Annals of Silvicultural Research
37 (1), 2013: 7-12

http://ojs-cra.cilea.it/index.php/asr

Research paper

Empirical modelling of chestnut coppice yield for Cimini and Vicani mountains (Central Italy)

Alice Angelini[1], Walter Mattioli[1*], Paolo Merlini[2], Piermaria Corona[2] , Luigi Portoghesi[1]

Received 26/11/2013 - Accepted 20/12/2013

Abstract - The prescription of stand rotation according to site conditions and economic targets requires yield information that expresses stand productivity under different site-classes. This is particularly relevant for the optimal management of chestnut coppices allowing the production of timber assortments sized differently. This paper reports a new yield model built for chestnut coppices of the Cimini and Vicani mountains (Central Italy), according to three site index classes. The model focuses on the development of stands after an intense thinning carried out at the ages of 13-14 years. The model is compared with two previous yield tables built for chestnut coppice forests living in the same area and including one site index class only. The study stresses the high productivity of chestnut coppices growing on the volcanic soils of Cimini and Vicani mountains and shows how the growth course following intense thinning allows to get stems with large mean volume at the end of rotation. In the light of the most recent studies on the causes of ring shake, i.e. the most relevant defect of chestnut wood, the negative consequences on timber quality originating from the current thinning regime are also outlined.

Keywords - forest management, yield table, thinning, rotation length

Introduction

Coppice is a silvicultural system extensively applied in Italy and in other Mediterranean countries to get quite exclusively firewood under relatively short rotations. Coppice management is based on cultivation techniques that generally result in the simplification of forest composition and structure to the benefit of wood production (Ciancio and Nocentini 2004).

According to the National Forest Inventory (Gasparini and Tabacchi 2011), coppices cover about 35% (i.e. 3.7 million hectares) of the forest area. Within the coppice area, chestnut (*Castanea sativa* Mill.) coppices are a case apart because this fast-growing species produces a wide range of easily marketable and quality assortments for agriculture, constructions, furniture and leather tanning industry.

In Italy, chestnut forests cover an area of 0.8 million hectares (Gasparini and Tabacchi 2011): 70% are managed as coppices with standards and the remaining 30% as orchards for fruit production. In the early fifties of the last century, the relationship between the two forms of cultivation was reversed compared to nowadays and it has been turning over time following the socio-economical changes affecting the rural areas and the spread of two destructive fungi causing, respectively, the chestnut blight (*Cryphonectria parasitica*) and the ink disease (*Phytophthora cambivora*). The domestic production of chestnut wood barely exceeds 0.9 Mm^3 per year, 63% being represented by timber assortments (ISTAT 2002). The current annual increment of chestnut stands is 5 Mm^3 (Gasparini and Tabacchi 2011): that means that the harvested volume could be significantly increased.

The rising demand of renewable resources, the versatility of the raw material also supported by technological innovation by the wood industry, and the need to diversify the productive activities in rural areas, are all together favourable factors to increase domestic chestnut wood yield. This perspective might be however hindered by the fragmentation of private forest land ownership and the inadequate organization of wood supply chain that makes difficult to guarantee the continuity in the supply and the quality of available products, as well (Pettenella 2001).

In the past, timber assortments from chestnut coppices were frequently characterized by relatively low economic value, mainly because of the small average size of the shoots at the end of cutting cycle, since relatively short rotations (16 to 20 years) were adopted, usually without any thinning. By contrast, in recent years, new management schemes based on longer rotations and selective thinnings, accord-

[1] University of Tuscia - Department for Innovation in Biological, Agro-food and Forest systems (DIBAF), Viterbo, Italy
[2] Consiglio per la Ricerca e la sperimentazione in Agricoltura, Forestry Research Centre (CRA-SEL), Arezzo, Italy
[*] Corresponding author: walter.mattioli@unitus.it

http://dx.doi.org/10.12899/ASR-749

ing to site condition and socio-economic context, have been experimentally developed to increase the timber value (Amorini and Manetti 2002, Lemaire 2009a). Research trials showed that gradual thinnings are being able to promote regular and moderate growth of tree rings, thus reducing the occurrence of ring shake, a chestnut wood defect that can significantly lower its commercial value (Fonti et al. 2002, Cosseau and Lemaire 2009).

