BIO Web of Conferences **56**, 01001 (2023)
43rd *World Congress of Vine and Wine*

https://doi.org/10.1051/bioconf/20235601001

Dryland farming viticulture in the context of climate change: Concept, practical bases and examples from the vineyards of Lanzarote and Santorini

Joël Rochard*

Vitis Planet, 10320 Bouilly, France

Abstract. Dryland farming corresponds *to "all the measures aimed at allowing cultivation in an arid environment, that is to say in the absence of irrigation and in the presence of low rainfall"*. For irrigated crops, this technique aims, beyond its strict definition, to use water sparingly, compatible with local availability. The vine is adapted to hot climates of the Mediterranean type, but extreme and repetitive conditions of aridity, without irrigation, can lead to a very significant drop in yields and sometimes to the mortality of the stumps. For centuries, winegrowers in Mediterranean regions have faced high temperatures, heat waves and periods of drought, and have developed production systems that are resilient to these arid conditions (grape varieties and rootstocks, management, agroforestry, etc). A few examples of high heritage value testify to the historical ingenuity of winegrowers, in particular the islands of Lanzarote in Spain and Santorini in Greece. adaptation of plants, traditional approaches to growing vines, particularly in areas with a Mediterranean climate, with various examples of practices that testify to the ability of humans to adapt to extreme conditions.

1 Introduction

+ Definition

Dryland farming is generally defined as *"For irrigated crops, this technique*, beyond its strict definition, aims at a rational use of water, compatible with local availability. For irrigated crops, this technique, beyond its strict definition, aims at a rational use of water, compatible with local availability. Vines are adapted to hot Mediterranean climates, but Extreme and repetitive aridity conditions, without irrigation, can lead to stump mortality. Outside of these exceptional conditions, moderate water stress generally leads to an increase in sugar content and a decrease in berry size, with better ripening of the grapes. In extreme conditions, prolonged water stress leads to a decrease in the quantity but also the quality of the grapes. This optimum water stress threshold varies according to the quality parameter to be favoured, notably phenolic components or aroma precursors.

---

* Corresponding author: rochard.joel@gmail.com

+ Notion of aridity

In the so-called drylands, which cover about 41 percent of the earth's surface, precipitation is less than potential evapotranspiration (PTE). Aridity results from the combination of low precipitation and high evapotranspiration, which is linked to high temperatures and wind. The term "desertification" *should be understood as "land degradation in arid, semi-arid and dry sub-humid areas as a result of various factors, including climatic variations and human activities".* It is therefore not only an advance of the desert but a process of progressive loss of soil productivity and loss of vegetation cover mainly due to human activities in drylands, when the aridity index, or ratio of rainfall (P) to potential evapotranspiration (ETP), is below 0.65. The soil, less protected by the plant cover, is thus made more sensitive to water and wind erosion, which leads to its progressive destruction. The consequences include a drop in fertility and a degradation of the water cycle. This in turn has a negative effect on vegetation and production. A spiral of degradation is then formed: without voluntary intervention, it can lead to irreversible desertification.

Photo 1: Vineyards in the Ica region of Peru. The extension of desert areas can lead to an invasion of vineyards by sand, Photo J. Rochard.

Regions with a hot desert climate are mainly found in the subtropical zone on either side of the tropics, where solar irradiation is almost uninterrupted and very high. Mild desert climates are generally found around the western coasts of the continents in tropical or even subtropical areas or at high altitudes that would have a warm desert climate if the elevation were lower. In South America, this climate is found near the Pacific Ocean in In North America, the Pacific coast of the Baja California peninsula. Beyond the very hot climate zones, the presence of extensive and long-lasting anticyclones, the distance from oceanic moisture sources, the sheltering effect behind mountain barriers (foehn effect) can also contribute to the accentuation of aridity (Fig. 1). In addition to water scarcity, high evaporation in arid areas contributes to an increase in soil salinity, which is detrimental to crop productivity. In the coming decades, it is likely that the current aridity conditions will spread to other areas, in connection with climate change (Photo 1). This is a major challenge that many wine growers around the world will face.

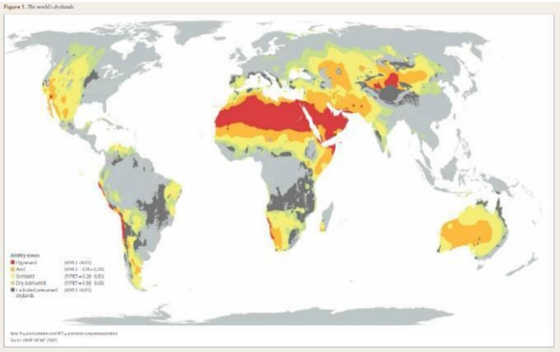

Figure 1. Current aridity levels in different regions of the world www.unep-wcmc.org.

SALT CONCENTRATION IN ARID AREAS

In addition to the lack of water, in arid zones, high evaporation contributes to an increase in soil salinity, which is detrimental to crop productivity. As J. L. Escudier et al. *Almost all waters contain dissolved salts and trace elements, many of which result from natural weathering of the earth's surface. In addition, drainage water from irrigated land, as well as possible effluents from urban and industrial wastewater, can have an impact on irrigation water quality. Salts and other dissolved substances begin to accumulate as water is absorbed by plants and evaporates from the surface. In the absence of natural leaching by winter rains, salinisation becomes inexorable. In theory, in dry areas, with very low rainfall, almost pure water is needed to avoid any concentration of non-volatile elements in the soil, and the formation of a crust."* [1]

The coastal zone is the meeting point of two types of groundwater: fresh water from the continental aquifers and salt water that permeates the land near the coast or penetrates the watercourses in the estuaries and can thus lead to salinisation of the groundwater. Freshwater, which has a lower density than saltwater, "floats" on top of saltwater. The saltwater intrusion has the shape of an inland dipping wedge, commonly referred to as the "salt wedge" (Fig. 2). Where salinisation is anthropogenic, overexploitation of aquifers is the main source of increased salinity. Climatic changes in coastal areas (rising sea level, lower low water flows and more or less marked increase in winter precipitation), irrigation with saline water, coupled with pressure on freshwater resources, lead to an increase in groundwater salinity locally, and in rivers near the sea mouths (Fig. 3).

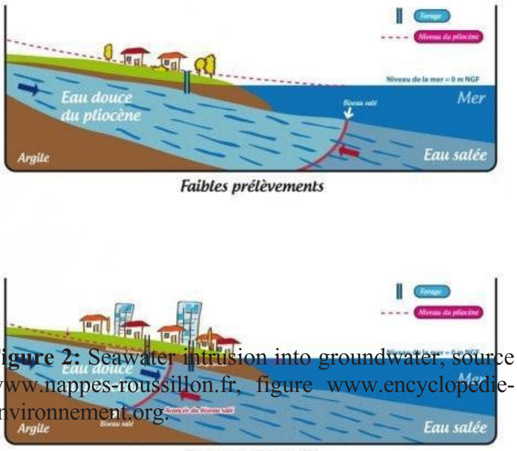

Figure 2: Seawater intrusion into groundwater, source www.nappes-roussillon.fr, figure www.encyclopedie-environnement.org.

