area		10	59.4	402	61.7	459
Ottawa Valley		7	70.5	444	61.0	412
Central and West		4	65.9	341	58.5	340
Michigan	3		52.0	298	58.7	402
Minnesota	9		72.9	408	61.6	365
Virginia	2		81.4	395	66.0	308
Mean			65.7	414	63.4	418

sular Ontario sources produced the largest 2-year plants. Keeping in mind the size of the experimental error, it is apparent that the local sources are best adapted. The farther away geographically and climatewise the collection is made, the poorer it does in the Petersham environment. Variation in growth rate between the sources from the different localities is not great, and there is no growth evidence or substantiating morphological observations to indicate the existence of well-defined ecotypes.[4] Rather, there is a clinical variation in growth behavior as would be expected for a tree which is common over a continuous range.

Even clearer evidence of the growth variation attributable to localities is given when the growth of the white pine is expressed in terms of *growth ratios*. This term is defined as the number of times the plant increased in dry weight during the growing season. The mean growth ratio for the first two years for the Massachusetts sources was 6.56, followed by 6.39 for New Hampshire, 6.29 for New York, 6.23 for Ontario, 5.89 for Michigan, 5.78 for Minnesota, and 5.60 for Virginia. On this basis, there is continuous decline in growth rate from Massachusetts north and west, and even greater decline for the southern Virginia collections. All differences proved highly significant by analysis of variance and subsequent t test.

In the course of the various trials, the seedlings were grown under various fertility levels. During the first year, growth in the Nichewaug and Doe Valley nurseries was comparable. The mean top dry weight of the 8 sources common to both nurseries was 70 milligrams for the Doe Valley and 65 milligrams for the Nichewaug nursery. During the second season, however, the poorer fertility and moisture conditions of the Doe Valley resulted in a mean topweight of 332 milligrams as against 421 for the Nichewaug.

Better growth, however, was obtained in the supplementary trials. The mean top

[4]In a later collection by Dr. Pauley, however, a 5-year-old collection from a North Carolina source is characterized by a distinctly bluish cast to the needles.

TABLE 6. Growth correlations of seed sources common to more than one trial.

Trials	Number of common sources	Correlation coefficient: Unadjusted values	Adjusted values
Nichewaug and Hydroponicum, first year	10	0.955 h.s.	0.631 sig.
Hydroponicum and Artificial soils, first year	10	0.941 h.s.	0.381
Nichewaug and Artificial soils, first year	10	0.887 h.s.	—0.033
Nichewaug and Artificial soils, second year	9	0.763 sig.	0.066
Nichewaug and Doe Valley, first year	8	0.759 sig.	0.431
Nichewaug and Doe Valley, second year	8	0.077	—0.412
Doe Valley and Pot Cultures, first year	10	—0.124	0.388
Nichewaug, first year, and Field trials	21	—0.393	—0.384
Nichewaug, second year, and Field trials	21	0.106	—0.550 h.s.
Doe Valley, first year, and Field trials	21	—0.077	—0.091
Doe Valley, second year, and Field trials	21	0.383	0.221

weight of the 10 sources grown in the pot cultures was 80 milligrams as compared to 67 milligrams for the same sources in Doe Valley. Both values are for the first year. In the seed weight experiment, the first-year weight of the 10 sources in the hydroponicum was 86 milligrams as compared to 69 milligrams for the artificial soil and 61 milligrams for the same sources in Nichewaug. After the second year, the weight of the 9 sources left in the artificial soils bed was 832 milligrams or more than twice as great as the 393 milligram average for the same source in Nichewaug.

Differences in nutrition clearly showed up during the first growing season. The hydroponicum provided the best growth, followed by the pot cultures, the artificial soils bed and the two nurseries. It was in the second year, however, that differences become pronounced with a difference of 500 milligrams mean top dry weight between the hydroponicum and the Doe Valley nursery, a difference that would be even greater were the seed size correction applied. In trials involving fertility levels, it would appear to be best to allow the seedlings to grow at least two years, for the effects of differing levels of nutrition are much greater the second year than in the first.

