Geographic Variation of Quaking Aspen in Wisconsin and Upper Michigan

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(Received for publieation June 12, 1966)

Natural variation and degree of genetic control over existing variation are important factors which must be considered when selecting characteristics to emphasize in a tree improvement program. The study discussed in this manuscript was carried out as part of a previously described tree improvement program (EINSPAHR and BENSON, 1964). The objectives of this study were to increase existing knowledge of the natural variation of wood, fiber, and growth characteristics and accumulate data needed for establishing base lines for judging growth and "wood quality" of quaking aspen.

Previous Investigations

A number of studies have been undertaken to investigate the natural variation of forest tree species. GOGGANS (1961), in a review discusses studies of variation and the interplay of heredity and environment as factors Controlling wood properties in conifers. THOR (1961) in a recent study describes natural variation in wood properties of Virginia pine and cites a number of additional studies of natural variation in southern pines. Recent studies within the genus Populus indicate that considerable natural variation occurs in growth, morphological characters, and wood properties. BARNES (1959) working with Lakes States aspen, found a wide range of interclonal variation in morphological characters and gross clonal development. Similarly, VAN BUIJTENEN, et *al.* (1959) discovered significant leaf and tree form differences between P. Cremuloides clones in Wisconsin and in a later study (VAN BUIJTENEN, et *al.*, 1962) reported significant differences in wood and pulp properties. VALENTINE (1961) reported that considerable variation existed in the specific gravity of the quaking aspen population of Northern New York; BROWN and VALENTINE (1963) presented data on variation in leaf morphology, specific gravity, and limited information on fiber length of quaking aspen; and EINSPAHR, *et al.* (1963), in a study of natural variation of triploid aspen, reported important genetically controlled differences in specific gravity, fiber length, fiber strength, tree growth, and pulp properties.

MARCET (1961), JOKELA (1964), FARMER (1964), and WALTERS and BRUCKMAN (1965) reported on studies of natural variation in cottonwood including differences discovered in leaf morphology, growth, and specific gravity.

Experimental Methods

Study areas were established in five geographic locations within the States of Wisconsin and Upper Michigan (*Figure* 1) to investigate the existence of geographic trends and provide data for establishing "base lines" for judging the relative quality of selected trees. Five stands were measured in each geographic area and three trees in each of three clones were sampled in each stand. This sampling procedure resulted in a total of forty-five trees being measured in each geographic area. Tbe stands sampled ranged in average age from twenty-three to forty-four years and were limited in location to medium and light-textured upland soils with water table levels at six feet or greater in depth. Measurements were restricted to the dominant and codominant trees of each clone. Information taken on each experimental plot included: (1) age, form, and rate of growth information; (2) specific gravity and fiber length based on four 10-millimeter increment cores; (3) soil and other site information based on soil samples taken from the "A" and "B" horizons; and (4) pulping information based on the micropulping of four to six 10-millimeter increment core samples per tree. Pulping information (fiber strength, pulp yield, and permanganate number) was based upon just one stand in each geographic area.

Tree growth was measured in terms of age, height, diameter at breast height, and form factor, and the corresponding tree volume in cubic feet was based upon the form factor volume table of MESAVAGE (1947). The crown volume was calculated using the crown diameter and length of live crown and assuming the shape of the crown was cone. Examination of breast height increment cores provided

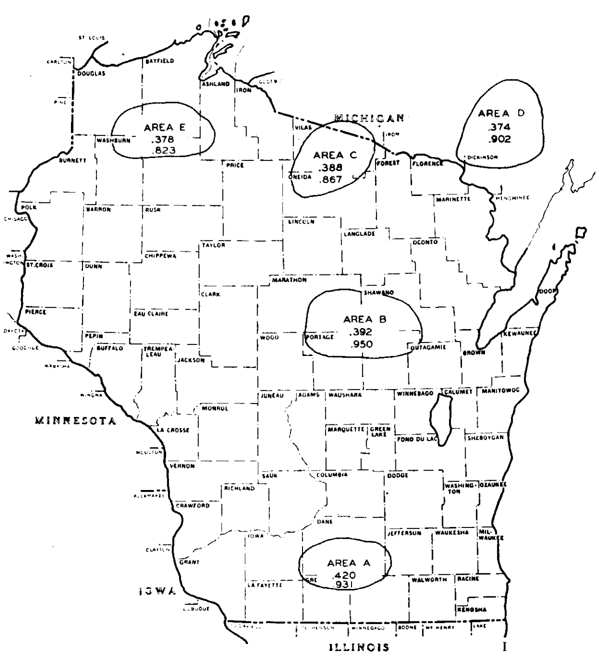

Figure 1. — Illustrated Are the Specific Gravities and Fiber Lengths of Study Areas Sampled in Wisconsin and Upper Michigan.