To find out the salt content of a soil, it is possible to measure conductivity (measured in millisiemens/cm). At the international level, the FAO has validated salt tolerance thresholds for crops. Grapevines are considered to be sensitive to salt. The tolerance threshold for vines is between 2 and 4 dS/m, equivalent to 1.28 g/l of dissolved salt in the saturated zone of the soil. According to the IFV, soil analysis limits are 150 to 200 mg NaCl/kg in sandy soil and 300 to 400 mg NaCl/kg in clay soil. Phytotoxicity is manifested by symptoms of burning of the

In the case of the leaves, necrosis and even leaf fall can occur. On the branches, in severe cases, the departure of rapid buds can be observed. These phenomena can lead to yield losses and even to the death of the plant.

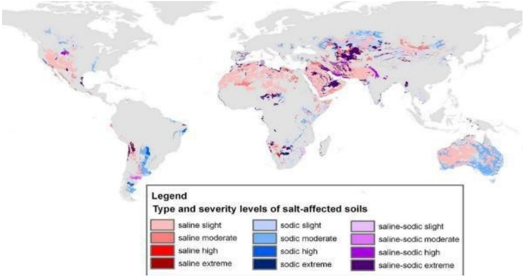

Figure 3: Distribution of saline soils in the world. Source Wicke et al, 2011, www.encyclopedie-environnement.org.

In parallel to the saline level, the concentration of sodium (Na) in water affects the permeability of soils and limits the infiltration potential. Indeed, sodium, in exchangeable form, replaces the Ca and Mg ions adsorbed on the soil clays and accentuates the dispersion of particles in the soil. This dispersion contributes to an alteration of the soil aggregates and the soil becomes compact when it is dry, thus reducing the infiltration speed of water and air, thus affecting its structure. Furthermore, with the increasing scarcity of water, the winter submersion of plots, a traditional practice to reduce salt concentration, which also allows the destruction of phylloxera larvae, may be called into question in the medium term.

Other solutions can be considered:

+ Regular maintenance of ditches and drainage systems.
+ Control of irrigation water quality.
+ Use of a resistant rootstock (1616 C, 216-3 Cl, G 1).
+ Calcium sulphate supply.

+ Regulation of water flow in the plant

Unlike the animal world, plants do not have the mobility to access water. Thus, evolution has helped shape their development and physiology so that they can adapt to the different climatic zones of the planet, both temperate and extreme (tropical or arid). In addition to its internal needs, the plant needs water to ensure its thermal regulation.

[2] Transpiration is regulated by the opening and closing of stomata. As stated by C. DOUSSAN and L. PAGES: *"When soil water becomes less available to feed the*

transpiration, the plant will limit the flow of transpiration by limiting gas exchange (and therefore evaporation) at the level of the leaves. But, in doing so, it also limits the entry of carbon dioxide, which is the basic element for the plant to build its biomass and grow, through photosynthesis. Plants are then often faced with the dilemma of 'thirst or hunger'. In the event of extreme drought, which is likely to recur with climate change, water stress can lead to plant death, as the plant does not replenish the reserves that are essential for its survival. Thus, plants must constantly find a survival balance, combining both the production of carbonaceous material and the limitation of water losses (Fig. 4).

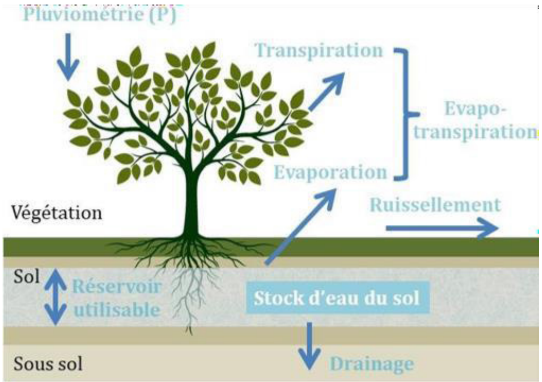

Figure 4. Water balance of the plant and the soil, after J. Aspar, www.paristech.fr.

+ Water transfer in the soil and the plant

Evapotranspiration generates a water supply from the roots, thus promoting the circulation of sap. This suction phenomenon, which opposes gravity, is very powerful since it allows, coupled with cohesion forces that maintain the water column, to bring water to the top of the largest trees. Evapotranspiration is also closely linked to photosynthesis: water transpires through the stomata, through which carbon dioxide from the atmosphere, useful for photosynthesis, flows in the opposite direction. The quantities of water stored in a plant and those used by its metabolism are infinitesimal compared to those that the plant must absorb due to losses through transpiration. When soil moisture is sufficient, plants transpire in direct relation to the amount of solar energy they receive. The more the plant is growing, the greater the amount it transpires. Conversely, when the soil is too dry and the plants lack water, their stomata gradually close, limiting transpiration the leaves. But this closure of the stomata also limits photosynthesis, slowing down the growth of the plant.

Leaf gas exchanges are at the origin of the two sap flows that run in opposite directions throughout the plant: the raw sap flow supplied by soil water circulates in the xylem vessels and meets the transpiratory demand of the leaves, while the elaborated sap ensures the distribution of the products of photosynthesis to the sink organs via the sieve tubes of the phloem (Fig. 5)

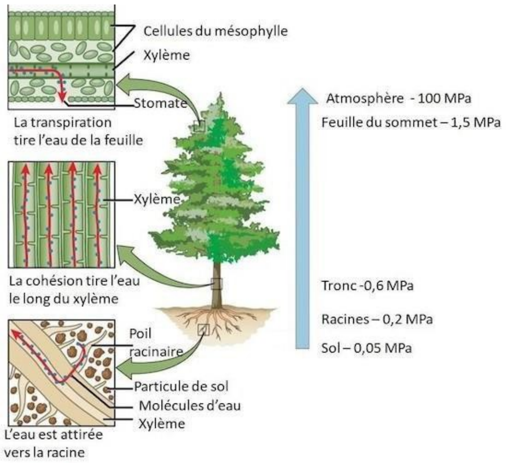

Figure 5: Water circulation in a tree, after -B. Saugier, . Saugier, www.encyclopedie-environnement.org.

2 Adaptation strategy of plants to aridity

+ Global strategy

To survive in arid zones, plants develop different specific adaptation strategies, the principles of which have often been adopted by humans to optimise agricultural and viticultural cropping systems (Figs. 6 and 7). N. Vartanian and G. Lemee state that*: "Two major types of adaptation, resulting from the specificity of the response to the physical concept of stress, can be distinguished: avoiding dehydration and maintaining the organism in a conservative state, at a high water potential level, or tolerating dehydration and lowering the water potential in the tissues, which implies equilibrium with the environment. Just as the overall resistance of plants that results from this differs considerably in its essential outcome, the mechanisms involved in these two types of regulation appear, in the current state of knowledge, to be fundamentally different: tolerating dehydration is a primitive character, linked to the intrinsic properties of the protoplasm, avoiding dehydration is the result of a continuous evolution, which is being perfected, in the conquest of the terrestrial environment.*

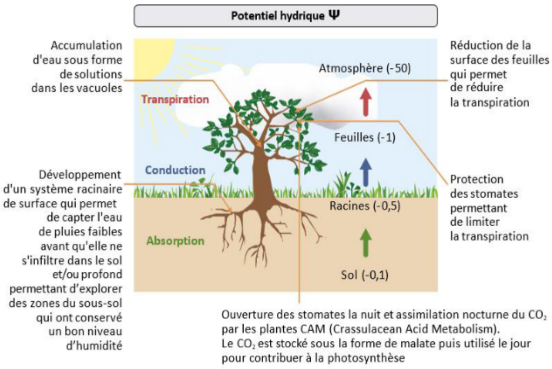

Figure 6. Water potential and main adaptation processes of plants to drought, after J. Rochard, figure www.oeno.tm.fr.

