



LIFE
Priorat

Manual of techniques for sustainable mountain viticulture

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**MANUAL OF TECHNIQUES FOR SUSTAINABLE MOUNTAIN VITICULTURE
LIFE-PRIORAT PROJECT**

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Prologue

This manual is the result of the PRIORAT project “Making mountain viticulture development compatibility with European Landscape Convention objectives” co-funded by the European Union LIFE programme and coordinated by Fundació Fòrum Ambiental.

The LIFE PRIORAT project arose in response to the growing sensitivity for the environmental impact of mountain viticulture. This is particularly the case in successful areas such as Priorat, which is currently experiencing a real boom in activity. This response is based on the certainty that the prosperity and economic progress of mountain viticulture cannot be achieved at the cost of the environment. In turn, the solutions proposed in this manual bear in mind the fact that mountain viticulture cannot cease to be financially feasible and, therefore, in a context of strong global competition, businesses will be forced to innovate in the way in which the vineyards are operated.

The endless creativity developed by Mas Martinet Assessoraments over its 15-plus years of experimental work in mountain viticulture has been used as a basis for this project. Thanks to Castillo de Perelada and Domaine de Cabasse, it was possible to compare the feasibility of such proposals in other environments, such as the Garbet estate in El Empordà and the Malmont estate in Côtes du Rhône, whereas the technical coordination and the huge task of disseminating the results of the project fell on Fundació Fòrum Ambiental, which took every effort to raise awareness of the challenges of mountain viticulture to reach all the players involved. The technical coordination was the responsibility of Dr. Moisés Cohen, a specialist in Climate - Plant - Soil and irrigation information management in precise agriculture, who objectively assessed the data obtained.

Furthermore, this project would not have been possible without the close cooperation of the project advisory committee formed by Professor Fernando Bianchi de Aguiar and Sara Colomera - both representing Centre de Recherches d'Études et de Valorisation pour la Viticulture de Montagne (CER-VIM), Professor Arno Simonis from DLR Mosel, Joan Queralt from DARP, Xavier Mateu from Centre de la Propietat Forestal de Catalunya, Pere Sala from Observatori Català del Paisatge, Josep Maria Milla, Salustià Alvarez - Chairman of the D.O.Q. Priorat Control Board, Ignacio Orriols - Director of La Estación de Viticultura y Enología de Galicia and, most particularly, Professor Alvaro Feliu, who was responsible for producing the manual and without whose devotion this manual would not have been possible.



The techniques presented are the result of fifteen years of experimentation in the Priorat region, with the end support of the LIFE project, and open the road to sustainable mountain viticulture. The publication of this Manual merely seeks to share the experience accumulated with others dealing in viticulture or areas related to it. Professionals may reflect on the different ideas offered and apply those considered appropriate, adapting them to their needs and to the conditioning factors of the land on which they carry out their activity. This is the true purpose of the Manual.

Despite this, the research and experimentation work must continue, because current knowledge remains insufficient to obtain excellence and because sustainability is an evolving process, the final point of which cannot be precisely defined and, furthermore, changes with the technological, environmental and social-economic environment. Mas Martinet is already working on the scientific consolidation of the main criteria outlined in this Manual and on the development of new ideas.

Carles Mendieta

Director of Fundació Fòrum Ambiental



1. Introduction

This Manual seeks to describe and assess the most evolved version of the techniques developed by Mas Martinet, with the support of the Life-Priorat project, to progress towards sustainable mountain viticulture. The Manual also provides useful knowledge to guide mountain viticulture decision-making.

The technical, environmental and financial aspects of mountain viticulture are covered in a synthetic and practical manner, although bearing in mind their complex nature. The Manual also seeks to be informative and, therefore, describes terms and concepts that may be familiar to professionals in the sector but that will help others, either producers or consumers, with less experience in viticulture understand their contents.

Mountain viticulture is characterised by the steep natural slopes of the land on which the vines are planted¹. In addition to this, Mediterranean areas are characterised by a low or medium annual rainfall (between 400 and 600 mm), although with episodes of very intense rain that often reach 100 mm in only a few hours and can exceed 200 mm in one or two days. This torrential rain is extremely erosive and is able to strip tons of soil per hectare.

Traditionally, Mediterranean mountain viticulture overcame these adverse natural conditions by using very time-consuming soil retaining techniques involving small dry stone walls, which had no significant impact on the morphology of the land. Furthermore, these walls made what was then manual work easier by reducing the slope of each terrace. In other cases, the proprietor lived with the slope and the erosion, accepting low production stock due to the lack of fertile soil and irregularity of the weather. These techniques, based on plenty of cheap manpower that offset low productivity, have shaped a very characteristic landscape over the centuries with a strong personality and balance and upon which part of the identity of some districts has been built.

The old vineyards that have remained are now a heritage that must be preserved as much as possible. However, except in cases with very specific purposes, the financial feasibility of new plantations is no longer possible using traditional techniques. Growing competition and the globalisation of the wine markets, together with relatively unfavourable natural conditions for crop mechanisation has forced

¹ The experiments developed within the framework of the project have been carried out on land with gradients of between 20% and 70%. The average gradient of the cultivated land in the Priorat region is 45% (24.2°).



mountain vine growing regions to introduce changes in the way in which vineyards are operated and to innovative in their productive and commercial strategy:

- Apply new techniques to increase productivity, maintaining or even increasing the quality of the grape.
- Stand out in the market by producing wines that combine a good basic quality with a strong personality, intelligently using the natural and human resources available.

With future generations in mind, long-term survival of mountain viticulture requires strong financial feasibility, with low vulnerability to inevitable market fluctuations.

However, the prosperity and economic progress of mountain vineyards cannot be achieved at the cost of the environment. Alongside the taste for good wines, social sensitivity for environmental protection has also increased. More particularly, mountain landscapes provide natural, visual, social and economic values that must be preserved. The symbiosis between the landscape and the wine culture is leading to a new tourist sector: wine tourist, which in some regions may be as economically relevant as the viticulture and its derived winery activities themselves.

One of the main techniques for increasing mountain vineyard productivity is by forming terraces for crop mechanisation. To a greater or lesser extent, land terracing using basic, badly thought out techniques leads to the breakdown of the landscape and the increase in erosion due to concentrated of run-off. Random terracing is environmentally unsustainable and, in particularly sensitive areas, may put the continuity of the wine production activity at risk.

However, the landscape does not have to be mummified. The land must be kept alive and production work must be permitted, provided this is done harmonically and without jeopardising its most emblematic views. The abandoning of the vineyard and loss of the mosaic landscape are just as bad as the proliferation of grossly terraced vineyards that monopolise the land due to their low productivity. The landscape must also be accessible and open and it must encourage compatible contact between viticulture and society.

The Mediterranean area also has a high risk of erosion of poor and sparse soils that form a natural resource of high value. In more arid areas, erosion may be the start of desertification processes that are extremely difficult to reverse.



Old vineyards in the Priorat region

Therefore, a fragile environment is another of the basic conditioning factors that the new mountain viticulture must include, especially that of the Mediterranean.

The profitable and environment-friendly development of mountain viticulture is not, therefore, an obvious matter. Economic and environmental sustainability may seem irreconcilable objectives and often present themselves as such. However, the recipe for environmental protection is no longer an

Why continue with mountain viticulture?

Despite the adverse orographic conditions for vine growing and the high production costs this represents, it is important to ensure mountain viticulture remains environmentally and financially feasible in order to:

- Uphold an activity in the rural mountain environment and avoid population drift. Prosperous economic activities must be added to the feeling of belonging to an area.
- Preserve unique landscapes formed over centuries of balanced work by mankind.
- Promote the mosaic use of land as one of the most appropriate measures of preventing forest fires, especially in Mediterranean areas. The vine has been proven to be a good fire-break.
- Conserve the variety of autochthonous grape especially adapted to the land and the climate of each area.
- Use the strong character of mountain regions to produce unique, top quality wines for the global market.

These historic, socio-economic and landscape-based values offer a relevant contribution towards the cultural and biological diversity of the planet and are an undeniable tourist attraction, the exploitation of which may have significant weight in the local economy.

In short, it is a case of using a strong local identity as a driving force for sustainability and platform for influencing global values.





impassable productive barrier but instead a socio-economic opportunity that is simple, despite its complexity: **(eco)innovation**. In the case of mountain viticulture, the increase in resource productivity and grape quality must offset the increase in vineyard construction and operating costs as a result of the prevention of environmental impact (negative external economic issues). As such, mountain viticulture may become a production activity with a present and a future and provide all its direct and indirect economic added value to the districts housing it.

The final social aim is to contribute towards rural development and to secure the population in the region through the creation of stable, quality jobs for both men and women that enable them to enjoy decent standards of living.

With these clearly established goals, the mountain viticulture developed by Mas Martinet is based on the integration of two apparently independent groups of techniques that provide all their sustainability potential when applied together:

- Sustainable terracing.
- Vine vigour control.

These techniques have been developed without bearing in mind the vine-growing limitations established by the regulations of the European wine production regions (irrigation, production per hectare, number of buds, etc.). This has been the case for two reasons:

- The heterogeneity of these limitations, which often respond more to a century-old tradition than solid scientific bases, and that have may have made perfect sense in times gone by but that must now be reviewed in light of current knowledge and technological possibilities.
- The very nature of an experimental and demonstrative project that seeks to open up new ways for sustainable mountain viticulture requires very clear final objectives, despite acting with complete freedom to meet them, with no pre-established conditions that restrict creativity before it can be expressed. Innovation also consists of questioning the traditional way things are done.

More specifically, it is the wine producing regions that must be ready for the new viticulture techniques arising, taking the necessary time to assess them carefully and decided how many should be integrated into existing regulations and in which manner, in order to modify or add to them.

2. Vineyard terracing

Terracing consists of the transformation of natural sloping land into a new profile formed by flat strips of a certain width (terrace), connected by new slopes of a higher gradient than the original natural slope of the land. This has two main functions:

- To preserve the soil and retain the water. In general, agricultural planting requires the previous clearing of the land to remove any existing plant life, including roots. The soil is therefore unprotected against erosion, which may act aggressively due to the natural slope of the land. The basic mission of terracing is the controlled runoff of rainwater so that soil erosion is avoided as much as possible. Furthermore, controlled runoff increases the possibilities of water infiltration to the root area of the plant.

The loss of soil fertility may be compatible with certain viticulture practices that base grape quality on a reduction in the production capacity of the stock. However, in the cultivation systems discussed in this Manual, maintaining the soil and its fertility is important for the plant to express all its vigour (see Chapter 3).

- To make working the vineyard easier, particularly through mechanisation with no labour-related risks of machinery overturning. Terraces act as flat service passageways from where all operations involved in vineyard cultivation can be carried out (pruning, disease control, collection, etc.). Slope maintenance work can also be carried out from the terraces. Vineyard mechanisation to increase productivity requires a terrace width that is the minimum necessary for the corresponding agricultural machinery to pass along.



Predominance of terraced vineyards in the Priorat region

The municipality of Porrera covers an area of 2.896 ha, which is equivalent to 16.5% the Priorat designation of origin area. The average gradient of the municipality is 46% and its altitude is mostly between 200 m and 600 m above sea level.

60% of traditional vineyards in Porrera were abandoned between 1986 and 2003, from the 256 ha of 1986 to the 107 ha of 2003. During that same period, terraced vineyards increased from 20 ha to 291 ha, a 1,450% growth. In the more recent period between 1998 and 2003, traditional vineyards grew barely 12% (from 95 ha to 107), whereas terraced vineyards increased by 260%, from 111 ha in 1998 to 291 ha in 2003. This strong increase in terraced vineyards has continued over the past four years.

As a whole, vineyards in Porrera increased by 44% between 1986 and 2003 and 93% between 1998 and 2003.

These figures are considered representative of the overall evolution of Priorat.

Source: R. Cots-Folch et al./Agriculture, Ecosystems and Environment 115 (2006) 88-96.

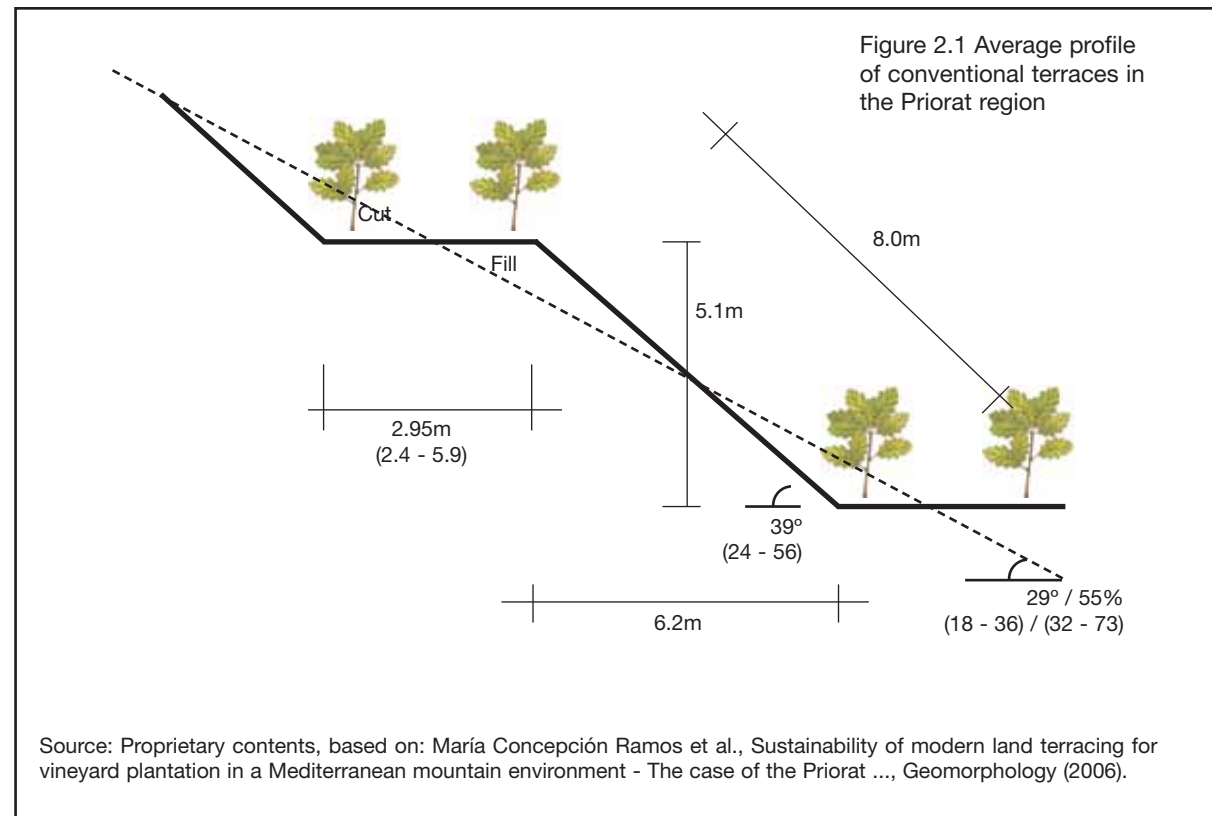
2.1. Conventional terraces

Terracing involves action on the mountain that modifies the natural conditions to a greater or less extent.



Work undertaken by the University of Lleida in the Priorat region characterises the main design parameters of conventional terraces built over the past decade (Figure 2.1). The following is of note:

- The width of terraces varies between 2.37 and 5.91 m, although most widths are between 2.4 and 3 m, with an average of 2.95 m, in order to be able to plant two rows of stock on each terrace with enough space between them for machinery to pass.
- The gradient of the terrace slopes varies between 24° and 56°, with an average of 39.4°, in areas with natural slopes of between 18° and 36° (32 and 73%), with an average of 29° (55%).





Quarry effect



Quarry effect



In general and synthetically, conventional terraces are built in line with a predominant criterion: the cost of construction. More complex financial calculations are not made, which bear in mind other costs with repercussions that may be greater in the long term (loss of useable land, terrace maintenance, low productivity, etc.). In addition to this is insufficient environmental and landscape sensitivity, especially by viticulture companies whose management is unfamiliar with the cultural tradition and identity of the mountain region in question.

This group of causes endures because there are no clear, objective and well-documented technical recommendations to guide vine growers and construction machinery operators.

The conventional design of terraces may lead to environmental and operational problems in vineyard operations.

2.1.1 Environmental problems

- Impact on the landscape

The steep natural gradient of the land, together with gentle artificial slopes and notable terrace widths lead to very high, long slopes that tend to disrupt the harmony of the landscape. A “quarry” effect is caused, especially when flat-land cultivation is sought to be reproduced in the mountains.

Forcing the construction of sections of straight terraces for easier vineyard control creates extremely artificial polygonal profiles that do not blend into the surroundings. Furthermore, this type of profile requires the transverse transportation of soil, making the work more difficult and expensive.



Flat land should not be reproduced on the mountain





Polygonal terraces generate an artificial landscape

- Soil erosion

Erosion may be intense due to the excessive length of slopes, thus increasing runoff, and especially due to a lack of a well-designed terrace drainage system:

- Continuous and constant slopes are not implemented along the entire terrace for controlled runoff. Furthermore, drainage crossways to the terraces are often not planned.
- Some terraces act as drainage for others, which generate an accumulation of sediments on recipient terraces.



Badly drained terraces. Lengthways slopes lead to lower points from where the water will run off downhill. If the rain is heavy, sideways runoff may cause significant damage to the vineyard.





