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Research paper

Cultivation techniques in a 34 years old farming oak (*Quercus robur* L.) plantation in the Arno valley (Tuscany)

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Abstract - This report aims to provide a description of the cultivation techniques adopted at the oldest oak pure plantation (age 34) established within the environmental restoration plan of soil dumps at the Santa Barbara ENEL Company opencast mine in Cavriglia (AR). The goals of the initial plan, following which the plantation was carried out, were to (i) verify the possibility of restoring the soil dump by using tree farming plantations and produce a range of valuable timber assortments; (ii) test the growth potential of the oak species in a pure plantation. The plantation, carried out with a stem density of 1,111 trees per hectare, was managed by targeted practices (pruning up to the stem height of 4-5 m and then undertaking four thinnings). A geometric-selective thinning was applied first and, later, periodical thinning from above was implemented, releasing, as a result, about 70 crop trees per hectare. In the meanwhile, it was possible to monitor the growth parameters concerning dbh, tree height and crown diameter. The stem quality and the presence of epicormic branches were evaluated in 2013 and the relationship between the presence of epicormic branches and tree characteristics were also analyzed. The wood production was compared with other European plantations, especially from France. Today, 34 years after the plantation got started, the site is an interesting case-study of tree farming as it plays a consistent role within the environmental restoration of the area. The applied management system allowed to reach a noticeable wood production level and also valuable timber assortments for industrial use. Crop trees (70 per hectare) reached a mean dbh of 38.1 cm, the height of 22.3 m at the age of 34.

Keywords - English oak, thinning, valuable timber, tree farming, plantation.

Introduction

English oak (*Quercus robur* L.) is a quite widespread species in Europe, with geographical distribution from the Atlantic coast of France and northern Portugal up to the Urals and the Caucasus, and from Britain and southern Scandinavia up to northern Greece, the Italian peninsula and the Pyrenees. In Italy, it is present in almost all the regions, especially in the North and mainly in the plains. English oak needs a constant and continuous level of water availability in the soil, proving to be susceptible to drought. In dry years, in fact, the more sized trees, may easily show typical phenomena of desiccation, in the upper canopy.

English oak prefers soils with shallow and stable groundwater, tolerating periodic flooding of the root system up to 2-3 months. Such behavior is made easier by the rather shallow roots, this allowing bearing the lack of oxygen in the soil, but making them less suited to preventing drought occurrence. The species is therefore naturally located at the base of slopes and at valley bottoms (Frattegiani 1996, Lemaire 2010, Mori et al. 2007, Sevrin 1997).

English oak is a very light-demanding species and it can be considered a pioneer tree, because of its ability to colonize open spaces and abandoned fields. Being so light-demanding, it requires a dynamic silvicultural approach with frequent thinnings, ensuring an adequate crown development and a regular diameter growth, in order to get the best growth performance (Lemaire 2010).

In Europe, English oak is cultivated for valuable timber production. At this purpose, many experimental trials have been set up to define suited management criteria and get valuable timber production in a shorter time-span than according to customary management system (Nebout 2006). All these trials are characterized by an initial phase (qualifying period) where the tree stand is maintained at high stem density to favor the natural pruning. This phase is necessary to get straight stems without branches. The best crop trees are then selected and frequent thinnings from above are carried out all around them

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(thinning phase) to get the free growth of crown and, at the same time, maintain the diameter growth of selected trees high and costant.

Experiences about this issue can be found in Britain since the 1950s with dense oak plantations aged 20 (Jobling and Pearce 1977, Kerr 1996). At the moment, similar management criteria are being applied in Central Europe (Lemaire 2010, Perin and Claessens 2009, Nebout 2006) and we also have, in Italy, a few cases aimed at getting valuable, large-sized stems in a shorter time, as compared with traditional management (Corazzesi et al. 2010).

Furthermore, while in central and northern Europe we have a good general ecological, genetic, eco-physiological, technological, silvicultural and operational knowledge concerning valuable oaks, in the Mediterranean area this background is limited and, moreover, the biological response of these oak species is not well-known. In spite of this, the residual oak stands in southern Europe are extremely important as a relict source of genetic variability (Aa.Vv. 1999, Ducci 2007).

