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Use of a Land Classification System in Forest Stand Growth and Yield Prediction on the Cumberland Plateau of Tennessee, USA*

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美國 테네시州 컴벌랜드 高原의 林分 成長과 收穫 豫測에 있어서 Land Classification System의 使用*

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ABSTRACT

Much of the Cumberland Plateau of Tennessee, USA is in mixed hardwoods for which there are no applicable growth and yield predictors. Use of site index as a variable in growth and yield prediction models is limited in most stands because their history is not known and many may not be even-aged. Landtypes may offer an alternative to site index for these mixed stands because they were designed to include land of about equal productivity. To determine vegetation by landtype, dependency between landtype and detailed forest type was tested with Chi-square. Differences in productivity among landtypes were tested by employing regression analyses and analysis of variance(ANOVA). Basal area growth was fitted to the nonlinear models developed by Moser and Hall(1969). Basal area growth and volume growth were also predicted as a function of initial total basal area and initial volume with linear regression by landtype and by landtype class. Differences in basal area growth and volume growth by landtype were tested with ANOVA. Dependency between site class and landtype was tested with Chi-square.

Vegetation types seem to be related to landtypes in the study area although the validity of the test is questionable because of a high proportion of sparsely occupied cells. No statistically significant differences in productivity among landtypes were found in this study.

Key words : basal area growth, volume growth, growth and yield predictor, site class, vegetation type

요 약

미국 테네시주 컴벌랜드 고원의 대부분은 혼합 침엽수림으로 되어 있어 기존의 성장과 산출 예측 방식을 적용하기 어렵다. 또한 그들의 역사가 알려져 있지 않을 뿐더러 많은 부분이 동령림이 아니기 때문에 성장과 수확 예측 모델을 만드는데 있어서 지위지수를 변수로 사용하는 것이 제한되어 있다. 임지형(landtype)은 거의 같은 수확을 내는 임지를 포함하도록 고안되어 있기 때문에 이런 혼효림에서 지위지수 대신 사용될 수 있다. 임지형을 사용한 식생 결정을 위해, Chi-square로 임지형과 임형(forest type)과의 의존성을 검사하였다. 임지형 사이에서 수확의 유의성은 회귀분석과 분산분석을 이용하여 검사되었다. 흉고단면적성장(basal area growth)은 Moser and Hall(1969)이 개발한 비선형 모델에 적용되었다. 또한 흉고단면적성장과 재적성장은, 임지형과 임지형급(landtype class)에 의한 선

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형 회귀분석을 통해 최초 총 흉고단면적과 최초 재적에 관한 하나의 함수로서 예측되었다. 분산분석으로 임지형에 따른 흉고단면적성장과 재적성장의 유의성을 검사하였다. 지위급(site class)과 임지형의 유의성은 Chi-square로 검사되었다.

표본 강도가 낮아 검증이 의심스러웠음에도 불구하고, 식생형(vegetation type)은 연구 지역 내 임지형과 관계된 것으로 보인다. 본 연구에서 임지형 간의 수확은 통계학적인 유의성이 발견되지 않았다.

INTRODUCTION AND OBJECTIVES

Stand level yield modeling has been well developed for even-aged stands of a single species. However, much planning for forest management is concerned with mixed species stands with both even-aged and uneven-aged. Methods for predicting future yields in such stands should be developed to facilitate forest management planning (Lynch and Moser, 1986). Much of the Cumberland Plateau of Tennessee supports mixed hardwoods for which there are no applicable growth and yield predictors. Use of site index as a variable in growth and yield prediction models is limited in most of these stands because their history is not known and many are uneven-aged. Landscape units may offer an alternative to site index for these stands because they are designed to include lands of similar productivity.

A landtype is the smallest unit of the landscape recognized in a land classification system. Smalley(1982) delineated 20 landtypes for the mid-Cumberland Plateau. He described the geology, soils, vegetation, productivity and management problems expected within each landtype. Productivity information was drawn from a variety of published material and, in some cases, was extrapolated from information applicable to adjacent areas.

The objectives of this study were :

1. to determine vegetation type and productivity by landtypes.
2. to develop growth and yield predictors for mixed hardwoods on the Cumberland Plateau using landtype as a variable.

LITERATURE REVIEW

In timber management, growth and yield predictors are basic tools used by foresters to predict stand volume and density, usually by diameter class, at various ages using initial or intermediate stocking, and site quality class. Mortality and volume growth for a five or ten year period can also be predicted from the same stand variables(Rennie, 1991).

Yield tables have been the primary method used by forest managers to forecast harvest volumes. Traditionally, yield tables have been prepared for even-aged stands of individual species or species groups. However, yield tables are merely a theoretical standard to which an actual forest stand may be compared. Consequently, several problems exist in their application. Other more effective means may be needed for future forest management tasks(Society of American Foresters, 1984).

Yield equations have replaced traditional yield tables. They are obtained from the mathematical integration of growth-rate equations, expressed primarily as a function of stand age(Clutter *et al.*, 1983).

