Ann. For. Res. 57(1): 149-162, 2014
DOI: 10.15287/afr.2014.182

ANNALS OF FOREST RESEARCH
www.afrjournal.org

Factors affecting industrial wood, material production yield in Turkey's natural beech forests

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Atik A., Yılmaz B., 2014. Factors affecting industrial wood, material production yield in Turkey's natural beech forests. Ann. For. Res. 57(1): 149-162, 2014.

Abstract. The objectives of the present study are to determine the most important factors affecting industrial wood material production yield in natural oriental beech forests in Turkey using a multifaceted approach and to help entrepreneurs consider these factors to develop more sensitive and realistic production plans. In Günye Forest Management in Bartın province of the West Black Sea Region of Turkey, 41 production units were chosen as the study area. The 1277 ha study area was included in the 2007 and 2010 production management plan. The general state of the stand, natural stand structure, and production methods and tools are the factors thought most strongly affect industrial wood material production yield; 26 variables representing these factors were evaluated in the study. Through multidimensional statistical analyses, including main components, factor and regression analysis, we found that the most important factors affecting production yield were fertility, aspect of land, skidding method, stand structure, skidding distance, growing stock, transportation and harmful abiotic factors. Production units were divided into three groups based on yield rates and the 26 variables, using discriminate analysis. From the results of the study, a sample model can be developed to help forest managers predict and plan annual industrial wood production more sensitively and realistically.
Keywords industrial wood, production, oriental beech, GIS, factor analysis, multiple regression analyses, discriminate analysis.

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Manuscript received March 27, 2014; revised May 14, 2014; accepted May 21, 2014; online first May 27, 2014.

Introduction

Forests are natural renewable reserves that supply biological diversity, fresh water, clean air, recreational possibilities and erosion prevention, in addition to forest products. Forests are natural reserves that shelter the highest biomass rate in the largest spatial area. Due to the vital services and functions they provide, forests are evaluated not only at national or regional scales but also at the global scale.

Nations use their forests in various ways according to their needs and can utilize forest reserves for the production of varied commodities and services (Pearce 1990). Global demand for forestry products is consistently increasing with technological development and population increase (Brooks 1997, Lyke & Brooks 1995).

As an economic sector, forestry can provide a base or substructure for other sectors through provision of raw materials and services. Forest management contributes to global socioeconomic development by creating added economic value and employment (Anonymous 2001, Karayılmazlar 2005).

Wood, the basic forestry output, is widely used as a raw material in more than ten thousand industrial products (Örs & Keskin 2000). In 2011, global industrial roundwood removal was 1.58 billion m^3 $year^{-1}$, of which Turkey accounted for 0.9%, or 13.5 million m^3 $year^{-1}$ (FAO 2011, Anonymous 2007, General Directorate of Forestry 2012a). Turkey's growing forest stock is approximately 1.5 billion m^3, and the current yield is 36.3 million m^3 $year^{-1}$, while the allowable cut rate (eta) is 16.5 million m^3 $year^{-1}$, set deliberately low to increase the forest stock. The proportion of eta dedicated to industrial wood production (i.e., the mean forest yield of industrial wood) is 82.3%. Log production is the most important at 31%, followed by the production of fiber chips (23%), paper wood (15%), industrial wood (7.6%), mine props (4.7%), electric posts (0.8%) and sticks for various uses (0.2%) (Anonymous 2007, General Directorate of Forestry 2013).

The forestry sector manages a biological entity that is wholly open to natural conditions and whose development depends on several geographic, edaphic and climatic factors (Acar & Ünver 2004). Industrial wood production may vary depending on factors such as forest structure, natural structure of production units and the methods and tools used for the production and removal of trees (Taranaki Regional Council 2013).

Forestry management is defined as the whole of activities involved in meeting public demands for forest commodities and services (Daşdemir 2001). Forest management differs from other types of land management in that forests are open to environmental factors, cover vast land areas and require long production times. Forest management is also different in that it requires consistency. Forestry management plans consider not only today's public needs for forestry commodities and services but also the needs of future generations.

The forestry sector constitutes a base for other sectors by supplying raw materials and contributes to socioeconomic development all over the world (Anonymous 2001, Daşdemir 2000). In rural Turkey, the forestry sector provides an employment rate of 13 million person-days $year^{-1}$ (Anonymous 2007).

In forestry, as in other sectors, it is important to accurately estimate the rate at which a commodity will be supplied to the market over a certain time period. The Turkish State Treasury owns 99% of Turkish forest area, the majority of which has natural characteristics (Anonymous 2007). Oriental beech is among the most important forest tree species in Turkey, providing valuable wood materials across 1,75 million ha, with 6 million m^3 $year^{-1}$ yield and 264 million m^3 growing stock (General Directorate of Forestry 2006). Beech also constitutes a large part of the potential natural vegetation in temperate Europe (Eşen & Zedaker 2004, Aubert et al. 2006, Reyer et al. 2010).