In Italy, English oak is particularly widespread in the lowlands and also in the alluvial plain of the Arno valley. Its presence has been greatly reduced since Middle Ages, following the diffusion of human settlements and the population increase, which was due to the progressive deforestation in favor of the agricultural practice. In addition, the widespread coppicing system did not support the species because of its lower sprouting ability compared with the other tree species associated in mixed forests.

Since the 1950s, the progressive re-diffusion of secondary forests, due to the abandonment of agriculture and pasture activity in the mountains and hilly marginal areas, has been noticeable, whilst more recently a growing attention towards the protection of lowland forests and the establishment of new forests has been developed. Since the 1980s, new plantations have been carried out in the Po valley (Pividori et al. 2015) under the financial support of both Regional governments and the European Union (set-aside, EEC Regulation 2080/92 and Rural Development Plans).

The widespread cultivation of English oak is linked to its timber value, workability and aesthetical features. Moreover, since a few decades, the market of valuable broadleaved trees acknowledges increasing prices to high quality trunks for veneers and furniture. In this latter case the market requires straight and healthy, cylindrical trunks, free of knots, with a larger than 50 cm diameter and a regular growth course, i.e. the awaited goals to be pursued when cultivating valuable tree species.

Since the late 1970s, in the Valdarno Aretino, over 240 hectares of plantations for timber production were carried out in a close cooperation between the Forestry Research Institute (now CREA-SEL) and ENEL Co., according to the Plan of environmental restoration of the wide landfill mining, stocking the thermal power station of Santa Barbara (AR).

English oak was the most used tree species in these reforestation activity. The reasons for this are twofold: on the one hand, English oak was chosen because of its own feature of pioneer species suited to the barren soil of the mining area, on the other hand, to test the opportunity to use the species, poorly known in Italy, in tree farming plantation for valuable timber production (Buresti 1984).

The plantation here analyzed and others carried out in the Santa Barbara district, resulted to be an important training for the experimental activity in tree farming. The significance of this site lies, therefore, in testing new pruning techniques and different thinning trials in addition to verifying the oak potential in the concerned area. The outputs of this experience were later applied at other Italian sites. Given the lack of specific models and information about planting and management for similar growth environments, the applied criteria described in this paper should be considered and evaluated as a fully experimental trial. This paper does not intend therefore to propose a model, but to report methods and results achieved so far.

The early goals may be summarized as follows: (i) restoration of an environment heavily modified, ensuring, first of all, the ground cover and then the recovery of biological activity in the soil, which was greatly reduced, if not absent, at the time of planting; (ii) checking the cultivation of English oak at this site and defining management techniques suited to produce valuable timber in a life-span of 40-50 years with the traits required by industrial processing.

Materials and methods

Study site

The area is characterized by an average annual rainfall of 927 mm and an average temperature of 13° C, with a dry period in July. The soil, at the time of planting, had very special characteristics, resulting from the accumulation of inert layers; soil texture was silty-clay, with a sub-acid pH and a balanced amount of the main nutrients (N, P, K), but also with a reduced presence of calcium (Buresti 1984).

Plantation design

The pure plantation was established in November 1979 in an area of 2,700 m^2, according to a square design with a spacing of 3 m and with a density of 1,111 trees per hectare. 1 year old oak seedlings were used, choosing a provenance which was close

to the site (the forest of Renacci). Extensive deep ploughing and hoeing all around the seedlings were implemented for two years after planting, to reduce weeds and shrubs competition. Pruning was carried out up to the height of 5-6 meters over the following years. Annual dbh inventory was carried out since 2000. Total height, tree crown insertion and dbh of dominant trees were periodically measured.

Thinning

The plantation underwent four thinning operations. The first thinning was carried out at the age of 13 (winter 1992) according to a mixed geometric-selective design. Tree crowns began to touch one another and it was necessary to intervene to prevent the occurrence of competition for light, which would negatively affect their diametrical growth.

Given the young age of the plantation and its still evident homogeneity, a geometric thinning was applied with rare exceptions. 50% of the trees were felled, following alternate diagonal rows; the selective criterion was applied only in few cases to preserve good-shaped trees (Buresti et al. 1993).

A second thinning was performed in 1996 with a selective criterion, still removing about the 50% of the trees. At this time, the worst and less vital phenotypes were felled, and also a relatively even distribution of the trees on the ground was maintained. Four years after the first thinning, tree crowns were already in contact but no significant reductions in diametrical growth were recorded. The surveys

View of the plot at the age of 24 years following the third thinning.

showed the progress of individual differentiation regarding tree vitality and stem shape and this is the reason why a selective design was applied for the second thinning (Buresti et al. 2000).

