Focus on canopy management and special tribute to Professor Nelson J. Shaulis who opened new ways in grapevine Biology and training systems.

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Abstract:
This article is a tribute and a testimonial to the viticultural science career of Professor Nelson Shaulis of Cornell University / Geneva New York State Agricultural Experiment Station. Professor Shaulis is best known for his promotion of canopy division and development of the Geneva Double Curtain – GDC in 1966 which sets out the principles of grapevine canopy management to avoid shade in grapevine canopies which affects grapevine growth, yield and fruit maturation. These principles became accepted as new fundamental criteria and encouraged further research in vine Biology and canopy management.
Key words: Canopy management, canopy division, Geneva Double Curtain, shade, grapevine Biology.

Introduction
This article is written as a focus on canopy management and a special tribute to Nelson Shaulis (1913-2000), former Professor of Viticulture at Cornell University's Geneva New York State Agricultural Experiment Station to which he was appointed in 1948. His research in New York was with Concord grapevines and conducted primarily at the Geneva Experiment Station as well as at Cornell's Vineyard Laboratory at Fredonia, and on grower's properties. Likely the most significant early publication of Nelson Shaulis was the description of the Geneva Double Curtain. Entitled "*Response of Concord Grapes to Light, Exposure and Geneva Double Curtain Training"* by Shaulis, Amberg and Crowe in 1966.
The present article points out the concept of canopy division and sets out to highlight Professor Nelson Shaulis's contribution to viticultural science and canopy management as observed by Alain Carbonneau and Giovanni Cargnello. They appreciate the reference data provided by Richard Smart who was a 1970s PhD student of Nelson Shaulis. Further supporting comment is made by two authors whose early career was influenced by Nelson Shaulis. The authors summarize also the impact of Nelson Shaulis on the studies of the late Professor Cesare Intrieri of Bologna University. This article is helped by analysis of Nelson Shaulis' publications, and by a public recognition of Nelson Shaulis during the 22nd G*i*ESCO meeting held at Cornell University in July 2023 delivered by Terry Bates of Fredonia, NY.

History of the concept of canopy division

The first inventor was Nature. Figure 1 shows a wild grape climbing in a tree whose canopy is naturally divided in order to intercept light.

Figure 1. *Vitis vinifera silvestris* growing in a tree and naturally creating separated tiers of sub-canopies (Bélesta – Ariège – France). © Alain Carbonneau.

The second known inventors were the Greeks and the Etruscans. Traditional open Vase was developed in ancient Greek vineyards (figure 2a). Fully split canopy called 'Cassone Padovano' was part of the Etruscan heritage in Northern Italy (figure 2b).

Figure 2. Left (a): traditional open Vase still used in Châteauneuf du Pape.
Right (b): Cassone Padovano as an old Etruscan heritage in Veneto.
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The third famous inventor was Professor Nelson Shaulis when he designed the Geneva Double Curtain – GDC (see the divided trellis and the two separated curtains in autumn in figure 3).

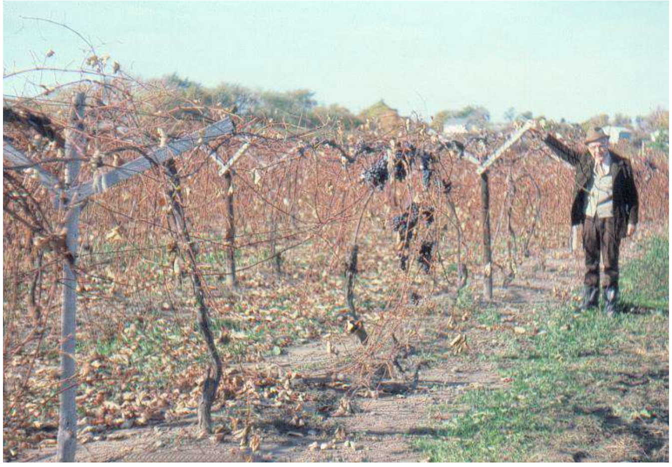

Figure 3. Nelson Shaulis showing the GDC on Concord grapes in Fredonia – 1975. © Alain Carbonneau.

The direct heirs: Richard Smart, Cesare Intrieri, Giovanni Cargnello, Alain Carbonneau. Figure 4 is a 'photo souvenir' of the meeting in Bordeaux organized by Alain Carbonneau in November 1985 which gathers the four researchers concerned by canopy management illustrating their choice of canopy division: GDC – 2 curtains down (Cesare Intrieri), Lyre – 2 inclined foliages up (Alain Carbonneau), Te Kauwhata Two Tiers – 2 superposed foliages up (Richard Smart), Harp – 2 off-centered up/down foliages (Giovanni Cargnello).

