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GROWTH INTERCEPT METHODS FOR PREDICTING SITE INDEX IN WHITE PINE PLANTATIONS

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Growth Intercept Methods for Predicting Site Index in White Pine Plantations[1]

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INTRODUCTION

Eastern white pine (*Pinus strobus* L.) has a limited natural range in Ohio, occurring as individual trees and in small stands at scattered locations, primarily in the eastern part of the state (4). However, growth of white pine is good on a wide variety of sites in Ohio, and it has been the species most extensively planted for reforestation since the advent of wide scale planting in the early 1930's.

Information is not available detailing the total area planted with white pine in Ohio. However, surveys of pine plantings have been made in two areas by the Ohio Department of Natural Resources (ODNR). Of some 11,000 acres planted up to 1960 in an eight-county area of east central Ohio, a high proportion was white pine (12). In the five-county Buckeye Hills Resource Conservation and Development Area in southeastern Ohio, approximately 6,000 acres of pine had been planted up to 1968, with more than 56% of volume in those stands being white pine. In addition, it was estimated that an additional 6,000 acres of pine (percent white pine not specified) had been planted in that five-county area from 1968 to 1978 (13). In the period 1961 to 1980, nearly 63 million white pine seedlings were sold by nurseries operated by the ODNR to land owners for planting throughout Ohio (14).

Information on growth of white pine in relation to changing site conditions in Ohio is limited. Studies in other areas indicate considerable differences in growth on areas of varying site quality. Thirty-five year site indices for natural white pine stands in New England ranged from approximately 35 to 55 feet (8), while in the Lake States they ranged from approximately 27 to 56 feet (9). Growth of white pine plantations in the southern Appalachians was considerably better, with 35-year site indices of approximately 49 to 98 feet (15).

Cumulative length of three or more annual height growth internodes beginning at or near breast height (BH) can be used to predict site quality in young stands for which annual height growth can be accurately determined. This technique, generally termed the growth intercept method,

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[1]Research reported here is based in part on work reported earlier by the authors (5).

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has a number of advantages: 1) it can be used to evaluate site quality in stands too young for use of conventional site index curves; 2) it can be measured easily and rapidly; 3) it eliminates the need to measure total tree age and height; and 4) by confining measurements to internodes above breast height, variation associated with slow growth during the establishment period can be reduced or eliminated (1).

Growth intercept techniques have been particularly useful for predicting site index in red pine *(Pinus resinosa* Ait.) stands. Ferree and others (7) and Day and others (6) found that 5-year height growth beginning with the first year above BH accurately predicted site quality in young red pine stands in New York, and in Michigan and Ontario, respectively. Gunter (10) extended the work of Day and others to stands of red pine which had undergone suppression by using 5-year growth beginning 1 year after release of stands by intermediate cuttings. Alban (1, 2) found that measuring the 5-year intercept beginning at 8, 10, or 15 feet above the ground resulted in significantly better prediction of 50-year height of red pine stands than starting the growth intercept at BH. In natural, even-aged stands of white pine in the southern Appalachians, Beck (3) found that in stands less than 15 years of age, estimates of site index from 5-year intercepts beginning at BH were as accurate as estimates made from polymorphic site index curves.

Purposes of the study reported here were: 1) to develop growth intercept methods for predicting site quality in white pine stands planted on old-field sites in Ohio; and 2) to develop modified growth intercept techniques for estimating site quality in white pine stands by combining easily measured soil and/or topographic factors with growth intercept measurements.

METHODS

Data for this study were collected as part of an investigation of relationships between soil and topographic factors and growth of eastern white pine in stands planted on old fields in the residual soils region of southern and eastern Ohio. A total of 148 plots, each containing three to five dominant and/or codominant trees (free of insect and disease damage, snow or ice breakage) were measured. A full range of topographic conditions was represented in the sample. Soils on plots were well and moderately well drained. Few stands in the sample area were found growing on poorly or somewhat poorly drained soils and trees growing on such soils were excluded from the study.

For trees on each plot, total age was determined from plantation records and age at BH was determined from increment cores. Only plots on which trees were 25 years or older at BH were used. Total age of trees from planting ranged from 29 to 50 years. Age at BH ranged from 25 to 43 years and averaged 33 years for all plots. Total height, height at 25 years from planting, and height for 25 years beginning with the BH annual increment were determined using a Spiegel Relaskop. Individual height internodes for the 12 annual increments beginning at BH and above were measured to the nearest 0.1 foot using a telescoping fiberglass rod.