The Chapman-Richards growth model(Richards, 1959 ; Chapman, 1961) has been used to model forest growth(Turnbull, 1963 ; Pienaar, 1965 ; Pienaar and Turnbull, 1973). The model is derived from basic biological principles and has proven to be very flexible in application. Clutter *et al.* (1983) express these relationships symbolically as :

$$dY/dt = \alpha Y^{\beta} - \gamma Y \quad \text{.........} (1)$$

where Y = size of the organism, t = time, α, β, γ = constants($\alpha > 0$, $0 < \beta < 1$, $\gamma > 0$).

In uneven-aged stands, such as those on the Cumberland Plateau, stand age has obscure meaning which causes difficulty in applying yield functions. Moser and Hall(1969) developed a yield prediction model for uneven-aged mixed northern hardwood and oak-hickory stands in Wisconsin based on the Chapman-Richards function.

Examination of basal area growth-rate data resulted in selection of equation 2 from a derivative form of Von Bertalanffy's generalized growth-rate equation(Richards, 1959).

$$dB/dt = nB^{m} - kB \text{ ......} (2)$$

where B = initial basal area, t = time, n, m, k = constants

Equation 3 relates stand volume to basal area.

$$V = b_0 B^{b_1} \text{ ......} (3)$$

where V = initial net volume, b_0, b_1 = constants

Differentiating equation 3 with respect to time yields a relationship(equation 4) that represents stand volume growth rate.

$$dV/dt = (b_1 V B^{-1})(dB/dt) \text{ ......} (4)$$

Substituting equation 2 in equation 4 yields a predictor of stand volume growth in terms of initial volume and basal area(equation 5)(Moser and Hall, 1969).

$$dV/dt = b_1 V[nB^{(m-1)} - k] \text{ ......} (5)$$

Most forest land classifications have been developed based on physical features alone, on vegetation features alone, or on a combination of physical and vegetation features. The approach using both physical and vegetation features has been called in several ways such as the "ecological", "ecosystem", "biophysical", or "biogeoclimatic" approach(Pierpoint, 1984). The holistic approach of integrating the pertinent ecosystem components into a classification system was initiated by Krauss and developed and expanded by Schlenker(1964) and others(Mühlhäusser *et al.*, 1983).

An ecological classification system provides a hierarchical organization for describing the forest. This system offers operational advantages for both the information users and the resource specialists who collect the data(Nelson *et al.*, 1984). Ecological classification draws lines of differences and similarities between various geographic areas, thereby enhancing extrapolation from the research results(Russell and Jordan, 1991).

Smalley(1982 ; 1986 ; and 1991) adapted the Land System Inventory of Wertz and Arnold(1975) in developing a site classification system for the Interior Uplands. The system can be described as a process of successive landscape stratifications which were based on the author's knowledge of the interaction and controlling influences of ecosystem components. Landtypes are the most detailed level of a 5-level hierarchy. They are visually identifiable areas that have resulted from similar climatic, geologic, and pedologic processes(Smalley, 1991). Each landtype is described in terms of nine elements : geographic setting, dominant soils, bedrock, depth to bedrock, texture, soil drainage, relative soil water supply, soil fertility, and vegetation. Also, forest management interpretations of productivity, management problems, and desirable species are included for each landtype.

STUDY SITE DESCRIPTION

Physiography and Geology

The Cumberland Plateau is the southern portion of the Appalachian Plateau, which extends in a southwesterly direction from the southern New York to central Alabama, USA where it disappears beneath Coastal Plain sediments. The Plateau(Fig. 1) covers an area of about 11,137,000km^2 in Tennessee - nearly one tenth of the state (Luther, 1977). The Plateau rises 243.8 to 609.6m above the Ridge and Valley Province on the east and 243.8 to 304.8m above the Eastern Highland Rim on the west(Fullerton and Bernard, 1977). The Plateau gradually decreases in elevation from north to south(Miller, 1974). Elevation of the Plateau averages about 609.6m, with some peaks in the Cumberland Mountains exceeding 914.4m(Springer and Elder, 1980).

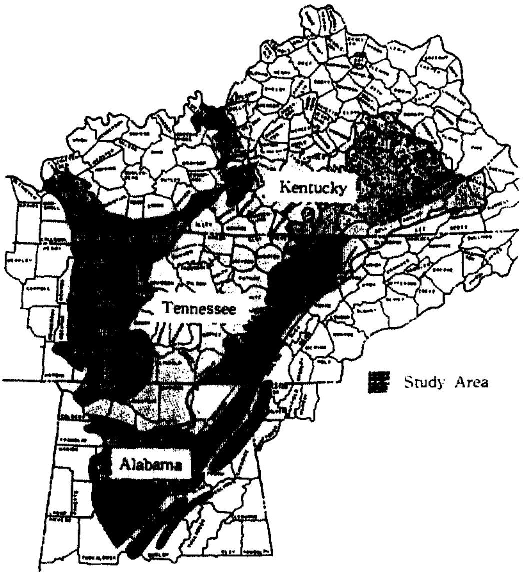

Fig. 1. Physiographic provinces and regions of the Interior Uplands in Alabama, Kentucky and Tennessee, USA(Smalley, 1982).

The Cumberland Plateau is capped by level-bedded, erosion-resistant Pennsylvanian sandstones, with more easily eroded Mississippian shales and limestones on lower slopes below the escarpment(Smalley, 1986). The Plateau has an undulating surface dissected by young valleys which become steeper and deeper toward the Plateau edges(Fenneman, 1938).

