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GROWTH RATE MODELING FOR WHITE POPLAR IN THE SOUTH EASTERN PART OF ROMANIA: AN IMPORTANT ISSUE OF FOREST CONSERVATION

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Abstract

Nowadays, the process of monitoring forested areas is a national requirement. The importance of forests in mitigating climate change is well known. On the other hand, the economic aspects of forest management are important too. From this point of view, inventorying and assessing the growth and yield rate of wooded areas is extremely important. Estimating growth rate per hectare unit and production level of forested areas in order to obtain and accurate inventory is important in determining the supply of wood. The present paper is based on the evaluation after 6 growing seasons. The sectors monitored are located along areas of relatively low elevation (280–450 m). The climatic gradient can also be neglected because of the character of the studied areas. The research was carried out in the southeastern part of Romania. The entire complex comprises 375 forested tracts. Only for white poplar we have included a set of 36 carefully selected forest sectors. The study's timespan was between 2010 and 2015, and data from the field have been used. The case study presented is white poplar, and the methods used are shown in a comparative way. Technological factors like consistence, density, etc. were carefully evaluated on the basis of direct observations and measurements. The recorded data were subsequently validated. The computer analysis, used on different optimization methods, was selected from the most employed series in the dedicated literature. Our results indicated that: (1) the evaluations of the estimated growth rate of production can be vary significantly when employing different statistical analysis and numerical methods; (2) by using numerical optimization models, the computer simulations can provide accurate estimates of the growth rate and, hence, the efficiency for a given forest inventory; (3) common numerical interpolation methods or neural network uses that do not always give consistent results. The specific numerical methods are preferable for a better assessment of the growth rate and existing inventory; and (4) investments in computer simulation methods and software should be encouraged in order to successfully reach a permanent inventory, to improve the efficiency of the logging operations, and to support environmental protection.

Keywords: *Growth rate; Numerical approach; Statistical analysis; Interpolation method.*

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Introduction

In the last years, assessing the damage caused by natural disasters has become a priority of governments and international organizations. This concern is justified by the fact that the compensations given for such losses often exceed the existing budgets and the national plans for economic and social development.

Environmental protection, and in particular forests protection, is an important goal of mankind, potentially mitigating the disastrous effects of climate change. During the last years, careful monitoring processes have been put into place in Europe and, in particular, Romania. It is estimated that until 2050, about 75% of the industrial wood supply will come from plantation forests. Similarly, for meeting the growing demand in wood fibres and biomass, it is estimated that around 50% of the plantations will be fast- or intensive-growth ones [1]. The sustainable development of forests and other natural resources requires a regional and national strategy of wood use [2]. This strategy must meet several requirements [3, 4]:

a) the protection and sustainment of forest resources for economic development;

b) the aggregation of the requirements to protect the environment with the social and economic demands.

The construction of a national strategy of wood usage requires compromises between the different goods and services that forests can provide [5, 6].

Nowadays, this strategy is increasingly applied for converting natural forests to plantations with higher yields. These trends also leave their mark on the biodiversity. Conversely, the afforestation of degraded or abandoned farmland appears to be a sustainable alternative, because this solution has the potential to provide wood and can mitigate climate variability [4, 6].

The research and development of methods for assessing forests and production volumes have provided a sound conceptual basis and principles of decision-making in forest management. The specialised literature provides a long series of different approaches, and an extensive range of models of implementation system, such as Bayesian networks [7, 8] statistical models [9], numerical models, etc. The resulting models have to be adaptable, since the context in which they will be applied is never the same [8].

The approach relying of modelling forest ecological systems was often chosen on account of the fact that other approaches are less suitable for evaluating agroforestry development [5, 7]. On the one hand, however, statistical analysis is best suited to experimental and empirical research, since it is difficult to make evaluations when interventions and exogenous actions occur [11]. On other hand, the economic approaches specific to such forest systems require long-term data collection, while the usability of the surveys structured in this way is relatively low, since their answers and results are often disregarded [3, 12].

The accurate modelling of systems allows for predicting outputs in the case of alternative input scenarios and for extension/development programs, being useful for identifying critical success factors or impediments [3, 13, 14].

In forest management and decision-making, a basic requirement has been to understand the relative values of the forest inventory in different exploitation conditions, and of the size values and market operating costs [15]. In other words, the basis for understanding the required trade-offs relies on developing tools that can provide a precise, consistent and reliable assessment of the regional forest inventory. Ideally, the system should be able to assess different variables, both the volume and the monetary value, on the basis of the forest inventory. Various methods for evaluating forests have been put forward throughout time, and most are based on variables such as total volume and size of marketable production [3, 16, 17].