Système racinaire dense et profond du buis

Tiges à côtes longitudinales du Cactus

Cuticule très importante du houx

L'Iris germanica se préserve pendant la période chaude sous forme de bulbe

Stockage de l'eau dans les cellules des sedums

Forme dense et compact du Ciste cotonneux

Figure 7. Examples of plant adaptation to arid conditions, after J. Rochard.

+ Root adaptations

Many dryland plants have developed deep and extensive root systems, allowing them to draw water from deep in the soil (e.g. boxwoods and kermes oaks). Sometimes, a highly developed surface root system allows immediate water harvesting from scarce rainfall.

+ Stem adaptations

Many cacti and euphorbias have longitudinal ribs on the stems which create temporary shading, preventing parts of the plant surface from being exposed to direct sunlight. The stems of many Mediterranean plants are strongly sclerotized, which limits water loss.

+ Leaf adaptations

Some dryland species have reduced or absent leaves, thus limiting water loss. This is the case, for example, with Spanish broom, succulents (cacti), thyme and lavender. Photosynthesis is then often mainly or solely carried out by modified stems. The umbrella pine has reduced leaves or needles, also limiting the leaf surface exposed to the sun.

+ Adaptations of the form

Some plants adopt a dense, compact shape that reduces their surface area exposed to the sun's rays, thus limiting evapotranspiration. For example, the leaves of lavender or rockrose may shrink or curl.

+ Location and protection of stomata

This morphological adaptation limits evapotranspiration. Some plants have their stomata located in cavities, or only on the underside of the leaf, such as oyat or oleander. Other plants, such as euphorbia, have developed large leaf pilosities to retain water, or have only the edge of their leaf facing the sun, or roll up their leaves at the hottest time of the day, such as thyme or the common fern.

+ Presence of hair

The presence of hairs increases the reflection of light and allows dewdrops to be caught in the morning. These hairs are found in many plants in the Mediterranean, particularly in the species of downy oak and cottony rockrose.

Holm oak and olive trees have these hairs on their underside, which protect the entrance of stomata, allowing an additional degree of transpiration regulation.

+ Limitation of evaporation

Some leaves (such as those of holly Ruscus asculeatus, aptenia, kermes oak, junipers, etc.) have a very large cuticle, giving them a waxy appearance. This cuticle limits water loss through evaporation. This adaptation is all the more important as these leaves are generally persistent in summer.

+ Storage of water in the cells

This is a strategy adopted by plants with fleshy leaves or by so-called "fat" plants, such as sedums or cacti.

+ Regulation of stomatal opening

The stomata, through which the plant transpires and absorbs the CO_2 needed for photosynthesis, constrict in hot weather to reduce water loss. This mechanism also slows down the entry of CO_2 and thus the photosynthesis reaction, limiting the growth of plants in summer. For example, aeonium only opens its stomata during the cool, damp hours of the night.

+ Avoidance of the dry season

Some plants spend the warm period as bulbs and reappear the following spring (e.g. iris germanica). Various annual plants die at the arrival of summer, after having dispersed their seeds.

3 Adaptation of vines to arid conditions

+ History

The initial management of wild, tree-climbing vines (hautain), sometimes retained in some regions, and then adapted with a mix of trees and vines (agroforestry), optimised the natural shading effect. For centuries, winegrowers in Mediterranean regions, who regularly faced high temperatures, heat waves and periods of drought, developed resilient production systems in an arid context. The goblet system, which is common in many Mediterranean regions, also made it possible to adapt to fairly dry summer conditions, due to its low leaf area. Gradually, this traditional management The southern part of the vineyard has often been abandoned, due to mechanisation constraints, to be replaced by trellising, with a higher level of potential evapotranspiration and consequently a greater sensitivity to drought (Fig. 8).

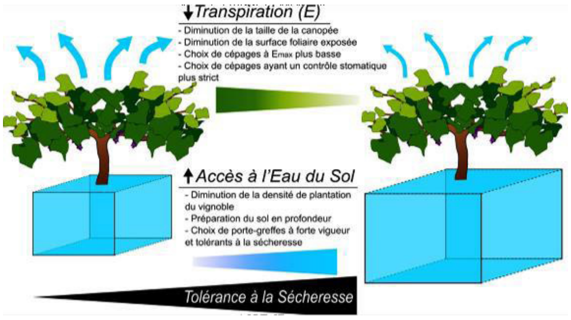

Figure 8. Summary of drought adaptation strategy of grapevines, after S. Dayer, M. Gowdy, C. Van Leeuwen, G. A. Gambetta. Dayer, M. Gowdy, C. Van Leeuwen, G. A. Gambetta.

+ Water requirements of the vine

The water supply of the vine is crucial for the basic physiological functioning of the plant (vegetative growth and photosynthesis). In the long term, repeated water stress can threaten the sustainability of the vine. Water requirements vary according to phenological stages. The vine is particularly sensitive to water needs between budburst and flowering (to feed leaf growth) and after the harvest to replenish carbon reserves. Between veraison and maturity, the vine can easily withstand a moderate water deficit (Fig. 9). The water available to the plant depends of course on the climatic conditions (sunshine, rainfall, wind, etc.) but also on the quality of the soil (nature, depth, useful reserves, grass cover), the sensitivity of the rootstocks and grafts and the pressure of parasites.

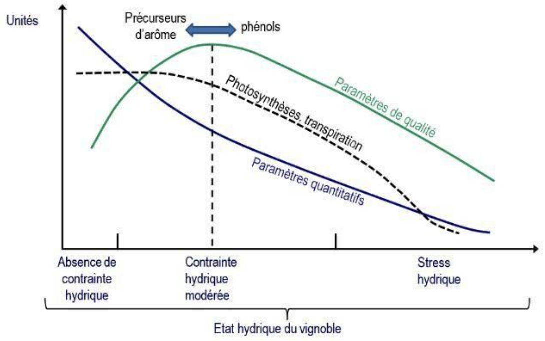

Figure 9: Influence of the water status on the qualitative, quantitative and physiological parameters of the vineyard, according to H. Ojeda INRAE.

