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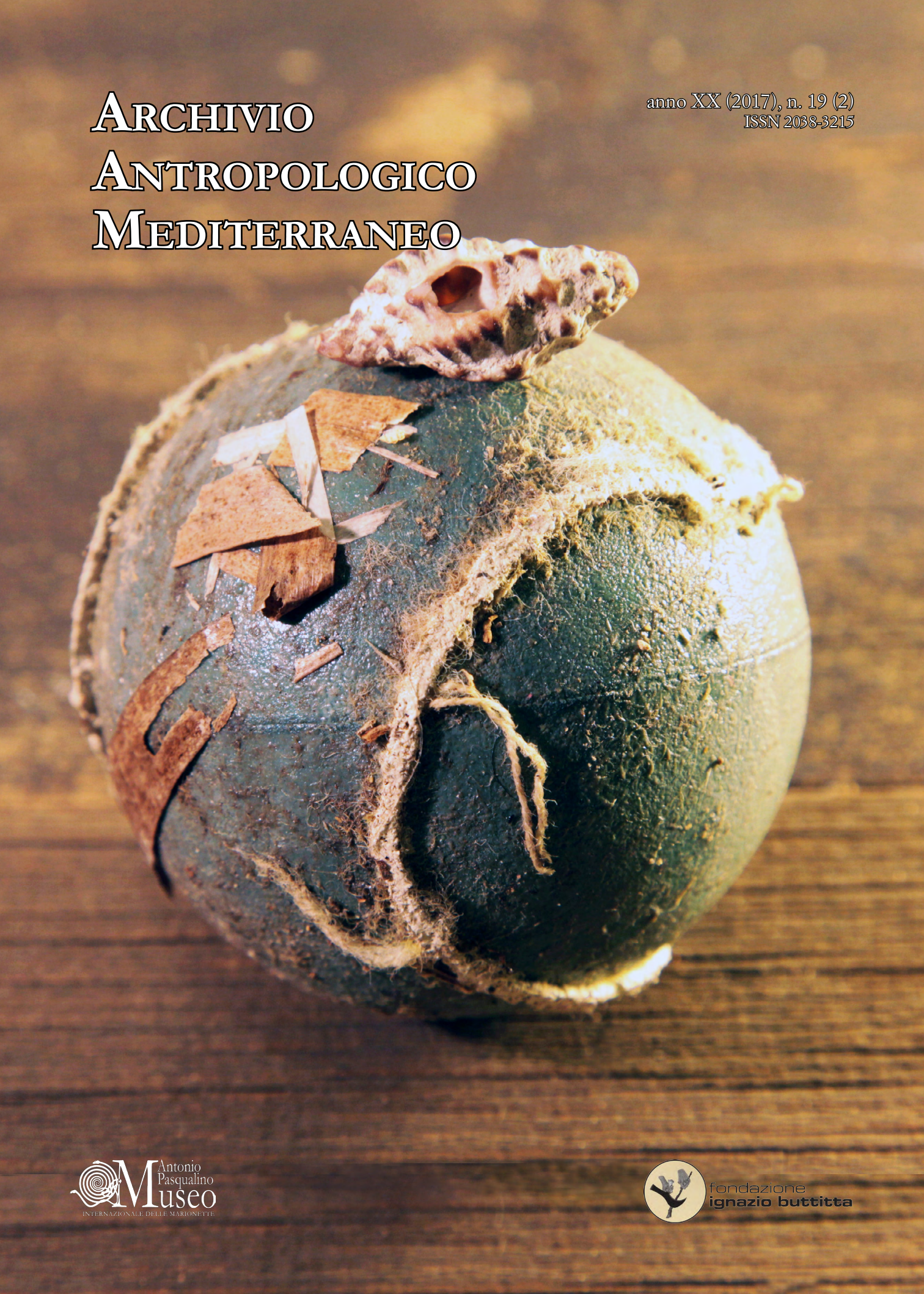

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DIPARTIMENTO CULTURE E SOCIETÀ

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In copertina: *Planet* (2015 Silvia Lelli photo ©)

Linda Johnson-Bell

# *Wine or Water? Viticulture's Global Water Footprint and Irrigation: an Unaffordable Luxury*

*Introduction*

Climatologists love wine. The *Vitis vinifera* is one of the most susceptible crops to changes in climate and «viticulture is famously sensitive to climate» (Hannah *et al.* 2013).Wine grape production occurs over relatively narrow geographical and climatic ranges, most often in mid-latitude regions that are prone to high climatic variability (between 30 degrees NS and 50 degrees NS latitude). And then, within this band, «premium wine grape production occurs within very narrow climate ranges» and further still, individual wine grape varieties have even narrower climate ranges, which further limit the areas suitable for their cultivation (Jones, Webb 2010). «These narrow niches for optimum quality and production put the cultivation of wine grapes at greater risk from both short-term climate variability and long-term climate changes than other crops» (Jones, Webb 2010). Further, «wine grape production provides a good test case for measuring indirect impacts mediated by changes in agriculture, because viticulture is sensitive to climate and is concentrated in Mediterranean climate regions that are global biodiversity hotspots» (Hannah *et al.* 2006).

Viticulture's harvest conditions and migration patterns serve as models for future climate scenarios. It is interesting then, that this thirsty $300 billion international industry (Wine: Global Industry Almanac 2012 and Market Line 2013) and its water crisis has largely escaped notice in the water competition debate. With more erratic harvest conditions existing within increasing temperatures (weather *vs* climate), the majority of the world's viticulturists are under threat from drought.

Water use in viticulture is essential in every stage of the production process, but irrigation is the largest use, and with temperatures rising, so is the need for water (Mozell 2014). When *Vitis vinifera* is grown outside its indigenous regions, typically warmer and drier New World climates, irrigation is used in areas where there is low rainfall during the growing season, and moisture in the soil profile is insufficient for healthy vine growth, allowing them to produce very high quality wine, which would not be possible under natural conditions (McCarthy *et al.* 2002). In the driest parts of Australia, for example, 99% of the water used in wine-making is for irrigation (Kilcline 2006). With climate change, now the grape's native climates are having to resort to irrigation in order to salvage harvest yields. This presents a problem: Irrigation is viticulture's number one adaptation ally, whilst it is mitigation's number one foe.

The world's vineyards are being re-mapped (Hannah *et al*. 2012). That's not new; they have always been changing. But the climatic changes were slower, permitting adaption. Today, we are witnessing an unparalleled rate of change. Coupled with the fact that never in the history of viticulture has the industry been so firmly and comprehensively entrenched in our economic and cultural identities. These changes will have varying effects on different wine regions that will depend on their ability to adapt: There is not a blanket solution. We do know that the relationship between temperature and wine quality is crucial in determining adaptation strategies. But most adaptation techniques, especially irrigation, negatively impact a wine's quality, its soil quality and hence, its specificity, the hallmark of its luxury status. Commercial, mass-produced wines will continue to adapt via technology: They are more impervious to a warming climate as long as they can sustain the increasing water prices. But achieving resilience in fine wine viticulture will mean finding the options that will establish the balance between economic viability, environmental sustainability and wine quality.

I came to the topic of climate change as a wine critic, author and judge for the past twenty-five years. I began to notice that the taste profiles of my favourite wines from the classic regions were changing: Chablis that were once crisp and mineral were flabbier and sweeter, and the *grands crus* of Bordeaux lost their elegance and sophistication, becoming highly alcoholic. Where alcohol by volume (ABV) levels, the standard measure of how much alcohol (ethanol) is contained in a given volume of an alcoholic beverage, were 12.5% when I began my career, gradually they grew to 13%, then

15%, and in some years, now even more. This heat on the palate has the effect of erasing any varietal character, meaning that you cannot differentiate a Sangiovese from a Tempranillo or a Merlot. It also erases any sense of terroir, or provenance – wines increasingly were tasting international, as if they were made anywhere.

So I began to ask questions, and my questions were not at all well-received. "Climate-change" is a dirty word in the wine industry. Wine producers, an inherently secretive lot to begin with, were not ready to accept what was happening, and even less, to share it with a wine writer wielding an iPad. But one day, I stumbled, literally, across the physical evidence and it all became so obvious to me, and my field work shifted from viticulture, to the effects of climate on viticulture. About 10 years ago, as I traipsed through yet another vineyard, I found myself in Emilia-Romagna, traditionally considered Italy's fertile "bread basket". The evidence was laid bare before me and my questions could no longer be brushed aside. It was a blistering hot harvest afternoon in mid-September, and I was standing under the shade of an olive tree, watching, as sweaty grape pickers frantically raced up and down the sloping hills before me. The soil beneath was dry, compacted, cracked. The owner, Edoardo, looked at me as he wiped his brow. He had to get the grapes in, now. Drought and heat had brought the harvest forward, weeks earlier than ever before, and, it had also caused all of his red varieties to mature at the same time. Normally they are picked at a staggered rate. A traditional wine producer who practices hand-harvesting, this meant that he did not have the manpower to harvest his grapes all at once, nor the ability to get them into the winery before they either died on the vine or oxidised under the sun. Meanwhile, his neighbour, a new international brand down in the valley, had planted her vines far enough apart so they could accommodate a mechanical harvester, and she had also invested in refrigerated units and parked them at the end of each row of vines so to keep the grapes cool whilst being transported to the winery. Worse, Edoardo confided that he noticed that she had resorted to some spray irrigation. All of these practices, considered normal in the New World (US, South Africa, Australia, Chile, etc.) wine regions, were not sitting easily with this Old World (Europe) purist. He struggled to save his 500 year-old family business. And it became clear to me that any climate-change deniers were not only insulting this man, but also the millions of other wine producers across the globe, who are fighting extreme weather events on the front-line.