For each plot, aspect, slope shape (even, convex, or concave), slope percent, total slope length, length of slope above plot, and slope position (percent distance from ridge) were determined. Soil profile descriptions were made using averages from two soil pits dug on each plot.

Data were analyzed using averages for the 3- to 5-tree plots as items. Correlation, simple linear regression, and/or multiple linear regression analyses were used to test relationships between height and: 1) years to reach BH; 2) various combinations of 3 to 10 annual height increments; and 3) selected 3- to 10-year height increments in combination with selected soil and/or topographic factors.

RESULTS AND DISCUSSION

Early Height Growth: From 4 to 11 years were required for individual trees on plots to reach BH after planting, and plot averages ranged from 4.7 to 7.2 years. Time required to reach BH showed little correlation with total height ($r = -0.006$), or 25-year height based on 25 years growth after planting ($r = 0.125$), or 25 years growth above BH ($r = 0.119$). This indicates that factors such as planting stock quality, planting method, vegetative competition, insect and animal damage, etc. which may influence establishment and early growth of seedlings are not closely related to site conditions which affect later growth. Similar results have been found in a number of other studies (1, 6, 7, 11, 16). Inclusion of height and age data from below BH introduces an unrelated error into site index estimates, and that error is most serious in estimating site index in younger stands. In sections that follow, **site index estimations will be based on height and age for growth from the base of the BH increment to the growing tip.**

Site Index Estimations Based on 3-, 5-, and 10-Year Growth Intercept Measurements: Six combinations each of 3, 5, and 10 annual increments were tested for relationships to actual heights of trees on plots for 25 years' growth beginning at BH (the maximum age for which heights were available for all plots). Simple correlations between individual 3-, 5-, or 10-year growth intercepts generally increased significantly as the base of the intercepts was moved upward from the BH increment to the first and second internode above BH (Figure 1). There was little change in correlation values when the base of intercepts was

FIG. 1.—Illustration of points on white pine stem used in estimating site index based on 3-, 5-, or 10-year growth intercept measurements: a = base of breast high (BH) annual height increment, b = BH annual height increment, c = first annual height increment above BH increment, d = base of second annual height increment above BH increment, and e = second annual height increment above BH increment.

begun three, four or five internodes above BH. Similar results were noted by Alban (1, 2).

Based on these results, Equations 1, 2, and 3 listed in Table 1 were developed using the length of 3, 5, and 10 height growth internodes beginning two increments above BH (Fig. 1, point d) in combination with age at BH (Fig. 1, point b) and height from the base of the BH internode (Fig. 1, point a) to the growing tip. Although these equations could be used to compute estimated site index values for any base age, they can be used most accurately for ages within the range of ages of trees sampled in the study. Accordingly, Equations 1, 2, and 3 were used to compute estimated site indices for white pine using a 35-year base age for 3-, 5-, and 10-year growth intercepts within the range of actual intercepts sampled in the field. These site index values are presented in Table 2. The range of values (57 to 89 feet) listed in Table 2 compares favorably with 35-year site indices (based on total height and age) reported by Vimmerstedt (15) for white pine plantations in the southern Appalachians (49 to 98 feet). They are considerably higher than 35-year site indices (based on total height and age) reported for natural stands by Frothingham (8) in New England (35 to 55 feet) and by Gevorkiantz and Zon (9) in the Lake States (27 to 56 feet).

Accuracy of height predictions increases consistently as the number of years included in the growth intercept increases, as can be noted for the r^2 values (which represent the proportion of height growth accounted for by equations) and standard errors (se) for Equations 1 to 3. Thus, in using Table 2, the maximum possible number of annual increments should be included for the purpose of estimating site index. However, availability of 3- and 5-year growth intercepts permits estimation of site index in very young plantations: from 5 to 7 years after trees reach BH.