The methods used presently are different, in the sense that they have been developed in different geographic regions, for different purposes. This situation could create confusion among forest managers, as to which approach is appropriate for their jurisdictions and objectives. Although commonly assumed that different methods would lead to similar results, a comparative study [16, 17] has shown that there are significant differences in the volume estimations obtained using different methods.

The objective of this paper is to examine and compare the available approaches and methods in order to estimate yield datasets concerning the growth rate, using white poplar as a case study. Another aim is linked to the requirement to preserve the forest and to minimize the phenomenon of deforestation.

Our goal is to provide forest managers and researchers with a basis for selecting the appropriate method(s) for operations meant to improve forestry practices and forest management planning, by incorporating the potential yield of the forests. The results of this study may also help in establishing timeframes during which timber harvesting would be prohibited, as a performance enhancer.

Materials and Methods

Study Locations

The study sites are all located in southeastern Romania, on publicly-owned forested land in the eastern part of Galati County (Fig. 1). Galati County is the main economic and industrial centre of southeastern Romania, and is located in the eastern part the country, on the confluence of the Siret and Prut rivers with the Danube. The Galati region has an area of 4466 square kilometres, which is about 1.9% of the country [4, 5, 15].

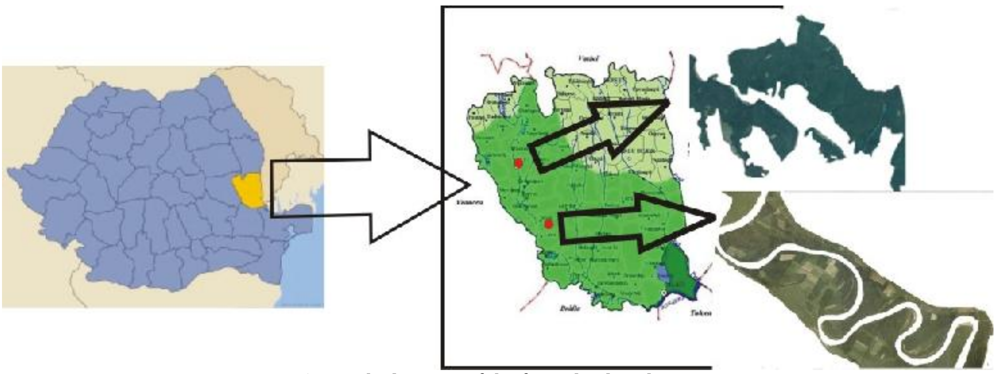

Fig. 1. The location of the forest land study area

Two different sectors belonging to the area of forest vegetation of the Covurlui Plateau have been selected for this study. The area is characterised by a continental climate, with cold winters and long, dry summers [4].

The areas were divided into different sectors according to the predominant species of trees, in order to produce homogenous sectors in terms of tree age and species [4, 5, 15]. A particular topographical aspect of this region is that the Prut and Siret valleys are oriented in such a way as to function as genuine couloirs that lead towards the centre of the county air masses coming from the steppe [4, 5, 15].

Although some plots are located on hilly terrain, all the studied areas are located on flat land with a slope almost always less than 5%. Since the terrain configuration is such that the majority of large watercourses drain southwards, and because of the way the air moves across the seasons, producing small quantities of precipitations that make up the additional core of hydrographic network, Galati County is located in what is the dry area of the country.

Soil characteristics

In 2003 Romania adopted a modern soil taxonomy classification system (SRTS), established by the Institute for Soil Research [4, 5, 15]. This classification is consistent with the requirements of the World Reference Base for Soil Resources (FAO, 1998) [4, 6]

The predominant soils in the county are the zones belonging to the classes shown in Table 1 [4, 15]:

Table 1. Galati County — soil distribution classes

Soils Classes	Surface area (ha)	Percent (%)
Protisoils	78654.97	21.48
Cernisoils	260778.76	71.23
Luvisoils	148.38	0.04
Hydrisoils	7756.10	2.12
Salsodisoils	3.00	0.001
Antrisoils	18769.81	5.12

The climate conditions described above were formed and evolved soils in the area, the terraces, with the parent material loess and loess deposits and fluvial deposits in the meadow and river-lake [4].

Protisoils (undeveloped soil) in soils are the early stage of formation, yet with an incompletely differentiated profile, with no diagnostic horizons.

Cernisoils – this class includes the following types: limestone mould, mould drafts, etc.

Luvisoils – include well differentiated profile soils, characterized by the presence of a clay horizon.

Hydrisoils – are formed under the influence of the prevailing excess moisture long, having, therefore, a particular fluid system that determines certain processes and properties of the soil.

Salsodisoils – include soils whose genesis, evolution and properties were and are influenced appreciably by easily soluble salts.

