JOURNAL OF THE FACULTY OF FORESTRY ISTANBUL UNIVERSITY
İSTANBUL ÜNİVERSİTESİ ORMAN FAKÜLTESİ DERGİSİ
ISSN: 0535-8418 e-ISSN: 1309-6257
Online available at / Çevrimiçi erişim Research Article / Araştırma Makalesi
http://dergipark.ulakbim.gov.tr/jffiu - http://dx.doi.org/10.17099/jffiu.52687

A comparative economic evaluation of bucking deciduous trees: A Case study of Oriental beech (*Fagus orientalis*) stands in Northeastern Turkey

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Received (Geliş tarihi): 04.08.2016 - **Revised (Düzeltme tarihi):** 07.09.2016 - **Accepted (Kabul tarihi):** 07.09.2016

Abstract: The optimum bucking method assists loggers to determine optimum bucking combinations that maximized total economic value of harvested trees. Several previous studies investigated performance of optimum bucking method on coniferous trees in Turkish forestry. In this study, economic gain of using optimum bucking method was evaluated in deciduous forest of Oriental beech (*Fagus orientalis*) trees in northeastern region of Turkey. Network 2000 program was used to run optimum bucking method in a sample application. The findings of sample bucking application in Giresun Forest Regional Directorate were deemed to represent the optimum bucking data in nearby regional directorates (Artvin and Trabzon). Then, the economic gain of using optimum bucking method in producing Oriental beech (*Fagus orientalis*) was estimated for whole northeastern region of Turkey. The capability of optimum bucking method was evaluated by comparing study results with the results from traditional bucking method. The results indicated that optimum bucking application using Network 2000 program increased, although statistically not significant, the average economic value of harvested deciduous trees by 14.37%, comparing with traditional method, mainly relying on loggers' experiences. The overall economic contribution of using optimum bucking in producing Oriental beech (*Fagus orientalis*) logs was estimated as 2,686,182.93 Turkish Lira (TL).

Keywords: Optimum bucking, network analysis, oriental beech, Turkey

Yapraklı ağaçların boylanmasında karşılaştırmalı ekonomik bir değerlendirme: Türkiye'nin kuzeydoğusundaki Doğu kayını (*Fagus orientalis*) meşcereleri örneği

Özet: Optimum boylama yöntemi, üretilen ağaçların toplam ekonomik değerini artıran optimum boylama kombinasyonlarına karar vermek için orman işçilerine yardım eder. Birkaç önceki çalışmada Türk ormancılığında iğne yapraklılar üzerine optimum boylama yönteminin performansı incelenmiştir. Bu çalışmada optimum boylama yönteminin ekonomik kazancı Türkiye'nin kuzeydoğu bölgesinde Doğu kayını (*Fagus orientalis*) yapraklı ormanlarında değerlendirilmiştir. Network 2000 programı örnek bir uygulamada optimum boylama yöntemini çalıştırmak için kullanılmıştır. Giresun Orman Bölge Müdürlüğünde örnek boylama uygulamasının bulgularının yakın bölge müdürlüklerinde de (Artvin-Trabzon) optimum boylama verisi temsil etmesi kabul edilmiştir. Ardından, Türkiye'nin tüm kuzeydoğu bölgesi için optimum boylama yöntemi kullanarak üretilen Doğu kayınının (*Fagus orientalis*) ekonomik kazancı tahmin edilmiştir. Çalışmadan elde edilen sonuçlar geleneksel boylama yöntemiyle elde edilen sonuçlarla kıyaslanarak optimum boylama yönteminin kapasitesi değerlendirilmiştir. Network 2000 programı kullanılarak gerçekleştirilen optimum boylama uygulamasının sonuçlarıyla orman işçilerinin tecrübelerine bağlı olarak gerçekleşen geleneksel yönteme ait sonuçlar karşılaştırıldığında, sonuçlar istatistiksel olarak anlamsız olmasına rağmen yapraklı ağaçların üretiminin ortalama ekonomik değerinde %14.37'lik artış göstermiştir. Doğu kayını tomruklarının üretiminde optimum boylamanın toplam ekonomik değeri 2,686,182.93 TL olarak tahmin edilmiştir.