*Wine: a crop by any other name?*

Whilst the effect of climate change on viticulture is immense, cultural traditions and consumer attachment to this commodity has protected it from scrutiny. With the present 2°C limit imposing new "planetary boundaries" and pitting science against politics (Von Storch, Krauss 2013), I would suggest that in the context of viticulture, the greater conflict is between science and culture. «The Anthropocene challenges the familiar distinction between nature and culture, which structured the order of knowledge and disciplines for such a long time» (von Storch, Krauss 2013). It is the failure to shift cultural perceptions of wine that risks slowing down its adaptation survival options, which are already limited by the vine lifespan's built-in time-line. This is perfectly illustrated by the viticultural appellation system in Europe, where law dictates the production area, the permitted maximum yields, production methods and which grape varieties can be grown in which geographical locations. The increasing heat and drought conditions are testing these classic pairings yet only a few winemakers are willing to challenge the cultural traditions in light of the unfolding science. For example: in the appellation of Margaux AOC in the region of Bordeaux, the permitted grape varieties are Cabernet Sauvignon (the dominant grape in all Left Bank blends), Cabernet Franc, Merlot, Petit Verdot and Malbec. But with climate change, winemakers are having to research and replant some of their old, indigenous varieties, such as Carménère. This variety was abandoned and nearly forgotten because it had difficulty reaching maturation in Bordeaux's (once) maritime climate. But since 2011, the owner of Château Brane Cantenac, Henri Lurton, has been using Carménère in the blend of his Grand Vin, explaining, «since this is one of the six historical varietals in Margaux, given global warming I thought it essential to reintroduce» (Decanter 2012). Further, there are winemakers, such as Florence Cathiard of Château Smith Haut Lafitte in Pessac Léognan, who has dedicated a small island in the middle of the Gironde as a private experimental nursery to test rootstocks and clones of current varieties as well as testing for new, future varieties. These forward-thinking, practical winemakers are in the minority, and their work is challenged by traditional wine laws as well as by those consumers who do not wish to see their cultural traditions change.

In a 2016 survey conducted by The Wine and Climate Change Institute, participants were asked if they would mind if well-known wine regions were to change their grape varieties, so long as the result was still a good-tasting wine. For example, if

Chianti were issued from Nero d'Avola rather than Sangiovese, or if Sancerre from Ugni Blanc instead of Sauvignon Blanc. 92% of respondents replied that "yes", they would mind. Several respondents commented that the question is "a stupid and impossible idea". And one participant commented that "this is like saying Spaghetti Bolognese will one day be made without tomatoes" (TWACCI 2016). There is no point attempting to argue with this respondent nor to point out that "spaghetti Bolognese" is not even a Bolognese tradition: the Bolognese use *tagliatelle* with their *ragu* with little or no tomatoes. This is the conflict between habits and innovation: the desire to cling to perceptions of what went on before despite science telling us that change is inevitable.

The link between social systems and food production systems in the context of wine production has become a tenuous one. Wine grapes are not often viewed as a "crop". I think that vineyards are portrayed as glamorous holiday destinations as opposed to places of agricultural production or as factories implementing highly-advanced technology. A plethora of travel companies offer exclusive wine-tasting tours, yet we never see holiday packages to visit a tea plantation or a wheat field. Wine makers reinforce this consumer bias by including gift shops, tasting rooms, restaurants and tourist accommodation into their business model. Every major wine region in the world has a designated "wine route". A good example is Alsace's Route de Vin[1], where there is a detailed map taking visitors from village to village to experience all of the local fairs, festivals, harvest events and traditions. Hence, the consumer views wine production as a benign "pasttime", heavy with emotional attachments to historical and cultural allegories. Wine producers also exhibit this behaviour of strong attachment. Theirs is either to historical and traditional regional practices or to profit and production-enhancing practices. Both mindsets retard the needed response to adaptation. Further, the majority of viticultural discourse, whether it be of consumer, wine producer or scientific origin, is productivity/yield focused, with the cause and effect relationship between yield and quality being poorly understood and usually misrepresented. This disconnect skewers the findings of many scientific papers on the topic, as the authors' approach is most often from a pure agricultural perspective (quantity) rather than a viticultural one (quality).

Tracing the tendrils of the grape vine through the Anthropocene explains why this crop may have an identity crisis. The crux of the debate surrounding this unofficial epoch is, firstly, the validity of its necessity, and then, its conception: should its commencement be the Neolithic, or Agricultural Revolution as opposed to the Industrial? Meaning, as this epoch is meant to determine the greatest point at which human activity separates the Earth from its natural geographic state and thrusts it into one dominated by human activity (Chernilo 2017). For the purposes of this paper, I prefer the Neolithic debut, particularly as wine grapes have undergone a long journey from wild, indigenous shrub, to highly cultivated cash crop. Which begs the question: Is it a staple or luxury crop? Or becoming something else?

### *What makes vine luxurious?*

What is a luxury crop? The traditional definition is that of a foodstuff not necessary for sustaining life. I might suggest that perhaps, in the larger context of climate change, the definition of "luxury" should be widened to include crops we simply cannot afford to grow when these crops employ the most extreme version of the act of farming. Today, crops such as apples, peaches and olives are defined as staple crops. Will climate change require such a manipulation of their growing environment that they become luxury items?

The *Vitis vinifera* is from the *Vitaceae* family and the genus *vitis*, the grape vine, contains some 60 different species, and the *vinifera*, the European grapevine, is the most important and the only species deemed suitable for wine production. The *Vitis vinifera* is indigenous to southern Europe and southwestern Asia. Evidence of vine cultivation and wine production has been traced from Georgia, c. 6000 B.C. (Spilling, Wong 2008) until it arrived in Greece (c. 4500 B.C.) where it then went to Italy. I would argue that it is at this point that wine makes its transition from a staple crop to a luxury crop: From something grown for personal, or local daily consumption, to an Egyptian ceremonial tool, to then a Phoenician trade product and finally, to a luxury item. The Romans invented the "grand cru" or first growth system, thereby elevating wine to a luxury. «Who can entertain a doubt that some kinds of wine are more agreeable to the palate than others, or that even out of the very same vat there are occasionally produced wines that are by no means of equal goodness, the one being much superior to the other?» asks Pliny the Elder in his *Historia Naturalis.* Wine's status continued to vary from bulk wines meant for sustenance to fine wines meant for pleasure and investment. Fast forward to the great 1970s boom of the New World wine industry which democratised the cultural and social habits of wine consumption (Howland 2014). This marked the modern distinction between wines

termed as "commercial" and those considered "fine wine". Whilst climate change is posing a threat to all viticultural production, it is a greater threat to fine wine – wines that herald from cooler climates, as heat is the enemy of subtlety and balance.

It might be useful to include here the definition of "fine wine", a highly subjective term. In its most basic interpretation, it is a reference to those wines that have attracted "blue chip" status, the *grands crus* of the industry. But fine wine is more than a balance of opinions and it is more than the market value of the wine. The crucial components to a fine wine would be balance, complexity, and most relevant for this topic, typicity. A fine wine tastes from whence it came, of the soil from which it is born. This means that a fine wine for this author's purpose does not need to be the most expensive. Rather, it refers to wines that are well-made and traditional as opposed to commercial and mass-market: Remember Edoardo and his neighbour.

Wine grapes distinguish themselves from other fruit crops as being a luxury crop, and then they further distinguish themselves from this agricultural category as well, as most luxury crops such as tobacco, sugar and tea, are plantation crops. And although other luxury crops such as coffee and chocolate require cooler climates for their quality-production, wine takes it several steps further: it is temperature that is key to all aspects of viticulture. The evidence is now clear that, with only minor other influences, it alone controls vine phenology, i.e. the vine's rate of physiological development through bud break to flowering, setting, *véraison*, and finally, fruit ripeness (Gladstone 2011). Gregory Jones refers to the grape as the agricultural «canary in the coal mine» in reference to the impact that climate change will have in wine production:

> Climate is a pervasive factor in the success of all agricultural systems, influencing whether a crop is suitable to a given region, largely controlling crop production and quality, and ultimately driving economic sustainability. Climate's influence on agribusiness is never more evident than with viticulture and wine production, where climate is arguably the most critical aspect in ripening fruit to optimum characteristics to produce a given wine style. History has shown that wine production occurs in relatively narrow geographical and climatic ranges. In addition, wine grapes have relatively large cultivar differences in climate suitability, further limiting some wine grapes to even smaller areas that are appropriate for their cultivation. These narrow niches for optimum quality and production put the cultivation of wine grapes at greater risk from both short-term climate variability and long-term climate changes than other broader acre crops (Jones *et al.* 2005).