Severe erosion on a slope, putting some stock at risk



Repairs on eroded slopes





Soil erosion by rainwater

Water erosion of soil is a complex phenomenon of degradation in which the force of the water breaks up, pulls away and moves the horizontal surfaces of the terrain. This is a natural process made worse by human intervention, particularly through certain agricultural practices. Water erosion acts through two basic mechanisms:

- **Impact of raindrops.** The tapping of drops of rainwater against the soil pulls off and moves its particles. In the case of very heavy rain, the force of the drops destroys the structural components of the soil. This process is accompanied by a decrease in porosity, given that most of the volume of pores in soil corresponds to the space between its aggregates. The erosive power of water is emphasised by the alternating of long periods of drought that leave the land dry, cracked and with no significant plant life to relieve the impact of downpours.
- **Runoff.** This is the water erosion mechanism par excellence. Rainwater that does not penetrate the soil runs along its surface and drags soil particles along with it. Runoff erosion depends on several factors: the rainfall, the density of plant cover, the topography of the land and the hydrological resistance and properties (penetration speed, water storage capacity and hydraulic conductivity) of the soil affected.

The following must be noted among the many negative impacts of erosion:

- Reduced thickness of the soil layer on the plots affected. In areas with scarcely developed soil, this may lead to a complete loss of the soil layer.
- Decreased soil fertility, associated to the leaching of minerals and the loss of organic matter and nutrients.
- Destabilisation of slopes and increased risk of landslides.
- Aggradation of adjacent areas (agricultural land, irrigation installations, roads, etc.) due to the effect of sediment dragging.
- Chemical substances from fertilisers and pesticides that are dragged along by sediments may eutrophicate or pollute watercourses.



Vineyard built by filling in a natural gully instead of forming terraces on the mountain with drainage to the gully



At the top of the photo, terraces that are too wide, with little soil use; slopes of varying height that make erosion control difficult

Both problems lead to an accumulation of water in land depressions, also due to sediments that act as a small dam. When this stagnation of water breaks, water and mud run off with notable destructive force, which is multiplied as they run downhill and may form gullies and cause extreme destruction.

The building of terraces should not invade natural watercourses such as gulleys or streams. With heavy rain, water will seek its natural course and will end up severely eroding the terracing. Any repair work undertaken, as well as being extremely expensive, will be useless in light of a new episode of Mediterranean rainfall. In these cases, the sediments dragged along as a result of erosion may be large and create serious problems downstream, such as the aggradation of neighbouring estates or roadway infrastructures.

- Slope instability

The studies carried out in the Priorat region by the University of Lleida¹ show that landslides are frequent, even with unexceptional episodes of rain. 74 different landslides were identified during the work in the municipality of Porrera. An exponential relationship was observed between the volume of the landslides and the length of the slope. The movements detected caused damage to plants and infrastructures (vine training, irrigation, etc.). Landslides also hindered or prevented machinery from running along the terraces. It is precisely this difficulty and the steep gradients that greatly complicate the access of the necessary machinery to restore damaged terraces.

When a loader is used for earthworks, the terraces are formed using the conventional technique of cutting the top part of the mountain and filling the bottom part. Hence, the moved (cut) soil is placed on the mountain in its natural state. This creates a fragile surface between the solid ground of the mountain and the soil on top, making landslides more likely (see Section 2.2.3).

- Low soil use

To obtain a certain grape production, an under-optimised design of the terraces (width, slope gradient, etc.) means that the soil surface used is far greater than that strictly required. For example, a terrace width of almost three metres is insufficient for three rows of stock but too much for machinery to run along with two rows of stock. The flat-land planting criteria cannot be reproduced in the mountains, where the land must be made the most of to minimise the traumatic effects that terracing always involves to some extent.

¹ María Concepción Ramos et al., Sustainability of modern land terracing for vineyard plantation in a Mediterranean mountain environment - The case of the Priorat ..., Geomorphology (2006).





Occupational risk: perpendicular accesses to level lines with an excessively steep gradient



Difficult to optimise cultivation work due to the varying width of the terraces

The landscape and hydrological conditioning factors mean that mountain soil is a scarce resource that must be used productively. As can be seen later on in the Manual (Section 4.1), the techniques developed in Life Priorat provide the same grape production as with conventional techniques, but using a much smaller area of land.

2.1.2 Vineyard operation problems

- Occupational risk

In some plantations, the roads to the terraces are too steep because they are laid out perpendicular to the level lines. This involves a labour-related risk with regards to machinery traffic. The risk is maximised on the bends accessing the terraces, particularly when driving a tractor and a trailer.

- Reduced labour productivity

The natural slope of the land is often variable along the level lines. A solution sometimes applied to prevent terraces with steep slopes from being built, which would make work difficult and worsen erosion problems, involves increasing the width of the terrace. A variable width must be used by planting a higher number of rows of stock, which leads to unproductive routes and complicated manoeuvres to access all the vines.

Another solution applied to avoid this problem is to build intermediate terraces that end up draining off into other terraces, generating the erosion problems already indicated.

Moreover, work cannot be comfortably carried out behind the inner row of stock (e.g. for slope maintenance work) that also tend to aggrade to some extent due to slope erosion.

- Heterogeneous soil fertility

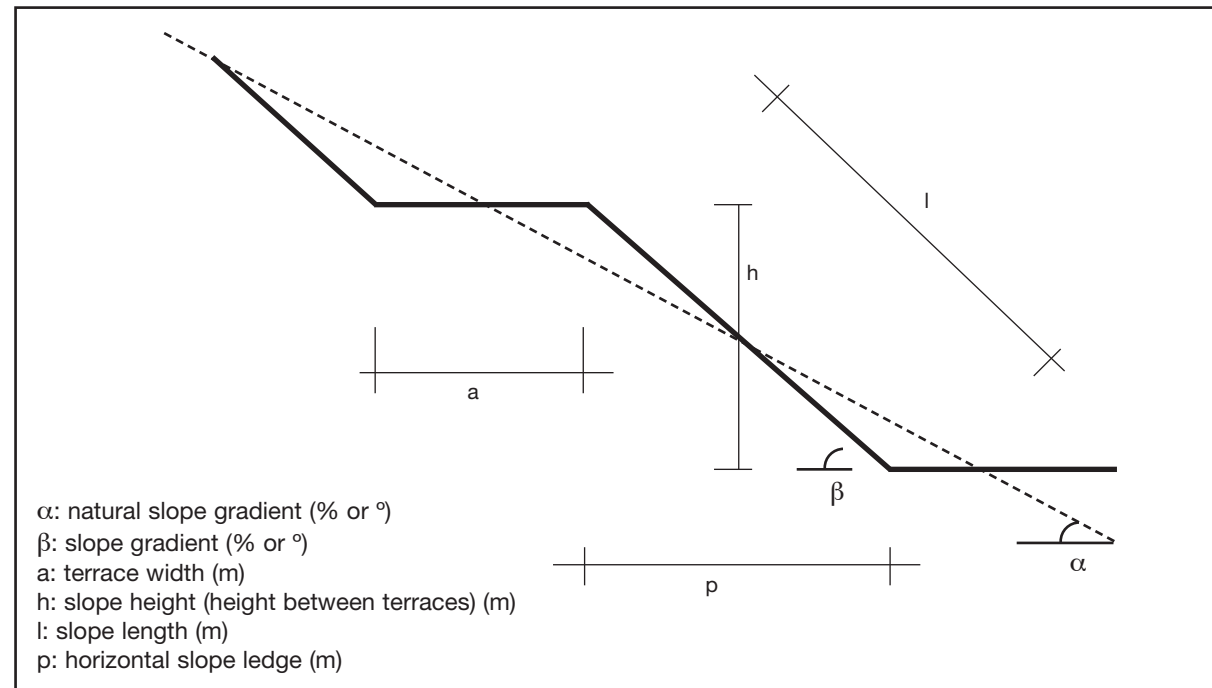
When the land is built using the conventional technique of cutting the top of the mountain and filling the bottom part, the inner row of stock is planted directly on a compact substrate without the top layer of soil, whereas the outer row (valley side) is planted on turned over soil. This means that fertility cannot be homogeneous.

2.2. Sustainable terracing techniques

The experiment carried out by Mas Martinet shows that the environmental and operative problems of conventional terraces can be overcome through the application of appropriate design criteria. This section describes the main criteria developed that have given good results in the Priorat region.

Figure 2.2 shows the different variables involved in the design of terraces:

- For a given normal slope (α), the terrace is defined by establishing any two of the remaining parameters. For example, if the width of the terrace (a) is established, on decreasing the slope (β) gradient, the height between terraces (h) increases. However, if the width of the terrace (a) is reduced, the slope (β) gradient can be decreased without increasing its height (h).
- The slope gradient (β) is always greater than the natural gradient of the hillside (α).





Centre left is a plantation on a terrace, with slopes measuring over 1.5 m in height. The appearance of the lower three terraces improves as the slope height decreases. On the right of the photo is a plantation on a slope that blend in very well with the landscape, as terracing is almost imperceptible



Natural land with a gradient of over 60%. The slopes do not exceed 2 m in height; slope plantation

2.2.1 Blending of terraces into the countryside

The basic design criterion is for the terrace-vineyard as a whole to adapt as much as possible to the natural morphology of the land, minimising land movements and introducing no artificial forms that could grossly stand out from their surroundings.

- In general, the height of the slopes (h) is limited to 1.5 m.

This criterion is basic so that aggradation does not disturb the harmony of the landscape. For greater slope heights, terracing becomes extremely visible and stands out from its surroundings, giving the vineyard the aspect of a quarry and the greater the high of the slope, the more noticeable it becomes.

In any terracing, the stock can be planted on the terrace or on the slope. When the vine is planted on the slope, the limitation of its height may be somewhat more flexible, as the plant life will help the slope blend into the surroundings. However, it is wise not to exceed slope heights of 2 m in any case.

- The width of the terraces (a) must be limited according to the natural gradient of the land, so that the above criterion is respected at all times, i.e. the slope height does not exceed 1.5 m.

Where small modern machinery is used, the terrace width may be as little as only 1.3 m. This is the terrace width preferred by Mas Martinet and the only one used currently in its plantations (the may reach 1.5 m in width in some cases). It only allows for one row of stock to be planted per terrace and requires the building of a greater number of terraces than those used were the width to accept two or more rows of stock, making the work more expensive. To compensate for this, the height of the slope is lower and the area can be adapted much more easily to the mountain morphology. A single row of stock on the outer part of the terrace also has advantages regarding the landscape, given that the eye of a distant observer follows the ends of the stock in a straight line, without it being broken by other rows of stock located on the inner part of the terrace. This also makes access to the slope easier for maintenance purposes.

Both this and the previous criterion are completely incompatible with the construction of large levelled areas for the reproduction of flat-land vines, particularly on steep natural slopes.

- The ground layout of the terraces follows the level lines that are generally curved. Polygonal layouts are avoided, as they give the vineyard an artificial look that stands out from its surroundings. This criterion makes the use of conventional, straight vine training difficult or means that shorter sections have to be used. However, this is not a problem if the vigour control techniques indicated in Chapter 3 are applied.



The plant life on the peak is respected



Terraces measuring a constant 1.3 m in width; note the constant lengthways gradient



The terraces follow the level curves with no polygonal shapes

- The line of mountain peaks (where the gradient changes), especially if steep, and its plant life are respected and terraces are started several metres downhill.
- The rocky outcrops and older trees, uniqueness, landscape value or representativeness of the agricultural past of the estate are preserved in the terraced area to break up the continuity of the vineyard (green islands) and to provide a shaded area where workers can rest. In larger vineyards, autochthonous trees may have to be specifically planted. If a large tree is incompatible with the implementation of the vineyard, it may be worth replanting it elsewhere. The huts and other buildings with a cultural or tourist value are also respected.



The plant life of any banks of the gulleys or streams running alongside the vineyard and the plant life on the border of the vineyard are also respected, not only for their contribution to the landscape but because they retain the soil, act as a visual reference and maintain agroforestry biodiversity.

On all accounts, the conservation of these areas is planned in advanced before the earthworks are started.

- The area around the access paths to the estates and the path itself are also worth attention. As well as connecting the vineyards or the crop-growing land, providing access to the estates and enabling agricultural machinery to get around, paths are a privileged platform for observing the countryside, from where the uniqueness and details of the region that are imperceptible from more distance observatories can be appreciated. Wherever compatible with agricultural use, paths are open and accessible for public use in order to find a meeting point between the wine culture and its landscapes and society and to help form part of the network of infrastructures supporting wine tourism.

New access paths to estates have been opened within the framework of the Life-Priorat project. Certain design criteria are considered particularly important:

- Widths over 5 m are avoided. Where necessary, small, wider sections are built for heavy vehicles to be able to pass each other.
- Slopes and borders are finished and protected from erosion using appropriate plant life.
- Lengthways and sideways slopes are ensured good runoff.
- Where necessary, soft paving is used that blends in with the countryside.
- The use of urban-type signposting is avoided.



Single trees and green islands in the vineyard

2.2.2 Prevention of erosion and controlled run-off of rainwater

- The terraces are built on a constant 3% lengthways slope and a 4-5% sideways slope towards the mountain. As a result, the vertical distance between terraces remains constant throughout.

To strictly respect this criterion, excavation machinery equipped with a laser level is used, as shown later on in this section. This involves precise building work that requires a person with specific training in driving the machine (the machines must be adapted to the mountain and not vice versa).



Terraces with a constant lengthways gradient and width



Slope finishing with a constant height by laser levelling



- All of the terraces drain off to side drainage channels. The terraces change the hydrological system of the mountain. Water no longer runs over the different natural slopes of the land until it reaches the water courses but is channelled along well-built terraces to concentrate at its end points, increasing its erosive force. As a result, it is extremely important to plan the safe channelling of this water to natural watercourses where it can cause no damage. Hence, all terraces must drain into drainage channels built for this purpose with the greatest guarantees of resistance and stability. The optimum solution will depend on the morphology and resistance of the mountain formation on which the vineyard is located.





Terraces with sideways drainage in erosion-resistant area



The length of the slope may be greater when the gradient is gentle and planting takes place on the slope itself

According to the experiment carried out in the Priorat region, drainage channels should be located on the versants of the mountain (“costers”) where the rock is erosion-resistant. The concave areas of the mountain (“comellars”) are avoided, where sediments are accumulated and the risk of erosion is maximum: the water would drag along sediments to leave them wherever its speed decreases, causing an overflow that would destroy the drain and part of the terraces and aggragate watercourses and infrastructures. It is true, however, that the channel could be excavated and reinforced with some kind of covering, although this would be a useless, unnecessary and artificial expense. Furthermore, it would mean that more fertile soil, a scarce resource in the area, would have to be removed and, as can be seen later on in this Manual, the Mas Martinet cultivation techniques mean that its entire value can be used. Therefore, despite sounding contradictory, the drainage must be built on the slopes of the mountain where only a few centimetres have to be dug for an erosion-resistant channel.

Under no circumstances does a terrace drain onto another terrace. As already indicated, this practice has been seen to generate ridges at the reception point, where water is accumulated until it acquires enough force to break the obstacle, causing a release of mud that has destructive effects on lower terraces. Where rainfall is moderate, this severe erosion problem will not be generated, although sediment may be accumulated, making the passing of machinery difficult.

- The terrace length between two drainage channels is limited to 200 m to avoid erosion on the terrace itself. Half of the terrace (100 m) drains towards one channel and the other half towards the opposite channel.
- Watercourses such as gulleys or streams are strictly respected. Under no circumstances are these watercourses filled to build terraces. Quite the opposite in fact. Terrace drainage ensures that these watercourses are reached without obstacles.
- On terraces, the length of the slopes (l) with a gradient of over 25% is limited to a maximum of 6 m. For greater lengths, water has been seen to acquire excessive kinetic energy and may erode the slope and accumulate sediment on the lower terrace, thus generating water accumulation and machinery movement problems. However, this limit may vary according to the type of soil and the extent to which the slope is protected, e.g. by plant cover.

On gentle slopes, the maximum length does not depend on the risk of erosion but on the limitations of the machinery to work on this slope from the terrace (e.g. for the application of treatments to prevent stock disease), although this should never exceed 10-11 m.

This limitation to the length of the slope has very few repercussions in practice if a slope height of below 1.5 m is respected.

- Maintaining the good condition of terraces at all times is a basic condition for ensuring controlled water drainage and, ultimately, the stability of all the terracing:
 - Any accumulation of sediments or other obstacles on the terraces that hinder or prevent water from passing must be removed. Water must drain along the length of the terrace without accumulating and jumping sideways towards the valley, which would dangerously increase its erosive force.
 - Maintenance must be increased on the narrow terraces built by Mas Martinet (1.3-1.5 m), given that the section available for water to pass is quickly used up in the event of an obstacle.
 - Maintenance is also particularly important on the access paths to the terraces where the gradient and the length of the slopes and, therefore, the risk of erosion and sediment accumulation are greater. Furthermore, significant flows from the entire lengthways drainage of different terraces can accumulate at these points.

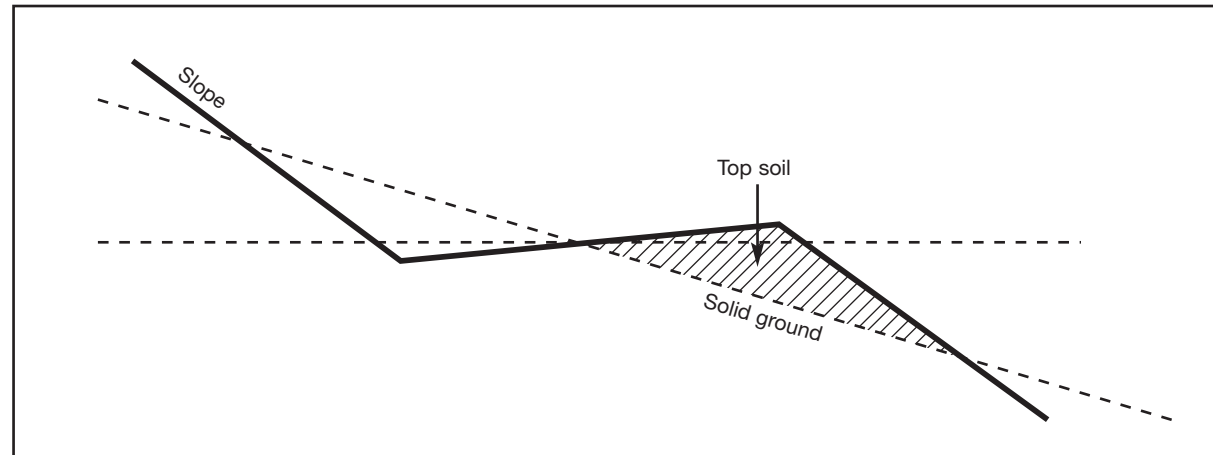
In Mediterranean areas where the episodes of heavy rain are relatively frequent, the controlled runoff of water is critical point in the construction of terraces. Where the necessary preventative measures are not strictly observed, extremely serious damage may be caused to the vineyard and adjoining areas, to the point of risking the survival of operations. The drainage network must be planned before starting terracing work.

