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Simultaneous modelling of stand volume yield, dominant height and basal area growth models

L. YUANCAI[1], C. P. MARQUES[2], J. M. BENTO[2]

[1]Research Institute of Forest Resource Information Technique, Chinese Academy of Forestry, Beijing, China
[2]Department of Forestry, Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal

ABSTRACT: Forest growth and yield models are often composed of a system of compatible, interdependent and analytically related equations rather than of a single equation. Most forest researchers have recognized that the forest stand dynamics system should be described by a system of simultaneous and interdependent equations. The two- and three-stage least squares (2SLS and 3SLS) and seemingly unrelated regression (SUR) techniques from econometrics have been widely used to estimate the coefficients of forest growth and yield model system. This study analyzes a system of three interdependent equations for predicting the future stand volume yield, the future stand dominant height and the future stand basal area for eucalyptus plantations as an integrated system given by initial stand conditions. The coefficients of the system are estimated from *Eucalyptus globulus* Labill. stands in the Central inland of Portugal by using 3SLS, SUR and OLS, respectively. The three methods are evaluated and compared on some statistic indicators. The results indicate that there is a small difference between the three approaches in the particular case, but the system estimation methods perform better for a system of simultaneously interdependent equations in theory. Therefore, the appropriate system estimation approaches are recommended for estimating coefficients in simultaneously interdependent systems of forestry equations.

Keywords: comparison; growth and yield model; simultaneous equation

Modelling methodology of growth models at present is becoming increasingly sophisticated as forest biometricians put forward new biological rationale, advanced statistical techniques, and powerful computing technology to solve growth and yield prediction problems.

An extensive variety of growth and yield models have been developed. However, growth and yield models, which describe forest stand dynamics by using data from permanent sample plots or inventory sample plots with real growth series, are often composed of a system of compatible, interdependent and analytically related equations (CLUTTER 1963; SULLIVAN, CLUTTER 1972; BORDERS, BAILEY 1986; BURKHART 1986; REED 1986; DANIELS, BURKHART 1988). Most forest researchers have recognized that there is a strong correlation and feedback mechanism between variables that are used to describe growth and yield relationships. Therefore, forest stand dynamics should be described by a simultaneous and interdependent system of equations rather than by separate and isolated individual equations.

In forest biometrics, there are two categories of methods for estimating simultaneous and interdependent systems of equations.

One method of estimating parameters in a system of equations is to fit one (or more) of the equations using Ordinary Least Squares (OLS) techniques and to solve for the coefficients in the other(s) by invoking the specified algebraic relationships between parameters (SULLIVAN, CLUTTER 1972). This solution has obvious shortcomings. As the parameter estimates are stochastic, the final result will depend on the arbitrary choice which equation(s) is(are) fitted and which is(are) derived. Thus, BURKHART and SPRINZ (1984), REED and GREEN (1984), BYRNE and REED (1986), KNOEBEL et al. (1986) and REED (1986) simultaneously estimated the structural parameters by minimizing the squared error loss function, which brought about a substantial improvement for the total system. However, BORDERS and BAILEY (1986) and LEMAY (1990) indicated that estimates obtained by minimizing squared error loss functions may not be con-

sistent or most efficient if the equations are simultaneous. The reason is that the method does not use the information on correlation between residuals of the remaining resultant estimators. VAN DEUSEN (1988) discussed the relationship of the minimization of error loss functions to the Seemingly Unrelated Regression (SUR) fitting technique, and showed that estimation based on minimizing squared error loss functions is very similar to the SUR techniques from econometrics, and suggested that if the system of equations belongs to the SUR framework, estimates of the structural parameters will be consistent and asymptotically efficient.

The other method of simultaneous fitting techniques widely used in econometrics is the so-called system method. For the system of forestry equations, FURNIVAL and WILSON (1971) have considered it as the first application of econometric fitting techniques to forestry systems to correct for simultaneity bias and contemporaneous correlation. Many other researchers have also discussed and used two and three-stage least squares (2SLS and 3SLS), and SUR techniques from econometric methods to estimate the structural parameters in a system of forestry equations (e.g. MURPHY 1983; AMATEIS et al. 1984; BURKHART 1986; BORDERS, BAILEY 1986; REED 1986; VAN DEUSEN 1988; BORDERS 1989; SOMERS, FARRAR 1991; LYNCH, MURPHY 1995; AMARO 1997; ZHANG et al. 1997). BORDERS (1989) discussed in detail three types of equation systems which are: (i) seemingly unrelated regression equations (SUR); (ii) recursive systems of equations; (iii) system of simultaneous equations, and described associated fitting methods in different types of equation systems, as well as an alternative parameter estimation procedure that can be used for any number of analytically related linear or non-linear equation systems.

It is evident from the given examples that a wide variety of cases exists where the systems of related equations are used in forestry. No single model can be expected to be the "best" for all the purposes that are practical, precise and common in forest prediction (BURKHART 1997). Therefore, when a growth and yield model is selected for forest prediction, one must think of a system of growth and yield models capable of providing logical and consistent estimates for varying degrees of stand details. Based on the idea, this study (i) analyzes a system of three interdependent equations for predicting the future stand volume yield, the future stand dominant height and the future stand basal area for eucalyptus plantations as an integrated system given initial stand conditions; (ii) applies some statistical methods to simultaneously estimate the structural parameters of the system. The cross-equation correlations and simultaneous nature exist between the error components of these equations. No attention is paid to the fact that the error terms from related equations are almost certain to be correlated, and the available information on the cross-equation interdependence is not utilized; (iii) evaluates different system estimation methods for the system of nonlinear equations

and compares them with the traditional single-equation technique based on OLS.

SYSTEM OF EQUATIONS

VARIABLES OF EQUATION SYSTEMS

In systems of interdependent equations, the variables occurring on the left-hand side (LHS) are referred to as endogenous variables (or dependent variables). They are the system outputs and are assumed to be determined by the joint interaction with other variables within a system. These endogenous variables may also appear as predictor variables on the right-hand side (RHS) of equations within the system. All variables that only appear on the RHSs of the equations in the system are referred to as exogenous or predetermined variables that are determined outside the system.

CLASSIFICATIONS OF EQUATION SYSTEMS

Pindyck and Rubinfeld in 1981, as referenced in BORDERS (1989), classified the systems of related equations into three categories: (i) seemingly unrelated equations, (ii) recursive equations and (iii) simultaneous equations. The nature of each type of equation system is different and it is very useful to understand the nature of different systems of equations for fitting them.

The types of structural models in different systems of equations are discussed and described below. The position of the zero elements in the **B** matrix indicates which endogenous variables do not appear in different structural equations. This is used as a criterion for distinguishing between various types of structures of different equation systems.

(i) System of seemingly unrelated equations:
If **B** is diagonal, i.e., if:

$$\mathbf{B} = \begin{bmatrix} B_{11} & 0 \dots\dots 0 \\ 0 & B_{22} \dots\dots 0 \\ \cdot & \\ \cdot & \\ 0 & 0 \dots\dots\dots B_{ii} \end{bmatrix}$$

Only one endogenous variable appears in each equation. This means that the equations are not simultaneous but seemingly related. A typical form of the seemingly unrelated equation system was discussed by BORDERS (1989). Obviously, there are no analytical relationships between equations if $cov(e_i, e_j) = 0$ for all pairs of error terms i and j. If $cov(e_i, e_j) \neq 0$, then the equations are related. When such cross-equation correlations are present, a three-step fitting procedure discussed by REED (1986) may be desirable for parameter estimation of this type of equation system.

Seemingly unrelated regression estimates are obtained by estimating a set of nonlinear equations with cross-equation constraints imposed, but with a diagonal covariance matrix of the disturbances across equations. These

parameter estimates are used to form a consistent estimate of the covariance matrix of the disturbances, which is then used as a weighting matrix when the model is re-estimated to obtain new values of the parameters. These estimates are consistent and asymptotically normal, and under certain conditions, asymptotically more efficient than the single equation estimates.

(ii) System of recursive equations:
If **B** is triangular, that is if:

$$\mathbf{B} = \begin{bmatrix} B_{11} & 0 & \dots\dots & 0 \\ B_{21} & B_{22} & \dots & 0 \\ \cdot & & & \\ \cdot & & & \\ B_{G1} & B_{G2} & \dots\dots & B_{GG} \end{bmatrix}$$

The system is known as a recursive system of equations. The system of recursive equations is a simultaneous set of regression equations fitted one at a time in a logical sequential order. The general condition that must be met to define a system of recursive equations is that the **B** matrix must be triangular (KMENTA 1971). That means a necessary condition for the recursive system to be estimated is that it is algebraically complete from the standpoint that the number of equations must equal the number of endogenous variables. In this case the solution for the gth endogenous variable involves only the first g structural equations. This means that all *G* structural equations are needed for the solution only in the case of the last endogenous variable Y_{Gt}. Notice that the first structural equation involves only one endogenous variable. For this type of equation system, ordinary least squares (OLS) can be used to obtain parameter estimates if there is no cross-equation correlation between error components of the various equations in the system (BORDERS 1989; LIU et al. 1989). In the strict definition of a recursive system, there is no correlation problem between the RHS endogenous variables and the error components of the LHS endogenous variables. However, this assumption relies on the fact that the error components for the equation in a recursive system are pair-wise unrelated. When such correlations exist, it is not true that RHS endogenous variables are not correlated with error components of LHS endogenous variables. Therefore, when cross-equation correlations exist in a system of recursive equations, the system is not recursive by definition (BORDERS 1989). Three-stage least squares (3SLS) and SUR estimation methods in econometrics must be used to estimate the parameters of the system.

(iii) System of simultaneous equations:
If **B** is neither diagonal nor triangular, it is defined as an integrated structure, or a system of simultaneous equations. A simultaneously interdependent system of equations exists when two or more variables in the system are jointly determined by the phenomenon being modelled in a system of interrelated equations, that means no logical sequential ordering of equations exists. A logical sequential ordering of equations appears unlike in (1) and

(2) discussed above. Such structures have commanded the greatest attention and provided the main subject for discussion in forest biometrics (AMATEIS et al. 1984; BORDERS, BAILEY 1986; BORDERS 1989). The relationships in such a system can be complex and may consist of variables that appear as both regressors and dependent variables as well as cross-equation correlations between error components. Furthermore, restrictions may be placed on parameters both within and across equations (BORDERS, BAILEY 1986; LYNCH, MURPHY 1995). Seemingly unrelated regression (SUR) and three-stage least squares (3SLS) from econometrics can be used to obtain consistent and asymptotically efficient parameter estimators for simultaneous systems.

SYSTEM OF ESTIMATED EQUATIONS

A system of three equations for eucalyptus plantation stands was selected for this analysis:

$$V2 = V1\ e^{[a1(1/t2 - 1/t1) + a2(1/H2 - 1/H1) + a3(\ln G2 - \ln G1)]} + \varepsilon1 \tag{1}$$

$$G2 = e^{[(t1/t2)\ln G1 + c1(1 - t1/t2) + c2(1 - H1/H2)]} + \varepsilon2 \tag{2}$$

$$H2 = b0^{\{1 - [\ln(1 - e^{-b1t2})]/[\ln(1 - e^{-b1t1})]\}} H1^{[\ln(1 - e^{-b1t2})/\ln(1 - b1t1)]} + \varepsilon3 \tag{3}$$

where: V_i is stand volume yield at time ti (m³/ha), G_i is stand basal area at time ti (m²/ha), H_i is stand dominant height at time ti (m), e is the base of natural logarithm (= 2.71828), $\varepsilon1$, $\varepsilon2$ and $\varepsilon3$ are error terms for equations (1), (2) and (3), respectively, $a_1–a_3$, $c_1–c_2$ and $b_0–b_1$ are parameters to be estimated.

The system of equations (1)–(3) regards stand volume yield, stand basal area and stand dominant height increment predictions as being simultaneous and interdependent. It is clear that within this system, variables G2 and H2 appear on the left-hand side (LHS) of the equations as well as on the right-hand side (RHS) of the equations in the system. Together with V2, they are the system outputs and are regarded as endogenous variables that are jointly determined by the joint inter-independence with other variables within the system. Variables that appear only on the RHS of the equations in the system are regarded as exogenous or predetermined variables. Their values are known and are not determined by the structure of the system.

As mentioned above, endogenous variables can occur on both the RHS and the LHS of an equation, and hence they are stochastic. The presence of endogenous variables in the system violates the independence assumption of OLS. In OLS, variables on the RHS are assumed to be uncorrelated with the error terms, and in fact they are usually assumed to be known constants. When stochastic variables appear in regression equations as predetermined variables on the RHS, there can no longer be independence between the RHS variables and the error terms of the equations (JUDGE et al. 1985). Since G2 depends on H2, and the observed value of H2 depends on the error terms $\varepsilon3$ application of OLS estimation techniques to equations (1)–(3) will yield biases and inconsistent parameter estimates, because of the obvious

correlations that will arise between explanatory variables and error terms.

METHODS

PARAMETER ESTIMATES OF SIMULTANEOUS SYSTEM OF EQUATIONS

To eliminate the bias and inconsistency of simultaneous equations (1)–(3), the two-stage least squares (2SLS) method, developed by Theil in 1953 and independently by Basmann in 1957 as referenced in KONTSOYIANNIS (1977), has been widely used in econometrics (JOHNSTON 1991) and in forest biometrics (BORDERS, BAILEY 1986; BORDERS 1989). In 2SLS, regression instruments (instrumental variables) are obtained in the first stage by employing OLS to estimate the reduced form equation. The series of predicted values of RHS endogenous variables are then generated as regression instruments. These instruments are used in the second stage of estimation, where least squares procedures are employed to estimate the parameters of the structural equation by substituting the regression instruments for the RHS endogenous variables, when they appear as explanatory variables in a structural equation. These predicted RHS endogenous variables are uncorrelated with the error components of the LHS endogenous variables, and resulting parameter estimates are biased in small samples but consistent, and are asymptotically unbiased in large samples (KONTSOYIANNIS 1977).

Three-stage least squares (3SLS) method extends two-stage least squares (2SLS) by applying generalized least squares procedures in the estimation of structural equations. The variance-covariance weighting matrix used in the generalized least squares estimation is derived from the residuals obtained in the second stage of estimation in 2SLS. The 3SLS estimator takes into account the correlations of error terms across the equation, and makes use of the information that may be available concerning the variance-covariance matrix of the error terms across different structural equations. Resulting estimates of the parameters for the entire system from 3SLS are consistent and asymptotically more efficient than those obtained from 2SLS when the cross-equation correlations are significant. But when the cross-equation co-variances are all zero, 3SLS and 2SLS will yield identical estimates.

Two problems frequently encountered in a simultaneously interdependent system of equations are the identification and the choice of instruments. Application of simultaneous equation estimation techniques requires that each equation in a system of simultaneous equations must be exact- or over-identification (AMATEIS et al. 1984; JUDGE et al. 1985; BORDERS, BAILEY 1986; JOHNSTON 1991). Identification requires that certain rank and order conditions be satisfied, that means the necessary conditions (order conditions) and the sufficient conditions (rank conditions) must be required to be satisfied. Criteria have been developed in order to make the identification of systems of equations possible for the simultaneous equations model that is linear in parameters and variables. It should be noted that non-linearity of variables and parameters rather complicates the identification process (JUDGE et al. 1985; BORDERS, BAILEY 1986). Also, the theory of fitting nonlinear systems of related equations is not complete (BORDERS 1989). However, the problem is not serious enough. AMEMIYA (1988) pointed out that non-linearity generally helps rather than hampers identification. For example, the number of excluded endogenous variables in a given equation need not be greater than or equal to the number of parameters of the same equation in a non-linearity model. HAUSMAN (1988) also pointed out that, speaking somewhat loosely, the identification problem no longer exists in fitting the system of non-linearity equations. As discussed by REED (1986), Zellner estimation (i.e. SUR) and 3SLS can be extended to such systems. Each equation in the system of non-linearity equations (1)–(3) has over-identification according to the criteria set by AMEMIYA (1988).

The problem of finding instrumental variables for simultaneous linear equations is relatively simple and straightforward, because in the linear case the instrumental variables arise from the reduced form equation. All the predetermined variables including the exogenous variables, the lagged exogenous variables, and the lagged endogenous variables for the entire system are chosen as instruments (JUDGE et al. 1985). Finding a proper set of instrumental variables in the systems of non-linearity simultaneous equations is a very difficult problem, and the theory for doing so is not complete either (JUDGE et al. 1985; BORDERS 1989) because the crucial difference between the nonlinear and linear simultaneous equation specification is that the former is the absence of a reduced form specification which allows the additive separation of jointly endogenous variables into a function of the predetermined variables and stochastic disturbances in the linear case. In the nonlinear case the reduced form specification has a complicated function that does not usually exist in convenient closed form (HAUSMAN 1988). The most disturbing aspect of nonlinear simultaneous equation estimators is that they are not invariant with respect to the choice of instruments. Different sets of instrument variables can lead to quite different parameter estimates even though the model specification and data remain the same. But no best choice of instruments exists (HAUSMAN 1988). In general, it is necessary that the number of selected instrument variables shall be at least equal to the number of regression parameters to be estimated in order to maximize the efficiency of instrumental variables and to reduce the simultaneous equation bias.

The system of equations (1)–(3) estimated in this study and other examples presented in forestry literature (AMATEIS et al. 1984; BORDERS 1989) have a clear resemblance to a special case of simultaneous equations discussed in *Classification of equation systems* section.

That means they are the recursive system of equations from the equation structure point of view. Forest biometricians usually work with models which have recursive relation in nature (sequential relationships between some equations) but which also exhibit cross-equation correlation between error com- ponents. The endogenous variable $H2$ in equation (3) is not a function of other endogenous variables, but the endogenous variable $G2$ in equation (2) is a function of $H2$ in equation (3), and the endogenous variable $V2$ in equation (1) is a function of $H2$ in equation (3) and $G2$ in equation (2). Application of OLS method to each of the structural equations leads to unbiased, consistent, and asymptotically efficient parameter estimates if the variance-covariance matrix of the structural errors for the recursive system of equations is diagonal. The RHS endogenous variables will be correlated with the error components of the LHS endogenous variables if significant cross-equations are present and the system is not recursive by definition (BORDERS 1989). Furthermore, the consistent estimators will not be produced by implementing OLS. However, nonlinear 3SLS and SUR could be used to estimate parameters (BORDERS 1989).

COMPARISON OF ALTERNATIVE METHODS OF ESTIMATION

The methods of estimating structural equations of a general interdependent system, especially recursive system of equations, have been discussed. Therefore, it might be of interest to compare the results obtained from the system of equations (1) and (3) by the different estimation methods, which are nonlinear ordinary least squares (NOLS) and nonlinear three-stage least squares (N3SLS) and nonlinear seemingly unrelated regression (NSUR). The results from NOLS are shown and compared to N3SLS and NSUR because NOLS is commonly used in applied work. In this case comparing various estimators is like comparing different guns on the basis of one shot from each. All estimates are accomplished by using TSP 386 program (TSP International 1990). The Gauss-Newton iterative method using the Taylor series expansion as described in AMEMIYA (1988) was applied to all fits because an advantage of the Gauss-Newton iterative method over the Newton-Raphson iteration is that the former requires only the first derivatives of expanding function.

The criteria of comparison in different methods of estimation are calculated for each equation according to the following indicators.

(i) Root mean squared error (RMSE):

$$RMSE = [1/(n-p_j) \sum(y_i - \widehat{y_i})^2]^{1/2} \quad (4)$$

where: n is the total number of observations, p_j is the number of parameters in the j-th equation ($j = 1, 2, 3$), y_i and $\widehat{y_i}$ are observed and predicted values of the dependent variables ($i = 1, 2, ..., n$).

(ii) The coefficient of determination (R^2):

$$R^2 = 1 - \sum (y_i - \widehat{y_i})^2 / \sum (y_i - \overline{Y})^2 \quad (5)$$

where: $\overline{Y}$ is the observed average value of the dependent variables.

(iii) The mean of estimated biases (e):

$$e = (1/n) \sum (y_i - \widehat{y_i}) \quad (6)$$

For the system of equations presented above, the variance-covariance matrix of residuals from OLS should be tested if the off-diagonal elements are significantly different from zero using the Lagrange Multiplier statistic test proposed by BREUSCH and PAGAN (1980) and described in JUDGE et al. (1985), and another statistic test adapted from Anderson in 1958 as referenced by AMATEIS et al. (1984). For the system of three equations in this analysis, the Lagrange Multiplier test is used, and the null and alternative hypothesis for the Lagrange Multiplier statistic test can be written as:

$H_0 : \sigma_{12} = \sigma_{13} = \sigma_{23} = 0$
H_1: at least one covariance is nonzero

where: σ_{12}, σ_{13} and σ_{23} are the co-variances between equations (1) and (2), (1) and (3), (2) and (3), respectively. The Lagrange Multiplier test for the three-equation system is given by:

$$\lambda_{LM} = n \sum_{i=2}^{m} \sum_{j=1}^{i-1} r_{ij}^2 = n \ (r_{21}^2 + r_{31}^2 + r_{32}^2) \quad (7)$$

where: n is number of observations, r_{ij}^2 is the squared correlation between errors in equations i and j, and calculated by:

$$r_{ij} = \frac{\widehat{\sigma}_{ij}}{\sqrt{\widehat{\sigma}_{ii}\widehat{\sigma}_{jj}}} \quad (8)$$

where: $\widehat{\sigma}_{ii}$ is an alternative way of the error variance σ_i for the i-th equation, $\widehat{\sigma}_{ij}$ is residuals covariance between the i-th equation and the j-th equation. Under the null hypothesis H_0, λ has an asymptotic $\chi^2_{(M(M-1))/2}$ distribution with $(M(M-1))/2$ degrees of freedom. M is the number of endogenous variables in the system. The null hypothesis is rejected if λ is greater than the critical value from a $\chi^2_{(M(M-1))/2}$ distribution at a $\alpha = 0.05$ significance level. Variance and covariance of residuals are available from the TSP386 program (TSP International 1990).

Anderson test for the system of three equations is shown by:

$$A = [n - (2p + 11) / 6] \ \text{ln} w \quad (9)$$

where: w is a determinant of the correlation matrix of error terms which is calculated according to the variance and covariance matrix of residuals for equation system [e.g. the correlation matrix of error terms can be calculated by equation (8)], n is the number of observations, p is the number of endogenous variables in the system and χ^2 is chi-squared value with $f = p(p - 1)/2$ degrees of freedom and $\alpha = 0.05$ level. The null hypothesis is rejected if A is greater than the critical value from a χ^2 distribution at a $\alpha = 0.05$ significance level.

This means that the assumption of independence between equations in the system is not reasonable. Considering that the two statistic tests of the Lagrange Multiplier and Anderson have the same significance and that the former is widely used, therefore, the Lagrange Multiplier test is used to test the variance-covariance matrix of residuals in this study.

MATERIALS

Remeasurement data from a *Eucalyptus globulus* Labill. forest inventory conducted by the SILVICAIMA company in Portugal in 1990–1995 were used (see YUANCAI 1998). A total of 169 plots from 11 locations were used for this study. The plots were remeasured at least twice (90 plots). Some were measured three times (49 plots) and four times (30 plots). 447 observations were produced from 169 plots (Table 1). The non-over-

Table 1. Statistics of the data set used for selecting the variables of different measures (*n* = 447)

	V (m³/ha)	G (m²/ha)	H (m)	t (year)	S (m)	N (trees/ha)	CL
Min	0.7	0.3	4.5	2.7	9.82	161	1
Max	218.8	23.8	25.9	11.0	26.61	2,050	4
Range	218.1	23.5	21.4	8.3	16.78	1,889	3
Mean	55.85	8.38	13.85	6.58	18.41	855	–
Standard deviation	51.16	5.25	5.41	2.25	2.86	272.32	–

Note: H – stand dominant height (m), G – stand basal area (m²/ha), t – stand age (years), V – stand volume (m³/ha), S – site index (base age 10), CL – site class, N – number of trees (number of trees/ha).

lapping and non-descending growth interval data were compiled for stand growth and yield equations in this study. That means the growth intervals were obtained from the first and the second, the second and the third, and the third and the fourth measurements. Table 2 shows a summary of statistics for 169 sample plots or 278 ob-

Table 2. Statistics of the data set with non-overlapping and non-descending (*n* = 278)

	V2 (m³/ha)	V1 (m³/ha)	G2 (m²/ha)	G1 (m²/ha)	H2 (m)	H1 (m)	t2 (year)	t1 (year)
Min	3.4	0.7	1.0	0.3	6.7	4.5	3.7	2.7
Max	212.6	175.4	22	18.9	24.8	23.4	11	10
Range	209.2	174.7	21	18.6	18.1	18.9	7.3	7.3
Mean	93.25	68.71	11.83	9.47	17.58	14.87	8.06	6.31
Standard deviation	59.38	51.63	5.41	5.62	4.95	5.55	2.1	2.14

servations (according to the growth interval of t1 and t2), which are used to estimate the parameters of the system of equations (1), (2) and (3).