Climate's determinant influence on viticulture means that climate variability directly determines vintage quality differences. Unlike other crops, the concept of annual vintage is recognised (chocolate bars, tea bags nor bananas, for example, are sold according to year). And, where vigour and high yields are sought after in most crops, in viticulture, they are detrimental to fruit quality. Low yields, achieved for the right reasons in the right conditions, are the desired result in quality wine-making practices. Fine wine prefers poor soils and moderate water stress to rich soils and ample food and water (Dion 1977). Quality-driven wine producers do not allow their vines to crop until 5-7 years of age, whereas since the advent of the New World boom, the average is now 3 years. And where fine wine producers keep older vines (*vieilles vignes*) in appreciation of their smaller, high-quality yields, commercial producers pull out vines at the age of 20 or so, considering them no longer sufficiently productive. Because the first year of growth in a vine's life is meant to build up nutrient stores, flower clusters that grow are usually cut back, so that the vine can focus its energy on establishing a strong root system. This is critical for both anchoring the plant and for absorbing water, nutrients, etc. the matter that comprises the "terroir". The deeper they are, the better. This is where the taste of the "place" of a wine comes from. Producing fruit too early is to the vine's detriment. Usually by the third year or fourth year of growth, a vine is ready to produce fruit of proper quality for winemaking. The longer one waits, the better the healthier, stronger and longer-living the vine will be. The goal used to be to have *vieilles vignes* of fifty-years or more of age, with small, intense yields. This is still the case amongst premium estates, but commercial market forces have forced the abandonment of this practice. It is common to see vines being productive at three years, and being pulled out by the age of twenty, having been exhausted by high yields. Wine's «long-lived system, for which the long time to maturity (1-2 decades) and in-place lifetime (3-5 decades or more) means that the rate of climate change and/or the rate at which variations in environmental tolerance can be exploited may impose adaptability limits» (Diffenbaugh *et al.* 2011). Producing a fine wine means allowing climate to dictate the time-line, as opposed to a mass-produced wine, where the production methods are imposed. Fine wine's two greatest tenets: temperature and time, are both luxuries the industry is no longer being afforded. But the most important ingredient in wine's "lux-

ury" profile, is its sense of place. Viticulture has elevated provenance to an art form: *terroir*.

### Terroir*: The magic trilogy of soil, climate and grape variety*

*Terroir* is one of the most evocative and much-debated terms in the wine lexicon. It can begin to be described with the word "soil": its richness in fertilising elements (this affects a plant's vigour); its structure (compact, rocky, or muddy); its mineral composition (granite, chalk or limestone); its colour (red soils warm faster in spring); and its topographical situation (on a hill, in a valley or a plain). Grape vines need soil that will store moisture, drain excess water; the best soils are not too fertile – rich soils produce very ordinary wines. Quality wine-making practices would include planting on hillsides where possible, rather than valleys, with tight planting densities, so to force vine competition and deep root structures. Commercial, or high-yield practices would favour planting in valley floors with wide planting densities so to aid irrigation and machine harvesting and to increase yields (Dion 1977, Wilson 1998).

But there is more to terroir than soil. *Terroir* is not a place, but a combination of circumstances. It cannot be manufactured, contrived or forced. *Terroir* encompasses a site's topography, hydrology, geology, sunlight and climate. Technically-correct wine can be grown almost anywhere, which is why we will not have to fear a global wine shortage. Even as wine regions are adapting to climate change and their output is shifting, there will always be enough "good" wine (Johnson-Bell 2014). Great wines, or fine wines, however, are more particular. They need *terroir* – this magic trilogy of soil, climate and grape variety. The real magician in this trick is the winemaker. Their role is to not interfere with Nature, but to assist the expression of the *terroir*, by not being too interventionist or too manipulative. One example would be the traditional winemaker who won't filter the wine, and if racking off the lees is required, will do so by gravity from cask to cask, not pumped. Or if the wines need to be fined, then fresh eggs are used, not processed fining agents. There are hundreds of decisions that a grape grower must make from planting to bottling and a traditional one will make those that allow the *terroir* to be best expressed. Ultimately, *terroir* must remain the incontestable and objective indication of a wine's quality. But this author does not contend that *terroir* is exclusive to the Old World vineyards, nor even to the wine grape. To suggest that one part of the Earth's crust varies so greatly in quality to another, makes no sense. But what is incontestable, is that when vines are irrigated so to keep root systems shallow, and they are also overworked by high yields and never get to the age of 70 or 90 years, then one never gets to taste their *terroir* – it never gets a chance. Crucially, any debate about *terroir* becomes moot in the context of climate change, as any *terroir*, whether in the Old or New World, is being erased by the raised temperatures (Jefford 2010[2], Bland 2013[3]).

### *Climate change and Wine: What is happening in the vineyards*

Climate change poses a greater threat to the production of fine wine than commercial, or mass-produced wines. Currently, many European regions appear to be at or near their optimum growing season temperatures, while the relationships are less defined in the New World viticultural regions. For future climates, model output for global wine producing regions predicts an average warming of 2° C in the next 50 years. Hannah *et al.*, in their 2013 paper, *Climate Change, wine, and conservation*, «demonstrate that, on a global scale, the impacts of climate change on viticultural suitability are substantial, leading to possible conservation conflicts in land use and freshwater ecosystems. Area suitable for viticulture decreases 25% to 73% in major wine producing regions by 2050 in the higher RCP 8.5 concentration pathway and 19% to 62% in the lower RCP 4.5. Climate change may cause establishment of vineyards at higher elevations that will increase impacts on upland ecosystems and may lead to conversion of natural vegetation as production shifts to higher latitudes in areas such as western North America. Attempts to maintain wine grape productivity and quality in the face of warming may be associated with increased water use for irrigation and to cool grapes through misting or sprinkling, creating potential for freshwater conservation impacts. Agricultural adaptation and conservation efforts are needed that anticipate these multiple possible indirect effects».

For regions producing high-quality grapes at the margins of their climatic limits, these results suggest that the future climate change will exceed a climatic threshold such that ripening of balanced fruit required for existing varieties and wine styles will become progressively more difficult (Jones *et al.* 2005). And data collected by INRA over the past thirty years have proved that combined with changes to certain cultivation methods, global warming has already pushed forwards the entire growing cycle of vines, from flowering to harvest.

«Today, grapes are harvested between two and three weeks earlier than they were thirty years ago. The berries are sweeter and less acid, which produces wines containing more alcohol and less acidity. In the longer term, climate change may also have an impact on yields, the varieties grown, diseases and pests. In southern France, the principal consequences may be a reduction in yields and wines that are more concentrated, including in alcohol. Higher quality is obtained when the lower yields are achieved by intention as opposed to disease or extreme weather events (drought or floods), which could equate to lower yields and poorer quality. In northern areas, grapes will ripen better, causing modifications to the aromatic profiles of wines. New regions may also start producing wine, such as Brittany or south-eastern counties in the UK» (INRA 2012).

Not everyone agrees with the predictions of *Hannah et al.* By way of riposte, Van Leeuwen *et al.* published in PNAS "Why climate change will not dramatically decrease viticultural suitability in main wine-producing areas by 2050". The authors do not debate Hannah *et al.* in their assertion that climate change will drive new vineyards into areas currently used for conservation. Nor do they disagree that «an increase in water use for irrigation might lead to major freshwater conservation impacts». Nor do they even dispute the eventual unsuitability of the current major wine regions for viticulture. They take issue with the time-line Hannah *et al.* have determined and with the data used to establish this time-line, disagreeing that «suitability for winegrowing of main wine-producing areas worldwide will dramatically decrease over the next 40 years». They argue that there were «major methodological flaws in ref. 1, mostly linked to (i) the misuse of bibliographical data to compute suitability index, (ii) underestimation of adaptations of viticulture to warmer conditions, and (iii) the inadequacy of the monthly time step in the suitability approach». Grape varieties are grouped as either cool-climate or warm-climate varieties, and they form a graduating scale that includes Muller-Thurgau as the "coolest white" to Nebbiolo as the "hottest red". When Hannah *et al.* constructed their suitability index, they used data comprising each grape variety's maximum temperature range, or Average Growing Season Temperature (AvGST) limit for suitability using groupings that «were constructed from empirical observations collected in premium wine-growing areas and not based on grapevine physiological modelling». Van Leeuwen argues that this was flawed, not peer-reviewed data and that in several of the classic premium wine regions that are now at the predicted AvGST maximum limits «high-quality viticulture is sustained in these regions despite increased temperatures and dry farming, because of both the evolution of consumer's preferences and implementation of adaptive strategies by growers». This author's fieldwork supports the work of Hannah *et al.* and discounts Van Leeuwen's conclusion.

Firstly, because consumers are still purchasing a product is not sufficient evidence of its suitability nor its quality. It is not because consumer trends adapt to a changing taste profile that one should take this as evidence that the wine is not experiencing a decrease in quality. Consumers are only able to purchase what is on the shelves. Having conducted once-monthly blind, comparative tastings over ten years, this author has evidence that when a consumer is given a choice between the same grape variety grown in two varying climates, they prefer the cool-climate version to the hot-climate version. In the Rhône, Burgundy and Bordeaux, ABV levels have increased to untenable heights. And again, as mentioned above, for many Bordeaux winemakers, their Merlot plantings are no longer viable and they are having to change the classic Bordeaux "recipe" by increasing their use of Petit Verdot or including resurrected plantings of Carménère. When asked if they could produce a 12.5% Bordeaux again if they wanted to, they replied "no", that the alcohol levels have run away from them and that they no longer have any control. In Champagne, the producers are using more Pinot Meunier in their blends to strengthen the structure being let down by the now less acidic and over-ripe Chardonnay. In the Rhône, there are winemakers who have had to take out their Riesling parcels because they were burning on the vine, and plant Syrah, instead. In Burgundy, a producer recently lamented to me that he is buying land in the cool hillsides of the Pyrenees because his world-famous Premier Cru Chardonnay no longer resembles the classic profile and he cannot bring himself to drink it. Does the consumer know this? Of course not. When the wine producers themselves tell us that their wines are changing unrecognisably and are no longer of the same quality, it is difficult to discount their testimony and to, instead, support the testimony of the authors. Logic dictates that one implements data from the most direct, first-hand and knowledgeable source.

Secondly, to rely upon the "implementation of adaptive strategies by growers" to ensure the greater longevity of these regions' viticultural suitability, is also untenable. This is the very problem. Most adaptation strategies further lessen wine quality and are ultimately, short-term solutions to a long-term issue and serve as mere plasters on the wound. Irrigation,

the largest adaption strategy is, as the same authors support, an abuse of our freshwater reserves. So they have contradicted themselves when they suggest that such an adaptation strategy will widen the suitability window for premium viticulture production.

