REVISING SOIL-SITE INFORMATION FOR BETTER USE BY FOREST MANAGERS

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Abstract.--Soil-site information is available for numerous commercial hardwood species of the eastern deciduous forests. Unfortunately this information is not being used to full potential. Research findings generally emphasize the final results as regression equations. Forest managers often lack the ability and confidence to measure the soil and site features needed to apply the equations. As a consequence useful soil-site information sits idle at a time when we need to combine site information with intensive silvicultural practices to meet present and future demands for wood.

High investments in site quality research justify assigning portions of a researcher's time to revising soil-site data for better use by the field forester. An example of how soil-site information can be revised is explained. A site quality map using the explained methods is presented for a small forest in southern Indiana. Site maps like this one can be revised or refined following field inspection and when tree site index is obtained. Creation of site quality maps could help put into use the vast quantity of site information presently available for many of our important species, both hardwood and conifers.

Additional keywords: Site quality, site mapping, hardwood site.

INTRODUCTION

The eastern hardwood forest cover types are being recognized again as a valuable resource and receiving renewed attention in research and management. We can recognize four general eastern hardwood areas: the central states and plains hardwoods dominated by oaks and hickories, the northern hardwoods in the Lake States, southeastern Canada and our northeastern United States, the Allegheny and Appalachian hardwoods, and the southern bottomland hardwoods. Most species that produce commercial log-size stems have a use and some are exceedingly valuable. Collectively the fifty or more commercial species found have many uses: veneer, furniture, flooring, turning stock, cooperage, chemical wood, etc.

Examples of intensive silviculture and management of our hardwoods are not abundant, these practices are still evolving. Supply and demand have for a long time dictated cutting only the best or highest value marketable

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trees. As a result of long-term application of this silviculture-management approach, we have aggregated a high proportion of low grade, cull or rough and rotten trees in our stands. The status of many stands is such that we are uncertain about the productive potential of many sites as there are few good trees and stands to make comparisons.

Foresters say we must know site quality -- the potential to produce biomass, or to produce good quality trees in order to make appropriate and effective silvicultural recommendations and management decisions. Just how important site quality can be is demonstrated in yield tables. Schnur's (1937) composite tables for second growth upland oak indicate that for average sites (SI-60) yield is 15,650 ft. b.m./acre (Int. 1/8) at 80 years. On excellent sites (SI-80) the yield is 27,250 ft. b.m./acre. A greater proportion of better grade logs should also be obtained from the better site.

We admitted some time ago that there is an information gap on site quality for much of the eastern hardwood region. To fill this void a great deal of effort has been applied in studying site quality relationships for our eastern hardwood species. Carmean (1975) cites at least 30 studies dealing with eastern oaks and 35 or more dealing with various other eastern hardwoods. Carmean intensively studied the site relationships for oaks in southeastern Ohio yet the information derived is not extensively used. Hannah (1968) reported on soil and site relations for oaks in Indiana, and McQuilkin (1974) reported on oak site relations in Missouri yet this information is not extensively used. Broadfoot (1969) studied site relations for numerous bottomland oaks in the mid south, but again the findings are used little. The same story can be repeated for numerous other studies. In the northeast Post and Curtis (1970) studied site relations for northern hardwoods in the Green Mountains of Vermont. While their work is often cited and the site index curves are used, the site relationships are rarely applied.

In most of the studies cited depth of horizons, horizon texture, internal drainage, and topographic features like slope position, steepness, shape, and aspect are correlated with site index. These relationships are usually expressed in the form of regression equations.

HOW TO GET SOIL-SITE STUDIES USED

To a forester whose primary responsibility is local management and who has had little experience in using regression equations, this manner of expressing site quality can be overpowering. In addition applying the equations usually requires making soil measurements and the forester may lack knowledge and experience in this field. As a result the forester seeks other information, uses methods he is acquainted with, and other knowledge at hand. Even within the National Forest system the staff soil scientists often do not use current soil-site information; in some eastern forests for example, ecological land typing is being done to identify site quality for tree growth and for other land uses. Soil-site information is often not effectively integrated with this method.

Perhaps again soil-site information is presented in a way that makes its use difficult and thus it is set aside.

How can these attitudes towards soil-site information be changed to get the job of site evaluation done? I see two approaches - one is for the forest manager to become more informed about site evaluation methods and transform the data into workable forms for his region. The other approach is for researchers doing work in soil-site to take their work one step further and put it in a form that can be more readily applied by the forest manager. The researcher must in part act as his own extension agent. Research administrators must reassess the role of the researcher, his relation to his client, and determine how best to get the study information used.