The equations developed by the SILVICAIMA company (not published) were used for estimating individual tree volume in cubic meters on the basis of each dbh and height of trees. The volume per hectare (m³/ha) is the sum of individual tree volume for eucalyptus plantations on the plots. The stand basal area for each plot, expressed by m²/ha, can be obtained by adding up the basal area of all the observed trees. The dominant height in meters is the arithmetic mean height of dominant eucalyptus trees.

RESULTS AND DISCUSSION

The upper half estimation of the variance matrix associated with the error terms of the component equations

Table 3. Variance-covariance matrix of residuals for the system of equations

	V2	G2	H2
V2	24.75658		
G2	0.84899	2.42168	
H2	0.49676	0.42061	1.41638

obtained from NOLS is shown in Table 3. Fitting statistics including the estimates of the parameters, the parameter standard errors and the ratio of the estimates to the standard errors from NOLS, N3SLS and nonlinear SUR methods are listed in Table 4. The root mean squared error (RMSE), the coefficient of determination (R^2), the mean of estimated biases (*e*) and other statistic values calculated according to (4), (5) and (6) for each of the three equations in the system are presented in Table 5.

In order to examine the variance and covariance matrix of the error terms in the system fitted by OLS method, the results from Table 3 are used. The Lagrange Multiplier statistic test of variance and covariance matrix of residuals for this system is calculated according to equations (7) and (8).

$$r^2_{21} = 0.84899^2/(2.41478 \cdot 24.75658) = 0.01206$$
$$r^2_{31} = 0.49678^2/(1.41638 \cdot 24.75658) = 0.00704$$
$$r^2_{32} = 0.42061^2/(1.41638 \cdot 2.41478) = 0.05173$$
$$\lambda = 278 (0.01206 + 0.00704 + 0.05173) = 19.6907$$

The critical value from a χ^2 distribution with 3 degrees of freedom at $\alpha = 0.05$ significance level is 7.81. Hence, the null hypothesis of zero co-variances is rejected and the cross-equation correlation is significant. The result calculated above indicates that the residuals of the cross-equation are correlated. Although the system of equations (1)–(3) is a recursive system, there are mutually correlated regression disturbances between the equations. Therefore, the system is not appropriately estimated using NOLS because NOLS applied to separate equations will not yield theoretically sound estimators, and will produce inconsistent or inefficient parameter estimates.

The fitted statistics in Table 4 indicate that the estimated coefficients using the three techniques do not appear to be markedly different. The standard errors of the coefficients from NOLS are generally smaller than those from N3SLS and NSUR. However, the NOLS estimates are inconsistent in theory so that the confidence intervals can be misleading and hypothesis tests cannot be appropriately performed. It is evident from Table 4 that the standard errors of the coefficients from NSUR are generally smaller than those from N3SLS. The possible explanation in this case is that N3SLS lacks an appropriate set of instruments to achieve the most efficient estimates. Nevertheless, NSUR method emphasizes maintaining the original nonlinear forms of the equations rather than choosing the proper instrumental variables, so that it enhances the significance of keeping the appropriately identified equation forms. For this particular example, if a comparison of the fitting techniques is made in terms

Table 4. Parameter estimation for a system of equations using NOLS, N3SLS and NSUR

Equation parameters	NOLS			N3SLS			NSUR		
	Estimation	Std. err.	t-ratio	Estimation	Std. err.	t-ratio	Estimation	Std. err.	t-ratio
(1)									
$a1$	−2.65829	0.191966	−13.8478	−3.07355	0.277428	−11.0787	−2.81399	0.193626	−14.5331
$a2$	−5.08874	0.659865	−7.71178	−4.36783	1.06747	−4.09176	−5.01301	0.669453	−7.48821
$a3$	1.00389	0.024833	40.4264	0.979842	0.061796	15.8561	0.979822	0.025009	39.1782
(2)									
$c1$	2.97718	0.095463	31.1867	3.03158	0.134876	22.4768	3.16467	0.094166	33.6074
$c2$	0.64155	0.134203	4.78049	0.548154	0.20228	2.70988	0.32935	0.135081	2.43818
(3)									
$b0$	29.3852	1.22142	24.0582	28.7501	1.20589	23.8414	29.4300	1.21748	24.1729
$b1$	0.131026	0.014601	8.97401	0.138039	0.015893	8.68532	0.129012	0.014259	9.04803

Table 5. Comparison of the different fitting techniques for the system of equations

Equation	Method	R^2	RMSE	e	Min e_i	Max e_i
(1)	NOLS	0.9931	5.0055	0.0929	−17.2991	21.0225
	N3SLS	0.9930	5.0339	0.00631	−18.0542	21.9957
	N-SUR	0.9931	5.0281	0.21047	−17.6522	21.9118
(2)	NOLS	0.9206	1.5608	0.0187	−6.1519	5.9674
	N3SLS	0.9205	1.5630	0.04039	−6.2694	6.0317
	N-SUR	0.9188	1.5747	0.07451	−6.5606	6.1755
(3)	NOLS	0.9442	1.1937	−0.0173	−2.8014	3.4687
	N3SLS	0.9444	1.1879	−0.0063	−2.8553	3.5073
	N-SUR	0.9442	1.1939	0.00157	−2.7677	3.490

Note: R^2, RMSE, and e are calculated according to equation (4), (5) and (6), Min e_i and Max e_i are the observed and fitted mean values of the endogenous variables

of the standard errors of parameter estimation in this system, the nonli-near SUR procedure provides more acceptable parameter estimates due to their smaller standard errors than those obtained from N3SLS (Table 4).

A comparison of the fitting techniques is also made in terms of the coefficient of determination (R^2), the root mean squared error (RMSE) and the mean of estimated biases (e) values commonly reported in regression analysis. The results in Table 5 indicate that different estimation methods give almost the same R^2 and RMSE values. For equations (1) and (2), with the exception of equation (3), the NOLS tends to have the highest R^2 values and the lowest RMSE values. The differences are, however, minimal. This is expected because the NOLS minimizes the sum of error squares, and the R^2 and RMSE generally produce the most favorable results for the NOLS from the sum of error squares. In many other comparison studies between system methods and ordinary least squares technique (MURPHY 1983; AMATIES et al. 1984; BORDERS, BAILEY 1986; LYNCH, MURPHY 1995), the R^2 and RMSE values also favored the ordinary least squares. Strictly speaking, at least from the point of view of hypothesis testing or interval estimation, the R^2 and RMSE values from NOLS are not directly comparable to those from system methods because estimates obtained from the NOLS are inconsistent, and the ordinary least squares method tends to give smaller

but inappropriate error variances. From Table 5, the predicted endogenous variables from three estimated methods are compared to the observed values. The mean values of the estimated biases indicate that both the stand yield equation and the stand basal area equation are slightly underestimated by the three methods, while the stand dominant height equation is slightly underestimated by NSUR but overestimated by NOLS and N3SLS. In particular, the NOLS estimators tend to have a larger bias but a smaller variance than the N3SLS for equations (1) and (3).

In general, in some cases of the particular example, the NOLS estimator performs better than N3SLS or nonlinear SUR, in others worse, and sometimes about the same. The differences between the methods are very small in Table 5. These results are very consistent with those of the previous applications (MURPHY 1983; AMATEIS et al. 1984; BORDERS, BAILEY 1986; LYNCH, MURPHY 1995). Although these data were used by different methods, the system of three equations performed similarly in practice, the N3SLS and nonlinear SUR look more theoretical.

As an example of the use of the equations including different estimation methods, let us suppose that the current inventory information in a 5-year old plantation shows that stand dominant height ($H1$) is 16.6 m, that stand basal area per hectare ($G1$) is 12.86 m²/ha, and that stand volume yield (over bark) per hectare ($V1$) is 49.9 m³/ha. Equations (1), (2) and (3) can now be used to estimate future stand characteristics at the age of 10 years. With the age (t_1) of 5 years and $H1$ of 16.6 m, $H2$ from equation (3) in NOLS, N3SLS and NSUR is estimated as 23.1 m, 22.88 m and 22.97 m, respectively. Equation (2) estimates that at age 10, $G2$ will be 18.2 m²/ha by NOLS, 18.97 m²/ha by N3SLS and 19.12 m²/ha by NSUR, respectively. Substituting these current and future stand characteristics into equation (1) and according to the same procedures provides an estimation of stand volume yield as 104.8 m³/ha, 106 m³/ha and 106.2 m³/ha, respectively. The estimations of stand volume yield per hectare showed obviously different values in relation to the estimated volume growth in the stand when the projection is made for different periods (3 years interval instead of

5 years interval). If a manager goes through this procedure for every year, he can develop a mean annual increment (MAI) curve to aid him to make management decisions.

For predicting eucalyptus plantation growth and yield, the system of equations in different estimation methods can be expressed as follows:

NOLS method,

$$V2 = V1 \ e^{[-2.6583(1/t2 - 1/t1) - 5.0887(1/H2 - 1/H1) + 1.0039(\ln G2 - \ln G1)]}$$
$$G2 = e^{[(t1/t2) \ln G1 + 2.9772(1 - t1/t2) + 0.6416(1 - H1/H2)]}$$
$$H2 = 29.3852 \ ^{\{1 - [\ln(1 - e^{-0.131 \ t2})]/[\ln(1 - e^{-0.131 \ t1})]\}} H1 \ ^{[\ln(1 - e^{-0.131 \ t2})/\ln(1 - e^{-0.131 \ t1})]}$$

N3SLS method,

$$V2 = V1 \ e^{[-3.0736(1/t2 - 1/t1) - 4.3678(1/H2 - 1/H1) + 0.9798(\ln G2 - \ln G1)]}$$
$$G2 = e^{[(t1/t2) \ln G1 + 3.0316(1 - t1/t2) + 0.5482(1 - H1/H2)]}$$
$$H2 = 28.7501 \ ^{\{1 - [\ln(1 - e^{-0.138 \ t2})]/[\ln(1 - e^{-0.138 \ t1})]\}} H1 \ ^{[\ln(1 - e^{-0.138 \ t2})/\ln(1 - e^{-0.138 \ t1})]}$$

NSUR method,

$$V2 = V1 \ e^{[-2.8140(1/t2 - 1/t1) - 5.013(1/H2 - 1/H1) + 0.9798(\ln G2 - \ln G1)]}$$
$$G2 = e^{[(t1/t2) \ln G1 + 3.1647(1 - t1/t2) + 0.3294(1 - H1/H2)]}$$
$$H2 = 29.43 \ ^{\{1 - [\ln(1 - e^{-0.129 \ t2})]/[\ln(1 - e^{-0.129 \ t1})]\}} H1 \ ^{[\ln(1 - e^{-0.129 \ t2})/\ln(1 - e^{-0.129 \ t1})]}$$

CONCLUSIONS

A simultaneously interdependent system of three nonlinear equations for predicting stand volume yield, stand basal area and stand dominant height growth has been presented and discussed for eucalyptus plantations grown in the Central interior of Portugal. The ordinary least squares (OLS) estimation method and system estimation methods such as seemingly unrelated regression (SUR) and three-stage least squares (3SLS) from econometrics were used to estimate the structural parameters simultaneously, and then the statistics of estimated results from the system methods were compared to those obtained from ordinary least squares. The results indicate that there is a small difference between the three approaches in the particular case but the system estimation methods perform better for the simultaneously interdependent system of equations in theory, especially, the 3SLS technique accounts for both simultaneity bias and contemporaneous correlations of the system of equations. Therefore, the appropriate system estimation methods are recommended for estimating parameters in simultaneously interdependent systems of forestry equations. Moreover, when there is a demand for the parameters to be the same in both the growth and yield equations in the system of equations, the system estimation methods would be more adequate than the ordinary least squares method.

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Simultánní modelování výnosu, horní výšky a výčetní základny porostu růstovými modely

L. YUANCAI[1], C. P. MARQUES[2], J. M. BENTO[2]

[1]*Výzkumný ústav informačních technologií pro lesní fond, Čínská akademie zemědělská, Peking, Čína*

[2]*Universidade de Trás-os-Montes e Alto Douro, lesnická katedra, Vila Real, Portugalsko*

ABSTRAKT: Růstové a výnosové modely lesa jsou často složeny ze systému kompatibilních, navzájem nezávislých a analyticky souvisejících rovnic spíše než z jedné rovnice. Většina lesnických vědeckých pracovníků již uznává, že systém dynamiky lesních porostů by měl být popisován systémem simultánních a navzájem závislých rovnic. Pro odhad koeficientů v modelu systému růstu a výnosu lesa se často používají regresní dvoustupňové a třístupňové metody nejmenších čtverců (2SLS a 3SLS) a metoda SUR (seemingly unrelated regression) z ekonometrie. Studie analyzuje soustavu tří vzájemně nezávislých rovnic použitých pro předpověď budoucího výnosu porostu, budoucí horní výšky porostu a budoucí výčetní základny porostů v eukalyptových kulturách jako uceleného systému daného počátečními podmínkami. Koeficienty systému se odhadovaly z dat o porostech *Eucalyptus globulus* Labill. ve středním Portugalsku použitím metod 3SLS, SUR a OLS. Tyto tři metody jsou srovnány a vyhodnoceny na základě stejných statistických ukazatelů. Výsledky naznačují, že mezi těmito třemi přístupy je v daném konkrétním případě malý rozdíl, ale teoreticky tyto systémové metody odhadu fungují lépe u současně vzájemně závislých systémů rovnic. Proto jsou doporučeny patřičné přístupy k odhadu systému pro odhad koeficientů současně navzájem závislého systému lesnických rovnic.

Klíčová slova: porovnání; růstový a výnosový model; simultánní rovnice

Corresponding author:

Dr. LEI YUANCAI, Research Institute of Forest Resource Information Technique, Chinese Academy of Forestry, Beijing 100091, P. R. China, tel.: 0086 10 62 88 91 99, fax: 0086 10 62 88 83 15, e-mail: lycai@info.forestry.ac.cn

Analyses of seed quality and germination in the Swiss Mountain Pine (*Pinus mugo* TURRA)

L. Hrabí

Palacký University, Faculty of Pedagogy, Olomouc, Czech Republic

ABSTRACT: This paper contains specific knowledge of detailed qualitative analyses of seeds of the Swiss Mountain Pine (*Pinus mugo* TURRA). Anatomical analyses, biochemical analyses and tests of germination were realized in 19 different individuals (from 19 areas) during four years of study. Uncommon results were obtained – incompletely developed embryos, polyembryony and abnormally germinating seeds.

Keywords: seeds of Swiss Mountain Pine; detailed analyses; incompletely developed seeds; polyembryony; abnormally germinating seeds

For many years nongerminating seeds or seeds with low germination have accounted for a large portion of Swiss Mountain Pine seed production (JURÁSEK et al. 1992; LOKVENC, ŠTURSA 1985). Some authors tried to stimulate seed germination by different physical and chemical methods (GOLJADKIN 1972; WORKS, BOVO 1972). Their future practical use has not been verified yet, and there is not much information about morphological, biochemical and cytogenetic seed analyses (BEWLEY, BLACK 1986).

The condition of the morphologically developed Swiss Mountain Pine seed is that the embryo takes more than 2/3 of the axial duct length (KHAN 1977). According to BEWLEY and BLACK (1986), ŠČERBAKOVA (1966) non-vital seeds are those in which the polyembryony exist. Morphological changes are probably connected with biochemical processes. The seed quality is investigated by the biochemical tetrazolium test (ČSN 48 1211 Zkoušky jakosti plodů a semen lesních dřevin [Fruit and Seed Quality Tests in Forest Tree Species]; REHAP 1983). Other methods are based on quantitative and qualitative changes of saccharides in seeds (SIMANČÍK 1967). It is only known from the cytogenetic analysis that plant species with big cell nuclei and low number of chromosomes are more sensitive to UV (ultraviolet) radiation than those with small nuclei and high chromosome number (KOVÁČIK et al. 1976), and that a standard karyotype of the Swiss Mountain Pine contains 24 chromosomes (PAZOURKOVÁ, PAZOUREK 1960).

It is clear according to the above-mentioned information that no complex qualitative investigation of the Swiss Mountain Pine seeds has been made until now. That is

why the aim of this experimental investigation was to study the vitality and quality of seeds and germination processes.

MATERIAL AND METHODS

The investigation was carried out for 4 years. Seeds from 19 individuals and from 19 areas of the Krkonoše Mts. (altitude 1,100–1,530 m a.s.l.) were examined. The origin of seed samples is given at the end of the Results section. After collection, seed extraction at 45°C and dewinging the seed analyses were made:

a) content of full seeds (4 × 100 from each sample), according to the Standard ČSN 48 2111 Jakost plodů a semen lesních dřevin (Fruit and Seed Quality in Forest Tree Species);

b) anatomical structure – content of vital and nonvital seeds (4 × 100 from each sample), analysed at the longitudinal section under a stereomicroscope Olympus (magnified 5 times), as nonvital were considered seeds with small embryos – smaller than 2/3 of the longitudinal length of the axial duct and seeds with 2 and more embryos – polyembryony;

c) biochemical analysis – study of seed vitality in tetrazolium solution (prepared and applied according to the Standard ČSN 48 2111); the development and colour were examined at a longitudinal section (4 × 100 seeds of each sample) under a stereomicroscope Olympus (magnified 5 times); nonvital seeds had other than red colour;

d) after these anatomical and biochemical analyses of each sample, the tests of germination (according to the

Table 1. Results of qualitative analyses and germination tests of the Swiss Mountain Pine seeds during the first year of investigations (Kleč I)

Altitude (m a.s.l.)	Sample	Content of full seeds (%)	Anatomical analyses (%)		Biochemical analyses (%)			Germination tests (%)		
			vital	nonvital	vital	nonvital	polyem-bryony	germinative energy	germination	anomalies
1,530	Kleč 1	43.0	35.0	65.0	28.3	64.9	6.8	1.5	6.5	0.8
1,480	Kleč 2	74.8	96.3	3.7	94.8	1.4	3.8	19.5	94.5	5.5
1,460	Kleč 3	60.3	33.3	63.7	25.0	74.2	0.8	1.8	16.8	0.5
1,420	Kleč 4	72.0	81.0	19.0	76.3	22.9	0.8	1.5	47.8	1.8
1,400	Kleč 5	72.3	66.3	33.7	61.8	31.9	6.3	15.8	58.5	4.5
1,390	Kleč 6	46.0	78.5	20.0	77.3	16.2	6.5	7.5	76.0	5.8
1,370	Kleč 7	71.0	48.8	51.2	47.8	51.7	0.5	1.8	42.0	0.5
1,360	Kleč 8	82.5	82.5	17.5	85.0	9.5	5.5	12.5	83.3	5.3
1,340	Kleč 9	57.3	99.0	1.0	96.5	2.0	1.5	38.0	98.3	1.5
1,320	Kleč 10	76.0	59.8	40.2	56.3	39.9	3.8	7.5	58.0	4.0
1,310	Kleč 11	93.3	16.3	83.7	12.5	87.2	0.3	0.5	3.5	0.0
1,300	Kleč 12	85.8	80.8	19.2	75.5	18.5	6.0	10.0	45.3	2.5
1,270	Kleč 13	68.5	24.0	76.0	23.5	74.2	2.3	3.0	10.5	0.5
1,265	Kleč 14	84.3	27.8	72.2	20.5	74.5	5.0	0.8	11.0	0.0
1,250	Kleč 15	73.3	79.0	21.0	76.5	16.0	7.5	10.5	77.8	2.8
1,200	Kleč 16	58.0	93.5	6.5	87.8	8.4	3.8	19.5	85.0	0.8
1,150	Kleč 17	58.0	96.0	4.0	97.3	2.7	0.0	27.8	98.3	8.0
1,120	Kleč 18	68.0	99.5	0.5	95.8	3.2	1.0	51.0	97.8	4.0
1,100	Kleč 19	80.0	96.5	3.5	92.5	7.0	0.5	47.8	89.8	2.0

Standard ČSN 48 1211 Sběr, jakost a zkoušky jakosti plodů a semen lesních dřevin [Collection, Quality and Quality Tests of Forest Tree Fruits and Seeds]) were carried out. Some anomalies during the process of germination were observed. Data on the germinative energy, germination, seed quality were statistically processed by arithmetical means and regression analyses in the different years of study (designated as Kleč I, Kleč II, Kleč III and Kleč IV).

RESULTS

The results of anatomical analyses, biochemical analyses and germination tests are given in Tables 1–8.

The first year of investigations

Data in Table 1 show that the content of full seeds was between 43 and 93.3% in different samples, content of vital seeds according to the anatomical analyses ranged from 16.3% to 99.5% and according to the biochemical analyses from 12.5% to 97.3%. The polyembryony was evident in 0.3–7.5% of the samples (with the exception of 1 sample). The results of germination tests show that germinative energy was 0.5–51.0% and germination amounted to 3.5–98.3%. Anomalies during the germination tests were found in seeds of many samples and they accounted for 8%. They were indicated by germination of green parts of epicotyls (see Fig. 1c).

Fig. 1 illustrates the unusually developed and nongerminating seeds and specifically germinating seed.

Fig. 2 shows a completely developed embryo of the Swiss Mountain Pine seed as seen under an electron microscope REM-JSM-35-Jeol.

Statistical analyses (Table 2) document significant correlations between altitude and content of full seeds and significant correlations between altitude and the germinative energy and germination. There was no statistically significant correlation between altitude and polyembryony.

The second year of investigations

Results of these analyses are shown in Tables 3 and 4. Content of full seeds ranged from 38.0% to 96.5%. Con-
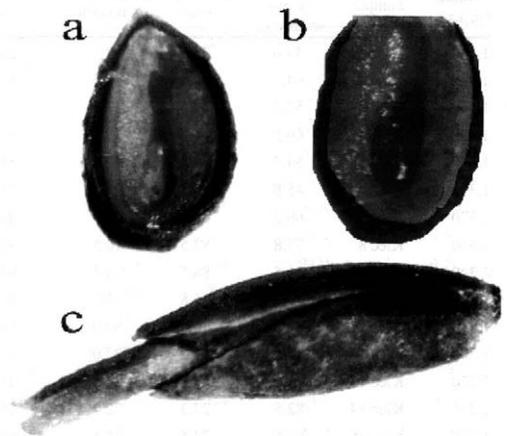

Fig. 1. The incompletely developed embryos and the atypically germinating Swiss Mountain Pine seed (a – polyembryony, b – incompletely developed embryo, c – atypically germinating seed)
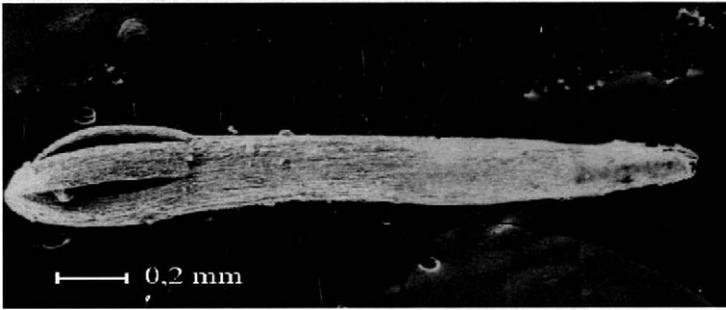
Fig. 2. The completely developed embryo of the Swiss Mountain Pine seed

Table 2. Regression analyses: influence of altitude on the quality of the Swiss Mountain Pine seeds during the first year of investigations (Kleč I)

$y_1 = 114.220 - 0.034 \, x_1$	$r = -0.327$	$r^2 = 0.107*$
$y_2 = 146.039 - 0.060 \, x_1$	$r = -0.266$	$r^2 = 0.071$
$y_3 = 147.645 - 0.064 \, x_1$	$r = -0.272$	$r^2 = 0.078$
$y_4 = -4.176 + 5.767 \cdot 10^{-3} \, x_1$	$r = 0.280$	$r^2 = 0.078$
$y_5 = 104.033 - 0.068 \, x_1$	$r = -0.549$	$r^2 = 0.302*$
$y_6 = 173.578 - 0.089 \, x_1$	$r = -0.326$	$r^2 = 0.106*$
$y_7 = 3.718 - 8.054 \cdot 10^{-4} \, x_1$	$r = -0.044$	$r^2 = 0.002$

Note: y_1 – content of full seeds; y_2 – anatomical analysis; y_3 – biochemical analysis; y_4 – polyembryony; y_5 – germinative energy; y_6 – germination; y_7 – anomaly of germination; r – correlation coefficient; x_1 – altitude; * – significant correlation between variables

tent of vital seeds according to the anatomical analyses was between 25.3% and 96.0% and according to the biochemical analyses between 25.3% and 92.0%. Polyembryony was evident in 0.3–6% of the samples. Germination amounted to 5.0–93.0%. Anomalies during

germination tests were similar to those of the previous year. They were evident in all samples with the exception of one – accounting for 7%.