[1]) The authors are Research Associate and Research Aide, The Institute of Paper Chemistry, Appleton, Wisconsin. The authors wish to acknowledge the financial support of this work by the Louis W. and Maud Hill Family Foundation of St. Paul, Minnesots and the nine pulp and paper companies who are members of the Lake States Aspen Genetics and Tree Improvement Group. The authors also wish to acknowledge the help of Mrs. MARIANNE HARDER and Mrs. DOROTHY OLSON for their assistance in carrying out the fiber length and specific gravity measurements and to acknowledge the work of JOHN BACHHUBER, Mrs. HARDER and Mrs. OLSON in handling computer problems. Appreciation is also expressed to the members of the Technology Section for their contribution to the pulping phases of the study and to W. WINK and members of the Paper Evaluation Section for making the zero-span tensile strength measurements.

the age determinations. Site index values for the stands were estimated using the site index curves published by GRAHAM, *et al.* (1963).

Specific gravity and fiber length data were obtained by taking appropriate measurements on four 10-millimeter breast height increment cores taken at right angles from each other. Core volumes were obtained by using a calibrated increment core borer and measuring the length of the saturated cores. The specific gravity values are expressed as grams of dry weight per cubic centimeter of green volume. Fiber measurements on all areas with the exception of three clones in Areas B and C were obtained by macerating the last ten annual rings from a minimum of two increment cores using sodium chlorite and acetic acid (SPEARIN and ISENBERG, 1947). The fiber lengths of 400—500 fibers were measured on this ten-year increment core segment. All fibers including cut, broken, and intact fibers 0.3 mm. and longer in length were measured by projecting the fibers on a ground glass screen at a magnification of fifty times. Fiber lengths were adjusted to age thirty by plotting the fiber length and age information on a previously prepared fiber length-age curve for quaking aspen. Three clones in Area B and three clones in Area C were part of a previous study and the fiber length at age thirty for the trees in the earlier study was obtained by dividing the increment cores into five-year age intervals, compositing portions of equal age and macerating according to the techniques cited above. Eighty fibers were measured for each interval, the fiber length-age curve for each tree prepared, and the age thirty fiber length obtained from this curve.

Soil pits were dug at each clone location, the soils of the upper twenty-four to thirty inches described, and samples of the "A" and "B" horizons taken for laboratory examination. The soil texture (percent sand, silt and clay) was obtained by the use of the hydrometer method as described by BOUYOUCOS (1936). Soil samples were submitted to the University of Wisconsin Soil Testing Service and information on the acidity and levels of essential soil nutrients (N, P, K, Ca, and Mg) were thus obtained. The data on soil nutrients presented are weighted average levels based upon nutrient levels and thickness of the A and B horizons. If multiplied by the factor of four, the values presented would be approximately equal to the total available soil nutrient in the upper twenty-four inches of the soil.

The pulping data presented were obtained by using a micropulping procedure that employs a kraft pulping system and a multiunit digester (VAN BUIJTENEN, *et al.*, 1961). This procedure makes possible the simultaneous pulping of seven small samples and the use of a sample size as small as fifteen grams dry weight. The techniques used and the cooking conditions are reported in detail in a recent paper by GARDNER and EINSPAHR (1964). The yield data presented are the percent yield of pulp and are based upon equivalent weights of wood in each digester. The permanganate number is a measure of the lignin in the pulp after cooking. Zero-span tensile strength measurements were conducted on test handsheets using the procedures described by WINK and VAN EPEREN (1962) and are interpreted as a measure of individual fiber strength.

Field sampling was so arranged that an analysis of variance of the form outlined in *Table 1* (SNEDECOR's hierarchical classification, 1956) was used to examine the sources of variation for the growth and wood quality data. A slight modification of the illustrated form of analysis was used in examining the soils and pulping data. DUNCAN's multiple range test (1955) was used to examine area means more closely when significant between area differences existed. In addition to the analysis of variance, a number of correlations were calculated relating tree growth, wood, and soil properties. Space does not permit a complete discussion of this phase of the work and information is presented on only a selected number of correlations. Specifically omitted were the relationships obtained between soil texture and available soil nutrients.

Results

Tables 2 and 3 provide a summary of the most useful tree growth, wood quality, and soils data collected for each geographic area and give the reader a feel for the variability encountered. *Tables 4 and 5* provide brief summaries of the results of the correlations and the analyses of variance calculations carried out on the above data. The multiple range test data in *Table 6* provide information indicating statistical differences between areas.