In our current practice of sharing responsibility, scientists in research organizations and at universities and colleges discover new information and generate new ideas. Extension personnel disseminate the information; the manager applies it. If the information needs modification, it may fall through the cracks. The extension agents may modify some information but there are some complex areas where these specialists no doubt feel limited. The researcher may be the best person to fill this communication void, and with handsome payoffs in terms of better use of his product. In the case of site quality he knows his data and the region where it was derived and presumably is the best person to make a workable interpretation of it.

Site Quality Maps From Soil-Site Equations

One good way to get soil-site information used is to transfer it to a map. Site index or site quality should be mappable on the ground like forest cover types and soil types. If site quality is traceable or related to the soil and site factors as we hypothesize, then we should conversely be able to link it back to these factors. If we solve the equations for the situation as seen on the ground, a site index or site quality map can be produced. If the manager had such maps available, he could make more reasoned decisions about expected growth, silviculture and management activities, and alternate land uses.

Ralston (1958) and Zahner (1967) have demonstrated construction of site quality maps based on data obtained in soil-site studies. I used similar methods along with the soil-site equations of Post and Curtis (1970) to construct site quality maps for two parcels of state forest land in Vermont. These maps are now being used as part of a comprehensive management plan. Kihn (1979) derived a soil-site equation based on modification of the Post-Curtis equation for a 3,000-acre forest owned by the Windham Foundation in central Vermont. The equation was then used to construct a site quality map with data collected from 140 additional sample points in the forest. The site map is now being used in management, and in research planning. Soil-site equations for spruce and pine plantations in Vermont are being used to construct a site quality map for an 80-acre state forest in eastern Vermont. This forest is a unique example of plantations dating from 1913 being used to revegetate worn

out, wind-eroded farmland on sandy soils. Tree-site index and soil-site index can be easily compared in this situation to verify the equations. All of these projects have been done by students as part of the required or elected training in their academic forestry program. More areas will be mapped as time permits and hopefully will serve to demonstrate the value of site quality maps derived from soil-site equations.

A Detailed Example

Another example of how soil-site research can be brought into the mainstream of forest management can be demonstrated with a study from southern Indiana (Hannah 1968). The soil-site study was done for white and black oak in the Norman and Crawford upland regions in the unglaciated portion of the state. The final products of this study were regression equations relating site index for white oak and black oak to soil and topographic variables. Site index tables were also derived relating site index to the most important variables. This site information is being used on the Hoosier National Forest but is used very little on other forest lands. Site information in this and many other studies sits on the shelf after a vast expenditure of money and effort to produce it. The information must be converted from the equations to a more usable form.

To illustrate how a site quality map may be made with what appears to be rather complex soil-site data, I have used the soil-site equation for white oak (Table 1) to construct a site quality map for the U.S. Forest Service Research Forest near Paoli, Indiana (Fig. 1). The Paoli Forest is approximately 600 acres in size, has substantial diversity of soil and topography, and should have important site quality differences.

If we use this equation and insert values for the variables as measured at different locations in the forest, we generate for the map a scattering of point estimates of site index. If we envision these values as elevations on a map, much as we view point elevation measurements in producing a topographic map, we can connect or define isosite lines. With this procedure we can delineate zones that include narrow ranges of site index. This procedure in principle is similar to the one used for developing a topographic map.

Obtaining Site Map Information - Through A Field Survey

Information to construct a site quality map can be derived in two ways. One method is to plan a survey of the area and select a sampling scheme to obtain the needed soil and topographic information at appropriate locations. A line survey should be made with lines oriented to cross the contours. Lines should be spaced so that one can see half the distance to the adjacent lines and consider sampling any apparent site changes between the sample lines. Realizing that soil and site quality varies with topographic position, one should plan in his sampling scheme to obtain the essential measurements on ridges, upper, middle and lower slopes, on benches and on ridgetop and valley flats. If considerable