The improvement of the quality of chestnut timber from coppices should take into duly account rotation lengths suited to growth potential under various site conditions. This asks for effective tools to assess the growth potential of chestnut coppice stands with respect to a given site.

In Italy, the available yield tables show the high productivity as well as the variability of chestnut coppices in terms of mean volume increment, it varying between 9 and 21 m^3 per hectare per year (Corona et al. 2002). However, most of the available yield tables are not framed by site-classes, thus limiting their use as operative support to silvicultural and management decision processes. This is the case of chestnut coppices on the Cimini and Vicani mountains in Central Italy, growing under a suitable environment for chestnut but variable as to ground slope, aspect and soil conditions. Two yield tables are available for these coppices: the first one is referred to the entire area of the Cimini and Vicani mountains (Cantiani 1965), whilst the second one is referred to coppices growing on the North-West slopes of these mountains (Lamani 1993); both tables are established with reference to an unique site-class and take into account rotations and thinning regimes no longer applied.

In the light of these considerations, the objectives of this study are to: a) building up a new empirical yield model for chestnut coppices of the Cimini and Vicani mountains, framed by site-classes and based on the most common thinning regime currently applied; b) comparing the new model with the preexisting ones to integrate knowledge about chestnut coppices in the studied woodland.

Study area

The Cimini and Vicani mountains are located in the north of Latium region. Pyroclastic rocks and lavas form the geological substrate of the relieves (Chiocchini 2006); soils, classified as andisols and identified as "black soils", are fertile, deep and loose with acid pH (Bernetti 1959). Mean annual temperature is 12.8°C. The hottest month is July with an average temperature of 22°C, and January is the coldest one (4.2°C). The minimum temperature is just below zero (-2.1°C). Annual rainfall ranges between 1,250 mm and 1,550 mm; summer drought is not actually recorded thanks to the humid air coming from the Thyrrenian Sea and the nearby Vico Lake, although a sub-arid period between July and August may occur (Blasi 1994).

The forest area is about 220 km^2, mostly covered by oak and chestnut coppices. Turkey oak (*Quercus cerris* L.) and beech (*Fagus sylvatica* L.) high forests characterize the flat top of Mount Cimino (1,053 m a.s.l.) and the west side of the Vico Lake valley. Public forest estates (mostly municipal) extend for several hundred hectares whilst the private ownership is very fragmented. Chestnut coppices grow in monospecific stands on about 8,000 hectares, between 550 m and 950 m a.s.l.. Their monospecificity is due either to the applied silvicultural practices and to the environmental conditions (distinctively, the volcanic soils where chestnut finds its optimal growth conditions).

An average of about 200 hectares of chestnut coppices are harvested or thinned per year. Rotation length ranges between 16 and 20 years (19 years, on average) under private properties and between 18 and 25 years (23 years, on average) under public properties. Chestnut coppices are usually thinned once at ages of 13-14 years. In a few public estates a second thinning is occasionally carried out 3-5 years before the end of the rotation. This study is focused on modelling coppice growth after the unique thinning usually applied.

Materials and methods

Three forest estates where chestnut coppices are prevailing were considered: the municipal property of Soriano nel Cimino along the slopes of Mount Cimino; the regional property near the village of San Martino al Cimino; the Mount Palanzana, where many small privately-owned stands are located. In each forest estate, five thinned stands of various ages (from 14 to 31 years) were selected. The boundaries of the selected stands were identified on colour ADS40 2008 aerial orthophotos (nominal geometric resolution: 1 m).

Three circular sample plots with 10-m radius were established in each stand, for a total of 45 plots. The location of plot center was randomly selected and reached in the field by GPS with sub-metric accuracy. In each sample plot the following attributes were measured: diameter at breast height (dbh) of live and dead shoots and standards, height of a sample of 15 shoots and the age of shoots, assessed by a tree corer on the stems of average dbh.