Anahtar Kelimeler: Optimum boylama, ağ analizi, doğu kayını, Türkiye

To cite this article (Atıf): Pak, M., Gulci, N., 2017. A comparative economic evaluation of bucking deciduous trees: A Case study of Oriental beech (*Fagus orientalis*) stands in Northeastern Turkey. *Journal of the Faculty of Forestry Istanbul University* 67(1): 72-79. DOI: 10.17099/ jffiu.52687

1.INTRODUCTION

In recent decades, population growth, industrialization, and economic development increased the public demands on forest resources, especially on wood based forest products, which represent the highest proportion in total economic value of forest resources in Turkey (Pak et al. 2010; Serin et al. 2010). The share of wood based forest products in the positive total economic value components of Turkish forest resources reach 68.35%, and the proportion of logs in the wood based products is about 38,22 % (Pak et al. 2010). This support the previous idea which the dominated forest management type in Turkey is the wood based forest management approach. The logs are considered to be the most important wood based forest product in terms of quantity and economic value in Turkish forest industry (GDF, 2010). Thus, it is crucial to minimize value loss and obtain maximum economic value from trees in log production.

After felling the trees, logs are produced by bucking a tree into shorter lengths with respect to required quality classes (Akay et al. 2010). Dividing a tree into the logs that maximize the economic value is called the optimum bucking method (Sessions, 1988). Currently, value loss during the bucking operation is one of the most important issues in Turkish forestry since the bucking is performed based on traditional method, mainly relying on loggers' experiences.

The studies in Turkey indicated that optimum bucking method can increase the economic value of coniferous trees by more than 10% (Akay et al. 2009; Akay et al. 2010; Akay, 2010; Serin et al. 2010). Considering that about 81.85 % of the logs in Turkey were obtained from coniferous trees in 2009, it can be realized that implementing optimum bucking method can significantly increase the economic value of harvested trees in Turkey (GDF, 2010).

In optimum bucking method, large number of bucking alternatives should be evaluated to determine the optimum bucking combination that maximizes the total economic value of a tree. Such a problem with many solutions can be solved by using computer assisted methods such as network analysis, dynamic programming, and heuristic techniques (Laroze and Greber, 1997; Laroze, 1999; Wang et al. 2004). The network analysis is the most common mathematical optimization method that searches for the shortest path, least cost route, and maximum flow value (Baskent, 2004).

The previous optimum bucking studies in Turkey only focused on logs of coniferous tree species. According to General Directorate of Forestry (GDF) in Turkey, the proportion of logs obtained from deciduous trees in 2009 was about 18.15% in which approximately 79.67 % of them was produced from beech trees (GDF, 2010).

In this study, the economic gain of using optimum bucking method with respect to Turkish forestry conditions was investigated in Oriental beech (*Fagus orientalis*) stands in northeastern region of Turkey. A stem-level optimum bucking method was implemented by using the network analysis based software, Network 2000. This software was developed by Chung and Sessions (2001) to determine the network that optimizes the total cost, considering the user defined decision variables. The capabilities of optimum bucking method were evaluated by comparing study results with the results from traditional bucking methods. Besides, the approximate economic contribution of using optimum bucking method in producing Oriental beech (*Fagus orientalis*) was estimated for northeastern region of Turkey.

2. MATERIAL AND METHOD

2.1 Study Area

The study area was selected from Oriental beech (*Fagus orientalis*) stands located in Yağlıdere Forest Enterprise Chief Unit (FECU) of Espiye Forest Enterprise Directorate (FED) in Giresun Forest Regional Directorate (FRD). The most of the log production from Oriental beech (*Fagus orientalis*) are obtained in Giresun FRD in 2009 (GDF 2010). Besides, beech trees in this FRD represent the general characteristics

of Oriental beech (*Fagus orientalis*) stands in northeastern region of Turkey. Thus, the data obtained from optimum bucking application was used to represent the optimum bucking data in other FRDs (Artvin and Trabzon) in the region (Figure 1). According to GDF (2010), the amount of log production obtained from Oriental beech (*Fagus orientalis*) in Artvin, Giresun, and Trabzon were 8155 m^3, 31314 m^3, and 3108 m^3, respectively.