It is interesting to add to Van Leeuwen's "consumer preferences" discussion that the trend now in the New World wine regions, especially in drought-ridden South Africa, is for "old vines"[4], which are non-irrigated. In fact, most consumers are not aware of the distinction between dry-farmed and irrigated vines, nor of the fact that in Europe, irrigation is widely banned. When they are made aware of the distinction, I have noticed that there often results a mobilising effect to rally support for the more ecologically sustainable strategy. Wine consumer trends are largely eco-orientated and the extensive use of fresh water for irrigation is not widely discussed in consumer forums. Their attention is intentionally drawn towards the more "soft" sustainability options, such as recycling, solar power, organic farming practices, or low-energy light bulbs.

Higher temperatures, especially at harvest, means more sugars in the fruit which means more alcohol in the wine once fermented. When the heat pushes the harvest dates up, shortening the growing season, the plant ripens at different rates. Wine producers harvest according to brix, or sugar levels, but often this means that the rest of the plant has not caught up: It is physiologically unripe. This produces the bitter, unripe taste of "green tannins". Too much alcohol can also be tasted on the palate as it dominates the acidity and minerality, erases the fruit and shortens the finish. An unbalanced wine is a wine that will not age well, and in the case of fine wine, its aging ability is compromised. As the German oenologist Volker Schneider describes in his work "Aromatic and Phenolic Ripeness": «Sugar content of the grapes defines exclusively alcoholic ripeness, i. e. the potential alcohol content. Beyond that one can also recognize a physiological ripeness, comprising aromatic and phenolic maturity. It is not directly bound to the alcoholic ripeness. At least not anymore, and even less as global climate change progresses. Therefore one can find completely unimpressive and one-dimensional high Brix wines»[5]. And phenolic compounds, extracted from grape skins and seeds, together with the aromatic compounds are the main factors are key to wine quality.

Christian Seely, Managing Director of AXA Millésimes, opened the first international symposium on "Alcohol Level Reduction in Wine" in 2013 with remarking that the increase in alcohol level related to climate change is one of our major challenges. This phenomenon observed all over the planet shows that grapes ripen more and more early, and would mainly result from global warming.

The typical and historical range is from 8%-12%. Now, in 2016, only three years later, these levels have been raised even higher. Averages in Chile, California, Australia and Southern France, are 14.5-15% and more. In order to combat these increased levels, wine producers are using a new technology, albeit discreetly. One in four bottles of "premium" Californian Pinot Noir and Chardonnay have been through the industrial alcohol removal process supplied by ConeTech in the past year. But this is a topic for another paper.

### *Climate change and wine: what should happen in the vineyards*

In general, the grapevine needs 25-35 inches (635-890 millimetres) of water during the growing season (spring and summer/budburst to harvest) to avoid stress. Balance is key: too much stress or high temperatures (35°C), and the vine shuts down, too little stress, and the vine is "spoiled". Ideally, this water requirement is met by natural rainfall.

The vine's growing season starts in spring with budburst (*débourrement*), followed by flowering in the summer (*floraison*) and then setting and ripening (*véraison*), finishing with harvest (*la vendange*) in September (or later, depending on wine style).

In Europe, the wine climate model, as with the A. J. Winkler heat summation method, is loosely based on Köppen's Group C: a sort of sub-set classification. They are: Mediterranean, Maritime and Continental. The *Vitis vinifera* does its best work when grown between the 30th and 50th parallel in both Hemispheres, for a little while longer, that is. This is what is shifting. Köppen's Group C includes climates with an average temperature above 10° C / 50° F in the warmest months and an average of between -3° and 18° C / 27° and 64° F in the coolest months, and already, the regions he included in his categories outside of his Group C are taking steps into viticulture, and some of the regions in is Group C will eventually no longer be able to sustain viticulture.

### *Wine's water footprint*

The water footprint of a product (good or service) is the volume of fresh water used to produce the product, summed over the various steps of the production chain. 'Water use' is measured in terms of water volumes consumed (evaporated) and/or polluted. The 'water footprint' includes three

components: consumptive use of rainwater (green water), consumptive use of water withdrawn from groundwater or surface water (blue water) and pollution of water (grey water). A water footprint is more than a figure for the total water volume used; it refers specifically to the type of water use and where and when the water was used (Hoekstra 2008). Water is used in every process of wine production. In the winery, it is used for crushing and pressing procedures, cleaning tanks, barrels, bottles, floors and other equipment. In the vineyards it is used for irrigation (blue water). In sites where irrigation is legally practiced, this is its greatest use of water. 83% of the surface under vine is irrigated in the New World as opposed to 10% in the Old World (Montpellier.inra.fr). It is the variables inherent in the practice of irrigation; from country to country; region to region; and micro-climate to micro-climate, that renders determining wine's water footprint, so difficult.

*Irrigation and the water footprint*

Incorporating all water sources, the Water Footprint Network reports that it takes an average of 109 litres of water for a 125 ml glass of wine. In drier countries, the average is higher (Australia = 120 litres and California = 131 litres) (WWF, 2014). These estimates are challenged by many New World oenologists. Larry Williams of UC Davis believes that the Dutch researchers at the WFN, failed to consider the higher yields in California and other non-European vineyards. While winery water use is rather standard across the industry, measuring water use via irrigation is quite the wild card. It requires that evapotranspiration be measured as well as water added to the vineyard. And the amount of irrigation required is dictated by planting density (row spacing), the rootstock, type of trellising, the soil's water-retention ability, site temperature, sunlight and wind speed. Williams argues that in California for example, because they have much higher yields than European vineyards, the water is being used efficiently and there is "more wine for the water buck" (Williams 2001). His research concludes that California vineyards, where he estimates that 90% of vineyards are irrigated, produce two to four times as much fruit as in Europe (Williams 2001). It is the mindset of his argument that lies at the very heart of the problem.

And in drought-ridden southern Spain, where limited irrigation is now permitted, researchers argue that the water footprint alone is not a viable enough indicator with which to measure water's "economic productivity". Blue water economic productivity in high value crops such as wine and olives relies not only on climatic conditions and yields, but on water use and the product's end value (Aldaya *et al*. 2010).

This shared argument overlooks the illogic of justifying increasing irrigation with maximum yields and thus, greater economic profitability, when maximum yields will ultimately lead to lower quality and lower economic profitability. Any profit afforded by the greater yields will eventually be consumed by the cost of the water. Wine risks being irrigated into non-existence. This sounds an unpalatable prospect, especially for those grape growers who irrigate. Hence the strident denial of this outcome. It is not easy to accept that one's livelihood is under such a threat. The drier it gets, the more producers irrigate, the more soils are destroyed by salination, the more diluted the wines become, the more expensive and scarce the water becomes and the crop is eventually no longer viable.

Wine's average global water footprint may not be enormous compared to other crops, or even other beverages, but it ranks as the most important fruit crop in the world in terms of production and economic importance (Cramer *et al*. 2006; Vivier, Pretorious 2002). This footprint is clad in some very high heels. According to the Water Footprint Network,

> water footprint measures the amount of water used to produce each of the goods and services we use. It can be measured for a single process, such as growing rice, for a product, such as a pair of jeans, for the fuel we put in our car, or for an entire multi-national company. The water footprint can also tell us how much water is being consumed by a particular country – or globally – in a specific river basin or from an aquifer. The water footprint has three components: green, blue and grey. Together, these components provide a comprehensive picture of water use by delineating the source of water consumed, either as rainfall/soil moisture (green) or surface/groundwater (blue), and the volume of fresh water required for assimilation of pollutants (grey/recycled).

Wine's footprint is also unique in that it varies dramatically according to country and even region. More so than any other crop, I would argue. Further, the blue water component (irrigation) is the variable in the equation that is most dramatically variable. So, where coffee or tea have amongst the highest global average embedded water content (blue and green), the water use is predominantly green water, not blue. «Though coffee, tea and rice – responsible for about 23 percent of the world's blue and green crop water use – are notorious wa-

ter guzzlers, the majority of these crops are grown using green water which has less of an impact on the environment than the use of blue water. In contrast, cotton, which only uses about 2% of agricultural water (green and blue), is 70 percent irrigated. Only about 15 percent of the world's crops are irrigated, but this tiny group is responsible for 70 percent of the world's blue water (freshwater) withdrawals» (Waterwise 2007), while 22 percent of the world's freshwater is used for industry and 8 percent for domestic use. When we remember that over 80% of the world's vineyards are irrigated, and as both the need for irrigation in current planted acreage increases as well as the additional acreage that will need irrigation as the warming trend continues, a theme emerges.

*Adapting to climate change*

Current adaptation strategies in the vineyards include rootstock and clonal selection, planting in higher altitudes and cooler coastal regions where both physically and legally possible, better canopy management, reduced tillage, trellising techniques, and changing to warmer-climate grape varieties, again, where legally permitted. «Fortunately, *Vitis vinifera* has a wide genetic diversity that can enable such shifts. However, within *Vitis vinifera*, there are few widely planted varieties that can produce quality wine in excessively warm climates» (Diffenbaugh 2011).

This is a pivotal era of the wine industry. The wines of the southern hemisphere will at first do better due to their coastal influence and their lack of any legal restraints imposed by European appellation laws. They will move south, closer to the pole, until they run out of space. Space is something the Northern Hemisphere has more of, which means that wine regions in this hemisphere, both Old and New, will ultimately home the majority of the world's wine production. Those regions in northern Europe will be the first to find our next classic *terroirs*. Old World wine production in the classic appellations will hang on for as long as it can using current grape varieties, trading on their established appellation "brands" until, with forced irrigation and heat, they become New World versions of their old selves. Full-scale replanting programmes will eventually be embraced, exploring first the forgotten indigenous grape varieties and then adopting others from other warmer regions. Many have already begun, others are adopting a "wait and see" policy. But again, as the old regions lose production, the newer regions will gain in production and balance will be restored (Johnson-Bell 2016).