Figure 4. Miming 4 choices of canopy division. © Alain Carbonneau.

Some growers also were in favor of canopy division such as Scott Henry in Oregon who developed some modalities of 'up and down' canopies, similar to some traditional systems in Northern Portugal such as Vinhos verdes up/down, or in North-East of Italy such as Casarsa Friuli. Notice that the first congress on Cool Climate Viticulture held in Oregon in 1984 allowed Scott Henry to present his technical choices. Figure 5 is a 'photo souvenir' taken during that congress in the David Adelsheim's commercial vineyard where Nelson Shaulis mimed his GDC, Richard Smart the TK2T, Alain Carbonneau the Lyre. Notice that since this event, Richard Smart developed most the Scott Henry's systems, which are more convenient to control than the TK2T in which the lower tier is trained upward while it would be easier to let it free or to train it downward.

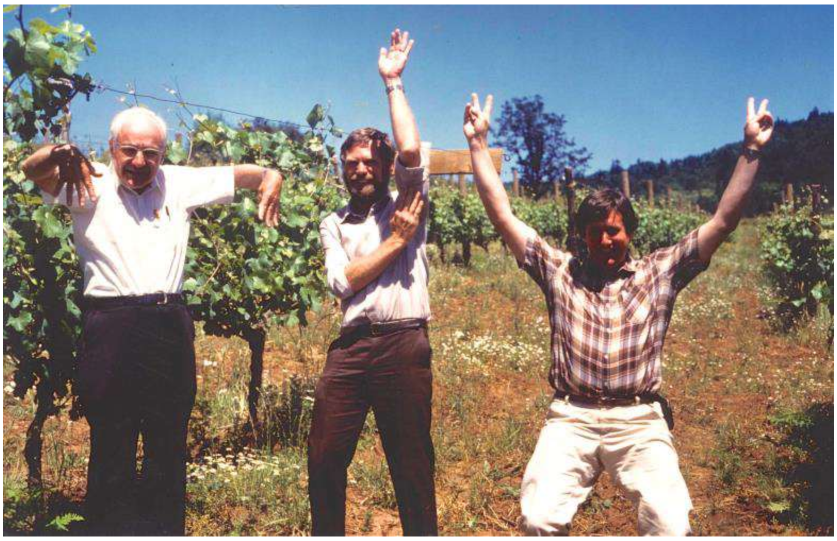

Figure 5. Oregon 1984: Nelson Shaulis (left) illustrating the canopy division downward in two curtains, Richard Smart (center) in two upward tiers, Alain Carbonneau (right) in two upward inclined parts. © (by courtesy of Geneva NY colleagues).

In fact the concept of *canopy division is a fundamental key in terms of vineyard management* and corresponds to option n°2 of canopy management:

1/ Single shape canopy: one concentrates on a single form and if a problem appears such as excess of vigor or shade, then one tries to solve it, not by changing the shape itself, but by changing other practices such as specific green operations, vine planting density, soil management.

2/ Double shape canopy: facing similar problems, one considers that part of the solution is to modify the shape itself, particularly by dividing the canopy, into two identical or different parts, in order to better control the microclimate of leaves and berries.

Option n°1 appears the most simple in terms of canopy management and adapted mechanization as well. But option n°2 of ***canopy division offers the possibility to control the microclimate while using quite large spacing between rows, which is an advantage in the context of the climate change by offering better capacity to produce strong roots and more chance to explore deep soil water reservoir. Besides, divided canopies can be fully mechanized in so far as adapted techniques exist; for instance mechanical harvesting by trunk or under-cordon shaking instead of lateral shaking.***

In the world of canopy architectures, Carbonneau and Cargnello (2003) identified 50 main models, among them 20 correspond to clearly divided canopies which demonstrates the importance of the concept of canopy division (figure 6).