The topography of the southern Appalachian Plateau is due to deformation occurring as early as Precambrian time, and as recent as the last major episode(Allegheny orogeny) occurring near the end of the Paleozoic Era. Sediments collected along the eastern edge of North America were buckled and fractured into a long, high ranges of mountains(Miller, 1974).

The western-most deformations associated with the Allegheny orogeny occurred as thrust faults and bedding plane faults along the eastern side of the mid-Cumberland Plateau. These various geologic events were responsible for the major structural features associated with the eastern Cumberland Plateau such as the Cumberland Plateau overthrust fault, Crab Orchard Mountains and Walden Ridge, Cumberland Block, Sequatchie and Elk Valley(Luther, 1977 ; Miller, 1974).

Climate

The weather of the Cumberland Plateau is influenced by cold, dry continental air masses from Canada and warm, moist air from the Gulf of Mexico(Smalley, 1982). The mean annual temperature of the Plateau is mostly in the range of 12.2 to 13.9℃(Springer and Elder, 1980). The temperature often falls below freezing at night from December to February. The Plateau has relatively cooler temperatures than the adjacent Ridge and Valley, and Eastern Highland Rim provinces with an approximately -16.1℃ decrease for every 304.8m increase in elevation(Dickson, 1960).

Average annual precipitation of the Cumberland Plateau is about 1,498.6㎜ which is higher than in the Ridge and Valley Province(1,016 to 1,270㎜ /year). Precipitation is well distributed throughout the growing season in most years. Since the Plateau has orographic precipitation, the region sometimes receives more precipitation during dryspells than adjacent physiographic provinces(Dickson, 1960).

Due to cooler temperatures, less potential evapotranspiration, and more precipitation, soil water deficits are much shorter and less frequent on the Cumberland Plateau and in the Unaka Mountains than in other parts of the State for soils with the same available capacity(Springer and Elder, 1980). However, tree growth on the Cumberland Plateau is reduced due to insufficient soil moisture for periods of several days up to six times each growing season(Smalley, 1982).

Soils

Soils of the Plateau formed either directly from Pennsylvanian-sandstones, siltstones, and shales, or from materials weathered from them(Springer and Elder, 1980). Sandstone outcrops are common on the slopes and cliffs. Much of the Plateau remains in forest(Francis and Loftus, 1977 ; Springer and Elder, 1980). The soils are for the most part highly leached Utilsols belonging to siliceous, mesic families(Francis and Loftus, 1977). Soils vary from deep to shallow ; however, most are about 0.6 to 1.2m deep to bed rock, and are generally well drained, loamy, strongly acid, and low in natural fertility(Springer and Elder, 1980). Shortages of nitrogen, phosphorous and calcium commonly limit tree growth (Francis and Loftus, 1977). Physical and chemical soil properties have been shown to vary along aspect and slope position gradients(Franzmeier *et al.*, 1969).

METHODS AND MATERIALS

Data Collection

Tree and stand data used were provided by the Forest Inventory and Analysis Work Unit(FIA), Southern Forest Experiment Station(SFES), Forest Service, USDA. This unit is responsible for assessing the forest resources of over a hundred million acres of forest land in seven south central states(Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas), and Puerto Rico(May, 1989).

Description of Data

This study utilized two levels of data which were routinely collected by SFES FIA personnel. One is tree level data which consists of individual tree measurements. The other is plot (sample location) level data which contains plot description variables and data from the tree level preprocessed up to a "per acre" basis for each sample location(May, 1989). These two data sets were obtained for the same sample locations for 1980 and 1989.

One plot level variable, site class, described below, was used in the statistical analysis. Site class is based on potential yield in cubic feet per acre at culmination of mean annual growth in fully stocked natural stands(Todd, 1990).

For this study, FIA personnel also determined landtype(Smalley, 1982)(Table 1) for each point at sample locations on the Cumberland Plateau.

Statistical Analyses

Subsetting of the data

FIA provided 1980 and 1989 data for 399 sample locations in 16 Cumberland Plateau counties (Table 2).

Sample locations classified as having significant cutting or other disturbances or lacking a dominant landtype were removed from the data set. Only 329 sample locations had a single or

Table 1. Summary of landtypes and landtype codes(LT)(Smalley, 1982)

Landtype summary	LT
Broad undulating sandstone uplands	1
Broad sandstone ridges - north aspect	2
Broad sandstone ridges - south aspect	3
Narrow sandstone ridges and convex upper slopes	4
North sandstone slopes	5
South sandstone slopes	6
Sandstone outcrops and shallow soils	7
Broad shale ridges - north aspect	8
Broad shale ridges - south aspect	9
Upper shale slopes - north aspect	10
Upper shale slopes - south aspect	11
Lower shale slopes - north aspect	12
Lower shale slopes - south aspect	13
Footslopes, terraces, and streambottoms with good drainage	14
Terrace, streambottoms, and depressions with poor drainage	15
Plateau escarpment and upper sandstone slopes and benches - north aspect	16
Plateau escarpment and upper sandstone slopes and benches - south aspect	17
Lower limestone slopes, benches, and spur ridges - north aspect	18
Lower limestone slopes, benches, and spur ridges - south aspect	19
Limestone outcrops and shallow soils	20