Soils Data

The soils supporting quaking aspen stands on the upland sites in the five geographic study areas varied considerably from area to area and stand to stand within areas *(Table 2)*. The soils were fairly uniform in Areas A and D and varied the greatest in Area B. An analysis of variance of a form similar to that illustrated in *Table 1* was used to examine the soil property variation. The differences between clones within stands were quite small and contributed only a minor amount to the overall variation. Highly significant (1% level) differences were obtained between areas and stands within areas in soil texture, pH, P, Ca, total exchangeable bases, and "A" horizon thickness. The statistical analysis of organic matter data indicated that there were highly significant differences between stands within areas while between area differences were significant only at the 5% level[2]). Potassium and magnesium were found to have highly significant differences between areas but there were no significant differences between stands within areas.

[2]) Highly significant indicates significant at the 1% level of probability while the term "significant" is used to indicate values significant at the 5% level of probability. NS is used when the correlation coefficients fall below 5% level of probability.

Table 1. — Outline of analysis of variance.

Source of variation	Degrees of freedom	Sum of squares	Mean of squares	Mean of squares is an estimate of
Total	224	"	"	
Areas	4	"	"	$\sigma^2 + 3\sigma_c^2 + 9\sigma_s^2 + 45\sigma_A^2$
Stands, within areas	20	"	"	$\sigma^2 + 3\sigma_c^2 + 9\sigma_s^2$
Clones, within stands	50	"	"	$\sigma^2 + 3\sigma_c^2$
Trees, within clones	150	"	"	σ^2

Table 2. — Summary of soils data.

Area	Stand	Sand, %	Silt, %	pH	OM, lb./acre ÷ 1000	Available, lb./acre				"A" Horiz. thick., in.	Site index
						P	K	Ca	Mg		
A	1	41.4	45.8	5.5	14	61	168	947	347	3.2	46
	2	43.1	40.6	5.9	12	34	138	1367	557	4.2	47
	3	49.6	43.8	7.4	22	32	113	3520	543	8.0	47
	4	55.1	31.0	5.6	10	71	133	1363	550	4.0	49
	5	43.0	44.5	6.6	16	51	159	2003	793	10.0	53
	Av.	46.4	41.1	6.2	14.5	50	142	1840	558	5.9	48.4
B	1	70.1	21.7	5.0	20	33	65	457	115	2.9	51
	2	69.7	20.7	5.3	20	73	90	847	165	2.0	54
	3	54.4	37.8	5.0	34	17	73	533	93	1.0	56
	4	32.9	48.0	5.0	19	10	82	823	232	4.6	67
	5	84.1	9.4	4.7	54	58	52	320	57	5.0	54
	Av.	62.3	27.5	5.0	29.4	38	72	596	132	3.1	56.4
C	1	77.7	17.4	5.1	11	138	58	373	95	2.8	53
	2	88.4	7.3	5.4	11	152	98	427	83	1.9	53
	3	62.8	32.5	4.9	36	17	72	407	60	0.8	58
	4	75.9	16.2	5.2	20	90	50	427	35	2.0	61
	5	76.5	15.6	5.6	20	75	63	1293	73	3.8	55
	Av.	76.2	17.8	5.2	19.4	94	68	585	69	2.3	56.0
D	1	91.7	7.0	5.7	10	224	80	323	83	1.4	44
	2	92.8	4.5	5.3	12	191	85	257	73	1.8	51
	3	85.5	11.5	5.4	14	141	83	310	77	2.8	52
	4	67.9	24.4	6.4	16	37	93	1053	217	2.5	50
	5	86.8	10.1	5.7	14	134	88	673	70	2.3	52
	Av.	84.9	11.5	5.7	13.1	145	86	523	104	2.2	49.8
E	1	82.1	13.5	5.3	11	157	70	412	78	2.7	48
	2	64.9	26.8	5.0	13	163	85	603	88	0.8	41
	3	88.7	8.8	4.9	13	130	80	317	58	3.7	43
	4	79.3	17.9	5.3	14	64	78	400	103	1.9	49
	5	45.5	49.3	5.4	18	94	108	730	143	3.3	44
	Av.	72.1	23.3	5.2	14.0	122	84	492	94	2.5	45
Grand	av..	68.4	24.2	5.5	18.1	90	91	807	192	3.2	51.1

Table 3. — Summary of growth, wood and pulping data.