Regarding irrigation, H. Ojeda states that [3] :

"This technique has been used for a very long time in the vineyards of the New World and is widely practised there. Its adoption in the French Mediterranean regions is much more recent and constitutes one of the first adaptations of the wine growers to the consequences of climate change. It is a tool that must be mastered to maintain both the quality and quantity of the harvest. Irrigation management is based on the one hand on the mastery of a technique for characterising the water status of the vine and on the other hand on a knowledge of the plant's responses to water stress according to its phenological stages. This knowledge will make it possible to define an irrigation strategy adapted to the objective of the vineyard (grape juice, white wines, red wines, ageing wines, etc.). In the south of France, vine irrigation has been a reality since the early 2000s. Languedoc-Roussillon is the main irrigated region in France with 26,000 ha (11% of the wine-growing area), followed by the PACA region with 10,000 ha of irrigated vines. This surface area is increasing because climate change and the current wine crisis require an evolutionary adaptation of cultivation techniques for Mediterranean vineyards. Indeed, the rise in average temperatures, accompanied by a significant increase in evapotranspiration, generates increasing drought during the cycle, which is induced by a strong and early water balance deficit".

Different tools can be used to establish a diagnosis of the water stress in the field:

- **Based on measurements at the plant level**: stomatal conductance, leaf water potential with the pressure chamber, transpiration with sap flow sensors, leaf and canopy temperature, dendrometry to measure the variation in trunk diameter, and determination of the isotopic ratio13C/12C.
- **Not based on direct measurements on the plant**: estimation of evapotranspiration from climatic data, soil water availability (tensiometers, electrical resistance, neutron probes...).

With regard to control, H. Ojeda, on the basis of scientific and empirical information, has established a model that defines an optimal water state in relation to the vegetative cycle and the intensity of stress (Fig. 10) :

- **Budding and flowering**: a good water supply favours the growth of the shoots without excess.

- **Flowering-setting**: the absence of water stress does not affect the setting rate.

- **Nouaison-véraison**: water stress during this period does not affect cell division but reduces berry volume. The controlled reduction of berries can be a quality objective in the case of red wines for ageing.

- **Véraison-maturité**: the water status during this period largely determines the type of wine. In the absence of stress, the wines are herbaceous, diluted and acidic; in the case of severe stress, the wines will be very tannic, hard and alcoholic.

- **Ripening and leaf fall**: the vine must recover its hydrous state so as not to disturb its active metabolism during this period.

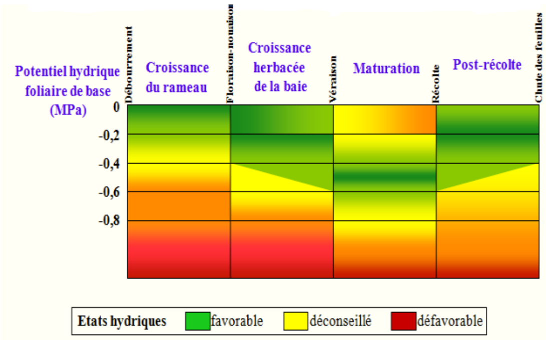

Figure 10: Interpretation of the basic water potential in according to the vegetative stages according to H. Ojeda.

UNDERGROUND IRRIGATION

It is based on the use of a drip watering system installed at a depth of about 40 cm (Fig. 11). This practice allows the creation of a wet bulb underground during irrigation (Fig. 12).

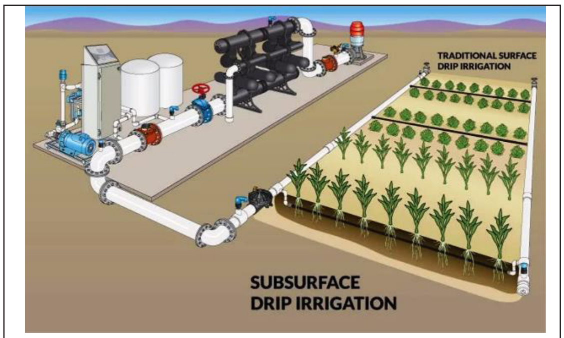

Figure 11. Principle o f subsurface irrigation, www.southernirrigation.com.

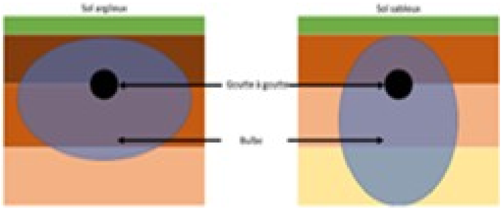

Figure 12. Depending on the type of soil, the profile of the irrigation bulb is different. Clay soils tend to retain water more easily due to their grain size and structure, and the bulb formed will expand. Bulbs in coarser soils will form a water column. www.vignevin.com.

In addition to limiting the risks of degradation of the surface drip irrigation system, as the IFV points out, this technique has many advantages, in particular

- **Water saving** compared to surface watering, as water is directly available at the roots,
- The opportunity to **regulate the weed population**, which usually develops under the surface water systems and absorbs part of the water supply during irrigation (the water source buried at 40cm does not allow their roots to draw this water).
- **Better durability**, underground, the system is protected from pest and machine damage.
- The possibility of **working the soil under the row of vines** without constraint (except for decavellation).
- **Greater root exploration** at depth.

Nevertheless, the investment at installation is more important than an overhead drip system (about 20% increase) and the detection of leaks and the maintenance of the pipes are more complex. Furthermore, installation in very stony soils is not recommended (risk of crushing or pinching the system and difficulty of installation).

The installation is generally carried out using a subsoiler to lay out the pipe network and a mini-excavator to place the combs and fittings.

Tasters must be adapted to the local context and production objectives: flow rate, pressure, diameter and spacing in order to adapt the quantity of water needed.

In order to ensure the durability and proper functioning of the drippers, they must have more specific technical characteristics than surface drippers: Flat dripper: its morphology will prevent the crushing of the drop formation system under the weight of the soil.

The IFV specifies some operational aspects to be taken into account:

- **Anti-siphon**: in soil, drippers can quickly become clogged by absorbing particles. The presence of a membrane prevents this from happening.
- **Anti-root**: in the presence of water, roots will tend to penetrate the inside of the irrigation tube. A transition lock will prevent clogging.
- **Self-regulation**: to ensure that each dripper is even, even in sloping fields, this technology allows for a constant pressure and a homogeneous flow.

Furthermore, regarding the risk of clogging, several precautions must be incorporated into the design and maintenance of the system:

- A **filtration system upstream of** the irrigated area is essential. In the form of disc or sand filtration, it ensures a filtration of the elements of the order of 150 microns.
- **Drainage systems** should be installed at the time of installation: a manifold, a drain valve placed downstream of each line, an air valve that prevents foreign bodies from being sucked into the pipes and crushed.

In addition, to detect any leaks or blockages, the installation of a **flow meter** ensures that water consumption is monitored. In addition, an annual purge is essential for the entire system.

+ Role of the soil

Drying out is the consequence of the absorption of water by the plants and/or the evaporation of water from the soil to the atmosphere (the sum of these two flows constitutes evapotranspiration). A distinction is made between the different types of water in the soil:

- **Gravity water** is available water that flows through the soil by gravity. It is more or less retained by osmotic forces and by imbibition forces.
- **Capillary water** is water that is available, on which the capillary forces are exerted.
- **Hygroscopic water is** unavailable water, as it is part of the soil's own constitution.

When the climate is constantly hot and dry, root growth in the surface horizons is difficult and the plant develops roots deep down in search of wetter conditions. Certain viticultural practices, limiting the superficial roots' easy access to water or nutritive factors, allow the vine to be more resilient to arid conditions (Fig. 13).