Statistical analyses (Table 4) show significant correlations between altitude and content of full seeds and between altitude and vitality according to the anatomical analyses and between altitude and germinative energy. There was no statistically significant correlation between altitude and polyembryony.

The third year of investigations

Data in Table 5 show that the content of full seeds in different samples was between 45.8% and 92%, content of vital seeds according to the anatomical analyses amounted to 32.3–94% and according to the biochemical analyses it ranged from 22.3% to 98.5%. Polyembryony was evident in all samples and accounted for maximally 9%. The results of germination tests show that germinative energy ranged from 0.8% to 50.5 % and germination amounted to 7.3–97.5%. Anomalies during the

Table 3. Results of qualitative analyses and germination tests of the Swiss Mountain Pine seeds during the second year of investigations (Kleč II)

Altitude (m a.s.l.)	Sample	Content of full seeds (%)	Anatomical analyses (%)		Biochemical analyses (%)			Germination tests (%)		
			vital	nonvital	vital	nonvital	polyembryony	germinative energy	germination	anomalies
1,530	Kleč 1	38.0	25.3	72.7	26.8	68.4	4.8	2.5	6.0	0.3
1,480	Kleč 2	64.5	89.5	10.5	82.5	15.7	1.8	14.3	82.3	4.8
1,460	Kleč 3	52.3	42.5	57.5	34.5	65.2	0.3	4.8	93.0	0.8
1,420	Kleč 4	66.5	71.8	28.2	69.0	30.0	1.0	8.3	94.3	0.5
1,400	Kleč 5	54.5	54.8	45.2	54.0	45.7	0.3	9.8	47.0	2.8
1,390	Kleč 6	45.8	79.5	20.5	73.8	26.2	0.0	13.3	68.3	3.0
1,370	Kleč 7	66.3	53.3	45.7	48.5	47.2	4.3	11.5	35.8	4.5
1,360	Kleč 8	77.8	83.5	16.5	81.5	12.7	5.8	11.3	84.5	0.0
1,340	Kleč 9	51.5	88.5	11.5	91.3	8.4	0.3	30.0	91.3	1.8
1,320	Kleč 10	72.0	66.8	33.2	56.5	41.5	2.0	24.8	83.5	0.3
1,310	Kleč 11	96.5	20.0	80.0	16.0	83.7	0.3	3.5	5.0	1.8
1,300	Kleč 12	82.8	73.0	27.0	77.8	16.2	6.0	11.3	54.0	0.0
1,270	Kleč 13	71.0	33.5	66.5	28.8	70.7	0.5	4.5	16.3	0.3
1,265	Kleč 14	82.5	27.3	72.7	25.3	74.7	0.0	2.3	16.0	0.0
1,250	Kleč 15	60.5	74.5	25.5	64.8	31.9	3.3	22.5	46.3	1.0
1,200	Kleč 16	56.5	87.5	12.5	77.3	22.7	0.0	22.8	80.5	1.3
1,150	Kleč 17	64.0	95.5	4.5	92.0	7.7	0.3	20.0	91.5	4.3
1,120	Kleč 18	72.8	96.0	4.0	89.3	10.7	0.0	22.5	91.8	7.0
1,100	Kleč 19	73.3	94.3	5.7	91.5	3.2	5.3	44.8	86.8	0.0

Table 4. Regression analyses: influence of altitude on the quality of the Swiss Mountain Pine seeds during the second year of investigations (Kleč II)

$y_1 = 139.695 - 0.057\,x_1$	$r = -0.508$	$r^2 = 0.258^*$
$y_2 = 155.102 - 0.063\,x_1$	$r = -0.314$	$r^2 = 0.099$
$y_4 = 0.110 + 1.389.10^{-3}\,x_1$	$r = 0.079$	$r^2 = 0.006$
$y_5 = 77.453 - 0.048\,x_1$	$r = -0.553$	$r^2 = 0.306^*$
$y_6 = 96.730 - 0.027\,x_1$	$r = -0.105$	$r^2 = 0.011$
$y_7 = 3.437 - 1.250 \cdot 10^{-3}\,x_1$	$r = -0.077$	$r^2 = 0.006$

Note: y_1 – content of full seeds; y_2 – anatomical analysis; y_3 – biochemical analysis; y_4 – polyembryony; y_5 – germinative energy; y_6 – germination; y_7 – anomaly of germination; r – correlation coefficient; x_1 – altitude; * – significant correlation between variables

Table 6. Regression analyses: influence of altitude on the quality of the Swiss Mountain Pine seeds during the third year of investigations (Kleč III)

$y_1 = 110.709 - 0.029\,x_1$	$r = -0.306$	$r^2 = 0.094$
$y_2 = 138.622 - 0.052\,x_1$	$r = -0.269$	$r^2 = 0.073$
$y_3 = 154.238 - 0.066\,x_1$	$r = -0.352$	$r^2 = 0.124^*$
$y_4 = -11.679 + 0.011\,x_1$	$r = 0.521$	$r^2 = 0.271^*$
$y_5 = 94.069 - 0.060\,x_1$	$r = -0.502$	$r^2 = 0.252^*$
$y_6 = 151.983 - 0.073\,x_1$	$r = -0.292$	$r^2 = 0.085$
$y_7 = 1.690 + 1.112 \cdot 10^{-3}\,x_1$	$r = 0.053$	$r^2 = 0.003$

Note: y_1 – content of full seeds; y_2 – anatomical analysis; y_3 – biochemical analysis; y_4 – polyembryony; y_5 – germinative energy; y_6 – germination; y_7 – anomaly of germination; r – correlation coefficient; x_1 – altitude; * – significant correlation between variables

germination tests were observed in a majority of the samples, accounting for 8.3% (Fig. 1c).

Statistical analyses (Table 6) document significant correlations between altitude and vitality (biochemically analysed seeds) and between polyembryony and germinative energy. No statistically significant correlation was determined between altitude and germination.

The fourth year of investigations

Table 7 shows the results of these analyses. Content of full seeds amounted to 54–78.3%. Content of vital seeds according to the anatomical analyses ranged from 25.8% to 96% and according to the biochemical analyses from 24.3% to 94.8%. Polyembryony was evident in all samples and its maximal value was 7%. Tests of germination show that germinative energy amounted to 4.5–34.5%

and germination to 7.8–93.3%. Anomalies during the germination tests were similar to those of previous tests (maximal value – 4.8%).

Statistical analyses (Table 8) show significant correlations between altitude and content of full seeds and other factors, but with the exception of polyembryony.

All 4 years of investigations into the qualitative characteristics provide these common results: incompletely developed embryos, polyembryony, anomalies during germination tests, significant correlation between altitude and content of full seeds, no correlation with polyembryony, no similar trend in other qualitative characteristics during the four years of study.

These results are important for a more complex study to be carried out in future.

Origin of samples: Kleč 1 – Luční hora; Kleč 2 – Stříbrná bystřina; Kleč 3 – Šarfova bouda; Kleč 4 – Úpské

Table 5. Results of qualitative analyses and germination tests of the Swiss Mountain Pine seeds during the third year of investigations (Kleč III)

Altitude (m a.s.l.)	Sample	Content of full seeds (%)	Anatomical analyses (%)		Biochemical analyses (%)			Germination tests (%)		
			vital	nonvital	vital	nonvital	polyembryony	germinative energy	germination	anomalies
1,530	Kleč 1	45.8	39.5	57.5	34.5	56.5	9.0	4.0	7.3	0.3
1,480	Kleč 2	70.3	92.5	7.5	82.3	15.2	2.5	25.3	84.3	4.3
1,460	Kleč 3	64.5	36.8	63.2	35.3	62.4	2.3	3.0	17.8	0.0
1,420	Kleč 4	80.0	85.8	14.2	79.5	18.2	2.3	5.0	65.0	8.3
1,400	Kleč 5	75.8	69.8	28.2	67.8	23.7	8.5	12.0	50.0	3.8
1,390	Kleč 6	52.8	88.0	10.0	84.0	11.2	4.8	21.0	78.3	4.5
1,370	Kleč 7	82.8	55.5	44.5	53.3	43.2	3.5	5.5	36.8	2.0
1,360	Kleč 8	83.5	84.5	15.5	83.3	13.9	2.8	20.0	38.3	7.5
1,340	Kleč 9	60.5	91.0	9.0	80.8	17.9	1.3	28.8	94.0	4.5
1,320	Kleč 10	83.5	73.5	26.5	74.3	19.7	6.0	8.0	66.3	3.8
1,310	Kleč 11	92.0	32.3	67.7	22.3	77.7	0.0	1.0	5.0	0.3
1,300	Kleč 12	80.8	87.0	13.0	84.3	11.7	4.0	11.3	59.8	1.8
1,270	Kleč 13	63.5	32.3	67.7	24.5	75.2	0.3	3.3	15.5	0.0
1,265	Kleč 14	83.8	35.3	64.7	28.5	69.5	2.0	0.8	13.5	0.3
1,250	Kleč 15	74.0	84.0	16.0	77.5	15.7	6.8	14.5	74.5	5.5
1,200	Kleč 16	59.0	93.3	6.7	87.8	9.2	3.0	18.8	80.0	1.0
1,150	Kleč 17	65.3	92.5	7.5	85.8	13.9	0.3	28.3	92.3	6.3
1,120	Kleč 18	72.0	94.0	6.0	98.5	1.5	0.0	50.5	97.5	4.3
1,100	Kleč 19	82.0	92.8	7.2	92.3	7.4	0.3	50.5	65.5	1.0

Table 7. Results of qualitative analyses and germination tests of the Swiss Mountain Pine seeds during the fourth year of investigations (Kleč IV)

Altitude (m a.s.l.)	Sample	Content of full seeds (%)	Anatomical analyses (%)		Biochemical analyses (%)			Germination tests (%)		
			vital	nonvital	vital	nonvital	polyem-bryony	germinative energy	germination	anomalies
1,530	Kleč 1	54.0	25.8	73.2	24.3	70.9	4.8	4.5	7.8	0.0
1,480	Kleč 2	68.8	88.5	11.5	88.3	9.4	2.3	23.5	87.3	4.8
1,460	Kleč 3	59.8	35.0	65.0	30.3	69.4	0.3	5.8	26.5	0.8
1,420	Kleč 4	62.5	78.0	22.0	75.0	21.2	3.8	24.8	64.5	1.3
1,400	Kleč 5	72.5	57.5	42.5	54.8	40.2	5.0	8.5	54.0	2.3
1,390	Kleč 6	55.8	73.8	23.2	70.5	23.2	6.3	11.8	65.3	0.3
1,370	Kleč 7	71.8	45.5	54.5	39.5	60.5	0.0	8.0	34.8	2.0
1,360	Kleč 8	68.8	35.8	64.2	39.5	57.0	3.5	5.3	31.8	0.3
1,340	Kleč 9	52.0	96.0	4.0	94.8	3.4	1.8	33.5	86.8	1.8
1,320	Kleč 10	67.8	58.8	41.2	57.5	37.7	4.8	15.8	35.5	0.3
1,310	Kleč 11	76.0	82.8	27.2	77.0	20.5	2.5	26.8	72.8	1.3
1,300	Kleč 12	66.5	55.5	44.5	54.0	40.2	5.8	5.8	34.8	0.3
1,270	Kleč 13	75.5	73.8	26.2	66.8	26.2	7.0	23.8	53.5	1.0
1,265	Kleč 14	77.0	47.5	52.5	47.8	52.2	0.0	14.0	33.0	0.3
1,250	Kleč 15	73.3	77.0	23.0	74.8	27.2	2.5	25.8	55.0	0.0
1,200	Kleč 16	57.8	80.8	19.2	78.8	20.2	1.0	32.5	84.3	0.3
1,150	Kleč 17	67.0	91.0	9.0	87.3	11.2	1.5	34.5	76.0	0.0
1,120	Kleč 18	76.8	95.5	4.5	94.0	4.2	1.8	26.8	90.5	0.0
1,100	Kleč 19	78.3	87.3	12.7	88.3	11.2	0.5	16.8	93.3	0.3

rašeliniště; Kleč 5 – Labská bouda; Kleč 6 – Krkonoš; Kleč 7 – Růžová hora; Kleč 8 – Liščí hora; Kleč 9 – Lysá hora; Kleč 10 – Velká Mumlava; Kleč 11 – Kotel; Kleč 12 – Tvarožník; Kleč 13 – Vosecká bouda; Kleč 14 – Šmídova vyhlídka; Kleč 15 – Vosecká bouda – forest stand; Kleč 16 – Černohorské rašeliniště; Kleč 17 – Pančavská jáma; Kleč 18 – Dvoračky-U hájenky; Kleč 19 – Dvoračky – a piste.

DISCUSSION

Referring to the practical knowledge of some authors (KHAN 1977; LOKVENC, ŠTURSA 1985; JURÁSEK et al. 1992), this study was concerned with some important aspects, qualitative analyses, germination tests and anomalies of the Swiss Mountain Pine seeds from the Krkonoše Mts.

Table 8. Regression analyses: influence of altitude on the quality of the Swiss Mountain Pine seeds during the fourth year of investigations (Kleč IV)

$y_1 = 113.274 - 0.035\ x_1$ $r = -0.536$ $r^2 = 0.288*$
$y_2 = 189.255 - 0.094\ x_1$ $r = -0.540$ $r^2 = 0.292*$
$y_3 = 188.728 - 0.095\ x_1$ $r = -0.550$ $r^2 = 0.302*$
$y_4 = -2.568 + 4.222.10^{-3}\ x_1$ $r = 0.242$ $r^2 = 0.059$
$y_5 = 71.991 - 0.041\ x_1$ $r = -0.504$ $r^2 = 0.254*$
$y_6 = 183.474 - 0.973\ x_1$ $r = -0.482$ $r^2 = 0.232*$
$y_7 = -5.007 + 4.567.10^{-3}\ x_1$ $r = 0.488$ $r^2 = 0.238*$

Note: y_1 – content of full seeds; y_2 – anatomical analysis; y_3 – biochemical analysis; y_4 – polyembryony; y_5 – germinative energy; y_6 – germination; y_7 – anomaly of germination; r – correlation coefficient; x_1 – altitude; * – significant correlation between variables

Analogously to the study of LOKVENC and ŠTURSA (1985) and to my own research (HRABÍ 1993, 1994), it was detected that nongerminating seeds accounted for a large portion of the Swiss Mountain Pine seed production. The seed vitality is usually analysed by the tetrazolium test, according to the Standard ČSN 48 1211. Morphological development can be analysed according to the embryo development, as reported by BEWLEY and BLACK (1986), KHAN (1977) or ŠČERBAKOVA (1966). Similar patterns, but modified ones, were used in this study. Specific results were obtained by these modified methods (HRABÍ 1999). Some abnormal changes in the seed structure probably influenced the process of germination. A complex of extreme factors could cause a high number of incompletely developed embryos or polyembryony. I think the most frequent negative factors were air pollution and UV radiation at these high altitudes. It is impossible to compare the results of these investigations with those of other authors because they are original. Incompletely developed embryos as well as polyembryony were documented in a majority of samples. The aspect of polyembryony should be related to the genus *Pinus* (ERDELSKÁ 1979). Contrary to other authors (BEWLEY, BLACK 1986; KHAN 1977), another atypical aspect of germinating seeds was observed during this experiment – some abnormally germinating seeds were found to germinate by green parts of epicotyls. These results cannot be compared with results of other authors (HRABÍ 1994, 1999) because the aims of their studies were not analogous. There could be more factors that influenced some negative features during this experiment. Not only external, but also some internal fac-

tors could contribute to the results – incompletely developed pollen grains, failure of pollination and fertilization and probably some mutations. Many different and precise analyses have to be carried out to investigate these anomalies in greater detail in the years to come.

CONCLUSION

Many atypical changes in the Swiss Mountain Pine seeds were observed. These structural and germination changes have not been established in the studied regions yet. Some atypical changes in vitality and during the germination tests were determined. The results show that the content of full seeds and altitude were in a significant correlation. The existence of polyembryony was evident, but its level was different during the four years of investigations (maximally 9%). The germinative energy and germination tests achieved different values during the experiment in the same samples of the individuals. Anomalies of germinating seeds were evident during this study and amounted to 8% maximally.

On the basis of my four-year research, the following studies can be recommended:
- To study the Swiss Mountain Pine seeds and embryos by biochemical methods based on the content of growth regulators during the period of seed development.
- To study environmental conditions – air and soil pollution by precise methods.
- To study the conditions for pollination.
- To investigate the karyotype of germinating seeds.

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Analýzy kvality a klíčivosti semen borovice kleče (*Pinus mugo* TURRA)

L. HRABÍ

Univerzita Palackého, Pedagogická fakulta, Olomouc, Česká republika

ABSTRAKT: Článek obsahuje poznatky o detailních kvalitativních analýzách osiva borovice kleče (*Pinus mugo* TURRA). Po čtyři roky se uskutečňovaly anatomické a biochemické analýzy a zkoušky klíčivosti u 19 jedinců z 19 lokalit. Zjistily se neobvyklé údaje – nekompletně vyvinutá embrya, polyembryonie a abnormálně klíčící semena.

Klíčová slova: semena borovice kleče; detailní analýzy; nekompletně vyvinutá semena; polyembryonie; abnormálně klíčící semena

V současnosti tvoří velkou část produkce osiva borovice kleče semena s nízkou klíčivostí nebo semena zcela neklíčivá. Z těchto důvodů se experimentovalo s různými metodami stimulace klíčení, ale dosud se nerealizovalo jejich použití v praxi. Také se dosud neuskutečnily komplexní kvalitativní studie. Proto bylo cílem experimentu studovat vitalitu a různé kvalitativní analýzy semen i průběh klíčení ve vztahu k nadmořské výšce.

Výzkum se realizoval po dobu čtyř sezon na semenech z 19 jedinců a 19 lokalit Krkonoš (z nadmořských výšek 1 100–1 530 m). Byly prováděny modifikované analýzy za účelem zjištění podílu plných semen a anomálií v jejich anatomické stavbě a také biochemické rozbory a zkoušky klíčivosti semen. Energie klíčení a klíčivost se vyhodnocovala statisticky.

Získané údaje jsou shrnuty v tab. 1–8 a anomálie stavby a klíčících semen dokumentují obr. 1 a 2.

Během prvního roku pokusů byly u různých vzorků semen zjištěny rozdílné údaje o jejich kvalitě. Anomálie klíčení dosáhly v průběhu zkoušek klíčivosti podílu až 8 %. Statisticky průkazný vztah byl registrován mezi nadmořskou výškou a podílem plných semen i mezi nadmořskou výškou a energií klíčení a mezi nadmořskou výškou a polyembryonií.

Ve druhém roce šetření dosahoval podíl polyembryonních semen vyšších hodnot. Anomálie v průběhu klíčení byly obdobné jako v první sezoně.

V následujícím roce byly zjištěny obdobné údaje jako ve druhém roce experimentálního šetření. Statisticky

průkazný vztah byl evidentní mezi nadmořskou výškou a biochemicky hodnocenou vitalitou semen, mezi nadmořskou výškou a polyembryonií a mezi nadmořskou výškou a klíčivostí.

Výsledky kvalitativních analýz čtvrtého roku šetření se příliš nelišily od jiných let. Byl opět zjištěn statisticky průkazný vztah mezi nadmořskou výškou a podílem plných semen a také jinými ukazateli kvality – s výjimkou polyembryonie.

Celý čtyřletý výzkum kvalitativních ukazatelů osiva borovice kleče dokumentují rozdílné údaje sledovaných charakteristik; byl však zjištěn statisticky průkazný vztah mezi nadmořskou výškou a podílem plných semen.

Studie dokumentuje specifické změny v kvalitě semen borovice kleče z různých lokalit Krkonoš. Jsou zde zachyceny detailní biochemické a anatomické změny, ale také anomálie klíčících semen v průběhu zkoušek klíčivosti. Často byl registrován nekompletní vývin semen a polyembryonie. U některých vzorků činil podíl nekompletně vyvinutých semen až 100 % a výskyt polyembryonie mezi vzorky semen dosahoval až 8 %. Energie klíčení se pohybovala v intervalu 0–71 % a klíčivost mezi 0–99 %. Také byly zjištěny neobvyklé úkazy, kdy některá semena klíčila zelenou částí epikotylu.

Veškeré tyto změny byly registrovány u semen ze stejných jedinců během čtyř sezon. Je velmi obtížné objasnit, čím byly neobvyklé jevy způsobeny. Několik perspektivních metod dalšího výzkumu je doporučeno v závěrečné části příspěvku.

Corresponding author:

RNDr. LIBUŠE HRABÍ, PhD., Univerzita Palackého, Pedagogická fakulta, katedra přírodopisu a pěstitelství, Purkrabská 2, 771 40 Olomouc, Česká republika, tel.: + 420 68 522 43 47, fax: + 420 68 523 14 00, e-mail: hrabi@pdfnw.upol.cz

The influence of different methods of autoclaving and dating of measurement on the rate of electrolyte leakage from oak tap root

M. Sarvaš

Forestry Research Institute, Zvolen, Slovak Republic

ABSTRACT: In this study sensitivity of the method of measurement of electrolyte leakage from oak tap root was examined. The influence of different intervals of measurement after stress treatment on the rate of electrolyte leakage was studied. The results showed that the rate of electrolyte leakage decreased in time after frost treatment (after 2 months by 100%). On the other hand, after desiccation treatment the rate of electrolyte leakage was the same. The rate of electrolyte leakage can be influenced not only by injury of cells but also by the methodology of measurement and therefore it is problematic to make a comparison of results obtained by different methods of measurement. It is necessary to use the same method of measurement for all variants.

Keywords: electrolyte leakage; physiological quality of planting stock; oak bare-rooted seedlings; tap root

The plant quality is a complicated complex of traits which in their interaction influence survival and growth. There are some simple methods (measurements of morphological parameters) to determine external damage of planting stock. But physiological quality plays a decisive role in successful survival and regrowth of plants after afforestation.

Besides plant damage, the physiological quality is influenced by other factors too. These factors very significantly influence key traits of planting stock quality. The nursery practice (undercutting, transplantation) has a considerable effect on root growth potential, different regimes of cold storage influence water content in plant tissues, and very important role is played by the end and beginning of dormancy which influence mitotic index and chlorophyll florescence.

The measurement of electrolyte leakage is one of the methods which is very often used for finding the actual physiological planting stock quality. DEXTER et al. (1932) described a principle of this method for the first time. In his study he concluded that the injury or killing of tissue, by cold or by any other means, involves disorganization of the substances essential for carrying on the processes of life. With such disorganization, it is well recognized that the cell loses its capacity to regulate the diffusion of its soluble contents. Upon this basis, it was assumed that the degree of injury from low temperature to overwintering and other plant structures might be correlated with the exosmoses of electrolytes and other material following exposure to cold. PALTA et al. (1977) writes that electrolyte leakage is an index of the semi-permeable properties of the cell membranes. MCKAY (1998) wrote that if fine roots are capable of maintaining a low level of electrolyte leakage it is probable that they would also be capable of water uptake.

The ability of cell membranes to control the rate of ion movement in and out of cells is used as a test of damage for a great range of tissue samples from seeds (SAHLÉN, GJELSVIK 1993), roots (MCKAY 1992, 1993, 1998; SARVAŠ 1998, 1999; SCHÜTE, SARVAŠ 1999), needles (BURR et al. 1990), stems (DEANS et al. 1995). Some works used the rate of electrolyte leakage from needles or shoots to determine frost hardiness (COLOMBO, HICKIE 1987; MURRAY et al. 1989). TINUS (1996) and TINUS and BURR (1997) used measurements of electrolyte leakage from needles to determine the time of autumn seedling lifting for cold storage and their results showed that there was indeed a relationship between cold hardiness at the time of lifting and field survival of white and red pine, but this relationship for Norway spruce was more complex.