The following stand parameters were calculated: number of shoots (live and dead) per hectare, number of standards per hectare, mean and dominant dbh of shoot and standard layer, mean and top height of shoots, wood volume of shoots and of standards. Top height was calculated as the regression height of the shoots with quadratic mean diameter of the 100 thickest shoots per hectare (Van Laar and Akca 2008). The wood volume was calculated through the volume tables by Castellani et al. (1984), the same used by Lamani (1993).

The collected data were used to establish a model predicting the top height of shoots (TH, in meters) as a function of stand age (A, in years). The anamorphic model proposed by Schumacher (1939) was adopted, as suggested by von Gadow and Hui (1999):

$$TH = b_0 \cdot \exp(-b_1 \cdot \frac{1}{A}) \qquad [1]$$

From this relationship, the site-index curve was derived (Sharma et al. 2002, Skovsgaard and Vanclay 2008), that is the predictor of site index (SI) from TH measured at a given age. SI is a standardized indicator of stand productivity, i.e. the stand top height at a selected index age. In this case, the age of 20 was chosen as index, since this is the average age of the sampled stands:

$$SI = TH * (\exp(9.777/A)/1.63044) \qquad [2]$$

Then, regressions were established to model the stand growing stock (V, in m^3 per hectare) and the number of shoots per hectare (N) as a function of A and SI under a bio-mathematically sound perspective (Corona 1995):

$$\hat{V} = SI^{c_1} * \exp(-\frac{c_2}{SI * A^2}) \qquad [3]$$

$$\hat{N} = m_0 + m_1 / \sqrt{A} + m_2 * SI \qquad [4]$$

where c_1, c_2, m_0, m_1 and m_2 are the model coefficients to be estimated.

From V and N the mean volume of a single shoot ($\hat{v}$, in m^3) can be calculated:

$$\hat{v} = \hat{V}/\hat{N} \qquad [5]$$

Since number of standards proved to be no-correlated with A (r = -0.08) and with SI (r = -0.1), it was deemed suitable to keep constant this stand parameter, i.e. equal to the average number of standards found in sample plots.

The total volume of standards is equal to their number times the mean volume of a single standard ($\hat{v}_{st}$, in m^3), which, in turn, was predicted as a function of SI and A under a bio-mathematically sound perspective:

$$\hat{v}_{st} = SI^{f_1} * \exp(-\frac{f_2}{SI * \sqrt{A}}) \qquad [6]$$

where f_1 and f_2 are the model coefficients to be estimated.

Results

Tab. 1 shows the statistical parameters of [1]-[3]-[4] and [6] models; all the model coefficients are characterized by $p<0.01$. Tab. 2 reports the resulting yield for chestnut coppices of the Cimini and Vicani mountains according to SI values equal to 14 m, 17 m and 20 m, corresponding to the site index range in the studied area (Fig. 1).

Site-index stresses the positive effect of thinning on stand volume and, especially, on mean volume of a single shoot, which doubles at age of 30 years moving from a site class to the upper one (Fig. 2). Mean increment culminates between 18 (SI=20) and 22 (SI=14) years, ranging from 7.2 to 13 m^3 per hectare per year. In the yield table of Lamani (1993) mean increment culminates at the age of 21 with 13.8 m^3 per hectare per year and the curve of top height as a function of age overlaps quite well the same relationship in our new yield model with SI=17.

The comparison with the yield table of Cantiani (1965) is difficult because height values are lacking here; then, the Eichhorn's rule (Eichhorn 1902, in Skovsgaard and Vanclay 2008) was applied. According to this rule, total production of wood volume at a given stand height is independent of age and site for a given site and species. It was used to attribute a SI value: in the Cantiani yield table the total volume at the age of 18 is 367 m^3 per hectare; in the yield table of Lamani this volume corresponds to an age of 21-22 and to a top height of about 17 m. In our new model top height of 17 m and age of 18 are equivalent to a SI between 17 and 20 m. This result is in agreement with data sampling in the most productive chestnut forests only, as for the yield table by Cantiani (1965).