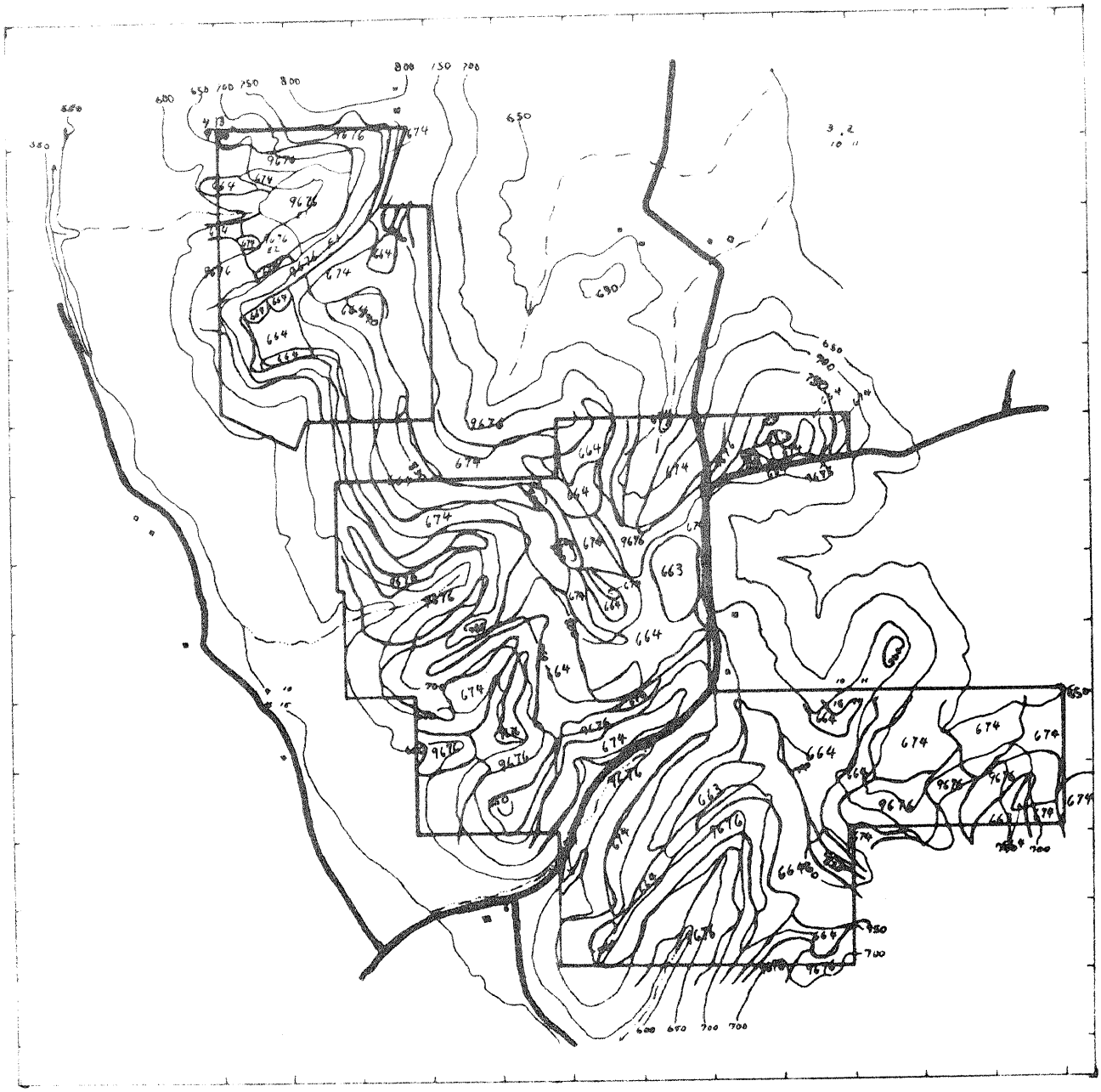

Figure 1. Topographic map of the Paoli Experimental Forest in Orange County, Indiana, supplemented with soil-series delineations as mapped by the Soil Conservation Service. (Soil series codes are: Tilsit-663, Zanesville-664, Wellston-674, Muskingum-9676).

Table 1. Soil-site equations and descriptions of variables in the Norman and Crawford Uplands, southern Indiana.