In general, several studies have concluded the possibility to find physiological quality of planting stock by measurements of electrolyte leakage. Unfortunately, it is problematic to make a comparison of separate results. Some works have used for testing samples from fine roots (MCKAY 1992, 1993, 1998; MCEVOY, MCKAY 1997; KERR, HARPER 1992), tap root (SARVAŠ 1998, 1999; SCHÜTE, SARVAŠ 1999), stem (COLOMBO et al. 1984; DEANS et al. 1995) and needles (TINUS 1996). There is a difference in medium in which the samples are placed during autoclaving (SARVAŠ 1998, 1999; MURRAY et al.

1989 – deionised water; MCKAY 1998 – distilled water; SMIT-SPINKS et al. 1985 – solution of $CaSO_4$). Moreover there were different ways of autoclaving and measurement.

The objective of this study was to find the influence of different duration of autoclaving on the rate of electrolyte leakage from oak tap root and changes of EL rate measured in different time intervals after stress treatments. Specific aim was to test changes of electrolyte leakage rate from tap root after same intensive stress factors on different dates.

MATERIALS AND METHODS

Two-years old bare-rooted seedlings of pendunculate oak (*Quercus robur* L.) which had been growing in a nursery of Lower Saxon Forestry Institute (360 m a.s.l., annual precipitation 800 mm, in vegetation period 400 mm, mean of annual temperature 7.6°C) were used in this study. The biometrical characteristics and age of tested planting stock are given in Table 1.

According to the modified method described by MC-KAY (1992) the electrolyte leakage from tap root (samples were taken directly under root collar) was measured in three different time intervals after stress treatments. The root system was washed in cold tap water to remove soil and rinsed in deionised water to remove surface ions. The sample length from tap root was 2 cm. Individual samp- les were put to 40ml universal glass bottles containing 30 ml deionized water of conductivity < 3 µS/cm. The bottles were capped and left at room temperature for 24 h. The bottles were shaken (5×) and the conductivity of bathing solution was measured using the conductivity meter LF 320 with built in temperature compensation 25°C. Then the samples were killed through autoclaving at 110°C for three different time intervals (10, 20, and 40 min). The second conductivity measurement was made 24, 48, and 72 h after the autoclaving. The total conductivity was:

$$EL\ (\%) = \frac{\text{conductivity after 24 h}}{\text{conductivity 24, 48 or 72 h after autoclaving}} \cdot 100$$

The electrolyte leakage was measured from 20 plants per variant.

Electrolyte leakage at different intervals after stress treatments

On 17. 11. 1999, there were realized two frost tests to determine the influence of different time period after

Table 1. Age and morphological traits of planting stock

	Oak
Age	2 + 0
Height (cm) $\pm s_x$	21 ± 7.5
Root length (cm) $\pm s_x$	19 ± 3.4
Stem diameter (mm) $\pm s_x$	4.5 ± 1.9
Root diameter (mm) $\pm s_x$	7.2 ± 2.2

stress factor on the rate of electrolyte leakage. The plants were placed to climatic rooms directly after lifting. The plants were kept in these rooms 6h/–3°C and 8h/–5°C. Next, electrolyte leakage was measured for 20 plants and 60 oak seedlings were placed to cold storage. During cold storage the root system was in polyethene bags (temperature 1–2°C, air humidity 90–92%). The rate of electrolyte leakage was measured in three different terms after frost tests.

A desiccation test was carried out with plants from the same seed plots on 2. 2. 1998. After the test, 60 plants were placed to cold storage (the same cold storage conditions as in frost tests) and in an interval of 3 weeks, 5 weeks and 2 months after the test electrolyte leakage was measured.

The influence different ways of autoclaving and interval of second measurement on electrolyte leakage

There was a different time of autoclaving used (10, 20, and 40 min) and different intervals of second measurement (24, 48, and 72 h after autoclaving) for finding its sensitivity. The longest time interval of second measurement was not used because there was a risk of contamination of samples due to microbial activity. The test was realized on 15. 10. 1997. The measurement of electrolyte leakage was carried out in unstressed planting stock directly after lifting.

Electrolyte leakage after stress treatment of same intensity on different dates

On three different dates, the cold test (2h/0°C) was realized with bare-rooted oak planting stock. Similarly, a desiccation test was carried out (4h – 15% air humidity/25°C) and following directly the stress treatments electrolyte leakage was measured.

RESULTS

Electrolyte leakage at different intervals after stress treatments

In this test, the influence of different intervals of measurement after stress factors on the rate of electrolyte

Table 2. The electrolyte leakage from tap root at different intervals after frost stress

Time interval after frost test	REL (%)			
	6 h/–3°C	Duncan	8 h/–5°C	Duncan
Directly after stress	22	A	37	A
1 week after stress	15	B	29	B
1 month after stress	11	C	16	C
2 months after stress	10	C	16	C
α		***		***
R^2		0.67		0.63

***P < 0.001 (means followed by the same letter are not significantly different)

Table 3. The electrolyte leakage from tap root in different intervals after desiccation stress

Time interval after	REL (%)	
desiccation test	24 h–15%/25°C	Duncan
Directly after stress	24	A
3 weeks after stress	20	B
5 weeks after stress	18	B
2 months after stress	24	A
α		***
R^2		0.23

***$P < 0.001$ (means followed by the same letter are not significantly different)

leakage was studied. After stress (frost and desiccation) planting stock was stored in climatic room for a different time and the rate of electrolyte leakage was measured. The electrolyte leakage decreased in parallel with time and after 2 months it was lower by 100% than directly after frost treatment (Table 2).

On the other hand, the electrolyte leakage decreased with time factor after desiccation treatment too, but there was not a rapid fall, and after two months the REL-values were the same as directly after stress (Table 3).

The influence of different ways of autoclaving and interval of second measurement on electrolyte leakage

These results did not show any marked differences in leakage between the intervals of autoclaving. Equally, the interval of second measurement did not play a big role in the rate of electrolyte leakage either (Table 4).

Electrolyte leakage after stress treatment of the same intensity on different dates

On three different dates, the cold test (2h/0°C) was realized with bare-rooted oak planting stock. The lowest values of REL (12%) were observed on 10. 11. 1997 (Table 5). Similarly, a desiccation test was carried out (4h – 15% air humidity/25°C) and following the stress treatments electrolyte leakage was measured. The highest EL was observed on 3. 6. 1998 (Table 6).

DISCUSSION

Electrolyte leakage at different intervals after stress treatments

The aim of the first part of this study was to examine the influence of different time intervals after stress treat-

Table 4. The electrolyte leakage from tap root after different time intervals of autoclaving and time of second measurement

Duration of auto-	REL (%) second measurement after		
claving (min)	24 h	48 h	72 h
10	16	14	14
20	16	15	13
40	14	15	13

Table 5. The electrolyte leakage from tap root after cold stress on different dates

Date	REL (%)	
	2 h/0°C	Duncan
10. 11. 1997	12	C
11. 5. 1998	14	B
3. 6. 1998	18	A
α		***
R^2		0.51

***$P < 0.001$ (means followed by the same letter are not significantly different)

ments on the rate of electrolyte leakage after stress factors.

After stress treatments, the plants were cold stored and the electrolyte leakage was lower by 100% after two months than directly after frost stress. The analysis of the values of electrolyte leakage showed that absolute values after autoclaving were similar and values of the

Fig. 1. Browning of oak root tissue three weeks after frost stress

first measurement changed during time. This fact can signal that injured cell membranes were closed during cold storage because REL values after autoclaving were the same. On the other hand, after desiccation treatment the REL values two months after stress were the same as directly after stress. Although the REL values two months after frost treatment were the same as for unstressed plants, it was possible to detect the root damage on the

Table 6. The electrolyte leakage from tap after desiccation test in different dates

Date	REL (%)	
	4 h–15%/25°C	Duncan
1. 4. 1998	12	C
11. 5. 1998	16	B
28. 10. 1997	18	A
3. 6. 1998	20	A
α		***
R^2		0.36

***$P < 0.001$ (means followed by the same letter are not significantly different)

basis of browning and changes in consistency of root tissue (Fig. 1).

The influence of different ways of autoclaving and interval of second measurement on electrolyte leakage

Next, the influence of different duration of autoclaving and second measurement on the rate of electrolyte leakage was examined. No marked difference between EL values was found. In this study, EL values slightly decreased with longer time of autoclaving and interval of second measurement. It probably means that a longer time of autoclaving is necessary for leakage of all electrolytes. On the other hand, there is in practice an applicable (fast) method to find the physiological quality of planting stock: sufficient time interval of autoclaving 10 min and allowing 24 h before second measurement. It is suitable to use 24 h interval of second measurement with respect to speed of the method, whereupon time for total measurement of electrolyte leakage is 48 h. Also, 10 min interval of autoclaving is sufficient to destroy cell membranes and to extract of cell sap in deionized water.

By using this methodology (10 min of autoclaving allowing 24 h before measurement) SCHÜTE and SARVAŠ (1999) found strong correlations ($r^2 = 0.97$) between electrolyte leakage from tap root and later regrowth of the terminal shoot. This correlation was detected on container and bare-rooted planting stock of oak after frost ($n = 15$) and desiccation ($n = 12$) stress treatments.

The same results of the influence of different length of autoclaving on EL from fine roots were reported MCKAY (1997, unpublished). On the other hand, DEANS et al. (1995) concluded that allowing 5–7 days after treatment for electrolyte leakage equilibration, followed by autoclaving 90–120 min at 121°C and allowing 24 h before measurement provides a reliable method for assessing freezing injury in small pieces of leafless stem tissues.

Electrolyte leakage after stress treatment of the same intensity on different dates

Changes of EL values were tested after stress factors of the same intensity, acting on different dates. The highest leakage was found for both stress factors in vegetation period. This increase in vegetation period against EL for planting stock in dormant status was about 40% after desiccation stress and about 33% after frost stress. COLEMAN et al. (1992) found that the average increase in hardiness of four subalpine conifers from August to December was 2.4 times for foliage and 1.4 times for roots. The same results are reported in several studies in which it is stated that planting stock in dormancy is hardier than during vegetation period (MEXAL, CARLSON 1981; RITCHIE 1986; RITCHIE, SHULA 1984).

CONCLUSION

– Measurement of electrolyte leakage from tap root is rapid, precise method for finding actual physiological quality of planting stock at relatively low cost.
– The rate of electrolyte leakage can be influenced not only by injury of cells but also by methodology of measurement and therefore it is problematic to make a comparison of results obtained by different methods of measurement.
– It is necessary to use for determining the physiological quality of planting stock the same method of measurement of electrolyte leakage for all variants.

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Vplyv rozdielnych postupov autoklávovania a času merania na rozsah straty elektrolytu z hlavného koreňa duba

M. SARVAŠ

Lesnícky výskumný ústav, Zvolen, Slovenská republika

ABSTRAKT: V štúdii sa zisťuje senzitivita metódy merania straty elektrolytu z hlavného koreňa duba. Pozornosť je venovaná hlavne vplyvu rôzneho časového intervalu na rozsah straty elektrolytu po stresovom faktore. Výsledky ukázali, že hodnoty straty elektrolytu klesli dva mesiace po umelom mraze takmer o 100 % v porovnaní s hodnotami zistenými tesne po stresovom faktore. Na druhej strane hodnoty straty elektrolytu po strese suchom mali aj po dvoch mesiacoch rovnakú úroveň ako po stresovom faktore. Úroveň straty elektrolytu nie je ovplyvnená len poškodením buniek, ale aj samotnou metodikou merania, a preto je problematické vzájomné porovnanie výsledkov získaných rôznou metodikou merania. Je potrebné používať pre všetky varianty rovnaký postup merania.

Kľúčové slová: strata elektrolytu; fyziologická kvalita sadbového materiálu; dubové voľnokorenné semenáčiky; hlavný koreň

Kvalita sadbového materiálu predstavuje rozhodujúci faktor pre úspešnú umelú obnovu lesa a zalesňovania. Celkovú kvalitu sadbového materiálu je možné rozdeliť na tri zložky: genetickú, morfologickú a fyziologickú. Dodržanie genetickej kvality je zabezpečené používaním reprodukčného materiálu zo zodpovedajúcich semenárskych oblastí. Práve fyziologická kvalita sadbového ma-teriálu je dôležitejšou časťou celkovej kvality a fyziologické poškodenie sadbového materiálu vo väčšine prípadov spôsobuje až 100% mortalitu vysádzaných kultúr. Problematické je však jej určenie. Vizuálnym pozorovaním je možné hodnotiť len morfologické parametre. Zisťovanie fyziologickej kvality je vo väčšine prípadov náročné na čas a technické vybavenie a samotné

zisťovanie trvá až niekoľko dní. Ďalej sú kľúčové znaky vyjadrujúce fyziologickú kvalitu ovplyvňované nielen samotným poškodením sadbového materiálu, ale aj ďalšími faktormi (podrezávanie, škôlkovanie, začiatok a koniec dormancie atď.).

Meranie straty elektrolytu je metóda, ktorá je veľmi často používaná na určenie aktuálnej fyziologickej kvality sadbového materiálu. Vo všeobecnosti viacero štúdií potvrdilo možnosti určenia fyziologického poškodenia semenáčikov a sadeníc lesných drevín pomocou merania straty elektrolytu. Výhodou tejto metódy je jej rýchlosť (výsledky sú k dispozícii do 48 hodín) a malé nároky na laboratórne vybavenie. Je ale problematické uskutočniť porovnanie jednotlivých dosiahnutých výsledkov (rozdielne metodiky vlastného merania).

Cieľom štúdie bolo zistiť vplyv rôzneho časového intervalu autoklávovania a rozdielneho časového intervalu po stresovom faktore na rozsah straty elektrolytu. Špeciálnym cieľom bolo testovanie zmien úrovne straty elektrolytu po stresovom faktore rovnakej intenzity v závislosti od fyziologickej aktivity sadbového materiálu. Na testovanie boli použité vzorky z hlavného koreňa dvojročných semenáčikov duba letného.

Výsledky štúdie ukázali, že na úroveň straty elektrolytu z hlavného koreňa nevplýva len rozsah poškodenia, ale aj samotný postup vlastného merania. Preto je problematické porovnávať výsledky získané rozdielnymi postupmi vlastného merania. Ďalej boli zistené štatisticky významné zmeny v strate elektrolytu z hlavného koreňa duba po strese mrazom a suchom v závislosti od fyziologickej aktivity sadbového materiálu. Z dosiahnutých výsledkov je zrejmé, že je potrebné používať rovnakú metodiku merania straty elektrolytu na určenie fyziologickej kvality sadbového materiálu.

Corresponding author:

Ing. MILAN SARVAŠ, PhD., Lesnícky výskumný ústav, T. G. Masaryka 22, 960 92 Zvolen, Slovenská republika, tel.: + 421 45 536 12 43, fax: + 421 45 536 11 92, e-mail: sarvas@fris.sk

A spatially explicit decision support system for locating forest roads

E. Pacola[1], J. Tuček[2]

[1]Technical University, Faculty of Forestry, Department of Forest Exploitation and Mechanization, Zvolen, Slovak Republic

[2]Technical University, Faculty of Forestry, Department of Forest Management and Geodesy, Zvolen, Slovak Republic

ABSTRACT: The paper presents theoretical elements of cartographic modelling of skyline yarding distances, and their implementation in a raster digital elevation model (DEM) within the ArcInfo™ environment. Modules for yarding distances are programmed in the Arc Macro Language (AML). The concept of Spatial Decision Support System (SDSS) for laying out forest roads with concern to terrain and technological criteria is also presented. The most important data source for SDSS is a cartographic model of skyline yarding distances. Powerful tools of map algebra programmed in AML with implementation of fuzzy logic are used in data processing.

Keywords: skyline yarding distances; digital terrain model; ArcInfo™; spatial decision support system; fuzzy logic

Typical forest areas in Slovakia have fairly extensive road network density (in some areas over 100 m/ha). However, the road class and the spacing of existing forest roads are very unfavourable. For example the ratio between main forest roads (asphalt surfaced) and other roads is 1:3 to 1:5. Another problem is the predominance of tractor skidding technologies. Tractor skidding has recently spread to mountainous terrain conditions (45% of the territory of Slovakia). In such conditions it is preferable to use skyline yarding technologies since, from an ecological perspective, it is essential to restrict the density of ground skidding trails.

Thus the primary issue concerning the siting of forest roads in Slovakia is not to develop a road network in previously unaccessible areas. On the contrary, transport planning in these conditions is focused on: (1) the placement of new hauling roads into the existing forest road network where areas are not fully opened up, (2) the reconstruction of selected skidding trails and some hauling roads (not asphalt surfaced) to main hauling roads and (3) the rehabilitation of skidding trails which are not worth rebuilding and using skyline technologies. The forest road planning manager in these cases focuses on judging the efficiency of the existing forest network. One of the basic criteria for this judgment is skidding and yarding distance.

In previous studies (TUČEK, PACOLA 1999) we concentrated on the evaluation of skidding and yarding dis-

tances using DEM. The proposed distance models linked with IDRISI geographic information system were not fully optimized models for opening up of a forest. The program lacked the means to rapidly develop and evaluate route location based on the digital elevation model.

In the present study we have focused on removing model limitation described in TUČEK and PACOLA (1999) and designing future SDSS for laying out forest hauling roads with respect to technological criteria as skyline yarding distance. At the same time, we have developed the theory of building a cartographic yarding distance model according to that described in TOMLIN (1990).

METHOD

The modules described here were created for the ESRI'S UNIX based ArcInfo environment. Powerful map algebra tools, tools for surface modelling and Arc Macro Language (AML) were used in the process of building specific models.

The analytical process is simply presented as follows. The source of information for building DEM was a forest topographic map in scale 1:10,000 with contour intervals of 20 m. Contours and geographic objects (compartment boundaries, roads, stream network) were digitized on-screen in the ArcView 3.0a. DEM used in calculating skyline yarding distances was built by ap-

plying an interpolation method for the creation of hydrologically correct DEM. This method is integrated in the GRID module called Topogrid (see ESRI 1994).

In the process of skyline yarding distance calculation we used the LATTICE (ESRI 1994) data structure together with GRID structure for performing the complicated operations of line-of-sight analysis.

REUTEBUCH (1988) sees the main problem of the route-projection routines as being conceptual. Routines rely on an algorithm rather than on the user's visual abilities and experience to guide the direction of the route. Applying a fuzzy reasoning mechanism which selects passing points shows that the direction of the route can be fully controlled in the algorithm.

The fuzzy rule based system which automatically lays out hauling roads is based on the fuzzy reasoning inference mechanism which uses the architecture proposed in TAKAGI et al. (1985, 1986, 1988 in TANAKA 1996). Their fuzzy reasoning mechanism is classified as the direct method and was devised using linear functions for the relevant rules. Fuzzy reasoning method using linear functions is based on the following architecture:

$Rule\ i$ IF x_1 is A^i1 and ... and x_n is A^in
  THEN $\quad y^i = c_0^i + c_1^i + \ldots + c_n^i x_n$
  $i = 1, 2, \ldots, r$

where: i – the superscript of rule,
  r – the total number of rules,
  $A_{ik}\ (k = 1, 2, \ldots, n)$ – fuzzy sets,
  x_k – an input variable,
  y^i – the output from the i-th rule,
  c_{ik} – the parameter of the consequence in the i-th rule.

The fuzzy reasoning value is obtained from the weighted mean:

$$y = \left(\sum_{i=1}^{l} w^i\, y^i \right) \bigg/ \sum_{i=1}^{l} w^i$$

where: w^i – the adaptability of the premise of the i-th rule
  and given by the equation:

$$w^i = \prod_{k=1}^{n} \mu_{A_k^i(x_k)}$$

where: $\mu_{A_k^i(x_k)}$ – the membership value of the fuzzy set A_{ik}.

The reasoning rules which are used in our system were constructed in YOSHIMURA (1997). We changed only the premise and consequence part of the rules to adjust them for the hauling road projecting conditions valid in Slovakia.
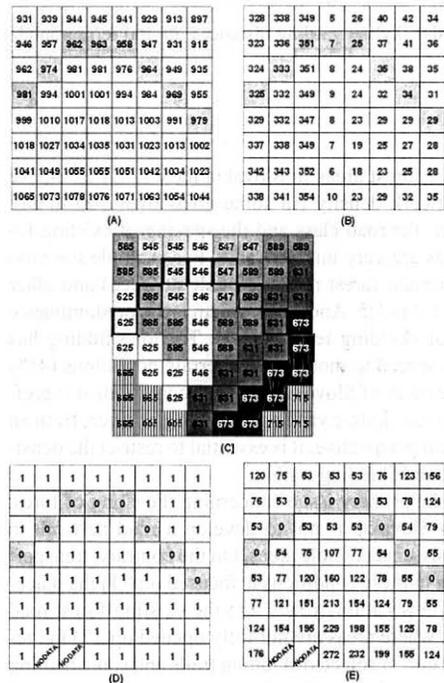
The fuzzy rule based system was programmed according to the theoretical foundations described in FULLÉR (1995).

The gradeline projection routine which connects two passing points is based on a concept of path distance model (GAO et al. 1996). The path distance model attempts to control the grade between two adjacent cells using a gradient factor. The gradient factor is a directional one and it considers the effect of the value gradient from a cell to its neighbour for the cost of travel between two neighbouring cells. Other factors, such as rockiness, environmental barriers, slope stability information, can also be controlled by a path distance model. This control is carried out by applying an isotropic cost surface which expresses the costs of movement in terms of distance equivalents.

CARTOGRAPHIC MODEL OF SKYLINE YARDING DISTANCES

The cartographic model of skyline yarding distances can be regarded as a map of distances measured from every cell as a length of the line of sight over the terrain to the nearest road cell (distance between the centre of the processed cell and the centre of the nearest road cell) (TUČEK, PACOLA 1999). The cartographic model is the result of data processing methods used on the collection of maps. Each layer conveys the following information: digital elevation model – aspect grid – cost allocation grid (defines for each cell the zone that achieves the minimum distance in order to reach the cell) – line of sight (evaluation of intervisibility) – slope distance of line of sight as a result (Fig. 1). Intervisibility between the processed cells and the deviation of the line of sight from

931	939	944	945	941	929	913	897
946	957	962	963	958	947	931	915
962	974	981	981	976	964	949	935
981	994	1001	1001	994	984	969	955
999	1010	1017	1018	1013	1003	991	979
1018	1027	1034	1035	1031	1023	1013	1002
1041	1049	1055	1055	1051	1042	1034	1023
1065	1073	1078	1076	1071	1063	1054	1044

(A)

328	338	349	5	26	40	42	34
323	336	351	7	25	37	41	36
324	333	351	8	24	36	38	35
325	332	349	9	24	32	34	31
329	332	347	8	23	29	29	29
337	338	349	7	19	25	27	28
342	343	352	6	18	23	25	28
338	341	354	10	23	29	32	35

(B)

585	545	545	546	547	547	889	889
585	585	545	546	547	589	589	631
625	585	545	546	547	689	631	631
625	689	585	546	689	889	631	673
625	625	585	546	689	631	631	673
625	625	625	646	689	631	673	673
625	625	625	646	631	631	673	673
625	625	625	631	631	673	673	715

(C)

1	1	1	1	1	1	1	1
1	1	0	0	0	1	1	1
1	0	1	1	1	0	1	1
0	1	1	1	1	1	0	1
1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	NODATA	NODATA	1	1	1	1	1

(D)

120	75	53	53	53	76	123	156
76	53	0	0	0	53	78	124
53	0	53	53	53	0	54	79
0	54	75	107	77	54	0	55
53	77	120	160	122	78	55	0
77	121	181	213	154	124	79	55
124	154	195	229	198	155	125	78
176	NODATA	NODATA	272	232	199	155	124

(E)

(A) DEM (cell resolution 50 m); (B) Aspect grid; (C) Cost allocation grid (controls the homogeneity under the line of sight); (D) Intervisibility evaluation; (E) Slope distance of line of sight.
Note: NODATA – keyword indicating that the cell is not visible from the point of observation

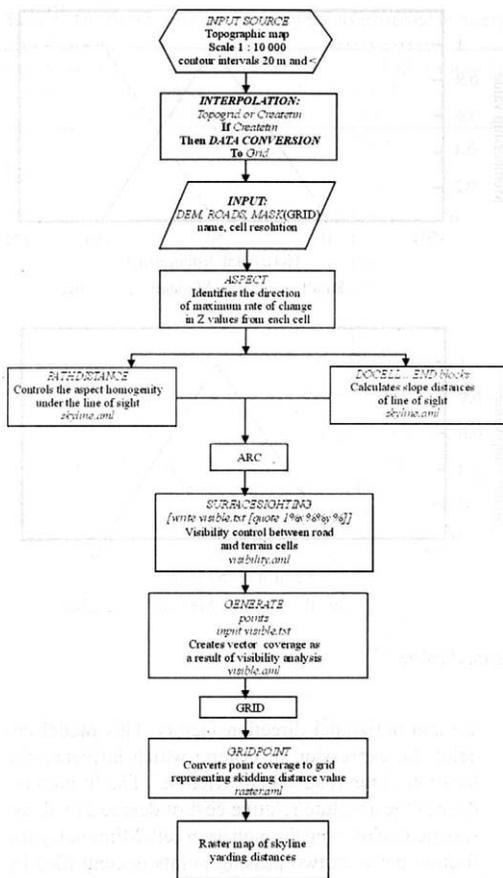Fig. 1. Cartographic model of skyline yarding distances

Fig. 2. Flow chart illustrating the method for calculating the values of skyline yarding distances from DEM

the gradient curve are checked in the process of carto-graphic modelling which proved to be the main problem. Skyline yarding distances model is a network model.

