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Counter-season cultivation of truffles in the Southern Hemisphere: an update

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Abstract

The cultivation of truffles in the Southern Hemisphere began in New Zealand in the mid-1980s and the first fruiting bodies of *Tuber melanosporum* were harvested in Gisborne in 1993. Cultivation started in Australia soon after and the first truffles were found in Tasmania in 1999. Now there are more than 150 mostly small truffières in New Zealand, and approximatively 200-250 plantations in Australia some of which are very large. Most of the productive truffières have been established with *Tuber melanosporum* Vittad. infected plants but more recently fruiting bodies of *Tuber borchii* Vittad. and *Tuber aestivum* Vittad. have been harvested. Chile followed by Argentina and South Africa were the next to get involved and produced in 2009, 2014 and 2015 respectively. Over the past 10 years alternative techniques have been tried in Italy, China and New Zealand in attempts to control contaminating ectomycorrhizal fungi in the nursery – arguably the most important problem facing the cultivation of truffles worldwide.

Keywords: Truffle cultivation; New Zealand; Australia; Chile; Uruguay; Argentina; South Africa.

Riassunto

Le prime coltivazioni di *Tuber melanosporum* nell'emisfero sud sono state realizzate nella metà degli anni 80 in Nuova Zelanda e il primo ascoma è stato trovato nel 1993 a Gisborne. La coltivazione del tartufo in Australia è iniziata lo stesso anno e nel 1999 è stato trovato il primo tartufo in Tasmania (Australia). Allo stato attuale sono state realizzate più di 150 piccole tartufaie di *T. melanosporum* in Nuova Zelanda e circa 200-250 in Australia, generalmente di più grandi dimensioni (fino a 35 ha). Nel 2016 la produzione di tartufi neri pregiati in Australia è stata di 13 tonnellate, ma si stima che nei prossimi anni possa raggiungere le 45 tonnellate. Più recentemente la tartuficoltura è stata introdotta in con successo in Cile, Uruguay, Argentina e Sud Africa che hanno fatto registrare la prima produzione di tartufi nel 2009, 2014 e 2015 rispettivamente.
L'introduzione della tartuficoltura in questi paesi ha richiesto un'attenta analisi delle caratteristiche climatiche per individuare le aree più idonee. Inoltre nella maggior parte dei casi le tartufaie sono state realizzate su terreni originariamente acidi o sub-acidi per cui è stato necessario correggere il pH mediante massicci ammendamenti calcarei.
La scarsità od assenza in molte di queste aree di altre specie vegetali ectomicorriziche e la correzione del pH hanno limitato le contaminazione in campo con funghi ectomicorrizici estranei che in Europa rappresentano uno dei maggiori problemi della tartuficoltura. Anche in questi paesi vi sono, tuttavia, delle problematiche. Ad

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esempio in Nuova Zelanda, come d'altra parte in molti altri paesi, si lamenta una scarsa qualità delle piante micorrizate oggi in commercio. Le tecniche alternative di inoculazione recentemente sperimentate in Italia, Cina e Nuova Zelanda potrebbero limitare le contaminazioni con funghi ectomicorrizici diversi dal tartufo inoculato.
Recentemente in alcuni di questi paesi (Australia e Nuova Zelanda) è stata introdotta con successo anche la coltivazione di *Tuber borchii* Vittad. e di *Tuber aestivum* Vittad.

Parole chiave: tartuficoltura; Nuova Zelanda; Australia; Cile; Uruguay; Sud Africa.

Introduction

This paper is an update of truffle cultivation in Australia and New Zealand (Hall et al., 2007; Zambonelli & Hall, 2007; Zambonelli et al., 2010; Hall & Haslam, 2012) and more recent attempts to cultivate truffles in other Southern Hemisphere countries.
The cultivation of truffles in the Southern Hemisphere began in New Zealand in 1987 when the first truffières were established in North Otago (45˚S), in the South Island. The first fruiting bodies were harvested in Gisborne (39˚S) in 1993. Cultivation started in Australia soon after, first in Tasmania and Western Australia, but then spreading to New South Wales, the Australian Capital Territory, Victoria and more recently South Australia. (Hall et al., 2007). Most of the early truffières were established with *Tuber melanosporum* Vittad. infected plants but more recently fruiting bodies of Tuber borchii Vittad. and *Tuber aestivum* Vittad. have been cultivated (Hall, 2016; 2017). Attempts have also been made to cultivate *Tuber magnatum* Pico.
The problems in truffle cultivation encountered in Australia and New Zealand were somewhat different from those in Europe. Most New Zealand's forests contain no ectomycorrhizal species although five species of ectomycorrhizal *Nothofagus* dominate particularly in the upland areas of the South Island. In contrast, Australia has many ectomycorrhizal trees very different from those which dominate in Europe (Castellano & Bougher, 1994). In both countries, European ectomycorrhizal fungi are almost exclusively restricted to parks, gardens and plantations of exotic trees that were accidentally introduced on the roots of plants by early European settlers. The imposition of severe quarantine controls in both countries particularly over the past two decades (e.g. Environmental Protection Authority, 2017) has severely limited the importation of not just dangerous pests and pathogens but also edible and beneficial mycorrhizal mushrooms.
The climates of Australia and New Zealand are extremely variable ranging from hot deserts of central Australia, to tropical and temperate rain forests of northern Australia and the western South Island of New Zealand but many areas have climates similar to those of many European truffle areas (Hall et al., 2016). The advantage that both countries have is that they produce truffles and other edible mycorrhizal mushrooms out-of-season to Europe.
Initially Hall et al. (1989; 1994) superimposed a map of the July and January isotherms for France and Italy (Arléry, 1970; Cantù, 1977) from the multi-volume tome "Climates of the World" (Landsberg, 1970-1995) onto Delmas's (1978) map of the distribution of *T. melanosporum* in France. The ranges were then tabulated and compared with the climatic conditions in various New Zealand areas. Later this table was extended to cover many other areas around the world where various truffles had been found or cultivated (Hall et al. 2016). Graphs of mean monthly temperatures were also plotted to compare the climate in several locations (Fig. 1). Areas with an annual rainfall greater than 1500 mm were assessed as unsuitable.