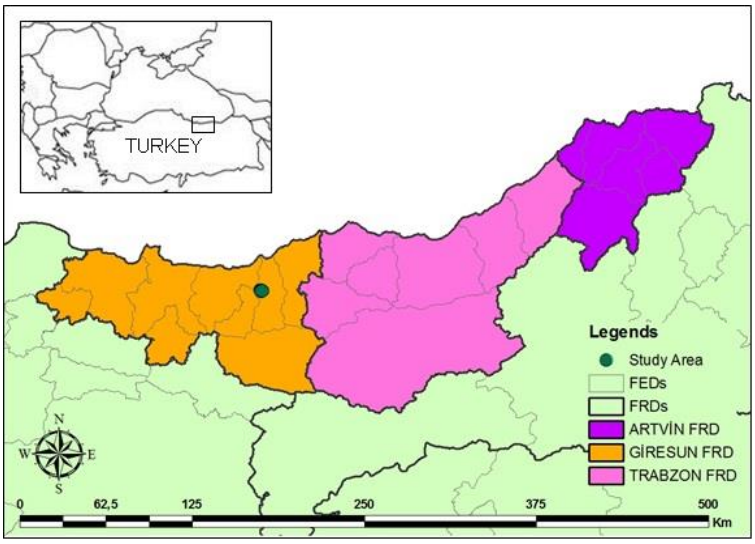

Figure 1. The study area
Şekil 1. Çalışma alanı

In the study area, the average elevation and ground slope were 1,305.37 m and 60.87%, respectively. The Oriental beech (*Fagus orientalis*) trees were cut and bucked using a chainsaw depending on traditional bucking methods in June 2009. To approximate the normal distribution, 30 sample trees were randomly selected to apply optimum bucking method. In the study, log diameter, log length, and log quality class were recorded for each log of the sample trees. A chain tape and compass was used to measure tree length and diameter at breast height, respectively. Besides, UTM coordinates and elevation were recorded at the stump locations of each sample tree using a hand-held GPS. During the harvesting operation, the logs were transported to the landing areas using ground-based manual skidding technique.

2.2 Optimum Bucking

The network analysis method is one of the commonly used mathematical optimization model to solve optimum bucking problems. There are three main components in network analysis model including links (arcs), intersection points (nodes), and link value. In optimum bucking method, tree is represented as a network consisting of potential logs. Potential bucking locations are nodes and potential logs between the nodes are links.

The value of the link represents economic value of the bucked logs. The log value can be computed by multiplying log volume by the unit price of the log. The mid surface formula (Huber Formula) is generally used to compute log volume (Carus 2002; Eq. 1):

$$V_i = \frac{\pi}{40000} d_i^{\,2} L_i \quad \text{.....(1)}$$

Where; d_i is mid diameter of log i (cm), and L_i is length of log i (m).

In this study, Network 2000 program was used to implement optimum bucking method. The program was developed to minimize the total cost in harvesting planning and transportation problems where link values originally represent the costs. In optimum bucking problems, however, link values represent the economic value of logs since the goal is to investigate the optimum bucking combination which maximizes the total

value of a tree. Thus, the economic values of logs were entered into the program in negative values, so that, Network 2000 program can find the optimum bucking combination with maximum value by searching for the path that minimizes the sum of negative values.

Network 2000 program consisted of two basic input tables including "Link" and "Sale" editors (Figure 2). The network system is introduced to the program by entering beginning and ending points (nodes) of each link and value of each link in "Link" table. In optimum bucking problems, value of each link is entered into the table in negative values. The entry and destination nodes of whole network system and total flow in the system are entered in "Sale" table. Network 2000 program provides a user with final reports in two formats: text format and graphical format. Text report includes various information about optimum solution such as total value and details about links, while graphical report indicates the links in whole network and only in optimum solution.