Several methods have been developed for determining the volume of growing stocks and woody raw materials of different species (Filho & Schaaf 1999, Wiant et al. 1992, Patterson et al. 1993a,b). Sun et al. (1977) determined the production rates of logs, mine props and industrial wood. The production plans of Turkish State Forest Management, the institute responsible for the conservation and management of Turkey's forest reserves, include a 10- year management period. In a management plan, the rate of total wood material to be removed is divided by the time period of the eta plan (10 year). However, due to differences in natural conditions and production devices, the amount of wood material may be different even though the yearly eta may be the same. This situation may cause great variability in the yearly base rate of wood material available to the market. The fluctuations in market supply can cause price instabilities and errors in accumulation and storage management plans and yearly income estimates.

Sale of planted trees is an important industry in several countries with large forestry sectors, such as USA, Germany, UK, and Russia, and this industry began to be implemented in Turkey in 1996. In 2012, total sales of planted trees accounted for 25% of yearly eta, reaching 4 million m^3 (General Directorate of Forestry 2013). Production yield must be calculated accurately to manage these trees effectively. Currently, estimation of the yield rate is conducted in field trials by a commission of the State Forest Management by measuring the number of chopped trees of different diameters and producing standardized wood materials. This method is not practical. In addition, industrial wood material from chopped trees is left in the field trial area. This wood may lose its value before the area is sold and the production process begins. If, for various reasons, the planted trees are not sold, this chopped material will decompose, lose its industrial wood value and be used for fuel.

Insect damage is among the most dangerous forest threats after human intervention. In Turkey's forests, different damaging insect species are active over an area of 600 thousand ha, costing 5.5 million USD each year. These insects may cause a growing stock loss of 1 million m^3 per year (General Directorate of Forestry 2012b). The epidemiology of bark insects depends on the availability of suitable hosts; collapsed or chopped trees are very attractive for insects and allow an increase in harmful insect populations over a very short time (Göktürk et al. 2010). Field trial trees used to determine yield rate in planted tree sale application are generally standardized by stripping off their bark. However, in some instances, they can be standardized with their bark intact. The tree components from which fiber and fuel are obtained are also hospitable to insect reproduction.

The objective of the present study is to determine the effects of the above factors on wood production yield per unit area. We apply multidimensional statistical analysis to oriental beech forests in Bartın, Turkey, to develop a model that can predict the yield rate, contribute to more accurate and realistic production plans, and help prevent declines in forest quality and quantity.

Materials and methods

The study area and data. The study was conducted on 41 production units across 1277 ha under management of the Bartın – Günye Forest and included a 4-year investment program. Production labor was supplied by the same cooperative. Industrial wood material was transported to the loading ramp by skidding and rolling.

Günye Forest management (41° 33' 00" -41° 21' 00" N, and 32° 14' 30"- 32° 22' 30"E) is in the Western Black Sea Region of Turkey (Figure 1). Data on production units were obtained from management plans (2001-2010; 2011-2020), including production and price records, field measurements and observations, and GIS.

Climatic data were obtained from a meteorological station in Bartın, 15.4 km away from the study area. At an altitude of 33 m, the mean annual, minimum and maximum temperature values are 12.6°C, 0.3°C and 18.8°C, respectively, while the mean annual precipitation is 1035 mm (Turkish State Meteorological Service 2013). The growing season is from April (11.1°C) to October (13.6°C; seven months total). Rainfall during the growing season is 527 mm (Table 1). The area has a Thornthwaite climate type of B_2B_1'rb4', a mesothermal climate with little or no water shortage, similar to an oceanic climate (Atik 2013 a,b).

First, 31 production variables thought to affect the yield rate of wood raw material were determined in natural oriental beech forest production units under consistent forest management. A multidimensional approach considered natural structures, physical location, forest structure, production methods and tools, and the relationship between these factors. Second, the number of variables was reduced