The possibility of laying out skyline yarding paths is based on the following assumptions:

Fig. 3. Raster map of skyline yarding distances

1. The skyline tower in the cell of road and the tail spar in the cell of a forest compartment are defined. If the distance between the two above mentioned cells exceeds the technological length of a cableway system, the layout of skyline yarding path cannot be calculated. The signal value which shows that the cell has not been reached in skyline logging operations will be assigned to the cell.

2. If the two cells under analysis can "see each other" and the angle deviation of the line of sight from the gradient curve does not exceed the user defined limit, then the skyline yarding path lay-out will be possible for those cells.

3. The skyline yarding distance will be calculated only for the two cells which fulfil both mentioned conditions (points 1, 2), but at the same time the calculated distance is the shortest path from all considered combinations which permit skyline yarding paths from the terrain cell to road cells.

4. If the intervisibility conditions between two cells are not fulfilled, a different signal value will be noted to the cell, indicating that a tree jack must be used for skyline extraction path.

The conditions described above must be satisfied to identify skyline yarding paths which are laid out in the direction of the gradient curve or along the permissible angle from the gradient curve (parallel, not fanned out routes).

Fig. 2 illustrates a process flow diagram for calculating skyline yarding distances in the ArcInfo™ environment. The result of routines creating cartographic model of skyline extraction distances can be seen in Fig. 3.

FUZZY REASONING INFERENCE MECHANISM AND PATH DISTANCE MODEL USED FOR LOCATING FOREST HAULING ROADS

The system designed for laying out hauling roads has to focus on identifying passing points on roads and is based on the evaluation of yarding distances which were modelled in the field. In the process of selecting passing points, grade and distances between points and yarding distances from existing roads are controlled by fuzzy reasoning mechanism using linear functions. Inference rules for fuzzy reasoning used in the proposed system were described in YOSHIMURA (1997). The rules implemented in this mechanism represent human thinking processes based on an expert designer's experience, skill and knowledge of specific conditions used to locate forest roads. The rules had to be adjusted for hauling road conditions pertaining to Slovakia (the maximum gradient of a hauling road is limited to 12%).

The inference rule equations are expressed as follows:

IF x_1 *is 'Big' THEN* $y_1 = -50x_1$ *(Very Small)*
IF x_2 *is 'Big' THEN* $y_2 = -100x_2$ *(Very Small)*
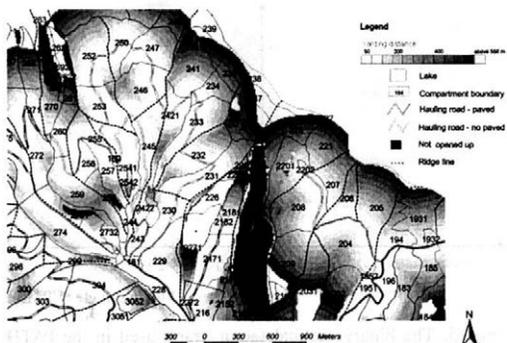*IF* x_1 *is 'Small or Medium' and* x_2 *is 'Medium or Small' and* x_3 *is 'Big or Medium' and* x_4 *is 'Big or Medium'*
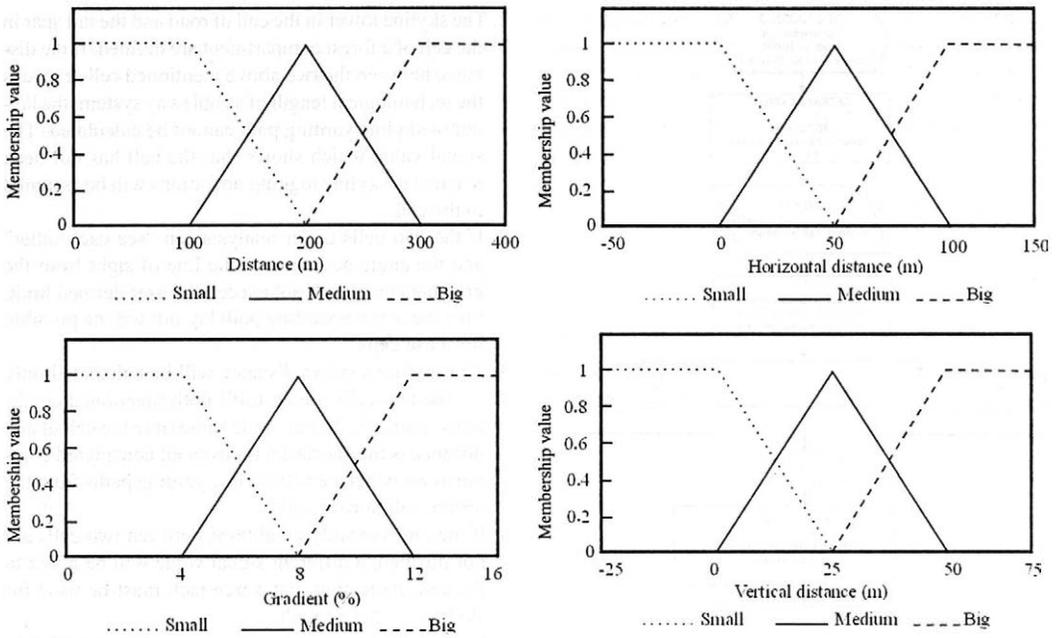
Fig. 4. Membership functions for fuzzy sets used in fuzzy reasoning mechanism

THEN $y_3 = 0.3x_1 - 20x_2 + 0.5x_3 + 6x_4$ (Big)

IF x_1 is 'Small or Medium' and x_2 is 'Medium or Small' and x_3 is 'Big or Medium' and x_4 is 'Small'

THEN $y_4 = 0.2x_1 - 30x_2 + 0.3x_3 + 4x_4$ (Medium)

IF x_1 is 'Small or Medium' and x_2 is 'Medium or Small' and x_3 is 'Small' and x_4 is 'Big or Medium'

THEN $y_5 = 0.1x_1 - 40x_2 + 0.1x_3 + 2x_4$ (Small)

IF x_1 is 'Small or Medium' and x_2 is 'Medium or Small' and x_3 is 'Small' and x_4 is 'Small'

THEN $y_6 = -5x_1 - 50x_2 - 0.5x_3 - 20x_4$ (Very Small)

where x_1, x_2, x_3 and x_4 are the factors such as the distance between passing points, gradient between passing points, horizontal distance toward the point on the road end and the vertical distance toward the point on the road end. These factors are described in detail in YOSHIMURA (1997).

The membership functions shown in Fig. 4 are applied to the actual values for four factors to determine the degree of truth for the premise of each rule.

The method for selecting passing points and laying out gradelines differs from the method described by YOSHIMURA (1997) in two ways:

1. The cells where the estimated skidding distance does not exceed the technological length of a cableway system route or effective tractor skidding distance are selected as possible passing points.

2. The passing points are interconnected by applying a directional path distance model (GAO et al. 1996) implemented in the Arc/Info GRID module PATHDISTANCE. The path distance model automatically lays out the gradeline between passing points using an additional factor in the distance measure (surface, gradi-

ent and horizontal direction factor). This model enables the expression of criteria which influence the location of the road called "friction". The friction indicates the absolute/relative cost or degree of risk assessment of moving through each cell. Minimizing the friction between two passing points is controlled by a gradient factor which takes into consideration the effect of the value gradient from a cell to its neighbours.

The formula used to calculate the lowest total cost to each of the neighbours and control gradeline projection is:
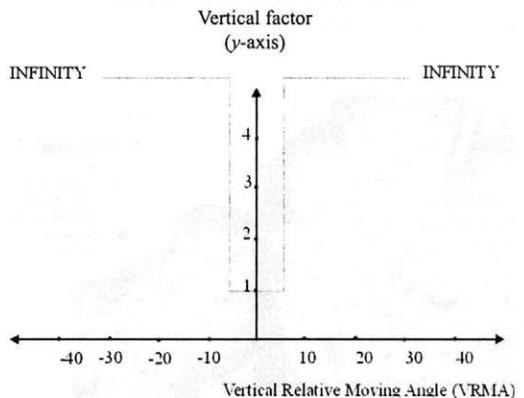
CostDistance = SurfaceDistance × VerticalFactor

Fig. 5. The binary vertical factor graph used in the PATHDISTANCE function

Table 1. The factor values for passing points extracted by fuzzy reasoning inference mechanism

Passing points (Points extracted by fuzzy reasoning inference mechanism)	Factor values for passing points extracted by inference mechanism			
	factor_1 (m)	factor_2 (%)	factor_3 (m)	factor_4 (m)
A.	196	7.7	157	14.6
B.	196	7.2	142	12.1
C.	189	7.5	90	12.0
D.	194	7.0	173	14.4
E.	187	8.5	132	13.5
F.	199	6.0	116	11.6
G.	199	5.4	164	8.4
H.	194	7.6	118	10.6
CH.	194	7.8	94	14.2
I.	197	5.37	115	8.9
J.	187	3.3	157	5.8

By using a Vertical Factor (VF), we can take into account the cost necessary to overcome the slope between two cells. The value of VF depends on the vertical relative moving angle – VRMA (see ESRI 1994) and is defined in our system as shown in Fig. 5:

$$VF = 1 \quad \text{if} \quad (0 \leq VRMA \leq 6)$$
$$VF = \infty \quad \text{if} \quad (6 < VRMA < 90)$$
$$VF = 1 \quad \text{if} \quad (0 \geq VRMA \geq -6)$$
$$VF = \infty \quad \text{if} \quad (-6 > VRMA > -90)$$

The VRMA is limited to 6 degrees following the maximum gradient of hauling road acceptable for Slovak terrain conditions.

RESULTS

The new cartographic model of skyline yarding distances built for ArcInfo™ GRID environment and SDSS system were verified in a called Zboj river included in the working-plan area Zboj. The study area is approximately 2,400 ha in size and situated in the Bukovské Vrchy Mountains in Eastern Slovakia. The area is configured with high undulations and an average slope gradient is 45%. Steep slopes above 40% occupy about 50% of area.

ROAD PROPOSAL COMPARED WITH EXISTING ROAD

Legend

N Proposed road
N Hauling road - paved
N Hauling road - no paved
Contour line
• Passing point
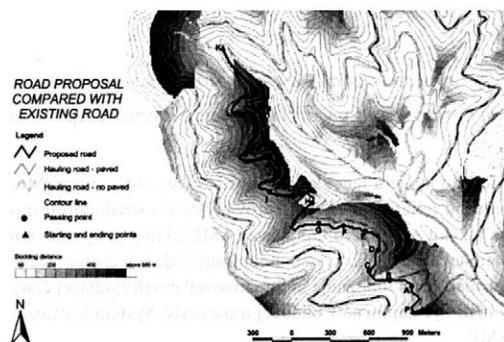▲ Starting and ending points

Skidding distance

N

Fig. 6. A forest road laid out using fuzzy reasoning system and directional path distance model

The hauling road density is 26 m/ha, of which 22 m/ha are not paved hauling roads. The density of permanent ground skidding roads is about 17 m/ha. The calculated forest road density and the theoretical value of area accessibility show very good possibilities for opening the forest up. Nevertheless, in terms of the forest tractor skidding technologies used terrain conditions and skidding road structures indicate that average skidding tractor distance is in reality very long, approximately 2,000 m (see also comments in Introduction).

Fig. 6 shows the recommended contour road proposal compared with the existing roads. Points A ~ J are passing points selected by using a fuzzy reasoning inference mechanism which is based on linear functions for decision rules. Factor values for passing points extracted by the inference mechanism can be seen in Table 1. Point "P" is a starting point and "K" an ending point which is selected by the user. It is apparent from the given figures that the system takes into account terrain conditions in the layout of roads and that the proposed output is very similar to the existing road.

This system, which automatically lays out the forest roads, was mainly designed to take into consideration terrain conditions, but supplementary sources of information can be used too. Difficult terrain features, e.g. extreme slopes, rockiness, environmental barriers, places where yarding distances exceed the technological length of a cableway system route may be identified in the model system. These defined features (negative barriers) cause difficulties in the planning of new roads. The system eliminates negative areas from being considered and thus ensures that forest roads will avoid these areas.

The information derived about skidding distances can support decision-making on where a new road is to be located and where existing ground skidding roads can be proposed for sanitation. The project of locating new sections of hauling roads was based on the idea that the skyline yarding distances between the new road and the existing valley road or contour road should not exceed the length of the maximum effective span for the proposed cableway system route. LARIX 550 (Czech Republic origin) is the most frequently used cableway

system in Slovak terrain conditions. From the technological point of view, a new road should be located for this cableway system inside the area where evaluated skyline yarding distances do not exceed 550 m in length. The location of the new hauling road in the position seen in Fig. 6 opens up the right bottom side of the valley. This part is not opened up if we consider only the existing contour road above the proposed road and the existing valley road.

In practice, a solution would have been to build only one contour road in the middle part of the left valley slope, but at present, this is not possible because of the already existing roads. However, if it had been possible to localise a contour road in the central part of the valley, it would have opened up the left side of the valley for proposed skyline yarding technology. This alternative assumes a minimum road density too. We have not presented this alternative. However, it could be carried out by using the above mentioned yarding distance model measuring distances from the valley line and ridge line. The system which automatically lays out forest roads would be used for gradeline projecting onto DEM in the next part of the analysis.

CONCLUSIONS

We have developed a cartographic model of yarding distances for the environment ESRI'S UNIX based on ArcInfo™. All problems encountered in distance modelling while using the Turbo Basic environment, i.e. limited raster spatial resolution, total area evaluated and computer processing time were eliminated. A new approach to distance modelling was introduced into a new system which automatically lays out forest hauling roads according to technological and terrain criteria. A fuzzy reasoning mechanism and path distance model implemented in this system have proved to be very successful in solving problems of determining an automatic route location based on the information extracted from the digital elevation model. All mathematical/conceptual models presented can provide a basis for future Spatial Decision Support Systems designed in order to meet the needs of end users – forest engineers involved in the planning of forest road networks.

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Automatizovaná lokalizácia lesných odvozných ciest systémom pre podporu priestorového rozhodovania

E. PACOLA[1], J. TUČEK[2]

[1]*Technická univerzita, Lesnícka fakulta, Katedra lesnej ťažby a mechanizácie, Zvolen, Slovenská republika*

[2]*Technická univerzita, Lesnícka fakulta, Katedra hospodárskej úpravy lesa a geodézie, Zvolen, Slovenská republika*

ABSTRAKT: V práci prezentujeme teoretické základy kartografického modelu lanovkovej približovacej vzdialenosti. Model približovacej vzdialenosti bol vytvorený pre rastrovú reprezentáciu reliéfu terénu a integrovaný do prostredia profesionálneho GIS ArcInfo™. Vlastné algoritmy modelu boli napísané v jazyku Arc Macro Language (AML), ktorý je vývojovým nástrojom spomínaného prostredia. Matematický a konceptuálny model expertného systému popísaný v ďalšej časti práce je základom budúceho systému pre podporu priestorového rozhodovania. Tento umožňuje automatizovať návrh riadiacej čiary za kontroly technických a technologických požiadaviek, ktoré by mali byť naplnené v budúcej trase cesty. Systém je založený na fuzzy inferenčnom mechanizme, bol vytvorený jazykom AML.

Kľúčové slová: približovacia vzdialenosť; digitálny model terénu; ArcInfo™; systém pre podporu priestorového rozhodovania; fuzzy logika

Tradičné metódy používané v plánovaní lesnej cestnej siete vychádzajú z individuálnych skúseností pracovníkov, ktorí navrhujú jednu alebo viac dopravných alternatív na vrstevnicovej mape. Grafický návrh je často doplnený výpočtom ekonomických a technologických ukazovateľov hodnotiacich kvalitu ktorejkoľvek z navrhovaných alternatív. Tento prístup je časovo veľmi náročný. Jednotlivec alebo skupina ľudí, ktorá sa zúčastňuje na riešení tohoto problému, často nedokáže komplexne zohľadniť všetky kritériá ovplyvňujúce výber optimálneho variantu.

Množstvo faktorov a alternatív môžeme hodnotiť, kontrolovať a modelovať v prostredí počítačových systémov. V počítačovom prostredí implementované algoritmické postupy simulačných, matematických metód a metód operačného výskumu dokážu kombinovať kriteriálne vstupy a predvídať správanie sa systému pri akejkoľvek zmene kritéria.

Kartografický model lanovkovej približovacej vzdialenosti je mapou vzdialeností definovaných dĺžkou šikmých zámer (trasa lanovky) vedených nad povrchom reliéfu terénu (obr. 1). Model lanovkovej približovacej vzdialenosti je sieťovým modelom. Výpočet dĺžky simulovanej trasy lanovky sa vykoná pre každú kombináciu bunky terénu s bunkami existujúcich ciest. Hľadá sa poloha bunky cesty, ku ktorej bude analyzovaná trasa najkratšia, a zároveň sa kontroluje orientácia terénu pod zámerou a priama viditeľnosť medzi analyzovanou bunkou terénu a bunkami existujúcich ciest. Tieto kontroly zabezpečujú výpočet vzdialeností len pre kombináciu buniek, ktorá zaručuje vedenie lanovkovej trasy po spádnici alebo v prípustnej odchýlke od smeru spádnice. Použitá metodika tvorby kartografického modelu teda zodpovedá predovšetkým možnosti paralelného vedenia lanovkových trás po spádnici. Vývojový diagram znázorňujúci spôsob výpočtu hodnôt lanovkovej približovacej vzdialenosti z DMT a rastrový model lanovkovej približovacej vzdialenosti je na obr. 2 a 3.

Pri vypracovaní novej metodiky pre riešenie problému lokalizácie svahových odvozných ciest sa vychádzalo z princípov vyhľadávania tzv. prechodových (kladných kardinálnych –passing–) bodov. Táto metóda je založená na teórii fuzzy množín a prvýkrát ju popísal YOSHIMURA (1997). Metóda bola prepracovaná pre podmienky a kritériá návrhu trasy cesty platné na území Slovenska a implementovala sa do prostredia UNIXového ArcInfa™. Rozhodujúca časť algoritmov využíva nástroje modulu GRID, ktorý pracuje s diskrétnou rastrovou štruktúrou. Nástroje mapovej algebry sú funkčne prepojené prostriedkami programovacieho makro jazyka Arc Macro Language (AML). Vytvorené moduly budú základom pre budovanie špecifického systému pre podporu priestorového rozhodovania – SDSS v prostredí ArcInfo™. Tento by mal byť zastrešený vlastným graficko-uživateľským rozhraním (GUI) a bude v sebe integrovať GIS, expertný systém a banku metód podporujúcich riešenie čiastkových optimalizačných problémov spojených s návrhom nových úsekov ciest a hodnotením účinnosti existujúcej alebo navrhovanej cestnej siete.

Corresponding author:

Ing. ERICH PACOLA, Technická univerzita, Lesnícka fakulta, T. G. Masaryka 24, 960 53 Zvolen, Slovenská republika, tel.: + 421 45 520 62 87, fax: + 421 45 533 26 54, e-mail: pacola@vsld.tuzvo.sk

Non-solid roadway degradation of forest roads from theoretical and practical aspects

L. ZELINKA

Technical University, Forestry Faculty, Zvolen, Slovak Republic

ABSTRACT: This article deals with the degradation process of non-solid roadways of forest roads with bituminous surface that was investigated for 10–15 years. The roadway degradation was described by determining the value of roadway deflection and for better orientation it was calculated as a change in operating performance, namely as the number of standard axles during the time of roadway use. The results indicate that the degradation process is gradual, of non-linear character. The calculated values will be used to determine "wear coefficients" which will help to plan the optimal time of roadway repair (overlay).

Keywords: degradation; theory; forest roads; course

BRIEFLY ON ROADWAY DEGRADATION THEORY

The roadway degradation (GSCHWENDT 1994) is taken to mean gradual deterioration of the roadway condition due to wheel traffic under certain climatic conditions (especially in spring time). Climatic conditions and the quality of roadway subsoil influence deterioration of the roadway condition, which results in deterioration of parameters which comprehensively define the roadway serviceability as well as the roadway mechanical efficiency (construction bearing capacity).

Assumptions about development and changes in the parameters defining the roadway condition are used in roadway management to draw up renewal and rehabilitation plans, to make decisions and to adopt roadway renewal strategy.

THEORETICAL ASSUMPTIONS

The real course of roadway degradation can be determined either from the roadway degradation as whole (it is more objective) or from a change in individual parameters of roadway serviceability which can also be simulated.

Assumed changes in parameters (of the general roadway condition) in dependence on time or repetition of the standard loading are expressed by degradation model. Degradation function is a mathematical expression of changes in roadway parameters or changes in the general roadway condition according to a certain degradation model and assumptions in dependence on time or repetition of loading.

In roadway management we need the following models and functions of degradation for:

– new roadways,
– roadways under reconstruction and renewal,
– existing roadways in use with different wheel traffic and under different climatic conditions.

The evaluation of economic effects is connected with determination of a suitable period for roadway renewal from the technical view. Technical and economic decisions have to be taken in accordance with maintenance and renewal strategies.

To determine the roadway degradation and to construct the model we usually determine and evaluate the roadway parameters on a certain section by repeated measurements. We can express the changes in average values in dependence on time or wheel traffic after statistical processing of parameters on a certain section of the road. The relation of absolute values of roadway and time or roadway and wheel traffic parameters is used for expression of the real course of roadway degradation in real time.

The relations between relative values of variables are used for the mathematical expression of roadway parameter changes in dependence on time or wheel traffic.

Distribution of models results from segregated and aggregated roadway evaluation to show the roadway serviceability and to evaluate the condition of roadway construction.

According to the formulation of degradation model (and degradation function) there are:
a) deterministic models – based on the relations and regularities valid for a physical model of roadway,
b) stochastic models – based on the calculation of the probability of occurrence of the observed condition.

According to the method of model derivation we can distinguish:

1. mechanical approach – it uses the knowledge and regularities from mechanics of construction degradation;
2. empirical approach – it uses all knowledge about roadway degradation obtained empirically;
3. combined mechanical and empirical approaches with application of theory and practical information.

The roadway properties may be evaluated:

a) in laboratory – by accelerated stress and testing,
b) in real conditions – in a network of roads.

However, the laboratory methods and measurements are not suitable for an independent empirical method. The method of degradation model combining mechanical and empirical approaches is used very often. The results of laboratory tests of physical properties of the materials are the basis for evaluation of the construction (degradation) under accelerated testing for example on a circular and straight course but especially in a network of roads.

The results from long-term measurements and observations (LTPP – long-term pavement performance) under real climatic conditions and wheel traffic are the most valuable. The relative time reduction to acquire needed data is possible by selection of suitable localities and conditions (their combination).

Two types of models are needed as concerns the planning of roadway maintenance and renewal in the network of roads:

– degradation models of new roadways,
– degradation models of rehabilitated (renewed) roadways.

We must distinguish the categories of "aggregated" and "segregated" models according to the fact whether the model reflects the aggregated evaluation of roadway condition or if it relates only the changes in a segregated parameter. The measurements for roadway renewal are several and therefore the models are "compound-combined" or "single-specific".

Degradation models based on aggregated coefficients – parameters can also be combined with different conditions. "The network analysers" are used for planning and roadway renewal in a network of roads as a whole. Other models are "specific" models for a selected section of the road with some roadway composition in combination with the existing conditions on this object – climatic load and wheel traffic.

For a prognosis of the course of roadway degradation the models and functions are needed which relate to segregated or aggregated evaluation of:

– roughness of roadway surface,
– evenness of roadway surface in square and longitudinal directions,
– mechanical efficiency (bearing capacity) of roadway,
– index of serviceability,
– surface condition, intensity and degree of surface damage,
– index of construction condition as well as other parameters.