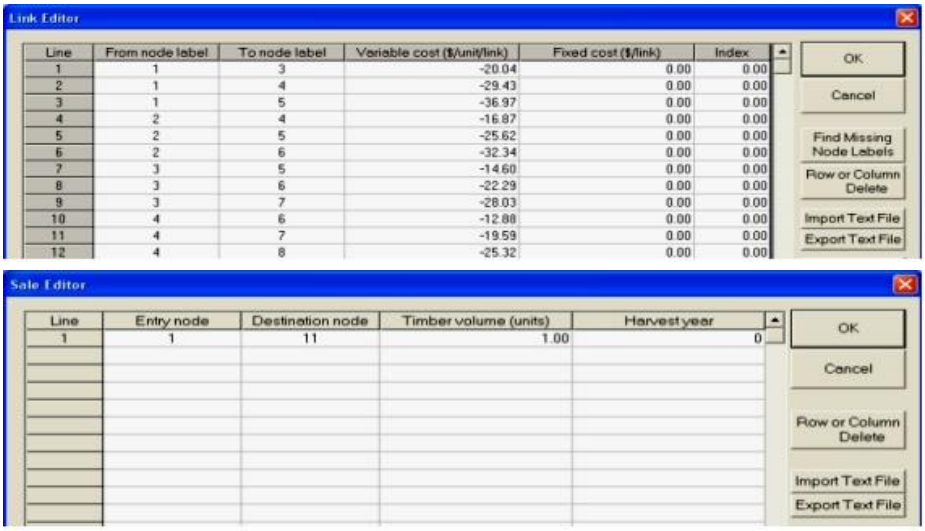

Figure 2. The partial views of Link (top) and Sale (below) input tables in Network 2000
Şekil 2. Network 2000'de Link (üst) ve Sale (alt) veri tablosunun görünüşü

2.3. Method Application

In method application, first, the basic field data required (log quality classes, log lengths and diameters) for traditional bucking method was entered into MS-Excel 2007 program. The unit log prices, obtained from Yağlıdere FEC based on the most recent local auction, were also entered into the program. The unit volume of each log was computed using the equation in Formula 1, and then, unit log price and log volume were used to determine economic value of each log. Finally, economic value of a tree bucked by a traditional method was computed by adding up economic values of all log of this tree.

For optimum bucking method, additional data including all available log quality classes, log lengths, log diameters, and unit log prices for possible log sizes and qualities were also entered into Microsoft Excel 2007 program. The economic value of each log was computed as explained above. In the application, alternative bucking combinations were generated by considering constraints including minimum log length (2 m), minimum mid diameter of log (19 cm), and maximum log length (4 m). Then, the data was loaded into Network 2000 program to search for the optimum bucking combination of a tree and maximum economic value of this tree.

In order to enter necessary data into "Link" editor of Network 2000 program, a separate page was prepared in MS-Excel 2007 program. This page, consisting of beginning and ending points of each log alternative and negative economic value of each log, was saved in text format to be automatically loaded into Network 2000 program. The data of entry and destination points of the network was manually entered into "Sale" editor.

2.4. Statistical Analysis

In statistical analysis, it was investigated if there is a significant difference for values of the sample trees between traditional bucking method and optimum bucking method. The average log lengths of sample trees produced by both methods were also evaluated in the analysis. One-way ANOVA with the significance level of 0.05 was implemented by using SPSS 15.0 statistic software. The study was applied on 30 randomly - selected sample trees to approximate a normal distribution in the study area. The breast height diameters were regrouped into three classes (small < 40 cm; medium = 40-50 cm; and large > 50 cm) to investigate the effects of different diameter classes on value gain of optimally bucked logs. Then, the volumes of trees were regrouped into three classes (low < 1.0 m^3; average = 1.0-2.0 m^3; and high > 2.0 m^3) to investigate the effects of different volume classes on value gain of optimally bucked logs.

3. RESULT AND DISCUSSION

The information about the sample trees including length, diameter at breast height, and volume are listed in Table 1. The UTM coordinates, elevation, and ground slope data are also shown in this table. The results indicated that average tree height, diameter, and volume were 22.10 m, 64.10 cm, and 1.16 m^3, respectively. The average elevation and ground slope were found to be 1305.37 m and 60.87%.