Soil-Site Equations for White Oak and Black Oak

White oak (126 plots): $R^2 = 0.84$

$$Y = 2.48209 - 12.42516/X_1 + 0.03026\,X_2 + 0.00110\,X_3 - 0.00114\,X_4 + 0.01751\,X_5 - 0.00383\,X_7 - 1.19984/X_7 - 0.00137\,X_8 - 3.19761/X_9 - 0.00082\,X_{10} - 0.00036\,X_{11} + 0.00010\,X_{12} - 0.00057\,X_{14} - 0.00010\,X_{15} - 0.00034X_{16} - 0.00097\,X_{17}$$

Black Oak (86 plots): $R^2 = 0.85$

$$Y = 2.68882 - 23.44295/X_1 - 0.00109X_1 + 0.03670\,X_2 - 0.18273/X_2 + 0.00126\,X_3 - 0.00524\,X_6 - 0.00076\,X_7 - 0.00108\,X_8 + 0.00035\,X_9 - 0.00056\,X_{11} - 0.00171\,X_{12} + 0.00050\,X_{13} - 0.00027\,X_{15}$$

Description of Variables for the Equations

Y = Logarithm of total tree height (feet)
X_1 = Total tree age
X_2 = Surface soil (A1 + A2 horizons) thickness (inches)
X_3 = Percent distance to ridge = (distance to ridge/length slope) 100
X_4 = [(sine azimuth from southeast) + 1] 100
X_5 = Slope shape (convex = 1; linear = 2; concave = 3)
X_6 = Slope steepness (%)
X_7 = Clay content of B2 horizon (%)
X_8 = Clay content of B3, BX, or C horizons (%)
X_9 = Silt content of B1 horizon (%)
X_{10} = Sand content of A2 horizon (%)
X_{11} = Stone content of B2 horizon (%)
X_{12} = $[(500 - 10{,}000/X_1)\ (100 - X_6)]\ 1/100$
X_{13} = $[(500 - 10{,}000/X_1)\ (X_3)]\ 1/100$
X_{14} = $[(500 - 10{,}000/X_1)\ (X_9)]\ 1/100$
X_{15} = $(X_2)\ (X_3)$
X_{16} = $[(X_2)\ (300 - X_4)]\ 1/10$
X_{17} = $[(300 - X_4)\ (100 - X_7)]\ 1/100$

variability is expected, a number of observations should be made within each physiographic position to derive a good average value for each soil and topographic features needed in the equation. Soil-site studies should ideally be finalized so that it is possible to measure the variables in the field with considerable ease. The need for additional complicated laboratory determinations should be avoided if possible. These are important concepts for researchers to keep in mind in expediting use of their equations. Basic knowledge of soils is obviously helpful to the practicing forester and most have this.

To obtain data for the Indiana equations, one should need only a soil auger, ruler, clinometer, compass and suitably designed field data sheets. With the auger one examines the soil profile and measures horizon thicknesses identifying them primarily by color change. Texture changes will also be apparent for some horizons. With some experience one can estimate the texture and approximate the proportions of sand, silt, and clay again by experience and by referring to a soil texture chart. Stone content can be determined by estimating the percent volume occupied in the designated horizon and doubling it to approximate stone content on a weight basis. This conversion is based on the assumption that average soil density is about 1.3gm/cc while average stone density is about 2.6gm/cc. Slope aspect can be determined with the compass and the sine value estimated from Table 2 or computed. Ridge positions or upland flats should be considered as having a north aspect. Slope position can be paced or approximated from topographic maps and slope shape can be easily judged as linear, concave or convex. This field information can be substantially supplemented and verified if soil maps and soil series descriptions are available for the area. At this stage soil-site information can be compared with site index-soil series information to strengthen the interpretations.

A survey for soil-site purposes can be linked to any planned timber inventory surveys. Soil-site information can be obtained on the timber inventory plots and supplemented at critical points along the survey line. If site index trees are measured on the timber inventory plots, comparisons can be made with the computed soil-site index and refinement made to achieve closer agreement and develop a more precise map.

Obtaining Site Map Information Without A Field Survey

As an alternate method when a thorough field survey cannot be planned, one can generate a workable map using the equations and other available printed information. Slope aspect, position and approximate steepness can be obtained from the topographic map. Slope shape can be considered linear on hillsides, convex on ridges unless they are clearly flat broad ridges, and concave for lower slopes. Soil maps and soil series descriptions can provide good estimates of horizon thicknesses, sand, silt, and clay proportions, and stone content. This information can be amended with any field experience one has in the area. Using these sources of information, one can use the relationships between soil types and topography to select positions where site index may be similar for a definable area but different from adjacent areas. The values can be plotted in their respective position on a map and zones of relatively uniform site index can be sketched in.