To evaluate the roadway condition it is possible to use two basic evaluation methods:

a) diagnostic evaluation,
b) visual evaluation.

The combination of both methods is used most frequently. The visual evaluation of roadway surface is generally primary and it is complemented by diagnostic evaluation with special equipment.

Degradation models and degradation functions for public roads in Slovakia are at their beginning for the time being due to a small number of measurements, they are in the phase of proposals. They will be based on the results of measurements on circular experimental roads of VÚIS – Cesty, s.r.o., Bratislava and the results of visual evaluations on a highway section D 61. The situation in the Czech Republic is similar.

The publication of the World Bank contains the prediction of roadway degradation, degradation models and functions with description of so-called HDM-III model (The Highway Design… 1987). There are presented the empirically determined relations for variable parameters (cracks, depth of tracks) in dependence on wheel traffic. These relations are defined for different types of roadway but their use is limited. The models are not valid for the conditions of roadway and subsoil frost penetration. The results of the World Bank relate to public transport and they are suitable mainly for a public network of roads with higher wheel traffic.

FERTÁL (1996) dealt with the problem of forest road damage in Slovakia. He evaluated the main forest roads with surface from penetration asphalt macadam following the visual evaluation namely of the occurrence of "the crack portion" and their increase during use. This author found that the practical service life of roadway surfaces and all roadways ends when the value of "the crack portion" amounts to 4%, that means eight years of roadway use in Slovak conditions.

The solution to this problem (on forest roads) in foreign countries is not known from available literature.

MATERIAL AND METHODS

To solve this problem, a long-time monitoring of changes in the bearing capacity of non-rigid roadways of forest roads with bituminous surface was carried out. The research was conducted mainly in the area of the Training Forest Enterprise Zvolen and also in other areas of Slovakia.

Monitoring of degradation processes on forest roadways began in 1976, more intensive since 1980. The roadway degradation is studied in real conditions (directly on forest roads) under different climatic influences, wheel traffic and constructional design of the roadway. The file of the studied roadways comprised new roadways, old roadways as well as roadways after overlay.

Unlike the public roads where evenness is the basic criterion for quality evaluation, it is the mechanical effi-

Table 1. Coefficients of regression equation and basic statistical characteristics for individual experimental sections

No.	Experimental sections	Section	Coefficients of regression equation			Square deviation	Residual variance	Correlation index
			A_0	A_1	A_2			
1	Hlboká		0.871	0.021	0.002	0.011	0.011	0.96
2	Bujačie		0.388	0.062	–	0.272	0.045	0.79
3	Žiarkov		0.512	0.124	–0.006	0.002	0.001	0.99
4	Hučava	III	1.673	0.042	–	0.186	0.047	0.65
5	Hučava	IV	1.703	–0.015	–0.050	–0.015	0.018	0.93
6	Hučava	V	0.697	0.156	–0.002	0.309	0.051	0.93

ciency (bearing capacity) of roadways in forest roads. The other parameters such as roughness, evenness (longitudinal and square) were not investigated (unlike the public roads) because these parameters are considered as complementary. It is so because the average speed of vehicles on forest roads is 18 km/h.

The course of roadway degradation was evaluated by measuring changes in the deflection value with a diagnostic equipment, arm deflectometer. Roadways were also evaluated visually, mainly the surface condition of the roadway (occurrence of pot-holes and cracks and other damage). The roadway deflection was measured every year in the spring season (after subsoil defreezing).

The deflection method was already described in another paper (ZELINKA 1981). The reversible roadway deflection was measured under different temperatures, the measurement points were determined by random selection at an average distance 30 m, the length of the investigated sections was 300 m or more. The data were processed by computing technique.

RESULTS AND DISCUSSION

The roadway degradation was investigated on 22 experimental sections. The results of monitoring on 6 experimental sections are published in this article. The following roads are represented by these sections:
– old gravel forest road paved with OK (covered bituminous stone),
– old forest road with PAH surface (penetration bituminous macadam) paved with 10 cm OK,
– new forest road with PAH and OK surfaces.
Each figure represents:
– course of deflection changes during the time of forest road (section) use (observation),
– operating performance expressed by the number of standard axles (ŠN) for 24 h,
– total quantity of timber hauled during the time of roadway use expressed by the number of ŠN.
Note: The roadway operating performance was determined by the method for testing and pavement which was already described in detail (ZELINKA 1989).

SHORT STATISTICAL EVALUATION

By monitoring the roadway degradation non-linear correlations – polynomial of degree II were found in most

cases on the basis of deflection changes (increase in deflection) within the file. Linear correlations were determined in a smaller number of experimental sections.

All sections presented in this article show non-linear correlations except the experimental section situated on Bujačie forest road where a linear correlation was found.

General relation for:
– linear correlation: $Y = A_0 + A_1 \cdot x_1$
– non-linear correlation: $Y = A_0 + A_1 \cdot x_1 + A_2 \cdot x_1^2$
where: Y – roadway deflection,
x – time of roadway use in years,
A_0, A_1, A_2 – regression coefficients.
The basic statistical characteristics for individual experimental sections are shown in Table 1.

Experimental section on Hlboká forest road (Fig. 1)

This experimental section is situated on an old, gravel forest road (25 cm layer of broken stone) which was paved with 12 cm layer of OK (covered bituminous stone). The measurement of deflection began 14 days after overlay. The graph shows a moderate increase in deflection in time, that means roadway gradual degradation. At the beginning of pavement the operating performance of roadway was 100 ŠN/24 h, after 5 years it was 60 ŠN/24 h, after another 5 years it was 28 ŠN/24 h. It is assumed that after another 8 years, i.e. after 15 years of operation, the operating performance will achieve the value 5 ŠN/24 h.

The average wheel traffic on this roadway does not exceed 1 SA/24 h, so there is some reserve before the limiting condition of the roadway is reached. (*Note:* the limiting condition of the roadway is a state when the wheel traffic does not yet cause either qualitative decrease or loss of bearing capacity, that means total and irreparable damage of the roadway by destruction.) It can be stated by visual evaluation of the roadway that the roadway is not damaged by wheel traffic for the time being. This road is damaged (pot-holes and other damage of the surface) on other parts than on the experimental section and the damage is caused mechanically (skidding, excavations).

Experimental sections on Bujačie – Trnavy forest road (Fig. 2)

These experimental sections are situated on an old forest road (constructed in about 1941–1942) which was gradually paved. The primary gravel roadway was paved
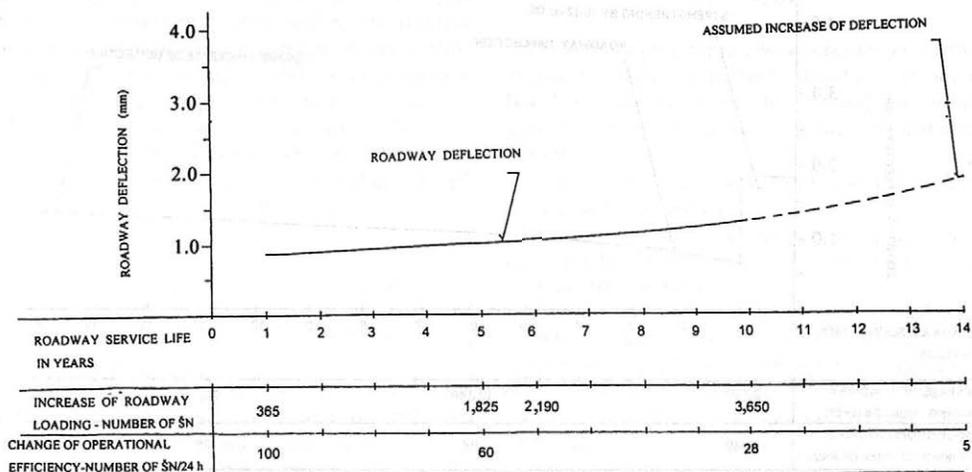
Fig. 1. The course of roadway degradation on Hlboká forest road expressed by an increase in the roadway deflection (in mm) and by changes in roadway operating performance given by the number of standard axles (ŠN) over 24 h during the time (years) of roadway use

with 10 cm PAH and in 1980 with 10 cm OK, the subsoil is clayey (3% CBR – California Bearing Ratio of soils), the altitude is 450 m a.s.l.

The course of deflection changes is similar to that on the former section, that means gradual, but the initial value is lower. It is connected with the thicker construction layer (10 cm PAH in addition).

The average wheel traffic on this experimental section is about 6 ŠN/24 h, therefore there is some reserve before the limiting bearing capacity is achieved. Visual evaluation reveals moderate crumbling effects on the upper part of the surface.

Experimental section Žiarkov (Fig. 3)

This experimental section is situated on the same forest road as the section Bujačie but it is at a longitudinal distance of about 4 km, its altitude is 750 m a.s.l. (the height difference is 300 m). Construction time, roadway construction, wheel traffic and bearing capacity of the subsoil (sandy loam – 4% CBR) are approximately the same on both sections.

A comparison of both deflections and the course of their increases shows that they are approximately the same. We can state that the large height difference and
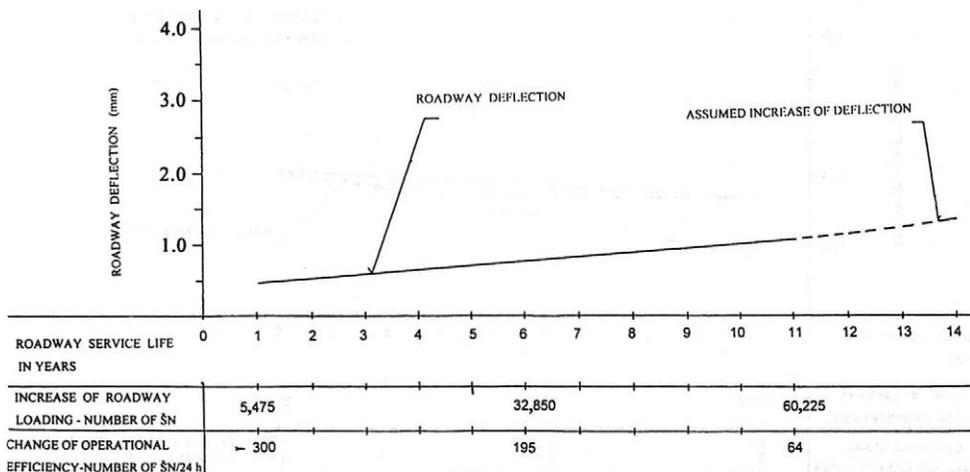

Fig. 2. The course of roadway degradation on the forest road Bujačie – Trnavy, section Bujačie, expressed by an increase in the roadway deflection (in mm) and by changes in roadway operating performance given by the number of standard axles (ŠN) over 24 h during the time (years) of roadway use
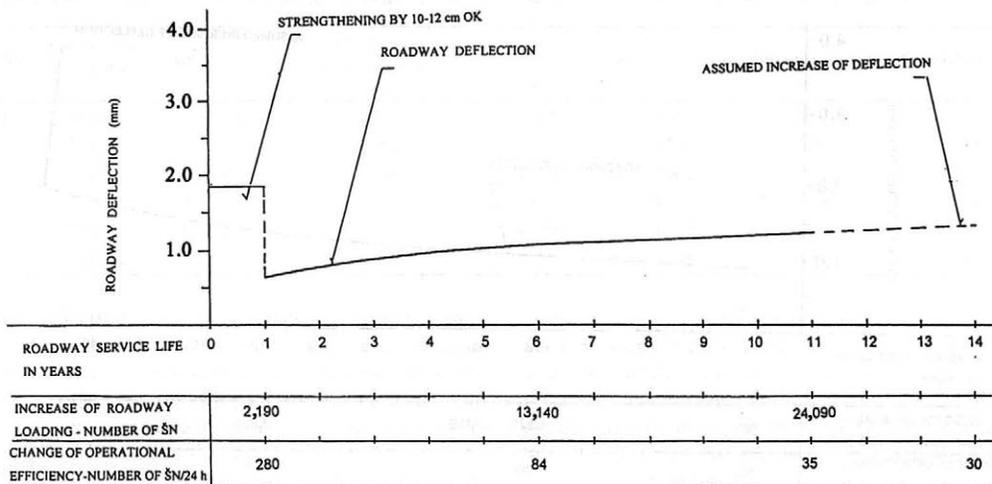
Fig. 3. The course of roadway degradation on the forest road Bujačie – Trnavy, section Žiarkov, expressed by an increase in the roadway deflection (in mm) and by changes in roadway operating performance given by the number of standard axles (ŠN) over 24 h during the time (years) of roadway use

the climatic conditions (moisture and temperature effects) did not influence the course of roadway degradation.

Visual evaluation reveals that this section is without any greater damage for the time being. Only moderate crumbling on the upper part of the surface was observed.

Experimental sections on Hučava forest road, sections III, IV, V (Fig. 4)

The forest road Hučava is a new forest road. Five experimental sections were established on this road. These sections differed are in the roadway construction and subsoil. All sections have approximately the same wheel traffic that does not exceed 6 ŠN/24 h.

We began to investigate the roadway degradation instantly in the first year of roadway use. Sections III, IV and V are described in this article.

Sections III and IV

The main difference between sections III and IV is in the surface layer. Section III is formed by 10 cm PAH
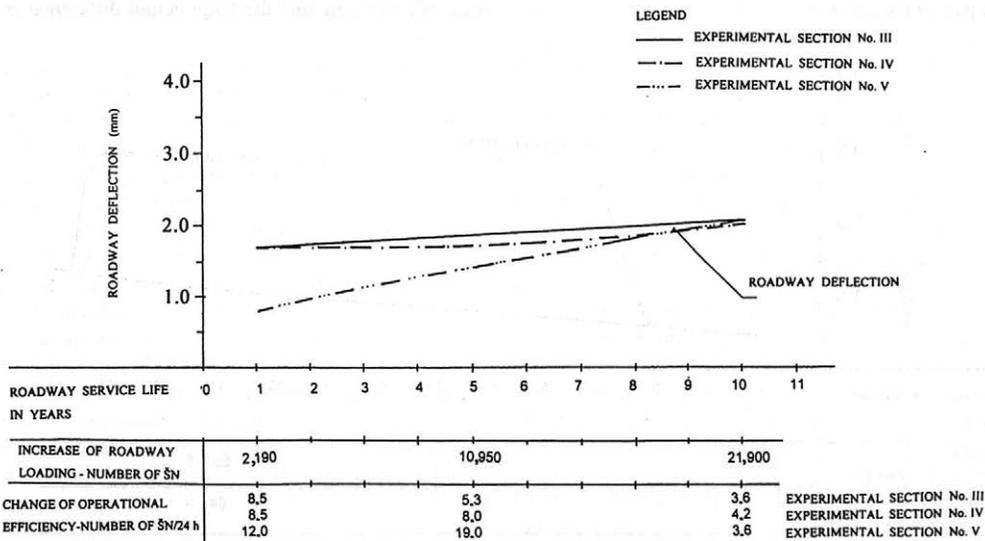

Fig. 4. The course of roadway degradation on Hučava forest road, sections III, IV, V expressed by an increase in the roadway deflection (in mm) and by changes in roadway operating performance given by the number of standard axles (ŠN) over 24 h during the time (years) of roadway use

plus 2 cm UN (sealing coat). Section IV is formed by 10 cm OK, which is the surface of better quality. The subgrade layer is broken stone of irregular thickness, 40 cm in wheel tracks except the centre and 25 cm on the roadway margins. The subsoil is loamy sand on both sections – 6% CBR.

The initial value of deflection is the same on both sections, with slight differences after some time. The course of degradation was more expressive on section III, with PAH surface, in comparison with section IV.

Section V

Section V follows after section IV. The construction of both sections is identical, the main difference is in the bearing capacity of the subsoil; it is sandy loam – 14% CBR in section V.

The graph illustrates that the initial value of deflection on section V was lower. After some time the deflection increase and degradation were more rapid and after 10 years they were equal. We can explain this fact by exposure. Section V is of N exposure while section IV is of S, SW exposures.

If we want to compare the obtained results with similar ones, then this comparison will be difficult.

No literature nor any other scientific sources are available that studied this problem, i.e. monitoring of degradation by instrumentation on special-purpose communications where the forest roads belong by their character. The same applies to public roads. Here the solution of a similar problem by the same instrumentation exists but only from the short-time aspect (1–2 years). This situation is similar in other countries, too. The degradation processes are better known in laboratory conditions but only for individual layers (especially for bituminous compounds) which were investigated by different methods and by different instrumentation. It does not allow to compare the results.

CONCLUSION

The problem of roadway degradation on forest roads following the change in bearing capacity has its regularities. They can be used for the planning of repairs or roadway pavement. Determination of roadway degradation following the change in roadway deflection and its determination by instrumentation is advantageous because it detects weak and strong places in the roadway construction. The visual appreciation is only a complementary evaluation parallelly to instrumentation.

The knowledge of roadway degradation can be used to calculate "bearing capacity coefficients". We can predict the process of roadway degradation on the basis of these coefficients as well as we can plan the optimal time of roadway repair.

Observations of degradation on these sections continue further and the results will be published after a longer time.

SUMMARY

The knowledge of the roadway condition in a network of roads is a crucial parameter for decisions on roadways. If we know the roadway condition, it is necessary to know the development of roadway degradation (degradation model).

Deterioration of the roadway serviceability is taken as the roadway degradation.

Wheel traffic, climatic effects, ageing effect, roadway wear and damage of constructional materials influence the roadway condition.

The sufficient bearing capacity is demanded for the main forest roads first of all. The other paramenters such as evenness (longitudinal and square), roughness are evaluated as complementary coefficients in forest roads with respect to the average speed of vehicles 18 km/h unlike the public (state) roads.

The roadway degradation on forest roads was evaluated according to changes in roadway bearing capacity during the time (years) of use on the basis of changes in roadway deflection. Old and new roads with bituminous surface were included in the studied file.

The length of an experimental section on the forest road was 300 m. There were 22 sections in total. An arm deflectometer was used as the measuring equipment. The reversible roadway deflection was measured with this instrument under the back axles of a vehicle loaded with 10 t. The qualitative condition of the section was complemented by a visual description of, for example, the occurrence of pot-holes, cracks and other damage. Measurement points were determined by random selection at an average distance of 30 m. Deflection was measured in the spring season after the subsoil defreezing (at the end of March, at the beginning of April) when the roadway has the lowest bearing capacity and when the wear process is the most expressive. The measurements were repeated every year. The data were processed by computing technique.

This article presents the results obtained during 10–15 year observations of degradation.

It is evident from the results that the roadway wear (degradation), i.e. higher deflection each year, permanently increases gradually on all experimental sections. It is represented by polynomials of degree I and II.

The roadway degradation is given by the number of standard (10 t) axles. At the beginning of roadway monitoring the operating performance was about 100 standard axles for 24 h. After 15 years of use the operating performance decreased to 5 standard axles for 24 h as a result of roadway degradation.

The results of roadway degradation will be used to determine "wear coefficients" which help to forecast the roadway degradation and to effectively plan the repair several years ahead.

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Degradácia netuhých vozoviek lesných ciest z teoretického a praktického hľadiska

L. ZELINKA

Technická univerzita, Lesnícka fakulta, Zvolen, Slovenská republika

ABSTRAKT: Článok pojednáva o degradačnom procese netuhých vozoviek lesných ciest s asfaltovým krytom, ktorý bol sledovaný v období 10–15 rokov. Degradácia vozovky bola zistená na základe hodnoty priehybu a pre lepšiu orientáciu vyčíslená zmenou prevádzkovej výkonnosti, a to počtom štandardných náprav počas doby užívania vozovky. Výsledky ukazujú, že proces degradácie je postupný a má prevažne nelineárnu závislosť. Dosiahnuté hodnoty poslúžia ako podklad pre zostavenie „únavových koeficientov", ktoré budú nápomocné pri naplánovaní optimálnej doby opravy (zosilnenia) vozovky.

Kľúčové slová: degradácia; teória; lesné cesty; priebeh

Nevyhnutným podkladom v systéme rozhodovania s vozovkami je znalosť vývoja stavu vozoviek cestnej siete. K tomu, aby sme poznali stav vozovky, je potrebné poznať vývoj degradácie (degradačný model) vozovky.

Skutočný priebeh degradácie vozovky ako celku alebo zmien „jednotlivých parametrov" funkčnej spôsobilosti vozovky môžeme modelovať degradačným modelom. Degradačným modelom sa vyjadrujú predpokladané zmeny parametrov v závislosti na čase alebo na počte opakovaní zaťaženia.

Štandardný postup pri zisťovaní degradácie vozovky a zostrojovaní modelu je taký, pri ktorom opakovanými meraniami s časovým odstupom zisťujeme a hodnotíme vozovky na konkrétnom úseku cesty. Po spracovaní súboru hodnôt parametra (parametrov) na tomto úseku môžeme vyjadriť zmeny strednej hodnoty parametra v závislosti na čase alebo na dopravnom zaťažení.

Vlastnosti vozoviek možno hodnotiť v laboratóriu, urýchleným namáhaním a pri reálnych podmienkach na ceste. Laboratórne metódy a merania nie sú však vhodné pre samotnú empirickú metódu. Typická a veľmi často využívaná metóda odvodzovania degradačného modelu je kombinovaná mechanicko-empirická. Výsledky laboratórnych skúšok fyzikálnych vlastností materiálov tvoria základ a sú podkladom pri hodnotení správania sa

(degradácie) konštrukcie pri urýchlenom skúšaní, napr. na kruhovej či líniovej dráhe, ale najmä na cestnej sieti.

Najhodnotnejšie sú výsledky z dlhodobých meraní a pozorovaní (LTTP – long-term pavement performance) pri reálnych klimatických podmienkach a dopravnom zaťažení. Vhodným výberom miest a podmienok (a ich kombinovaním) je možné relatívne skrátenie času pre získanie potrebných údajov. Pre prognózu priebehu degrádacie vozovky sú potrebné modely a funkcie, ktoré sa týkajú hodnotenia:
– drsnosti povrchu vozovky,
– rovnosti povrchu v priečnom a pozdĺžnom smere,
– mechanickej účinnosti (únosnosti) vozovky,
– indexu prevádzkovej spôsobilosti,
– stavu povrchu (intenzity a rozboru porúch povrchu),
– indexu stavu konštrukcie, ale aj ďalších parametrov, akými môžu byť napr. visual condition index, index stavu vozovky vypočítaný na základe výsledkov vizuálnej prehliadky, zámerov a porúch vozovky.

Uvedený príklad sledovania degradácie vozovky je veľmi náročný z finančného, časového a technického hľadiska. Pre lesné cesty sa tu javila určitá výhoda v tom, že základnou požiadavkou (kritériom) na lesných cestách je ich mechanická účinnosť (únosnosť) vozovky. Na základe toho sa degradácia vozovky lesných ciest sústre-

dila na sledovanie mechanickej účinnosti (únosnosti) vozovky, a to v reálnych podmienkach (klimatických, dopravných), pretože by bolo technicky a finančne veľmi obtiažne vytvoriť podmienky v laboratóriu alebo na kruhovej dráhe.

Metóda hodnotenia degradácie vozovky bola založená na hodnote priehybu vozovky a jeho zmeny (nárastu) počas doby (roka) užívania. Celkový rozbor predstavoval 22 pokusných úsekov s priemernou dĺžkou 300 m.

Na meranie priehybu bol použitý pákový priehybomer, ktorým sa meral vratný priehyb vozovky pod zadnou nápravou nákladného auta, zaťaženého 10 t. Kvalitatívny stav hodnotiaceho úseku bol ešte doplnený vizuálnym popisom stavu vozovky – predovšetkým krytu vozovky, napr. výskytom výtlkov, trhlín a iných poškodenín. Meracie body boli určené náhodným výberom s priemernou vzdialenosťou 30 m. Doba merania priehybu bola vždy v jarnom období, a to po rozmrznutí podložnej zeminy (koncom marca, začiatkom apríla), kedy je vozovka najmenej únosná. Meranie sa opakovalo každý rok a namerané hodnoty boli vyhodnotené pomocou výpočtovej techniky.

Článok prezentuje výsledky, ktoré boli získané za 10–15 rokov sledovaním degradácie vozovky.

Výsledky postupu degradácie sú uvedené na obr. 1–4, kde je zaznamenaný nárast priehybu vozovky v závislosti od doby (roka) používania. K tomuto priehybu bola pre lepšiu názornosť vyčíslená prevádzková výkonnosť, vyjadrená počtom prejazdov štandardných náprav (1 štandardná náprava sa rovná účinku zaťaženia 10 t).