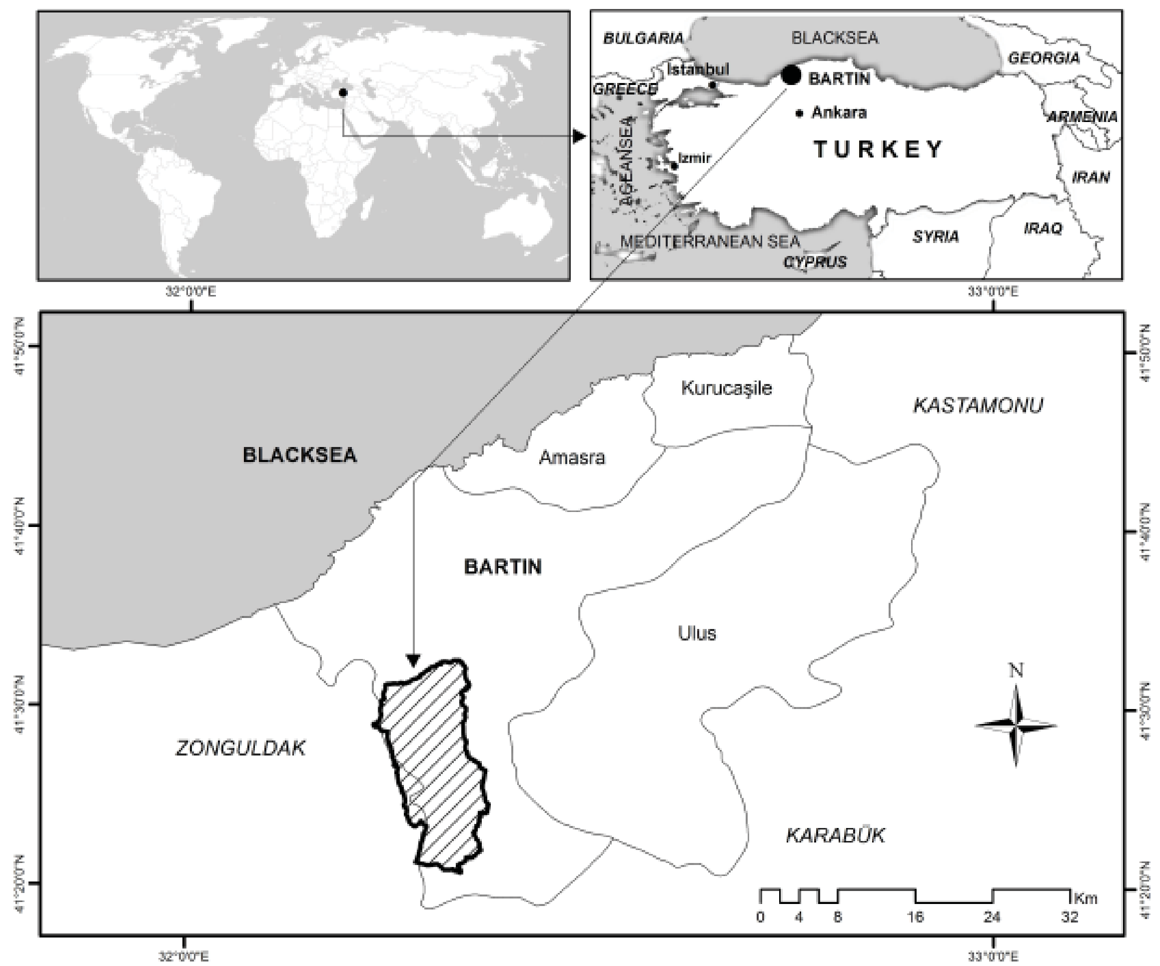

Figure 1 Location of the study area

Table 1 Climate data from Bartin Meteorology Station

Elements of balance	Months 1	2	3	4	5	6	7	8	9	10	11	12	Annual Mean
Mean temp. (°C)	4.1	4.7	7.0	11.1	15.5	19.7	22.0	21.6	17.6	13.6	8.9	5.7	12.6
Mean max. temp (°C)	9.1	10.2	13.0	17.7	22.0	25.9	28.1	28.1	24.8	20.3	15.4	10.9	18.8
Mean min. temp (°C)	0.3	0.5	2.4	6.0	9.7	13.3	15.6	15.5	12.0	8.8	4.3	1.8	0.3
Rainfall (mm)	105.0	82.5	72.6	57.9	52.1	73.4	62.9	77.5	88.4	114.8	116.8	131.1	1035

to 26 and divided into three main groups: general stand conditions, stand structure and production methods and tools. The group, name, code, unit average, standard deviation and scale of the 26 variables are presented in Table 2.

Evaluation of data

Factor analysis (Harman 1967, Yılmaz et al. 2010) was used to evaluate all variables simultaneously and to determine the most important factors affecting the production yield rate. For factor analysis, a data matrix with *N x n* (26 x 41) dimensions was input to a principal component model using the Varimax criterion and Kaiser Normalization (Hair et al. 1992).

In addition, the yield rate of industrial wood production types (log, paper wood, mine prop, industrial wood and fiber chip) and total industrial wood production yield rate were accepted to be dependent variables. The most important variables affecting yield rate in the factor analysis were investigated using regression analyses. Production units were divided into groups according to yield values and the sensitiveness of this new grouping was tested using discriminate analysis (Yılmaz et al. 2010). The ArcMap 10, MS Office and SPSS 18.0 software packages were used to process, transfer and statistically analyze the data.

Results

Most important factors affecting industrial wood production yield. At the first stage of data evaluation, principal component analysis was used to divide variables into groups to determine the most important fac-