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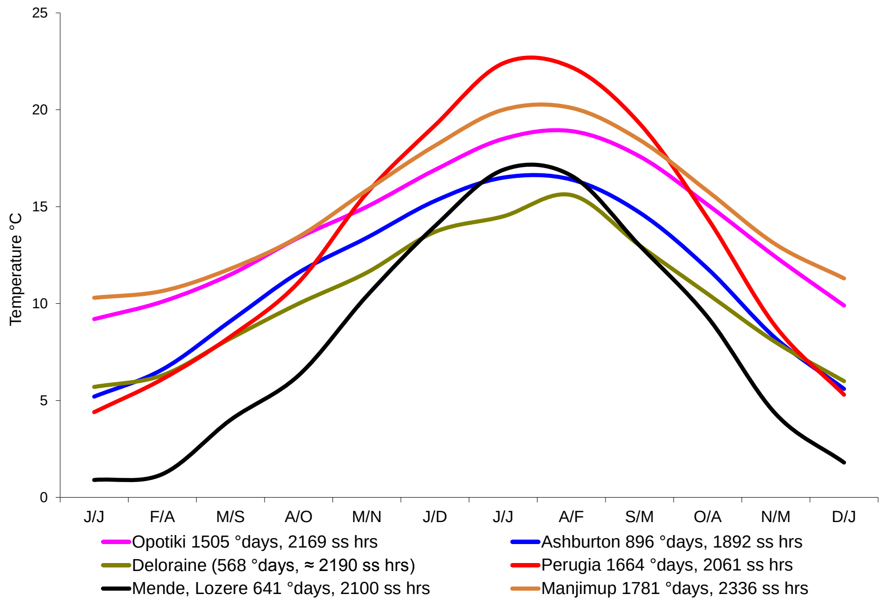

Fig. 1. Mean monthly temperature curves for the warmest (Perugia) and coolest (Mende, Lozère) places to produce the Périgord black truffle in Europe compared with the warmest and coolest places in New Zealand (Opotiki and Ashburton), the coolest place in Australia (Deloraine) and Manjimup, a very productive area in Western Australia.
Fig. 1. Confronto fra le temperature medie mensili delle località fra le più calde (Perugia) e più fredde (Mende, Lozère) di produzione di *T. melanosporum* in Europa e quelle più calde in Australia (Deloraine) e più fredde in Nuova Zelanda (Opotiki e Ashburton).

Truffle cultivation in New Zealand

Production of infected seedlings

The concept of growing truffles in New Zealand for out-of-season Northern Hemisphere markets was first mooted by Ian Hall in 1979 following the first production of *T. melanosporum* truffles in France and Italy in 1977 (Chevalier & Dupré, 1990). Because of the dangers of importing pests and diseases it was not possible to import *T. melanosporum* infected plants from Europe and French and Italian companies were not prepared to part with their newly devised methods, Ian Hall had to develop his own methods. The problems were not just the development of an inoculation technique but also finding the essential biological materials as well as the risk of setting sail onto an unknown sea.

Initially only *Quercus robur* L. (English oak) and *Corylus avellana* L. (hazelnut) were used as host plants because seed was readily obtainable, both species grow well throughout New Zealand and were found to readily form mycorrhizas with *T. melanosporum* using the methods developed by Ian Hall. *Quercus ilex* L. was introduced only more recently. In the 1980s commercial species of truffle were not present in Southern Hemisphere countries so they had to be imported from Europe. This was risky because of the dangers of importing contaminants such as less valuable species, for example, *Tuber brumale* Vittad., *T. aestivum* and *Tuber indicum* Cooke & Massee as well as fungal contaminants, yeasts, nematodes and insects often present inside truffles (Pacioni et al., 2007; Buzzini et al., 2005; Hall et al., 2007). To limit the risks all the truffles were certified and carefully checked at origin but they often deteriorated en route which caused problems getting them approved by biosecurity personnel.