Site Index Estimations Based on 3-, 5-, and 10-Year Growth Intercepts in Combination with Selected Topographic and/or Soil Factors: A number of topographic and soil factors were tested in combination with growth intercepts for estimating site index in white pine stands. Two factors, slope position (percent distance from ridge) and total soil depth, added significantly to regressions and provided the greatest increases in precision of prediction equations. Equations 4 to 12 in Table 1 were developed combining 3, 5, and 10 growth increments beginning 2 years above BH with slope position and/or total soil depth for predicting height growth of white pine. As may be noted by r^2 values and standard errors, precision was improved consistently as the number of internodes included was increased and topographic and soil data were added to equations. When slope position was added to growth intercept, r^2 values increased by 4 to 7%; when total soil depth was added, precision was increased by 1 to 7%. When slope position and total soil depth were included with 3-, 5-, and 10-year growth intercepts, r^2 values were improved to 0.75, 0.82, and 0.84, respectively.

Tables 3, 4, and 5 were developed using Equations 4 to 12 for estimating 35-year site index in white pine plantations. As noted above, most accurate site index estimates can be made using 10-year growth intercept in combination with slope position and total soil depth. However, inclusion of shorter internode lengths in combination with only slope position or total soil depth should also provide very acceptable site index estimates.

Reliability of Growth Intercept and Growth Intercept in Combination with Slope Position and/or Total Soil Depth for Predicting Site Index: The reliability of equations developed for predicting site index in white pine stands was tested in two ways. Average 25-year or total heights (from BH to growing tip) of trees on individual sample plots were compared with values computed using the different equations. All equations predicted 25-year or total heights within ± 5% of actual heights on more than 50% of plots, within ± 10% on more than 82% of plots, and within ± 15% on 93% or more of plots. In addition, data were collected for 53 check plots in stands throughout the study area representing approximately the same range of conditions found on sample plots. Actual 25-year and total heights were compared with computed values and all equations predicted heights within ± 5% of actual values for 40% or more of plots, within ± 10% on 69 to 78% of plots, and within ± 15% of actual heights on 87% or more of plots. In no case on either study or check plots did computed and actual heights differ by as much as 20%.

USE OF TABLES 2 TO 5 FOR PREDICTING SITE INDEX IN WHITE PINE STANDS

A number of factors should be considered to insure that good estimates of site indices of white pine stands are obtained when using Tables 2 to 5. First, the study on which those estimates are based was carried out in stands on well and moderately well drained soils in the residual soils area of southern and eastern Ohio. Accuracy of predictions for white pine stands growing in other areas or on somewhat poorly or poorly drained soils has not been tested.

It is important to obtain accurate measurements of the length of 3-, 5-, or 10-year growth intercepts to be used in making site index estimates. Lengths can probably be obtained most accurately by using a measuring rod such as that used in this study. If a Relaskop, Abney level, or similar instrument is used, measurements will be more accurate if the instrument is rested on top of a tripod or Jacob staff rather than hand held. For any given method of measurement, time required to make 3-, 5-, or 10-year intercept measurements will be approximately the same.

As noted previously, including as many height growth increments in height intercepts as possible will help to improve accuracy of height growth estimates. Additionally, inclusion of slope position and/or total soil depth will further improve the accuracy of site index estimates. Data collected should be representative of the area for which site quality estimates are to be made. Whether using 3-, 5-, or 10-year growth intercepts, measurements should be made and then averaged for several dominant or codominant trees (scattered throughout the stand) which have not been affected by suppression or damage which might affect height growth. A minimum of 5 to 10 trees should probably be used in smaller stands and possibly 10 to 20 or more (depending on size) in larger stands.

Tables 3, 4, and 5 contain slope position and/or total soil depth as factors used in estimating site index. Many stands may cover most of a slope and soil depth can vary greatly within each stand. Site index estimates will be most accurate if separate estimates are made for different portions of such stands. For example, a large stand stretching from ridgetop to bottom of the slope might be subdivided into three portions, upper, mid-, and lower slope, and estimates, including separate growth intercept measurements, made for each portion. If estimates are desired for the stand as a whole, growth intercepts should be made throughout the stand, and averages for those trees should be used in conjunction with the mid-slope position for estimating average site index. If Tables 4 and 5 containing soil depth are to be used, total soil depth should be determined at a number of locations: probably a minimum of three in smaller stands and possibly five to ten or more in larger stands, depending on size and variability.