Table 2 Groups, variables, labels, units and some statistics of the variables

Group	No	Name of variable	Label	Unit	Mean	Std. Dev.	Scale
General conditions of stand	1	Eta per ha (allowable cut)	ALWBH	$m^3\ ha^{-1}$	13.2	6.3	4.2-32.5
	2	Growing stock per ha	GSTCK	$m^3\ ha^{-1}$	203.2	60.6	131-367
	3	Annual volume increment	VOLINC	$m^3\ ha^{-1}$	3.8	1.4	0.4-6.6
	4	Stand height	HEIGHT	m	30.3	2.7	27-35
	5	Stand site quality degree	SSQUD	-	2.2	0.7	1-3
	6	Actual number of trees	NTREE	$n\ ha^{-1}$	344.2	148.9	139-689
	7	Actual basal area	BASAR	$m^2\ ha^{-1}$	18.8	8.2	1.6-35.3
	8	Weighed diameter class	DIAMTR	-	3.4	1.4	2-5
	9	Density of rhododendron	RHODO	-	2.9	0.7	2-4
	10	Density of other living cover	OTCVR	-	1.8	0.8	1-4
	11	Litter cover	LITTR	-	2.6	0.9	1-4
	12	Stand trunk quality	QUALT	-	2.6	1.0	1-4
	13	State of abiotic harm in the stand	ABIOT	-	2.1	1.2	1-5
Natural structure	14	Elevation	ELEV	m	491.7	114.4	290-750
	15	Slope	SLOP	%	52.9	8.2	37-70
	16	Aspect	ASPECT	-	5.1	2.6	1-8
	17	Soil Depth	SDEP	-	1.9	0.3	1-2
	18	Erosion Level	EROS	-	2.4	0.5	1-3
	19	Stoniness	STON	-	1.9	0.3	1-2
	20	Average ground skidding distance	AVSKID	m	298.4	81.9	110-550
	21	Skidding direction	SKIDIR	-	1.1	0.3	1-2
	22	Transportation distance	TRNDIS	km	11.8	2.2	7.4-16.0
Production methods and tools	23	Skidding unit price	SKDPR	$TL\ (m^3)^{-1}$	39.5	11.7	12.9-60.5
	24	Transportation unit price	TRNPR	$TL\ (m^3)^{-1}$	25.9	4.9	15.6-35.2
	25	Type of tools used in skidding	TYPTL	-	1.9	0.6	1-4
	26	Type of tools used in transportation	TRNTL	-	1.9	0.3	1-2

tors affecting yield rate. Among the 26 variables, 8 components or factors whose variance was greater than 1 were extracted (the Kaiser Criterion). Thus, 26 variables were reduced to 8 factors. According to the results of the principal component analysis with rotation, 82% of total variance among the 26 variables was explained by these 8 factors (Table 3). In the principal component analysis, the component matrix was rotated by the Varimax method for more reliable and easier scientific explanation. Factors were named and interpreted according to the rotated component matrix. Factors that have a dominant factor loading value above an absolute value of 0.5 are shown in Table 4 (Harman 1967, Yılmaz et al. 2010). Among the 26 variables in the data set, the QUALT variable was the only variable to have a dominant factor loading in both factors 1 and 3.

The most important factors to affect industrial wood production yield and the variables representing them are shown in Table 5. 81.86% of industrial wood production yield is dependent on these factors.

Accepting the five classifications of industrial wood (log, paper wood, mine props, industrial wood, and fiber chip) to be dependent variables, along with total yield, the effects of the 8 most important factors affecting yield rate were evaluated in multiple regression models (Table 6).

Categorization of production units for their industrial wood production yield. Production units were divided into 3 groups according to pre-analysis industrial wood production rates, as shown in Table 7. Afterwards, the sensitivity of these groups was tested using 26 variables and discriminant analysis.

Two discriminant functions were obtained from the analysis, and these can be used to group production units according to the rates of industrial wood production. Table 8 gives standardized canonical coefficients and parameters for these functions.

Table 3 Total variance explained

Factors	Initial eigen values			Rotation sums of squared loadings		
(Components)	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	6.59	25.34	25.34	3.30	12.72	12.72
2	4.09	15.75	41.09	3.27	12.59	25.32
3	2.99	11.50	52.59	3.19	12.28	37.60
4	2.03	7.80	60.39	2.50	9.62	47.23
5	1.82	7.00	67.39	2.49	9.60	56.83
6	1.34	5.14	72.52	2.42	9.31	66.15
7	1.30	4.99	77.52	2.31	8.90	75.06
8	1.13	4.33	81.86	1.76	6.79	**81.86**
9	0.82	3.16	85.02			
10	0.69	2.64	87.66			
11	0.63	2.42	90.09			
12	0.54	2.06	92.15			
13	0.41	1.58	93.73			
14	0.33	1.27	95.01			
15	0.30	1.14	96.15			
16	0.24	0.93	97.09			
17	0.17	0.64	97.73			
18	0.16	0.59	98.33			
19	0.14	0.55	98.88			
20	0.09	0.35	99.24			
21	0.08	0.30	99.54			
22	0.06	0.24	99.78			
23	0.04	0.13	99.92			
24	0.01	0.05	99.97			
25	0.01	0.02	99.99			
26	0.00	0.01	100.00			

Note. The bold number represents total variance explained by 8 factors

Table 4 Rotated component matrix

Variables	Factors (components)							
	1	2	3	4	5	6	7	8
SSQUD	0.909							
HEIGHT	-0.902							
STON	0.764							
QUALT	-0.536		-0.522					
ASPECT		0.843						
OTCVR		-0.837						
LITTR		0.787						
RHODO		0.777						
TYPTL			-0.840					
SLOP			0.765					
SDEP			-0.685					
EROS			0.659					
VOLINC				-0.850				
DIAMTR				0.761				
NTREE				-0.758				
AVSKID					0.882			
SKDPR					0.824			
SKIDIR					-0.813			
GSTCK						0.813		
HEIGHT						0.786		
ALWBH						0.650		
TRNPR							0.888	
TRNDIS							0.882	
TRNTL							-0.558	
ELEV								0.835
ABIOT								0.650

Note. Numbers represent dominant factors (greater than 0.5 in absolute value). The abbreviations are similar to Table 2.