Table 2. Sample location distribution by county for each subset of analyses

CT	CO	number of sample locations by subset									
		OD	1	2	3	4a	4b	4c	5a	5b	5c
BL	7	29	24	16	6	13	16	16	19	23	21
CU	35	55	40	28	19	26	27	28	36	39	33
FE	49	42	27	21	11	13	17	19	16	22	19
FR	51	22	22	15	9	10	15	15	15	22	19
GR	61	29	26	17	11	13	15	17	20	22	21
HA	65	10	8	7	4	6	6	7	7	7	5
MA	115	40	36	26	14	17	18	23	27	28	21
MO	129	41	34	32	16	17	30	31	19	32	24
OV	133	17	14	11	8	4	8	10	5	11	8
PI	137	6	5	4	3	4	4	4	5	5	3
PU	141	12	11	9	7	4	7	7	4	9	9
SC	151	30	24	20	16	10	17	19	12	20	15
SE	153	24	21	18	10	12	13	17	15	16	16
VB	175	24	21	13	7	11	13	13	15	19	18
WA	177	6	6	5	4	3	4	5	4	5	5
WH	185	12	10	7	5	7	7	7	10	10	10
Total		399	329	249	150	170	217	238	229	290	247

Abbreviations - CT : county, [BL : Bledsoe, CU : Cumberland, FE : Fentress, FR : Franklin, GR : Grndy, HA : Hamilton, MA : Marion, MO : Morgan, OV : Overton, PI : Pickett, PU : Putnam, SC : Scott, SE : Sequatchie, VB : Van Buren, WA : Warren, WH : White], CO : county code, OD : original data.

dominant landtype and entered step 1 of the statistical analysis.

In subset 2, sample locations with less than 70% of the 1980 basal area in trees surviving from 1980 to 1989 were dropped(Table 2).

To reduce variability among sample locations, only those with an initial basal area of 50sq.ft./acre were included in subset 3.

Subsets 4a, 4b, and 4c(Table 2) each started with sample locations included in subset 2. Landtypes having 16 or more sample locations were included in subset 4a. Sixteen was considered the minimum number of plots necessary to represent general dominant landtypes over the Cumberland Plateau.

Similar landtypes were grouped into landtype classes(LTCL).

LTCL 1 - sandstone uplands(LT 1).
LTCL 2 - sandstone ridges(LT 2 and 3).
LTCL 3 - north sandstone slopes(LT 5).
LTCL 4 - south sandstone slopes(LT 6).
LTCL 5 - shale(LT 8, 9, 10, 11, 12, and 13).
LTCL 6 - escarpment and upper sandstone slopes and benches(LT 16 and 17).
LTCL 7 - limestone(LT 18, 19, and 20).

Those sample locations in landtype classes with 16 or more sample locations were retained in subset 4b. In subset 4c, sample locations were grouped into broad categories for contrasts in analysis of variance.

Sandstone - LT 1, 2, 3, 4, 5, 6, 7, 16, and 17.
Limestone - LT 18, 19, and 20.
Shale - LT 8, 9, 10, 11, 12, and 13.
Outcrops - LT 7 and 20.
Ridges - LT 1, 2, 3, 4, 8, and 9.
North aspect - LT 5, 10, 12, 16, and 18.
South aspect - LT 6, 11, 13, 17, and 19.

Sample locations in landtypes 14 and 15 were removed since they did not fall in any of the contrast groups.

For analyses of site class and of detailed forest type, tree category(cutting, mortality and other causes) was not important because site class and detailed forest type are plot level variables. Thus, 329 sample locations were again considered for subsets 5a, 5b, and 5c. In subset 5a, sample locations were excluded when the number of 1989 sample locations in a landtype was 16 or less. In subset 5b, sample locations were removed when number of 1989 sample locations in a landtype class was less than 16. To reduce variability among detailed forest types(FTYPEX), sample locations were dropped from 329 to 247 in subset 5c. In this subset, FTYPEX not appearing more than 19 times in a landtype were excluded. Nineteen was selected because it was considered to be the minimum number that was large enough to cover general dominant forest types in the study area. Seven forest type classes(FTCL) were grouped.

All statistical tests in this study were tested on probability level 95%(α=0.05).

Regression of growth on initial value

Equations 2 and 5 were fitted using PROC NLIN(SAS, 1988) for basal area growth and volume growth over 329 sample locations(subset 2). These models were selected because of their biological basis and Moser and Hall's(1969) success in similar stands. Linear regression of basal area growth and volume growth on initial basal area and initial volume, respectively, was run using PROC GLM(SAS, 1988) by both landtype and landtype class because of poor results obtained with equation 2.

Tests for homogeneity of regression coefficients with covariance

Homogeneity of regression coefficients(Steel and Torrie, 1960) was tested using covariance analysis. Regression coefficients were calculated for each landtype(subset 4a) and for each landtype class(subset 4b). Overall regression coefficients were calculated with PROC GLM(SAS, 1988), and the estimates of SS(sums of squares)model, SSerror, SStotal, and degree of freedom(df) were obtained from the regressions by both landtype and landtype class.

Estimate of maximum R^2

Variability among sample locations was high. Sample locations were grouped into 20sq.ft./acre classes(basal area class) in landtype(from data set 4a) and in landtype class(subset 4b). Within-class corrected sums of squares(CSS) were calculated. These were summed and subtracted from the overall CSS. The difference was divided by the overall CSS and multiplied by 100 to estimate the coefficients of determination for a perfect fit, i.e., a model passing through each class mean.