Within two years of beginning research, a few hundred *T. melanosporum* infected plants were produced and in spring 1987 two small truffières were establish in North Otago (45°S) on rendzina soils with pH 7.8 – 8.1. Considerable publicity surrounded these first experiments and generated a demand for *T. melanosporum* infected plants by the general public. It was therefore decided to set up a small facility to produce sufficient

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T. melanosporum infected plants to meet market demand. Because almost all New Zealand native plants form arbuscular mycorrhizas there are very large areas free of ectomycorrhizal fungi that might compete with *T. melanosporum*. Ian Hall considered it unacceptable to supply potential growers with *T. melanosporum* infected plants grossly contaminated with other ectomycorrhizal fungi on their roots. It would also have been negligent and exposed his employer to possible legal action through consumer protection legislation. A legal action in Australia that was settled out of court demonstrates that Ian Hall's concerns were justified (Australian Federal Court, 2004). Until the early 2000s all the truffle mycorrhized trees were produced by Crop and Food Research with a success rate of around 95% (Hall & Zambonelli, 2007). Crop & Food Research lost Ian Hall in 2004 and two years later stopped producing plants in favour of a number of independent companies. These have had varying measures of success but 30 years on from those initial experiments contaminated plants and plants with little or no truffle on their roots are still being offered for sale. Clearly either the New Zealand Fair Trading Amendment Act (Parliamentary Counsel Office, 2017a) or the New Zealand Sale of Goods Act, in particular section 15 (Parliamentary Counsel Office, 2017b), need to be used. Alternatively, new legislation similar to that being considered in some Italian regions (Bagnacavalli et al., 2012) needs to be considered. Contaminated trees are perhaps the biggest problem facing the cultivation of truffles worldwide (Hall et al., 2007, Donnini et al., 2001) so as well as legislation a number of alternative techniques are being tried in Italy (Iotti et al., 2016), China and New Zealand (Hall pers. comm.) to avoid the contamination of plants at the nursery stage.

Truffière establishment and maintenance

Much of the North Island is covered with soils derived from acidic volcanic ash while many soils in the South Island are derived from low pH greywacke, argillites, schist, granites, diorites, gneiss, amphibolites, gabbros, basalts, andesites, dacites or loess (Wandres, 2010; Wikipedia, 2016). While New Zealand does have soils derived from limestone and marble, these cover a relative small part of the country compared with the truffle growing countries of Europe (Institute of Geological & Nuclear Sciences, 2008; Riddolls, 1987).

Because of the lack of high pH soils in New Zealand, research was carried out to determine if truffles could be grown in New Zealand on naturally low pH soils to which lime had been added. As a rough guide between 1.5 and 2 tonnes of lime per hectare per 10 cm soil depth was found to raise the soil pH by 0.1, i.e., in a truffière established in Nelson to raise the top 30 cm of a soil from a pH of 5.9 to 7.9 (the optimum for *T. melanosporum*) required about 90 tonnes of lime per hectare. This lime had to be worked into the soil so that it was spread evenly throughout the profile.

Prior to planting, weeds were eliminated, the soils worked this time to about 150 mm using tines, and irrigation equipment then installed—extended periods of drought can occur almost anywhere in New Zealand. Fences and windbreaks were erected around the perimeter of most of the truffières to keep out stock and wild pigs and for protection from the desiccating effects and physical damage caused by wind, which can be very strong in many parts of the country (Fig. 2a). In most truffières individual plants were protected by 15-cm square by 60-cm high KBC tree shelters to guard against rabbits which are a big problem in New Zealand agricultural lands (Hall et al., 2007).

Between 1987 and 1993 French recommendations were followed (Grente & Delmas, 1974) and around 800 trees were planted per hectare. All of the truffières were planted with two *C. avellana* 2.9 m apart, alternating with a single *Q. robur* along the rows, and with the rows about 4.5 m apart. However, a planting density of 400 per hectare is now believed by some to be better in the cooler parts of the country (Hall et al., 2001; 2007). Pruning, tillage and general maintenance were similar to recommendations published by Sourzat (1989) and largely follow the Pallier method.

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Fig. 2. Aspects of truffle cultivation in New Zealand (a, b & c), Australia (d, e & f) and South Africa (g, h & i). Windbreaks (a); first *T. borchii* found in New Zealand near Christchurch under a *Pinus pinea* (b); flags planted in the locations where the truffles were indicated by the truffle dog and where the truffles will be harvested over the following few days (c); a *T. melanosporum* truffière with alternate oaks and hazels (d); truffle dogs are often not trained to indicate precisely where a truffle is in the ground (e & f); truffles from a *T. melanosporum* truffière on an extremely sandy soil (g); a brûlé under an oak (h); truffles damaged by slugs (i).

Fig. 2. Alcuni aspetti della tartuficoltura Nuova Zelanda (a, b & c), Australia (d, e & f) e Sud Africa (g, h & i). Reti frangivento (a); il primo *T. borchii* trovato in Nuova Zelanda, vicino a Christchurch, sotto un *Pinus pinea* (b); bandierine piantate nei punti indicati dal cane da tartufi dove i giorni successivi verranno cercati e raccolti i tartufi senza cane (c); una tartufaia di *T. melanosporum* con querce e noccioli alternati (d); i cani da tartufi spesso non vengono fatti raspare il terreno e spetta al tartufaio individuarne l'esatta posizione nel suolo (e, f); tartufaia di *T. melanosporum* realizzata in un terreno estremamente sabbioso (g); una bruciata sotto una quercia (h); tartufi danneggiati da lumache (i).

Some farmers have not followed best practice such as not pruning sufficiently or irrigating too little or too much which may have been the cause of crop failure. In some areas of the North Island with a subtropical climate and where the soil has not been tilled, immature superficial truffles have been produced. In other truffières the soil has been worked too deep which has drastically decreased production.

The most widespread problem encountered was a very large fall in available iron, boron, copper, manganese and/or zinc concentrations as the pH was raised leading to plant deficiencies particularly in *Q. robur*. This was generally easy to reverse by the application of relatively small quantities of compounds containing these elements. That *T. melanosporum* was able to survive and proliferate in the modified New Zealand soils with subsequent trace element deficiencies corrected, has been key to the scale and distribution of plantations in the other Southern Hemisphere countries.