Table 1 - Statistical parameters of yield models established for chestnut coppices of the Cimini and Vicani mountains.

Model	Coefficients	Value	Stand. Err.	R^2
[1]	b_0	27.333	2.280	0.458
	b_1	-9.777	1.589	
[3]	c_1	2.103	0.021	0.743
	c_2	3269.445	388.500	
[4]	m_0	2564.157	978.050	0.412
	m_1	11599.748	3277.014	
	m_2	-197.046	41.359	
[6]	f_1	0.663	0.169	0.375
	f_2	186.192	40.640	

What most distinguishes the three yield models is the curve describing the development of shoot number as a function of age, which highlights the difference in the rotation length and thinning occurrence (Fig. 3). The yield table by Cantiani stipulates

Table 2 - Yield predictions for chestnut coppices of the Cimini and Vicani mountains with reference to site-indexes of 14, 17 and 20 m (TH = top height; *V* = standing volume; N = number of shoots; v = mean volume; MAI = mean annual increment of standing volume).

Site Index = 14							
SHOOTS						STANDARDS	
age (years)	TH (m)	V (m^3ha^{-1})	N (nha^{-1})	*v* (m^3)	MAI ($m^3ha^{-1}year^{-1}$)	*V* (m^3ha^{-1})	MAI ($m^3ha^{-1}year^{-1}$)
15	11.9	91	2801	0.033	6.1	6.3	0.4
16	12.4	103	2705	0.038	6.5	7.0	0.4
17	12.8	115	2619	0.044	6.7	7.8	0.5
18	13.3	125	2540	0.050	7.0	8.5	0.5
19	13.6	135	2467	0.055	7.1	9.3	0.5
20	14.0	143	2399	0.060	7.2	10.0	0.5
21	14.3	151	2337	0.065	7.2	10.7	0.5
22	14.6	159	2279	0.070	7.2	11.5	0.5
23	14.9	165	2224	0.074	7.2	12.2	0.5
24	15.2	171	2173	0.079	7.2	13.0	0.5
25	15.4	177	2125	0.083	7.1	13.7	0.6
26	15.7	182	2080	0.088	7.0	14.4	0.6
27	15.9	187	2038	0.092	6.9	15.1	0.6
28	16.1	191	1998	0.096	6.8	15.8	0.6
29	16.3	195	1960	0.100	6.7	16.6	0.6
30	16.5	198	1923	0.103	6.6	17.3	0.6

Site Index = 17							
SHOOTS						STANDARDS	
age (years)	TH (m)	V (m^3ha^{-1})	N (nha^{-1})	*v* (m^3)	MAI ($m^3ha^{-1}year^{-1}$)	*V* (m^3ha^{-1})	MAI ($m^3ha^{-1}year^{-1}$)
15	14.4	165	2209	0.075	11.0	13.2	0.9
16	15.0	183	2114	0.087	11.4	14.4	0.9
17	15.6	199	2028	0.098	11.7	15.6	0.9
18	16.1	214	1948	0.110	11.9	16.8	0.9
19	16.6	227	1876	0.121	12.0	18.0	1.0
20	17.0	239	1808	0.132	12.0	19.2	1.0
21	17.4	250	1746	0.143	11.9	20.4	1.0
22	17.8	260	1687	0.154	11.8	21.5	1.0
23	18.1	269	1633	0.165	11.7	22.7	1.0
24	18.4	277	1582	0.175	11.6	23.8	1.0
25	18.7	284	1534	0.185	11.4	24.9	1.0
26	19.0	291	1489	0.196	11.2	25.9	1.0
27	19.3	297	1447	0.205	11.0	27.0	1.0
28	19.5	303	1407	0.215	10.8	28.1	1.0
29	19.8	308	1368	0.225	10.6	29.1	1.0
30	20.0	312	1332	0.234	10.4	30.1	1.0