Area	Stand	Age, yr.	Ht./age, ft./yr.	D.B.H./age, in./yr.	Vol./age, cu. ft./yr.	Cr. vol./age cu. ft. $\times 10^{-3}$	Form factor	Sp. gr., g./cc.	Fiber length, mm.	Fiber strength, lb./ir.	Pulp yield %
A	1	34	1.45	0.19	0.16	7	74	0.433	0.909		
	2	31	1.58	0.20	0.16	20	76	0.417	0.917		
	3	35	1.47	0.22	0.17	17	73	0.397	0.943	60.8	51.2
	4	25	1.78	0.27	0.19	28	74	0.424	0.978		
	5	44	1.42	0.17	0.18	8	78	0.427	0.906		
	Av.	34.0	1.54	0.210	0.172	16	75.1	0.420	0.931		
B	1	35	1.62	0.22	0.20	22	78	0.400	0.984		
	2	35	1.68	0.22	0.24	31	80	0.398	0.952		
	3	36	1.71	0.24	0.33	40	83	0.391	0.926	56.0	52.4
	4	23	2.48	0.31	0.27	35	75	0.387	0.943		
	5	33	1.72	0.21	0.20	27	80	0.383	0.943		
	Av.	32.7	1.84	0.241	0.246	31	79.1	0.392	0.950		
C	1	41	1.51	0.17	0.18	19	79	0.382	0.815		
	2	35	1.63	0.22	0.21	41	74	0.391	0.821		
	3	40	1.60	0.21	0.26	27	80	0.375	0.808	64.4	51.8
	4	37	1.83	0.26	0.37	44	80	0.393	0.982		
	5	30	1.85	0.26	0.22	34	75	0.402	0.910		
	Av.	36.8	1.68	0.226	0.251	33	77.5	0.389	0.867		
D	1	44	1.20	0.17	0.13	24	76	0.382	0.890		
	2	40	1.49	0.19	0.14	33	77	0.385	0.912		
	3	30	1.75	0.22	0.17	36	77	0.369	0.898	67.7	51.2
	4	41	1.43	0.18	0.17	27	78	0.365	0.892		
	5	34	1.67	0.22	0.18	32	78	0.372	0.918		
	Av.	37.8	1.51	0.197	0.160	30	77.1	0.375	0.902		
E	1	42	1.34	0.18	0.17	18	75	0.376	0.744		
	2	36	1.27	0.18	0.13	13	76	0.369	0.724		
	3	42	1.19	0.20	0.16	27	74	0.387	0.874	63.4	51.2
	4	37	1.45	0.20	0.16	28	72	0.379	0.857		
	5	38	1.28	0.19	0.15	22	76	0.380	0.915		
	Av.	39.2	1.31	0.188	0.154	22	74.7	0.378	0.823		
Grand	av.	36.1	1.58	0.212	0.196	26	76.7	0.391	0.895	62.5	51.6

Table 4. — Summary of correlation coefficients information by geographic areas.[1])

Variables	A	B	C	D	E	Combined
Tree vol./age						
Ht./age	NS	(5)	(1)	(1)	(1)	0.560(1)
Form factor	(1)	(5)	(1)	NS	(1)	0.455(1)
Crown vol./age	NS	(1)	(1)	(1)	(1)	0.583(1)
D. B. H./age	(5)	(1)	(1)	(1)	(1)	0.694(1)
Fiber length	NS	NS	(1)	NS	NS	0.267(1)
OM	NS	NS	NS	NS	NS	0.331(1)
P	NS	NS	NS	NS	NS	-0.299(1)
Site index	(5)	(5)	(1)	(1)	(1)	0.779(1)
Ht./age						
Crown vol./age	(1)	NS	(1)	(1)	NS	0.477(1)
D. B. H./age	(1)	(1)	(1)	(1)	(1)	0.781(1)
Fiber length	(5)	NS	NS	NS	NS	0.321(1)
Age	-(1)	-(1)	-(1)	-(1)	-(1)	-0.735(1)
Clay	NS	(1)	NS	NS	NS	0.400(1)
P	NS	NS	NS	NS	NS	-0.329(1)
Site index	NS	(1)	(1)	(1)	(1)	0.857(1)
Form factor						
Age	NS	(1)	(1)	NS	NS	0.164(5)
Site index	NS	NS	NS	NS	NS	0.384(1)
Crown vol./age						
D. B. H./age	(1)	(1)	(1)	(1)	(1)	0.629(1)
Age	-(1)	NS	NS	-(1)	NS	-0.256(1)
Silt	-(1)	NS	NS	NS	NS	-0.296(1)
K	NS	NS	NS	NS	NS	-0.365(1)
Mg	NS	NS	NS	NS	NS	-0.360(1)
Total ex. bases	NS	NS	NS	NS	NS	-0.324(1)
Site index	NS	NS	NS	(1)	NS	0.580(1)
D. B. H./age						
Fiber length	NS	NS	(1)	NS	(1)	0.336(1)
Age	-(1)	-(1)	-(1)	-(1)	NS	-0.684(1)
Clay	NS	(1)	NS	NS	NS	0.318(1)
Site index	NS	(1)	NS	(1)	NS	0.655(1)
Sp. gravity						
Fiber length	NS	NS	(5)	(5)	(5)	0.318(1)
Sand	NS	NS	NS	NS	NS	-0.307(1)
Clay	NS	NS	NS	NS	NS	0.405(1)
K	NS	NS	NS	NS	NS	0.432(1)
Ca	NS	NS	NS	NS	NS	0.343(1)
Mg	NS	NS	NS	NS	NS	0.541(1)
Total ex. bases	NS	NS	NS	NS	NS	0.415(1)
"A" horiz. th.	NS	NS	(5)	NS	NS	0.341(1)
Fiber length						
Age	-(5)	NS	NS	NS	NS	-0.246(1)
Clay	NS	NS	(5)	NS	NS	0.344(1)
P	NS	NS	NS	NS	NS	-0.357(1)
Site index	NS	(5)	NS	NS	NS	0.287(5)