Analyses of variance

ANOVAs were run to test for differences in basal area growth and volume growth(subset 4c) between logical groups of landtypes. Contrasts used were (1)parent material : sandstone, limestone, and shale, and (2)aspect : ridge, north facing, and south facing slopes.

Contingency tables

Differences in productivity by landtype result in different distributions of sample locations over site class(SITEC) among landtypes(LT) or over SITEC among landtype classes(LTCL). Contingency tables were constructed with LT and SITEC(subset 5a), and with LTCL and SITEC (subset 5b) for 1989 data. Independence was tested with Chi-square. To determine whether there were positive relationships between LT and detailed forest type(FTYPEX) and between LTCL and forest type class(FTCL), two independence tests of 1989 data : (1)LT and FTYPEX(subset 1) and (2)LTCL and FTCL(subset 5c) were tested with Chi-square.

RESULTS

Nonlinear and Linear Regressions

Nonlinear regression of basal area growth using all 329 sample locations

Fitting the Chapman-Richards model(Equation 2) to predict basal area growth from basal area resulted in a small coefficient of determination(R^2) and standard errors 5 to 12 times the coefficients(Table 3, run 1). Also, correlations among regression coefficients were high with n having a 0.9997 correlation with k.

In an attempt to reduce the variability, plots with an initial basal area of 50sq.ft. per acre or less were dropped. Coefficients were estimated starting with values based on Moser and Hall's (1969) results(Table 3, run 2). A second set of regression coefficients was estimated starting with an initial range for each coefficient that included the initial values used in run 2(Table 3, run 3). Although the residual sums of squares

Table 3. Results of nonlinear regression to predict basal area growth from basal area with Chapman-Richards model

Run	No. of Sample Locations	Initial Conditions	Estimated Coefficient	Asymptotic standard error	Residual sum of squares	R^2(%)
1	249	n = -0.8 to -0.1 by 0.1	-0.587	7.483	8192.970	26.6
		m = 0.75 to 1.15 by 0.1	1.118	0.653		
		k = -1.2 to -0.3 by 0.1	-1.211	7.934		
2	150	n = -0.5	-0.318	28.735	4521.938	20.8
		m = 1.0	1.088	5.751		
		k = -0.5	-0.692	30.457		
3	150	n = -0.8 to -0.1 by 0.1	-0.747	99.925	4572.530	20.7
		m = 0.75 to 1.15 by 0.1	1.049	5.218		
		k = -1.2 to -0.3 by 0.1	-1.150	101.856		

were very similar for these two sums, the estimates of coefficients n and k were quite different. As with run 1, the standard errors of the coefficients were much larger than the coefficients and the intercoefficient correlations were all 0.9999. To get R^2(Table 3), predicted value (e.g., DB) for each plot(location) was calculated. Deviations of predicted and observed value were squared and added(residual SS). Finally, residual SS was subtracted from corrected SS(CSS), and this value was divided by CSS, and multiplied by 100. Because of the very poor results with basal area growth, no results are reported for volume growth.

Linear regression of basal area growth and volume growth by landtype

Basal area growth(DB) was predicted as a function of initial total basal area(TPBAPA) with a simple linear model(equation 6) and also with a model having a linear, quadratic, and cubic term(equation 7). These models were fitted with data in step 4a(Table 2) to evaluate the strength of the relationship between basal area growth and landtype.

$$DB=5.1281+0.1654(TPBAPA) \quad\cdots\cdots(6)$$

$$DB=4.0295+0.2680(TPBAPA)-0.0023(TPBAPA)^2+0.00002(TPBAPA)^3 \quad\cdots\cdots(7)$$

The simple linear model itself(p-value=0.0001), intercept(p-value=0.0001), and TPBAPA(p-value =0.0001) were significant. R^2 was 0.3000. None of coefficients of the cubic model were significant [intercept : p-value=0.2344 ; TPBAPA : p-value = 0.1685 ; $(TPBAPA)^2$: p-value = 0.5025 ; $(TPBAPA)^3$: p-value=0.4408].

Similarly, volume growth(DV) was predicted as a function of a linear term of initial total net volume(TPNVPA)(equation 8) and as a function with a linear, quadratic, and cubic term(equation 9).

$$DV=139.3446+0.2934(TPNVPA) \quad\cdots\cdots(8)$$

$$DV=221.2055-0.2115(TPNVPA)+2.6878\times 10^{-4}(TPNVPA)^2-0.0669\times 10^{-8}(TPNVPA)^3 \quad\cdots\cdots(9)$$

The linear model itself(p-value=0.0001), intercept(p-value=0.0006), and TPNVPA(p-value= 0.0001) were all significant. R^2 was 0.3091. None of coefficients of the cubic model were significant except intercept(p-value=0.02) [TPNVPA : p-value = 0.9940 ; $(TPNVPA)^2$: p-value = 0.2539 ; $(TPNVPA)^3$: p-value=0.2440].