Table 5 Factors affecting yield rate

Factor No	Name of factor	Weight of factor (%)	Indicator variable of factor	Weight of variable
1	Stand site quality degree	12.72	SSQUD	0.909
2	Aspect	12.59	ASPECT	0.843
3	Type of tools used in skidding	12.28	TYPTL	-0.840
4	Annual volume increment	9.62	VOLINC	-0.850
5	Average ground skidding distance	9.60	AVSKID	0.882
6	Growing stock	9.31	GSTCK	0.813
7	Transportation unit price	8.90	TRNPR	0.888
8	Abiotic harms	6.79	ELEV	0.835
Total		**81.86**		

Table 9 presents the results of the discriminant analysis classification according to 26 variables; the post-analysis groups of new production units are presented in Table 10 and Figures 2, 3. When the 26 variables in the classification were considered instead of the yield rate, two production units in the 2nd group (No 6 and 26) changed to the 3rd group, while one production unit in the 3rd group (No 13) changed its group to the 2nd group (Table 7). The classification success was 92.7%.

Discussion

According to Table 3, the first component is the most important factor and explains 12.72% of total variance. Factor 1 is composed of variables SSQUD, HEIGHT, STON and QUALT. Among the factors, it is stand site quality that has the largest factor loading (0.909). Increases in stoniness and decreases in stand site quality have negative effects on stand height and stand trunk quality. Factor 1 is called the yield rate,

Table 6 Results of multiple regression analyses explaining variation in percentage efficiency

	1. Model: Dependent variable log			2. Model: Dependent variable paper wood			3. Model: Dependent variable mine prop		
	Coefficient	Std error	Sig.	Coefficient	Std error	Sig.	Coefficient	Std error	Sig.
(Constant)	46.361	19.558	0.024***	-15.162	17.699	0.398	22.986	9.740	0.025***
SSQUD	-2.917	2.904	0.323	-3.579	2.628	0.183*	-0.623	1.446	0.669
ASPECT	0.625	0.794	0.437	0.271	0.718	0.708	-0.837	0.395	0.042***
TYPTL	10.267	3.210	0.003***	-2.102	2.905	0.475	-0.089	1.598	0.956
VOLINC	0.725	1.447	0.620	-1.477	1.309	0.268	0.822	0.720	0.263
GSTCK	-0.032	0.032	0.323	0.100	0.029	0.002***	-0.023	0.016	0.165*
AVSKID	-0.044	0.022	0.053**	0.024	0.020	0.231	-0.015	0.011	0.189*
TRNPR	0.184	0.381	0.633	0.372	0.345	0.289	-0.189	0.190	0.327
ELEV	-0.039	0.016	0.022***	0.017	0.015	0.261	-0.003	0.008	0.735
R^2	0.559			0.462			0.312		
F-statistic	5.074			3.428			1.817		

	4. Model: Dependent variable industrial wood	5. Model: Dependent variable fiber chip wood	6. Model: Dependent variable industrial total						
	Coefficient	Std error	Sig.	Coefficient	Std error	Sig.	Coefficient	Std error	Sig.
(Constant)	23.320	13.228	0.087**	-13.325	15.941	0.409	64.180	20.291	0.003***
SSQUD	-1.916	1.964	0.337	-1.065	2.367	0.656	-10.100	3.013	0.002***
ASPECT	0.324	0.537	0.550	1.763	0.647	0.010***	2.146	0.823	0.014***
TYPTL	0.245	2.171	0.911	-5.859	2.616	0.032***	2.462	3.330	0.465
VOLINC	0.646	0.978	0.514	1.789	1.179	0.139*	2.505	1.501	0.105*
GSTCK	-0.040	0.022	0.071**	-0.004	0.026	0.868	0.001	0.033	0.986
AVSKID	0.006	0.015	0.672	0.028	0.018	0.135*	-0.001	0.023	0.976
TRNPR	-0.096	0.258	0.711	0.644	0.311	0.046***	0.914	0.395	0.027***
ELEV	0.008	0.011	0.467	0.005	0.013	0.703	-0.012	0.017	0.484
R^2	0.181			0.384			0.605		
F-statistic	0.883			0.032			6.132		

Note. * Significant at the 0.20 level ($P < 0.20$). ** Significant at the 0.10 level ($P < 0.10$). *** Significant at the 0.05 level ($P < 0.05$).

and the SSQUD variable is representative of this factor.

Factor 2 is composed of the ASPECT, OTCVR, LITTR and RHODO variables. Aspect affects the density of rhododendron, other living cover and litter cover. Due to increased microorganism activity in south-facing directions, litter cover decomposes faster. Therefore, litter cover in the stand is generally thinner. As the direction proceeds from south to north, the density of rhododendron and other living cover increases, depending on humidity. Living cover, especially rhododendron, can cause raw wood material to fracture, hit, strip and cleave when skidded to the loading ramp. This situation may result in economic and even production losses. With ASPECT as the indicator variable, Factor 2 is called land aspect.