[1]) The correlation coefficients are not listed on an area by area basis, only the level of significance is given. NS = not significant, (1) = significant at the 1% level, (5) = significant at the 5% level.

The soils data were compared with the site index information. The percent clay and exchangeable bases which were correlated with the percent clay were the soil factors which contributed most to site differences. Examination of the correlations[3]) between soil properties, growth, and wood quality factors *(Table 4)* indicated that the clay content and the level of phosphorus appeared to be the soil properties that have the most influence on tree growth and wood quality. The clay content within geographic areas did not vary greatly and this resulted in nonsignificant within area correlations. When the data for all areas were combined, height growth, diameter growth, specific gravity, and fiber length increased with the percent clay content. The level of phosphorus was negatively correlated with the percent clay and positively correlated with the percent sand. As a result of this relationship, there developed a somewhat unexpected negative correlation between the level of phosphorus and such properties as tree volume growth, height growth, and fiber length.

Tree Growth

Height growth, diameter growth, tree volume growth, crown volume growth, and form factor were the growth characteristics compared. Height growth varied considerably between clones within stands, between stands within areas and as the analysis of variance calculations reveal *(Table 5)*, highly significant differences were obtained for all levels of comparisons including between area differences. Area B contained stands having the youngest average age and was the area that had the most rapid height growth. Area E, the area with the oldest stands, had the slowest height growth. Volume growth and diameter growth had patterns of variation very similar to height growth with the exception that between area differences for diameter growth were not statistically significant. Form factor also followed a similar pattern of variation with the exception that for all levels of comparison, the variation was less pronounced and the "F" values were significant only at the 5% level of probability.

Highly significant correlations were obtained between tree volume growth and height growth, diameter growth, form factor, crown volume growth, fiber length, and site index. Also of interest was the existence of the often re-

[3]) All possible correlations were run between the variables listed in *Tables 2 and 3*. The correlations were run on an area by area basis and then again using all data combined. All "soil characteristic by soil characteristic" correlations have been omitted and only those correlations in which a highly significant correlation was obtained using the combined data and/or at least two of the area correlations were highly significant are presented in *Table 4*.

Table 5. — Summary of F values used in examining variation between clones, stands within areas and areas.[1])

Source of variation	D.F.[2])	Age	Ht./age	D.B.H./age	Tree vol./age	Crown vol./age
Areas	4	1.36(NS)	4.38(5)	2.19(NS)	6.13(1)	4.54(1)
Stands within areas	20	5.43(1)	3.95(1)	4.29(1)	2.80(1)	1.80(5)
Clones within stands	50	11.5(1)	8.66(1)	4.99(1)	3.89(1)	2.99(1)
Source of variation	**D. F.[2])**	**Form factor**	**Sp. gr.**	**Fiber length**	**Yield, %**	**Zero-span tensile strength**
Areas	4	3.21(5)	15.4(1)	4.47(1)	1.09(NS)	6.54(1)
Stands within areas	20	2.24(5)	0.0(NS)	4.39 (1)	—	—
Clones within stands	50	1.43(5)	2.37(1)	3.03(1)	1.65(NS)	2.04(NS)

[1]) F values provide information on the existence of significant difference between areas; stands within areas and clones within stands. NS = not significant, (1) = significant at the 1% level, (5) = significant at the 5% level.
[2]) The degrees of freedom for yield, % and zero-span tensile strength are: Areas — stands within areas — 0, and clones within stands — 10.