It can therefore be concluded that the risk of erosion does not depend on the natural gradient of the land but on the design of the terraces: a badly designed vineyard on a 25% gradient will experience more erosion than well designed terraces on a 50% gradient.



2.2.3 Construction technique used for terraces and slope stability

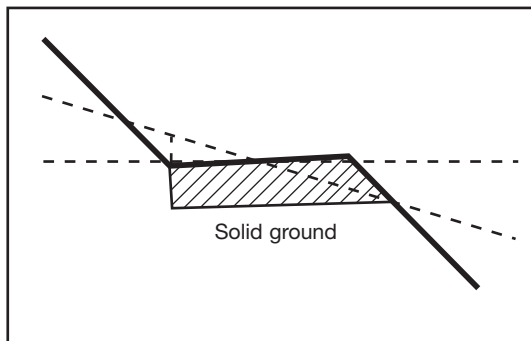
When the construction technique of cutting the top part of the mountain and filling the bottom part is used, a fragile surface between solid ground and the soil on top is created that often leads to landslides, even during unexceptional episodes of rain (see Section 2.1). Where terraces run perpendicular to the N-S direction of the general slate units strata of the Priorat unit, the risk of landslides is greater.



In view of this situation, the constructive solution applied to Mas Martinet terraces has proven to be effective, even in torrential rain. It consists of ploughing and turning over the soil mass to a depth that is sufficient to ensure all the terrace rests on a base of solid ground that slopes slightly inwards. The greater the natural gradient of the land the deeper the ploughed soil must be to ensure that any contact with the solid mountain is almost horizontal. In practice, a minimum depth of 1 m is plough, which is the average depth reached by the roots of the vine (agronomic criterion).

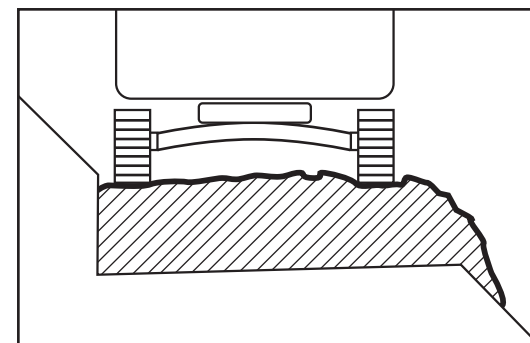
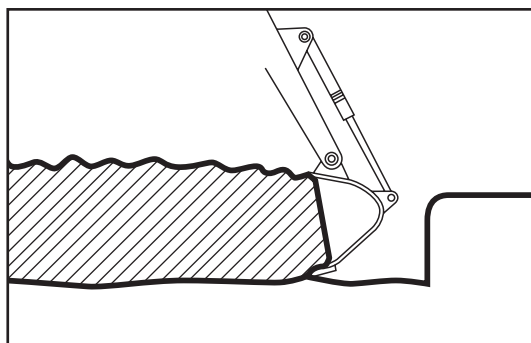
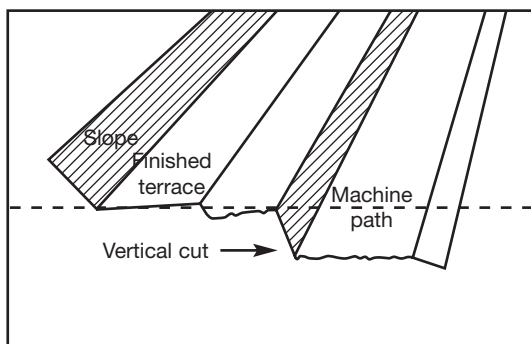
Even when applying this construction technique, there may be minor problems of landslides, particularly during episodes of fine rain that penetrates the outside of the soil. If these landslides are appropriately fixed during the first two years of the terraces, the problem is solved and will not occur in subsequent years, given that the terracing settles.





The full sequence of the construction system for a new terrace once the one above it is complete is as follows:

- The backhoe excavator opens up a path measuring around 3.5 m wide so that the machine can move forwards and makes a more or less vertical cut on the inside of the new terrace. Using the machine, the path is levelled until the height in relation to the upper terrace is kept almost constant along its entire length.
- The soil on the path is ploughed to a sufficient depth so that the new terrace rests entirely on solid ground. As already indicated, this depth depends on the natural gradient of the land (with a minimum of 1 m).
- The laser levelling machine is then installed. The backhoe excavator finishes the inner slope of the upper terrace and levels the inner part of the slope and inside of the terrace being built at the same time so that the lengthways gradient is 3%. The excess soil is placed on the outside of the same terrace so that the already levelled inside is higher.
- The machine runs along the terrace so that the inside tread marks the exact dividing line with the slope and the outside tread runs over and compacts the excess soil. The sideways slope of the terrace is then corrected to around 4-5% towards the inside, placing any excess soil on the outside of the terrace.
- Finally, the width of the terrace is marked (e.g. 1.3 m) and cut by the backhoe excavator as it moves along the terrace.





Terraces with a constant width following level curves



Zigzagged accesses to terraces to improve occupational safety

Once the width has been established, the slope height will depend on its gradient (β) and on the natural gradient of the land (α). The stable gradient of the slopes is a function of the internal angle of friction and cohesion of each type of soil ploughed. A direct cutting laboratory test assesses these basic parameters. In line with the construction technique used on terraces developed by Mas Martinet, the experiment on the Priorat “Licorella”¹ slate soil shows that slopes with a gradient of up to 65° - 70° are stable.

All experiments carried out by Mas Martinet regarding the construction of sustainable terraces have been undertaken in collaboration with the company Coll de la Teixeta (www.teixeta.cat) located in Falset (Priorat, Tarragona).

2.3.4 Effective and safe vineyard operations

- As already indicated, the terracing land is ploughed to a minimum depth of 1 m so that the roots of the vine have fewer problems in spreading at any point of the plantation. Furthermore, the earth retains water more easily, as it increases its fine material content. Where the earth is not turned over, water in slaty earth such as that of the Priorat region tends to escape through cracks or a layer of sludge is formed that allows for run-off without infiltration.
- The width of the terrace remains constant throughout as, therefore, does the number of rows of stock in order to avoid non-productive movement or complicated manoeuvres with machinery.
- Access to the terraces is zigzagged so that the gradient does not exceed 10-15%. This leads to the loss of a certain amount of space and the formation of small slope sections with a height or length above the maximums indicated, although occupational safety when moving with machinery is gained. With steep gradients, the risk of overturning the tractor is considered inadmissible, particularly at points where terraces are entered on a bend and where towing a trailer or other machinery.

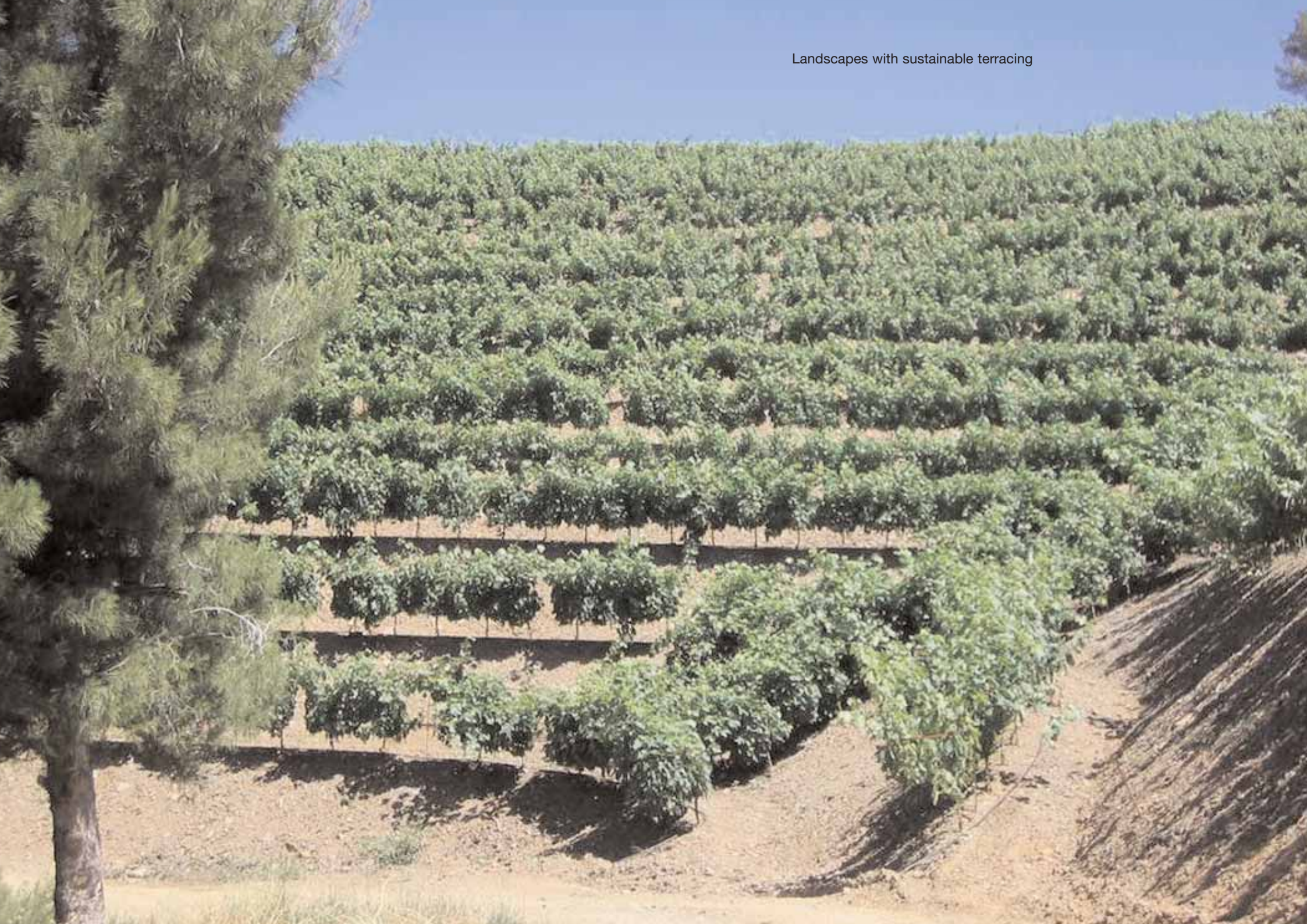
¹ Licorella: metamorphic slate rock



Landscapes with sustainable terracing



Landscapes with sustainable terracing



3. Vine vigour control

The terraces built using Mas Martinet techniques are environmentally sustainable, although they may have two disadvantages from a vine grower's point of view:

- They keep the soil more fertile and retain more water than conventional terraces. This does not sit well with predominant viticulture criteria, according to which excessive fertility and production is incompatible with grape quality.
- The construction cost is higher than that of conventional terraces. According to the latest experiments carried out in the Priorat region, the terraces built using Mas Martinet techniques cost between 30,000 Euros/ha and 36,000 Euros/ha.

The grape quality and financial feasibility of the vineyard are obtained through vine vigour control, the second group of techniques presented in this Manual:

- Plant architecture (including pinching).
- Precise irrigation.
- Plantation framework.
- Clearing.

In fact, the vigour control techniques described in this chapter overcome the two disadvantages of building sustainable terraces for the vine grower. The conventional plantation develops between 4,500 and 5,500 linear metres of production branch per hectare, with an ELA close to 7,000 m². As indicated later on in this Manual (Section 4.1), the application of vigour control techniques to sustainable terraces provides around 12,000 linear metres of production branch and an ELA easily in excess of 20,000 m², maintaining and even increasing the grape quality, preserving the soil and retaining rainwater. The greater productivity of the vineyard using vigour control techniques provides the same grape production as with a smaller piece of land. Therefore, as well as the environmental benefits described in Chapter 2, reforestation is reduced for the vineyard plantation.



Two additional techniques are also described that are not strictly necessary for vine control but that do improve its effectiveness and eco-efficiency:

- Plant cover.
- Disease control using a specific model.

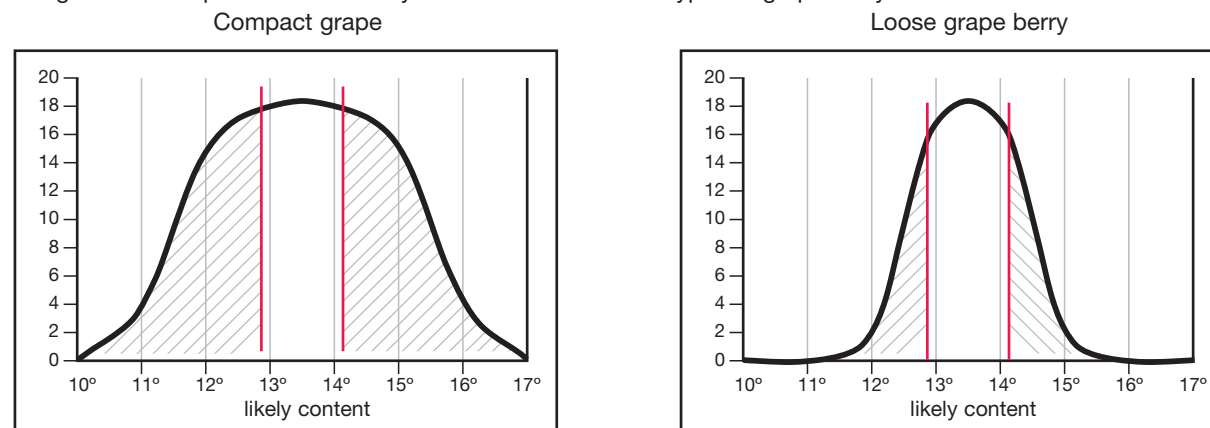
3.1. Technique basics

In the Priorat region in the early 90s, old vines produced the base grape for preparing good wines. As a result of Mas Martinet's experience in old vineyard operations, it was seen that grapes with small, loose berries were suitable raw material for top quality wines:

- Loose berries have more space to grow, are more aerated and exposed to the sun, making them less vulnerable to blight and rotting and, above all, ripen much more evenly.

This basic observation was proven by ripening tests that compared large, compact-berry grapes with small, loose-berry grapes. The curves indicated in Figure 3.1. show the likely alcohol content for each grape berry in graph form. In the case of the compact grape, a high percentage of berries either do not reach or exceed the required alcohol content. This percentage is much lower for loose grapes. In other words, with regards to the average values required, the compact grape is much more disperse (standard deviation on the Gauss curve) than the loose grape, thus explaining the difference in quality.

Figure 3.1 Comparison of the likely alcohol content of two types of grape berry



Grape ripening and wine quality

During ripening, the sugar to have accumulated in the plant through photosynthesis passes through the sap to reach the grape. Through the action of sunlight, the hypodermic cells of the berry (in the skin) perform the enzymatic synthesis of the polyphenols and the aromas using the sugar. The polyphenols form an extremely wide and diverse group of compounds (tannins, flavonoids, etc.) that give the wine colour, bouquet and flavour. It can be said that all the characteristics subsequently reflected in the wine are from the sugar of the reserves that synthesise the polyphenols during ripening.

Ripening forms part of the vine's reproductive strategy:

- When the fruit ripens, it gives off smells that attract animals.
- Animals eat the ripe fruit.
- In the ripe fruit, the seeds are already covered with lignin that animals cannot digest. They therefore expel them without spoiling them and allow the plant to reproduce.

The quality of a wine is determined by three main characteristics:

- Balance.
- Concentration.
- Character.

- Balance. A wine is balanced when its aromas and flavours are faultless and reduce gradually until they disappear, with no sudden changes or peaks.

Balance depends primarily on the ripeness of the grape. If the grape is not sufficiently ripe, green tannins are extracted during maceration that are responsible for different problems in the wine: astringency, dry mouth, acidity, etc. Excess ripeness causes sweetness with excessive tastes of dried fruits or figs. It is therefore extremely important for all grape berries to reach the required level of ripeness at the same time, i.e. evenly, with no excessively ripe berries next to others that are still green.

- Concentration: as well as the quality of the polyphenols and aromas, their quantity is also important so that the wine can mature correctly and produce evolving aromas during ageing. If the grape contains a small quantity of polyphenols, the biological activity of the wine during ageing will alter all the compounds and the wine will lose its required characteristics.

- Character: this characteristic enables wines with a good basic quality (balance and concentration) to stand out. The character of a wine depends on the "terroir", the climate, the grape variety and the author.

Whereas the balance and concentration can be assessed quite objectively by an expert, character is much more subjective. As with any work of art, the character of a wine can adapt to a greater or less extent to the specific tastes of each individual.



- If wines are to be produced for ageing (vintage), small berries have a larger specific skin area containing polyphenols, tannins, aromas and all the substances that, in sufficient concentrations, enable the wine to evolve.

It is clear that, if grape berries are separate and have a larger specific surface (surface per unit of volume), they receive more solar radiation and ripen more evenly, expressing all the aspects of the variety and the land harmoniously in the wine, making it different to other wines. And this is the basic aim.