The number of seed sources replicated in more than one trial was not great, varying from eight to ten in the various paired trails. None the less, significant correlations were obtained between the behavior of the same seed sources in paired trials in several instances (Table 6). The highest correlations were obtained for unadjusted top weights after the first year between the three most precise trials—the hydroponicum, the artificial soils, and the Nichewaug nursery. The simple correlation coefficients ranged from 0.887 to 0.955. Significant correlations were also obtained using unadjusted top weights for seed sources replicated in both the Doe Valley and the Nichewaug nurseries. Other comparisons involving the Doe Valley nursery, however, were not significant.

When adjusted top weights were used, thus eliminating the effect of varying seed weights, significant results were obtained only for the seed sources used in the Nichewaug and the hydroponicum tests. Other paired trials gave correlation coefficients approaching statistical significance, and there seems little doubt but that significant results might have been obtained had a larger number of seed sources been replicated, or had more seedlings of each seed source been grown. Growth rates characteristic of a given seed source apparently occur under a wide range of soil fertility levels. In

TABLE 7. Field plantings. 1955 diameter and weeviling data compared with nursery data by groups of seed sources.

Seed source group	No. of sources	Seed rdw	Second year top wt. (mg.) Adjusted	Unadjusted	1955 Mean diam. (cm.)	1955 Ave. no. weevilings per stem
NORTH FIELD—DOE VALLEY NURSERY						
T. S. V & VI	2	12.6	404	366	9.92	1.92
Wilder's	9	11.6	409	388	8.73	2.14
S. C. II & XI	3	10.3	356	381	8.44	2.07
T. S. IX	6	14.4	500	406	9.49	2.10
T. S. IV	1	9.9	374	402	9.46	2.22
Mean	21	12.2	425	391	9.05	2.10
SOUTH FIELD—NICHEWAUG NURSERY						
Massachusetts	8	9.5	445	458	8.70	1.81
New Hampshire	9	10.3	480	476	7.86	1.73
New York	1	8.6	400	490	7.74	1.74
Ontario	3	8.1	409	529	7.10	1.67
Mean	21	9.6	453	477	8.07	1.76

small trials, though, a carefully designed and controlled experiment is necessary to establish the correlation. A larger number of sources or a larger number of plants within each source should be grown under carefully controlled conditions to determine the extent to which growth rate and soil fertility levels are interrelated.

Field Trials

When measured in 1954-1955, the two field trials could not be classified as successful plantations. Survival was poor and the live trees had been rendered bushy by repeated killing of the leader by the white pine weevil. Nevertheless, the behavior of the different seed sources is in accordance with their early behavior in the two nursery trials.

Survival in both the North and South Fields is poor, being 52.6 percent in the North Field planted with local stock from the Doe Valley nursery, and 42.6 percent in the South Field planted with local and distant stock from the Nichewaug nursery. Survival is particuarly poor in a depression in the west corner of the North Field, apparently the result of frost conditions. The chief cause of low survival, however, was the severe drought of 1941, the year of planting.

Survival is higher for the local sources than for the distant sources. Overall survival for the local sources is 52.6 for those in the North Field and 50.8 percent for those in the South Field. In contrast, the non-local or distant sources in the South Field survived at the rate of only 37.4 percent.

Because of the weevil damage, growth measurements were confined to basal diameter. Use of the balanced incomplete randomized block design in each trial permitted the adjustment of the mean diameters of each seed source to reduce the effects of site variation within the planting site. The procedure is the same as that described for top weights in the nursery.

The analyses of variance for the two nursery trials are summarized at the bottom of Table 3. After 15 years' growth of trees in the North Field and 14 years' growth in the South Field, the differences in growth between seed sources is significant at the 5 percent level.

When the seed sources are grouped according to stand and locality (Table 7), the results clearly parallel the earlier nursery trials. There is no evidence to indicate that local ecotypes exist. In the North Field, the mean diameters of the trees from each stand show no consistent variation with stand, stand age, soil type, or original seed weight.

The trees from distant sources, though, are definitely growing at a slower rate than those from local sources. The more distant the collection the poorer the growth. The 14-year-old local trees in the South Field have an average diameter of 8.70 centimeters as compared to 9.05 for the 15-year-old local trees in the North Field. The New Hampshire strains have a diameter of only 7.86 at 14 years, followed by 7.74 for the single New York collection and 7.10 for the three Ontario sources. These differences are highly significant according to the *t*-test except for the New Hampshire-New York comparison.