Antrisoils – are cropped soils and dirt. In this class were included soils that had well-differentiated profiles.

Experimental design

The study was conducted on 356 sectors of forest. This article presents the results of the plots with 100% species of white poplar [4]. Measurements were made every year near the end of the growing season (September–October). In each experimental plot, an area equal to the surface unit was selected, and measurements were carried out. The following parameters were taken into account: current age, composition, consistency, average density, allocation unit of surface area, volume of harvest.

Recording of the field measurements and methods of analysis

For validating the results, two sets of measurements were conducted for each plot [3, 18, 19]. To determine the production volume, procedures described in the literature [3, 8, 10] were applied.

The numerical analysis procedures employed are those found in the specialised literature, by resorting to statistical analysis software (StatSoft Statistics) [19, 20] or specific calculation procedures (MATLAB) [20].

The used methods are:

1. *Method of field records*: this process includes a standard set of measurements conducted for each section of the studied area. The sectors' boundaries were shaped so as to be homogeneous in terms of composition consistency and the current age of the trees. The reason behind this division was primarily technological [3, 4, 8, 17, 21].

Field readings were used to fetch the raw database records. This was followed by the procedures for checking and validating the measurements [17, 19, 21].

In total, all of the 365 sectors were monitored between 2010 and 2015, and thus a consistent database was obtained. In this article the data for 36 parcels containing only white poplar, found in the conditions described above, have been used.

The following parameters were evaluated for each monitored sector: current age, growth rate, composition — the concentration of the various species of trees per unit area, consistency and density — the number of copies per unit of surface area, the volume of the timber produced per unit of surface.

The recordings were made two times a year by trained personnel for data consistency. Validated data were included in the database, which includes a total of 24,276 plots averaged data included in the study. This database was analysed using several methods in order to obtain a model as closely possible.

2. *Methods of statistical analysis*: methods for analysis of variance (ANOVA) of multifactorial type were used. Likewise, statistical analysis methods and multi-variety type, such as PCA, were also used.

The value of the confidence coefficient which characterizes is considered equal to 0.05 (acceptable value in most studies) [19, 23]. Each time this condition was met, it was marked. The programs are recognized and used worldwide (StatSoft Statistica X and MATLAB). The methods of statistical analysis were used in the early stages of the study. The various correlation coefficients between the measured sizes were assessed. Marked cases in which the correlation coefficients have been significant. Analyses were performed in order to identify the key parameters. The method used was the MANOVA analysis (StatSoft Statistics). For the comparison and confirmation procedures, investigative methods using PCA (StatSoft Statistics X and MATLAB) were applied [19, 23].

3. *Numerical methods*: in the present study, we have used several techniques for numerical analysis and interpolation [19, 20]. For interpolation, as a rule there were used primarily software programs that contain procedures and predefined interpolation methods. Thus, in all studied cases the interpolation methods were used with predefined type: (a) quadratic; (b) distance weighted least square interpolation method; (c) non-linear interpolation by considering that the neural network; and (d) multi-dimensional specific polynomial interpolation method with mixed terms. The general criterion for optimizing interpolation was considered Sum of Square Errors (SS) [11, 19]. As is known, this criterion requires that the sum of squares of deviations to be the minimum for optimal interpolation [11, 19, 23].

3.a) For *quadratic interpolation* type we could highlight the dynamic character of the models identified. At the same time we have highlighted the limited character of these second-order mathematical models.

3,b) For *polynomial interpolation* applications predefined in the statistical analysis they were also able to put out the dynamic character of the models identified. At the same time it showed the quality of interpolations to be superior to those obtained by second-order mathematical models. For these models it was revealed yet about and limited character of these models.

3.c) *methods of interpolation and fitting* by using neural networks are very effective methods used in recent years. Necessarily for high performance, Radial Basis Function (RBF) and Multilayer Perceptron (MLP) neural network type have been chosen [11, 22]. These structures were shown to be unreliable, especially when 3 layers of neurons were used [22]. For the present study, a total of 20 different neural network structures of RBF and of MLP type were constructed, of which the best six were retained [22, 24].

3.d) *interpolation method* by *analytical polynomial function with mixed terms* [20]. This method is less found in the literature, because of the complexity and volume of calculation involved. The advantage of the method is that it allows increased degree polynomial interpolation, thus avoiding the emergence of the Runge effect [22]. The Runge effect, which causes oscillations obtained from fictitious functions, has negative consequences on the implications resulting from the use of these models. This method, used successfully in systems that have significant changes in relation to certain state parameters, could be used successfully in this case [20].

Results and Discussions

The first step in data analysis was the calculation of the correlation coefficients for the monitored magnitudes. The coefficients of correlation are presented in Table 2.