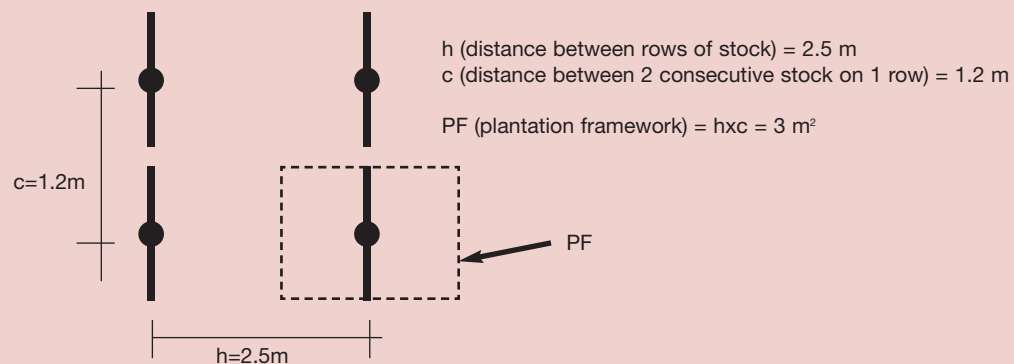
Vigour, plantation framework and root soil volume of a stock

The vigour of a plant is the strength of its vegetative activity. Technically, Mas Martinet defines the vigour of a stock as “the weight of the wood in the form of shoots that adult stock is capable of producing during one vegetative cycle”. Vigour is expressed in grams. For example, stock may have a vigour of 300 g or 1,400 g.

The vigour of dependent stock depends primarily on the variety of the vine, the fertility of the soil and the climate.

The plantation framework (PF) is the area defined by the space between rows of stock forming the service passageway or middle width and the distance between stock on the same row.

The root soil volume (RSV) is that available for the growth of stock roots without touching neighbouring stock. The RSV is determined by the plantation framework and the depth at which the roots are active, which may be 1 m.



It was also observed that the autochthonous varieties of Cariñena and Grenache on young vines planted in fertile land produced extremely compact bunches with very large berries that, once collected, had a deficient level of even ripeness (berries still green with others over-ripe).

Moreover, old vines are known to produce a quality grape for two reasons:

- The traumatic damage to the stock caused by yearly pruning prevents sap from passing and reduces its vigour, thus leading to grapes with small, loose berries.
- Plantations on steep slopes without terracing (“costers”) also reduce the vigour of the plant, given that any fertile soil is dragged away by the rain. In this case, erosion is the cause of lower, yet higher quality production.

The problem is as follows: in new terraced plantations with fertile soil with no erosion and water retention for penetration, the stock expresses all its vigour and tends to produce very large, compact grapes. Its berries no longer ripen at the same time and, as a result, the vine loses quality.

To date, the conventional solution given to this problem of quality consisted of “making the plant suffer” to reduce its vigour: no irrigation, no tilling, less fertilisation, etc. In other words, vigour is dealt with like a defect that must be corrected to obtain lower products of a higher quality, similar to that of old vines.

However, the basis of the Mas Martinet technique is to consider vigour as a virtue of the plant - showing its good condition - not as a defect and trying to **redirect it towards quality fertility**. A large part of the experiments carried out by Mas Martinet since 1997 have focused on optimising vigour management of the autochthonous varieties in the new terraced plantations.



3.2. Plant architecture

3.2.1 Shoot diameter

Mas Martinet therefore knew what the grapes should be like, although it was unaware how to obtain these on young vines planted on terraces. Initial experiments based on leaving fewer bunches on the stock or on reducing the distance between stock did not give the expected results: the grapes remained large and compact.

Finally, the hypothesis that experiments have proven to be true was posed: the morphology of the grape is related to the diameter of its shoot. It was seen that shoots exceeding 10 mm in diameter produce compact grapes, but if the diameter is between 6 and 8 mm, the grape berries are small and loose (Figure 3.2).



Figure 3.2 The morphology of the grape is related to the diameter of its shoot

To ensure that the shoots were thin enough, a larger number of shoots were left on the stock so that competition between them would lead to the required reduction in size. Where the vigour of the plant, which is inherent to its characteristics and growing conditions, is distributed among few shoots, these would be thick and long. However, where the same vigour or amount of wood is to be distributed among a larger number of shoots, these will be thinner and shorter (Figure 3.3).

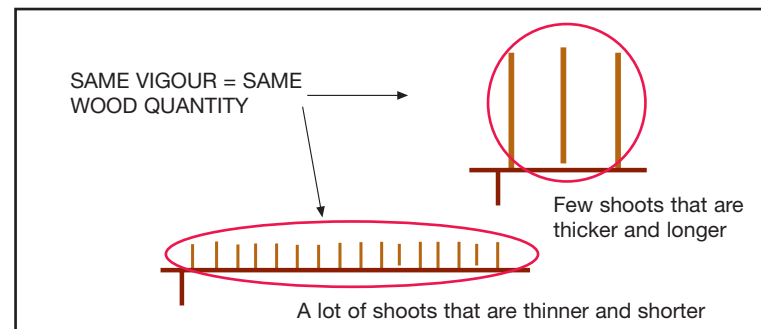


Figure 3.3 Competition among shoots for the same vigour



Compact Grenache grape



Loose Grenache grape

Experiments at Mas Martinet estimated that the optimum shoot was between 6 and 8 mm in diameter, around 1.2 m long and between 45 and 55 g. in weight.

3.2.2. Vine training

In “T” or “cordón royat” vine training with a distance between stock of 1.2 m, between 10 and 14 shoots are normally left with an average distance of 8-10 cm between them. It is also necessary to leave a larger number of shoots for the same plant vigour and, therefore, the production branch must be lengthened without varying the plantation framework. To do so, Mas Martinet has developed two new forms of vine training:

- Vine training with double production branch or “double training”
Whereas the length of the production branch in cordon royat vine training is equal to the distance between stock, in double vine training the length is doubled without modifying the distance between stock. This vine training consists of tightened wires between two metal frames located every 5 or 6 vines, which means that it can only be used when the terrace area is basically straight.



- Individual ring training (circle)

Given that terraces follow the level of the natural slope and do not adopt polygonal shapes, the straight sections of vine training are not generally a good solution. Where vine training cannot grow lengthways along the terrace, then the solution involves circular vine training. The length of the production branch allowing for this type of vine training is over 3 times greater than the linear distance available between stock (diameter): $\pi \times \text{Ø}$, i.e. $3.14 \times \text{Ø}$.

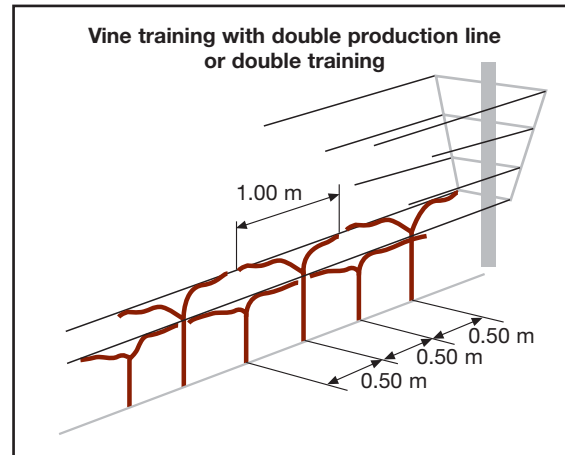


Conventional “cordon royat” vine training

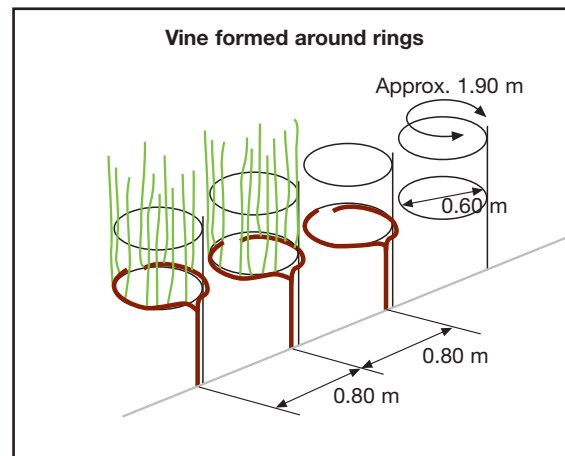
Vine training and production branch

Vine training is formed by fixed supported upon which the plant architecture is developed so that the shoots can grow sufficiently ordered and separated to provide aeration and sun exposure of the grape, pruning, the application of pesticides, collection and, in general, all viticulture work.

The production branch is the length of woody stock from which the shoots grow.



Vine formed by double production line



Ring vine training



In new vine training, the technique consists of leaving an average distance between shoots of 7 cm. In double vine training, with a distance between stock of 0.5 m, up to 14 shoots per stock may be left, i.e. 14 shoots per linear metre of production branch. Where vine training in rings of 0.6 m in diameter is used, stock may house up to 27 shoots, as the production branch measures 1.88 m (once again, 14 shoots per linear metre of branch).

Therefore, there is more space for a larger number of shoots depending on the vigour of each stock. For example, in a plantation with a distance between stock of 0.5 m, if the stock has a vigour of 500 g then 10 shoots would be left. If the stock has a vigour of 600 g then 12 shoots would be left.

Compared with conventional vine training, for a certain plantation framework, new vine training not only allows for a longer production branch on stock but also increases the effective leaf area (ELA). This provides a higher ratio between the ELA and the root soil volume (ELA/RSV), a parameter that, as seen later on, is essential for controlling the ripeness of the grape in adverse weather conditions. Furthermore, stock with a higher ELS may increase its production without reducing the concentration of polyphenols in the grape, as its larger “solar panel” enables it to synthesise larger amounts of sugars (Figure 3.4).

Effective leaf area (ELA)

The effective leaf area (also known as exposed or active) is formed by the leaves of the plant directly exposed to solar radiation. The greater the ELA, the more solar energy the plant can attract for synthesis, through the chlorophyll function, of the sugars required for growth and fruit ripening.

There is no single universally-accepted way of measuring ELA. A simple method consists of “scanning” the leaves on the shoot and measuring their area using computer software. However, not all the leaf area can be considered effective, i.e. directly exposed to solar light, given that in practice some leaves cover (shade) others, particularly if the shoots tend to intertwine.

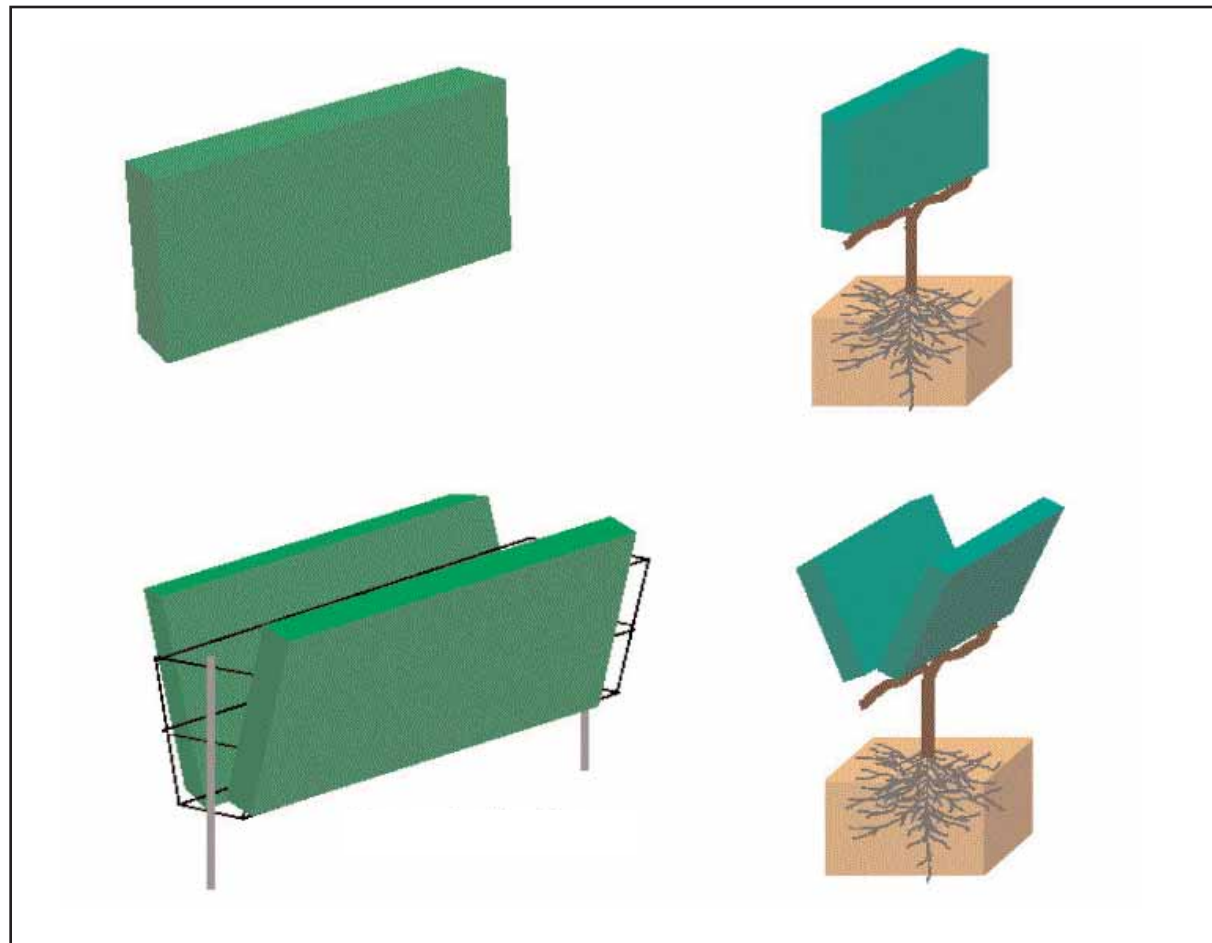




Leaf area in double vine training

New vine training offers an orderly layout of shoots so that the ELA is spread continuous and effectively, thus reducing the shading effect and the overlapping of leaves. Mas Martinet is assessing the ELA of each of the grape varieties and its relationship to quality production at its Priorat plantations. As a conservative measure, this Manual adopts an average ELA value of varieties planted of 0.14 m² for each shoot developed.

Figure 3.4 The effective leaf area may be doubled without increasing the plantation framework and, as a result, the root soil volume



3.3. Precise irrigation

3.3.1 Basic functions of water

Thanks to the chlorophyll function of the vine leaves (ELA), the plant photosynthesises sugars, accumulates them in the reserve tissue and uses them as required to carry out its functions. Throughout its vegetative cycle, the plant must produce the necessary amount of sugar for three purposes:

- To grow until all the foreseen shoots are developed and to form the effective leaf area.
- To reach optimum ripeness of the grape berries.
- After harvesting, to keep enough reserves to restart growth the following year.

The availability of water plays a predominant role during these processes of the vegetative cycle. Water has two basic functions:

- Intracellular water takes up the space inside the cells and acts as a universal solvent. All the biochemical reactions that the plant needs for its metabolism (synthesise hormones and proteins, transform sugar, etc.) are produced in the aqueous medium of the cell. This water is not used up in its supply and its volume does not vary, in order to maintain a constant osmotic pressure.
- Extracellular water takes up the interstitial spaces between the cells and is basically taken in through the roots and released through the leaves after circulating around the wood and bast vessels. The capacity of the plant to adapt to its surroundings depends on this. When the environmental temperature increases, the plant evaporates its extracellular water through leaf transpiration to cool the plant. Bear in mind that the chlorophyll function stops if the leaves reach a temperature of over 36-37°C. The leaves must be cooled to be able to continue photosynthesising the sugars.

If, during the hot months, there is less external water (that collected by the roots and that contained in air humidity) than that required by transpiration (more demand than supply), the plant uses its intracellular water. This causes a change in its osmotic pressure and, as a result, the plant's metabolism is modified:

- To transpire less and lose less water, it reduces the leaf area by eliminating the leaves around the base of the shoot, constricting the sap conducting vessels. These leaves turn yellow and fall off.
- It partially or totally dries the grape berries, which wrinkle and turn into raisins before dying off. These grapes will not longer ripen correctly and will affect the quality of the wine (strong acidity, green tannins, etc.).



Therefore, a shortage of transpiration water (hydric stress) has two harmful effects: plant dehydration, with the loss of leaf area and grape berries and a reduction in photosynthesis activity with, as a result, less available sugar production for ripening.

However, when there is excess extracellular water in relation to that required for transpiration (more supply than demand), the plant synthesises growth hormones and uses the sugar from the reserves to grow. This must take place during the spring months when the plant must develop all its growth and form ELA, although it must be avoided from early July until the grape is harvested, as described in the following section.

3.3.2 Need for irrigation water throughout the vegetative cycle

For the plant to correctly develop its vegetative cycle and for all the grape berries to reach the appropriate ripeness, the amount of water available to the plant is essential and must be controlled at all times:

- During the spring months, the plant needs water to grow. If it does not rain, water must be provided through irrigation. Too much water during this period has no significant negative repercussions, except for the wasting of a scarce resource. A lack of water would prevent the plant from expressing all its vigour and reaching the required architecture. If some shoots do not grow enough, the ELA will not be entirely formed and, as a result, will not attract the necessary solar energy to ripen all the target grape production correctly. Furthermore, it will be more vulnerable to an episode of heavy rain during ripening (late August and September).
- During the month of June, the plant must reduce its growth rate to stop completely early July. Growth is no longer necessary because the required architecture has already been formed and because it is not foreseen in the means of controlling the plant. Were it to continue growing, the shoots would double in size and the ELA would not increase. The sugars synthesised by the chlorophyll function must be accumulated in the reserves to await mobilisation for grape ripening during August and September. Irrigation must be reduced until the soil moisture is sufficiently distant from the field capacity, so that the plant can transpire to cool itself and continue with the chlorophyll function to accumulate sugar reserves, although without synthesising growth hormones that would lead to the sugar being used.