Site Index = 20							
SHOOTS						STANDARDS	
age (years)	TH (m)	V (m^3ha^{-1})	N (nha^{-1})	*v* (m^3)	MAI ($m^3ha^{-1}year^{-1}$)	*V* (m^3ha^{-1})	MAI ($m^3ha^{-1}year^{-1}$)
15	17.0	187	1618	0.116	12.5	22.4	1.5
16	17.7	204	1523	0.134	12.8	24.2	1.5
17	18.3	220	1437	0.153	12.9	25.9	1.5
18	18.9	234	1357	0.172	13.0	27.6	1.5
19	19.5	246	1284	0.192	13.0	29.3	1.5
20	20.0	257	1217	0.211	12.9	30.9	1.6
21	20.5	267	1155	0.231	12.7	32.5	1.6
22	20.9	276	1096	0.252	12.6	34.0	1.6
23	21.3	284	1042	0.273	12.4	35.6	1.6
24	21.7	291	991	0.293	12.1	37.0	1.5
25	22.1	298	943	0.316	12.0	38.5	1.5
26	22.4	304	898	0.339	11.7	39.9	1.5
27	22.7	309	856	0.361	11.5	41.3	1.5
28	23.0	314	815	0.386	11.2	42.7	1.5
29	23.3	319	777	0.411	11.0	44.0	1.5
30	23.5	323	741	0.436	10.8	45.3	1.5

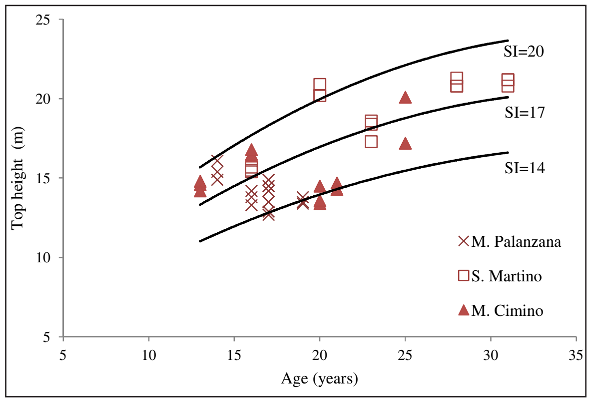

Figure 1 - Top height as a function of age and site-index in chestnut coppices of the Cimini and Vicani mountains. Values measured in the sample plots are also showed.

two thinnings: at 6 years 25% of shoots is harvested, whereas a second thinning at the age of 12 years reduces further stem number of 30%. The model by Lamani stipulates only one thinning at 13 years, with a removal of 37%. In the management practice of the last period, the intensity of the only thinning at the age of 13-14 years has further increased to get a higher stumpage value, and this condition is present in the new model here established. It is noteworthy that, even following the heavy thinning currently applied, tree mortality in coppice stands remains high: from 31% (SI=14) to 51% (SI=20) of the shoots become suppressed from the age of 15 years to the age of 30 years.

The number of standards is relatively low and it does not significantly affect stand volume: forest owners attribute to such trees, grown relatively isolated, a low economic value because of the epicormic branches and of the high probability of ring shake occurrence.

Discussion and conclusions

The interest of the new yield model presented here for chestnut coppices of the Cimini and Vicani mountains relies upon the high potential productivity of these stands in terms of woody mass and average size of the shoots at the end of rotation, as well.

Stand growth is largely influenced by site-class. The top height-age curves corresponding to SI=14, SI=17 and SI=20 overlap the first three site-classes of chestnut yield tables established by Lemaire (2009b) in France characterizing stands managed to produce high value timber assortments. This is an interesting evidence since many small woodworking companies located in the nearby of the Cimini and Vicani mountains import a lot of chestnut timber from France, neglecting local production because of an alleged low quality.