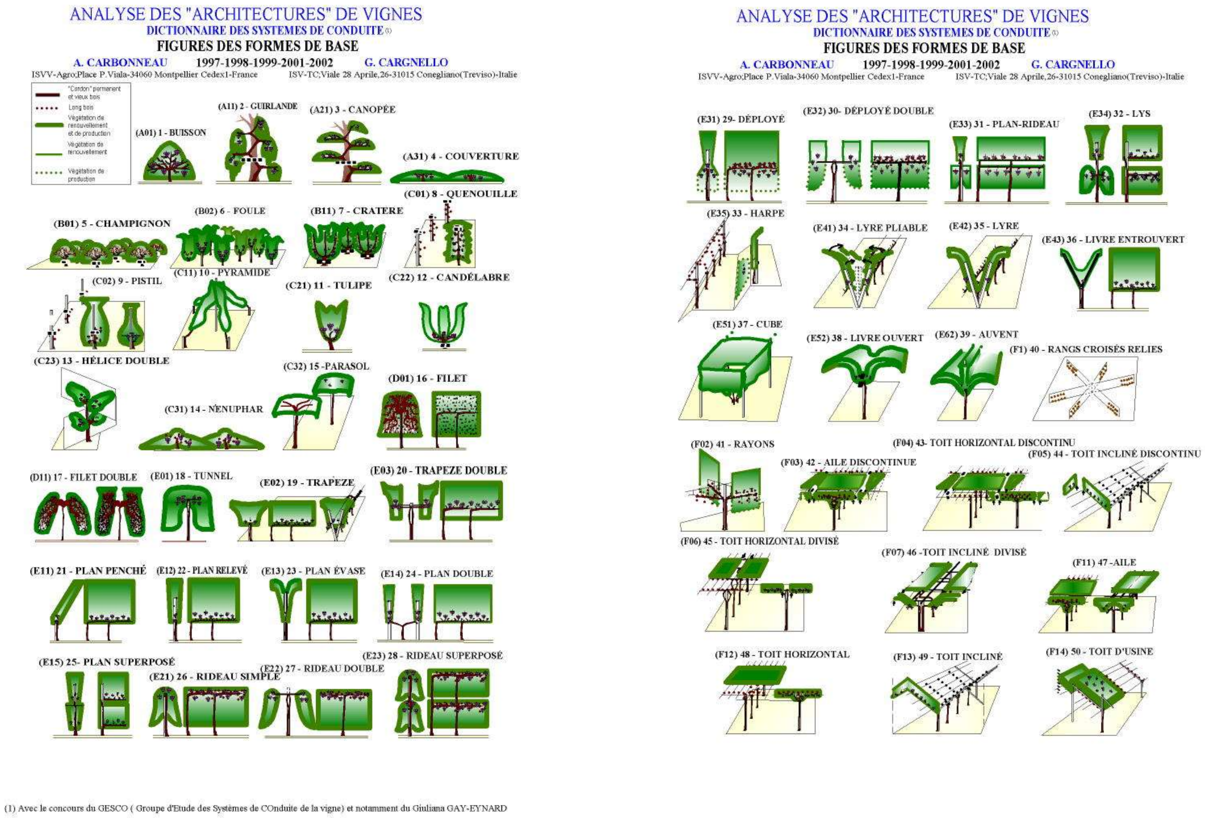

Figure 6. Schemes of the 50 models of canopy architectures, called 'formes de base', identified in the world, some being widely used, others only at a regional level. [Carbonneau and Cargnello (2003), reproduced by Carbonneau and Torregrosa (2020)]. On the figure divided architectures correspond to n°s: 2,3,10,12,13,17,20,24,25,28,30,31,32,33,34,35,37,41,45,46. © Giovanni Cargnello.

Summary of Nelson Shaulis'research on canopy management and grapevine Biology

1/ GDC design and justification

Nelson Shaulis and his team designed and proposed the Geneva Double Curtain (GDC) as a new training system based on canopy division, downward bearing and large spacing. It is particularly adapted to vigorous vines and profits by all technical and mechanical adapted facilities. This was published by Shaulis et al (1966).

Previously, Shaulis and Kimball (1955) studied the importance of vine vigor and shoot density or exposure in a very vigorous Concord vineyard. An increase in the number of shoots per foot of row, increases shading, and decreases both the rate of fruit maturation and the fruitfulness (crop per node). There is a superiority in vine growth, in yield and in fruit maturation when natural shading is decreased. Further, a study of vine density at two sites shows that fruitfulness as well as fruit maturity are affected by buds per foot of row, and not by spacing between rows. It is concluded that the yield-limiting problem is shading within the row. Those conclusions explain why Shaulis et al (1966) introduced their paper writing "*An increase in the number of fruitful shoots per acre is the basis of increased yield per acre*".