Table 2. The coefficients of correlation

	Current age (years)	Consistence (percent)	Volume (m^3/ha)	Growth (m^3/year/ha)	Extracted volume (m^3 production unit)	Density (no. specimens / ha)
Current age (years)	1.0000 (p= ---)	.3422 (p=.000)	.9136 (p=0.00)	.4739 (p=.000)	.2071 (p=.002)	-.1657 (p=.015)
Consistence		1.0000 (p= ---)	.3398 (p=.000)	.4751 (p=.000)	.0325 (p=.636)	.8129 (p=0.00)
Volume (cubic m/ha)			1.0000 (p= ---)	.4416 (p=.000)	.1649 (p=.015)	-.1768 (p=.009)
Growth (c. m./year/ha)					.0289 (p=.673)	.2122 (p=.002)
Extracted volume (c.m./ production unit)					1.0000 (p= ---)	-.0964 (p=.159)
Density (no. specimens /ha)						1.0000 (p= ---)

The first observation relates to the coefficient of correlation between the volume of production per unit area, and the current age of the plantation. The value of this coefficient specifies the strong relationship between the age of the trees and the volumes recorded. It should be noted that the registered volume of production for the unit of surface is actually only the integration result of the value of the growth rate over time.

Necessarily, there have been examined and investigated how the growth rate varied depending on the current age. The results of this analysis are shown in Fig. 2. In contrast to other works from the literature in which only the interpolation quality by mixing different types of models is tracked, in the present paper a single form of mathematical models has been used. It can be seen that there is a family of similar curves with clearly different interpolation parameters (Fig. 2).

The fact that neighbouring forest plots with the same declared soil structure and the same climatic conditions, stated different growth rates with different coefficients is very interesting. This observation prompted a univariate test of significance for Growth, i.e. an ANOVA statistical analysis, with a very interesting conclusion: the consistence, i.e. the equivalent area covered by the tree crown per surface unit, plays an important role. The ANOVA analysis coefficients are shown in Table 3, and represents the first model.

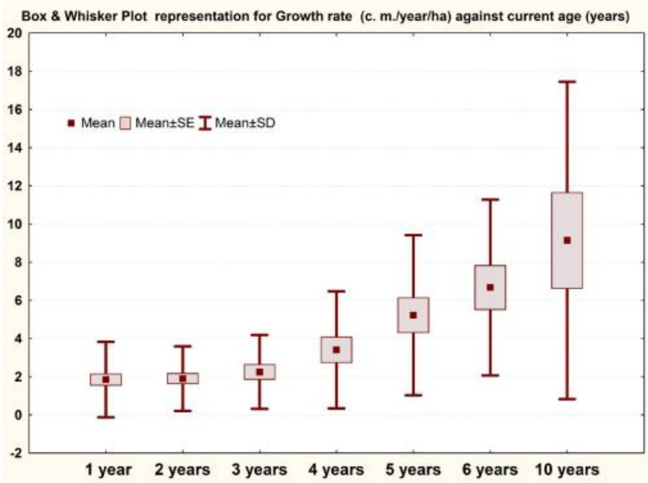

Fig. 2. The growth rate variation depending on current age

Table 3. The univariate test of significance analysis coefficients

	SS	Degrees of Freedom	MS	F	p
Intercept	2.383	1	2.3832	0.26235	0.609043
Current age (years)	307.172	1	307.1720	33.81447	0.000000
Consistence	336.682	1	336.6817	37.06299	0.000000
Error	1934.901	213	9.0840		

From Table 3 it can be seen that both parameters — current age and the consistence of the studied plantations – have a clear influence on the rate of growth ($p < 0.001$).

One such topic is less studied in the literature and therefore the analysis of the influence of the consistence on the growth rate is valuable issue in this respect.

Table 4 presents the test characteristics for the proposed model in Table 3 —namely the possibility of explaining the growth rate magnitude on the two monitored parameters — the current age and the consistence. The p coefficient value reveals that this pattern is acceptable and can be used ($p < 0.0001$).

Table 4. The test of SS whole Model vs. SS residual (*Populus alba* database)

	Multiple - R	Multiple - R²	Adjusted - R²	SS - Model	df - Model	MS - Model	SS - Residual	df - Residual	MS - Residual	F	p
Growth rate	0.92473	0.85513	0.83393	234.514	6	39.0857	39.7288	41	0.968995	40.336	0.000

Both values for quality assessment model, i.e. R-square and Adjusted R-square, and the p coefficient values highlight the quality of this model. Note the size of SS, which represents the sum of squared errors (Table 3). However, the ANOVA method is considered to be a special case of linear regression, which in turn is a special case of the general linear representation. All these procedures consider the observations to be the sum of a model (fit) and a residual (error) to be minimized. All the next presented models will be improvements of this representation.