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The only pests and pathogens encountered in New Zealand have been powdery mildew and wood wasps, but generally these did not require treatment. A concern has been the possible long term impact of *Phytophthora kernoviae* Brasier, Beales & S.A. Kirk, a potentially serious pathogen on *Q. ilex* and *Q. robur* (Brasier, 2008; DEFRA, 2017; Gardiner et al., 2015; Ormsby, 2017). This has been present in soils in both indigenous and exotic forests in several regions of the North Island as early as the 1950s but strangely no diseased plants other than *Annona cherimola* (custard apple) have ever been recorded (Ramsfield et al., 2007).
The contamination of *Tuber* infected plants in the field was very low in all the truffières. When Alessandra Zambonelli inspected root samples from different truffières in the 1990s she was very surprised to find virtually no contamination with other ectomycorrhizal fungi. In contrast in Italy it is common to find many other ectomycorrhizal morphotypes (Zambonelli et al., 2005; Donnini et al., 2001). In New Zealand the most common contaminants were *Scleroderma* sp. and *Hebeloma* sp. but only when the trees were planted into areas where these contaminants were already present. Overall *Q. robur* was more prone to contamination by these fungi than *C. avellana*.
The efforts to exclude contamination by *Tuber* species, was only partially successful. In the first productive Southern Hemisphere *T. melanosporum* truffière located near Gisborne on the east coast of the North Island (39°S) *Tuber maculatum* Vittad., probably from a nearby willow tree, invaded the truffière and appeared to replace *T. melanosporum*. However, after a modified management regime was put in place, *T. melanosporum* production began. *T. maculatum* mycorrhizas were also found in other truffières located near poplar or willow trees (Zambonelli, unpublished data). It has since been found that *T. maculatum* is widespread in New Zealand (Guerin-Laguette et al., 2012) and was probably accidentally introduced on plants imported by early European settlers and was not an unlikely contaminant of *T. melanosporum* inocula, which appears to be suggested by Guerin-Laguette et al. (2012).
T. brumale has also been identified in some New Zealand truffières (Guerin-Laguette et al., 2010). Generally contamination has been minor but in some truffières *T. brumale* totally dominates suggesting either a significant failure in the nursery or that the soil and/or climatic conditions favoured it over *T. melanosporum*. In contrast, despite imported truffle at times containing much more *T. indicum sensu lato* than *T. brumale* (Hall pers. comm.), Guerin-Laguette et al. (2010, 2012) did not detect any *T. indicum* mycorrhizas in New Zealand's truffières. For most truffières it is assumed that minor *T. brumale* contamination originated from small pieces of *T. brumale* trapped inside cracks on the surfaces of *T. melanosporum* truffles. Less likely is that *T. brumale* was accidentally introduced by early European settlers in a manner similar to *T. maculatum* and was widespread before the introduction of *T. melanosporum.* Had this been the case, collections of *T. brumale* would surely have joined *T. maculatum* in Landcare Research's herbarium (2017).

Yields

The first Southern Hemisphere *T. melanosporum* truffles were found on 29 July 1993 (Ian Hall's birthday), exactly five years after planting, in his brother's truffière near Gisborne on the east coast of the North Island (39°S) (fig.3). Of the 11 Périgord black truffières that had been established up to 1990, 8 produced with yields ranging from about 20 kg/ha to 350 kg/ha 10 years after planting. All of these are situated north of Christchurch and between the latitudes 38°S to 43°S and most were established on naturally acidic soils.
The highest New Zealand yield has been from a small truffière near Ohiwa in the Bay of Plenty (38°S) that had been established in 1988 on a volcanic ash soil with a natural pH of 6.2, a site that would have been treated as very unlikely in France (Fig.4).
T. aestivum truffières were also established in New Zealand and the first produced in the late 1990s in North Otago (Hall, 2017) but it was not until 2012 that commercial quantities were found in North Canterbury (Turner, 2012). However, generally this truffle has been overlooked in New Zealand in favour of the

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Périgord black truffle and bianchetto truffles. However, its long fruiting period from early autumn to the start of the Périgord black truffle harvest makes it a worthwhile species.

The first *T. borchii* was found under *Pinus pinea* L. near Christchurch in July 2006, only 3 years after planting (fig. 2b). Commercial quantities were found the following year in a nearby *Q. robur* and *C. avellana* truffière only four years after planting (Hall, 2016). New Zealand's most southerly productive truffière also produced *T. borchii* after 3 years. It is situated just north of Invercargill where the climate is a little warmer than north of Edinburgh, Scotland, where *T. borchii* is found growing naturally (Hall et al., 2016).

Fig. 3. Alan Hall's Gisborne truffière through the years: a. Year 0. Before planting showing the willow in the back left-hand corner thought to be the source of *Tuber maculatum* that invaded the truffière a few years after planting. *T. maculatum* is common on willows and poplars in New Zealand. b) Year 1. Strong brûlés developed on almost every tree 8 months after planting. c) Year 4. Additional lime was applied to readjust the pH which fell because of the decomposition of grass clippings left in situ. Note the very rapid growth of the common oak (*Quercus robur*). d) Year 8. Alan Hall with Alessandra Zambonelli who had just found the first truffle of the first commercial harvest in the Southern Hemisphere. e) Year 9. The brûlés spread rapidly and covered all the truffière from about the fifth year. f) Year 17. The common oaks grew about 1 metre a year and soon overtopped the hazels (*Corylus avellana*). The power pole on the right is 8 metres high.