Finally, Tables 2 to 5 present site index values on a 35-year base rather than the traditional 50-year base commonly used for estimating site quality for tree species in Ohio. Although this was done primarily because of the range of ages of trees sampled in this study, the 35-year site index values presented in Tables 2 to 5 reflect growth rates for white pine which can provide a variety of products with relatively short rotations. With proper management, it should be possible to produce adequate volumes of small dimension and/or "chip" products in 35 years or less on even the poorer sites. On better sites, height and diameter growth should be adequate to produce trees large enough to provide higher value sawlog-sized products with similar rotations. On study plots, 35-year old trees reached diameters up to 18 to 19 inches.

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TABLE 1.—Multiple Regression Equations Developed for Predicting Height of White Pine (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) Using Growth Intercept Singly and in Combination with Slope Position and/or Total Soil Depth.

Equation 1: $\log_e \text{Ht} = 4.48 - 21.82\ (1/\text{Age}) + 0.055\ (\text{3-Yr Growth Int})$
$r^2 = 0.62,\ se = 0.079$

Equation 2: $\log_e \text{Ht} = 4.28 - 21.74\ (1/\text{Age}) + 0.048\ (\text{5-Yr Growth Int})$
$r^2 = 0.73,\ se = 0.067$

Equation 3: $\log_e \text{Ht} = 4.16 - 22.67\ (1/\text{Age}) + 0.030\ (\text{10-Yr Growth Int})$
$r^2 = 0.79,\ se = 0.059$

Equation 4: $\log_e \text{Ht} = 4.44 - 20.78\ (1/\text{Age}) + 0.051\ (\text{3-Yr Growth Int}) + 0.00095\ (\%\ \text{Dist from Ridge})$
$r^2 = 0.69,\ se = 0.071$

Equation 5: $\log_e \text{Ht} = 4.26 - 20.88\ (1/\text{Age}) + 0.045\ (\text{5-Yr Growth Int}) + 0.00078\ (\%\ \text{Dist from Ridge})$
$r^2 = 0.79,\ se = 0.060$

Equation 6: $\log_e \text{Ht} = 4.15 - 21.88\ (1/\text{Age}) + 0.028\ (\text{10-Yr Growth Int}) + 0.00068\ (\%\ \text{Dist from Ridge})$
$r^2 = 0.83,\ se = 0.055$

Equation 7: $\log_e \text{Ht} = 4.47 - 21.85\ (1/\text{Age}) + 0.046\ (\text{3-Yr Growth Int}) + 0.0033\ (\text{Tot Soil Depth})$
$r^2 = 0.68,\ se = 0.075$

Equation 8: $\log_e \text{Ht} = 4.29 - 21.76\ (1/\text{Age}) + 0.044\ (\text{5-Yr Growth Int}) + 0.0018\ (\text{Tot Soil Depth})$
$r^2 = 0.76,\ se = 0.063$

Equation 9: $\log_e \text{Ht} = 4.17 - 22.63\ (1/\text{Age}) + 0.029\ (\text{10-Yr Growth Int}) + 0.0010\ (\text{Tot Soil Depth})$
$r^2 = 0.80,\ se = 0.059$

Equation 10: $\log_e \text{Ht} = 4.42 - 20.69\ (1/\text{Age}) + 0.040\ (\text{3-Yr Growth Int}) + 0.0011\ (\%\ \text{Dist from Ridge}) + 0.0037\ (\text{Tot Soil Depth})$
$r^2 = 0.75,\ se = 0.065$

Equation 11: $\log_e \text{Ht} = 4.27 - 20.81\ (1/\text{Age}) + 0.039\ (\text{5-Yr Growth Int}) + 0.00088\ (\%\ \text{Dist from Ridge}) + 0.0023\ (\text{Tot Soil Depth})$
$r^2 = 0.82,\ se = 0.056$

Equation 12: $\log_e \text{Ht} = 4.16 - 21.75\ (1/\text{Age}) + 0.026\ (\text{10-Yr Growth Int}) + 0.00074\ (\%\ \text{Dist from Ridge}) + 0.0016\ (\text{Tot Soil Depth})$
$r^2 = 0.84,\ se = 0.054$

TABLE 2.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) for White Pine Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH.

3-Yr Growth Intercept*		5-Yr Growth Intercept†		10-Yr Growth Intercept‡	
Length	Site Index	Length	Site Index	Length	Site Index
ft	ft	ft	ft	ft	ft
4	59	8	57	19	59
5	62	9	60	21	63
6	66	10	63	23	67
7	70	11	66	25	71
8	73	12	69	27	76
9	78	13	72	29	80
10	82	14	76	31	85
11	87	15	80	33	89
		16	84		
		17	88		

*Based on Equation 1, Table 1.
†Based on Equation 2, Table 1.
‡Based on Equation 3, Table 1.