Table 1. Information about the sample trees
Tablo 1. Örnek ağaçlar hakkında bilgi

Tree	UTM Coordinates		Elevation	Slope	Length	Diameter	Volume
	North (m)	East (m)	(m)	(%)	(m)	(cm)	(m^3)
1	4510781	38465899	1320	50.00	21	52	1.78
2	4510791	38465912	1323	62.00	22	64	2.72
3	4510782	38465901	1321	50.00	34	112	11.75
4	4510766	38465879	1320	65.00	19	58	2.23
5	4510813	38465829	1331	80.00	17	43	1.17
6	4510844	38465862	1340	55.00	30	75	5.04
7	4510855	38465884	1335	45.00	32	84	8.12
8	4510849	38465895	1334	60.00	29	84	7.72
9	4510865	38465890	1340	60.00	14	32	0.63
10	4510894	38465868	1340	70.00	30	83	6.49
11	4510942	38465848	1328	65.00	21	54	2.52
12	4510958	38465849	1333	40.00	14	32	0.59
13	4510997	38465845	1321	80.00	15	44	1.11
14	4511057	38465838	1339	60.00	15	52	1.62
15	4511098	38465840	1334	85.00	32	92	7.80
16	4511129	38465857	1337	75.00	18	57	2.28
17	4510731	38465884	1309	90.00	13	34	0.61
18	4510694	38465895	1300	59.00	30	102	9.36
19	4510677	38465900	1302	75.00	30	81	6.55
20	4510650	38465919	1292	40.00	16	51	1.49
21	4510622	38465933	1292	85.00	15	44	1.05
22	4510593	38465957	1280	50.00	30	90	7.60
23	4510555	38465974	1290	40.00	21	62	2.90
24	4510478	38466011	1279	50.00	12	35	0.59
25	4510571	38466978	1283	50.00	27	81	5.81
26	4510578	38466984	1289	60.00	34	118	10.85
27	4510389	38466007	1260	40.00	18	52	1.72
28	4510269	38466006	1239	80.00	22	65	3.61
29	4510213	38465988	1226	60.00	14	36	0.77
30	4510180	38466976	1224	45.00	18	54	1.94

The results indicated that bucking combinations suggested by optimum bucking method were different than the combinations generated by traditional bucking method in all sample trees. The average log length was longer in optimum bucking method (3.38 m) than that of traditional method (2.39 m). Statistical analysis also indicated that there was a significant difference between the average log lengths produced by optimum bucking method and traditional method ($p<0.005$).

It was found that there was no significant difference between the economic value of trees harvested by optimum bucking and traditional bucking methods ($p > 0.05$). However, results also indicated that using optimum bucking method has potential to increase the average economic value of sample trees from 621.99 TL to 659.09 TL (Table 2). Thus, the average economic value of sample trees was increased by 14.37% when implementing optimum bucking method, even though there was no significant difference between the methods. In a single-tree based optimum bucking study implemented on deciduous trees reported the average economic value gain of 10-11% (Wang et al. 2009).

Table 2. Log lengths, economic values, and value gain for sample trees by bucking methods
Tablo 2. Boylama yöntemleri göre örnek ağaçların tomruk boyları, ekonomik değerleri ve değer kazancı

Sample Trees	Average Log Lengths (m)		Economic Values (TL*)		Value Gain (%)
	Traditional Method	Optimum Bucking	Traditional Method	Optimum Bucking	
1	2.00	4.00	263.33	307.1	16.62
2	2.00	3.00	379.23	459.36	21.13
3	2.60	3.25	2004.00	2210.66	10.31
4	2.67	3.20	342.26	383.33	12.00
5	2.17	3.25	166.72	193.87	16.28
6	2.45	3.38	738.33	855.04	15.81
7	2.42	3.22	1360.16	1491.34	9.64
8	2.42	3.22	1181.29	1334.04	12.93
9	2.75	3.67	86.34	89.81	4.01
10	2.33	3.50	961.47	1119.66	16.45
11	2.71	3.17	395.01	429.43	8.71
12	2.00	3.33	81.42	102.06	25.35
13	2.75	3.67	154.16	170.18	10.39
14	2.40	4.00	234.11	263.8	12.68
15	2.42	3.22	1283.74	1409.47	9.79
16	2.00	3.50	367.15	436.77	18.96
17	2.50	3.33	82.09	102.87	25.31
18	2.80	3.50	1495.70	1575.98	5.37
19	2.25	3.86	1053.13	1162.95	10.43
20	2.00	3.00	198.99	236.61	18.91
21	2.20	3.67	132.71	160.37	20.84
22	2.89	3.25	1319.01	1397.88	5.98
23	2.25	3.60	426.81	515.63	20.81
24	2.25	3.00	72.91	84.24	15.54
25	2.18	3.43	826.10	970.1	17.43
26	2.90	3.22	1845.93	1986.06	7.59
27	2.14	3.00	251.79	305.01	21.13
28	2.11	3.17	564.04	640.85	13.62
29	2.75	3.67	103.18	109.78	6.40
30	2.29	3.20	288.45	348.3	20.75