*Irrigation as an adaptation technique*

Irrigation is both a question of waste and taste. "Irrigation" is a wide term, encompassing a variety of practices according to the amount of water used and the frequency with which the water is applied: from flood, or furrow irrigation, to spray irrigation, and to drip, or trickle irrigation, and then from first day of the growing season and throughout to harvest, or once a week, or once a day, or continuously. Unirrigated vines are forced to dig down deep to find moisture and they pick up nutrients through the soil formations as they do this. Irrigated vines often miss out on vital nutrients because their root systems remain on the surface, where the moisture is. As Emmanuel Bourguignon, the French soil ecologist, explains, «irrigation allows the vine to be lazy; the roots stay in the top forty centimetres of soil and don't seek out the goodness in the subsoils and sub-solum. Permanent irrigation leads to a shallow root system. If your roots stay in that horizon you will end up with some slight vigour problems» (Gibb 2013). Then some quantity-driven producers make it even easier for the vines. They add fertilisers to the water in the drip irrigation system ("fertigation"). This way, the vines are fed and watered without having to get out of "bed". When vines are over-fed, over-watered and over-exposed to sun and heat, they will not develop any "character". Shallow root systems also leave the plant more vulnerable to drought.

It is accepted that irrigation contributes to higher yields, wider leaf area, more vegetative growth and larger berries. The debate lies in whether or not these responses constitute a negative effect on wine quality. Excessive irrigation produces less-flavourful crops. James Wong, of the Royal Horticultural Institute tells us that when absorbed through the roots and pumped into the cells of leaves and fruit, water dilutes the concentration of sugars, vitamins and aroma chemicals within the cells, watering down their flavour. A 2008 Spanish Tempranillo concluded that irrigation had some negative effects on wine composition. It altered the balance between malic and tartaric acids, led to an increase in wine pH, and caused a small decrease of anthocyanin and colour (Intrigiolo, Castel 2008). And numerous studies have confirmed that reducing irrigation effects fruit nutritional quality by increasing anthocyanin and phenolic concentrations (Chaves *et al.* 2010, Bravdo *et al.* 1985) whether they be pomegranates, tomatoes or peaches.

Horticultural principles do not discriminate. The world's best winemakers modestly refer to themselves as "farmers". The first winemaker to teach me this was Aubert de Villaine, owner of

Domaine de Romanée-Conti. It was a rainy, damp Burgundian afternoon in 1995 and I was interviewing him for the French wine magazine I edited. My publisher and I had spent nearly four hours in his gravel-floored, cobwebbed cellars, barrel tasting magnificent vintages of Richebourg, Grands-Echezeaux and his monopolies of the La Tâche and Romanée-Conti vineyards. Asked how he created such wines, he said that the secret is to remember that he is merely a farmer, growing fruit, who simply enables nature to do what it does best. This humble, hands-off approach is in direct contrast to those winemakers who have explained to me that they see themselves as those who can manipulate nature in order to produce the exact style and amount of wine that they want. The decisions a winemaker has to make, from planting to bottling, all fall into either one of these two approaches. That said, every wine producer will have his or her opinion as to where to draw the line through the middle of the vast grey area between them. Bourguignon continues:

> Irrigation's increased vigour, or vegetative growth, creates a large canopy, which is particularly problematic in sunny climates because it increases photosynthesis resulting in high sugar and potential alcohol levels. You end up getting massive photosynthesis – high level of sugar and high alcohol potential. So you dilute the terroir, but you tend to increase the varietal character. You can have a good canopy and make a good varietal wine. That's fine if you are making an entry-level fruity wine, but you can forget about minerality and sense of place (Gibb 2013).

Which is sometimes the desired result: consider a New Zealand Sauvignon blanc compared to a Sancerre. Bourgignon is clear, irrigation is qualitatively suitable «if you are making an entry-level fruity wine. If you want to be unique, irrigation will make that very difficult» (Gibb 2013).

Irrigation in European vineyards has always been illegal, partially, to reduce yields during the 1930s and 1950s when over-production and low prices were an issue, but also in acknowledgement of the qualitative advantage. Now, with the recurring droughts in many parts of France, the INAO and the EU are having to relax irrigation laws in the Mediterranean. Spain can irrigate under certain conditions since 1996.

In Italy, too, the laws are relaxing. As the winemaker Giorgio Rivetti of La Spinetta in Piedmont writes:

> Until April of 2013, the D.O.C. and D.O.C.G. regulations prohibited irrigation for our Italian vineyards. That changed, however, on April 19 when Italy's Minister of Agriculture passed a decree (n. 6858 – 19 April 2013) allowing emergency irrigation for D.O.C., D.O.C.G. and I.G.T. wines that are currently dry farmed.

The circular is careful to point out, however, that irrigation is to be used only in extreme situations and not as a means to force or increase yields. In any case, the issue is controversial and undoubtedly complicated, and likely, as in most cases, there is not a definite right or wrong way of doing things. For now, however, wines in Piedmont are produced without irrigation – in respect of tradition, the terroir, and the environment – and at La Spinetta they always will be. Irrigation, especially when excessively implemented, can decrease the overall quality of the grapes, and therefore the wines, by increasing yields. Many wineries in the New World use just this method in order to produce more fruit and more wine, which they are then able to sell at lower prices. Another potential negative influence on quality is the disruption of a wine's natural expression of terroir (Rivetti 2013).

And in Chianti Classico, Article 4 of the production zone regulations for a D.O.C.G states: «The vineyard layout, types of vine training and pruning methods must be such as to not modify the special characteristics of the grapes and the wine. In particular, any form of vine growing on horizontal roofing, tent-type, is prohibited. No forced growth is permitted, although emergency irrigation is allowed». This clearly suggests that irrigation forces growth for greater yields.

In France, in December 2006, irrigation also became legal. But again, under certain circumstances (Décret n° 2006-1527, JORF n°282 du 6 décembre 2006, p. 18338, n°27). But in the official decree, the most efficient method of irrigation, drip, has been outlawed in preference for spray irrigation. And the period of irrigation has been limited to between 15 June and 15 August, which is the flowering and ripening seasons, as opposed to between budburst and flowering, or any other time, making it difficult for producers to have any control over their crops. Further, AC /AOC producers must apply to the INAO for permits in such detail that the crop risks failure before the required permissions are decided. It does not come easily to them and they are keen to perfect the balance between minimum irrigation and quality. Along with irrigation as their primary adaptation techniques, they are, as mentioned above, experimenting with unused, but legal indigenous grape varieties, and or, introducing those varieties from warmer climates […] such as Greek or southern Italian varieties (Dufourcq, Yobregat 2013).

*Methods of irrigation: Flood, furrow sprinkler and drip*

Historically, surface, or flood irrigation has been used in viticulture. It uses gravity to release a flood of water across the vineyard. This provides little control over the amount of water used. Furrow irrigation, a variant of flood, allows small channels to run between the rows, which gives a bit more control. Surge irrigation is a subset of furrow irrigation and the water supply is pulsed on and off in planned time periods. Sprinkler, or spray, irrigation involves erecting sprinkler systems throughout the vineyard about 65 feet (20 metres) apart. The sprinklers can be set in advance and with a predetermined amount of water. This is a better method than flood or furrow, but still leaves very little control over how much each plant receives. The most efficient method, which can also be more expensive in terms of equipment and maintenance, is drip irrigation, where water supply lines are laid out along the vine rows, giving each plant its own dripper. Depending on the crop, water applied under drip irrigation is approximately half as much as under flood irrigation (Ward 2008). As Robert E. White points out in his book *"Understanding Vineyard Soils"* micro irrigation systems (drip), offer the best means of accurately applying predetermined amounts at known rates, targeted to specific areas with minimum losses. Hence the efficiency of water use can be as high as 80%-90% for well-managed systems. And although easily automated and controllable by wireless signals, are the most capital intensive

Deciding how much water to use in irrigation depends on the site, its soil type, the stage of vine growth, row spacing, size of vine's canopy and the amount of rainfall occurring during the growing season. Again, the variables are different from country, to region, and to even micro-climates in a region, and to different varietals within those micro-climates. For example, the coastal wine grape production areas in California are characterized by warm days and cool nights, although high temperatures (104-116° F / 40-46° C) may occur for a few days each growing season. Some areas may have fog lasting late into the morning. Rainfall is greater in northern coastal valleys and diminishes further south. In coastal valleys, evaporative demand can range from 35 to 50 inches (88-127 cm) of water throughout the growing season (between bud break and the end of October). Many of the soils in the coastal production areas are clay loam to clay-type soils, which hold more water than sandy-type soils. Since the majority of rainfall occurs during the dormant portion of the growing season in these areas and vineyard water use can be greater than the soil's water reservoir after the winter rainfall, it is argued that supplemental irrigation of vineyards is required at some point during summer months (Williams 2001).

It is worth noting here that as climate change is bringing more erratic climatic events to the vineyards, early spring frost as well as unexpected late frosts are becoming a recurring hazard, often destroying a large portion of the vines. The tragic irony of this exaggerated vintage variation, is that in many regions, winemakers have lost 30% of their crop to frost in April or May, only to have the surviving vines decimated by drought in August. So proponents of irrigation argue that irrigation solves both of these problems as it is often used as a frost protection method. But the best irrigation method for frost protection is flood or over-head sprinkler, as it keeps the ice wet and gains a few degrees in temperature[6]. The best method of irrigation, drip irrigation, is not the best for frost protection.