The quadratic approach model represents an improvement of the previous linear model. The expression for these models is of the form:

$$F = a_0 + a_1 x + a_2 x^2 + b_0 xy + b_1 y + b_2 y^2 \qquad (1)$$

Where x represents the consistence value and b is the current age magnitude. In figure 3 are represented the obtained models for each year of study. In this representation the vertical axis represent the growth rate magnitudes, and the horizontal axes are the consistence and the current age. The representations from Fig. 3 depicted the models found for the recorded database for each year. Although these quadratic models are more performant than above (the size for SS being smaller), these representations still have some shortcomings. One deficiency comes from the significant modification of the obtained results from one year to another. Thus, if in 2010 the maximum value of growth rate per unit of surface obtained for trees of 30 years old reached a value 10 cubic meters, for the next year the value doubled (Fig. 3b). Another deficiency relates to a drastic change in the shape of the represented surface, which corresponds to s significant change in the evolution of production (Fig. 3f).

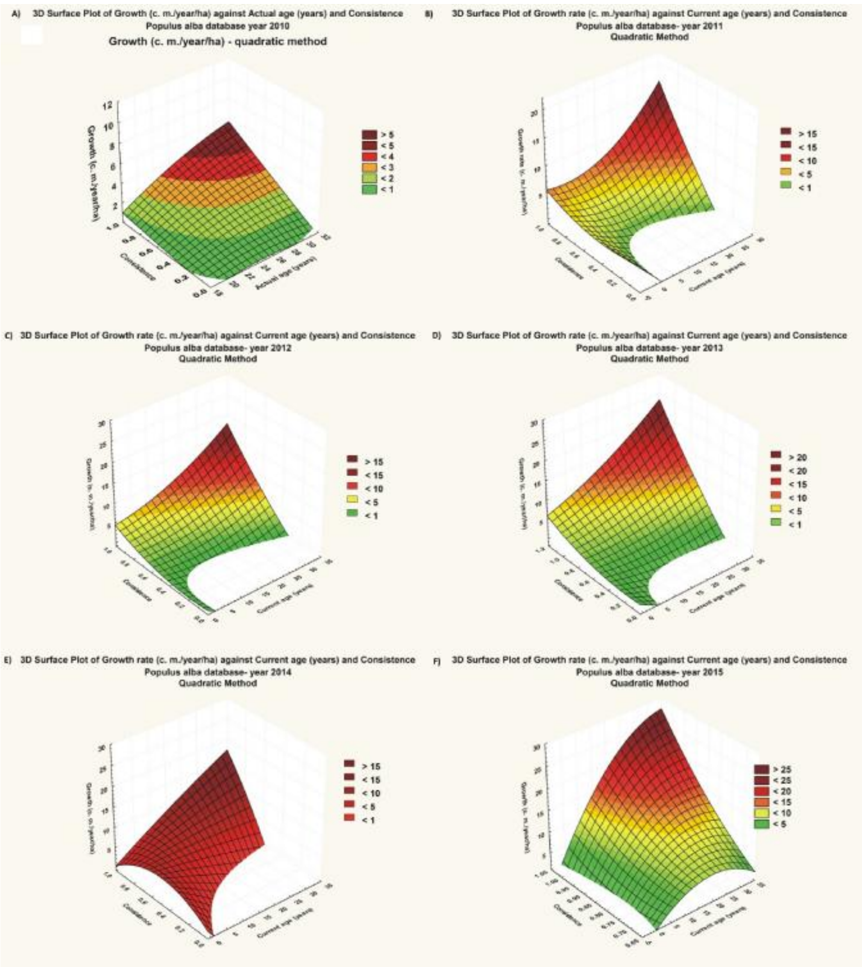

Fig. 3. The growth rate models using quadratic interpolation expressions

The distance weighted least squares approach model represents an additional improvement of the previous quadratic model (Fig. 4). The distance-weighted least squares method fits a curve to the data by using a specific procedure: a second-order polynomial regression is computed for each value on the X variable scale to determine the corresponding Y value such that the influence of the individual data points on the regression decreases with their distance from the particular X value [20, 22]. Although the distance weighted least squares models are more performant than quadratic representations, these approaches still have some shortcomings. A major shortcoming lies in the high value of the growth rate in the case of a void consistence (Fig. 4e).