Factor 3 is composed of the TYPTL, SLOP, SDEP, EROS and QUALT variables. The slope of the land determines the type of skidding tools employed. In production units with gentle slopes, tractor traces may be constructed for mechanized skidding. Animals may be used to skid wood materials when the slope does not allow mechanized skidding. In steeply sloped areas, where machines or animal power cannot be used to skid wood materials, products are removed by hand-rolling and throwing. The last method is thought to reduce wood material yield the most. Therefore, factor 3 is called skidding method, and TYPTL is its indicator

Table 7 Groups of production units according to yield rate before analysis

Group of production units	No. of production units	Rate of industrial wood yield (%)	Group of production units	No. of production units	Rate of industrial wood yield (%)	Group of production units	No. of production units	Rate of industrial wood yield (%)
Group 1	12	113	Group 2	34	94	Group 3	8	80
	11	109		36	93		9	78
	21	107		16	92		33	78
	30	106		39	92		23	77
	41	105		3	91		25	76
	29	101		38	91		1	75
	22	100		26	90		27	71
	28	96		6	88		13	68
	2	95		31	88		24	67
	10	95		14	87		15	66
				37	87		7	63
				5	86		18	60
				17	85		20	57
				35	84		19	44
				4	83			
				32	83			
				40	83			
High Yield rate ≥ 95%			Moderate yield rate 81-94%			Low yield rate ≤80		

Table 8 Standardized canonical coefficients and some parameters of discriminant functions

Variable	Function 1	Function 2	Variable	Function 1	Function 2
ALWBH	-1.111	0.544	SDEP	-0.294	0.615
GSTCK	1.059	-0.756	EROS	0.293	0.109
VOLINC	-1.660	0.339	STON	-0.163	0.571
HEIGHT	0.679	-0.926	AVSKID	4.305	-3.093
SSQUD	2.170	-1.142	SKIDIR	0.393	0.662
NTREE	1.292	-0.007	TRNPR	5.975	-1.624
HEIGHT	-0.036	-0.161	SKDPR	-4.371	4.346
DIAMTR	-0.749	0.356	TRNPR	-5.876	1.403
RHODO	-1.189	1.331	TYPTL	0.982	0.048
OTCVR	-0.976	0.744	TRNTL	0.718	1.267
LITTR	1.302	-0.065	Eigenvalue	9.470	1.294
QUALT	-1.165	0.004	% of variance	88.000	12.000
ABIOT	-0.309	-0.145	C. correlation	0.951	0.751
ELEV	0.284	0.447	Wilks' lambda	0.042	0.436
SLOP	1.992	-2.043	Chi-square	81.059	21.172
ASPECT	-2.403	-0.034	Sig.	0.006	0.683

Table 9 Classification results

GROUP		Predicted group membership			Total
		1	2	3	
Original Count	1	10	0.0	0.0	10
	2	0	15.0	2.0	17
	3	0	1.0	13.0	14
Percentage	1	100	0.0	0.0	100
	2	0	88.2	11.8	100
	3	0	7.1	92.9	100

variable.

Factor 4 is composed of the variables VOLINC, DIAMTR and NTREE, which represent yearly increase in growing stock per hectare of production unit, the number of trees and weighted average diameter; these factors are correlated with each other. As the weighted average diameter of a stand increases, the

Table 10 Groups of production units according to yield rates after discriminant analysis

Groups of production units	Number of production units	Name of production units
High yield rate	10	12, 11, 21, 30, 41, 29, 22, 28, 2, 10
Moderate yield rate	16	34, 36, 16, 39, 3, 38, 31, 14, 37, 5, 17, 35, 4, 32, 40, 13
Low yield rate	15	8, 9, 33, 23, 25, 1, 27, 24, 15, 7, 18, 20, 19, 26, 6