Table 6. — Summary of multiple range tests.[1])

Height growth, ft./yr.		Volume growth, cu. ft./yr.		Specific gravity, g./cc.	
B	1.84	C	0.251	A	0.420
C	1.68	B	0.246	B	0.392
A	1.54	A	0.172	C	0.389
D	1.51	D	0.160	E	0.378
E	1.31	E	0.154	D	0.375

Fiber length, mm,		Fiber strength, lb,/in.	
A	0.950	D	67.7
B	0.931	C	64.4
D	0.902	E	63.4
C	0.867	A	60.8
E	0.823	B	56.0

[1]) Methods used are those described by DUNCAN (1955). The area means that are joined by the line at the right do not differ statistically (5% level of probability).

ported negative correlation between the age of the stands and height and diameter growth.

Wood and Fiber Properties

Specific gravity and fiber length at age thirty were determined for forty-five trees in each area. *Table 3* illustrates the between area and within area variation encountered. Examination of the fiber length data indicated there were highly significant differences between clones within the stands, between stands within the areas and between areas. Despite these differences no well-defined geographic trends in fiber length were evident. Areas A and B, which had soils with the highest amount of clay and the lowest levels of sand, had the longest average fiber length. The average fiber length for the northern areas suggests there is an east-west fiber length trend. The multiple range test for the area means also indicates that the area means presented differed significantly. Variation between the stands within Area C, however, seems to indicate that this trend may be a chance occurrence. The highly significant fiber length-tree growth correlations[4]) and the height growth-soils correlations suggest that the east-west fiber length trend is due to soil differences. The highly significant F value for clones within the stands indicates genetic variation and the importance of genetic influences on geographic trends. Fiber length (age 30) was correlated with height and diameter growth and factors influencing tree growth, thus suggesting the possible overriding influence of local site quality and genetic factors on geographic trends.

Specific Gravity

The specific gravity of the aspen stands studied varied considerably between clones within the stands while the variation between stands within the areas was relatively small. The analysis of variance calculations (see *Table 5* for F test results) indicated there were highly significant differences between areas and between clones within stands and no significant difference between stands within areas. For specific gravity there appears to be a south to north trend of decreasing specific gravity and the multiple range test of treatment means *(Table 6)* indicated Area A (specific gravity 0.420) represented one population, Area B (specific gravity 0.392) and Area C (specific gravity 0.389) were a second population, and Areas D (specific gravity 0.375) and E (specific gravity 0.378) were from a third population. Specific gravity, although not correlated with soil properties on a within area basis, was correlated when all of the data were combined and a larger overall variation in soil properties and specific gravity values were involved. Soils no doubt contribute to the geographic trend noted in specific gravity but the fact that the soils differ from stand to stand within geographic areas without a complementary significance between stand variation in specific gravity suggests that other climatic factors are in operation. The lack of significant specific gravity-tree growth correlations suggests less dependence of specific gravity on growth rate and site quality than seems to be the case for fiber length.

[4]) Fiber length was significantly correlated with height growth, diameter growth, and tree volume growth.

Fiber Strength[5]) Pulp Yield and Permanganate Number

Increment core samples from one stand in each geographic area were pulped using the discussed micropulping procedure. Although the data do not permit testing for stand-to-stand variation within areas, a measure of within stand and between area differences was obtained. Zero-span tensile strength was found to differ significantly (1% level) between areas but not between clones within areas. Yield of pulp failed to differ significantly either between clones within stands, or between geographic areas. The multiple range test of the area means for fiber strength indicated fiber strength values were similar for Areas C, E, and A and the significant differences between areas resulted from Area B and Area D differences. No geographic trends appeared to exist in fiber strength values.

The data on the forty-five trees that were pulped were combined and all possible simple correlations were calculated between fiber strength, pulp yield, fiber length, specific gravity, tree volume growth, diameter growth, height growth, crown volume growth, and age. *Table 7* summarizes all significant correlations between fiber strength, pulp yield, and permanganate number and the other growth characteristics listed. The correlations between the several growth characteristics described above were of the same magnitude as listed earlier in *Table 4* and were not repeated in *Table 7*.

Zero-span tensile strength was found to be negatively correlated with pulp yield, specific gravity, diameter growth, and volume growth. These results are in agreement with an earlier study on triploid quaking aspen, EINSPAHR, *et al.* (1963) and suggest the necessity for independent selection of trees with high fiber strength within those trees exhibiting rapid growth and satisfactory specific gravity. Absent is the fiber length-fiber strength correlation reported in the above triploid quaking aspen study. The nature and method of obtaining the age thirty fiber length

[5]) Zero-span tensile strength measurements, as indicated earlier, are interpreted as a measure of fiber strength and the two terms have been used interchangeably in this report.

Table 7. — Significant correlations of pulping data.

Variables		r Values[1])
Zero-span tensile	Pulp yield	—0.489(1)
	Permanganate no.	—0.437(1)
	Specific gravity	—0.385(1)
	D. B. H./age	—0.295(5)
	Tree vol./age	—0.384(1)
Pulp yield	Tree vol./age	0.323(5)
Permanganate no.	Tree vol./age	0.377(5)

[1]) Correlation coefficients followed by the levels of significance (1) = 1% level, (5) = 5% level.

values apparently resulted in the anomalous results described[6]).