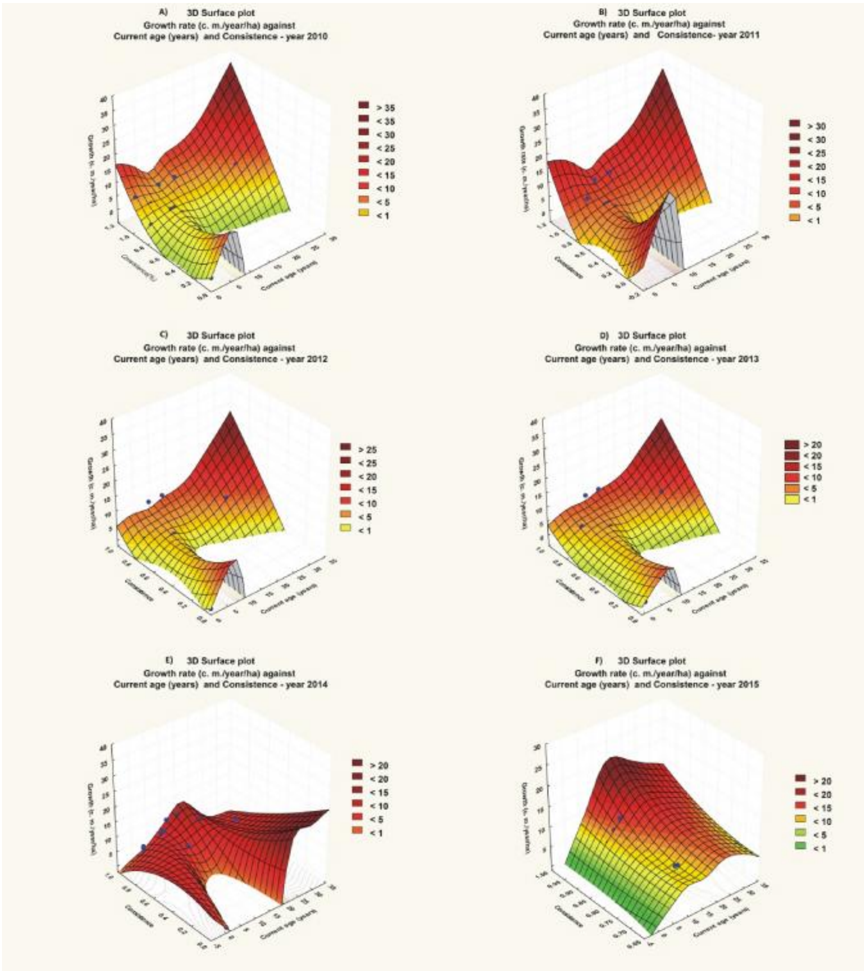

Fig. 4. The growth rate models using distance weighted least squares interpolation method

The next type of models studied is based on the use of neural network (Fig. 5). In this case, based on the values of the two parameters monitored, i.e. consistence and current age (considered as input parameters), we can obtain assessments of growth rate, regarded as an output value. These models have better efficiency than previous models. In this approach it was used the previous obtained results in the interpolation method domain [23]. For these models a total of 20 different RBF and MLP type structures were considered, and the most performant 6 models were retained. Efficiency data are shown in Table 5.

The ANN structures of RBF and MLP type are recommended for multi-dimensional interpolation of functions that occur in significant variations in the fitting process. Many works in this field have shown that the use of these structures led to remarkable results [23, 24].

Pursuant to this approach, the data set was used in sampling, for the operation of training and testing and model validation, respectively. Sampling was done according to other common works in the literature - i.e. 80% of the data were used for training and testing of the network, and the remaining 20% for the validation of models [23, 24]. On the other hand, these neural networks require databases with very large entries, as each parameter for performance match each structure with the best results (Table 5). The structural parameters for each network are presented in Table 6.