Linear regression of basal area growth and volume growth by landtype class

The same procedure used for the landtype was applied to landtype class. Basal area growth(DB) was predicted as a function of initial total basal area(TPBAPA) with a simple linear model(equation 10) and also with a model having a linear, quadratic, and cubic term(equation 11). These models were fitted with data in subset 4b(Table 2) to evaluate strength of the relationship between basal area growth and landtype class.

$$DB=5.2958+0.1625(TPBAPA) \quad\cdots\cdots(10)$$

$$DB=3.7303+0.2976(TPBAPA)-0.0029(TPBAPA)^2+0.00002(TPBAPA)^3 \quad \cdots\cdots (11)$$

The linear model itself(p-value=0.0001), intercept(p-value=0.0001), and TPBAPA(p-value=0.0001) were significant. R^2 was 0.2923. The cubic model(p-value=0.0001) was significant. TPBAPA(p-value=0.0843) was almost significant. The other two independent variables were insignificant [intercept : p-value=0.2020 ; $(TPBAPA)^2$: p-value=0.3462 ; $(TPBAPA)^3$: p-value=0.2966]. R^2 was 0.2966.

Volume growth(DV) was predicted as a function of a linear term of initial total net volume (TPNVPA)(equation 12) and as a function with a linear, quadratic, and cubic term(equation 13).

$$DV=154.2930+0.2919(TPNVPA) \quad \cdots\cdots (12)$$

$$DV=190.9391+12.5429(TPNVPA)+1.7560\times10^{-4}(TPNVPA)^2-0.0486\times10^{8}(TPNVPA)^3 \quad \cdots\cdots (13)$$

The linear model itself(p-value=0.0001), intercept(p-value=0.0001), and TPNVPA(p-value=0.0001) were significant. R^2 was 0.3080. The cubic model(p-value=0.0001) was significant. The intercept(p-value=0.0254) was significant. The rest of the independent variables were not significant [TPNVPA : p-value=0.6119 ; $(TPNVPA)^2$: p-value=0.4031 ; $(TPNVPA)^3$: p-value=0.3492]. R^2 was 0.3114.

Test for Homogeneity of Regression Coefficient Using Covariance

Simple linear regressions of basal area growth as a function of initial total basal area and volume growth as a function of initial total volume were run by landtype and landtype class. Regression coefficients for basal area growth and for volume growth among landtypes and among landtype classes were homogeneous based on covariance analysis(Table 4).

Estimate of Maximum R^2

The coefficients of determination for "perfect" fit are presented in Table 5. The R^2 values from linear regression were 55% to 70% of the R^2 expected with a "perfect" fit.

ANOVA of Basal Area and Volume Growth

There were no statistical differences among sandstone, limestone, and shale, or among outcrops, ridges, and slopes for either basal area growth or volume growth(Table 6).

Contingency Tables

Chi-square test of landtype(LT) and site class(SITEC)

Because Chi-square p-value was 0.05, the null hypothesis that LT and SITEC were independent was rejected. Dependency suggests that po-

Table 4. Adjusted degrees of freedom(df), reduced sums of squares(SS), and F value(F) from test for homogeneity of regression coefficient using covariance analysis by landtype(LT) or landtype class(LTCL).

	df	SS	F
LT on basal area growth	6	141.55	0.7334
LT on volume growth	6	477464.95	1.2485
LTCL on basal area growth	6	135.59	0.6966
LTCL on volume growth	6	438311.94	1.1271

Table 5. Comparison of coefficients of determination(R^2) for "perfect" fit with R^2 of simple linear regression for basal area growth and volume growth by landtype(LT) and landtype class (LTCL)

	LT("perfect" R^2 : simple linear regression R^2)	LTCL("perfect" R^2 : simple linear regression R^2)
Basal area growth	50.37% : 30.00%	44.95% : 29.23%
Volume growth	55.97% : 30.91%	48.19% : 30.80%

Table 6. P-values of contrasts for basal area growth and volume growth.

Contrast	P-value	
	basal area growth	volume growth
Sandstone vs Limestone and Shale	0.4991	0.8405
Limestone vs Shale	0.1668	0.1670
Outcrops vs Ridges and Slopes	0.4370	0.1496
Ridges vs Slopes	0.1751	0.1337
North aspect vs South aspect	0.1626	0.2497

tential yield of stands on the Cumberland Plateau is related to landtypes. However, validity of this test was questionable since high proportion(49%) of the cells had expected counts less than 5.

Chi-square test of landtype class(LTCL) and site class(SITEC)

Since Chi-square p-value was 0.147, the null hypothesis that LTCL and SITEC were independent could not be rejected. They were independent, i.e., when landtypes were grouped into landtype classes, the relationship between potential yield and landtypes was weak. Again, validity was questionable because 50 percent of the cells had expected counts less than 5.

Chi-square test of landtype(LT) and detailed forest type(FTYPEX)

The Chi-square test of landtype(LT) and detailed forest type(FTYPEX) indicated that landtype and forest type were dependent($p\text{-value} < 0.000$). This suggested that specific vegetation types occur on specific landtypes. However, 97% of the cells had expected counts less than 5 which raised questions about the validity of this test.

Chi-square test of landtype class(LTCL) and forest type class(FTCL)

To reduce variability among the detailed forest types, those with less than 19 sample locations were dropped. The remaining sample locations with dominant forest types were assigned values of 1 to 7 for forest type classes(FTCL). A Chi-square test of landtype class(LTCL) and FTCL rejected the hypothesis that LTCL and FTCL are independent($p\text{-value} < 0.000$). Therefore, forest type classes were related to landtype classes (Table 7). Again, validity was still questionable since 86% of the cells had expected counts less than 5.