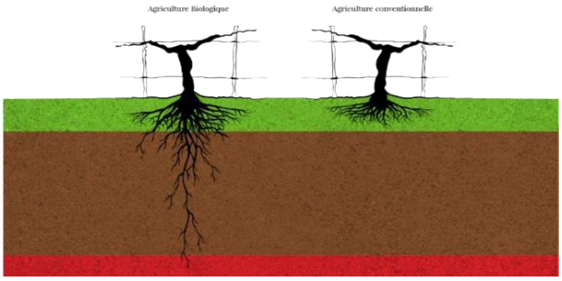

Figure 13. Schematic comparison of conventional and organic root systems, www.chateaudelhospital.fr.

During the course of the year, soils, especially in their upper horizons, undergo alternating wetting and drying. This results in moisture profiles in the soil that vary greatly in time and space, depending on whether the soil is bare or cultivated, and whether it is a rainy period or not. These moisture variations imply water transfers that contribute either to recharging the soil or, on the contrary, to partially emptying it of its water. The rewetting of the soil profile is done by infiltration of rainwater or irrigation water; it can also result, but generally to a lesser extent, from capillary rise from the water table or from damp subsoil layers.

SOIL AND PLANT WATER BALANCE

The state of the soil water reserve can be assessed by means of a water balance, which involves the water "inputs" (rain and irrigation) and "(consumption by plants, drainage, etc.)

beyond the roots). This simplified approach does not take into account capillary rise, nor contributions or losses by runoff, which can be significant in certain situations and which it is then necessary to integrate into the reasoning. Concerning drainage, it is considered that once the reserve is full at the level of the root zone, the surplus brought by rain or irrigation is drained in depth and is not exploitable by the crop. The water reserve exploited by the roots depends on the rooting depth, which varies according to the nature and management of the soil (bare, ploughed, grassed, weeded, etc.),
For a given rooting depth, the water reserve varies according to :

- the load of coarse elements (gravel, pebbles);
- the texture of the soil and in particular the proportion of sand, silt and clay (Figs. 14 and 15);
- the organic matter content.

Some of the water in the soil remains strongly retained and unavailable. The balance sheet only takes into account the water that can actually be used, i.e. the water that plants are able to extract.

As an indication, the Useful Reserve (UR) for a non-stony soil varies from :

- 0.9 to 1.2 mm/cm for a coarse texture (sand),
- 1.3 to 1.6 mm/cm for medium texture,
- 1.8 to 2.0 mm/cm for fine texture (clay, silt-clay, sand-clay).

The Plant Usable Reserve (PUR) is estimated to be between half and two thirds of the Useful Reserve.

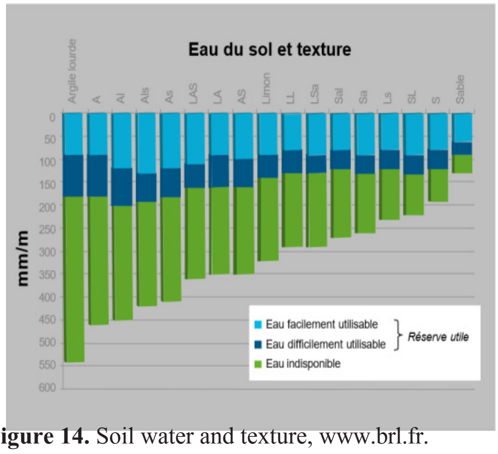

Figure 14. Soil water and texture, www.brl.fr.

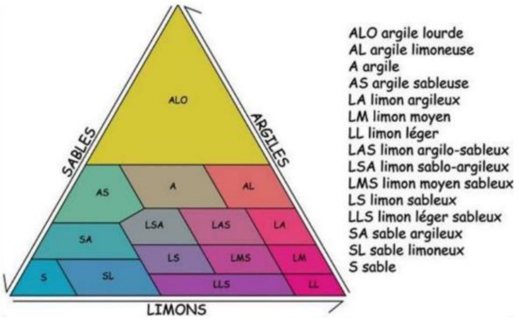

Figure 15. Simplified soil texture classification www.aujardin.org.

Water in the soil is not immobile: it is constantly moving, more or less quickly, from one point to another and in all directions (not only vertically as is often thought). These movements are always dependent on differences in water potential. As water is a solvent, its movements are accompanied by those of the solutes it carries (dissolved salts, pesticides, etc.), but also of suspended particles and microbial organisms. This can lead to pollution risks for deep waters and/or the accumulation of salts on the surface.

Mulching consists of covering the soil around plantations with mulch made of different materials of natural, organic or mineral origin. Man is reproducing here what is done naturally on a forest floor. When the soil is bare, water loss through evaporation is very high. In addition to these losses, there are those due to the evapo-transpiration of the plants, whose roots are strongly heated in summer. In addition, during heavy rainfall, the mulch acts like a sponge and prevents water from gullying the soil without penetrating it, and keeps the soil cool and loose in summer. Thus, mulching limits water loss and at the same time reduces the development of weeds.

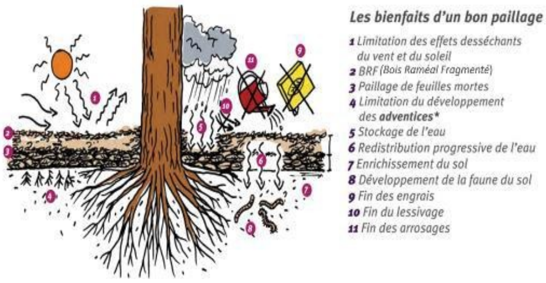

Figure 16. Mulching consists of covering the soil around plantations with mulch made of different materials of natural, organic or mineral origin, figure www.tco.re.

The microbial biomass of the soil also influences the relationship between the plant and the water as the says C. DOUSSAN and L. PAGES: *"The rhizosphere is a place of intense exchanges (water, mineral elements), with in particular the exudation of carbon compounds by the plant (sugars, amino acids, exopolysaccharides, etc.) at the roots, which can represent up to 30% of photosynthesis. This input of carbon into the soil strongly stimulates microbiological activity, which will have a considerable impact on the geochemical environment of the rhizosphere compared to the soil further from the roots. In relation to water, biological activity in the rhizosphere can generate organic compounds that modify the water properties of the soil. These can be surfactants, such as phospholipids, which decrease the surface tension of water and can decrease the water holding capacity of the soil or decrease its hydraulic conductivity in unsaturated conditions. They can also be exo-polymers, especially exo-polysaccharides, which, on the one hand, by their high water absorption capacity can increase the water retention capacity of the soil and, on the other hand, by becoming hydrophobic when dry, can hydraulically disconnect the root from the soil for a longer or shorter period of time during a drought and delay the subsequent rewetting.*

JAR IRRIGATION

It is an ancestral technique known by other names, including: olla, oya, clay, cápsulas porosas, potes de arcilla, riego por succion, terradria, terradrya, idria, buried canaries, porous ceramic vessels, pitcher farming, pitcher irrigation, porous buried. This underground irrigation technique is water-efficient and particularly suitable for small farms in arid areas. The agronomist Fan Shengzhi mentions pitcher irrigation 2000 years ago in China. Researcher T.M. Stein considers that the technique may have originated in North Africa and Iran. Other researchers in Latin America believe that it originated in the Roman Empire. The technique is based on the use of low-fired clay pots that are buried up to the neck, regularly filled with water, to irrigate the plants placed around them (Fig. 17). The porous walls will gradually let the water escape, which favours its absorption by the roots at depth. This results in significant water savings (50-70%). The flow rate of a jar depends on the type of soil, evapotranspiration, the height of the water in the jar and its hydraulic conductivity (which varies according to its composition and manufacture).