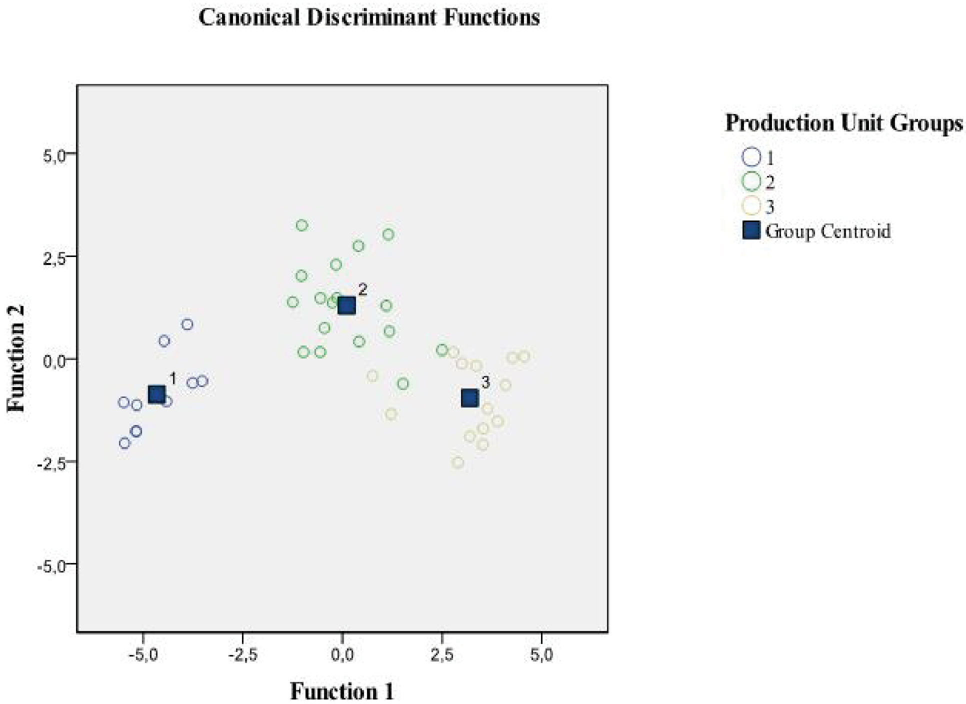

Figure 2 Distribution of production units for discriminate functions 1 and 2

number of trees per hectare decreases, and the yearly growing stock of the stand increases. Increases in yearly average growing stock and in stand mean diameter may also increase industrial wood production yield. In some cases, the branches of trees are suitable for industrial wood materials and thus contribute to an increased yield rate. Factor 4 is called stand structure, and its indicator is the VOLINC variable.

Variables of AVSKID, SKDPR and SKIDIR were included in Factor 5. All three variables are associated with the removal of wood raw materials from production units, i.e., skidding methods. Skidding distance and direction, together with slope, determine the price of skidding. Especially in areas where the skidding direction is from bottom to top, prices may increase three-fold. As the skidding distance increases, the possibility of damage to wood materials increases. Field observations show that where production costs are high, people work more carefully and take precautions to prevent industrial material damage. Therefore, based on the characteristics of the variable with the highest factor loading, AVSKID (0.882), Factor 5 is called skidding distance.

Factor 6 is composed of the variables GSTCK, HEIGHT and ALWBH, which represent the growing stock and the volume of wood materials to be removed per unit area (ha) and are correlated. The type of management is an