Poor condition of the field trials resulting from low survival and heavy weeviling make it improbable that a high degree of correlation would be found between the behavior of individual collections in the nursery and in the field. Such indeed is the case (Table 6).

Surprisingly, a highly significant negative correlation was found between the adjusted second year Nichewaug top weight and the mean diameter of the same sources in the South Field. In other words, the larger the mean weight of a seed source after two years, the smaller the diameter would tend to be twelve years later. The correlation coefficient is not large (—0.550) and the negative regression may simply be due to an over-correction in the seed weight adjustment in 1940. At the same time, it is interesting to note that negative regressions are indicated by several of the non-significant correlations summarized in Table 6 and by the correlation between 8-year-old volume and seed weight for the 11 trees carried over in the seed weight trial. The point warrants further investigation.

The field trials confirm over a 14-15 year period the more extensive 2-year nursery trials in showing eastern white pine to be a species which is relatively homogeneous in its biotype, and which fails to exhibit clearly-defined ecotypes, although it does clearly show a clinical variation in growth behavior. Unusually large and vigorous specimens are rare and mass selection of seedlings in the nursery seems to offer little possibility for the improvement of this species. The present study confirms the finding of Ellertsen (1955) who reported that only 9 "super-seedlings" had been chosen out of 3,758,000 seedlings in the T.V.A. nursery. None of these outgrew their average-sized controls.

Virtually all the dominant and codominant trees in the field plantings had been badly deformed by the white pine weevil. As is usual, the weeviling was more severe in the larger and more open-grown trees. There was no evidence that any given source had been weeviled more severely or less severely than the others when differences in size and spacing had been taken into account.

In Table 7, the average number of weevilings per tree is given for each group of seed sources. As in the case of the diameter values, weeviling does not appear to differ markedly between the collections from the five local stands. In the South Field, however, the local sources are weeviled the most, followed by the New York and New Hampshire strains, while the Ontario collections are weeviled the least. Since this trend closely parallels the mean diameters of the same groups, it is logical to conclude that the local trees are weeviled the most simply because they are the largest trees, while the Ontario are weeviled the least because they are the smallest. No evidence was found indicating genetic resistance to weeviling independent of tree size or exposure.

Summary

Tests of 159 collections of eastern white pine (*Pinus strobus* L.) over two years in two experimental nurseries, and of 42 of the same collections for 13 years after-

wards in two field plantings provide information on the early development of this species as related to locality of seed collection, the tree from which the collection was made, and seed weight. The tests were carried on by the Maria Moors Cabot Foundation for Botanical Research at the Harvard Forest, Petersham, Massachusetts, from 1937 to 1955.

Seed weight is the most important factor affecting the size of 1-year white pine seedings and must be taken into account before the growth rates of even 2-year-old seedlings can be determined. In a limited test, however, no residual influence of seed weight was found after 8 years.

The great majority of the collections were from individual open-pollinated mother trees. Individual collections varied in their growth rates to a highly significant degree, but there is no indication that such variation is correlated with local diversity in site. There is thus no evidence that local ecotypes, identifiable on a growth rate basis, are present in the Petersham area. No distinct ecotypic diversity based on growth rate was discernible among the various geographic sources studied. Rather, variation in growth rate suggests a clinical pattern. The farther the collection was made from the Petersham area, and the more diverse the conditions of climate and site, the poorer the seed source did in the Petersham area. Plants from local seed grew best, followed in order by New Hampshire, New York and Ontario, Michigan, Minnesota, and Virginia sources.

Limited replication of 23 seed sources in more than one seedling trial indicated that growth differences between sources probably persisted independently of soil fertility levels, although the evidence here is not conclusive. Two-year-old seedlings showed much greater response than one-year plants to different fertility levels, and it would be desirable to grow white pine seedlings at least two years in any test involving nutrition.

Evidence of genetic diversity in growth rate among individual Petersham white pine mother trees suggests that careful selection of both parents and their controlled interpollination will yield progenies of increased vigor. Such improvements, however, have little to recommend them until weevil-resistant strains are isolated or adequate weevil control methods are perfected.

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