Since I was unable to return to the area and obtain soil and topographic data in the field, the site quality map presented for the Paoli Forest (Fig. 2) was constructed using the soil-site equation for white oak and information from the topographic map, soil map, and soil series descriptions. The site index 50 values are considered an average for the zone with a range of $\pm$ 5 feet. Site index was computed by setting age

Table 2. Corresponding sine of the azimuth values for 15° intervals ((as measured from the southeast) + 1x100) for true slope aspects.

True Azimuth	Sine of the Azimuth Computed from the Southeast (135°)	True Azimuth	Sine of the Azimuth Computed from the Southeast (135°)
0 and 360	29	180	171
15	13	195	187
30	3	210	197
45	0	225	200
60	3	240	197
75	13	255	187
90	29	270	171
105	50	285	150
120	74	300	126
135	100	315	100
150	126	330	74
165	150	345	50

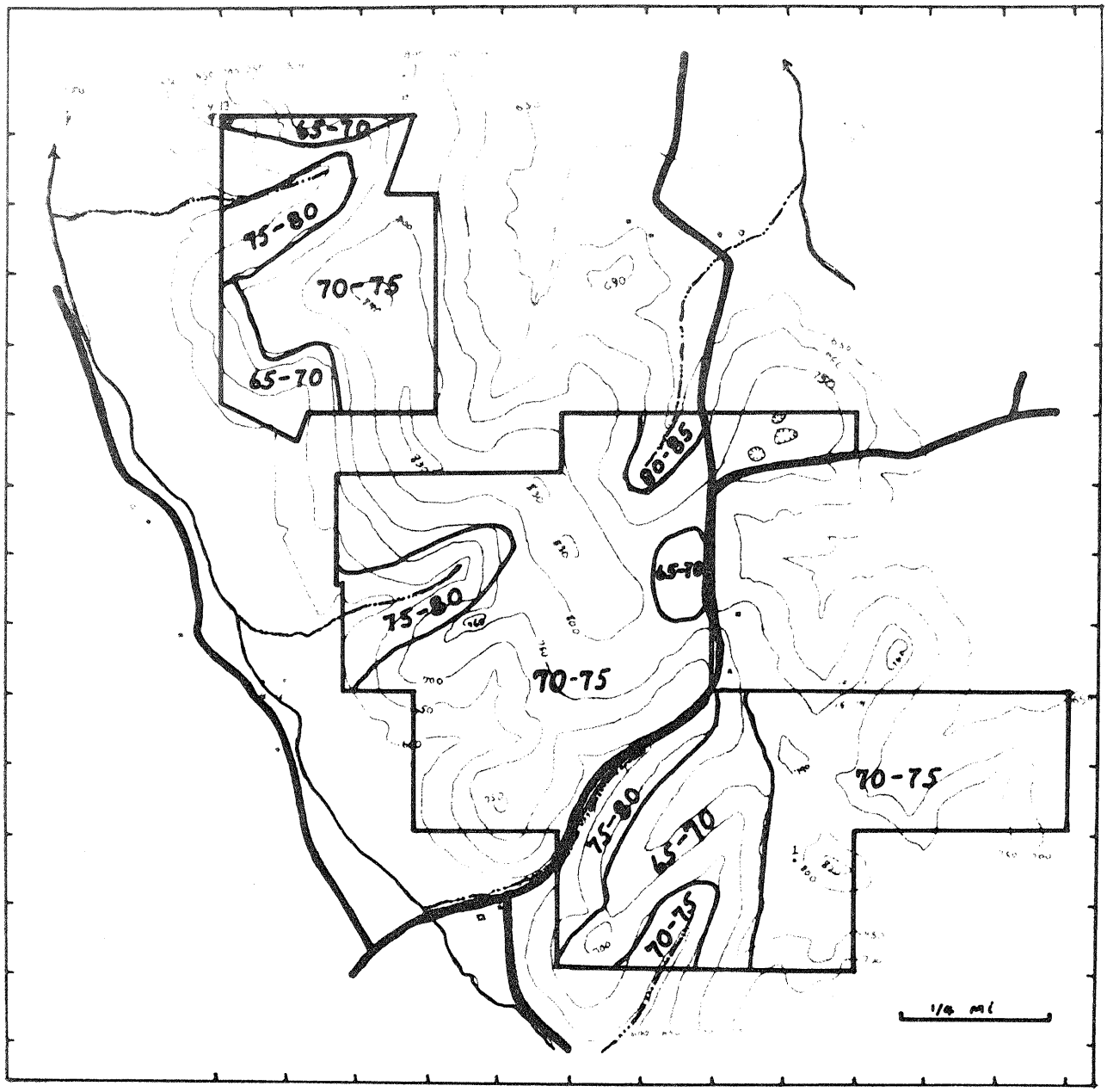

Figure 2. Topographic map of the Paoli Experimental Forest in Orange County, Indiana, showing computed site quality zones with a 10-foot range based on the soil-site equation for white oak derived by Hannah.