*Flood irrigation's bloated past*

Argentina is a good example of flood irrigation use, which is the worst form of irrigation in terms of both water conservation and fruit quality, as it soaks the vine's root system. Flood irrigation is only suitable for bulk wine production (Robinson 2015). When the Spanish settlers made their way to Mendoza, they found a fertile oasis in the middle of an arid desert. The indigenous tribes, such as the Huarpes, had created a sophisticated flood irrigation system conveying water from the Rio Mendoza, which is supplied by the spring and summer snowmelt from the Andes. These channels featured advanced hydrodynamics techniques which allowed the regulation and control of the flow of water, allowing efficient use of the scarce resource. The system supplies both Mendoza's residents and all its viticulture with water. Irrigation channels have been extended and added to, but the system remains the same. Water is rationed between vineyards and farmers through the opening and closing of miniature flood-control gates. Once in the vineyards, the growers use the same technique to flood irrigation channels around the base of their vines (Arellano 2014). Though most producers here acknowledge that drip irrigation is more efficient, few are making the change (Argentinian Wine Association 2016). Producers there believe that their «desert climate and advanced irrigation system gives Mendoza's grape growers a unique advantage. With complete control over the watering of their vines, and in combination with the hot

daytime temperatures and cool nights during the grape ripening seasons, conditions are almost ideal for growing grapes with ripe, intense fruit characteristics and good acidity levels» (Argentinian Wine Association 2016). This is another example of how mind-sets need to change, as does the language they use to communicate with the consumer. Consumers buying an Argentinian wine will not know about flood irrigation nor its effects on the environment or wine quality.

*Drip irrigation*

Within drip irrigation, the "on-the-wire" method is the most common. The "surface" method is the simplest, most cost-effective and most versatile form and is used when weed control is chemical under the vine and drip lines are laid on the soil surface under the vine along the trunk line. The sub-surface method is the most aesthetic, reliable, and efficient technique because the laterals are buried 25-50 cm (10-20 inches) under the soil. This means that they are protected from weather and mechanical machines, that evaporation water loss is reduced by 10-20% as compared to a surface drip, and that the water is applied precisely to the centre of the root zone.

Unlike the conventional irrigation methods, drip irrigation does not consist of using the soil as a water reservoir since the horizontal water distribution is limited and depends on the hydraulic conductivity properties of the soil. Therefore, this method requires frequent irrigations in order to eliminate water percolation to soil layers bellow the major root zone. Drip systems are normally designed to supply the water requirement of at least one day during the top season. At the beginning and at the end of the season, when the water requirements are low (due to low evaporative demands and low canopy surface irrigation), frequencies may vary between one and two per week. During the major season, frequencies may increase to daily or every other day. Sandy soils require more frequent irrigations than heavy soils. Crop evapotranspiration (ET) is higher under drip irrigation, which reflects higher water depletions that support the typically greater yields (Ward, Pulido-Velazquez 2008).

The trick for winemakers is to find the perfect balance between water efficiency and the low yields associated with quality wines. Although many wineries world-wide are switching to drip-irrigation, and although even those that use irrigation adhere to the "less-is-more" mindset, the reality is that drip-irrigation is very expensive, and flood irrigation is still being used despite the knowledge that it causes severe environmental damage, from water-logging and increasing soil salinity, to raising the water tables.

*Irrigation and water stress*

This means that even when using irrigation, quality-driven producers use strategies to mimic nature's "water stress". Controlled water stress is when the vine receives sufficient water during the budding and flowering period but not too much during the ripening period. This is also called "deficit irrigation". We can control water stress by using Regulated Deficit Irrigation (RDI). For example, in the inland areas of the US's Pacific Northwest, rainfall averages only 4 to 12 inches per year (10 to 30 centimetres) and the most-used irrigation practice has been RDI which more than 60% of the wine grapes grown in Washington are grown using this method (Davenport *et al.* 2008). By withholding water during the period between when the grapevine first sets fruit and *véraison*, both the vegetative growth is controlled, and the size of the grape berry is reduced, which means more concentrated wines. Again, it is all about balance. Over-irrigating produces a wine that is low in alcohol and colour, and has a thin, weedy and dilute palate. Whilst vines that are highly water-stressed can also produce poor quality grapes with much lower colour, flavour and tannin than vines that have experienced low or moderate levels of water stress (Gawel 2016). This is because "highly water-stressed" is not a normal dry-farming, rain-fed environment or context. "Highly-stressed" is an extreme drought condition that will produce poor quality grapes and indicates that the climate is unsuitable for viticulture.

There is another irrigation approach called Partial Rootzone Drying or PRD. It involves "tricking" the vines into thinking that they are stressed, by watering only one side of the root ball at a time. By doing so, the vines, slow down their lateral shoot growth (decrease their vegetation), yields are not affected and the amount of irrigation water needed is nearly halved (McCarthy *et al.* 2002). But this technology is still being researched both in viticulture and with other agricultural crops (Gençoğlana *et al.* 2006). PDR may not be as effective as is hoped in regions with excessive evaporation or a heavy demand for supplementary irrigation.

*Irrigation and soil salinity*

Soil salinity is another problem with irrigation (Sidari *et al.* 2008, Cramer *et al.* 2006) and the

problem is not confined to viticulture. This happens when groundwater levels are close to the surface. In clay soils this may be within 3 metres of the surface, whereas on sandy and silty soils it is less. Capillary forces bring water to the surface where it may be evaporated, leaving behind any soluble salts it is carrying. Arid soils are the most susceptible: Australia, North Africa, and California are all experiencing soil salinity. When salt levels get high enough in the vine, the leaves start to display "leaf burn" or browning. Salts also change the structure of the soil itself and the way the roots grow and that effect the vines, and wines. Soil salinity means potentially phytotoxic salt components such as sodium, chloride and boron, which can cause crippling decreases in vine vigour or even vine death at elevated levels[7]. Winemakers in southern Australia are battling with both irrigation salinity and dryland salinity, which both create toxic concentrations of ions and render viticulture unviable (Biswas, Bourne, McCarthy, Rengasamy 2008). One farmer, who prefers to remain unnamed, explained to me that it was the very act of farming that is increasing the dryland salinity because the indigenous plants have been destroyed for the cultivation of wine grapes, and that he and his neighbours will keep relying on irrigation to guarantee as high a yield as possible so to "stay in the game", even though he understands that doing this means one day his plants will stop producing fruit and die.

Correcting soil salinity is currently a highly-active area of research. With so many global hectares rendered barren due to irrigation-induced salinity, it seems logical to investigate methods to both mitigate and rectify salinity damage. The best way to decrease soil salinity is to drench or to flush the soil with fresh water: such as mountain run-off, rainfall or rivers. But if the vineyards suffering from soil salinity had such freshwater reserves at their disposal in the first place, they would not be irrigating. Currently, in agriculture in general, the primary solution is leaching 10-20% of the irrigation water, then draining and discharging it. Strip cropping is also used but is not applicable to viticulture. In heavily flood-irrigated crop areas, such as India, subsurface drainage is proving to be an effective tool to combat both waterlogging and salinity (Ritzema *et al.* 2010). Another approach might be to use ridging, a soil preparation practice meant to aerate water-logged vineyards, as a remedy to over-irrigated soils (Myburgh, Moolman 2013). There is also research being done on the effect of organic materials (e.g., furfural residue and its biochar) has on the physical and chemical properties of saline soils with low fertility (Wu *et al.* 2014).

Soil salinity research tends to focus on its physiological and metabolic effects, as opposed to its effect on chemical composition, volatile aroma compounds and sensory characteristics on wine – its taste. Interestingly, it has been determined that there may be some grape varieties that are better suited than others to the influence of soil salinity, such as the Nero d'Avola in Sicily (Scacco *et al.* 2010). To determine other varieties that perform well in salinated soils would prove a useful adaptation tool for winemakers as they experiment with replanting.

### *How much longer is irrigation viable?*

To sum up the correct position on irrigation, I would turn to the work of John Gladstone:

> It therefore seems clear that no established irrigation system can provide the desired slight, to moderate stress, other than transiently, in the typical situations, where substantial irrigation is needed. Dependence on drip or other irrigation to the extent that it starts to supplant natural root distribution must, by contrast, be at the expense of grape and wine quality. And while that sacrifice may still be commercially worthwhile for inexpensive wines, it is incompatible with quality viticulture and especially for individually terroir-based wines. High prices for these depend on their uniqueness and site typicity. These characteristics depend on an intimate relationship among roots, subsoil, underlying geology and climate that cannot be reconciled with any major need for irrigation.

For those who continue to use irrigation as an adaptation technique, they will be placing themselves in a holding-pattern until either the price of water or the lack of water, renders viticulture unviable, and also running the risk of causing such levels of soil salinity that no other crops could be sustained either. While many wine producers are looking at ways to reduce their water usage in the winery, they still continue to irrigate. Wine-producing regions are cloaking their climate change crisis in the garb of prolific "sustainability" credentials and encouraging winemakers to sign up to ubiquitous carbon neutrality programmes. For example, in South Africa, on the Wines of South Africa web-site, under "Sustainability", then "Environmental Sustainability" and then finally, "Climate Change", we find the statement: «Climate change is expected to directly impact on South Africa's mean annual temperature and rainfall ranges, influencing pest and disease distributions, flowering and fruiting seasons, and ground water

resources»[8], and we see that they have established a sustainability certification, "Integrity & Sustainability" Certified, but nowhere in their sustainability guidelines do they recommend not irrigating. This is also the case for the Napa Valley Vintners Association and their main web-site[9] eventually takes you to their "Napa Green" certification program, which strives to encompass the whole vineyard property to "the benefit of the Napa River Watershed" but again, ignoring the greatest "non-green" threat of blue-water use, irrigation is permitted for certification. To not be able to irrigate would be the death knell for too many wine producers in terms of unviable low yields or even entire crop loss, and this is, understandably, a stark reality to contemplate.