Nelson Shaulis payed more attention to definitions and word meanings which deepened some fundamentals in basic vine Biology (Shaulis et al, 1966): the interior shoots produce less ripe fruits, and all exterior shoots produce riper fruits; vines with shortened canopies had a substantially higher *ratio of leaf area to canopy surface area* (which is a useful shading index); these same canopies with more shading produce less ripe fruits; a related experiment shows that exterior shoots also produced better visual cane ripening (cane bark).

Nelson Shaulis detailed the effects of *shoot positioning* and bearing (upward or downward). He observed that when shoot positioning was not controlled, many vigorous shoots are nearly horizontal along the top of the canopy, causing considerable shading of those below. A vigorous external shoot therefore can cause more shading than if the shoots were all deliberately trained (positioned), for example vertically and separated one from another. In present grapevine training systems, they are positioned vertically upwards in the row, so the spacing between shoots in the row direction determines the degree of shading. Obviously the smaller the distance between shoots, the greater is the leaf area per unit length of row, and so the greater the shading.

Concerning *shoot bearing*, being gravimorphic, many grapevine shoots tend to grow upwards, and they are naturally less vigorous if they grow downwards. Therefore, downwards growing shoots may be grown more closely together and still might avoid shading, due to less leaf area per shoot.

NB: In fact one must consider separately the main shoot and its main laterals in the basal part. Carbonneau and Torregrosa (2020) noticed that an upward shoot is generally more vigorous than a downward shoot, but the laterals at the basal part of a downward shoot tend to be particularly vigorous and upward in its arched part, which tends in fact to stimulate vigor in the fruiting zone. Concord grapes naturally privilege downward bearing shoots which limits this effect, but on many *Vinifera* grapes, such as Cabernet-Sauvignon, the stimulation of laterals in the fruiting zone of a bending shoot is particularly intense.

2/ GDC microclimate

Nelson Shaulis next considered the *light and temperature environment* inside the GDC. The less sunny and cooler climate of northern New York State allows to reveal effects of shading inside the canopy. Using a photographer's light meter, Nelson Shaulis showed that light levels of interior leaves were only 1% to 10% of that incident on exterior leaves. Growth cabinet studies confirmed that such low light levels strongly reduced fruit ripening. Similarly, too cool temperatures were found limiting to ripening, again by growth-cabinet studies, and by field measurement. He demonstrated that both berry and leaf temperature increase with sunlight level, and that leaf temperatures were typically below optimum values for ripening in this particular environment. Therefore he proved that Concord fruit production and quality could be increased by increasing leaf and fruit temperature just by avoiding shading. Thus the local interest for the GDC training was demonstrated. This was the start for other regions growing other varieties to experiment the GDC model.

Besides that technical interest, the GDC studies were the support of the research on canopy microclimate. The *interception of sunlight* was about doubled by dividing the canopy into two separated curtains, which is equivalent to double canopy length per acre. Besides, further experimentation showed that shoot spacing along the curtains was the major determinant of fruitfulness, and that this relationship was inverse; the more shoots per foot of curtain, the lower was the fruitfulness due to increased shading in the renewal zone (Shaulis, 1982). Further, lower shoot density and less shading were associated with increased basal bud fruitfulness (Shaulis and May, 1971).
Nelson Shaulis was particularly concerned by the distinction between *microclimate inside and outside the canopy*. For the 60-day period from budburst to fruit set, vine leaf area is limited, and short shoots are more erect and described as ‘exterior’. In the month following fruit set, this situation changes, and free bearing shoots become more downward and lie one on the other, creating severe shading. Competition for light becomes intense and remains so until leaf-fall. Interior shoots receive less light, photosynthesis is inhibited, leaves have aged and fallen earlier, and maturity is less. The effect of the GDC training is that it maintains effectively more exterior shoots.
Nelson Shaulis’ research was the support of Richard Smart’ research, first in Geneva NY during his PhD (Smart, 1973, 1974, 1976) when he used the *GDC as a study model*, after in Australia and New Zealand. Richard Smart studied many aspects of canopy microclimate and physiology (Smart et al, 1982a and b; Smart, 1984). He also worked on other concepts of canopy division such as the TK2T and the ‘Scott Henry’s’ (Smart and Robinson, 1991).
Finally, *a very important parameter which was less studied in this period is the fruit microclimate in relation to quality elements*. Due to canopy division and downward training which can be forced by shoot positioning (helped by swinging arms and movable wires), the sunlight exposure of the fruit zone/renewal area is encouraged, and so is fruit maturity and fruitfulness. This was proven as an advantage for Concord grapes in northern New York State. Nevertheless, in most of *Vinifera* vineyards, the GDC showed an over exposure of the grape berries, which was demonstrated as a disadvantage for wine quality (Carbonneau, 1980). Some researchers (Cargnello, 1986.3; Intrieri and Poni, 1993) experimented and developed the GDC, while proposing to add some foliage wires above the pruning wires in order to protect the fruits from over exposure. But in fact that modifies deeply the architecture based on two separated curtains into an intermediate between the ‘Double Curtain type’ and the ‘Lyre type’, in any case a difficult system to train.