Following the French and Belgian experiences (Sevrin 1997, Baar at al. 2005, Baar 2010, De Potter et al. 2012), the third thinning did not concern the whole plantation, but a few crop trees: 70 superior phenotypes per hectare were chosen and a thinning from above was performed around them.

According to Lemaire (2010), a regular and sustained diametric growth of the crop trees is provided by wide and well-lighted crowns, with green branches for at least half of total stem height.

Three main criteria were followed for selecting the crop trees:

View of the plot at the age of 34 years following the fourth thinning.

Final crop tree. Age 34 years.

1. Average distance between the trees of about 12 meters;
2. Preference for the most vital and dominant trees;
3. Preference for the trees with the following stem qualities: straightness, knots absence, lack of injuries or pathogens.

Following the selection of crop trees, further thinnings were carried out in 2003 and in 2013, surrounding competitors were progressively felled to increase the space available for the crown development. About 40% of the trees were removed in 2003, and about 33% in 2013.

At each thinning operation, the stem volume of the felled trees was measured analyzing the stem sections, up to the top diameter of 5 cm, in order to build up a local volume function of the English oak plantations in the Arno valley (Marchi et al., forthcoming).

Epicormic branches

One year after the last thinning, a survey of the epicormic branches distribution was conducted to record their presence, their age and distribution along the stems. The data were analyzed according to the Pearson's χ^2 test. The aim of the analysis was to identify the possible relationship between the presence of epicormic branches, the tree position within the plantation (edge tree, inner tree) and the Dch/H (crown diameter to total tree height ratio).

Results and discussion

Mensurational parameters

The analysis of dbh and the total tree height datasets was focused on the crop trees, i.e. on trees concerned since the third thinning. Fig. 1 and 2 show the regular and sustained increase both of dbh and tree height, their values being on average 38.1 cm and 22.3 m, respectively, at the age of 34.

The analysis of the dbh current level (c.a.i.) of the crop trees (Fig. 3) highlights its decrease since 2001 (age 22), which was triggered because of the starting competition for the light. To avoid this effect and the loss of crown reaction, a further thinning was recommended. The thinning, carried out in 2003, at the age of 24, had beneficial effects, i.e. it gave rise to the positive trees reaction to the major light availability and we had the recovery of c.a.i. to value higher than 1 cm.

Dbh c.a.i. kept rather stable and sustained up to 2010, with a heavy reduction in the very dry year 2007 (age 28). Since 2010, the reduction of dbh c.a.i. would have required a timely thinning, which was carried out only in 2013, when a collapse of average dbh c.a.i. up to 0.5 cm yr^{1} took place.

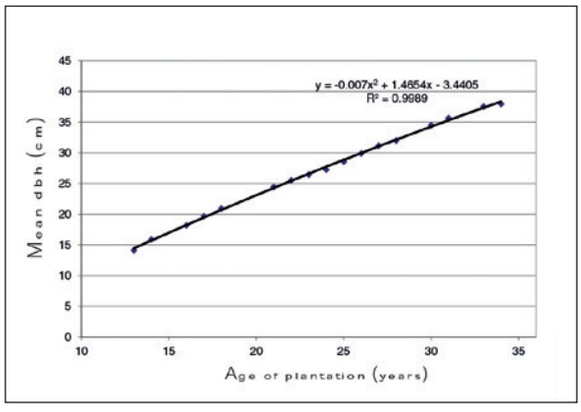

Figure 1 - Crop trees: trend of mean dbh.

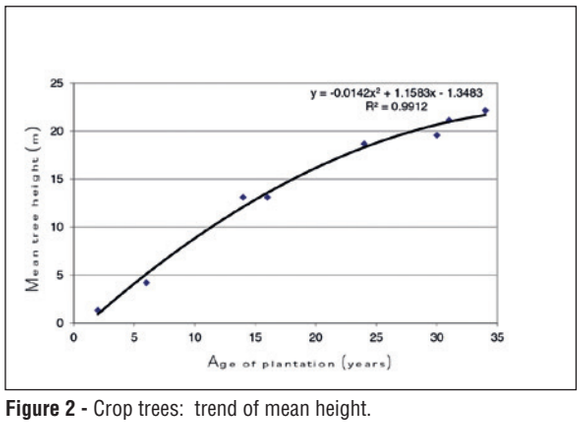

Figure 2 - Crop trees: trend of mean height.