Despite these efforts at sustainability, we find a disconnect between the wine producers and the consumers, as the producers are not communicating their struggles in either the trade or consumer press. They keep the real issues out of the public arena. I have a very difficult time convincing winemakers in Napa Valley to admit they are in any real danger. There are those who do not believe it is happening, and others who don't care because they feel they cannot do anything about it. Most wine producers feel that any attempts to change are futile because it is only the "big brands" that can afford the technology to adapt to climate change. But the real problem cannot be "adapted" away. At some point, irrigation as an adaptation technique, and not irrigating as a mitigation solution, will collide.

To go beyond adaptation, to become resilient in viticulture, means not only adapting to protect low, healthy yields, but also to protect quality, or its "luxury" status will be lost. Quality-driven products need different solutions to other crops and industries. Many regions understand that the *Vitis vinifera* will one day outstay its welcome and will have to pack its bags and migrate to cooler climes. So assisting winemakers envision this outcome is part of being resilient to climate change. The winemakers who do not embrace such realities, however unthinkable, risk being the ones who will be destroyed by adversity as opposed to merely being changed by it.

*Dry farming: not a new "trend"*

> The European wine industry doesn't just frown upon the supplementation of rainfall; it forbids the practice (with a few exceptions; most European countries permit irrigation for newly planted vines, and some have begun loosening regulations in the case of drought). If you water mature vines in France, for instance, you may find your *appellation d'origine contrôlée*, the industry's all-important certification of place, revoked. Adding unnatural quantities of water, the thinking goes, means meddling with a wine's terroir, its unique expression of place. Even in California, grape growers relied on rain alone until the 1970s, when drip irrigation was introduced to the state. The grapes responsible for establishing Napa Valley as a world-class wine region in the middle of that decade – from brands like Stags' Leap and Château Montelena – all came from dry-farmed vineyards. Over the years, however, commerce eclipsed custom. Irrigating vines, American farmers found, invariably increased yields. And more grapes per acre meant more profits per acre. Once the connection with yield had been established, many U.S. banks began refusing loans to vineyards that didn't promise to irrigate. Today, the majority of California wineries irrigate their vineyards even in years, and areas, with plentiful rainfall (Wallace 2015)[10].

But with rising water costs and increasing water restrictions, New World wine producers are finally connecting the dots between dry-farming, deep root growth, plant longevity (old vines) and *terroir*. In fact, there are pockets of dry-farmers in the Sonoma hills with old parcels of Zinfandel. Ted Seghesio once recounted the story of how his great-great-grandfather left his family vineyard in Piedmont came to Alexander Valley in 1895 to plant Zinfandel (or what we now know is Primitivo). Many of their oldest parcels, some 70 years-old, are still dry-farmed. And on the other side of the world, there is a growing movement of dry-farmers in Swartland, many of whom have always practiced dry-farming. Winegrower Nadia Sadie explained to me that recently that the tonnages are extremely small and that «financially, this is of course only viable if wines are sold at a top end price point. This is however not always the case and therefore not financially viable to all producers».

Financial incentives aside, the qualitative benefits of dry-farming are finally being recognised by New World producers. As Oregon winemaker Tyson Crowley tells Imbibe Magazine:

> We're talking about are more distinct and complex wines. When vines are irrigated, the root system of the plants stays near the surface of the soil because that's where the resources live. But with dry-farmed vineyards, especially in hot climates, the vines are forced to go finding water to sustain themselves. As the root system digs deeper into the earth, the vines start to tap into harder materials like rock and limestone. The deeper the roots

> go, the more powerful the message of that place becomes. All of that character ultimately pulls up into the flavor of the wine (Janzen 2017).

As stated above, dry farming is what Europe has always done, until recently. Dry farming is not though, simply "not irrigating". Dry farming entails careful soil preparation and husbandry so that any winter rainfall, and a minimum of 9 inches are required, is retained in the soil and roots so to sustain the vine through the growing season, when there is no rainfall, unlike in Europe where rainfall is all year round (usually!). Not all vineyards will be suitable: the best soils to hold water are clay loam or sandy loam, and the soil has to be deep. No crop can be drought-resistant if in shallow soil. Dry farming preserves water resources but also lowers yields, which is not what many producers want. The resulting fruit will also be denser and sweeter (Bravdo *et al.* 1985, Chaves *et al.* 2010) which means a wine with greater concentration and potential for longevity.

It is crucial that a plant be dry-farmed from the time of its planting. This is what forces the roots down into the soil looking for water and nutrients. As stated earlier, many New World wine regions have uprooted their old vines, vines that started life dry-farmed, in favour of planting younger more vigorous and productive vines. It is time to go back to past practices. Dry farming is not a "new" thing. The New World mindset is such that producers refer to the wines produced from their irrigated parcels as "conventional wines" whilst those issued from the dry-farmed parcels as wines made the "new" way. If dry farming and its resultant lower yields had been more widely embraced at the inception of the New World viticultural expansion, they would be in a better position in the face of the continued onslaught of drought, than they are today. As the Old World, anti-irrigation, pro-dry farming view held by many Portuguese winemakers in the Douro contends, there was never a need for irrigation there for 300 years and those who used irrigation before and those who are using irrigation now, to increase their yields, have created a vicious cycle.

Grape farmers using irrigation as a sort of insurance policy against low yields and low profits argue that dry farming is too "high risk". It has been confided to me that they feel too "at risk" if they cannot rely on their irrigation systems in times of drought. But I would argue that the climatic tipping points that render dry farming the "safer" method, have arrived. I think that as water costs become increasingly prohibitive, and as climate change and water usage legislation is increasingly implemented, thus rationing water use for irrigation, that grape farmers will be faced with no other choice other than to dry farm or to diversify. And a second tipping point, when higher temperatures prohibit vine growth and irrigation salinity causes soil death, then their only choices will be to cease viticulture or to migrate. It seems that a logical alternative would be to transition from irrigation to dry farming, if the farmer's soil permits this, and thus save on the costs of water use, water licences, irrigation infrastructure, repair and maintenance. To counter-balance the loss of yield, then it would make sense to market the wine as "dry farmed" and create a consumer trend around this, just as has been done with "organic" wines and "unfiltered" wines. The grape farmer should engage the public in such a way that they are made to feel informed and powerful in their purchasing choices, campaigning that they only purchase and drink wines that they know have not been irrigated.

### *Conclusion: Water or Wine?*

We are moving ever closer to this scenario. Over the last decade, grape growers in SE South Australia have had their water entitlements converted to volumetric allocations, experienced a reduction in annual rainfall and seen a rise in the salinity of irrigation groundwater. Most wine producers have shifted from flood and sprinkler irrigation, which was still widely used in the last decade, to precision drip-irrigation (Stevens *et al.* 2012). Still, thousands of grape growers have not been able to afford their water bills and have had to cease their production. In Australia's Riverina wine region, severe drought conditions have forced more than 10,000 families, mostly sheep and wheat farmers, off their land. Wine producers are also having to cease their business activities. The creeks and streams of the Murray-Darling river system is where around 1,300 growers produce more than 400,000 tons of mainly Shiraz, Cabernet Sauvignon and Chardonnay grapes, about a quarter of Australia's total. These vineyards have «relied on highly regulated irrigation systems flowing from enormous reservoirs in the nearby Snowy Mountains» and can do so no longer. Many vineyards have been abandoned to soil salinity, unable to grow any crop at all. But in general, winemakers are faring better than other farmers because their business is deemed so important to the local economy that it has been guaranteed water.

When an environment is contrived to such an extent that every step of the growing and production process has to be manipulated and manufactured; when local government legislation prioritises viticultural export products in lieu of food crops; and

when the very essence of a crop's value and identity is altered beyond recognition, then assisted migration at a forced pace may be the only option. In the reality of the current water crisis, debates over the existence of *terroir*, the definition of "fine wine", the "most efficient" method of irrigation, or a New World *vs* Old World mindset, become moot trivialities. Might it be time to, once again, only maintain viticulture in climates where it is most suitable: In climates where it can thrive with natural rainfall? Wine is not food and the world needs more food, not wine. Can we really afford the luxury of irrigating wine?

## Notes

[1] http://www.alsace-wine-route.com (last access October 2017).

[2] http://www.decanter.com/features/alcohol-levels-the-balancing-act-246426/ (last access October 2017).

[3]http://www.npr.org/sectionsthesalt/2013/05/06/181684846/with-warming-climes-how-long-will-a-bordeaux-be-a-bordeaux (last access October 2017).

[4] http://oldvineproject.co.za/ (last access October 2017).

[5] http://www.schneider-oenologie.com/english-site/downloads/aromatic-and-phenolic-ripeness.pdf (last access October 2017).

[6] http://cetulare.ucdavis.edu/files/81997.pdf (last access October 2017).

[7] https://www.winesandvines.com/features/article/49785/The-Dangers-Of-Soil-Salinity (last access October 2017).

[8] http://www.woa.co.za (last access October 2017).

[9] http://www.napavintners.com (last access October 2017).

[10] https://modernfarmer.com/2015/12/dry-farming-wine/ (last access October 2017).