Fig. 3. Evoluzione della tartufaia di Alan Hall negli anni: a) Anno 0 prima della piantagione. Si può notare un salice, nell'angolo dietro a sinistra, che è stato la fonte della contaminazione con *Tuber maculatum* che ha invaso la tartufaia pochi anni dopo l'impianto. *T. maculatum* in Nuova Zealnda è comune sotto pioppi e salici. b) Anno 1. Già otto mesi dopo l'impianto si sono sviluppate evidenti bruciate sotto le piantine. c) Anno 4. Calcitazione effettuata per correggere il pH che si era alzato causa la decomposizione delle piante erbacee lasciate sul posto. Si può notare la crescita rapida delle querce (*Quercus robur*). d) Anno 8. Alan Hall e Alessandra Zambonelli che hanno appena trovato il primo tartufo coltivato commerciale dell'Emisfero sud. e) Anno 9. Le bruciate fin dal quinto anno coprono tutta la tartufaia. f) Anno 17. Le querce sono crescite un metro all'anno e hanno sovrastato i noccioli (*Corylus avellana*). Il palo della luce sulla destra è alto 8 metri.

There are about 150 truffières in New Zealand but most are relatively small compared with many in other Southern Hemisphere countries so the total number of trees planted probably does not exceed 40,000. This is a reflection of the failure of big business to take a role in the industry and, compared with Australia and Chile, a lack of government participation, and a withdrawal of research funding at a critical stage in the mid-

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1990s. Finding the truffles with dogs is offered by companies which increases the cost of the harvesting. Harvesting by independent harvesters is also infrequent so many truffles can rot in the soil (fig. 2c).

Fig. 4. Chantal Dupré and Gerard Chevalier look on in disbelief as the first truffle of the day is sniffed out by Juliet, Brian Bassett's stand-in for a truffle dog. This is one of the world's most productive truffières and was established on a deep volcanic ash soil with a natural pH of 6.4.
Fig. 4. Chantal Dupré e Gerard Chevalier osservano increduli il primo tartufo del giorno trovato da Juliet Brian Bassett che si è sostituita al cane da tartufi. Questa è una delle tartufaie più produttive al mondo ed è stata realizzata su un suolo profondo vulcanico con pH originale di 6,4.

Prices for New Zealand produced T. melanosporum truffles

Because New Zealand growers are producing truffles counter season to France, Italy and Spain and sell directly to the consumer, they receive around €2000/kg for premium quality *T. melanosporum* truffles-about the same price as preserved truffles retail in Australia. Most of these truffles have been consumed in New Zealand although small quantities have been exported to Australia, eastern Asia and North America.

Truffle cultivation in Australia

New Zealand's success in the early 1990s did not escape the attention of those in other Southern Hemisphere countries particularly Australia followed by Chile, South Africa, Argentina and more recently Brazil and Uruguay. The first questions they asked were the same as those pondered by the New Zealanders: do we have areas with the right climates and if we don't have the right soils how do we make them suitable? Using the two methods used in New Zealand (Hall et al. 2016; Fig. 1) climatic data could be easily compared.
Truffle cultivation in Australia was introduced about 6 years later than in New Zealand initially by Peter Cooper and Duncan Garvey in Tasmania. The first *T. melanosporum* mycorrhized *C. avellana* were planted in northern Tasmania in 1993, the same year that New Zealand produced its first truffles. The first Tasmanian *T. melanosporum* truffles were produced six years later on 18 June 1999 (Tasmanian Truffles 2017). Since these first positive results steady development of plantations followed in other regions so by 2005 truffle production was occurring in Western Australia (WA), Victoria (VIC), New South Wales (NSW) and Tasmania (TAS). There are now between 200 and 250 plantations containing around 250,000 trees

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covering approximately 600 ha (Fig. 2d). Most plantations cover between 1 and 5 ha with the largest covering 35 ha in Western Australia (Fig. 5).

Fig. 5. A small section of Al Blakers' truffière (Pancia, 2016) near Manjimup, Western Australia.
Fig. 5. La tartufaia Al Blakers (Pancia, 2016) situata vicino a Manjimup, Australia occidentale-

Acidic soils have also been used in Australia and the establishment of the truffières has required dramatic pH adjustment. Tree spacing can vary greatly depending on orientation and local climate. However it is common to plant rows with an 8 m spacing and the trees 3 m apart within the rows to give about 400 plants/ha – a density half that in the early New Zealand truffières. Host trees at first were mainly *Corylus* sp. but in more recent times most plantings are combinations of *Q. ilex*, *Q. robur* and/or *Quercus suber* L. The utilization of *Q. suber* for truffle cultivation is quite surprising because it is known to prefer acidic soil whereas most truffles require soils having a pH ranging between 7.5 to 8 (Zambonelli & Branzanti, 1989).