Jar irrigation is simple and economical, it ensures stable irrigation and is adapted to the needs of the plant, but with some disadvantages: difficulty of installation, low mobility, fragility of the material.

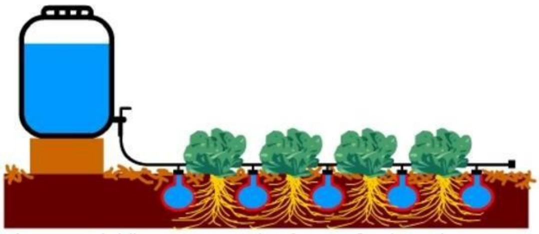

Figure 17. Gravity supply system for jar irrigation, www.lavierebelle.org.

+ Grape varieties

Although adaptation to drought differs according to the type of plant (Fig. 19), significant variations also exist within the same species. Thus, as viticulture has developed throughout the world, winegrowers have been able to find grape varieties, most of which come from the Mediterranean area, that can ensure quantitative and qualitative production in arid areas, with or without irrigation.

As L. G. Santesteban [4] states: *"Traditional grape varieties of the Mediterranean regions are known for their good adaptation to drought and heat waves. Agiorgitiko, Grenache, Aglianico and Mourvèdre are examples of widely grown red varieties that are well adapted to extreme climates. As this is widely recognised, the gradual introduction of some of these varieties into other climates, made possible by climate change, could be a medium-term adaptation tool. Reconnaissance missions carried out in Mediterranean countries in search of minority and forgotten varieties have shown that some of the varieties found have longer vegetative periods and higher acidity than most commonly cultivated varieties.*

+ Rootstock

As the IFV states (Fig. 19): *"Among all the factors that influence the production criteria of a vineyard, the rootstock holds an essential place: it establishes the link between the soil and the grape variety, and consequently influences its nutrition*

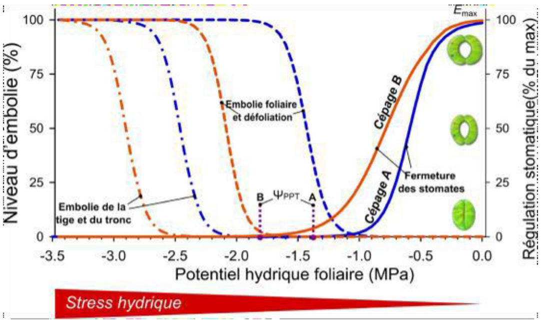

Figure 18. An example of the sequence of vine responses to drought for two generic grape varieties ('A' and 'B'). Many characteristics such as maximum transpiration (Emax), speed of stomatal closure, point of loss of turgidity (YPPT), and thresholds for embolism formation in leaves and stems, can vary between grapevines and together define their drought tolerance for the current year and possibly the next. Publication by S. Dayer, M. Gowdy, C. van Leeuwen, G. A. Gambetta.

The American rootstock parents of European vines are mainly derived from Vitis Riparia, Vitis Berlandieri and Vitis Rupestris. The American parents of European vine rootstocks are mainly from Vitis Riparia, Vitis Berlandieri and Vitis Rupestris. The latter comes from the south and west of the USA and can, thanks to its extensive roots, reach even the deepest layers of the soil and thus make use of deep water reserves. Vitis riparia is best suited to sites with a better water supply. Vitis Berlandieri has intermediate properties regarding drought tolerance.

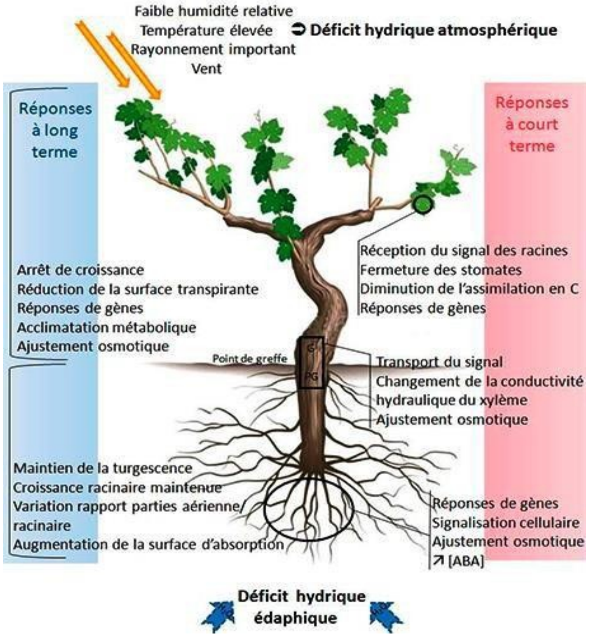

Figure 19. Main mechanisms involved in the regulation of water saving by the rootstock www.passion.vignobles.free.fr.

Figure 20. Rootstocks most adapted to drought and delaying the phenological cycle, conferring higher vigour, reducing the K+ content of grapes and adapted to salinity, after N. Ollat et al. [5].

+ Driving mode

The management system is defined as the set of criteria that determine the architecture of the stock and the vineyard: the density and geometry of plantation, the height of the trunk and the training pruning, the renewal pruning, the method of trellising, and the green operations. Through his initial choices (grape varieties, rootstocks, density, pruning method) and during the vegetative phase (trimming, leaf removal), the winegrower is constantly confronted with compromises to be found between a sufficient leaf surface, ensuring the desired production, and a limitation of transpiration, associated with a low plant surface Fig. 21). Sometimes, in extremely hot conditions, it is necessary to maintain an umbrella effect with vegetation on the upper surface to avoid drying out and scalding of the grapes.

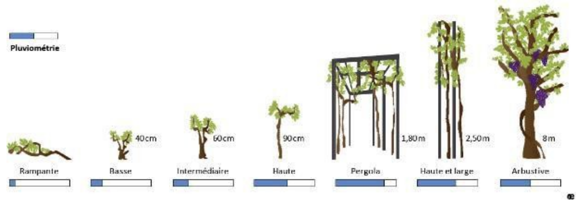

Figure 21. Rainfall requirements of the different types of vineyard management. L. V. Elías Pastor has established a scale of rainfall requirements for the main types of vine management. For low-growing vines, water requirements are higher for trellised vines, especially compared to the traditional goblet system, figure www.oeno.tm.fr. [6].

+ Shading effect

Shading makes it possible to modify the microclimate of the vineyard by acting in particular on temperature and evapotranspiration (Fig. 22). Beyond the vines, shading contributes to the comfort of the personnel working in the vineyard. Different solutions can be envisaged:

- Trees and hedges

The mix of vines and trees, which was very often used in Mediterranean areas, has often been abandoned with the imperatives of mechanisation. From Contemporary forms of winegrowing agroforestry, adapted to technical constraints, are once again being developed (Photo 2). In addition to modifying the microclimate and accentuating the shading effect, this approach, which contributes to the image of the vineyard, helps to promote biodiversity and protect the soil, with the production of valuable biomass.