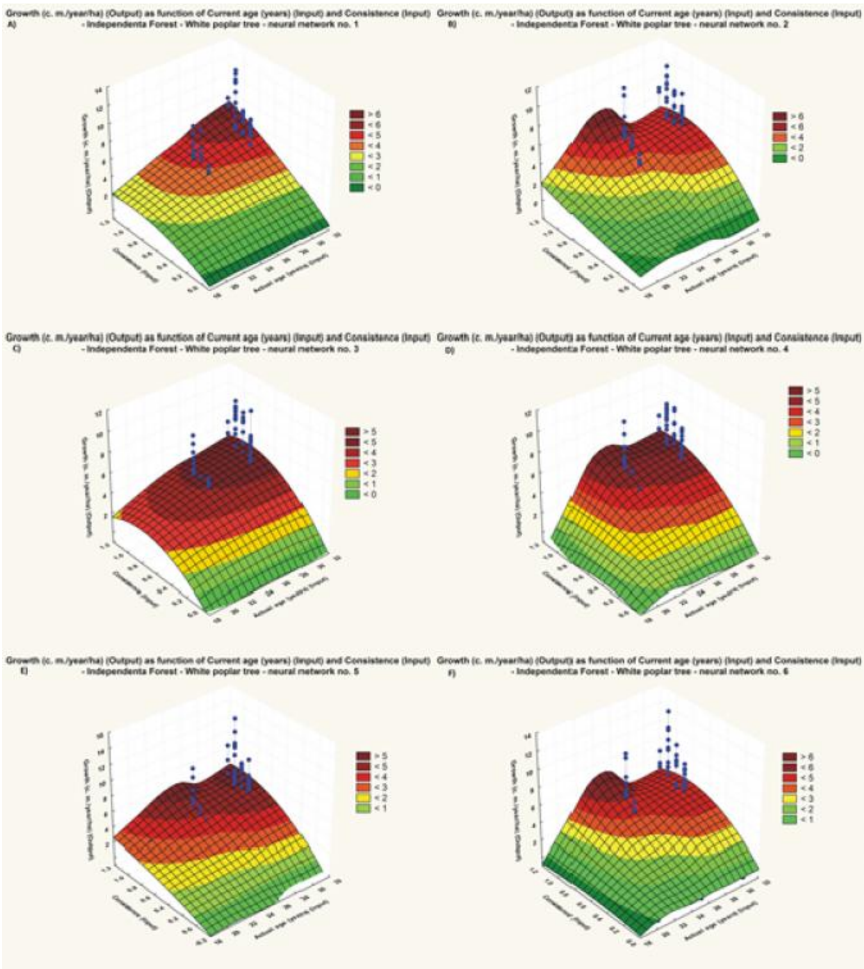

Fig. 5. The growth rate models using neural network interpolation method

In Figure 5 are shown the results of models built. For ease of analysis, the data points were shown for comparison purposes. Note that these models offer lower values than the experimental ones (Fig. 5a - 5f). Although the training errors are quite small, the final results do not always correspond to the experimental values.

This led us to the idea of building a specific model, to improve the results obtained up to that point. In this respect, a technique was used taken from other systems, which changes their properties rather than the change of status parameters [20].

Table 5. The neural network interpolation performance

No. crt.	Net. Type	Training perf.	Test perf.	Validation perf.	Training error	Test error	Validation error
1	RBF	0.617001	0.579831	0.454419	0.029046	0.036605	0.051537
2	RBF	0.719975	0.591009	0.617389	0.021189	0.034348	0.039542
3	MLP	0.659374	0.586917	0.452141	0.024967	0.034581	0.050288
4	RBF	0.693041	0.584725	0.491657	0.022864	0.034798	0.047879
5	MLP	0.654044	0.582093	0.459993	0.025232	0.035040	0.049566
6	MLP	0.717736	0.618197	0.594872	0.021339	0.032467	0.040531

Table 6. The neural network structural parameters

No. crt.	Net. Type	Training algorithm	Error function	Hidden activation	Output activation
1	RBF	BFGS 37	SS	Logistic	Exponential
2	RBF	BFGS 73	SS	Logistic	Logistic
3	MLP	BFGS 54	SS	Logistic	Tanh
4	RBF	BFGS 101	SS	Logistic	Logistic
5	MLP	BFGS 57	SS	Logistic	Exponential
6	MLP	BFGS 43	SS	Exponential	Exponential

The multidimensional polynomial with mixed terms models approach represents an improvement of the previous linear model. The expression for these models is of the form:

$$F = A_0 + A_1 t + A_2 t^2 + .. + D_0 xt + .. + B_1 x + B_2 x^2 + .. + \\ + C_1 y + C_2 y^2 + E_0 yt + .. \qquad (2)$$

Where t represents the current age, x represents the consistence value and y is the current age magnitude. In figure 6 are represented the obtained results for SS magnitudes against the polynomial rank of the multidimensional models for each of the considered independent parameter. In this representation, the vertical axis represents the SS magnitude, and the horizontal axis lists the polynomial rank for time series, consistence magnitude and, respectively, for current age. It could be observed that the time series brings no significant improvements. The best performances are by the consistence polynomial expansion series and especially by the current age polynomial expansion series (Fig. 6).

The mixed terms which are introduced by the D and E coefficients (2) succeed in eliminating the effects of the Runge phenomenon for high order polynomial interpolation [20]. In this way we can get an accurate model with much smaller errors of assessment in comparison to the models discussed above (Fig. 7).

In table 7 are presented a series of configuration and the optimal polynomial model – model no. 6 expressed by the relation (2) and represented in figure 7. In this way we can obtain the finest analytical model for white poplar growth rate evaluation against the state measured parameters.