Table 7. Number of sample locations by landtype class(LTCL) and forest type class (FTCL)

FTCL / LTCL	1	2	3	4	5	6	7	total
1	6	8	7	2	26	0	0	49
2	5	1	5	0	22	2	0	35
3	3	2	4	0	20	0	1	30
4	4	3	3	2	15	3	1	31
5	0	1	0	1	11	0	1	14
6	1	3	1	7	23	6	6	47
7	0	1	2	6	19	5	8	41
total	19	19	22	18	126	16	17	247

DISCUSSION

Since landtypes and detailed forest types are dependent, forest types can be predicted by landtype on the Cumberland Plateau in Tennessee, USA. Also, landtype classes and forest type classes are dependent. However, both have so many cells with 5 or fewer observation that the tests are of questionable validity.

The Chapman-Richards model was selected to predict basal area growth from initial basal area for this study because of its sound biological basis and because of Moser and Hall's(1969) success in similar stands. Predicting basal area growth with it was not successful in this study, with low R^2 values and estimated coefficients having "0" within their confidence intervals. When the plot number was reduced by eliminating low basal area plots to try to reduce the variability among them, asymptotic standard error(ASE) increased while residual sum of squares(RSS) decreased by about 50% and R^2 got slightly smaller (Table 3).

Basal area growth and volume growth was linearly related to initial basal area and initial volume by landtype and landtype class. However, the low R^2 values indicated weak relationships. It suggests that past stand productivity on a specific landtypes can be related to future productivity on the same landtype. However, the strength of the relationship found here is not enough to be used in predicting growth.

A test for homogeneity of regression coefficient using covariance showed that regression coefficients for basal area growth and volume growth among landtypes and landtype classes were homogeneous. It did not support the hypothesis that there were significant differences in productivity among landtypes and among landtype classes on the Cumberland Plateau.

The R^2 values for the linear regression reached 55-70% of the expected R^2 values with a "perfect" fit. This indicated that the linear regressions were reliable as a basis for testing hypothesis about productivity.

Also, five orthogonal contrasts among logical groupings of landtypes demonstrated that there was no statistically significant productivity difference among landtypes. This result agreed with results from the nonlinear regression using the Chapman-Richards model and the analysis with linear regression.

Showing that landtype and site class were dependent, a Chi-square test of landtype and site class suggested that potential yield of hardwood stands on the Cumberland Plateau was related with landtypes even though the test was somewhat questionable. However, when the landtypes were grouped to landtype classes, the Chi-square test did not support the argument that a positive relationship exists between the productivity and landtype. The poor relation between landtype and productivity may be due to a number of reasons. After initial training of field crews, no field checking of landtype classification was conducted. This possibly allowed misclassification of a significant number of plots. The number of plots in many of the landtypes may have been too few to separate differences in productivity from random noise. Finally, there may not be real differences in productivity among landtypes.

CONCLUSIONS AND RECOMMENDATIONS

This study suggests that there may be a relationship between landtype and forest type on the Cumberland Plateau in Tennessee, USA. However, there are no significant differences in productivity among landtypes and among landtype classes on the study area. Assuming that landtype determination by field crews was correct, this particular analysis suggested that it is not easy to predict basal area growth and volume growth on Cumberland Plateau using landtype. Several explanations can be suggested why no significant difference was found in productivity among landtypes. A possible reason may be that there were too few plots to adequately represent the many landtypes.

One way of establishing plots can be recommended. For sample plots, select more than 500 distinctive sampling locations having capacity to grow commercially valuable hardwoods in the study area. By doing so, disturbed sample locations can be avoided in advance. Locate each sample point within each designated landtype boundary. Establish 14 points within each sample location so that it can represent more accurately a landtype of the sample location. Use a grid pattern to locate sample points so that there can be an even distribution over the sample location with points far enough apart to be independent. At this time, the location of the sample points results in equilateral triangles with sides of 25m. Assign a dominant landtype when a plot has at least 9 points out of 14 with the same landtype. Quality monitoring is recommended.

LITERATURE CITED

1. Chapman, D.G. 1961. Statistical problem in population dynamics. Pages 153-168 in Proc. Fourth Berkeley Symp. Math Stat. and Prob. Univ. Calif. Press, Berkeley.
2. Clutter, J.L., J.C. Fortson, L.V. Pienaar, G.H. Brister, and R.L. Bailey. 1983. Timber Management : A Quantitative Approach. John Wiley & Sons. 333pp.