- This humidity must be maintained during the hotter months (July and August) and, therefore, the amount of irrigation required becomes more important: The plant needs the right amount of water - no more (growth in detriment to sugar reserves for ripening), no less (hydric stress and plant dehydration, with the loss of ELA when the humidity of the root soil drops to levels close to wilting point). However, excessive specific rainfall in July or early August does not necessary affect the grape quality, as the plant still has time to redirect its metabolism and accumulate enough sugar.

Soil moisture, field capacity and wilting point

Soil moisture is defined as the weight of water present in the soil per unit weight of dry soil.

Where:

Msw: moist soil weight

Dsw: dry soil weight (dried in oven to 110°C)

Therefore, moisture M (in %) = $(Msw - Dsw) / Dsw * 100$

After heavy rain, soil may be saturated with water (all its pores are full of water) to a certain depth. When the rain stops, part of this water (that contained in the larger pores) drains by gravity to lower layers at a speed that depends on the permeability of the soil. Once this infiltration has occurred, the moisture level remaining is known as the field capacity. Therefore, the field capacity is the maximum moisture the soil can retain once all the gravitational water has migrated to the lower layer, which is why it is also known as the water retention capacity.

Where no new water is soaked up, the soil continues to lose water by evaporation and by plant transpiration (in this case, vines). Water absorption by plants becomes more and more difficult as the soil moisture decreases, until the plant can no longer absorb any more water because the force of the particles and soil salts is greater than that the roots can apply. The soil moisture at this time is known as wilting point, i.e. the level of moisture when the plants can no longer absorb any more water.

In the Priorat “Licorella” slate soil, the field capacity and wilting point are around 17% and 7%, respectively.



- The situation becomes critical when the plant is concentrating on ripening (late August and September), given that there is not enough time to redirect a change in metabolism. The plant must direct the sugar towards berry ripening. Too much water would be counterproductive, although not because the accumulation of sugar would be stopped or because of a grape compacting effect (morphology is determined with the distribution of vigour and there is no longer cellular multiplication in the grape), but because the change in plant metabolism towards growth would leave ripening unattended (the activity of the hypodermic cells of the grape berry responsible for using solar radiation to transform the sugar in polyphenols, tannins, aromas and colour, etc.) would be reduced, with negative effects on the quality of the wine. It is then that control of the situation becomes more important. This is achieved using two basic mechanisms:
 - The soil moisture, which remains sufficiently distant from the field capacity, must be concentrated as much as possible within a section of 15 cm around the roots of the stock (which is achieved by using underground irrigation, as described in Section 3.3.4). Hence, the soil can absorb any heavy rain at its lower layers and the soil moisture prior to the episode of rain is re-established in a few days. Irrigation during this period must be as precise as possible.
 - The high ratio between the effective leaf area and the root soil volume of the stock (ELA/RSV) in Mas Martinet architecture is of the utmost importance here (Figure 3.5). In fact, the need for transpiration water (demand) per unit of supply in the roots is large enough to absorb a specific increase in soil moisture following heavy rainfall. Under these conditions, the risk that excess water be generated and the plant's metabolism change towards growth is much lower than in a plantation with a comparatively weaker demand. In general, greater demand per unit of supply provides greater control over the plant at all times, i.e. with greater dependence on the fate of the weather.

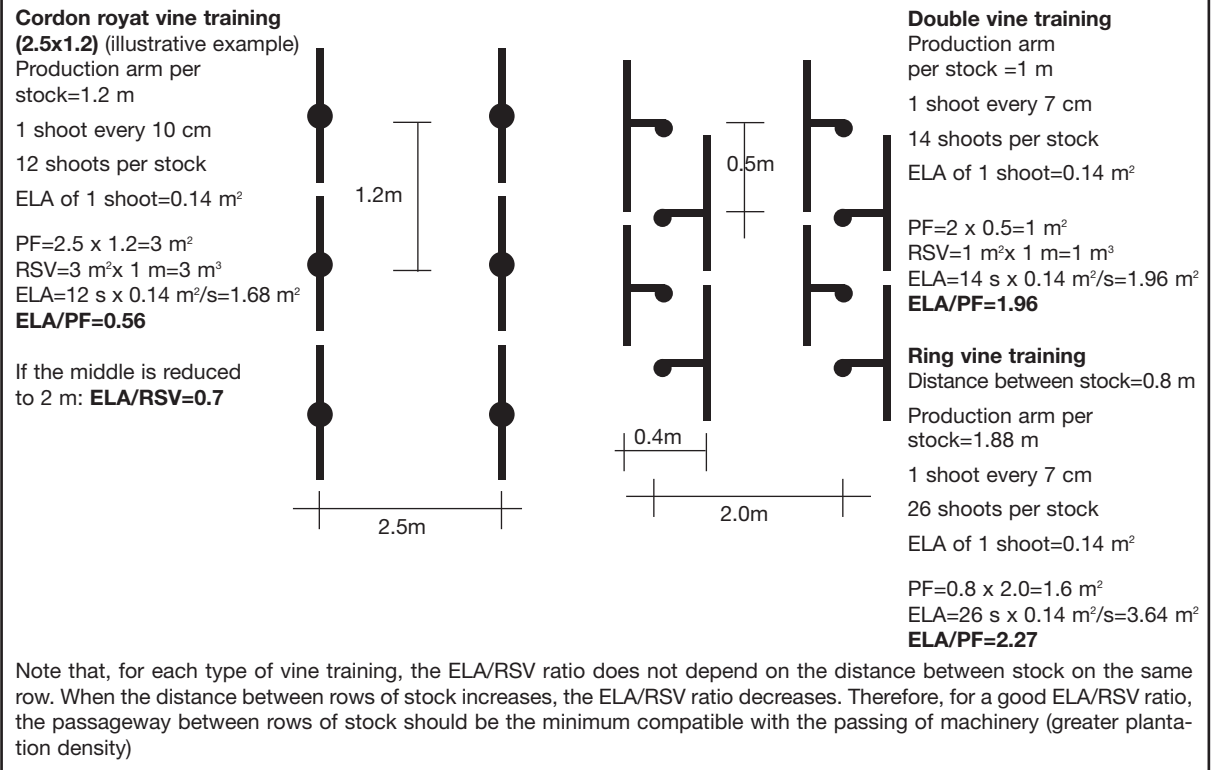
In synthesis, the plant must have the water it needs: If it has too little water, then it must be supplied (irrigation) and if it has too much then it must be possible to effectively dissipate it. Managing the water available to the plant means that its vital functions can be controlled:

- Growth control (the plant expresses all its vigour and forms the foreseen architecture).
- Hydric stress control: the necessary sugars are accumulated for ripening and the plant remains hydrated to keep its ELA in good condition and ensure the grape berries continue to develop.
- Ripeness control: Changes in metabolism due to too much water are avoided and the grapes obtain the appropriate quality and quantity of polyphenols, aromas and likely alcohol content.

It can be said that the time of irrigation is just as important or even more so than the amount of water provided.



Figure 3.5 Ratio between the effective leaf area and the root soil volume: a key parameter



3.3.3. Control of the hydrous state of the plant

The plant behaves like a water deposit that absorbs it from the soil and loses it through its leaves.

When the vine uses its extracellular water to transpire with greater or less intensity, its volume reduces. During times of low demand (night time, cloudy days), the plant collects water through its roots from the moisture in the soil and recovers its initial volume. This activity is constant and the contractions it causes (of several tenths of a micron) can be measured in the trunk using movement sensors known as dendrometers, made using alloys that do not dilate with temperature.



Dendrometers (to measure stock trunk diameter variations)

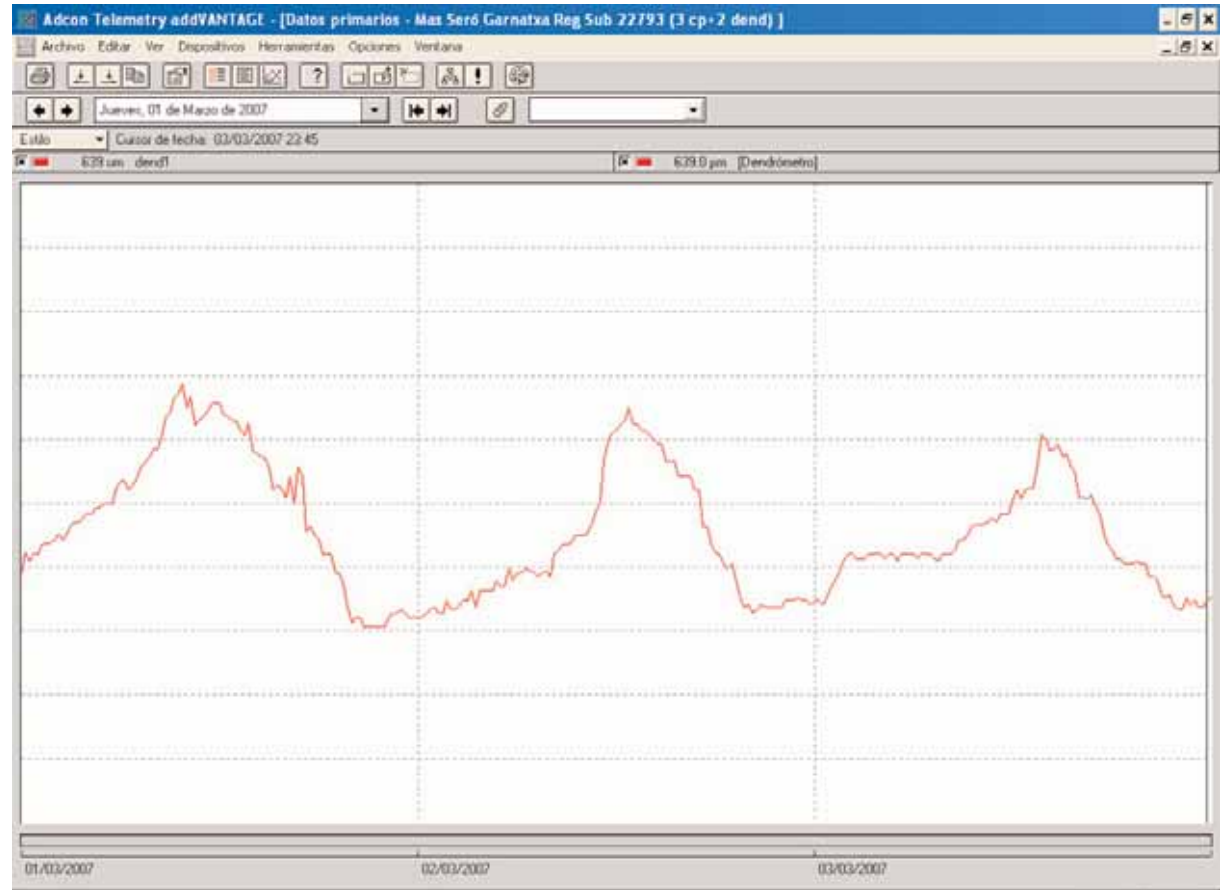


Figure 3.6 Daily dendrometer oscillations

The extent of daily trunk contraction reflects the intensity of the demand on the hydrous reserves of the plant.

Between the minimum value of one particular day and the maximum value of the following day, the increase corresponds to the hydric recovery plus the vegetative growth.



Trunk diameter variations (TDV) give two indicators of great value for the hydric control of the plant (Figure 3.7): the maximum daily contraction (MDC) and daily growth (DG). If this latter parameter is accumulated over time, this gives the accumulated daily growth (ADG).

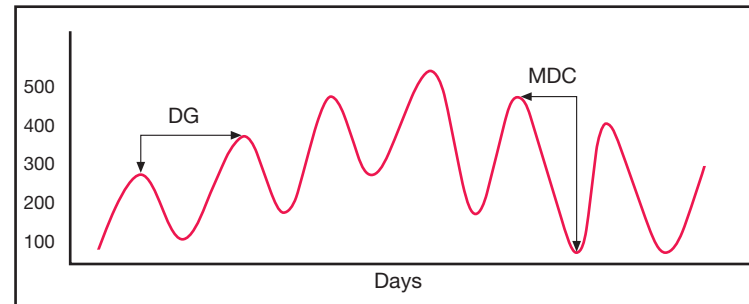


Figure 3.7 Indicators for the hydric control of the plant based on dendrometer readings. On the Y-axis: dendrometer reading in microns

Source: Moisés Cohen et al. Nutri-fitos 2003.

The daily growth (DG) is a good indicator of the plant's hydrous state. Under severe hydric stress, the trunk diameter decreases continuously that is only recovered when the plant has enough water available again to transpire.

Depending on the water needs of the vine during its vegetative cycle described in the previous section, the dendrometer graph must appear as indicated in Figure 3.8:

- During the spring months, the dendrometer graph must be ascending. The daily growth (DG) indicator must be regularly positive, i.e. the ADG must increase.
- During hot months and until the harvest, the dendrometer graph must be primarily flat. The DG is nil or of a small value.

The only exception may arise during veraison (two or three weeks during which the grape changes colour, early July in Figure 3.8): The sugar concentration increases considerably and, with this, the osmotic potential, which creates strong demand on the plant's hydrous reserves leading to the consequent decrease in the trunk.

After veraison, where the dendrometer shows a continued drop, the plant is suffering from hydric stress that puts ripening at risk: Irrigation is necessary for the plant to be able to cool itself and so that the leaves do not close its stomata and photosynthesis¹ detained. Where the graph is ascending, this indicates excess supply and irrigation must be reduced or stopped.

- After the harvest, the day is shorter and cooler and natural humidity is normally high. As such, irrigation loses relevance. During this part of the cycle, maintaining the leaves in good phytosanitary

condition (fungus free) is considered most important so that the residual chlorophyll function can remain active. The synthesised sugars will be used to start growth the following spring.

Figure 3.8 Balanced dendrometer graph



In red: dendrometer graph

In blue: graph of the soil moisture sensor at a depth of 50 cm.

¹ Some grape varieties have response behaviours to weather and soil parameters that are somewhat different to the general rule. A very notable case is that of the Merlot variety, as was seen on the Mas Martinet estates in the Priorat region. In situations of high temperatures and low relative humidity, the plant is incapable of absorbing irrigation water through its root system to overcome stress, even with the soil at field capacity. This affects photosynthesis and, as a result, the quality of the grape and the wine. Relative humidity is a decisive factor in the plant restarting its hydrous functions. Experiments show that the Merlot variety does not find its best potential in semi-arid areas such as the Priorat region (Merlot is from the Bordeaux region, with high relative humidity as it is where two large rivers join).

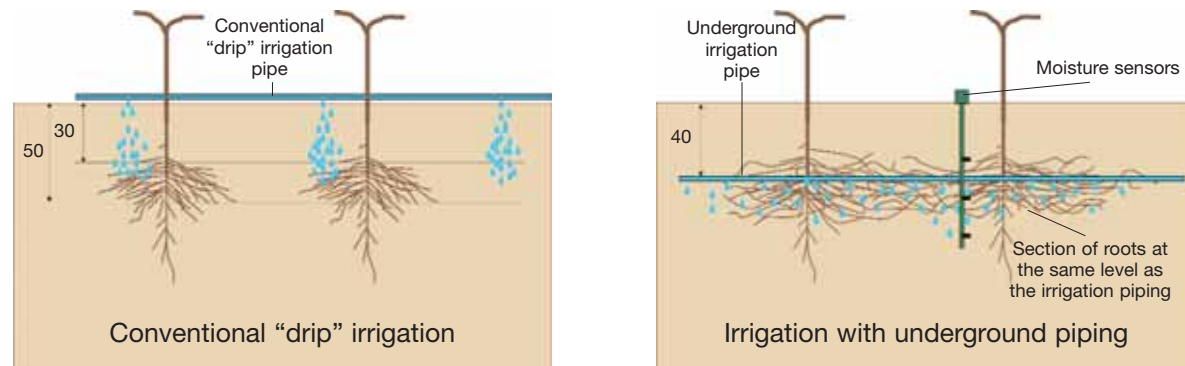


The dendrometer data is extremely useful because it provides information on the hydrous state of the plant a long time before the effects of a possible imbalance are visible (excessive growth, grape dehydration, leaf wilting, etc.). Bear in mind that it may be several weeks before the visible consequences of hydrous imbalances can be seen.

3.3.4 Irrigation application and control

The need for precise irrigation that maintains the appropriate soil moisture at all times without wasting water led Mas Martinet to experiment with the installation of an underground drip irrigation system. Thus, the water reaches the roots more directly without getting lost on the soil surface where it is not required. To do so, a specially-prepared piping system was used so that the roots did not put pressure on or obstruct it. It contains water outlet emitters every 40 cm and is 40 cm underground.

In conventional drip irrigation, the water piping system is placed above ground level. For the water to reach the roots, it is first necessary to saturate the top part of the soil, which leads to an unnecessary waste of water, made even worse by surface evaporation that may become quite severe.



With underground irrigation, a moist area is created around the roots.

However, the first year of irrigation must be above the surface because the roots have not yet fully developed. From the second year, irrigation can be placed 40 cm underground.

Precise irrigation requires sufficiently precise knowledge of the amount of water to be given to the soil during each session, i.e. when irrigation must be stopped, without waiting for the response from the plant through the dendrometer readings.



Sensors for measuring soil moisture at three depths: 35 cm, 50 cm and 70 cm

To do so, moisture sensors were fitted in the soil at three depths: 30 cm, 50 cm and 70 cm, providing the necessary information, e.g.

- When the soil moisture on the roots is low and the plant begins to have problems to extract the necessary water.
- When the field capacity is being reached and irrigation must be stopped so as not to saturate lower levels.

The data from the moisture sensors are radio transmitted to the control office where it is processed and the appropriate decisions made at all times. Irrigation can be started from that same office and can even be automatically programmed.

Figure 3.9 gives a guideline as to how the soil moisture levels must be kept during the vegetative cycle.