Similar to New Zealand most commercial plantations have fully automated irrigation systems installed and have fences and tree shelters to guard against damage from wild animals. *T. melanosporum* is the primary species planted by Australian growers representing 95% of all plantings. Other species being trailed are *T. borchii*, *T. aestivum* and *T. magnatum.*

The worst problem encountered in Australia has been truffle rot caused by bacteria and fungi found in the soil and initially inexperience in truffle harvesting using trained dogs like in New Zealand (fig. 2e). Agronomic practices, like soil tillage, are now used in attempts to control truffle rot. In 2016 Australia produced 13 tonnes of Périgord black truffles and if all of the current plantings begin fruiting production is expected to reach 45 tonnes (fig. 2 f) (Stahle pers. comm.).

Truffle cultivation in South Africa

The southern tip of South Africa is about 35°S so low lying areas on the south coast are much too warm for truffle cultivation. For example, Cape Town at 34°S has a mean monthly temperature in June and July of 13°C. However, like in Italy, Greece and other southern European counties, cooler winter temperatures can be found at higher elevations. Assuming a lapse rate of 0.65°C per 100 metres mid-winter temperatures similar to Opotiki in New Zealand (9°C) should be found at an altitude of 600 metres close to the south coast but higher further north. For example, George at a latitude of 34°S and an elevation of 195 m (dateandtime.info, 2017) has a mean July temperature of 13°C (Wikipedia, 2017) so land 400 metres higher should have acceptable mid-winter temperatures while summer temperatures would still be within the range of those in Europe (Fig. 9).

The first truffle plantations were established primarily with *Q. robur* and to a lesser extent *C. avellana*. The most recent plantation was established with *Q. ilex* which seems to be more suited to the local climatic conditions. The soils where the truffières are located originally had acidic soils with a pH ranging between 4.5 and 6.5 but were corrected to pH 7.9 (in water) by liming. Many South African soils are very sandy and towards the lower left corner of the soil textural graph (Fig. 6). At least two truffières have been established on these.

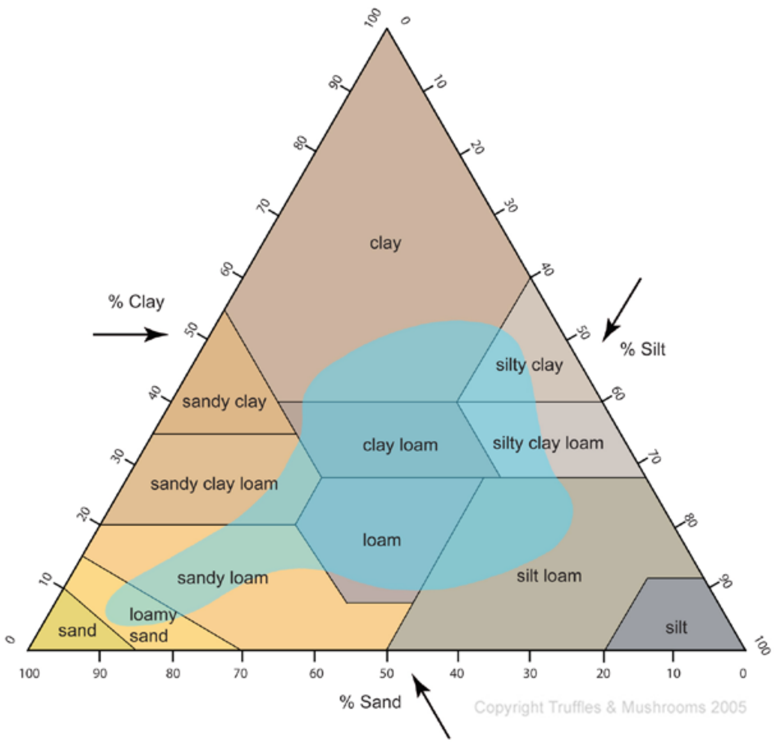

Fig. 6. The central area shaded blue are soils that are suited to the cultivation of the Périgord black truffle (*Tuber melanosporum*). After Delmas, 1978.
Fig. 6. Nell’area centrale sono indicati in azzurro i suoli idonei alla coltivazione del tartufo nero pregiato (Delmas, 1978)-

In 2015 the first black truffle was reported in South Africa from a plantation near Dullstroom in Mpumalanga nine years after planting. The same year another truffle was found in a 5 year old truffière located in Western Cape, Villiersdorp, established by Woodford Truffles (Fig. 2h). In 2016 a further two truffières also established by Woodford Truffles, near George in Western Cape Province and near Kokstad in KwaZulu-Natal Province, also began producing. Some truffles were damaged by local soil fauna and research on these is being conducted to try and limit damage (fig. 2i). It remains to be seen if production from *Q. ilex* will be as high as those achieved by a mixture of *Q. robur* and *C. avellana* as used in New Zealand and some parts of Australia.

