



# Black Truffles and Oak Trees in France and in Europe

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## ABSTRACT

The black truffle *Tuber melanosporum* Vittad. is a xerophilous mycorrhizal fungus, suited to limestone soil. Since its common host tree is the oak, one often speaks of “truffle-oak cultivation” to produce truffles. Two species are well-known as very favorable for truffle cultivation: *Quercus pubescens* Willd. and *Q. ilex* L. Other species are used for truffle production with variable interest according to the region. In Southwest France, where *Q. pubescens* and *Q. ilex* are appreciated by truffle growers, the appearance of a fungal disease on the former has promoted its replacement with *Q. cerris* L. In the Southeast, *Q. robur* L., (the selection distributed as ‘Michelin’), is planted as well as *Q. pubescens* and *Q. ilex*. In Catalonia, *Q. coccifera* L. and *Q. suber* L. are mycorrhized and cultivated for truffle production. In the other regions of Spain, *Q. faginea* Lam. is commonly used with *Q. pubescens* and *Q. ilex* while in Italy, *Q. petraea* (Matt.) Liebl. can be added to this list. Other oak species are sometimes planted with more or less success.

**Keywords:** *Tuber melanosporum* Vittad., truffle cultivation, mycorrhizal fungus

## Truffle oaks and truffles

Truffle oaks and truffles share a long history in southern France. We use the term “truffle oak” to describe a mycorrhizal symbiosis between trees and fungi that has developed either naturally or following human intervention.

One species of truffle that has acquired a reputation beyond France, a country known for its culinary traditions, is the black truffle *Tuber melanosporum* Vittad., also known as the Périgord truffle or *mélano*. The main areas where these truffles are harvested in France are in the Southwest: Lot, Dordogne, Aveyron, Tarn, Tarn et Garonne, and Corrèze, and parts of the Southeast: Drôme, Vaucluse, Var, Alpes de Haute-Provence, Gard, Hérault. Production has also developed in other regions, like the Languedoc-Roussillon, Poitou-Charentes, and Loire, which sometimes suffer drawbacks due to the climate. Black truffles (and other species) are also naturally present in Italy and Spain. Some other countries have also started growing truffles (New Zealand, Australia, Chile, Argentina, and the United States).

In France, the main botanical species of truffles harvested amongst the score that grow naturally are:

Périgord black truffle (*T. melanosporum* Vittad.); white summer truffle (*T. aestivum* Vittad.); Burgundy truffle (*T. uncinatum* Chatin) – this species is increasingly considered by the scientific community to be an ecotype of *T. aestivum*; winter or “musky” truffle (*T. brumale* Vittad.); Bagnoli truffle (*T. mesentericum* Vittad.); “dog-nose” or red truffle (*T. rufum* Pico); “hollow” truffle (*T. excavatum* Vittad.); white truffle (*T. maculatum* Vittad.) – found in Provence (Riousset et al., 2001; 2012).

Oaks are the quintessential host trees for the mycorrhizal association (a symbiotic association beneficial to both organisms) necessary for truffle production. The fungus absorbs minerals from the soil (particularly phosphorus and mineral nitrogen), thanks to its greater capacity to extract water and minerals than those of root hairs, and passes on these benefits to its host tree. The tree photosynthesizes, producing carbohydrates that provide nourishment for the fungus in its vegetative form (mycorrhizae, mycelium, and stromata), as well as for its fruiting body (ascocarp), according to recent research during the SYSTRUF program (a 4-year French research program on truffles). Thanks to this relationship, mycorrhizae develop on the tree roots and this triggers their fruiting mechanism that, in turn, results in the truffle harvest.

In their natural environment, truffle oaks can be identified by the presence of a vegetation-free area around or near their trunks, known as a “scorched” zone. Several hypotheses have been put forward to explain this “scorched” effect: the herbicidal action of the mycelium (production of phytotoxic substances), its monopolization of water resources in the soil, or a parasitic action of the mycelium on the plant’s root tissues. These three factors are probably at work within the scorched zone.