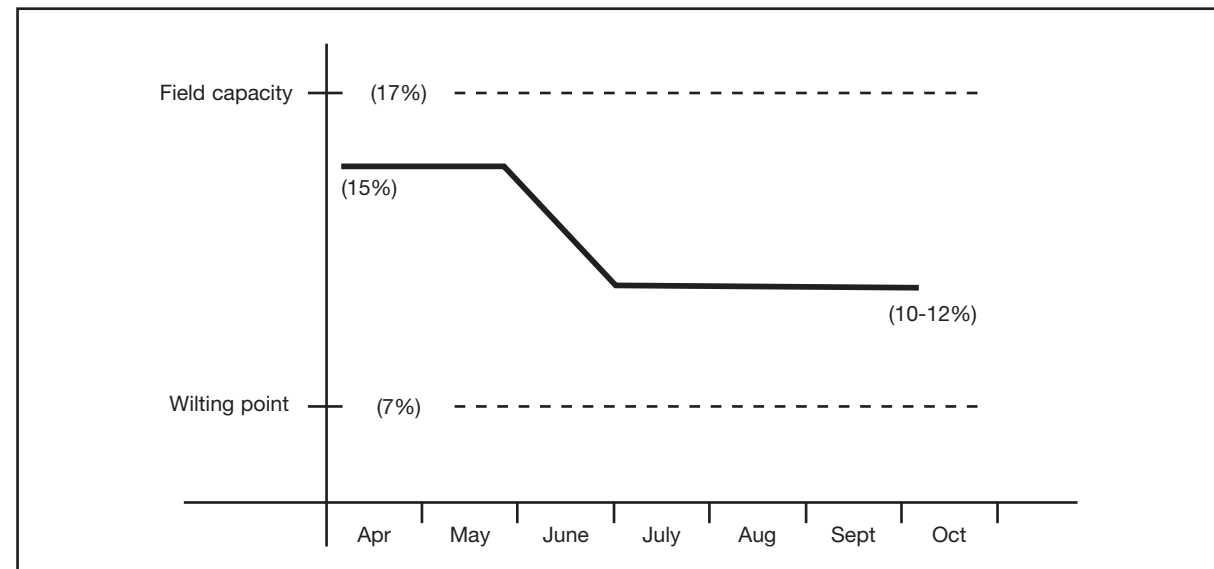


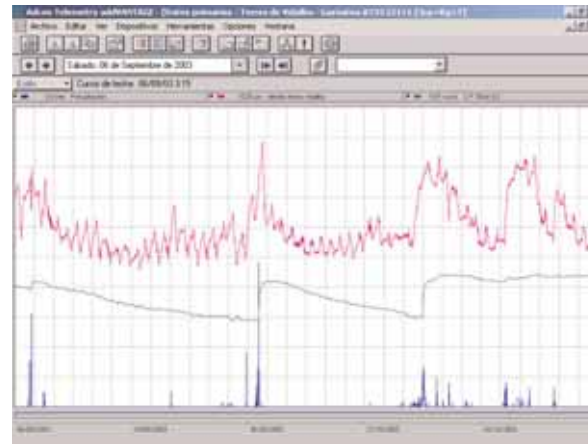
Figure 3.9 Relative soil moisture levels that must be kept during the vegetative cycle (illustrative in Priorat “Licorella” slate soil)



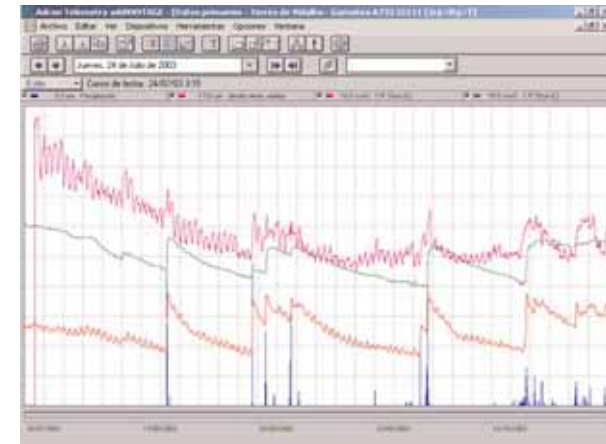
The drip irrigation installation must also be precise, i.e. when irrigation is stopped then dripping onto the roots must quickly stop. It must be taken into account that irrigation is installed on a terraced estate with steep slopes and that the water in the upper pipes tends to accumulate on lower levels due to gravity. Hence, the emitter system must ensure irrigation can be controlled at every height of the vineyard. The stock at lower altitudes must not receive more irrigation than those situations at higher levels. This strict control is not as necessary during the growth period of the plant because excess water will not cause significant problems, although it is essential as of June.

The experiments carried out by Mas Martinet within regards to applying precise irrigation and its control using dendrometers and moisture sensors were carried out in collaboration with two supplier companies:

- Netafim, Irriwise system (supplied in Spain by Regaber): drip irrigation including the applications for automatic irrigation, dendrometers and soil moisture sensors.
- Adcon (represented in Spain by Verdtech): dendrometers and soil moisture sensors.

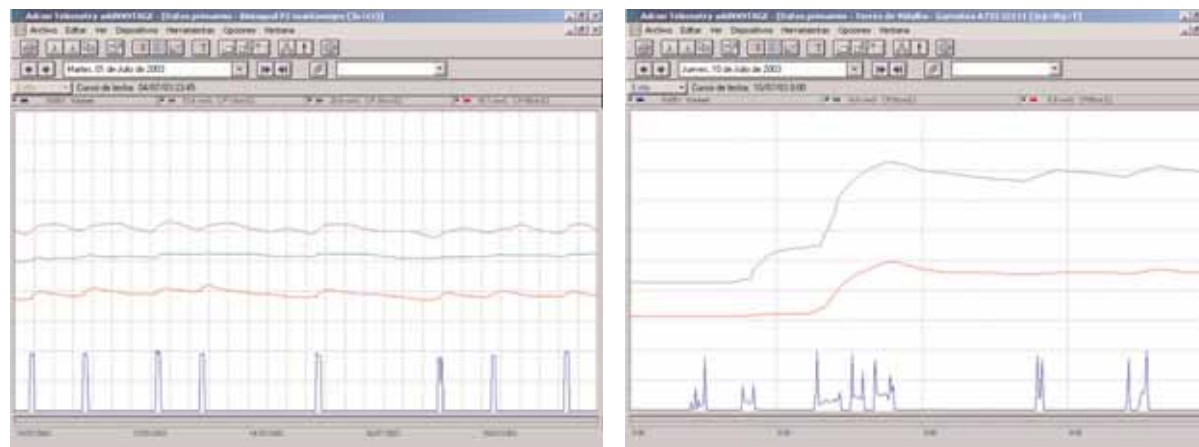


The episodes of rain keep the soil moist and the dendrometer graph remains balanced



The dendrometer indicates a risk of hydric stress during August. Irrigation and rainfall balance the situation





Irrigation: comparison between quality drip emitters and irregularly working emitters

3.4. Plantation framework

As indicated in Section 3.3.2, a shorter distance between rows of stock reduces the plantation framework (PF) without altering the effective leaf area (ELA) of the stock, thus increasing the ELA/RSV ratio. A high ELA/RSV ratio makes all vine growing control processes easier, although particularly that of ripening.

The distance between stock on the same row completes the definition of the plantation framework. This distance has no impact on the ELA/RSV ratio, although it does play a decisive role in the speed with which the plant's architecture is formed:

- All foreseen shoots with their optimal dimensions (1.2 m in length, 45-55 g in weight and 6 to 8 mm in thickness).
- The effective leaf area (an average of 0.14 m² on each shoot) so that the plant synthesises the amount of sugar it needs during its vegetative cycle.

The sooner the foreseen architecture is formed, the sooner target production with the required quality will be obtained. The Mas Martinet experiments showed that if the stock on the same row are placed closer together, the production branch is formed more quickly (Chart 3.1). It was also seen that stock



closer together leads to a more uniform distribution of the shoots. The vine is a liana plant (climber, creeper) and tends to develop larger and denser shoots on the production branch (furthest away from the trunk). If the stock is close together, this effect has a smaller impact.

Chart 3.1 Impact of the distance between stock on the formation of the plant's architecture. Double vine training

Distance between stock on the same row	Stock production arm	Production arm formed over 3 years
m	m	%
1.5	3	45
1	2	75
0.5	1	100

With stock 0.5 m apart and applying the form of control developed by Mas Martinet and irrigation, the vineyard can complete development of the entire production line during the third year. In general, it was concluded that the increase in production obtained by bringing forwards architecture formation easily offsets the greater investment in the plantation.

In double vine training with stock at a distance of 0.5 m, the length of the production branch is 1 m. If shoots are left every 7 cm, 14 shoots would be possible and, therefore, the stock should reach a vigour of around 700 g (45-55 g/shoot). This would be achieved by irrigation (and fertilisation) to offset any bad weather and soil problems that might exist. Hence, the required vigour would be distributed optimally among the shoots. Bearing in mind that the ELA of a shoot is 0.14 m² and with production for an initial vintage wine of 0.6 kg/m² ELA (see Section 3.5), theoretic production of a stock would be:

$$14 \text{ shoots/stock} \times 0.14 \text{ m}^2 \text{ ELA/shoot} \times 0.6 \text{ kg/m}^2 \text{ ELA} = 1.18 \text{ kg/stock}$$

If the rows of stock are 2.5 m apart, there would be 8,000 stock per ha (10,000/2.5/0.5) and production would be 9,440 kg/ha (8,000*1.18). If the distance between rows is reduced to 2 m, as work with smaller tractors is then possible, the theoretic production capacity would reach 11,800 kg/ha.

On an estate with thousands of vines, not all will reach the required vigour at the same time and cultivation practices must be adapted until this is achieved. In other words, 100% of the production branch will have been developed by the third year, although longer will be needed to reach the theoretic production of the vineyard.

In practice, some vines are not feasible or do not reach the vigour required by the maximum plant architecture. In other cases, the distribution of heads and buds does not allow a shoot to be left an average of every 7 cm and vigour must be limited. Furthermore, to make cultivation work easier, the vigour of all stock is normally equalled in each of the areas into which the vineyard can be divided. **In view of this, real production is normally between 60% and 80% theoretic production**, theoretic being considered as that corresponding to the ELA resulting from leaving a shoot every 7 cm.

To conclude, when vigour control techniques are applied, the plantation framework is determined using three criteria:

- High ELA/RSV ratio.
- Speed in obtaining the target production (in quantity and quality).
- Passing of machinery.

In general, the Mas Martinet techniques require high plantation density (first two criteria) compatible with the passing of machinery that should specifically be small (1 m wide tractor).

3.5. Stock clearing

Grape production with a sufficient concentration for a wine to keep depends on the effective leaf area, which determines the stock's capacity to synthesise sugars for ripening.

Mas Martinet experiments show that target production with vigour distribution is placed between 0.5 and 0.9 kg of grape per m² of ELA. For a first wine, production must be close to the lower limit and, in the case of a second wine, the top limit will be used. Young wines would accept a higher limit.

However, these values are a reference based on experimental trials and do not yet respond to sufficient scientific evidence. Some important questions still stand in relation to the quality of the polyphenols and the aromas and to the likely alcohol content.

Experiments and studies on these matters will have to continue over forthcoming years.



What is considered sufficiently verified is that the group of vigour control techniques is effective in sugar synthesis and, therefore, production per m² of ELA may be somewhat higher than in a conventional plantation.

It must be underlined that this production of between 0.5 and 0.9 kg/m² ELA may be obtained in the shape of large, compact grapes or small, loose grapes. **The morphology does not depend on stock production but on the diameter of the shoot**, which adapts by distributing the vigour between a larger or smaller number of productive shoots. Other architectures, such as the Lyra vine, are designed to increase ELA and with it production, although without influencing grape morphology.

With Mas Martinet architecture, each stock has a larger number of shoots and, therefore, produces a greater amount of grapes. To adapt production of between 0.5 and 0.9 kg/m² ELA, stock clearing is of greater significance here than in other architectures (Figure 3.10). The following depends on clearing:

- To reach the required ripeness of the grape berries (concentration, likely alcohol content).
- After harvesting, to keep enough reserves to restart growth the following year.

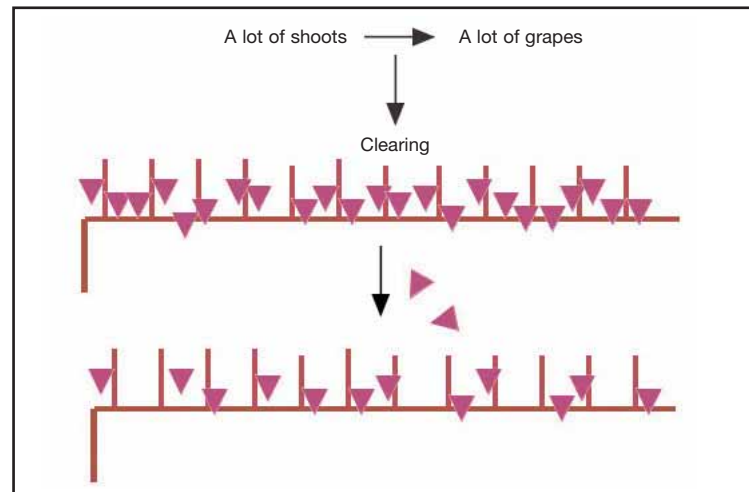


Figure 3.10 Clearing is essential with vigour control techniques

The weight range of one grape produced using vigour control techniques is known for each different variety. Using this weight, the number of grapes to be left on each vine² in order to respect production per unit of ELA can be calculated.

² Using vigour control techniques, the average is estimated at between 0.7 and 0.9 bunches per shoot.

In general terms, it is worth clearing as soon as possible, as it is considered pointless to allow bunches to grow that are later to be thrown away. It is also used to remove the grapes formed on shoots that have not reached optimum growth in order to increase the behaviour of the plant feeding these shoots to ensure full growth the following year. Clearing is completed during veraison, with grapes with a more compact morphology. However, Mas Martinet is experimenting on how the time and intensity of clearing influences ripening and the likely alcohol content. Clearing may be designed according to the alcohol content required (e.g. if clearing is moved to mid-September, when ripening is already well advanced, skin ripening may be completed without significantly increasing the likely alcohol content).

3.6. Synthesis of the basic control parameters

When Mas Martinet techniques are applied, the vigour of the vineyard stock, its production and the quality of the grape are not left in the hands of the weather or soil conditions of each vineyard but can be controlled using four forms of intervention by the vine grower (Figure 3.10):

- Vine training and pinching (plant architecture).
- Irrigation (or fertilisation).
- Plantation framework.
- Clearing.

Grape quality depends to a great extent on its morphology, which in turn depends on the plant architecture achieved through vine training. However, production depends on the intensity of clearing in relation to the ELA of the stock, according to the type of wine to be produced.

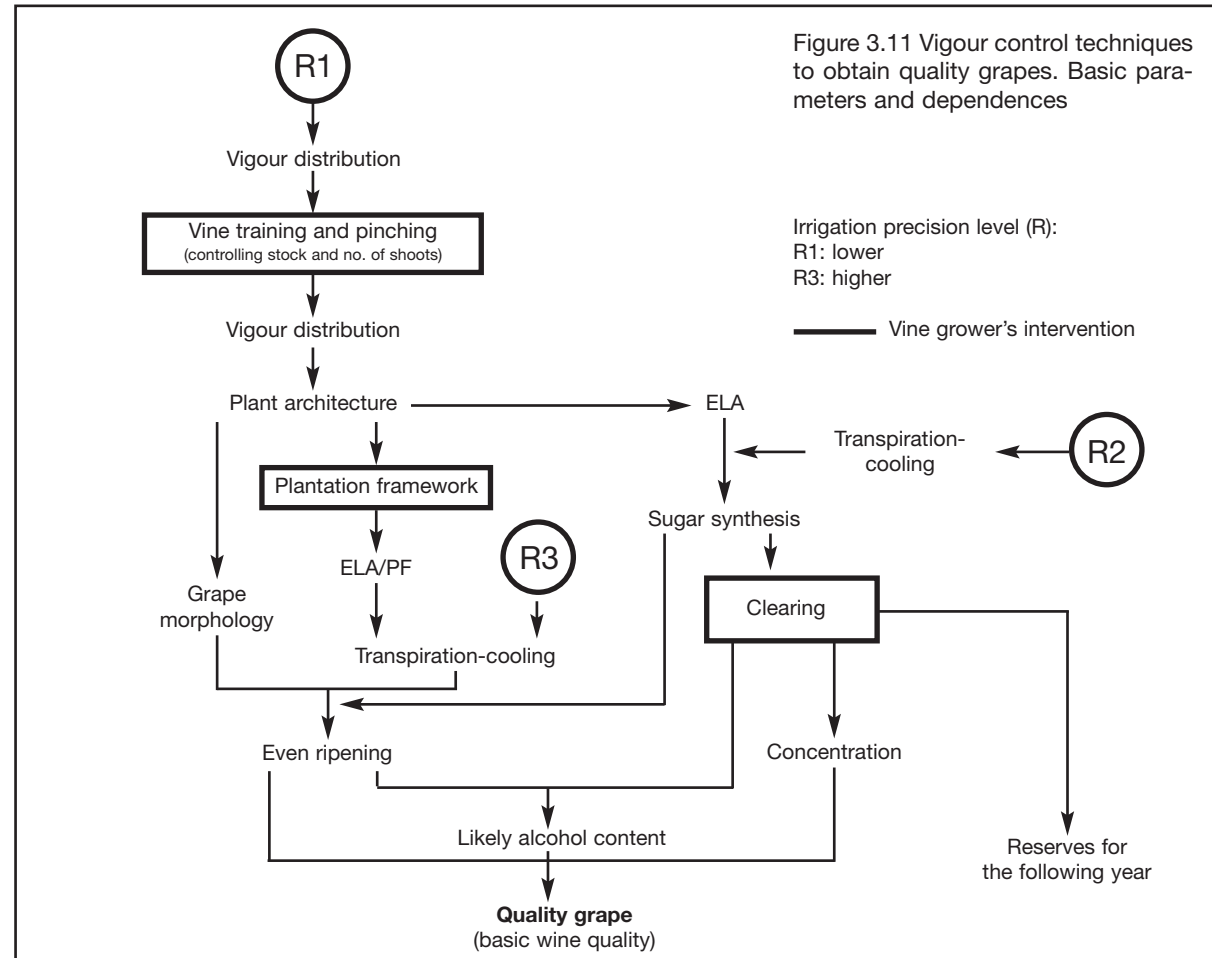
Within the plantation framework, the speed with which the target production is reached with the required quality can be controlled by the distance between stock on the same row. The distance between rows, together with the plant architecture, determine the ELA/RSV ratio, i.e. the ratio between stock demand and supply. The higher the demand in relation to supply, the greater the capacity to control the weather and soil conditions to intensify or accelerate the processes or to slow down or stop them.