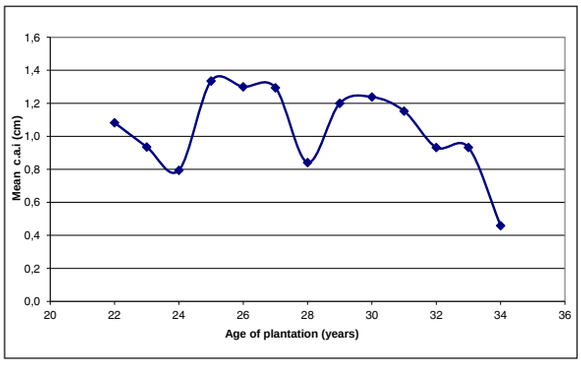

Figure 3 - Crop trees: dbh c.a.i. trend.

Figure 4 - Crop trees: crown diameter trend.

If we take into account the pattern of crop trees' crown diameter increase (Fig. 4), there is evidence of the regular growth, without any remarkable change over time.

In a few European papers some mensurational parameters related to common oak stands (in free-

Table 1- Variation of mensurational parameters with plantation age.

Year	plant. age	n. trees (n ha^{-1})	mean dbh (cm)	tree height (m)	tree volume (m^3 ha^{-1})	removal (m^3 ha^{-1})	canopy cover (%)
1993 pre-thin.	14	1,111	12.5	11.0	73.06		/
1993 post-thin.	14	588	14.2	10.9	40.17	32.89	/
1996 pre-thin.	18	588	17.2	12.4	84.63		/
1996 post-thin.	18	281	20.0	/	43.74	40.89	63%
2003 pre-thin.	24	277	25.6	17.8	113.88		79%
2003 post-thin.	24	164	27.9	/	73.90	39.98	57.6%
2013 pre-thin.	34	157	36.9	22.2	146.04		84.7%
2013 post-thin.	34	105	37.7	22.3	101.82	44.22	72.5%

growing and unthinned) are being compared. These parameters are defined as "shape parameters" and provide an indication of English oak growth pattern (Lemaire 2010, Perin et al. 2009, Jobling et al. 1977).

A synthetic competition index, applied to determine the competition level as a function of the crown width, is given by crown diameter to total height ratio (Dch/H). The right balance is achieved with values varying between 50% and 60%.

At the Santa Barbara plantation, Dch/H values between 40% and 60% were measured, i.e. very close to the optimal readings highlighted by the French trials. Even the index height of crown insertion to total height ratio (Hi/H) provides optimal figures, lower than 40% and typical of trees with deep crowns.

Accounting for stem volume felled at the different thinning times reported in Tab. 1 and Fig. 5, its value was fairly constant at each intervention, with a total removal of 158 m^3 per hectare. Total mass reaches 260 m^3 ha^{-1}.

Epicormic branches

Data analysis say that, at the present time, the 33% of trees do not host any sort of epicormic branches. The 57% of the stem sprouts are one year old and produced after the last thinning (2013). The 53% of one year sprouts were present on two trees. These are not located at the plantation edge and do not show a low Dch/H relationship. In the case, the genetic component is probably prevailing and plays an basic role in the phenomenon (Servin 1997, Attocchi 2013a). The χ^2 analysis highlighted that trees with Dch/H values lower than 0.5 showed an increased frequency of sprouts. This index is considered reliable to evaluate the tendency to the emission of epicormic branches. Dch/H value in the range 50-60% highlights crowns wide and deep enough to be less prone to new epicormic branches production in English oak (Lemaire 2010).

Pruning, and especially thinning play an important role in the management of oak plantations as a stimulus to the production of new epicormic shoots (Attocchi 2013a). From medium to low tree density plantations, pruning is necessary to get valuable timber productions whilst, in the most dense plantings, natural pruning is usually prevailing and it is integrated only when necessary (Spiecker 1991, Weaver and Spiecker 1993, Attocchi 2013b). The risk of newly-established epicormic shoots may be reduced by early and progressive pruning, carried out only around final crop trees. At each pruning time, the lower branches have to be removed only to get a clean bole free of branches up to 50% of total stem height. At this type of plantation a clean bole of 5-6 m (25-30% of final height) may be considered an awaited goal. Where possible, a basic role is to preserve the dominated layer and favor, in this way, both natural or artificial establishment of an understory (which is characterized by shade-tolerant species, able to reduce the direct enlightenment of the stems). Recently in a few European countries, mixed plantation are being preferred, intercropping oaks or other valuable broadleaved species with nurse trees (alders, hornbeams, limes, etc.) and shrubs like (hazel, elder, etc) (Hochbichler 1993, Buresti et al. 2006).