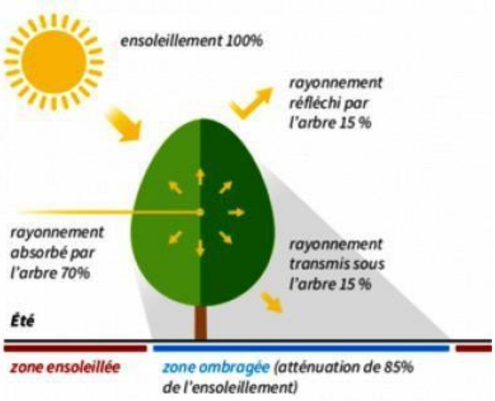

Figure 22. Shading effect of a tree ©Ademe, based on Akbari et al. 1992.

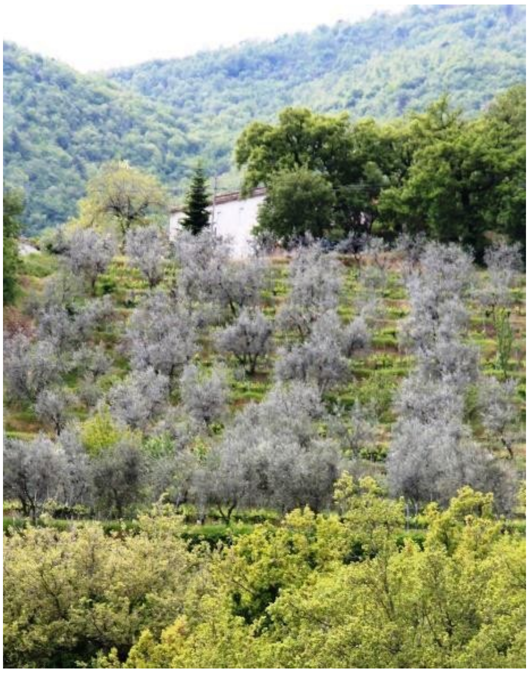

Photo 2. Traditional agroforestry in a traditional Italian region of Tuscany, Photo J. Rochard.

In addition to single trees, tall hedges can also be planted to reduce the force of the wind as well as providing shade (Photo 3).

Photo 3. Rows of trees in vineyards to reduce wind and increase shading in the McLaren Vale region of Australia, Photo J. Rochard.

- Nets

Nets are mainly used to combat hail or bird damage. More often than not, they limit to a certain extent the insolation of the vine. Beyond this classic protective effect, various experiments conducted throughout the world aim to mitigate global warming, with variations concerning the design, colour and positioning of these nets (Fig. 4). An experiment conducted by O. Jacquet of the Vaucluse Chamber of Agriculture tested black nets with different mesh densities, providing respectively 30%, 50% and 70% shading (compared to 15% for classic anti-hail nets) on the experimental vineyard of Piolenc, planted in cordon palissé with Grenache. The system was set up after flowering, then reassembled after harvest. The nets covered 80% of the foliage (only the top of the row was not covered).

Photo 4. An example of coloured shade netting, www.agrowplastics.com.

During the heatwave year of 2019, a delay in ripening of more than ten days was reached with nets that had 70% shading.

- Agrivoltaics

By shading the panels, which are controlled in real time according to the needs of the plant, the agrivoltaic system reduces the amount of water used for agriculture and reduces the thermal amplitude under the structure. Positioned high and controlled according to the physiological needs of the plant, the panels contribute to a microclimate in the vineyard, while producing electricity (Photo 5). Thanks to the shading provided by the panels, which are controlled in real time, the agrivoltaic system can reduce potential evapotranspiration by about one third. At the same time, the system can reduce the impact of frost and hail to some extent.

Photo 5. Shading effect of Sun Agri's Agrivoltaics technique, www.sunagri.fr, at Domaine des Nidolères, in the Roussillon vineyards, Photo J. Rochard.

4 Examples of vine adaptation to arid regions

+ Lanzarote Island

La Geria, a region on the Spanish island of Lanzarote (Canary Islands) is the valley where the famous Malvasia wine is produced (Fig. 23). This desert and volcanic Canary Island, lacking fresh water, was not a favourite place for viticulture, but the winemakers have raised the island from the ashes by shaping a landscape unique in the world with hundreds of thousands of small black sand craters that each house a vine [7].

Porous stone mulch farming is an agricultural technique that has been used for thousands of years in various arid and semi-arid areas of the world. It consists of covering the soil surface with a layer of stones with the main purpose of conserving water. The island is made up of 10 to 20 million year old volcanic material, but there are other elements

The lava field of Timanfaya Park, formed during the various eruptions from 1730 to 1736. The volcanic ash, or lapilli, is called *picôn* in the Canary Islands, and *rofe* or *arena* on the island of Lanzarote. This volcanic sand prevents evaporation because this layer of small rocks isolates the soil from the environment, thus preventing moisture from escaping by evaporation into the atmosphere. Various studies have shown that this protective layer can retain eight times more water than uncovered soil and reduces evaporation by 92% when it is 10 cm thick. Outside of natural deposition areas, sandblasting is sometimes used for annual crops. The high porosity of volcanic sand and its hygroscopic nature allow it to retain moisture from the substrate through small holes in the rock granules that facilitate the passage of condensed or precipitated water overnight. This retention capacity is also put to good use with low walls, formed of volcanic blocks, arranged in a circular fashion around each vine, also protecting it from the wind (Fig. 23 and Photo 6).

Figure 23. The Canary Island of Lanzarote: located 130 kilometres west of the Moroccan coast *Sources maps, left: Le Monde; right: Alain Gioda les vignes de Lanzarote, book "agricultures singulières", IRD Éditions, 2008)* [8].

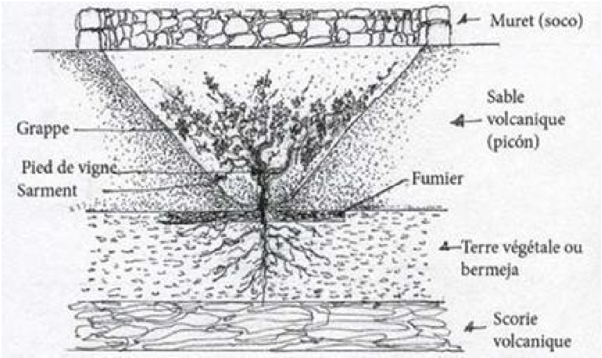

Figure 24. Cross-section of a 'geria' in Lanzarote. Conical funnel-shaped depressions are dug in the volcanic ash, so that the plants can reach the arable land. These holes are called *geria* and have given their name to the eponymous region "La Geria". The depth of the pit is determined by the amount of *rock* that was present in the area. It can reach up to 3 metres in some places in La Geria. At the bottom of these individual craters, the vine is protected from the wind by small walls, which are built in the shape of a half moon on one side of each *geria*. Called *zocos*, they form the singular landscape of the region. Source: Santiago Aleman Lanzarote and the wine landscape and culture, editions. Remotas, 2018) [9].