The difference with more common cultivation methods lies in the way of balancing stock vigour with plant architecture:

- In general, conventional methods are based (with no precise justification) on balancing down: irrigation is limited, fertilisation is limited, low fertility soils are sought, etc. until the stock vigour is low enough to be distributed among the few shoots left on each vine.



- The vigour control method is based on balancing up: using vine training and precise irrigation techniques to ensure the stock expresses all its varietal vigour for distribution among a much higher number of shots. The method also has an added benefit the higher ELA/RSV ratio helps make ripening independent to the weather conditions.



3.7. Additional techniques

3.7.1 Plant cover

Vines have traditionally been worked for two main reasons:

- To close off the evaporation channels formed in the soil in order to retain more water.
- To remove weeds that compete with the stock for rainwater during growth periods and increase the risk of blight.

Working the land also has certain disadvantages:

- It breaks up lumps of soil that protect the organic matter from aerobic degradation (Figure 3.12)
- It creates surface mud that prevents water penetration and increases runoff and, with it, the risk of erosion.

Figure 3.12 Lack of physical protection for organic matter through working the land



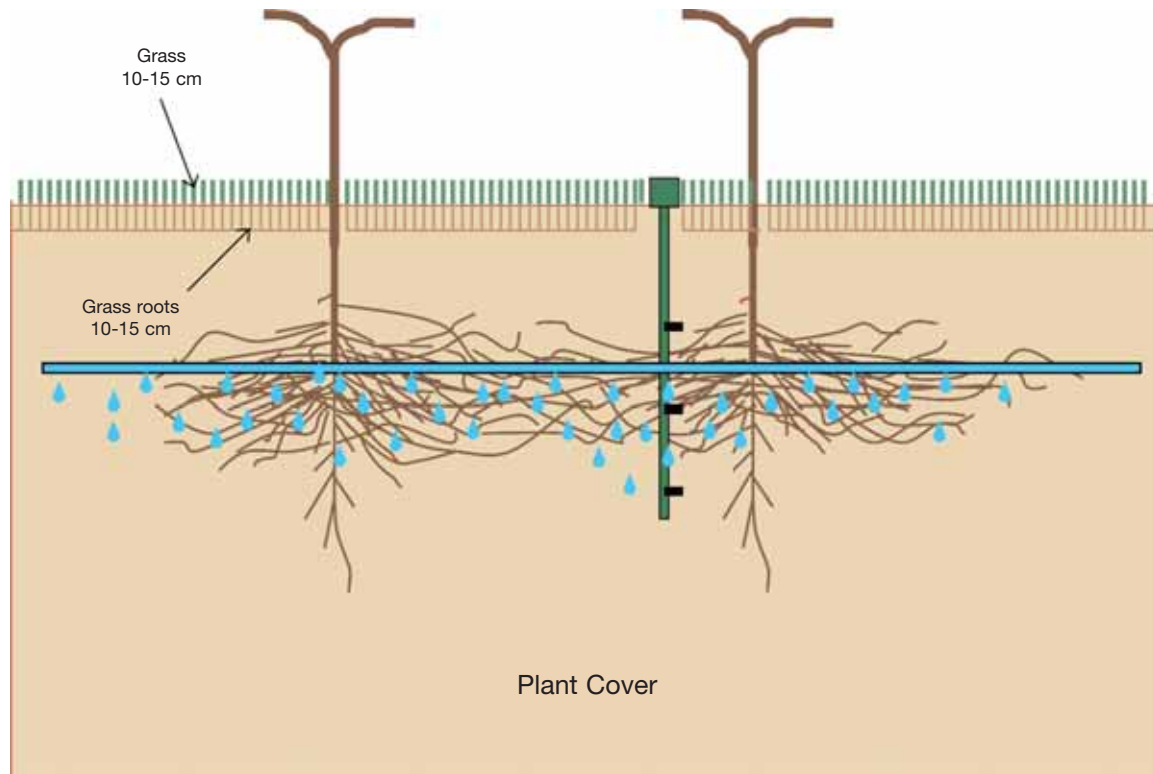
An alternative to working the land used by some conventional plantations involves the application of herbicides.

Under no circumstances do vigour control techniques consider working the vineyard, as they are perfectly compatible with the development of plant cover on terraces and on slopes. Plant cover does not respond to an apparent need to reduce stock vigour, increasing the competition for water, but to the notable benefits it provides³:

³ The use of plant cover is in line with European Union recommendations through the Common Agricultural Policy (CAP). More specifically, the fight against erosion in fragile mediums promoted by the CAP encourages the following measure for the growth of woody crops on terraces: "On plots with average slopes of over 10 % and soils with insufficient permeability, in order to avoid run-off problems, plant cover must be established in the centre between rows, covering a minimum of 50% of the surface using wild flora or planting cultivated species. The specific effects of run-off produced by torrential rain must be immediately corrected." (See Annexe II of Royal Decree 708/2002).



- Grass must be regularly cut (clearing) to work the land and improve the health conditions of the crop. Cut grass is left on the terrace and a biotype is created that turns organic matter into humus, thus increasing soil fertility and its resistance to degradation (erosion, compacting).
- Grass avoids direct impact of rainwater on the soil, which decreases the formation of crusts that favour surface run-off. Hence, water infiltration to the roots is increased and erosion prevented.





Plant cover being formed

The growth of plant cover using quick grass may be developed in two ways:

- Plant the appropriate quick grass (reproduction using tufts and shallow roots so that it only competes for the surface moisture of the soil, which is extremely ephemeral and has less impact on the vine).
- Cut other spontaneous grass before flowering so that it cannot reproduce and allow the quick grass to colonise the soil.



Quick grass

Moreover, it has been seen that working on terraces with a single outside row of stock ends up lowering the inside of the upper slope. The ploughed land is accumulated on the inside of the terrace and may even change the direction of the sideways slope of the terraces, which would lead to the lengthways draining system breaking up and a serious risk to the stability of the entire terracing.



3.7.2 Control of disease and blight

The risk to the vine is primarily concentrated into three diseases caused by fungus:

- Oidium (Cendrosa): The most important damage is located on the roots, as strong attacks cause the skin to stop growing, making the fruit crack and tear. Shoots also wither and the penetration of grey mould (*Botrytis cinerea*) is favoured.
- Mildew: This is one of the most famous and most serious diseases, as if the weather conditions are favourable, it can attack all the green organs of the vine to cause losses of up to 50% or more of the harvest.
- Botrytis (grey mould): This is seen on herbaceous organs (leaves, shoots and flower fruits), on cuttings-grafts in warm stratification chamber and primarily on bunches.

In general, three strategies can be applied for controlling these diseases:

- Systematic application of phytosanitary productions at several times during the vegetative cycle of the vine, independent to the external risk. The same applications are repeated every year.
- Collective model: The application of phytosanitary products follows the instructions of a wine producing district body created by local governments or by farming associations. These bodies base their recommendations on general risk assessment models that are fed on data from the weather stations located in the district.
- Specific model: Each vineyard provides a set of specific data from its own estate for an interactive risk assessment model that provides results that are more closely adapted to the situation of the estate.

This latter strategy has been experimented, applying a specific model from Holland. The following information must be added frequently to the model:

- Plant growth speed.
- Vegetative state (current time of the cycle).
- Grape variety (more or less sensitive).
- Level of plant densification or compacting.
- Weather data regarding the estate. It is therefore wise to install a weather station on the vineyard.
- Historic weather data from the closest or most representative station.
- Specific conditions of the estate (presence of a disease or blight on a neighbouring vineyard, stock affected on the vineyard itself, etc.).



Weather station on the vineyard

The model returns the risk to which the vineyard is subjected for the different diseases. If the risk exceeds a certain threshold, a preventative treatment must be applied. If the correct action is not taken, the model sends another warning and the application of a curative pesticide may then be recommended, normally of a higher toxicity than the preventative application.

Fungicides for the control of vine disease

The main diseases attacking vines are caused by phytopathogenic fungi. Fungicides used to control these diseases can be classified in three groups, according to the way they act with regards to the plant:

- Contact: these act on the green organs entering in contact with the product. They are used in a preventative manner, i.e. to prevent the disease from taking hold of the plant. Once the disease has taken hold, they are no longer of use to eliminate it (they are not curative). Rainfall of over 10 l/m² washes the product away and the plant becomes unprotected. Another disadvantage is that their action is limited to the treated organs (those with which they come into contact) and those forming after the treatment are unprotected.
- Penetrating: as their name indicates, they penetrate the treated organs and are, therefore, not washed away by rain. Their effects are preventative and curative (once the disease has affected the plant). They do not protect untreated parts.
- Systemic: these penetrate the inside of the tissue and are transported by the sap, thus also protecting shoots formed after application. They are essentially curative and are not washed away by the rain.

Preventative contact fungicides based on copper and sulphur compounds are the most commonly used. They are also the most environment-friendly, as the main ingredients exist in nature.

Penetrating and systemic fungicides are synthetic and, therefore, are foreign to the environment. If used, they must be alternated so that fungi do not become resistant.



Experience must be accumulated and a learning curve followed on the use of the model in order to enter the appropriate data at all times and to interpret the results. If this is achieved, however, the model is extremely effective and avoids many different unnecessary applications in relation to the other two strategies, with the consequent financial and environmental savings. It can be said that the specific model and experience may become true risk management. For example, the results from Mas Martinet in the Priorat region for 2006 were as follows:

- Systematic treatment of oidium: 6 applications (preventative and curative); Mas Martinet: 2 preventative applications.
- Systematic treatment of Mildew: 5 applications; Mas Martinet: none.
- Systematic treatment of Botrytis: 3 applications; Mas Martinet: none.

The collective model for the district gave intermediate results.

Minimisation of the use of fungicides by using the specific model can be considered sufficiently experimented, with good results.

In the Priorat region, wineries often follow the collective model whereas farmers selling the grapes prefer systematic treatments to avoid any risks, except where their customers indicate another form of procedure.

Among other controlled diseases and blight that are not included within the model, the following are of note:

- Grape moths: This is blight, the damage of which is caused by the first-generation larva that destroys the floral buds, flowers and even recently-appearing fruit. The second and third-generation larva produce more severe damage and even loss of the entire crop. The trap system is used to count moths and to decide when an insecticide is necessary.
- Root rot: This disease is caused by the fungus *Armillaria mellea* that takes hold of the stock roots and causes them to rot. It affects specific stock and only spreads through contact among roots. It has no treatment. The affected stock must be pulled up, the hole cleaned and covered and irrigation removed. Before planting the vine, all roots must be removed and the land turned over so that it is aired and dried, thus causing fungus inactivation.



4. Comprehensive sustainable mountain viticulture management

The integration of terracing techniques into those of vigour control allow for sustainable mountain viticulture to be developed from an environment, economic and social viewpoint based on two mainstays:

- In eco-designed terraces, the two types of new vine training are used for optimum soil use, which is essential for increasing the productivity of the remaining production factors. Depending on the topographic profile of the natural land, planting takes place on both slopes and on the terraces themselves to obtain the best results.
- Once planting is complete, all the necessary information is obtained and prepared regarding the condition of the soil, the plant and the environment for easier decision-making as to the application of the remaining vigour control techniques.

With this in mind, comprehensive vineyard control is implemented. One of the main characteristics of this viticulture is controlling the even ripeness of the grape berries with very low dependence on the weather.

4.1. Soil productivity: planting on terraces or on slopes

As indicated in Section 2.2.1, one of the basic design conditions of terraces is to limit the slope height to ensure it blends in with the surroundings. Once fixed, this height must be constantly maintained along the entire length of the terraces. This ensures that the terraces have a uniform gradient of 3% in order to control the runoff of rainwater to avoid erosion.

Moreover, the gradient of the slope on terraces cannot exceed a maximum as of which the risk of instability is significant. This theoretic maximum, which can be estimated using sufficiently representative soil cutting tests, must also involve a safety factor. As already said, the extensive experience of Mas Martinet in the building of terraces in the Priorat region proves that slopes with a gradient of up to 65° are safe¹, provided that the construction technique described in Section 2.2.3 is applied.

¹ In some vineyard, 70° has been used with good results



Given that terraces must have a constant, minimum width for machinery to pass (1.3 m), the greatest difficulty in maintaining the height of the slope below 1.5 m without its gradient being over 65° arises in the area of the estate where the natural gradient is at its maximum. If, in other areas of the estate, the natural gradient decreases, the height of the slope can be maintained by reducing its gradient.

Therefore, the construction of terraces must begin in the area of the estate where the natural gradient is at a maximum. At this point, a decision must be made as to whether the vineyard is to be planted on the terrace or on the slope, as this decision will determine the height of the slope and, given that this height must remain constant, it will also determine planting on terraces or slopes if the natural gradient drops along the terraces.

To make this basic decision, the design conditions of the terrace must initially be established. As explained in Section 2.2, Mas Martinet applies the following design conditions at the current stage of the experiments:

- Maximum slope height: 1.5 m (2 m if planting on the slope).
- Terrace width: 1.3 m.
- Maximum slope gradient: 65°.
- Maximum slope length for gentle gradients (as a guideline <25%): 11 m.
- Maximum slope length for gradients > 25%: 6 m.
- Vine training type: double vine training when planting on the slope and circular training when planting on the terrace (double vine training can also be used, particularly if the terraces have a relatively straight layout).

Once these conditions have been established, two causes can be presented in relation to the natural gradient of the land:

- The natural gradient remains significantly constant along the entire length of the terrace (although it may vary sideways in peak-valley direction).
- The natural gradient decreases significantly along the terraces.

In the first case, the best solution is to plant on the terrace, whatever the natural gradient (Chart 4.1).



Chart 4.1 Comparison between slope and terrace planting with constant natural gradient

	Natural slope (%)	20	30	40	50	60
Circular plantation on terrace	Terrace width (m)	1.3	1.3	1.3	1.3	1.3
	Slope gradient (°)	32	43	51	58	62
	Slope height (m)	0.38	0.57	0.77	0.95	1.15
	Slope length (m)	0.7	0.8	1.0	1.1	1.3
	No. of terraces per ha	52	52	52	52	52
	Theoretic ELA (m²/ha)(1)	24,504	24,504	24,504	24,504	24,504
Double vine training plantation on slope	Terrace width (m)	1.3	1.3	1.3	1.3	1.3
	Slope gradient (°)	14	22	32	42	52
	Slope height (m)	1.31	1.51	1.44	1.46	1.47
	Slope length (m)	5.4	4.0	2.7	2.2	1.9
	No. of terraces per ha	15	19	27	34	40
	Theoretic ELA (m²/ha)(2)	18,371	17,796	16,774	16,605	16,920
Theoretic ELA (slope height <2 m)	19,757	19,036	18,629	18,680	18,856	

Theoretic ELA: effective leaf area of all stock planted in 1 ha; calculated for shoots of 0.14 m² of ELA with an average space between shoots of 7 cm.

(1) The limiting factor is the horizontal ledge of the slope (parameter p in Figure 2.2), which must be over 0.6 m so that the ring of the upper terrace does not interfere with passing along the lower terrace (with a sufficient gap). This prevents the use of slopes with a higher gradient.

(2) The limiting factor is the height of the slope (maximum 1.5 m), which prevents more gentle gradient slopes from being used. Where the height of the slope is limited to 2 m, the resulting ELA increases to the values of the lower row.

If the gradient decreases along the terraces then the slope gradient will also have to decrease to keep the height constant. Therefore, the horizontal ledge of the slope (distance between two consecutive terraces) will increase. With this new geometry, it may be of interest to continue planting on the terrace or change from the terrace to the slope. Depending on the natural gradient and on the extent of the lengthways variations of the slope, the optimum will be different. To obtain a precise result, a 3D model



must be prepared to introduce the topography of the land and the design conditions of the terraces. However, certain illustrative criteria can be established based on a 2D model:

- If the average gradient of the land is only slightly less than the maximum (e.g. up to 33% less), all the vineyard should be planted on the terrace.
- If the average gradient of the land is much less than the maximum (e.g. up to 66% less), all the vineyard should be planted on the slope.
- In intermediate cases, planting should be started on the terrace and the slope then used at the point where the vineyard develops, which will depend on the average gradient: the further away the average gradient from the maximum, the earlier planting should be changed to the slope.

In all cases, planting on slopes makes viticulture work more difficult:

- Precise irrigation of intermediate stock (that is not on the terrace but on the slope) is more complicated because it is on a gradient.
- Access to intermediate stock may require climbing the slope on foot. Where the slope gradient exceeds 30-35%, steps must be installed.

It also has advantages, however:

- The height of the slopes is greater and, therefore, fewer terraces are required.
- Double vine training is cheaper than ring vine training.

In general, it is only wise to plant on slopes when the ELA gain is significant (e.g. over 15%), although this will depend on the criteria of each vine grower.

One way of making slope growing easier is to plant only the end two stocks on the terraces and leave the liana plant to develop its production branch along the slope with no intermediate stock. To do so, Mas Martinet is carrying out experiments in order to answer two questions:

- Is it possible to accelerate plant growth to form the entire production branch in fewer years through irrigation?
- How does the grape quality vary as the shoots grow further away from the stock?