The two oak species preferred by French truffle growers are downy (*Q. pubescens* Willd.) and holm oak (*Q. ilex* L.). In addition to these two species, Austrian oak (*Q. cerris* L.), the *Q. robur* L. selection ‘Michelin’, kermes oak (*Q. coccifera* L.), and cork oak (*Q. suber* L.) are all worthy of mention. Portuguese oak (*Q. faginea* Lam.) is also used for truffle growing in Spain and sessile oak (*Q. petraea* (Matt.) Liebl.) in Italy. In China, *T. indicum* is harvested under *Q. incana* Roxb. (synonym of *Q. leucotrichophora* A. Camus) (Riousset et al., 2001; 2012).

The above-mentioned oaks (plus other trees) are “truffle trees” because they are



1/ *Quercus pubescens* and the “scorched zone” that indicates the presence of truffles.

ectomycorrhizal, i.e., they can be infected by fungi and produce ectomycorrhiza, in which (unlike endomycorrhiza) the mycelial threads (hyphae) do not penetrate inside the root tissue cells. In the case of ectomycorrhiza, the truffle hyphae and the root cortical cells form a Hartig net.

### ***Truffle and truffle-oak ecology***

Black truffles, *T. melanosporum*, are found in environmental conditions suited to their xero-thermo-calcicole ecological requirements. In fact, a good truffle-producing environment – and one enjoyed by oaks – is defined by several specific environmental features including soil type and climate.

Truffle-producing soils are limestone or calcareous, usually with a water pH between 7.8 and 8.3. They are well-aerated and well-drained, and have good biological activity. Truffle-producing soils are present in many parts of France, on limestone formations from various epochs, which determine some of their characteristics. Among these formations, secondary limestone is particularly significant, especially from the Jurassic and Cretaceous periods. Excellent truffle soils are also found on Tertiary formations (Oligocene, Eocene) and Quaternary alluvial deposits. These limestones contain variable amounts of calcium carbonate, the critical chemical compound in the carbonate content of truffle-producing soils. The hardest rocks (lithographic) have a calcium carbonate content above 90%, whereas calcareous sandstone has a high silica content and generally under 10% calcium carbonate.

The climate for *T. melanosporum* truffles is subMediterranean to Mediterranean with oceanic, montane, or even continental influences. The two key limiting factors are prolonged summer droughts and excessive winter cold, which freezes the truffles in the soil. Truffles grow on sites with good sun exposure. The traditional truffle-producing



2/ A *Quercus robur* truffle plantation in the foreground, and a *Q. ilex* truffle plantation, in the background (Drôme).

regions of Southwest (Lot, Dordogne, Tarn, Tarn-et-Garonne, etc.) and Southeast France (Vaucluse, Drome, Var, Alpes de Haute-Provence, Gard, etc.) have favorable climates for truffles. In Europe, black *T. melanosporum* truffles are produced between the 40<sup>th</sup> and 47<sup>th</sup> parallels. Latitude 40°N corresponds to the truffle fields in the Teruel area in southern Spain and those in the Loire Valley are around 47°N. Truffles may also be produced further north, in Burgundy, for example. There is a natural truffle field in the Verdun area (48°N) highly reputed for its black truffles. But northern producers are penalized in years when a cold snap freezes the truffles in the ground, while slightly warmer temperatures further south may save the harvest.

The climate required by truffles may be summarized in the following 4 points:

- relatively damp and warm in spring, with no late frosts, to promote the growth of mycelium and the fruiting of the truffles (starting in late spring);
- hot summers with thunderstorms, to bring the rain needed for the truffles to develop;
- no early frosts that destroy the truffles and no excessive rainfall in the autumn (as was the case in October/November 2012, particularly in the Périgord that had 300 mm of rain in some areas like in Sainte-Foy-de-Longas);
- winters with no hard frosts that freeze the ground solid for several days, as this is likely to destroy the truffles (five morning frosts with temperatures around -10 °C will freeze the truffles) and moderate rainfall to ensure that the truffles are harvested in good soil conditions.