Base Lines for Judging Tree Growth and Wood Quality

Standards or "base lines" with which to compare wood properties and growth characteristics of individual trees are necessary if the forest geneticist is to properly select individual trees to be used in tree improvement work. One of the objectives of this study was to provide data that could be used in establishing base-line information for quaking aspen. Of particular interest was the establishment of base lines for comparing the specific gravity, fiber length, fiber strength, and growth rate of selected trees with the average of the population from which the trees were selected. The analysis of variance and the comparisons of geographic area means revealed that for a single property or characteristic, because of the differences between geographic areas, several base lines were required. Calculations of the base-line curves for all important growth, wood, and fiber properties are under way and three examples are included for illustration purposes. The procedures used consisted of plotting the selected property over age, calculating the least squares regression line for the data and then calculating the statistical zones of one and two standard deviations above and below the mean value. The data in the illustrations required the use of the linear regression procedure while for certain data curvilinear regression calculations may be required. When significant linear or curvilinear relationships do not exist, a mean value for the population and the standard deviation of the mean can be used for comparison purposes.

Figures 2, 3, and 4 illustrate base-line curves for height growth, specific gravity, and age thirty fiber length. The solid line is the average for the data and the dashed lines are one and two standard deviations above and below the average data. By plotting the information for an individual tree over the age of the tree an indication is obtained of how this tree ranks in relation to the other trees in the population.

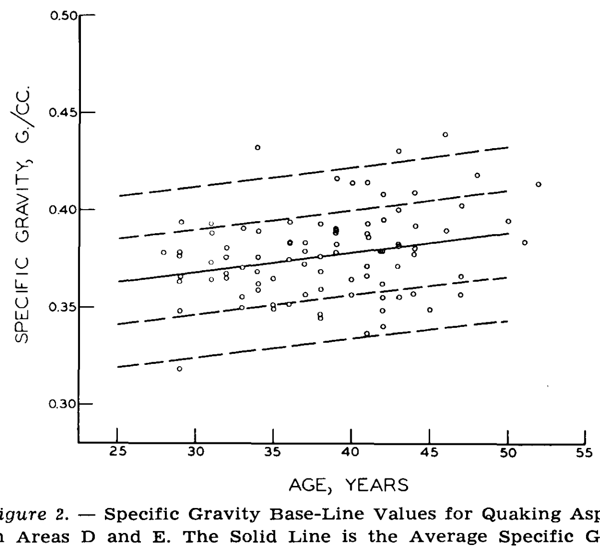

Figure 2. — Specific Gravity Base-Line Values for Quaking Aspen in Areas D and E. The Solid Line is the Average Specific Gravity. The Dashed Lines Are One and Two Standard Deviations Above and Below the Average Values.

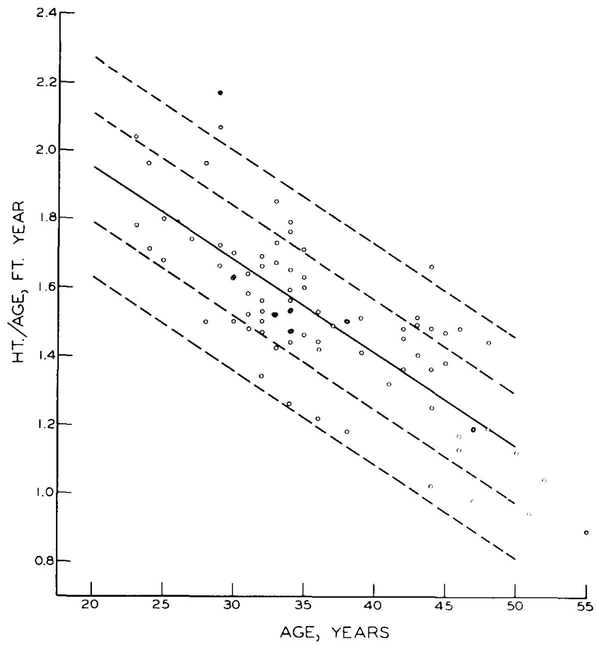

Figure 3. — Height Growth Base-Line Values for Quaking Aspen in Areas A and D. The Solid Line is the Average Height Growth and the Dashed Lines Are One and Two Standard Deviations Above and Below the Average Height Growth (Ht./Age).