Truffle cultivation in South America

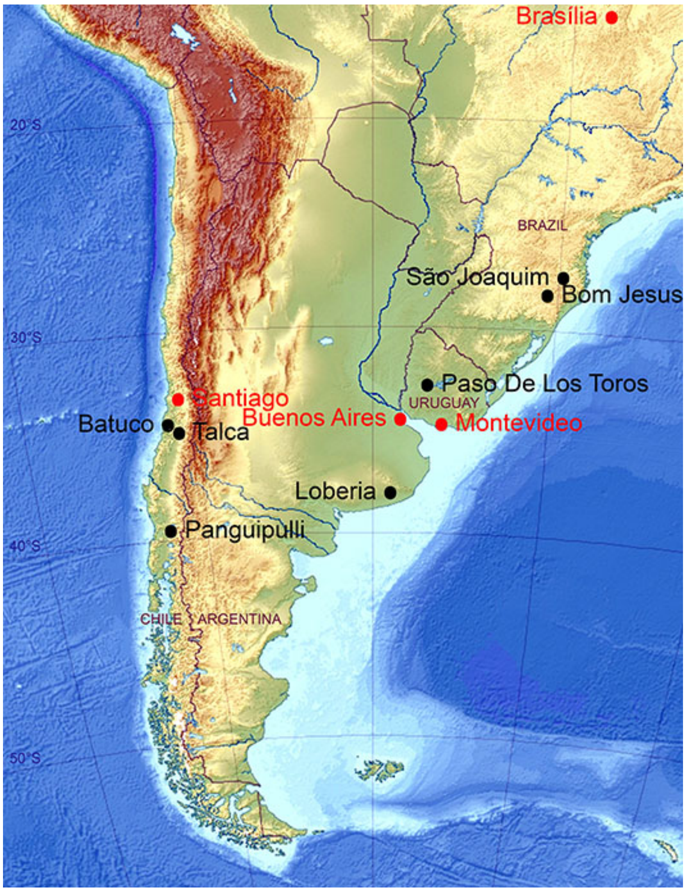

Fig. 7. Locations (black lettering) of some productive truffières in Chile and Argentina and some potentially suitable locations in Uruguay and Brazil (underlying map from Wikipedia 2015).
Fig. 7. Località (in nero) di alcune tartufaie produttive in Cile, e Argentina e località situate in aree potenzialmente idonee alla tartuficoltura in Uruguay e Brasile.

Chile

Chile, which spans latitudes 17°S to 57°S, has climates ranging from warm desert, warm and temperate Mediterranean to tundra, was an obvious country to look at the cultivation of truffles. The initiative was led by Ricardo Ramírez in the Department of Forest Sciences at the Universidad Católica del Maule starting in the early 2000s. There has also been a significant input by Santiago Reyna at the Polytécnica de Valencia in Spain (Ramírez et al., 2011). The whole project was part of the Chilean government's aim at diversifying the agricultural sector and producing high value crops for international markets (Programa Fondef- Fondo de Fomento al Desarrollo Científico y Technológico, 2017). The first truffière was established in 2003 and over the following 4 years 70 hectares were planted in Metropolitan, O´Higgins, del Maule, Bío-Bío, Araucanía y Los Ríos, Los Ríos y del Maule (Duao) and Panguipulli (Región de Los Ríos) with a large part of the funding supplied by the Chilean Ministry of Agriculture. Some climatic data for these areas are shown in Fig. 8. Sensibly, molecular techniques were developed for controlling the quality of plants (Cordero et al., 2011) so that now Agro Bio Truf can guarantee its plants are mycorrhized with *T. melanosporum*.

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The first Chilean *T. melanosporum* truffles were harvested in May 2009 in a 5 year old truffière at Panguipulli, Región de Los Ríos (40°S, elevation 268 m) (Extra Noticias.cl, 2010). The following year truffles were found under *Q. ilex* at Duao (36°S, 163 m elevation), about 12 km southwest of Talca (35°S). In 2011 truffles were also harvested near Quepe and Chufquen, Traiguén (38°S, elevation 120 m) 4-5 years after planting (Andean Truffles, 2011). According to Agro Bio Truf (2017) the total investment by the Chilean Government and private investors over the past 14 years in establishing nearly 400 hectares of truffières containing more than 155,000 trees was US$800,000 (Agro Bio Truf, 2017; Ramírez, 2015). As with any new venture there are issues that need to be studied. For example, there is still a need to determine what host plants best suit particular soils and climates and how yields per hectare might be increased beyond 10 kg/ha and closer to those achieved in New Zealand and Australia (Ramírez, 2015).

Argentina

Like Chile, Argentina spans a wide range of latitudes between 22°S and 55°S and has areas that have temperature ranges that should suit the cultivation of truffles. These are found in the central southern part of the country, especially to the south of Buenos Aires. The first truffles were found in August 2014 in Lobería in the Buenos Aires province (Mercosur 2016). The mean monthly temperatures there are similar to where Périgord black truffles have been found elsewhere in the world (Fig. 8; Meteoblue, 2017).