The results of these experiments are not yet available.



To show the increase in productivity achieved by combining the terracing techniques with those of vigour control, Chart 4.2 compares the soil area required to produce 10,000 kg of grapes (equivalent to around 8,600 bottles of wine) for three forms of cultivation:

- Conventional terraces with the following characteristics:
 - Terrace width: 2.3 m (2 rows of stock on each terrace).
 - Slope gradient: 45° (100%).
 - Formation: cordon royat.
- Mas Martinet terraces and ring vine training on the terrace.
- Mas Martinet terraces and double vine training on the slope.

In all cases, the natural gradient of the land remained constant at 40%.

As shown by experience, the real ELA is seen to be 65% its theoretic value (see Section 3.4). This also occurs in conventional plantations, given that some stock is not feasible and other does not reach the expected ELA.

In line with Chart 4.1, ring vine training provides the best results. Somewhat more than 1 ha of land is required to produce 10,000 kg of quality grapes. Conventional planting has a lower productivity and requires more than 3 ha of land.

Note that, if 6,000 kg/ha are collected in a conventional plantation like the one considered, the resulting production per m² of ELA is 1.3 kg, which is very high for preparing a quality wine that can withstand a good ageing process. The significant parameter is not production per ha, as regulations are often limited to, but **production per m² of ELA truly developed on productive stock**.

In other words, for each plot, variety and weather, etc. the optimum ratio between ELA and the production of a quality grape can be assessed, although there is no optimum ratio per ha. As explained in the previous sections, it is worth noting that **production is not linked to the number of shoots** but to the ELA. The number of shoots depends on the vigour of the stock in order to obtain grapes with the appropriate morphology for their quality.



Chart 4.2 Comparison of the productivity of different mountain vineyard designs
(natural land gradient: 40%)

	Terraces	Conventional	Mas Martinet	
	Vine training	Cordon royat	Double vine training on slope	Circles on terrace
Slope gradient	°	45	32	55
Terrace width	m	2.3	1.3	1.3
No. of terraces	unit/ha	26	27	52
Slope height	m	1.5	1.4	0.7
Production branch length per ha	m/ha	5,200	8,180	12,252
No. of stock	unit/ha	4,333	8,180	6,500
Theoretic No. of shoots	unit/ha	52,000	116,862	175,032
ELA per shoot	m ² /unit	0,14	0.14	0,14
Theoretic ELA per ha	m ² /ha	7,280	16,361	24,504
Real ELA per ha (65%)	m ² /ha	4,732	10,634	15,928
Real quality production (first wine) ⁽¹⁾	kg/m ²	0.6	0.6	0.6
Real quality production (first wine)	kg/ha	2,839	6,381	9,557
Area required to produce 10,000 kg per year	ha	3.5	1.6	1.1

(1) See Section 3.5





Dendrometer and soil moisture sensor



Data transmitter from the vineyard to the central office

4.2. Comprehensive vineyard control

Once planting has been developed, the crop must be managed every year:

- Adjust the vigour of the stock required for the formation of the plant's architecture regarding vigour control techniques.
- Decide on the time and the duration of irrigation.
- Apply the necessary treatments for the control of disease and blight.

In order to collect and prepare the necessary information at all times for decision-making regarding crop management, the vineyard is divided into plots that can behave in a similar way in terms of vigour and their response to irrigation:

- Soil conditions (fertility, porosity, etc.).
- Stock variety.
- Underground or surface irrigation.

The resulting plots will cover a variable area depending on each case (e.g. from 0.5 ha to several ha).

The following method is used to adjust the stock vigour each year during winter pruning:

- 30 to 35 sample stocks are selected from each plot.
- The shoots from each sample stock are classified according to their size and are weighed to obtain the vigour. Depending on the results, the irrigation guidelines (ferti-irrigation) are decided on and the production targets of the plot determined for the following year.

As already indicated, reaching a production close to the target value may require several years, once the stock has developed its entire production branch.

To obtain the supporting information for irrigation decision-making, the following is installed on each plot:

- 2 dendrometers on two representative stocks.
- 2 soil moisture sensors next to the dendrometers.
- 1 radio transmitter: this sends the readings of the dendrometers and the sensors to the central computer where estate operations are controlled.



A weather station is also installed on the vineyard (valid for all plots), which is equipped to measure the following parameters:

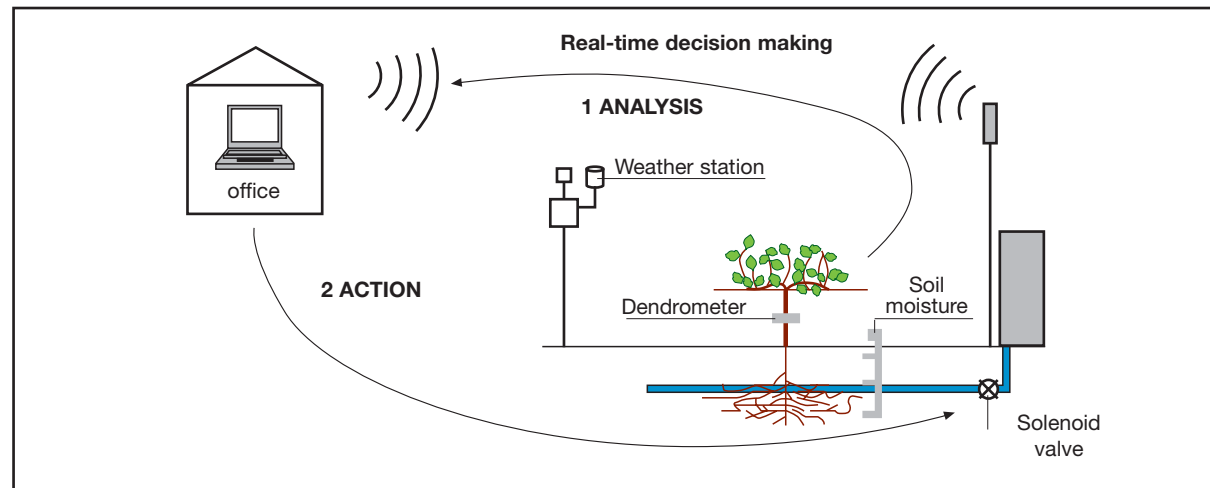
- Ambient temperature.
- Soil temperature.
- Rainfall.
- Relative humidity.
- Wind speed and direction.
- Vine leaf moisture.
- Solar radiation.

The weather station² has several functions:

- To add to the information from the dendrometers and sensors for irrigation management.
- To obtain weather forecasts useful for planning viticulture work.
- To provide the data required for the control of disease and blight.

The information measured by the equipment installed on the vineyard is transmitted to the central computer where it is stored and processed for real-time decision-making. In turn, the irrigation orders

Figure 4.1 Information technologies applied to viticulture



² The Mas Martinet experiments regarding weather stations were carried out in collaboration with Adcon (represented in Spain by Verdtech)

for each plot can be run from the central control, acting on the solenoid valves that open or close the run of water at the different levels of the estate. The system records the start time and the duration of irrigation at each level and on each plot, as well as the flow of water used.

All the information generated either through automatic devices (e.g. irrigation flow or dendrometer variations) or manually prepared (shoot size, pesticide applications, etc.) must be recorded and subjected to analytical accounting, given that what is not measured cannot be managed. It is ultimately a question of ensuring the traceability of the quality of each batch of grapes and wine with the crop management decisions.

Hence, through the experience accumulated and the assistance of the relational and data interpretation models, productivity, quality, resource savings and environmental protection can be continuously improved.

These techniques are particularly appropriate for mountain plantations, which are often small (from only a few hectares to several dozen hectares). The application potential for large operations of hundreds or thousands of hectares is smaller, as business criteria regarding process standardisation that are easily systematically repeatable are normally introduced.

4.3. Eco-efficient mountain viticulture

Mas Martinet techniques provide eco-efficient viticulture, i.e. the added economic value is increased while environmental impact is decreased, by reducing the use of natural resources and preventing their degradation or pollution (providing more with less).

For example, a winery can obtain its wine bottle production decided upon based on business and market considerations, occupying much less land than if conventional techniques are used. The efficient use of land has extremely important environmental consequences in the form of preserving the landscape, reducing erosion and saving water and fertilisers, etc. Likewise, the grape quality increases its value and this is achieved with a low dependence on the weather conditions.

4.3.1 Environmental sustainability

The integration of terrace design and construction and vigour control techniques together with the addition of plant cover and disease prediction techniques provides for the development of environmentally sustainable mountain viticulture. Chart 4.3 shows the environmental benefits explained in detail throughout the Manual.



Chart 4.3 Synthesis of environmental benefits

Benefits/techniques		Optimised terrace design	Vigour control and precise ferti-irrigation	Plant cover on terraces and slopes	Disease forecasting model
Landscape preservation	Blending in of terraces. Use of mosaic terroir without vine monopolisation	X	X		
Preservation of soil and its fertility	Prevention of erosion, compacting and loss of organic matter	X		X	
Prevention of pollution	Minimisation of run-off and polluting leaching (nutrients, toxics)		X	X	X
Greater resource productivity	More and better (grape) production with less materials (soil, water, fertilisers, pesticides)		X		X

4.3.2 Economic and social sustainability

The financial feasibility of the techniques for environmental sustainability has been assessed in two cases:

- Small vineyard (2 ha) belonging to one self-employed farmer who works his own vineyard and sells the grapes to a wine producer. He has one small tractor. The winery supplies him with the basic information on disease prevention and irrigation guidelines.
- 15 ha vineyard belonging to a wine producing company. It appoints staff for cultivation work. It has its own machinery and central office to prepare information and make decision.

The vineyard is planted on land with a natural gradient of 40% using terraces measuring 1.3 m wide and ring vine training with terrace planting. In both cases, Mas Martinet comprehensive management techniques are applied. The real target production per ha is set at 9,500 kg/a (see Chart 4.2). The hypothesis is established that grape production evolves as follows:

- Year 1: 0% of real target production.
- Year 2: 30%.
- Year 3: 80%.
- Year 4: 100%.

The production targets are summarised in Chart 4.4.

4.4 Production hypothesis for financial assessment (vigour control)

Type of operation	Vineyard		Real production
	Ha	No. of plots	Kg/yr.
Self-employed farmer	2	1	19,000
Wine producing company	15	8	142,500

Chart 4.6 shows the annual investment and operating costs in the two cases given.

The following hypothesis is used to calculate the financial results:

- Constant inflation of 2.5% per year.
- The farmer invests using all his own capital.
- The company finances 40% of the investment at a nominal interest rate of 5%, with quarterly settlements (5.1% APR) and 0.25% opening commission.
- The sale price or value of the grape is 1.4 Euros/kg.

The financial results are summarised in Chart 4.5.

Chart 4.5 Financial feasibility of the vineyard using Mas Martinet techniques

		Farmer	Company
Project IRR at 20 years	%	9.6	0.24
Financial IRR (leveraged)	%		0.35
Investment return period	years	11	20
Pre-tax profits, once target production is reached	euros (euros 2007)	20,000	50,000



The annual profits for the farmer can be considered sufficient. The company has a low IRR, given that its main business is the sale of wine.

As well as the added environmental and economic value, both direct and indirect, the Mas Martinet techniques help towards social sustainability with two specific contributions being particularly noteworthy:

- The quantity and quality of the grape harvest is independent to the weather conditions to a great extent. This fact, together with the high productivity of resources, provides strong financial feasibility under good conditions to withstand the ups and downs of the market. This leads to increased job stability.
- The use of information technologies, analytical and environmental accounting systems and crop management based on relational and data interpretation models requires significant intellectual work that may be adapted and is continuously improving. As a result, more skilled jobs are created with greater possibilities of continuous training in a wide range of subjects and, therefore, more attractive to youngsters and, most particularly, more accessible to women.

Moreover, the terrace access and phytosanitary control techniques lead to improved occupational safety for workers.



Chart 4.6 Investments and operating costs for the financial assessment of Mas Martinet techniques

Natural slope: 40%. Terraces: slope gradient: 52°, terrace width: 1.3 m, 5,200 lm of terrace/ha
 Vine training: rings with a diameter of 0.6 m every 0.8 m, production branch for one ring = 1.88 m, ELA = 3.6 m²/ring, no. of shoots = 26 shoots/stock
 Number of rings/stock per ha = 6,500 (5,200/0.8); theoretic ELA = 24,500 m²/ha; 9,500 kg/ha
 2 ha vineyard: 1 plot. Farmed by one self-employed farmer who sells the grape to a wine producer
 15 ha vineyard: 8 plots. Farmed by a wine producing company.

Investment		Amortisation (a)	Depreciation (a)	2 ha	15 ha
Terracing (including tree and shrub clearing, removal of rots and stone crushing)	30,000 euros/ha	20		60,000	450,000
Stock	1 euro/stock	20		13,000	97,500
Vine training	5 euros/stock	20		65,000	487,500
Machinery	Tractor, trailer, pesticides		10	9,000	30,000
Boxes and other tools			10	4,000	8,000
Irrigation pond		20		24,000	54,000
Irrigation installation (including hut, fertiliser storage tanks, pumps, programmer, etc.)	12,000 euros/ha		15	24,000	180,000
Weather station + blight forecasting contract			15	0	6,000
Soil moisture sensors + dendrometer + data recording and transmission (datalogger)	2 measuring points x plot		10	3,000	24,000
Total investment				202,000	1,337,000
Operating costs					
Staff				0	90,000
Phytosanitary products				1,200	9,000
Machinery maintenance				450	1,500
Disease forecast and equipment maintenance				0	3,000
Various (insurance, consumables, etc.)				500	5,000
Total costs				2,150	108,500



5. Conclusions

Some of the new terraced vineyards are not environmentally sustainable, given that they do not blend in well with the countryside and are exposed to erosion and landslides. Moreover, obtaining a quality grape in new conventional vineyards is generally based on maintaining low soil productivity and the types of vine training and plantation framework used lead to a very high ratio between stock supply and demand. All this makes them vulnerable to market crises and to extraordinary episodes of weather. More specifically, the economic fragility of new plantations is a barrier for small-scale farmers to take on higher investments that require the building of environmentally optimised terraces.

Traditional crop techniques are maintained in new vineyards and could be called the myth of technology:

- In the current market, it is easier to justify the price of grapes through low productivity rather than through the application of technology. This favours wines with a quality that is sustained on the “terroir”, i.e. under the unrepeatable weather and soil conditions of a certain place. People cannot dominate the quality of wine, which depends exclusively on natural factors. Technology and quality are relatively incompatible.

This commercial strategy is increasingly weak and will end up jeopardising the regions that defend it, which will be unable to compete with the new world and with the European regions that, as well as a good “terroir”, combine crop control with the appropriate knowledge and technology.

- It is sometimes preferred to continue with traditional plantations because no specific knowledge is required other than the traditional experience of our ancestors. For example, in the case of irrigation, the time to irrigation and its duration must be known, as well as making investments. If no irrigation is implemented, no knowledge is necessary because the weather decides.

Along these lines, technology-intensive (energy) viticulture based on standardised and repetitive processes that are easy to mechanise must not be confused with **knowledge**-intensive viticulture where technology is only a means of helping increase the productivity of semi-automated processes with a different treatment for each plot on the vineyard and even for each stock.



Viticulture practice cannot remain stuck in the past when biochemical, soil, weather and hydraulic knowledge and communication and data processing technologies have progressed so much. Many mountain wine producing areas must ask themselves why this is the case. Innovation and, more particularly, eco-innovation must play a more significant role in viticulture.

The Manual presents the terracing and vigour control techniques developed by Mas Martinet over the past 15 years with the final support of the Life project. The techniques described open up the way for mountain viticulture that is sustainable, i.e. environment-friendly, financially feasible and socio-culturally beneficial and accepted. More specifically, they preserve the land and the landscape while increasing vineyard productivity and grape quality and creating skilled jobs suitable for employing women. The sustainable innovation of Mas Martinet may also be useful for promoting the wine culture and wine tourism.

Control of grape ripening leaves the “terroir” and the variety in the background to ensure human involvement plays a leading role through intelligent incidence that makes the work of nature and sensitivity easier for composing wines.

The techniques described in the Manual provide the best results when applied together, i.e. as a whole. They are valid for any type of vineyard, although their main area of application is small or medium-scale operations with vigorous grape varieties (e.g. Grenache and Cariñena, the autochthonous varieties of the Priorat region). On flat land requiring no terracing, the vigour control techniques are recommended to optimise production in terms of both quantity and quality.

In short, the experience of Mas Martinet is a prime contribution to the sustainability of a strategic activity for Mediterranean Europe and, more particularly, for Catalonia: top quality wine production using mountain viticulture.

However, the final destination is nowhere in sight. Research must continue to increasingly adapt the techniques developed and complete their scientific documentation. The experiments carried out over the past 15 years confirm that the road taken is the right one and must be continued.



Corollaries

- Productivity is essential for financial development and knowledge is the key factor for improved productivity. However, a knowledge-based economy requires great demands on producers, on the public authorities and, in short, on people who have spent time and efforts on increasing their preparation. Continuous training becomes vital.
- Technological innovation is a way of increasing productivity, although it must be environment-friendly, financially feasible and socio-culturally acceptable.
- The dichotomy between the environment and development is generally false, provided that the public and private players involved are willing to overcome it and commit the necessary resources for (eco-)innovation. If this is the case, the environment acts as a salutary lesson for innovation, efficiency and productivity and what was perceived as a barrier becomes an opportunity.
- Innovation means, to a certain extent, questioning the traditional way things are done. To make innovation easier, the rules governing any area, including viticulture, should establish final goals but leave enough freedom or be sufficiently flexible in relation to the means to meet these goals.
- The balance between identity and globalisation, between culture and economy, is a strength for innovation and sustainability that must be used to its full potential.



Moscatel variety in the Penedès region (flat-land vineyard)



Unmodified head-pruned stock



Modified stock with circular vine training

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