*1 Turkish Lira (TL) = 0.34 Unites States Dollar (USD) (Source: Turkish Republic of Central Bank, 05 May 2016)

The effects of different breast height diameter classes (i.e. small, medium, and large diameter classes) and volume classes (i.e. low, average, high volume classes) on value gain of harvested trees when using optimum bucking method were investigated. Statistical analysis indicated that there was no significant difference on value gain of harvested trees with different diameter or volume classes ($p > 0.05$). The

maximum average value gain was received from the medium diameter class, followed by small, and then large diameter classes (Table 3). For the volume classes, average volume class provided the maximum average value gain, followed by low, and then high volume classes.

Table 3 Value gain (%) of harvested tress by diameter and volume classes
Tablo 3. Üretilen ağaçların çap ve hacim sınıflarına göre değer kazancı (%)

Classes	N	Mean	Minimum	Maximum
Small Diameter	5	15.32	4.01	25.35
Medium Diameter	3	15.84	10.39	20.84
Large Diameter	22	13.96	5.37	21.13
Low Volume	5	15.32	4.01	25.35
Average Volume	8	17.20	10.39	21.13
High Volume	17	12.76	5.37	21.13

The overall gain of using optimum bucking method on production of Oriental beech (*Fagus orientalis*) logs extracted in northeastern region of Turkey was estimated by average unit value (TL/m^3) of sample trees bucked by both methods and total log production (m^3) in specified FRDs (Artvin, Giresun, and Trabzon FRDs). In this study, it was assumed that extra cost of using optimum bucking method was negligible. In this study, the average unit value of trees was found to be 536.85 TL/m^3 and 599.94 TL/m^3 for traditional and optimum bucking methods, respectively. These figures were used to represent the optimum bucking data in other two FRDs (Artvin and Trabzon) in the region.

The results indicated that the highest total value gain was obtained in FRD of Giresun, followed by Artvin, and Trabzon (Table 4). The overall total value of Oriental beech (*Fagus orientalis*) logs bucked by traditional bucking method was estimated as approximately 22,857,462.45 TL, it was found as 25,543,645.38 TL when using optimum bucking method.

Table 4 The economic value gain of using optimum bucking method in specified FRDs
Tablo 4. Belirli OBM'lerinde optimum boylama yöntemi kullanımının ekonomik değer kazancı

FRDs	Average Unit Value (TL/m^3)		Total Volume	Total Value Gain
	Traditional	Optimum	(m^3)	TL
Artvin	536.85	599.94	8155	514,498.95
Giresun	536.85	599.94	31314	1,975,600.26
Trabzon	536.85	599.94	3108	196,083.72

4. CONCLUSION

In this study, Network 2000 program was used to evaluate the economic gain of applying stem-level optimum bucking method in Oriental beech (*Fagus orientalis*) stands located in northeastern region of Turkey. The results from optimum bucking application taken place in Giresun FRD indicated that bucking patterns suggested by optimum bucking method were different than the patterns produced by the loggers using traditional bucking method. Using optimum bucking method increased the average economic value of sample beech trees by 14.37%. Economic value gain of applying optimum bucking method during production of Oriental beech (*Fagus orientalis*) logs in northeastern region of Turkey was estimated as 2,686,182.93 TL in the region. The overall results from this study suggested that optimum bucking method has great potential to increase the economic value of log production in Turkey. Some suggestions for future research on optimum bucking application shall include: implementing optimum bucking method not only saw log production but also other wood based products (i.e. telephone poles, mine poles, industrial wood, pulp wood, fiber-particle wood, and sapling wood) and developing an independent software to run optimum bucking method.

ACKNOWLEDGEMENT

This study is funded by The Scientific and Technological Research Council of Turkey (TUBITAK) with the project number 108O125.

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