### ***Natural truffle fields and truffle fields planted around oak trees***

*T. melanosporum* is considered to have the same organoleptic qualities, whether it is

harvested in its natural environment or from a plantation. There are no morphological or qualitative variations and certainly no difference in species between wild and farmed truffles.

### Natural truffle fields

These usually form under moors, scrublands, or turf, around oaks naturally contaminated at random.

### The first truffle-oak plantations

The first attempts at truffle cultivation involved planting truffles like potatoes. One such trial was carried out by Buffon, the famous naturalist, who attempted in vain to plant freshly collected truffles on his estate at Montbard, in Burgundy. In fact, truffle growing started approximately 200 years ago, by sowing acorns. Today, truffles are still cultivated indirectly, using the host tree to obtain the mushrooms.

The invention of truffle growing is attributed to Joseph Talon, a farmer and truffle hunter in Croagnes, a hamlet near Saint-Saturnin-les-Apt, in the Vaucluse. He created the first “artificial” truffle fields in year X of the French Revolution (Olivier et al., 1996; 2002; 2012). Henri Bonnet reports that, when Talon took ownership of a small farm, he purchased a few hectares of land to graze his flocks (Bonnet, 1869). In order to obtain a source of heating wood, he sowed sessile and holm oak acorns on the land. Eight or ten years later, he found superb truffles growing there. He then decided to coppice the trees *en rabassaiéré* (from the word *rabasso*, a common name for truffle in Provence) and the truffle harvest increased from year to year. Others followed his example, particularly another Joseph Talon, his cousin, who was apparently responsible for the “artificial” truffle fields created mainly in the vicinity of Apt, Buoux, and Les Agnès (Vaucluse). The Talon method, which can be summarized as, “If you want to harvest truffles, plant acorns!” was applied systematically by Mr. Rousseau, a truffle dealer in Carpentras, who created 7 hectares/17.29 acres of cultivated truffle fields on his Puits-du-Plan estate in 1847.

Truffle cultivation, based mainly on downy and holm oak trees, was then applied more widely in Provence and Southwest France, as described in detail by many authors, especially: Chatin, 1860; Bosredon, 1887; Ferry de La Bellone, 1888; and Pradel, 1914.

### Growing truffles

The revolutionary marketing in 1974 of seedlings mycorrhized by truffles gave new hope to truffle growers following a huge decline in production after the First World War. Truffle growing consists of planting certified mycorrhized trees, mainly oaks, in limestone soils, in areas with a favorable climate. In France, the mycorrhization of the trees by *T. melanosporum* is certified by INRA (Institut national de la recherche agronomique) for two tree nurseries and by CTIFL (Centre Technique Interprofessionnel des Fruits et Légumes) for all of the others. Some local and regional authorities grant subsidies to truffle growers, on condition that they plant certified mycorrhized trees. Approximately 300,000 certified mycorrhized trees are produced and sold in France every year and two-thirds of them are oak trees. Holm and downy oaks represent 80-90% of the trees planted.

## ***The truffle-bearing characteristics of various oak species***

Downy oak, a typically sub-Mediterranean species, is certainly the tree with the greatest affinity for *T. melanosporum* truffles. This is due to its adaptation to the *causses* (dry limestone plateaus in Southwest France) and the fact that its roots grow at a rate



3/ *Quercus suber* truffle plantation (Pyrénées-Orientales).

compatible with mycorrhiza propagation. Truffle production used to begin when the trees were around 10- to 15-years-old. But today in intensive, irrigated plantations it has been brought forward to the age of 5 to 6. Downy oak is recommended for plantations in both Southwest and Southeast France, but sulphur treatments are required to prevent powdery mildew infection in the spring. The recent appearance of sensitivity to anthracnose among oak trees in the Périgord has led some growers to prefer Austrian oak (*Q. cerris*).