3. Dickson, R.R. 1960. Climates of the States : Tennessee. U.S. Dept. of Commerce, Weather Bureau. Govt. Print. Off. Washington, D.C. 16pp.
4. Fenneman, N.M. 1938. Physiography of the Eastern United States. McGraw-Hill, New York. 714pp.
5. Francis, J.K., and J.S. Loftus. 1977. Chemical and Physical Properties of Cumberland Plateau and Highland Rim Forest Soils. USDA For. Serv. Res. Pap. SO-138. 44pp.
6. Franzmeier, D.P., E.J. Pedersen, T.J. Longwell, J.G. Byrne, and C.K. Losche. 1969. Properties of some soils in the Cumberland Plateau as related to slope aspect and position. Soil Sci. Soc. Amer. Proc. 33 : 755-761.
7. Fullerton, R.O., and R.J. Bernard. 1977. Tennessee Geographic Patterns and Regions. Kendall/Hunt Pub. Co., Dubuque, Iowa. 150pp.
8. Luther, E.T. 1977. Our Restless Earth : the geologic regions of Tennessee. The Univ. of Tenn. Press, Knoxville, TN. 94pp.
9. Lynch, T.B. and J.W. Moser, Jr. 1986. A growth model for mixed species stands. For. Sci. 32 : 697-706.
10. May, D.M. 1989. Forest survey information systems in the south central United States. Pages 189-196 in Adlard, Philip ; Rondeux, Jacques ; eds. Forest growth data : capture, retrieval and dissemination : proceedings of the joint IUFRO workshop ; Gembloux, Belgium. Gembloux, Belgium : Faculty of Agriculture Gembloux, International Union of Forestry Research Organization : 189-196.
11. Miller, R.A. 1974. The Geologic History of Tennessee. Tenn. Div. Geology Bull. 74. 63pp.
12. Moser, J.W., and O.F. Hall. 1969. Deriving growth and yield functions for uneven-aged forest stands. For. Sci. 15 : 183-188.
13. Mühlhäusser, G., W. Hubner, and G. Stummer. 1983. Die Forstliche Standorskarte 1 : 10,000 nach dem baden-wurttembergischen Verfahren. Mitt. Vereins f. forstl. Standortsk. u. Forstpflz. 30 : 3-13.
14. Nelson, D.O., W.E. Russell, and G.W. Stuart. 1984. The ecological classification system in the national forest system, eastern region. Pages 270-276 in Proc. of symp. Forest Land Classification : Experience, Problem, Perspectives. Madison, WI.
15. Pienaar, L.V. 1965. Quantitative Theory of Forest Growth. Ph.D. dissertation, Univ. of Washington, Seattle.
16. Pienaar, L.V., and K.J. Turnbull. 1973. The Chapman-Richards generalization of Von Bertalanffy's growth model for basal area growth and yield in even-aged stands. For. Sci. 19 : 2-22.
17. Pierpoint, G. 1984. Forest land classification Rationale and overview. Pages 6-10 in Proc. of symp. Forest Land Classification : Experience, Problems, Perspectives. Madison, WI.
18. Rennie, J.C. 1991. Use of land classification on the Cumberland Plateau. Pages 90-92 in Proc. of symp. Ecological Land Classification : Applications to Identify the Productive Potential of Southern Forests. USDA For. Serv. Gen. Tech. Rep. SE-68.
19. Richards, F.J. 1959. A flexible growth function for empirical use. J. Exp. Bot. 10 : 290-300.
20. Russell, W.E. and J.K. Jordan. 1991. Ecological classification system for classifying land capability in Midwestern and Northeastern U.S. National forests. Pages 18-24 in Proc. of symp. Ecological Land Classification : Applications to Identify the Productive Potential of Southern Forests. USDA For. Serv. Gen. Tech. Rep. SE-68
21. SAS Institute, Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. Cary, NC : SAS Institute Inc. 1028pp.
22. Schlenker, G. 1964. Entwicklung des in Sudwestdeutschland angewandten Verfahrens der forstlichen Standortskunde. Pages 5-26 in Standort, Wald und Waldwirtschaft in Oberschwaben. "Oberschwabische Fishtenreviere." Stuttgart.
23. Smalley, G.W. 1982. Classification and Evaluation of Forest Sites on the Mid-Cumber-

land Plateau. USDA For. Serv. Gen. Tech. Rep. SO-38. 59pp.

24. ______. 1986. Site Classification and Evaluation for the Interior Uplands : Forest Sites of the Cumberland Plateau and Highland Rim/Pennyroyal. USDA For. Serv. Southern Region. Tech. Publ. R8-TP9. 521pp.
25. ______. 1991. No more plots ; go with what you know : developing a forest land classification system for the interior uplands. Pages 48-58 in Proc. of symp. Ecological Land Classification : Applications to Identify the Productive Potential of Southern Forests. USDA For. Serv., Southeastern Forest Exp. Stn. Gen. Tech. Rep. SE-68.
26. Society of American Foresters. 1984. Forestry Handbook. ed. Wenger, K.F. John Wiley & Sons, New York. 1335pp.
27. Springer, M.E., and J.A. Elder. 1980. Soils of Tennessee. Univ. of Tennessee. Agric. Exp. Stn., Knoxville, TN. Bull. 596. 66pp.
28. Steel, R.G.D., and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc. 481pp.
29. Turnbull, K.J. 1963. Population Dynamics in Mixed Forest Stands. Ph.D. dissertation, Univ. of Washington, Seattle.
30. Todd, C.L. 1990.(Description of plot and tree variables, 1980 and 1989, permanent plot data). USDA Forest Service, Southern Forest Exp. Stn. Forest Inventory and Analysis. 105pp.
31. Wertz, W.A. and J.F. Arnold. 1975. Land stratification for land-use planning. Pages 617-629 in Proc. Fourth North American forest soils conference ; 1973 August ; Quebec, Canada.