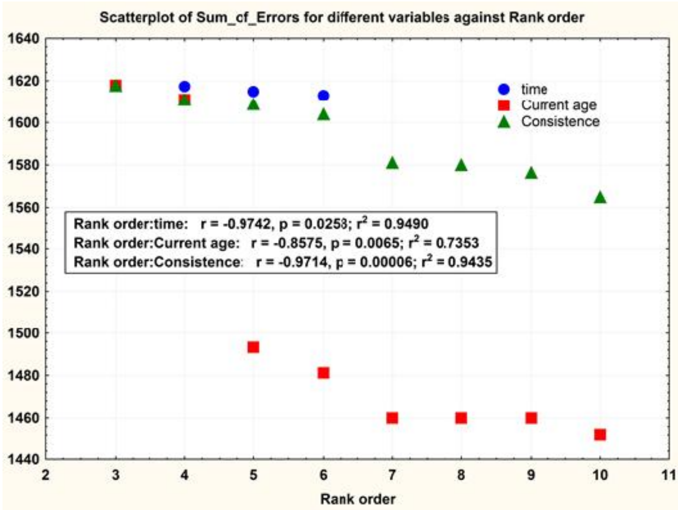

Fig. 6. The obtained results for SS magnitudes against the polynomial rank of the multidimensional models for each of the considered independent parameter

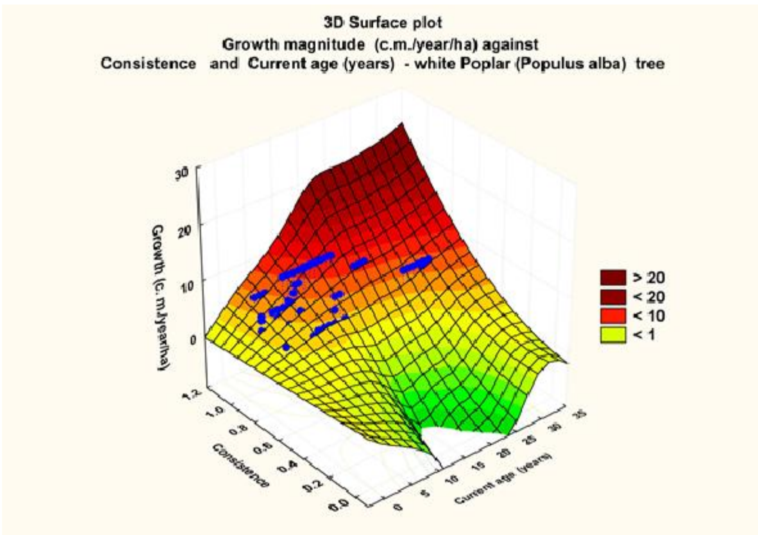

Fig. 7. The representation for the optimal multidimensional model with mixed terms configuration

Table 7. The multidimensional polynomial configuration for optimal result

No. crt.	Polynomial rank for time series	Polynomial rank for consistence series	Polynomial rank for current age	Polynomial rank for D and E coeff.	SS magnitude
1	7	10	10	5 - 5	1491.943077
2	8	10	10	5 - 5	1498.170268
3	7	10	11	5 - 5	1516.363699
4	7	10	11	5 - 6	1513.405674
5	7	10	11	8 - 6	1474.639669
6	7	10	11	10 - 6	1473.909667
7	7	11	11	9 - 5	1483.962850

Conclusion

This study showed that the least studied factors like consistency and density are the main factors that must be considered in order to obtain high yield in the plots with poplar. The significant influence of these factors resulted in a greater effect on the growth rate and yield and production volume. The analysis was made based on several methods, and was performed by comparison. The influence of the environmental gradient has proved to be of secondary importance, and these effects have been neglected.

For this purpose, a study was conducted between 2010 and 2015. The study included a total of 365 parcels of forest in southeastern Romania. There were monitored a series of 8 technological parameter, which assessed the influence on the rate of growth. Statistical analysis showed that for each type of tree, there are a number of essential parameters. To obtain a valuation model growth rate, we have tested several methods of analysis. Numerical approximation methods included in various programs of statistical analysis proved to be ineffective. Approximation methods based on using neural networks were found to be not very effective. For this reason, a specific mathematical model, with a special structure has been built. The evaluations performed with this model have been shown to be superior to all previous representations tested. The construction algorithm and the results are presented in this article with white poplar as case study.

The problem of use and exploitation of forests is a current issue of worldwide concern. The optimization of costs and maximisation of production purposes are carefully sought nowadays, due to a national demand for preserving forests. We believe that the resolution advanced in this study provides a solution of international interest.

For preserving forest ecosystems, an important aspect could be achieved by changing the current harvest age of white poplar from 25 years to 30 years. According to our built model, the increase in the harvest age would produce an increase in timber production of at least 10 percent (Fig. 7).

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