Z výsledkov sa uvádza: na všetkých pokusných úsekoch bol zaznamenaný neustály nárast priehybu, a tým postup degradácie vozovky od jedného roka ku druhému (obr. 1–4). Po vyčíslení sa jedná o polynóm I. a II. stupňa. Degradácia vozovky pre lepšie praktické použitie bola prevedená cez hodnotu priehybu na počet prejazdov štandardných 10 t náprav. Na začiatku sledovania vozovky bola napr. prevádzková výkonnosť 100 štandardných náprav (obr. 1) a po 15 rokoch používania sa vplyvom degradácie vozovky znížila na päť štandardných náprav za 24 hodín. Obdobný priebeh degradácie vozovky bol zaznamenaný na ostatných pokusných úsekoch (obr. 2–4) a na ďalších, ktoré nie sú uvedené v článku. Obecne sa dá konštatovať, že s narastajúcou hrúbkou živičného krytu vozovky je postup degradácie miernejší. Najväčší vplyv na postup degradácie vozovky má intenzita dopravy. Vplyv klimatických podmienok (teplota, vlhkosť a pod.) má síce určitý vplyv na degradáciu vozovky, ale štatisticky nebola zistená významnejšia závislosť.

Výsledky skúmania degradácie vozovky sa využili pri zostavení „únavových koeficientov", ktoré boli zapracované do metódy *Diagnostika stavu a zosilňovanie netuhých vozoviek lesných ciest* (ZELINKA 1989), ktorá umožňuje predpovedať – naplánovať optimálnu dobu opravy (zosilnenia) vozovky až 15 rokov dopredu, čo umožní lepšie hospodárenie s finančnými prostriedkami.

Corresponding author:

Doc. Ing. LADISLAV ZELINKA, PhD., Technická univerzita, Lesnícka fakulta, T. G. Masaryka 24, 960 53 Zvolen, Slovenská republika, tel.: + 421 45 520 62 77, fax: + 421 45 533 26 54, e-mail: valtyni@vsld.tuzvo.sk

Prices of spruce timber and costs of spruce timber logging

V. Petrášová, J. Mecko, R. Petráš

Forest Research Institute, Zvolen, Slovak Republic

ABSTRACT: The paper presents detailed analysis of price trends of spruce timber assortments and the own costs of spruce timber logging in the state forests of Slovakia in the period 1988–1997. Besides average prices also variation coefficients are available. Costs of timber logging were analyzed according to the respective logging operations such as felling, skidding, timber handling and transportation as well as logging related activities. In the period of observation the prices of spruce timber increased according to assortments 2.7–3.8 times in comparison with 1988. Also the costs of spruce timber logging increased 4.0–5.7 times. The costs of timber logging in the period of observation were increasing relatively evenly but the prices of timber were increasing mainly until 1992.

Keywords: spruce; assortments; timber price; logging costs

Annual harvest in the Slovak Republic is about 5.5–5.8 million m³ of timber. Though the tree species composition of felled trees as well assortment composition are diverse, this volume influences the forest sector very significantly, particularly the forest economics. The volume of timber, tree species and assortment composition influence significantly also the revenues and the costs of the economic result. Since 1990 macro-economic conditions in forestry commercial activities have changed very importantly. It was particularly in the introduction of market prices for raw timber and competitive environment on the labour market as well as providing of goods services.

Though timber prices have their own importance in forestry, the issues of price formation were not paid appropriate attention in former Czechoslovakia. It was similar for the analysis and development of price formation. We can mention from the older publications the paper by POLENO (1984) dealing with analysis and prognosis of timber price trends, then the papers by HALAJ et al. (1990) and PETRÁŠ et al. (1992).

After 1990 more marked changes occurred also in the dynamics of trends of raw timber prices. Forestry circles responded to this fact, by that time already in the independent Czech Republic and Slovak Republic, and they regularly published surveys of average prices of raw timber according to the basic quality classes of timber. In the Czech Republic such surveys were published in Lesnická práce or in the Survey of Timber Prices of the Institute for Wood Technology Research and Development in Prague using the data from the Czech Statistical Office. The surveys contained average prices from the

supplies of raw timber to domestic market according to quality classes for logs, namely quality class I, II, IIIA, IIIB, IV, V and VI, and main commercial tree species but also to some neighbouring countries. In the Slovak Republic a similar survey is being published by the Institute for Forest Management Lesoprojekt Zvolen using statistical data from statistical reports Les D (Ministry of Agriculture of SR) 2-04. This survey is being published for a higher number of tree species than in the Czech Republic, but quality classes of logs IIIA and IIIB are incorporated into one average price. A shortcoming of both surveys is that they do not contain timber prices according to diameter classes of logs.

Costs of spruce timber logging in Slovakia were studied comprehensively only by HALAJ et al. (1990) and PETRÁŠ et al. (1992). They studied the costs to express a net yield of value production. They derived an inductive procedure and constructed the basic algorithm for the quantification of costs of the whole logging process.

MATERIALS AND METHODOLOGY

Background data to judge the trend of raw timber prices and the costs of its production were obtained from the statistics of state forest enterprises in Slovakia for the years 1988–1997.

TIMBER PRICES

Timber prices were derived according to basic assortments, it means quality classes of logs, namely I, II, IIIA, IIIB, V and VI quality class, and diameter classes of logs

Table 1. Average realized prices (SKK/m³) and variation coefficients of realized prices of raw timber assortments in state forests of Slovakia for spruce and fir

Quality	Class Diameter	Price Variation coefficient	1988	1991	1992	1993	1994	1995	1996	1997
I	3	SKK	935	2,215	2,434	2,470	2,558	2,664	2,719	2,694
		(%)		2.2	3.4	2.1	1.3	1.2	4.7	4.1
	4	SKK	1,040	2,463	2,702	2,743	2,810	2,900	2,963	2,901
		(%)		2.2	3.1	1.9	3.2	1.8	4.9	4.2
	5	SKK	1,080	2,557	2,806	2,849	2,918	3,013	3,077	3,022
		(%)		2.2	3.1	1.9	3.2	2.0	5.0	5.1
	6	SKK	1,130	2,676	2,935	2,980	3,053	3,149	3,216	3,150
		(%)		2.2	3.1	1.8	3.2	1.8	4.8	4.0
Realized volume (m³)			–	6,340	4,587	3,351	2,420	3,041	1,386	561
II	2	SKK	665	1,599	1,829	1,854	2,021	2,142	2,182	2,217
		(%)		5.4	3.9	6.4	8.7	8.3	4.7	3.1
	3	SKK	790	1,911	2,166	2,195	2,288	2,428	2,504	2,580
		(%)		6.4	3.7	6.2	8.1	5.2	2.7	3.6
	4	SKK	835	2,021	2,290	2,321	2,418	2,567	2,647	2,777
		(%)		6.4	3.6	6.0	8.0	4.9	2.6	5.1
	5	SKK	875	2,118	2,399	2,431	2,532	2,685	2,768	2,835
		(%)		6.4	3.6	5.9	7.9	4.8	2.4	3.1
	6	SKK	920	2,225	2,519	2,554	2,660	2,818	2,904	2,902
		(%)		6.4	3.5	5.9	7.9	4.9	2.3	2.0
Realized volume (m³)			–	19,700	12,795	9,941	8,859	11,940	9,683	10,244
III A	1	SKK	341	840	1,042	1,052	1,072	1,279	1,257	1,259
		(%)		3.9	6.2	6.8	17.1	11.3	6.5	5.5
	2	SKK	480	1,164	1,451	1,495	1,495	1,717	1,724	1,790
		(%)		3.5	5.2	6.2	10.9	7.8	3.4	5.9
	3	SKK	530	1,286	1,599	1,617	1,661	1,894	1,900	2,003
		(%)		3.4	5.3	6.1	10.9	8.3	3.6	6.5
	4	SKK	520	1,262	1,572	1,589	1,629	1,848	1,879	1,972
		(%)		3.4	5.7	6.5	11.1	8.8	5.1	7.8
	5	SKK	505	1,237	1,531	1,545	1,580	1,787	1,821	1,926
		(%)		4.0	6.2	6.9	11.1	8.9	4.9	9.5
	6	SKK	496	1,204	1,503	1,514	1,560	1,718	1,720	1,876
		(%)		3.4	6.2	6.9	10.9	10.3	5.2	12.3
Realized volume (m³)			–	333,311	267,956	268,512	331,352	385,559	451,225	481,798
III B	1	SKK	287	691	892	885	864	1,031	991	943
		(%)		8.3	8.0	6.9	11.5	7.5	6.9	4.7
	2	SKK	403	945	1,223	1,211	1,203	1,417	1,386	1,396
		(%)		6.7	5.7	4.5	6.5	6.2	7.5	8.0
	3	SKK	447	1,049	1,364	1,352	1,346	1,559	1,527	1,547
		(%)		6.7	6.2	5.5	6.3	5.2	5.9	7.5
	4	SKK	438	1,028	1,338	1,324	1,318	1,532	1,498	1,529
		(%)		6.7	6.2	5.5	6.4	5.8	6.4	8.6
	5	SKK	427	1,002	1,307	1,292	1,281	1,480	1,450	1,497
		(%)		6.7	6.3	5.6	6.8	5.8	5.9	9.7
	6	SKK	418	980	1,279	1,262	1,253	1,420	1,390	1,459
		(%)		6.7	6.5	5.5	6.5	6.7	5.7	11.4
Realized volume (m³)			–	248,702	201,095	267,035	254,780	300,066	429,225	423,421
V		SKK	287	667	661	674	661	721	816	790
		(%)		4.0	3.8	3.2	8.0	7.5	4.6	3.3
Realized volume (m³)			–	389,395	302,167	512,609	588,399	624,054	647,787	633,946
VI		SKK	94	246	211	188	192	249	242	255
Sofwood		(%)		12.4	5.3	7.1	9.4	20.0	23.9	18.4
Realized volume (m³)			–	100,992	56,933	107,276	125,272	120,051	140,767	126,570
Realized volume in total (m³)			–	1,098,440	845,533	1,168,724	1,311,082	1,444,711	1,680,073	1,676,540

Table 2. Average coefficients of costs and wage tariffs for timber logging

Coefficient		Year							
		1988	1991	1992	1993	1994	1995	1996	1997
Of additional charges	value	1.40	1.36	1.36	1.26	1.31	1.28	1.30	1.28
to basic man-hours	index	1.00	0.97	0.97	0.90	0.94	0.91	0.93	0.91
Wage tariff	value	12.94	15.30	21.00	23.70	26.90	29.30	33.40	37.40
(SKK per man-hour)	index	1.00	1.18	1.62	1.83	2.08	2.26	2.58	2.89
Of bonuses to basic	value	1.28	1.12	1.10	1.17	1.16	1.24	1.29	1.26
wage	index	1.00	0.88	0.86	0.91	0.91	0.97	1.01	0.98
Of conversion of wage	value	1.19	1.74	1.74	1.85	1.84	1.91	1.88	1.84
costs to direct costs	index	1.00	1.46	1.46	1.55	1.55	1.61	1.58	1.55
Aggregate	value	27.59	40.55	54.66	64.64	75.21	88.82	105.30	110.99
(SKK per man-hour)	index	1.00	1.47	1.98	2.34	2.73	3.22	3.82	4.02

1–6+ from price lists obtained from state forest enterprises for the years 1991–1997. Though the organizational structure of these enterprises changed several times for the mentioned period, we can state that particularly the state forest enterprises Západoslovenské lesy Bratislava, Stredoslovenské lesy Banská Bystrica, Severoslovenské lesy Žilina, Východoslovenské lesy Košice, Lesy TANAP as well as Vojenské lesy a majetky (Military Forests and Estates) Pliešovce influenced price formation for raw timber in the Slovak Republic. Based on the offer and volume of timber supplies from these enterprises average prices of raw timber were calculated according to quality classes and diameter classes of logs. Average price represents weighted arithmetical mean where the weight is the volume of supplied timber. Variation coefficients of these prices were calculated as well. Their values are listed in Table 1. In 1988 there were still uniform wholesale prices which changed to market prices in 1991. The volume of spruce timber supplies was higher than 1.0 million m³ in these enterprises each year, except 1992. Even in the year 1996–1997 it amounted to almost 1.7 million m³. These volumes show that the example incorporates a dominant volume of felled spruce trees in the Slovak Republic.

COSTS OF TIMBER LOGGING

Studied costs of raw timber logging were namely the costs of the whole logging process, i.e. the costs of felling, skidding, handling, transport as well as of other related operations. It means they incorporated the costs of all logging operations starting from tree felling up to its transportation to customers as well as other related works, such as repair and maintenance of forest roads, log yards and cross-cutting lines. Direct costs were investigated in each operation separately by means of the following partial coefficients:
1. coefficient of additional charges to basic man-hours,
2. wage tariffs,
3. coefficient of bonuses to basic wage,
4. coefficient of conversion of wage costs to direct costs.

By means of the product of all four coefficients we derived an aggregate coefficient that gives unit costs of respective logging operations in SKK per 1 man-hour of the work. The coefficients for felling, skidding, handling and timber transportation are listed in Tables 2–5. Real direct costs of the above-mentioned logging operations for concrete conditions are to be derived as a product of unit costs and standard work for this operation expressed in man-hours per 1 m³ of processed timber. Table 6 presents only direct costs of other logging operations in SKK per 1 m³ of felled timber. Direct costs of the whole logging process are calculated as a sum of direct costs of all operations. In case it is necessary to convert direct costs to prime costs, it is sufficient to multiply direct costs by the coefficient of overhead costs. This coefficient had an average value 1.55 for the period of investigation.

Necessary data for the calculation of cost coefficients of all logging operations for the years 1992–1997 were

Table 3. Average coefficients of costs and wage tariffs for timber skidding

Coefficient		Year							
		1988	1991	1992	1993	1994	1995	1996	1997
Of additional charges	value	1.26	1.39	1.39	1.23	1.23	1.24	1.23	1.24
to basic man-hours	index	1.00	1.10	1.10	0.98	0.98	0.98	0.98	0.98
Wage tariff	value	12.01	14.85	21.00	23.70	27.40	29.30	33.40	37.40
(SKK per man-hour)	index	1.00	1.24	1.75	1.97	2.28	2.44	2.78	3.11
Of bonuses to basic	value	1.25	1.13	1.10	1.15	1.13	1.19	1.18	1.30
wage	index	1.00	0.90	0.88	0.92	0.90	0.95	0.94	1.04
Of conversion of wage	value	3.34	3.26	3.26	3.89	4.19	4.39	4.76	4.60
costs to direct costs	index	1.00	0.98	0.98	1.16	1.25	1.31	1.43	1.38
Aggregate	value	63.18	76.04	104.68	130.41	159.57	189.80	230.75	277.33
(SKK per man-hour)	index	1.00	1.20	1.66	2.06	2.53	3.00	3.65	4.39

Table 4. Average coefficients of costs and wage tariffs for timber handling

Coefficient		Year							
		1988	1991	1992	1993	1994	1995	1996	1997
Of additional charges	value	1.20	1.24	1.24	1.17	1.17	1.15	1.18	1.18
to basic man-hours	index	1.00	1.03	1.03	0.98	0.98	0.96	0.98	0.98
Wage tariff	value	10.85	12.10	19.00	21.40	25.10	26.40	30.40	34.40
(SKK per man-hour)	index	1.00	1.12	1.75	1.97	2.31	2.43	2.80	3.17
Of bonuses to basic	value	1.26	1.12	1.10	1.16	1.22	1.23	1.24	1.28
wage	index	1.00	0.89	0.87	0.92	0.97	0.98	0.98	1.02
Of conversion of wage	value	1.70	2.13	2.13	2.93	2.43	3.24	2.88	3.08
costs to direct costs	index	1.00	1.25	1.25	1.72	1.43	1.91	1.69	1.81
Aggregate	value	27.89	35.79	55.20	85.10	87.06	120.99	128.11	160.03
(SKK per man-hour)	index	1.00	1.28	1.98	3.05	3.12	4.34	4.59	5.74

Table 5. Average coefficients of costs and wage tariffs for timber transportation

Coefficient		Year							
		1988	1991	1992	1993	1994	1995	1996	1997
Of additional charges	value	1.11	1.11	1.11	1.07	1.07	1.07	1.07	1.07
to basic man-hours	index	1.00	1.00	1.00	0.96	0.96	0.96	0.96	0.96
Calculation of basic	value	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
(km/km)	index	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wage tariff	value	10.87	13.50	21.00	23.71	27.47	29.29	33.37	37.36
(SKK per man-hour)	index	1.00	1.24	1.93	2.18	2.53	2.69	3.07	3.44
Of bonuses to basic	value	1.26	1.10	1.10	1.13	1.14	1.19	1.21	1.20
wage	index	1.00	0.87	0.87	0.90	0.90	0.96	0.96	0.95
Of conversion of wage	value	3.50	7.71	7.71	5.92	5.53	5.15	5.39	4.99
costs to direct costs	index	1.00	2.20	2.20	1.69	1.58	1.47	1.54	1.43
Aggregate	value	66.51	158.86	247.12	212.14	231.62	240.09	291.09	299.21
(SKK per man-hour)	index	1.00	2.39	3.72	3.19	3.48	3.61	4.38	4.50

Table 6. Average coefficients of costs of other operations

Coefficient		Year							
		1988	1991	1992	1993	1994	1995	1996	1997
Aggregate	value	58.58	27.72	27.72	84.50	77.00	124.00	146.50	136.50
(SKK per man-hour)	index	1.00	0.47	0.47	1.44	1.31	2.12	2.50	2.33

obtained from accounting reports and statistics of some working-plan areas, affiliated forest enterprises (OLZ) and state forest enterprises. The analysis was made down to the level of concrete records of tasks, namely 6,855 for felling, 8,032 for skidding and 3,098 for timber handling. Selection of concrete working-plan areas was made with regard to the distribution of spruce, the proportion of spruce in selected working-plan area being higher than 50%. According to affiliated forest enterprises the following working-plan areas were included:

– OLZ Čierny Balog – Šaling, Osrblie, Hronec, Dobroč, Č. Balog, and Sihla,
– OLZ Beňuš – Polomka, Pohorelá, Č. Skala, Beňuš, Švermovo and Závadka,
– OLZ Námestovo – Zubrohlava, Trstená, Oravice, Or. Polhora, Námestovo and Habovka,
– OLZ Oravský Podzámok – Zákamenné, Párnica, Paráč, Or. Podzámok, Lokca and D. Kubín.

Arithmetical means of cost coefficients were calculated on the basis of data from these working-plan areas

and affiliated forest enterprises. Wage tariffs were derived from higher collective agreements. The costs for the years 1988 and 1991 are taken from HALAJ et al. (1990) and PETRÁŠ et al. (1992).

RESULTS

TIMBER PRICES

We can see from average realized timber prices in SKK/m^3 in Table 1 that timber prices have increased for all quality and diameter classes. The only exceptions are quality classes V and VI, it means pulpwood and fuelwood, in which their prices did not change in some years or they slightly dropped. Regarding the coefficients of variation presented in Table 1 for each average price, we can state that unit prices varied a lot between forest enterprises. Coefficients of variation ranged from 2 to 10% for most assortments and calendar years. If we compare their values between calendar years we can state that the
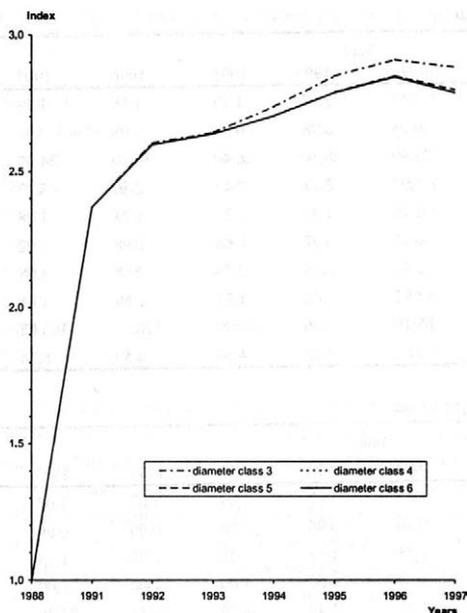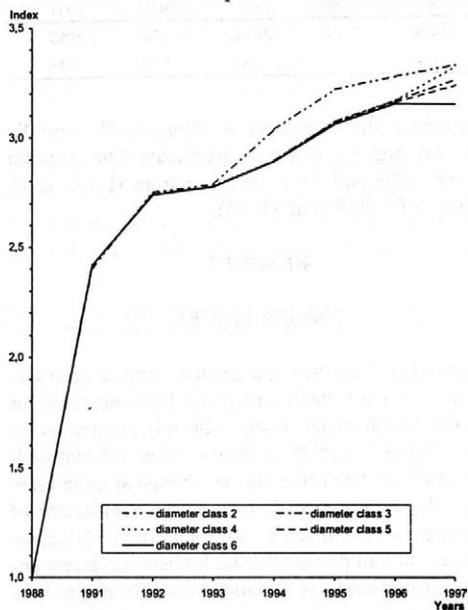
Fig. 1. Development of the indexes of timber prices for the years 1988–1997 for spruce of quality class I of logs ($I_i = c_i/c_{1988}$)
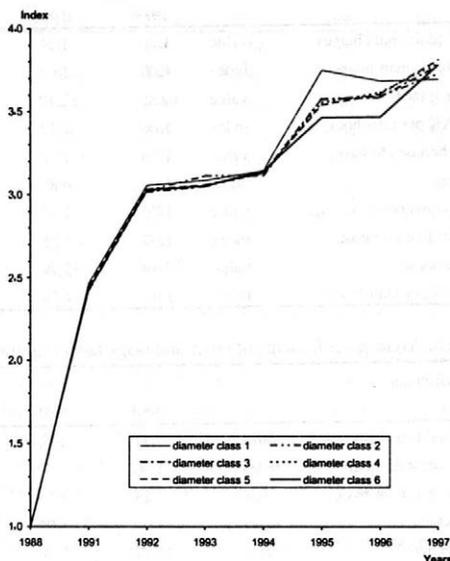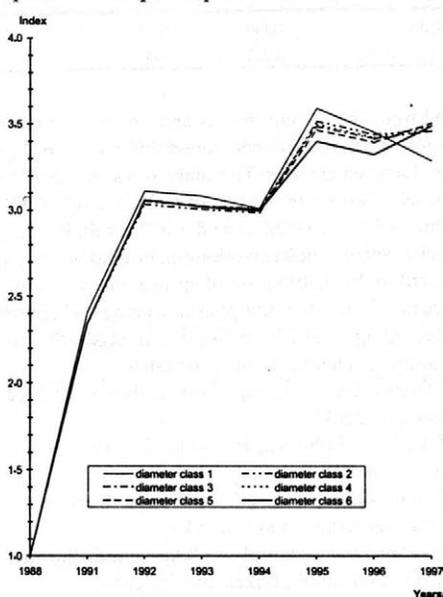

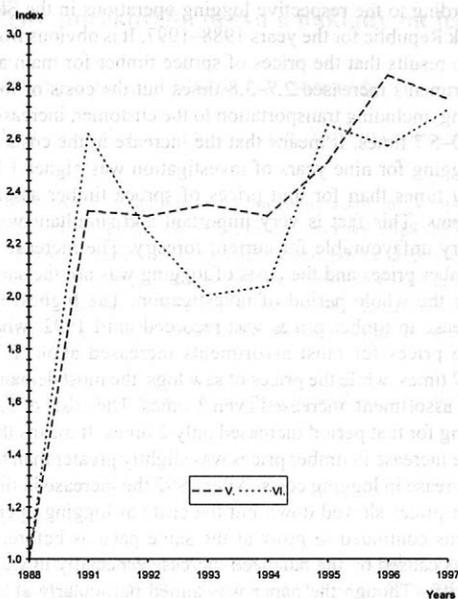Fig. 3. Development of the indexes of timber prices for the years 1988–1997 for spruce of quality class IIIA of logs ($I_i = c_i/c_{1988}$)

highest variation coefficients were reached in 1994, when they ranged from 8 to 11%. This difference is obviously related with a strong wind calamity resulting in a great volume of salvage felling, and consequently, a large volume of timber on the market. It meant for the forest enterprises affected by this calamity that they received lower prices and higher variability of timber prices. With normal distribution of unit prices of timber close to arith-

metical mean we can state that 68% of enterprises had average timber prices with the range ± 1 multiple and 95% of enterprises with the range ± 2 multiple of variation coefficient. This range of unit prices of timber could provide sufficient space for its full realization on the market.