TABLE 3.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) for White Pine Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH in Combination with Slope Position.

Intercept Length	Ridge	Upper	Mid	Lower	Bottom
	Slope Position (Percent Distance from Ridge)				
	0%	25%	50%	75%	100%
ft			site index, ft		
3-Year Growth Intercept*					
4	57	59	60	62	63
5	61	62	63	65	66
6	64	65	67	68	70
7	67	69	70	72	74
8	71	72	74	76	77
9	74	76	78	80	81
10	78	80	82	84	86
11	82	84	86	88	90
5-Year Growth Intercept†					
8	56	57	58	59	60
9	58	60	61	62	63
10	61	62	64	65	66
11	64	65	66	68	69
12	67	68	70	71	72
13	70	71	73	74	76
14	73	75	76	78	79
15	77	78	80	81	83
16	80	82	83	85	87
17	84	85	87	89	91
10-Year Growth Intercept‡					
19	58	59	60	61	62
21	61	62	63	64	65
23	65	66	67	68	69
25	68	70	71	72	73
27	72	74	75	76	77
29	76	78	79	80	81
31	81	82	84	85	86
33	86	87	88	90	91

*Based on Equation 4, Table 1.
†Based on Equation 5, Table 1.
‡Based on Equation 6, Table 1.

TABLE 4.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH in Combination with Total Soil Depth.

Intercept Length	Total Soil Depth, Inches				
	12	18	24	30	36
ft			site index, ft		
3-Year Growth Intercept*					
4	59	60	61	62	63
5	61	62	64	65	66
6	64	65	67	68	69
7	67	69	70	71	73
8	70	72	73	75	76
9	74	75	77	78	80
10	77	79	80	82	83
11	81	82	84	86	87
5-Year Growth Intercept†					
8	57	58	58	59	59
9	59	60	61	61	62
10	62	63	64	64	65
11	65	66	66	67	68
12	68	69	69	70	71
13	71	72	72	73	74
14	74	75	75	77	77
15	77	78	79	80	81
16	81	82	82	84	85
17	85	86	86	87	88
10-Year Growth Intercept‡					
19	60	60	60	61	61
21	63	63	64	64	65
23	67	67	68	68	68
25	71	71	72	72	73
27	75	76	76	76	77
29	80	80	81	81	81
31	84	85	86	86	86
33	89	90	91	91	91

*Based on Equation 7, Table 1.
†Based on Equation 8, Table 1.
‡Based on Equation 9, Table 1.

TABLE 5.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH in Combination with Slope Position and Total Soil Depth.

3-Year Growth Intercept*					5-Year Growth Intercept†					10-Year Growth Intercept‡				
Intercept Length	Slope Position	Total Soil Depth 12	24	36	Intercept Length	Slope Position	Total Soil Depth 12	24	36	Intercept Length	Slope Position	Total Soil Depth 12	24	36
ft		SI, ft			ft		SI, ft			ft		SI, ft		
4	Upper	58	61	63	9	Upper	59	61	62	19	Upper	59	60	61
	Mid	59	62	65		Mid	60	62	64		Mid	60	61	62
	Lower	61	64	67		Lower	62	63	65		Lower	61	62	63
5	Upper	60	63	66	10	Upper	61	63	65	21	Upper	63	63	64
	Mid	62	65	68		Mid	63	64	66		Mid	63	64	65
	Lower	64	67	70		Lower	64	66	68		Lower	64	65	67
6	Upper	63	66	69	11	Upper	64	65	67	23	Upper	65	66	68
	Mid	65	68	71		Mid	65	67	69		Mid	66	67	69
	Lower	66	69	73		Lower	67	68	70		Lower	67	69	70
7	Upper	65	68	71	12	Upper	66	68	70	25	Upper	68	70	71
	Mid	67	70	73		Mid	68	70	72		Mid	70	71	72
	Lower	68	72	76		Lower	69	71	73		Lower	71	72	74
8	Upper	68	71	74	13	Upper	69	71	73	27	Upper	72	74	75
	Mid	70	73	76		Mid	70	72	74		Mid	73	75	76
	Lower	72	75	79		Lower	72	74	76		Lower	75	76	78
9	Upper	71	74	77	14	Upper	72	74	76	29	Upper	76	77	79
	Mid	73	76	80		Mid	73	75	77		Mid	77	79	80
	Lower	75	78	82		Lower	75	77	79		Lower	79	80	82
10	Upper	73	77	81	15	Upper	74	77	79	31	Upper	80	82	83
	Mid	75	79	83		Mid	76	78	80		Mid	82	83	85
	Lower	77	81	85		Lower	78	80	82		Lower	83	85	86
11	Upper	77	80	84	16	Upper	77	80	82	33	Upper	84	86	88
	Mid	79	82	86		Mid	79	81	84		Mid	86	88	89
	Lower	81	85	89		Lower	81	83	85		Lower	87	89	91