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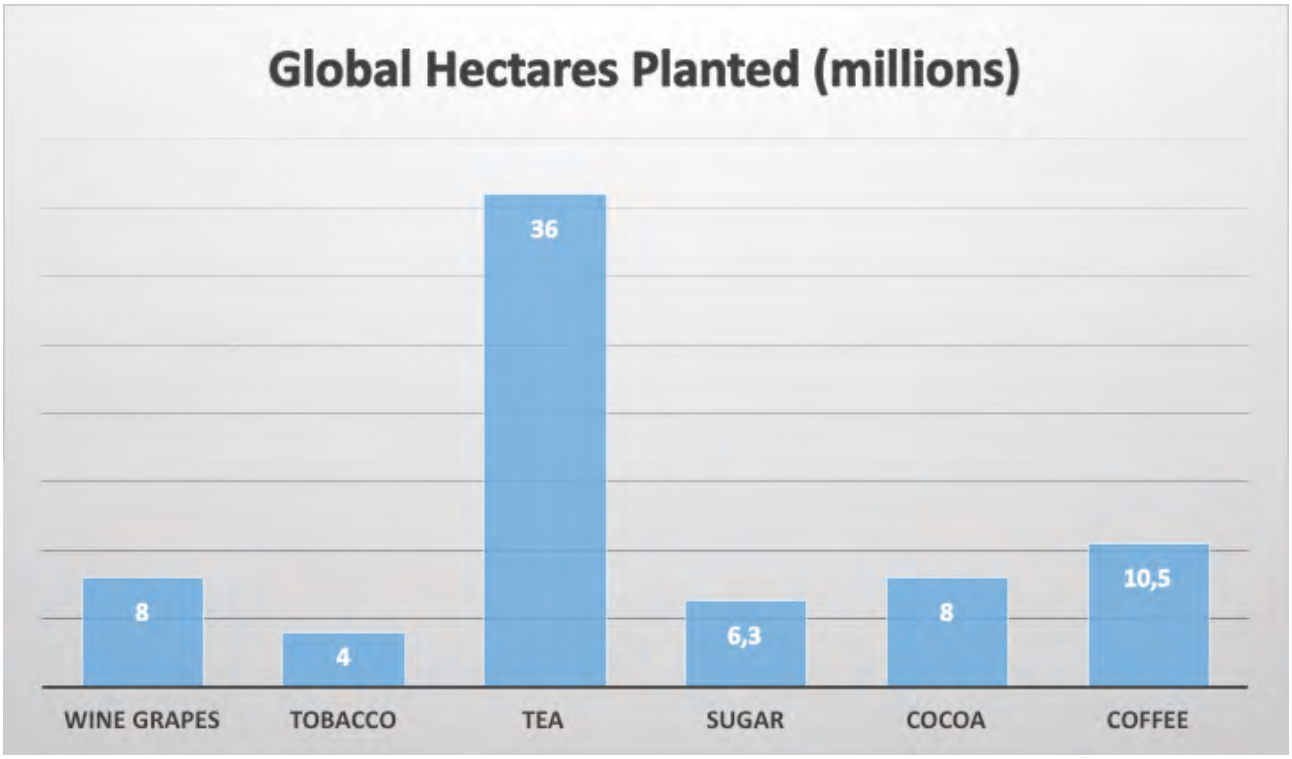
| WINE CLIMATES | CLIMATIC CHARACTERISTICS | EXAMPLES |
|---|---|---|
| Mediterranean | Has two sub-sets: Hot Summer (Csa) and Warm Summer (Csb). Hot Summer is what we consider to be "typical": average monthly temperatures higher than 22 C / 71.6 F during warmest months and an average in the coldest months of 18 to -3 C / 64 to 27 F or between 18 to 0 C / 64 to 32 F. Hot, dry summers and mild, wet winters. High summer temperatures can be cooled by nearby large bodies of water. Growing seasons are long and of moderate to warm temperatures. Little seasonal change with temperatures in the winter generally warmer than those of maritime and continental climates. During the grapevine growing season, there is very little rain fall (with most precipitation occurring in the winter months) which increases the risk of drought. Climate change is seeing more and more Csb sites move into Csa classification. | Tuscany, rest of Italy, Greece, Spain, Israel, Lebanon, Southern Rhone, Languedoc-Roussillon, Provence, Portugal (ex. Douro), Slovenia, Croatia, California, Western Australia |
| Maritime | Köppen's Cfb, broadly. Regions that are close to large bodies of water (oceans, estuaries, inland seas). Also has a long growing season but often suffers from excessive rain and humidity which bring disease. Clear seasonal changes, but not as erratic. Warm summers, rather than hot, and cool rather than cold, winters. | Bordeaux, Muscadet, Willamette Valley, Long Island, most of New Zealand, Southern Chile |
| Continental | Köppen's Cfb, Dfb. Hot summers and moderately cold winters. Acute seasonal changes throughout growing season. Hot temperatures during the summer and periodic ice and snow in winter. Usually inland. Big dips in temperature between day and night. Winter and Spring have risks of hail. | Columbia Valley, Burgundy, Rioja, Piedmont, Northern Rhone, Douro Valley, Loire Valley, Austria, Hungary, Romania (the entire Black Sea basin), Russia, Turkey, Columbia Valley, Canada, Mendoza |

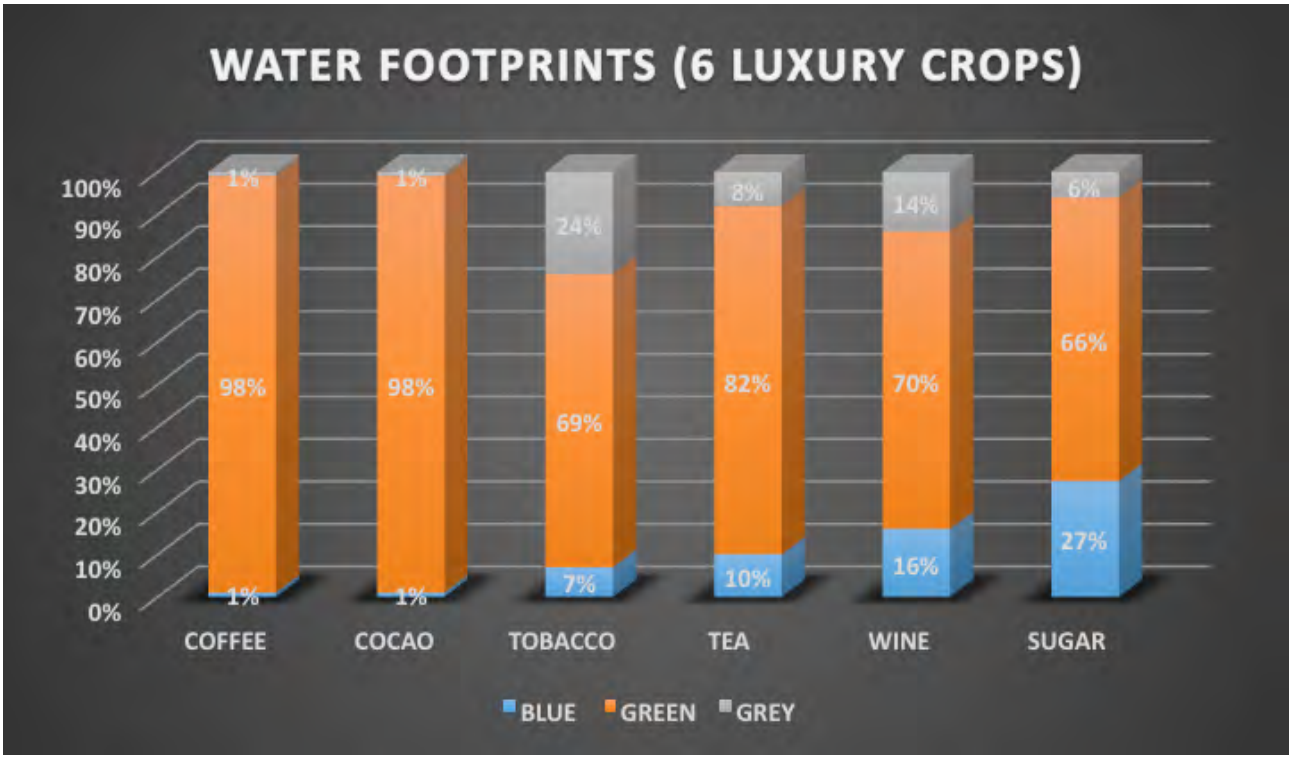
(Source: TWACCI.org)




Whilst wine is only represents 8 million hectares of the total 11.3 billion global hectares planted (and of the 883.33 million hectares of cropland) (Source: WWF, 2014), it is a $300 billion global industry set to increase by 1.36 (2.86 CAGR) between 2014-2019 (Source: TechNavio, 2014) having had a 3.5% increase in the past five years.

| | **Global Average Water Footprint** | **Green / Blue / Grey** |
|---|---|---|
| COFFEE | 130 litres for 1 cup of coffee (20,000 l. per kg) | 98% green, 1% blue, 1% grey |
| WINE | 110 litres for a 125ml glass | 70% green, 16% blue, 14% grey |
| TEA | 27 litres for a 250ml cup of tea | 82% green, 10% blue, 8% grey |
| BEER | 74 litres for a 250 ml glass | 85% green, 6% blue, 9% grey |
| MAIZE | 1222 litre/kg | 77% green, 7% blue, 16% grey |
| SUGAR | 1782 litre/kg | 66% green, 27% blue, 6% grey |
| DATE | 2277 litre/kg | 41% green, 55% blue, 4% grey |
| RICE | 2497 litre/kg | 68% green, 20% blue, 11% grey |
| COTTON | 2495 litre for a shirt of 250 gram | 54% green, 33% blue, 13% grey |
| BEEF | 15415 litre/kg | 94% green, 4% blue, 3% grey |
| CHOCOLATE | 17196 litre/kg | 98% green, 1% blue, 1% grey |

A selection of Global Average Water Footprints (WWF, 2014).




(Source: Mekonnen and Hoekstra, 2010).