BIOMIMETICS APPLIED TO WATER HARVESTING IN DESERT CONDITIONS

Nature has invented prodigious devices from which humans can draw inspiration. The *Stenocara*, a beetle living in the Namibian desert, manages to survive without water (Fig. 25). Every morning it climbs to the top of a high dune, positions itself upwind and spreads its elytra, whose waxed surface is covered with microscopic bumps. The oceanic fog pushed inland then magically condenses and a drop of water appears allowing the Stenocara to drink. To quench its thirst, it leans forward and the drops of water slide down micro-grooves in its carapace to its mouth opening. In addition, this beetle is surprisingly resistant to heat, as infrared reflectors on its back help it to withstand high temperatures. Since then, many laboratories have been trying to create materials inspired by the structure of the Stenocara's elytra. Chilean engineers have rediscovered and developed a technique for "harvesting" water from the fog by means of technical nets known since time immemorial to the nomads of the Rùb El Khali, the immense Arabian desert (from which the low stone walls surrounding the vineyards in Lanzarote are inspired). The small Chilean village of El Tofo, situated at an altitude of 780 metres and 360 kilometres north-west of Santiago in a desert area, has developed a device with large nets that condense tiny droplets of water (Photo 7). A 12 × 3.5 metre net produces approximately 180 litres of water per day. This technology requires no energy, and provides clean, safe water.

Figure 25. Water harvesting by the *stenocara* beetle, living in the Namibian desert, www.nicolabarbisan.files.wordpress.com.

Photo 6. View of the Geria sector, Photo J. Rochard.

Photo 7. Water harvesting nets in the Chilean village of El Tofo. www.nicolabarbisan.files.wordpress.com.

+ Santorini Island

On Santorini, grapevines have been cultivated for 3500 years (Fig. 26). When the volcano erupted around 1620 BC, the island was covered with a layer of pumice, which in some places is over 60 metres thick (Fig. 27). Production conditions are made difficult by the lack of rain and strong wind. In the absence of rainfall, the vines receive sea mists during the summer nights which deposit a significant amount of water. On the surface, the porous soil absorbs the nightly humidity and this is why the vines have numerous rootlets on the surface. The almost total absence of clay has allowed the vineyard to be preserved from phylloxera. The arid and windy conditions of the island were overcome by ancestral techniques to protect the vineyard from drought. The human response to this inhospitable environment was the invention of the kouloura, known as the "gobelet en couronne" (Photo 8). This is a very old technique that has been perfected over time. It consists of braiding the shoots into a crown to protect them from the wind and sand and at the same time reduce evapotranspiration.

Figure 26. Positioning map of the Greek island of Santorini, after C. Frankel [7].

Figure 27. Caldera of the Greek island of Santorini. Initially round, it collapsed through its centre and the crater is buried under water. Wikipedia.

Photo 8. Ampelis" vine from the island of Santorini in Greece. To form these baskets, the winegrowers use a pruning system called the "crown goblet", which is based on bending and interlacing the best shoots selected each year. This ancestral practice, which requires patience and experience, is still practiced with the *Assyrtiko* grape variety. Photo J. Rochard.

5 Conclusion

Even if the vine remains one of the most water-efficient crops, winegrowers in many regions are already facing periods of severe water stress as a result of climate change. Extreme vineyards, such as Lanzarote and Santorini, bear witness to the intelligence and self-sacrifice of people in developing these arid soils [10]. In desert regions where irrigation is essential, lack of water and/or increased salt levels could lead to the rapid destruction of these vineyards. In many other regions, especially in Mediterranean climatic zones, the progressive increase in aridity could lead to the eventual abandonment of viticulture, mainly in connection with

with the decrease in profitability (Fig. 28). Irrigation is a major agronomic tool to control the water status of the vineyard according to the characteristics of the plot, the vintage and the production objectives, but the question of the availability, but also the technical and financial accessibility of the water resource is now raised. It is important to consider that, apart from the production of table grapes, vineyards are at the origin of wine, a cultural product, which does not have a direct food function. Even if the added value per hectare is often higher than that of food crops, it is not certain that viticulture will be a priority for access to water in many regions over the next few decades, in a context of increasing scarcity. This challenge justifies, beyond the optimisation of irrigation when necessary, experimenting with cultivation methods inspired by arido-viticulture, by limiting the water needs of the vine by the choices of implantation and cultivation.

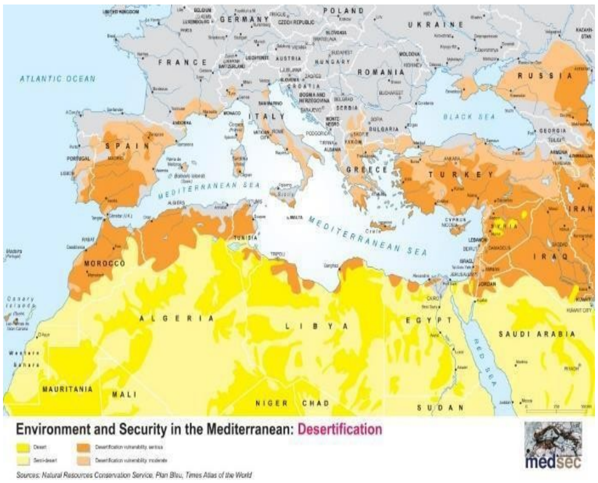

Figure 28. Desertification risk map of the Mediterranean area. Source: Natural Resources Conservation Service. Plan Bleu. Times Atlas of the world.

References

1. J.-L. Escudier, B. Gillery, H. Ojeda and F. Etchebarne, Salinity management of irrigation water for viticulture, 41st World Congress of Vine and Wine, BIO Web Conf (2019). *Salinity management of irrigation water for viticulture | BIO Web of Conferences (bio-conferences.org)*
2. Synthesis of the expert report carried out by INRA at the request of the Ministry of Agriculture and Fisheries (2006) https://hal.inrae.fr/hal-02824089/document
3. H. Ojeda, Precision qualitative vine irrigation, Le Progrès Agricole et Viticole N°7 (2007). https://www1.montpellier.inra.fr/pechrouge/images/irrigation.pdf
4. L. G. Santesteban, (Re)-Learning from Mediterranean viticulture, Ives Technical Reviews (2020), https://doi.org/10.20870/IVES-TR.2020.3788
5. N. Ollat, Amélioration variétale comme moyen pour s'adapter au changement climatique, rendez-vous TechniLoire (2013) file:///C:/Users/rocha/Downloads/actes_du_colloque.pdf
6. L. V. Elias Pastor, El paisaje del vinedo una mirada desde la antropologia, Eumedia (2011)
7. J. Rochard A vineyard in extreme aridity: Lanzarote, Oenologists' magazine No. 181 October (2021)
8. Gioda, les vignes de Lanzarote, book "agricultures singulières", IRD Éditions (2008)
9. S. Aleman, Lanzarote and wine landscape and culture, eds. Remotas (2018)
10. J. Rochard and J. Pérard, Paysages viticoles de climats extrêmes Revue des Œnologues No. 145 S Novembre (2012)