Stem quality

Following the last thinning, stems of selected trees were individually classified on the basis of the stem quality at the end of the crop cycle (Nosenzo et al. 2008). The 41% of the crop trees had a first stem, 2.5 m long, attributable to Class A, i.e. suitable for the more profitable uses, such as veneer. The 47% had a first stem attributable to Class B, suitable

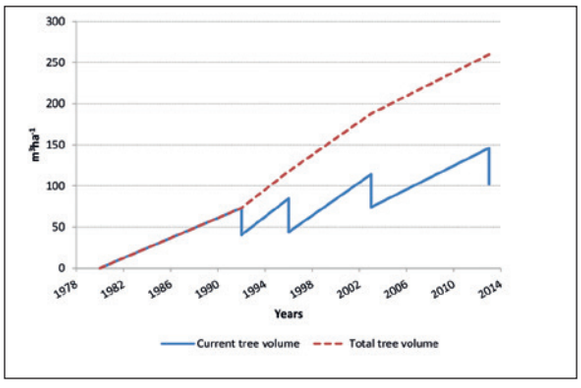

Figure 5 - Current and total tree volume trends.

for fine saw timber, while the 12% had a first part attributable to class C, i.e. to standard saw timber.

Conclusions

The soil condition at the time of plantation was extremely poor: no vegetation cover in any form or organic layer were present. The current well-established tree farming plantation fully satisfies the manifold goals of environmental recovery expected by the owner, ENEL Co., on the landfill grounds, i.e. stabilize the soil; limit the erosive action of running water on bare soil; form again an organic layer; restore the biological growth medium and the landscape. At the time of the implementation, and according to the already achieved experience, the chances of a successful establishment of the plantation were really uncertain, in terms of both tree species choice (design, pure or mixture) and physical environment of introduction.

Under this perspective, the trial may be considered as a fully experimental implementation. 34 years later, not only the goal of mining area restoration, but also the results in terms of trees' growth performance have been reached. The limited practices implemented in the soil after the plantation, confirm the ability of English oak to act as a pioneer species and to colonize difficult and poor soils, provided that a good water availability is being ensured.

Dbh c.a.i. varying from 0.8 to 1.2 cm is a quite good performance both in terms of growth and of growth-steadiness along the full time-span up to 2011. The sharp reduction occurred over the last two years is basically linked to the delay of the fourth thinning operation and to the particularly unfavorable rainfall pattern in 2011 and 2012. At the age of 34, crop trees have achieved an average diameter of 38.1 cm and an average height value of 22.3 m; these performances are fully comparable with those of the French forests - first site-class (Lemaire 2010). The total wood production at the site is about 260 m^3ha^{-1}, where the standing volume is about two-thirds of the intermediate yield at the age of 34. This ratio being an own attribute of this type of tree farming.

Due attention has to be paid over the cultivation-span to crowns cover fulfilment, given their prolonged compression causes the death of long-shaded lower branches, the consequence being the loss of trees' ability to react further to thinning occurrence and the reduction in diameter growth.

The rule to keep deep enough crowns in the plantation management has to be underlined, as well as to get and maintain Dch/H values above or close to 0.50. This rule has probably also limited the sprouting of epicormic branches along the stem which often occurs as a result of delayed thinning, producing a reduction of wood quality.

Even if today a few design features of the original plantation could be improved further to current experience, the case-study may be considered a relevant trial for two reasons. The first relates to the potential of English oak which, if properly managed, can ensure interesting results in terms of wood production on relatively short rotations. The second highlights the importance, for the plantation design, of giving each crop tree a suitable space for crown development (Buresti et al. 2006, Buresti Lattes and Mori 2009, Buresti Lattes and Mori 2012). It is fundamental to increase this individual available space over time, as a function of the progressive expansion of the crowns. This is, actually, the only way to ensure the active photosynthetic area, capable of maintaining constant and high radial stem increment.

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