*Based on Equation 10, Table 1. †Based on Equation 11, Table 1. ‡Based on Equation 12, Table 1.

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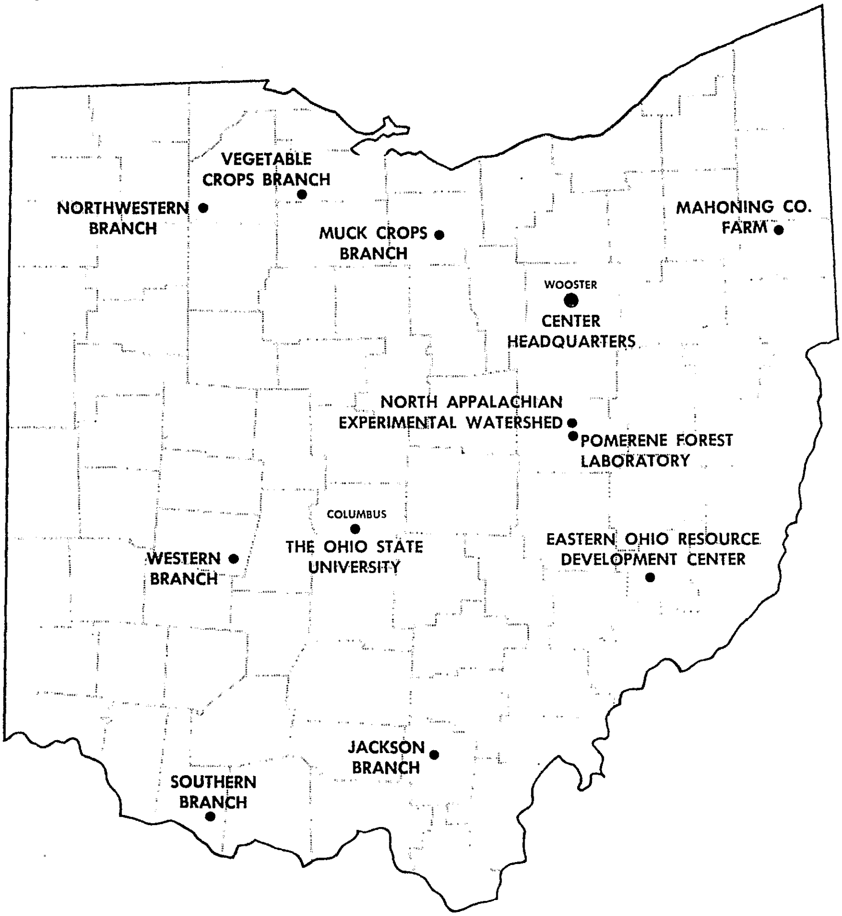

Ohio's major soil types and climatic conditions are represented at the Research Center's 12 locations.

Research is conducted by 15 departments on nearly 7,000 acres at Center headquarters in Wooster, eight branches, Pomerene Forest Laboratory, North Appalachian Experimental Watershed, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres

Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres

Jackson Branch, Jackson, Jackson County: 502 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Appalachian Experimental Watershed, Coshocton, Coshocton County: 1047 acres (Cooperative with the Science and Education Administration/Agricultural Research, U. S. Dept. of Agriculture)

Northwestern Branch, Hoytville, Wood County: 247 acres

Pomerene Forest Laboratory, Coshocton County: 227 acres

Southern Branch, Ripley, Brown County: 275 acres

Vegetable Crops Branch, Fremont, Sandusky County: 105 acres

Western Branch, South Charleston, Clark County: 428 acres