For better comparison and generalization of the trends of spruce timber prices price indexes were calculated

Fig. 2. Development of the indexes of timber prices for the years 1988–1997 for spruce of quality class II of logs ($I_i = c_i/c_{1988}$)

Fig. 4. Development of the indexes of timber prices for the years 1988–1997 for spruce of quality class IIIB of logs ($I_i = c_i/c_{1988}$)

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Fig. 5. Development of the indexes of timber prices for the years 1988–1997 for spruce of quality class V and VI (softwood) of logs ($I_i = c_i/c_{1988}$)

from average prices as the ratios of average prices of timber in concrete calendar year to the timber prices in 1988. Thus price indexes express relative changes in prices in comparison with the prices in 1988. The development of price indexes for diameter and quality classes I, II, IIIA, IIIB, V and VI of spruce logs for the years 1991–1997 is illustrated in Figs. 1–5. We can state according to their trend that the prices increased until 1992, whereas for quality classes VI and V of logs the prices increased 2.2–2.3 times, for classes I and II 2.6 – 2.7 times and for classes IIIA, IIIB almost 3.0 times. In the years 1993–1997 the prices did not increase so abruptly, and in some cases, also a slight drop was recorded. Particularly, for quality classes IIIA, IIIB of the logs the price index has increased 2.7–2.8 times, for classes I and II 2.8–3.3 times, and for classes IIIA, IIIB 3.8 and 3.5 times, respectively. It means the price index increased about 0.2–0.8 times for all quality classes of logs in the last five years, i.e. the average annual increase by 0.04–0.16 only. In comparison with previous years 1990–1992, when the index increased 2.2–3.0 times in the last 3 years, this increase was very small. Regarding the assessment of the trends of timber prices for the whole period, it means by the year 1997, according to the quality classes of logs we can state that the highest increase, namely 3.5–3.8 times, was recorded for saw logs of quality classes IIIA and IIIB, and the lowest increase for fuelwood and pulpwood, namely only 2.7–2.8 times.

Figs. 1–4 illustrate the development of price indexes according to diameter classes of logs. We can state that

all diameter classes of logs in quality classes I and II have very similar price indexes until 1993. In quality classes IIIA and IIIB it applied until 1994. Some changes occurred in the following years but mostly for the lowest and highest diameter classes. Their difference from mean diameter expressed by price index has the value about 0.1–0.2.

COSTS OF TIMBER LOGGING

Tables 2–5 show partial cost coefficients as well as aggregate coefficients for investigated logging operations such as felling, skidding, handling and timber transportation according to the calendar years 1988–1997. From these coefficients given in Tables 2–5 their indexes were also calculated as the ratios of the coefficient in the respective calendar year to the coefficient from the year 1988. Regarding the coefficient of additional charges to basic man-hours we can state that in 1988 the highest additional charges were in felling, namely 40%, followed by skidding with 26%, handling with 20% and timber transportation with 11%. The values of this coefficient changed for nine years but mostly decreased by the year 1997. In relative values they dropped by 2–9% but the proportions between logging operations were preserved. Coefficients of bonuses to basic wages have very balanced values for the logging operations. In 1998 the bonuses in these operations amounted to 25–28%. Though their trend for the period of investigation was relatively dynamic, in 1997 they amounted to 26–30%, except transportation with 20%. Thus we can state that the bo-
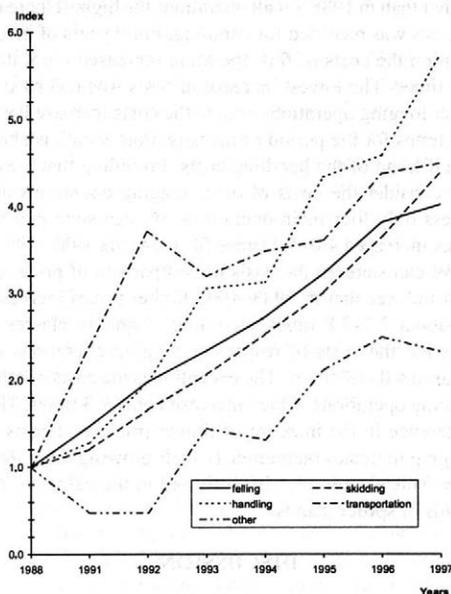

Fig. 6. Development of the indexes of logging costs for the years 1988–1997 for spruce

nuses were very variable, and they amounted to 10–30% for the whole period and all operations. For the period of investigation wage tariffs changed the most of all, when in felling they increased by 289%, skidding by 311%, handling by 317% and transportation by 344%. Unanimously, for the whole period, the coefficients of conversion of wage costs to direct costs have increased. Their development according to the respective operations was not the same and their values have not increased so significantly as for wage tariffs. For all operations their values have increased by about 40–80% since 1988.

Tables 2–6 present aggregate coefficients of costs that were calculated as a product of wage tariffs, coefficient of additional charges to basic man-hours, bonuses to basic wage and conversion coefficient of wage costs to direct costs. Aggregate coefficient is expressed in SKK per 1 man-hour of work separately in each operation. One exception is other related operations, in which aggregate coefficients of costs are expressed in SKK per 1 m³ of felled timber. Based on the aggregate coefficients of costs according to calendar years also their indexes were calculated as the ratios of coefficient in the respective calendar year to the coefficient in the basic year 1988. The development of these indexes is illustrated in Fig. 6. Regarding their values the indexes of costs of felling and skidding were increasingly growing and had a relatively balanced trend. In the final year 1997 the costs of these two operations increased 4.0–4.4 times in comparison with the basic year 1988. The costs of timber transportation increased very rapidly, particularly by the year 1992, when they were higher 3.7 times. For the whole period of investigation the costs of transportation were 4.5 times higher than in 1988. Of all operations the highest increase in costs was recorded for handling. For 9 years of investigation the costs of this operation increased more than 5.7 times. The lowest increase in costs was recorded in other logging operations, where the costs increased only 2.3 times for the period of investigation, which is about a half trend of the handling costs. Providing that we do not consider the costs of other logging operations and assess only four main operations, we can state that the costs increased 4.0–5.7 times for the years 1988–1997.

We can state on the basis of comparison of price and cost indexes that in 1988–1997 timber prices increased by about 2.7–3.8 times according to quality classes of logs but the costs of respective logging operations increased 4.0–5.7 times. The exception is the costs of other logging operations, which increased only 2.3 times. This difference in the increase of timber prices and costs of logging indicates unanimously their growing disproportion. This situation is also reflected in the values of net yields of spruce stands.

DISCUSSION

The trends of unit prices of spruce raw timber according to quality and diameter classes of logs are assessed in the paper as well as the trend of spruce timber costs ac-

cording to the respective logging operations in the Slovak Republic for the years 1988–1997. It is obvious from the results that the prices of spruce timber for main assortments increased 2.7–3.8 times but the costs of logging, including transportation to the customer, increased 4.0–5.7 times. It means that the increase in costs of logging for nine years of investigation was higher 1.3–1.9 times than for unit prices of spruce timber assortments. This fact is very important and simultaneously very unfavourable for current forestry. The increase in timber prices and the costs of logging was not the same for the whole period of investigation. The highest increase in timber prices was recorded until 1992, when the prices for most assortments increased about 2.2–2.7 times, while the prices of saw logs, the most demanded assortment, increased even 3 times. The costs of logging for that period increased only 2 times. It means that the increase in timber prices was slightly greater than the increase in logging costs. After 1992 the increase in timber prices slowed down but the costs of logging operations continued to grow at the same pace as before. It was caused by the balanced increase especially in wage tariffs. Though the paper was aimed particularly at the analysis of the trends of the prices of spruce timber assortments and logging costs for the years 1988–1997, it is possible to obtain also more general related information and to forecast future trends. Though spruce timber has very good technical and technological properties, it is very improbable that its price will increase at the same pace as in the period of 1990–1992. We expect a slight increase gradually up to the balance with higher prices in neighbouring countries. The increase in the costs of spruce timber logging is relatively strong and permanent. Regarding the continuous increase in the living costs, we can also expect a permanent pressure on the increase of wage tariffs and wage costs. Regarding these facts, it is necessary to take into account not only lower yields of spruce timber but also the lower rate of return in the whole forestry.

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Ceny smrekového dreva a náklady na jeho ťažbu

V. PETRÁŠOVÁ, J. MECKO, R. PETRÁŠ

Lesnícky výskumný ústav, Zvolen, Slovenská republika

ABSTRAKT: Práca obsahuje podrobnú analýzu vývoja cien sortimentov smrekového dreva a vlastných nákladov na jeho ťažbu v štátnych lesoch na Slovensku za roky 1988–1997. Okrem priemerných cien sú k dispozícii aj variačné koeficienty. Náklady na ťažbu dreva sa analyzovali podľa konkrétnych ťažbových činností ako je ťažba, sústreďovanie, manipulácia a odvoz dreva, ale aj ostatné ťažbové činnosti. Počas skúmaného obdobia sa zvýšili ceny smrekového dreva podľa sortimentov 2,7–3,8-krát v porovnaní k roku 1988, ale náklady na jeho ťažbu podľa ťažbových činností 4,0–5,7-krát. Náklady na ťažbu dreva sa počas skúmaného obdobia zvyšovali približne rovnomerne, no ceny dreva stúpali hlavne do roku 1992.

Kľúčové slová: smrek; sortimenty; cena dreva; náklady na ťažbu

V práci sa analyzuje vývoj cien sortimentov smrekového dreva a vlastných nákladov na jeho ťažbu v štátnych lesoch na Slovensku za roky 1988–1997. Podkladové údaje pre analýzu sa získali z evidencie podnikov štátnych lesov v Slovenskej republike za roky 1988–1997. Ceny dreva sa odvodili podľa základných sortimentov, t.j. akostných tried výrezov I, II, IIIA, IIIB, V a VI a hrúbkových tried výrezov 1–6+ z ponukových cenníkov podnikov štátnych lesov. Z týchto cien a objemu dodávok dreva podľa podnikov sa vypočítali podľa vzorca pre vážený aritmetický priemer priemerné ceny surového dreva a ich variačné koeficienty. V roku 1988 to boli ešte jednotné centrálne stanovené veľkoobchodné ceny, ktoré sa od roku 1991 zmenili na trhové.

Skúmané náklady ťažby dreva zahŕňajú v sebe celú ťažbovú činnosť, t.j. náklady na ťažbu, sústreďovanie, manipuláciu, odvoz, ale aj ostatné ťažbové činnosti. Sú to teda nielen náklady na všetky priame ťažbové činnosti od zrúbania stromu až po dopravu dreva k jeho odberateľovi, ale aj ostatné činnosti, ktoré s ťažbou dreva súvisia, ako je napr. oprava a údržba lesných ciest, skladov dreva a pod. Priame náklady sa skúmali v každej činnosti samostatne prostredníctvom týchto parciálnych koeficientov:

1. koeficienta prirážok k základným normohodinám,
2. mzdových taríf,
3. koeficienta prémií k základnej mzde,
4. koeficienta prepočtu mzdových nákladov na priame náklady.

Súčinom všetkých štyroch koeficientov sa odvodil súhrnný koeficient, ktorý vyjadruje jednotkové náklady na príslušnú ťažbovú činnosť v Sk na 1 normohodinu vykonanej práce. Uvádzané koeficienty pre ťažbu, sústreďovanie, manipuláciu a odvoz dreva sú v tab. 2–5. Skutočné priame náklady na uvádzané ťažbové činnosti sa pre konkrétne podmienky odvodia ako súčin jednotkových nákladov a normovanej práce na túto činnosť, vy-

jadrenej v 1 normohodine na 1 m³ spracovaného dreva. V tab. 6 sú uvedené len priame náklady na ostatnú ťažbovú činnosť v Sk na 1 m³ ťaženého dreva. Priame náklady na celú ťažbovú činnosť sa vypočítajú ako súčet priamych nákladov za všetky činnosti. V prípade, že by bolo potrebné prepočítať priame náklady na vlastné, je treba vynásobiť priame náklady koeficientom réžie, ktorý mal za skúmané obdobie priemernú hodnotu 1,55. Potrebné podklady na výpočet nákladových koeficientov všetkých ťažbových činností za roky 1992–1997 sa získali z účtovnej a štatistickej evidencie vybraných lesných hospodárskych celkov, lesných závodov a podnikov štátnych lesov.

Z priemerných realizovaných cien dreva v Sk/m³ v tab. 1 je vidieť, že pri všetkých akostných a hrúbkových triedach sa ceny z roka na rok zvyšovali. Výnimkou je len akostná trieda V a VI, teda vlákninové a palivové drevo, kde v niektorých rokoch sa ich ceny prakticky nemenili, alebo aj mierne poklesli. Variačný koeficient dosahoval u väčšiny sortimentov a kalendárnych rokov hodnoty 2–10 %. Pre porovnanie a zovšeobecnenie cenového vývoja sortimentov smrekového dreva sa z priemerných cien vypočítali aj cenové indexy ako podiely cien dreva v konkrétnom kalendárnom roku k cenám v roku 1988. Podľa ich vývoja na obr. 1–5 môžeme konštatovať, že relatívne najväčší cenový nárast bol do roku 1992. V rokoch 1993–1997 sa ceny zvyšovali miernejšie, alebo v niektorých prípadoch aj mierne poklesli. Pri hodnotení vývoja cien dreva za celé obdobie, t.j. do roku 1997 podľa akostných tried výrezov môžeme konštatovať, že najväčšie, a to 3,5–3,8-krát, bolo pri piliarskych výrezoch triedy IIIA a IIIB a najnižšie pri palive a vlákninovom dreve – len 2,7–2,8-krát. Na obr. 1–4 je znázornený aj vývoj cenových indexov podľa hrúbkových tried výrezov. Z ich vývoja podľa kalendárnych rokov môžeme konštatovať, že všetky hrúbkové triedy výrezov v akostnej triede I a II majú do roku 1993 a v akostnej

triede IIIA a IIIB až do roku 1994 veľmi blízke cenové indexy. Po týchto rokoch síce nastáva určitá zmena, ale väčšinou len pre najnižšie a najvyššie hrúbkové triedy.

V tab. 2–5 sú uvedené parciálne nákladové koeficienty, ale aj súhrnný koeficient pre ťažbu, sústreďovanie, manipuláciu a odvoz dreva podľa kalendárnych rokov 1988–1997. Z nich sa vypočítali aj indexy ako podiely koeficientov v konkrétnom kalendárnom roku ku koeficientu v roku 1988. Podľa koeficienta prirážok k základným normohodinám môžeme konštatovať, že v roku 1988 boli najväčšie prirážky – a to až 40 % – v ťažbe, 26 % v sústreďovaní, 20 % v manipulácii a len 11 % v odvoze dreva. Za deväť rokov sa jeho hodnoty rôzne menili, ale väčšinou klesali až po rok 1997.

Koeficienty prémií k základným mzdám majú medzi ťažbovými činnosťami veľmi vyrovnané hodnoty. V roku 1988 boli prémie vo výške 25–28 %. I keď ich vývoj za skúmané obdobie bol pomerne dynamický, celkove môžeme konštatovať, že prémie boli veľmi variabilné a za celé obdobie a všetky činnosti dosahovali hodnoty 10–30 %. Za sledované obdobie sa jednoznačne najviac zmenili mzdové tarify, keď pri ťažbe dreva sa zvýšili o 289 %, pri približovaní o 311 %, pri manipulácii o 317 % a pri odvoze dreva až o 344 %.

Jednoznačne sa za celé sledované obdobie zvýšili aj koeficienty prepočtu mzdových nákladov na priame. Ich vývoj podľa činností nebol rovnaký a ich hodnoty sa nezvýšili tak výrazne ako pri mzdových tarifách. Za všetky činnosti sa ich hodnoty zvýšili od roku 1988 približne o 40–80 %. V tab. 2–6 sú aj súhrnné koeficienty nákladov vyjadrené v Sk na 1 normohodinu práce osobitne v každej činnosti. Výnimkou je len ostatná ťažbová činnosť, ktorá má súhrnné koeficienty nákladov vyjadrené v Sk na 1 m³ ťaženého dreva.

Zo súhrnných koeficientov nákladov podľa kalendárnych rokov sa vypočítali aj ich indexy ako podiely koeficientov v konkrétnom kalendárnom roku ku koeficientu v základnom roku 1988. Vývoj týchto indexov je znázornený na obr. 6. Stále rastúci a pomerne vyrovnaný je trend indexov nákladov pre ťažbu a sústreďovanie dreva. V konečnom roku 1997 sa náklady na tieto dve činnosti zvýšili 4,0 a 4,4-krát. Náklady na odvoz dreva boli 4,5-krát vyššie. Zo všetkých činností má najväčšie zvyšovanie nákladov manipulácia dreva, a to o viac ako 5,7-krát. Najmenšie zvyšovanie nákladov bolo v ostatnej ťažbovej činnosti, kde za sledované obdobie náklady stúpli len 2,3-krát, čo je približne polovičný trend z nákladov v manipulácii dreva. Keď by sme vynechali náklady na ostatnú ťažbovú činnosť a hodnotili len štyri hlavné činnosti, môžeme konštatovať, že za roky 1988–1997 sa náklady na ich vykonávanie zvýšili 4,0–5,7-krát.

Porovnaním cenových a nákladových indexov môžeme konštatovať, že ceny dreva za roky 1988–1997 sa zvýšili podľa akostných tried výrezov približne 2,7–3,8-krát, ale náklady jednotlivých ťažbových činností 4,0–5,7-krát. Výnimkou sú náklady ostatnej ťažbovej činnosti, ktoré sa zvýšili len 2,3-krát. Toto rozdielne zvyšovanie cien dreva a nákladov ťažbovej činnosti jednoznačne poukazuje na ich stúpajúcu disproporciu, ktorá má veľmi nepriaznivý dopad na obhospodarovanie aj takej výnosovej dreviny, ako je smrek.

Corresponding author:

Ing. VIERA PETRÁŠOVÁ, CSc., Lesnícky výskumný ústav, T. G. Masaryka 22, 960 92 Zvolen, Slovenská republika, tel.: + 421 45 531 41 19, fax: + 421 45 531 41 92, e-mail: vpetras@fris.sk

INFORMATION

Many-sided functions of forests: a strategy for sustainable development of forest ecosystems

(Sub-module 2A8 of the UNDP project *Towards Sustainable Development of the Czech Republic: Building National Capacities for Sustainable Development*)

In the Czech Republic (CR), forest ecosystems represent (1) a substantial national wealth producing environment-friendly raw materials (particularly wood) as a renewable natural resource, and (2) an irreplaceable environmental component determining essential elements of the cultural landscape. Research into the above-mentioned sub-module thus proceeded along two interrelated subject routes toward a holistic assessment of the sustainable forest management (hereafter the SFM).

Like in the neighbouring Central European countries, many-sided functions of forest ecosystems and the SFM have to be analysed not only with regard to their natural substance, but also with regard to the legal property of particular owners, such as natural persons and legal entities, municipalities and the state. In a democratic system, the forest cannot be only an object of independent vision and private wishes, but also a matter of political, economic, sociological and legal realities.

Analysis of the current status of forest ecosystems, and identification of principal issues related to their effective management, was the basic task of the project's sub-module. Proposals of some strategic measures and for the SFM intend to summarise essential recommendations for a sustainable production of forest goods, and for continual utilisation of human-required services.

FOREST ECOSYSTEMS AS A NATIONAL WEALTH

Fundamental prerequisite of sustainable development of forest ecosystems

Reconstruction of one-species coniferous – primarily Norway spruce and Scots pine – stands is a fundamental prerequisite of sustainable development of forest ecosystems. These plantations cover about 67.5% of the CR's forest area and play an important role both in the wood production and environmental functions of public interest. Implementation of their conversion calls for raising necessary capital to cover additional costs incurred to

forest owners. These costs were calculated at around CZK 0.75 billion a year, to compensate for the increased costs of artificial regeneration in prevailingly one-species stands which should be enriched by deciduous tree species in accordance with the primary forest ecosystem composition.

Restoration of the prevailingly one-species coniferous stands into forest ecosystems marked by high ecological stability and resistance towards stress factors should also be in accordance with predicted alterations of forest sites, resulting from the global climate change. The following measures are proposed in the project's sub-module to achieve these goals:

Proposed measures

In the range of forest administration:

– To enhance the activities of national authorities of supervision operated by the Ministry of Agriculture and Ministry of Environment of the CR towards the stepping-up of extension services, educational, advisory and *initiating* programmes referring to owners and administrators of forests.

– To accomplish a system of granting subsidies, additional cost payments and compensation of *prejudices*, jointly with an efficient control of the use of social overhead capital means, based on unbiased reference documents and data, and on determined urgency and needs of public interest. This system should be associated with the methodology of regional forest development plants (RFDP) and with their links with the working plans of particular forest owners, *i.e. the concrete making full use of their general recommendations in forest management plans* (FMP) and forest management outlines (FMO). Differentiation of the system according to forest ownership types is also of importance.

– To ensure *disposable items* corresponding to the national economy status, which would be available in social overhead capital sources, such as the state budget or relevant funds.

In the area of forest policy strategy:
- *Qualified* pilot studies into the real trends in demand for wood of deciduous tree species, and into the efficiency of forest holdings (particularly also to encourage the association of small forest holdings). In the CR they are more then 100,000 forest owners with the forest holding below 2 ha.
- A conceptual political study based, e.g., on National Forestry Programme of the CR to reveal human society's participation in the management of forest systems, resulting in sustainable production of goods and services desired by the public at large.

FOREST ECOSYSTEMS – AN IRREPLACEABLE COMPONENT OF THE ENVIRONMENT

In the area related to the irreplaceable role of forest ecosystems in the environment, the sub-module dealt with the identification of principal non-wood-producing functions beneficial to the public, and therefore purpose-controlled. As a pre-condition of particular environmental and social services provided by modern forestry, special measures should strengthen the desired financial means to support advisable effects, and suppress or attenuate undesirable factors.

Various kinds and intensities of goal-oriented non-wood producing care are needed for 58% of CR's forest area, and it also refers to 46% of the area of today's category of the commercial forest.

Long-term recommendations

To implement the state forestry and environmental policy:
- To enrich forestry policies with differentiation of various forest ownership types from the viewpoint of public interest in the forest *mission*, and to define clearly the policy of subsidies, defrayments of costs and recompenses of activities in favour of public interest.
- In the environmental policy, to consider all forest ecosystems as an irreplaceable component of the environment, not only due to their natural essence, but also due to their managed functions which is generally beneficial to the inhabited landscape and human society.

To implement the land-use and forestry planning:
- To ensure that regional forest development plans (RFDP) include an offer of forestry services based on the functional potential of forest ecosystems, and real public demand for particular environmental and social services identified by monitored public interest. Confrontation of the forestry supply with the demands for particular services will enable the establishment of general guidelines for forest management and calculations of capital needed.
- To elaborate a system of links between the conceptual (Regional Forest Development Plan – RFDP) and the working plans (Forest Management Plan – FMP and

Forest Management Outline – FMO) so that particular projects can be proposed by individual owners and administration of national forests. To facilitate unbiased judgement of national authorities according to real needs passed on the projects, and to encourage also their rational projects taking into account both the efficiency and correctness of the objectives.
- To ensure that methodologies, instructions, etc. are developed and compiled for particular *functional* measures, and by doing so, to promote real *designing* by owners, real public *orders*, qualified consultancy and meaningful supervisory activities in the right of recovery of national authorities.

Short-term recommendation

To amend urgent topics contained in Forest Act No. 289/1995, particularly the following ones:
- new conception and application of forest categorisation as a tool of state forestry policy and administration (primarily formed as a tool of the forest management),
- *mission* and contents of regional forest development plans (RFDP) as common tools of state forestry and environmental policies,
- reality-reflecting conception of landscape amelioration, including torrent control, as a service of public interest in the cultural landscape protection,
- realistic conception of the care for forest ecosystems in special-category forests, including the forests in large-scale protected areas of nature conservation.

To analyse and mutually adjust the problem areas in environmental legislation, which primarily holds for:
- Act 292/1991 on the Czech Environmental Inspection *with* the forest protection competence, which are significant tools in the environmental functions of fo-rests whose role deserves many-sided activities in comparison with the general ecosystem conservation,
- final legal solution to the supreme state supervision of the Ministry of Environment, as amended by Forest Act No. 289/1995, as to the proper application of incentives resulting from the field operation of the Czech Environmental Inspection,
- inclusion of particular beneficial-to-public, environmental and social functions of the forest into the sphere of *active interests* of the *environmental department*, also with regard to the needs of human-inhabited cultural landscapes,
- analyses of links between Acts No. 17/1992, 114/1992 and 289/1992 so that their application can be based on *material truth* and not only on general axioms and *ideological wishes*.

Vladimír K r e č m e r , Bohuslav V i n š et al.

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