Holm oak is particularly well-suited to the Mediterranean climate and its rocky limestone soils. It is ideal for plantations in Southeast France, both on the Valensoles Plateau and in the Languedoc countryside, as well as in the deeper soils of the Tricastin area. It is increasingly popular among truffle growers in the Southwest. It is low-maintenance (minor pruning) and is recommended for non-irrigable plantations. Its disadvantage is its sensitivity to frost. Young, poorly lignified tissues are destroyed by any sudden drop in temperature below 0 °C/32 °F

The ‘Michelin’ selection of pedunculate oak is appreciated in the Southeast. It will produce truffles at an earlier age than holm oak in the Vaucluse and Drôme areas. Early bud-break makes it vulnerable to late frosts in the Southwest. In countries in the Southern Hemisphere, where truffles have been grown for the past two or three decades (New Zealand and Australia), pedunculate oak, sometimes known as English oak, produces truffles, but requires extensive pruning and trimming. It is also sensitive to early frosts, particularly in Tasmania (Australia).

Kermes oak is an excellent producer in the naturally calcareous environment of the Mediterranean scrublands in the Corbières and Hérault areas but it is relatively little used in truffle cultivation as it gives variable results, especially in Southwest France. Truffle hunters know that their truffle-hunting dogs do not like to get close too these prickly, shrubby trees looking for truffles!

Austrian oak is increasingly widely grown but only recently used for truffle growing. It is mainly planted in areas where the downy oaks are infected with anthracnose. Truffle production starts very early, when the trees are 5- to 6-years-old. As they are fast growing, they need to be strictly pruned to leave space for truffles to develop in the plantation.

Portuguese oak (*Q. faginea*) has replaced downy oak in many plantations in Spain, where it is easy to identify as it does not lose its leaves until late winter (marcescent foliage). Although it prefers cooler soils, the Spanish use it confidently for truffle production, together with holm oak. Its use is unknown in France.

Cork oaks very rarely produce truffles, as they prefer granite or shale soils with an acid pH. *T. melanosporum* may be produced naturally when the calcium content of the environment is temporarily raised (e.g., crushed limestone used on a roadbed further up the slope). They do not seem to suffer from the high-calcium environment when they are planted on deep limestone soils to produce *T. melanosporum*. However, their vigorous growth obliges truffle growers to prune the trees severely.

Sessile oak (*Q. petraea*) is not very well-known for *T. melanosporum* production in France. It is reported as a "...good producer of Burgundy truffles (*T. uncinatum*) on limestone plateaus in Burgundy and Lorraine, often mixed with hornbeam." (Chevalier, et al., 1997). It is known for the production of the famous white truffles of the Piedmont in Italy (*T. magnatum*) (Granetti, et al., 2005).

*Q. incana* Roxb. (= *Q. leucotrichophora* A. Camus) is reported as a *Tuber indicum* producer in China.

### ***Some practical aspects of truffle growing***

Once the plantation is in place, its maintenance consists of cultivating the oak trees together with the truffles. This requires maintaining the soil, controlling the water supply, pruning the trees, and treating diseases, mainly those affecting the trees.

#### **The soil**

The soil is traditionally maintained by tilling, as truffles grow larger in a well-aerated, living, environment with good water reserves. Traditionally the soil was tilled by hand, to a depth of 5-8 cm/2-3 in, using tools with one or more tines once the soil had settled. If the land is tilled with a tractor, the tined tools used are cultivators or tine harrows, while some growers prefer disc harrows that do not pull on the roots. Manual tillage using a hoe, known locally as a *bigos* (a tool with 3 or 4 tines), is preferable for trees that produce very good crops, taking care not to cut the roots.

In principle, this soil maintenance, necessary for the truffles, does no damage to the truffle oaks although some consider that harrowing the soil with mechanical tools may damage the root system. The use of tractor-driven tools has been cited as one cause of the decline in truffle production, due to deeper tillage of the soil and the resulting destruction of many fine, mycorrhized, truffle-bearing roots. Other producers take exactly the opposite view and trim the roots with tractor-driven tools to stimulate the growth of fine new roots likely to develop mycorrhizae.