in the equation to 50 years. Since the equation is solved for Log 10 ht, the antilog value was then obtained indicating height in feet.

In solving this equation I called on prior experience on the forest and region and used other available data. Values for soil depth and soil texture expressed as percents of sand, silt and clay in the various horizons were obtained from published soil series descriptions. Percent stone content was estimated from series descriptions and prior experience. Average A horizon depth was used for upper slope and ridge positions and increased for lower slope and bottom positions. Slope positions for sample points were estimated using contour lines to identify the ridge and bottom. Slope aspect was determined from orientation of the contour lines. Percent slope steepness was assigned based on prior experience and judgements of closeness of the contour lines.

The selection of sample points was obtained by combining the soil map and contour map, searching across the general contour of the area, and selecting points representing different topographic positions on the various soil types. These points were marked on the map and site index computed. The array of points was studied and keeping in mind how site quality can change with soils and topography zones of similar site quality were extended from the sample points to identify a relatively uniform site area. The final result is the site map of Figure 2.

If a field survey is made to obtain data for site quality, more precise information can obviously be obtained. Slope position, steepness, aspect, and shape can be easily measured. Most of the soil information can be obtained using a soil auger. Published soils maps, soil series descriptions, and aerial photos will serve as useful supplements. The same general principal for sampling variations in soil and topography, computing site index, and drawing the map still apply.

Refinements In Making A Site Map

Most soil-site equations are not tested for accuracy of prediction with independent data. The method of map construction used in this example further involves generalizing and thus other inaccuracies can be introduced. Variations in soil characteristics from the modal soil series description for example cannot be easily incorporated. These variations can be minimized with an on-site survey. With either method of map construction it is important at some point to field check the map and determine how it agrees with tree site index or other measures of site performance. The map can then be revised where necessary to more accurately portray site quality differences. Field checking can be done by the mapper but the management forester should also be prepared to revise maps as new information is obtained.

In the example described here the white oak equation was solved for

60 different locations in the forest using a portable programmable calculator.[1/] If site quality maps were to be created for large areas, it would be a simple matter to write a program for the equation, specify a format for data input and have the site index values derived by a large computer. Computer capabilities are now available at many centers that permit digitizing the base map, computing and plotting the site index values on the map and sketching the site quality boundaries. This approach to production of site quality maps should be practical for federal, state and industrial forest management agencies. Other landowners can obtain access to and assistance with these services through forest consultants and computer service firms. While equipment is available to simplify the mathematical and cartographic operations, the methodologies I describe here remain about the same whether one completes the job on a small calculator or computer.

CONCLUSIONS

Methods presented in this paper demonstrate that soil-site information expressed as a regression equation with variables and coefficients that collectively look awesome can be utilized and put to work in the form of a site quality map. Like a soil map or a forest-type map, it may have some errors, and inclusions of higher or lower sites within a mapped site zone. With intensive surveying, field checking and revision these inclusions can be minimized or their magnitude reduced. The derived map should be considered an approximation and a guide to comparative site quality among various land parcels. Confidence in the map can be gained and refinements made as one obtains growth information following a period of management. The site quality map should provide a better estimate of the site situation than the less quantified judgments often used to answer the nagging question "What is the site quality." Site maps also serve as a permanent benchmark for future reference and comparison.

A good deal of site quality information is available in equation form and gathering dust. If we really need to know information on site quality of our forest areas, let's dust it off and put it into map form using methods similar to those described here. The methodology is not difficult. Soil scientists who produced the data should consider assisting in this knowledge transfer by creating site maps for demonstration areas and conducting training sessions for management foresters. Soil scientists with the U.S. Forest Service, the Soil Conservation Service and with other federal and state agencies and private industry should be up to the task of making this information applicable in the field.

[1/] Kenneth Signorello, a graduate student in Forestry at the University of Vermont prepared the calculator program.

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