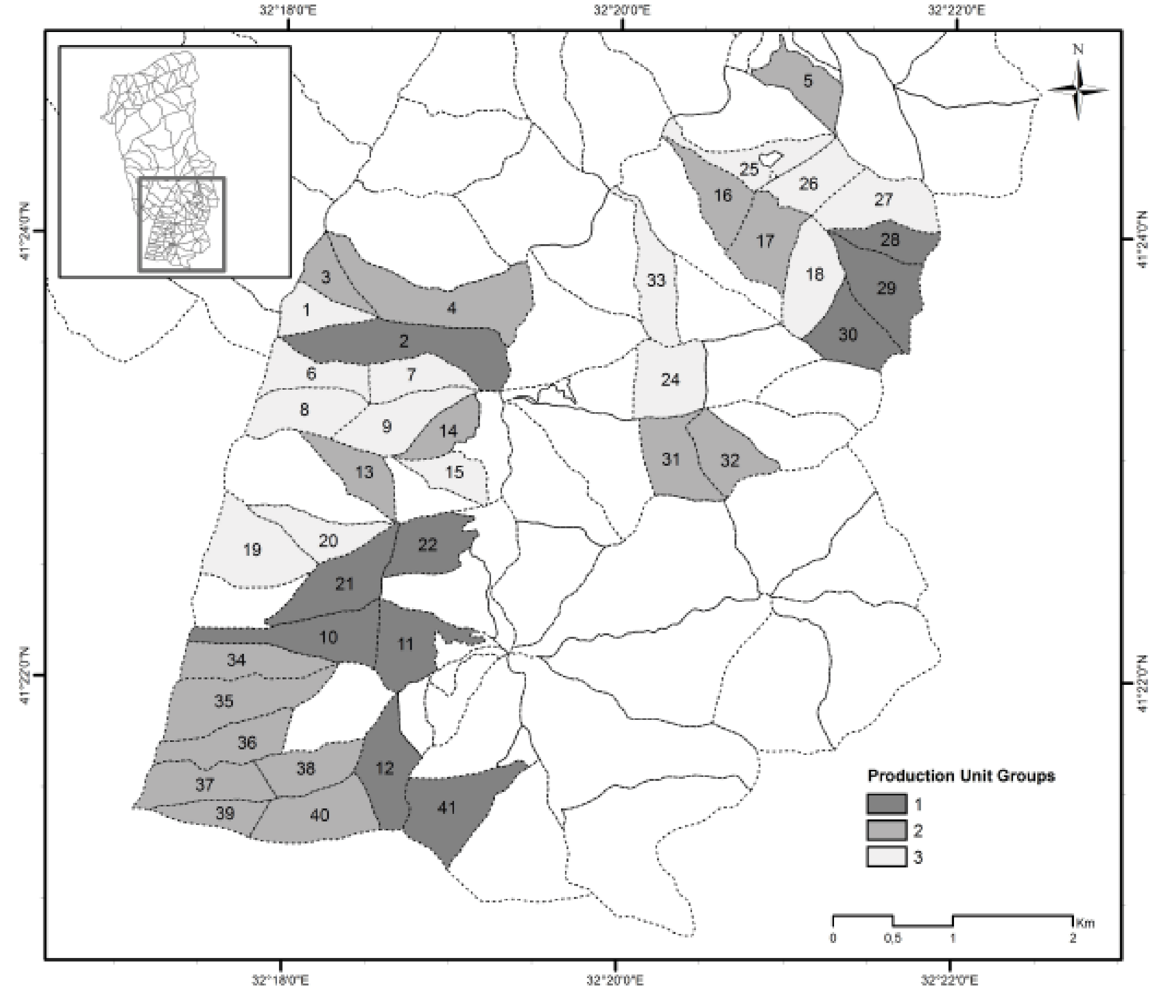

Figure 3 Location of production units on the map for their yield rates

important parameter in determining growing stock in the eta estimation. In spite of a high stock increment, there may be conditions under which the stand does not have optimal structure because of stock deficiency. In this case, planning should first include stock increment. On the other hand, increment rate decreases with a high growing stock. This effect may lead to a different estimate of eta because the stand deviates from its optimal structure. In such forests, production yield may increase with the use of branches as industrial wood material. Therefore, Factor 6 is called growing stock and is represented by GSTCK variable.

Factor 7 is composed of the TRNPR, TRNDIS and TRNTL variables. Transportation refers to transport of wood materials from the loading ramp to a storage area where they will be sold. When calculating the unit price for transportation, both type and distance are considered. Trucks are used for transport in the area, even though tractors may be preferred when roads are not suitable for trucks. However, only three of 41 tractors are used for transportation. The use of tractors for transportation may have two different negative impacts on yield. One is that these devices can only carry materials up to a length of 2 to 3 m. In order to fit logs to tractors, they are chopped into smaller parts, causing quality losses by turning wood materials into industrial wood. The second negative impact of tractor use is the greater use of time, labor and oil. Because of these costs, smaller diameter material remains in the units, reducing the amount of industrial and fiber chip wood. Because the variables are related to the effect of transportation on yield, Factor 7 is called transportation and is represented by the TRNPR variable.

Factor 8 includes the positively correlated variables ELEV and ABIOT and reflects sources of abiotic harm to a stand. Increasing elevation in production units may cause wind damage and an increased rate of cracked trees. Collapsed trees have priority for removal from the area before chopping desirable trees. These trees may be fully or partially rotten and therefore cause industrial losses. Broken trees may be found among the trees planned to be cut, which also causes wood material losses. For this reason, Factor 8 is called abiotic harms and is represented by the ELEV variable.

In the first regression model, 55.9% (R^2 = 0.559) of log production yield is explained by TYPTL, AVSKID and ELEV, 44.1% is expressed by SSQUD, ASPECT, VOLINC, GSTCK and TRNPR. From this perspective, tools used in skidding, mean distance and production elevation have significant effects on log production.

In the second regression model where the dependent variable was paper wood, 46.2% (R^2 = 0.462) of paper wood production is expressed by the GSTCK variable, while the SSQUD variable remains weak. From this perspective, paper wood production increases as growing stock per unit area in a stand increases.

According to the third regression model, 31.2% (R^2 = 0.312) of mine prop production is expressed by aspect, and the GSTCK and AVSKID variables remain weak in expressing this change. The most important variable affecting mine prop production is land aspect.

In the fourth regression, 18.1% (R^2 = 0.181) of industrial wood production yield change was associated with the GSTCK variable. Growing stock value per unit area is the most effective variable affecting mine props.

According to the fifth regression model, 38.4% of changes in the production of fiber chips are explained (R^2 = 0.384) by the ASPECT, TYPTL and TRNPR variables.

In the 6th regression model, 60.5% (R^2 = 0.605) of changes in total industrial wood production yield rate are expressed by the SSQUD, ASPECT and TRNPR variables. The VOLINC variable was determined to be a weak explanatory variable. Therefore, our study of the Günye Forest Management, including 41 oriental beech production units, found that stand site quality, aspect and transportation costs are significant variables affecting wood production yield.

Conclusions

Even if the eta values of two production units are the same, the rate of industrial wood material may differ due to geographic features, stand structure and production methods and tools. A production plan based only on yearly eta values can cause large deviations from production targets by the end of production period. As a result, an imbalance of demand to supply may be observed in the industrial wood raw material market.

All of the 41 production units of Bartin – Günye Forest Management are composed of pure oriental beech (*Fagus orientalis* Lipsky.). Factors affecting yield were evaluated via an objective, multifaceted approach. Industrial wood production yield is largely dependent (82%) on eight factors: fertility, aspect of land, skidding method, stand structure, skidding distance, growing stock, transportation and abiotic harms. In addition, production units were divided into three yield groups (high, moderate, low) according to their yield percentages according to discriminate analyses.

Production units in the study area have high, moderate and low yield percentages at rates of 24.4, 39 and 36.6%, respectively. To obtain a well-balanced production supply, these yield groups should be considered in management of yearly production units. In addition, these findings may improve calculation of selling prices and yield estimation of growing stock.

The present study dealt with the factors affecting wood production using multidimensional statistical analyses and different methodological approaches. The variables evaluated were partly obtained from management plans, united price calculation notebooks and digitized forest maps in GIS.

The findings of the present study depend on time and location. However, they may help private firms determine yield percentage and supply industrial wood material to market while considering different geographical structures, plant species, forest structure, management methods, production tools and methods.

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