#### **Water control**

During the first two years after planting, water control is to stimulate new growth on the trees. Then, when truffle production has started, it is not the trees that need watering but the truffles. Once the truffles are formed, in May or June, the aim of watering is to keep them alive. During the production phase, watering takes into account both the truffle cycle, with the most sensitive or critical period in August, and the fact that truffles are drought-resistant (up to 20-25 days on average, provided that temperatures are not excessively high). The truffles are usually formed in June. Microsprinkling, with low-flow sprinklers (40-80 litres/hour) operating at low pressure (1-2 bars), provides a

practical, economical solution. This system requires good filtration on the water intake. It is unnecessary to water unproductive scorched zones. Watering takes place every 15-20 days in July (20-25 mm/0.8-1 in); every 10-12 days in August (20-25 mm); and every 15-20 days in September (20-25 mm). Covering the soil with branches lengthens the time the truffles can resist drought and makes it possible to offset a lack or shortage of water.

### Pruning and thinning

Different regions prefer different approaches to pruning truffle trees. A new approach has been defined by the Montat Truffle-Growing Research Unit (Sourzat, 2008). This consists of maintaining the mycorrhized tree in an equilibrium where the truffle fungus is stronger than the tree. This relationship is expressed in terms of the radius of the scorched zone (Rb) and the radius of the tree canopy (Rf). The assumption is that the scorched zone should always be larger, as expressed by:  $R_b \geq 1.5 R_f$ . The general rules are as follows:

- Start by pruning non-producing trees to give the truffle-producers more room.
- Prune productive trees later to maintain sustainable production.
- Truffle-producing trees should be pruned gradually. To reduce the risk of failure, it is advisable not to prune all the trees in a plantation at the same time, but only one-third each year.

- Pruning is carried out in early spring, generally in March. August pruning is most effective for reducing trees vigor.

- Thinning is based on the same principle as pruning. When the truffle mycorrhizae no longer have space to expand (e.g., in a clearing), they stop producing. A. De Bosredon had already observed this in 1887: “A truffle field that stops expanding, that is no longer moving in any direction, starts to waste away and soon dies.” The fact that a closed environment results in the end of truffle production can be explained by the loss of room for expansion in which case the truffle can no longer exercise the virulence necessary for it to bear fruit. It should also be added that, in addition to requiring an expansion area,



4/ Truffle plantation mainly with kermes oaks (*Quercus coccifera*) in the Pyrénées-Orientales.

truffles need host-trees (oak) with young, growing roots. Thinning consists of eliminating 60-80% of the trees in a plantation, which generally has 300-400 trees per ha (2.5 ac). Once thinning reaches a certain level, it is better to cut down the plantation and plant a new one.

The impact of pruning and trimming on the health of the oak trees is not really taken into consideration (it is done for the truffles!) other than by recommending that pruning take place in spring. However, certain practices, particularly in Italy (Sourzat, 2009), involve pruning and trimming almost all-year-round using a wide range of tools, from secateurs to chain saws, and hedge-trimmers. In France, the oaks are pollarded at a height of 2 to 3 m/6.7-9.9 ft. To a certain extent, truffle oaks are mistreated to promote *T. melanosporum* truffle production.

### The main parasites of truffle oaks

The list of oak parasites treated by truffle growers is limited by comparison to the number of known diseases and pests.

1. Oak powdery mildew, which takes the form of a white, fuzzy coating on the oak leaves, mainly affects downy and pedunculate oaks. The damage is generally prevented by spraying the trees with micronized colloidal sulphur in late May to mid-June.

2. Oak anthracnose, a fungal disease that is especially widespread in the Périgord and northern Lot areas, causes premature leaf drop on durmast oaks. Successful treatment trials have been carried out using prochloraz and mancozeb, available commercially. Experimental treatment with 46 g prochloraz as the active ingredient in 100 litres water sprayed on the oak foliage once per month, from late May to late August, gave satisfactory results. Austrian oak is now being planted instead of durmast oak as a preventive measure.