The economic value of chestnut stands does not only depend on wood productivity. The technologi-

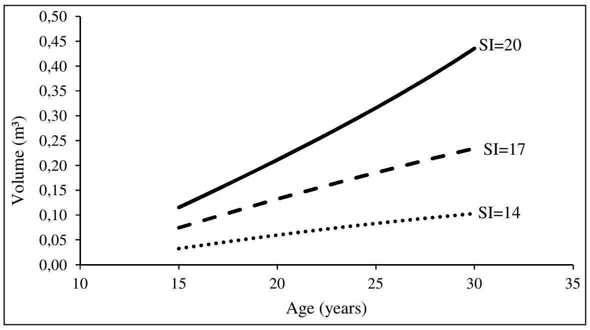

Figure 2 - Mean wood volume of shoots as a function of stand age and site index in chestnut coppices of the Cimini and Vicani mountains.

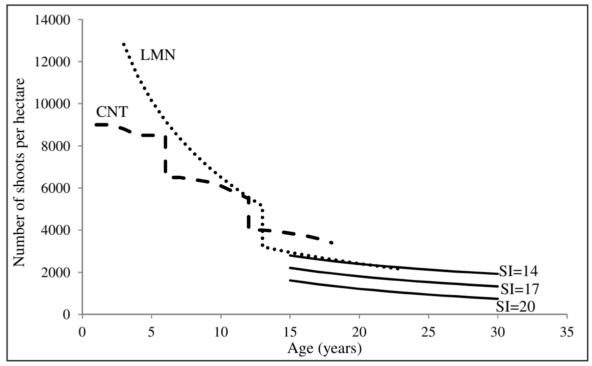

Figure 3 - Chestnut coppices of the Cimini and Vicani mountains: number of shoots per hectare as a function of stand age and site-index predicted by the new yield model (solid line) compared with the yield tables by Cantiani (CNT; dashed line; two thinnings) and by Lamani (LMN; dotted line; one thinning).

cal quality of timber influence greatly the income of forest owner, as well. Spina and Romagnoli (2010) observed that chestnut wood from the coppices of the Cimini and Vicani mountains is more affected by ring shake than wood coming from other chestnut coppice areas in Italy. This defect limits the use of chestnut wood for the most valuable assortments, especially those used as structural elements of buildings and furniture. Several interacting factors affect the phenomenon of ring shake under a single basic principle: an imbalance between the tensions being activated in the wood and the opposing cohesion forces (Fonti et al. 2002). Silvicultural practices can be very effective in preventing the defect or in reducing its incidence. Various studies conducted in different countries showed that abrupt changes in radial growth favour the ring shake occurrence (Cousseau and Lemaire 2009). Thus, it is essential to keep the diameter annual increment sustained and regular, e.g. to apply thinning before the growth rate declines because of competition (Cousseau and Lemaire 2009). For shoots growing in unthinned chestnut coppice stands in Central Italy, a critical age for ring shake establishment proves generally to be between the age of 12 and 14 years (Spina and Romagnoli 2010). Becagli et al. (2006) highlight the importance of anticipating the age of thinning to counteract ring shake occurrence. On the other hand, too intense thinnings may affect negatively chestnut wood quality: if ring width exceeds 6 mm, wood density and its own properties, tend to decrease (Fioravanti 1999).

The new yield model presented here points out that a unique intense thinning allows to get on average large-sized stems, but this might result in a lower quality of the final product. The intense resprouting after clearcutting, the soil fertility that speeds up self-thinning process and the incidence of diseases emphasize an early shoots' mortality. Thus, the regular reduction of interindividual competition would allow both the increase of stem quality and the decrease of deadwood accumulation and fire risk (Agee and Skinner 2005).

The new yield model integrates well the previous models developed by Cantiani (1965) and by Lamani (1993), while taking into account site-index. It improves the knowledge on chestnut coppices and provides to the forest owners of the Cimini and Vicani mountains an useful tool for making decisions about optimal rotation. It may be helpful in introducing innovation in chestnut coppice silviculture and supporting the enhancement of timber supply to gain more attention even from the most demanding woodworking companies.

Acknowledgements

Thanks are due to the anonymous reviewers for their constructive criticisms.

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