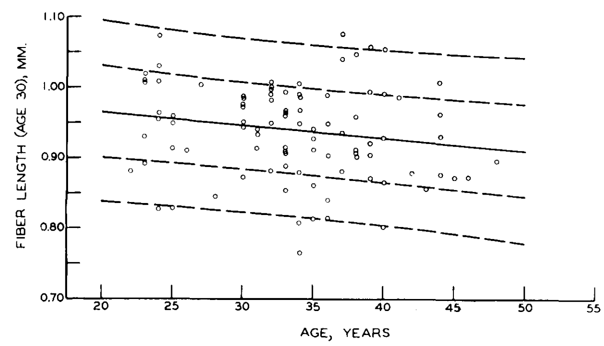

Figure 4. — Fiber Length at Age 30 Base-Line Values for Quaking Aspen in Areas A and B. The Solid Line is the Average Fiber Length and the Dashed Lines Are One and Two Standard Deviations Above and Below the Average Values.

Comparison of fiber length at some standard age is extremely useful and requires the measurement of fewer fibers. A family of harmonized curves, similar to those used by foresters for calculating site index, was used to adjust the fiber length to age 30. This procedure is something of a compromise because previous experience with individual trees demonstrated that there were differences between trees in the initial fiber length and the slope of the fiber length age curve. Fiber length-height growth correlations suggest reasons for the differences between trees. The negative age 30 fiber length-age trend, although significant at only the 6 to 7% level of probability, seems to indicate that the curves used to adjust fiber length to age 30 were overcorrecting for the older aged trees. When unadjusted fiber length-age correlations were calculated for the data used in the base-line illustration *(Figure 4)*, there was the expected highly significant positive correlation between fiber length and age.

[6]) In the earlier fiber length-fiber strength comparisons (Einspahr, *et al.*, 1963), fiber length measurements were based upon the pulp samples used in making the zero-span tensile strength handsheets, while in this study separate increment core samples were used to obtain the age 30 fiber length data.

When zero-span tensile strength was plotted over age, it was obvious that the age range of the trees used was extremely narrow (32—44 years) and that satisfactory age-related base lines could not be established. Considerable zero-span tensile strength variation existed between trees of the same age and these data are an example in which the area mean values and the standard deviation from the mean should be used as a basis of comparison. Zero-span tensile strength values for Areas D, C, and E were considered to be from the same population and a common mean and standard deviation was calculated for use as a base line ($X = 65.2$ and $s = 4.1$).

Summary and Conclusions

Natural quaking aspen stands in five geographic areas were measured, wood samples obtained, and soils data taken as part of the experimental procedure. The results of a statistical comparison of the data indicated that there existed a well-defined south-to-north trend of decreasing specific gravity. No geographic trend was evident for fiber length, fiber strength, pulp yield, or any of the tree growth characteristics.

The percent clay and the exchangeable bases which were correlated with the percent clay were the soil factors that appeared to have the most influence on tree growth. Fiber length was correlated with height and volume growth and several soil properties. The lack of geographic trend in fiber length seems to have resulted from the overriding influence of genetic and local site factors. The positive correlations of fiber length to specific gravity, height growth, and volume growth, simplifies the selection of these important properties for genetic improvement. The negative correlations of fiber strength with specific gravity, tree volume growth, and diameter growth suggest the need for independent selection for this property.

The data collected on growth and wood quality provided suitable information for establishing "base lines" for judging the potential of selected trees. Highly significant differences were obtained between clones within stands and stands within areas for a number of important growth and wood properties. Such differences are encouraging and suggest properties in which genetic variation is sufficient to warrant consideration as properties to emphasize in a tree improvement program.

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Chiasma Frequency in Pinus roxburghii Sarg. and P. elliottii Engelm.

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(Received for publication June 16, 1966)

Sax and Sax (1933) reported a detailed study of chiasma frequency at meiosis in microspore mother cells in 22 species of conifers belonging to *Taxaceae* and two sub-families of *Pinaceae*. Among the pines the study was confined to only five species of *Pinus* viz., *P. banksiana*, *P. jeffreyi*, *P. nigra*, *P. strobus* and *P. thunbergiana*. Later Sax (1960) studied meiosis in interspecific hybrids involving Himalayan, Japanese and American species of white pine. He concluded that though these species were geographically separated for very long period, they appeared to be similar in chromosome constitution and genetic compatibility. Mergen *et al.* (1963) studied microsporogenesis in *P. echinata* Mill. and *P. taeda* L., but chiasma frequency in these species was not reported. The objective of the present study was to determine the chiasma frequency in two species of *Pinus*, viz., *P. roxburghii* Sarg. (Chir pine) and *P. elliottii* Engelm. (Slash pine), a pine introduced in Dehra Dun from the U. S. A.

Two trees for each species were chosen and the male strobili were prefixed in Carnoy's fluid (6 : 3 : 1) for two