3. Defoliating caterpillars caused considerable damage in the 20<sup>th</sup> century (1930-31), even destroying some truffle plantations by devouring all the foliage on the durmast oaks. The main culprits are *Lymantria dispar* L. caterpillars and the Plant Protection Service recommends biological pest control using *Bacillus thuringiensis* Berliner, also commercially available.

4. Oak roller moth (*Tortrix viridana* L.) caterpillars roll the young leaves into tubes to provide shelter for their cocoons. The damage is noticeable starting in April and the treatment is similar to that applied in the case of defoliating caterpillars.

5. Oak moths (*Lithocolletis joviella* Const.) live on holm oak leaves. The larvae remove the leaf cuticles to eat the inner tissue. The products used to treat defoliating caterpillars are also effective in this case.

6. Leopard moths are nocturnal members of the superfamily *Cossoidea*, whose larvae sometimes infest oak branches. It is curious to observe that the destruction of the top of an oak tree by leopard moth larvae is sometimes accompanied by the start of truffle production.

7. The oak burncow is a beetle that causes similar damage to leopard moths on holm and durmast oaks. It is advisable to burn any branches infested with this pest.

8. Oak canker or phomopsis causes swellings on the bark and crevasses of varying depths on the branches. This fungus is favored by imbalances and causes damage when the trees are suffering from drought or poor upkeep.

9. Lichens are not parasites. They colonize tree branches when the air is damp and unpolluted. However, truffle growers often have the impression that the proliferation of lichen on the branches is depriving the tree of nourishment.

10. Large and small animals may cause worrying damage to plantations. Wild boar

cause the most damage in young plantations, where they uproot the saplings, while in more mature plantations they dig up the soil looking for earthworms and often disturb immature truffles. The usual preventive measure is to install an electrified fence.

### ***Future prospects***

Climate warming is a limiting factor for truffle production. *T. melanosporum* is tending to spread northwards in France, in conjunction with holm oaks. Research at INRA has demonstrated how truffles accompanied oak trees in their recolonization of France after the last Ice Age, approximately 10,000 years ago. This work (highlighted by Francis Martin at INRA, Nancy) was based on phylogenetic analyses and considered the genetic and geographical distances between genotypes (Murat et al., 2004).

Initial results obtained by cloning mycorrhized oaks with different truffle strains is one avenue to be explored for improving truffle growing (Chevalier et al., 2008). Thanks to experiments carried out over more than 9 years by INRA in Clermont-Ferrand in Southeast France (Valensole), Gérard Chevalier demonstrated that the geographical origin of the truffles used to inoculate saplings of the same clone of downy oak had a major influence on production. This researcher has also collected around sixty strains of good truffle-producing downy oak from all over France. These strains were isolated by Jean-Philippe Lemaire (INRA) starting in 1998. These clone mothers are conserved by the State Tree Nursery at Guémené-Penfao (Loire-Atlantique). The Robin Tree Nursery (France) took cuttings from an excellent downy oak in the Hautes-Alpes and inoculated it with truffles from the production site. This clone is now commercially available. In Europe, certified mycorrhized truffle oaks are used to produce four truffle species: *T. melanosporum*, *T. uncinatum*, *T. aestivum*, *T. magnatum*.



5/ Nursery of mycorrhized oaks for *Tuber melanosporum* production.

The French Truffle Growers Federation is working on restoring truffle production to its earlier abundance, particularly through a scientific program (SYSTRUF) funded by ANR (Agence nationale de la recherche) and a series of experiments subsidized by FranceAgriMer and several local and regional authorities. While the quality of the plant material is no longer, apparently, a limiting factor, particularly with the mycorrhized seedlings certified by INRA and CTFIL, production seems to be subject to other constraints, particularly frequent summer droughts and fungal contamination from durmast oak woods around truffle plantations. Ultimately, this shows that, while oak trees are the best friends of truffles, they may also be their worst enemies.

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