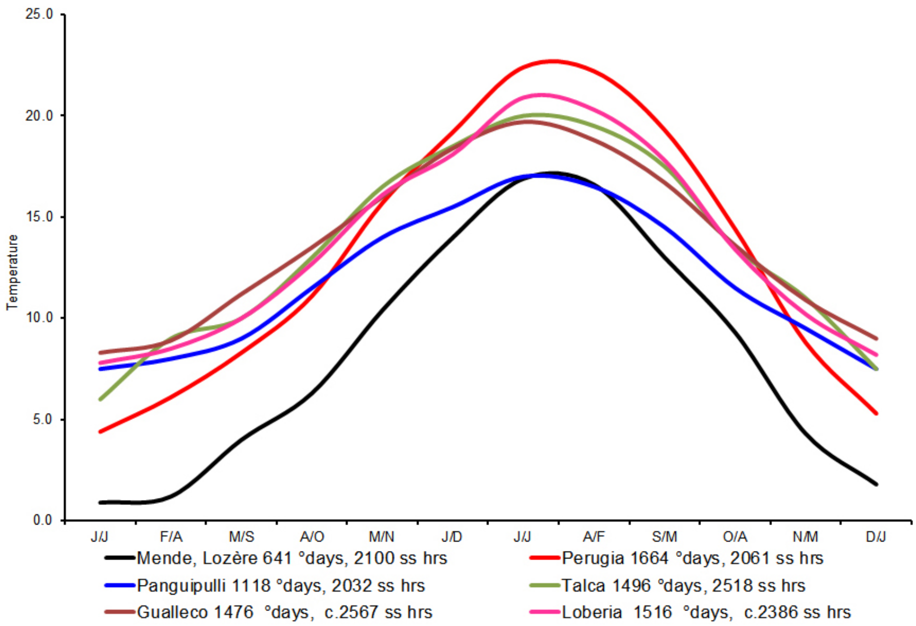

Fig. 8. Mean monthly temperature curves for three meteorological stations adjacent to productive truffières in Chile (Gualleco - 8 km from Batuco, Talca and Panguipulli) and a productive truffière in Argentina (Lobería) compared with those for the warmest (Perugia) and coolest (Lozère) places to produce the Périgord black truffle in Europe.
Fig. 8. Confronto fra le temperature medie mensili di tre stazioni metereologiche adiacenti le tartufaie produttive del Cile (Gualleco - 8 km da Batuco, Talca e Panguipulli), la tartufaia produttiva in Argentina (Loberia) e quelle produttive in Europa più calde (Perugia) e più fredde (Mende, Lozère).

Brazil

Most of Brazil is far too hot both in winter and summer for the cultivation of truffles. However, the climate in the most southern part of the country (Fig. 9) is considerably cooler particularly in upland areas. A talk on the possibility of growing truffles in this part of Brazil was given by Ian Hall at a conference in Manaus-

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Amazonas (Hall 2013). In this paper he showed that the mean monthly temperatures in Säo Joaquim and Bom Jesus were very similar to those in Manjimup, Australia and Opotiki, New Zealand, respectively.

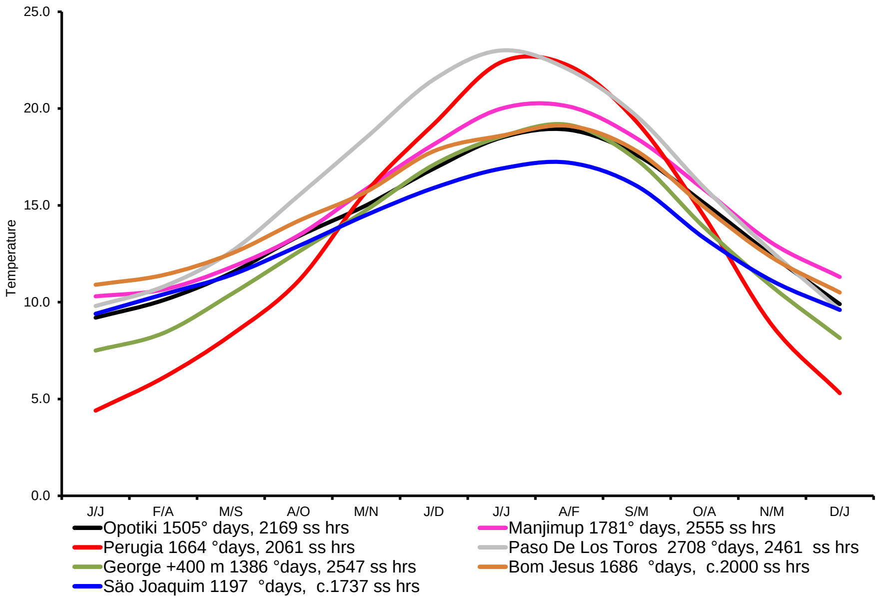

Fig. 9. Mean monthly temperature curves for Paso De Los Toros (Uruguay), Säo Joaquim and Bom Jesus (Brazil), and calculated temperatures on a site 400 metres higher than George, South Africa, compared with the meteorological stations near productive truffières at Opotiki, New Zealand, and Manjimup, Western Australia, and Perugia, Italy.
Fig. 9. Confronto fra le temperature medie mensili di Paso De Los Toros (Uruguay), Säo Joaquim e Bom Jesus (Brasile), le temperature calcolate ad una altitudine superiore di 400 m rispetto a George (Sud Africa) e quelle delle stazioni metereologiche vicine alle tartufaie produttive di Opotiki in Nuova Zealanda, Manjimupin Australia occidentale e Perugia in Italia.

Uruguay

Paso De Los Toros in the centre of Uruguay is at 35°S (Fig. 9) and has a mean daily temperature of 9.8°C in July, only 0.5°C warmer in July than Manjimup, Western Australia, whilst the mean January temperature is only 0.5°C warmer than Perugia. It would seem that providing suitable soils can be found in these areas production of the Périgord black truffle is feasible.

Conclusion

The successful cultivation of truffles in the Southern Hemisphere, in a completely different context to Europe, has provided insights that are of great value to trufficulture in Europe such as the demonstration that it is possible to modify an acidic soil to make it suitable for several species of truffle.
Despite the significant initial problems encountered particularly in New Zealand, significant industries have now been established based on the cultivation of truffles and other edible mycorrhizal mushrooms for consumers in the Southern Hemisphere and for off-season markets in the Northern Hemisphere. For example, Périgord black truffle production in Australia in 2016 was about 13 tonnes and projected production is estimated to reach 45 tonnes in a few short years.

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