3/ Reasoning pruning and morphological descriptors
Bases are found in Kimball and Shaulis (1958).
Balanced pruning is recommended to retain vine size. The winter pruning bud load is desirably in proportion to weight of cane prunings.
Large retained bud numbers per vine cause lower vigor shoots.
Shoot vigor is estimated by the mean weight of cane prunings.
Vine vigor is measured as the total weight of cane prunings.
The impact of vine vigor on shading can be assessed by the index of weight of prunings per m of row or canopy.
Canopy shading can be assessed by the ratio of canopy surface area to leaf area.

4/ Interaction between Nelson Shaulis, Henry Studer and the late Cesare Intrieri regarding the full mechanization of the GDC

Shaulis and his Geneva colleague engineer Stan Shepherdson are credited with the early introduction of mechanization of harvesting and pruning of vineyards in America and other countries. (Shaulis et al, 1960; Shepardson et al, 1962; Shaulis et al, 1964; Shaulis et al, 1973). These innovations, as for the NY State developments of America's first mechanical harvest and pruning contributed greatly to Shaulis' and Cornell's reputation.

The major development was the design of *vertical shaking under the pruning wire by Henry Studer* and its application to the GDC performed by the Shaulis'team (see references above).

Besides, Professor Cesare Intrieri of Bologna University, Italy, first met Shaulis in 1971 at Geneva, and Cesare Intrieri became an early proponent of the GDC. He introduced the Geneva Double Curtain and transposed it into the Single Curtain-SC (Cortina Semplice) to commercial Italian vineyards in the Emilia-Romagna region. He was particularly interested in mechanization. The development of mechanical pruning and harvesting with vertical shaking for these training systems was the subject of the Honorary Research Lecture to the ASEV in 1993 (Intrieri and Poni, 1993).

Notice that another method of mechanical harvesting was developed by Henry Studer and experimented in cooperation with Giovanni Cargnello, the *trunk shaking* (Cargnello and Studer, 1980). *It is suitable for open Vase (Alberello) or other open or 'non-linear' architecture.*

Authors specific interactions with Nelson Shaulis

Alain Carbonneau met Nelson Shaulis for the first time in Bordeaux in 1974 where he demonstrated his experimental factorial design Latresne INRA experimental vineyard comparing 10 major models of grapevine training systems, with different attributes of foliage height and width, direction – upward or downward, canopy division – single or divided, and differing fruit exposure (Carbonneau 1980). Traditional forms of horizontally divided canopies emulating closer rows were described/found in Europe (Carbonneau and Cargnello, 2003; Carbonneau and Torregrosa, 2020). Nelson Shaulis invited Alain Carbonneau to study the GDC in the following year at Geneva NY. Alain Carbonneau appreciated the opportunity to learn the GDC principles and related methodology, and to establish collaborations with Cornell University and Richard Smart.

Nelson Shaulis' main contributions to our research are:

- Methodological rigor in vineyard experimenting and results interpretation,
- The definition of new vine descriptors, extending the approach to Ravaz (1909) with the 'yield to pruning weight' balance,
- Precision in managing the GDC, as one of our 10 major models,
- The first information about the effect of canopy management on production and ripening of grapes, the basis of future developments (Carbonneau, 1990),
- The concept of the vine plant as a whole, prior to the first modeling of the functioning of the vine (Carbonneau, 1987) and subsequently the biological triptych concept (Carbonneau, 1996).

Finally, the conclusions of our trials were in favor of the architecture 'wide rows, high-thin foliage, divided, upward bearing' which led to the Lyre trellis as an alternative to the GDC model (Carbonneau, 1990). In terms of canopy management the reason was that downward trained shoots over-exposed fruit and stimulated lateral vigor in the fruiting zone. It appears useful to maintain some foliage above the fruiting zone, but using a trellis not so high than in the GDC (see 'GDC fruit microclimate').

Notice that the choice of the Lyre, in particular versus the GDC, was also justified by the trunk height which is medium, thus allowing to be installed in low vigor situations which often correspond to the most qualitative ones; ad above all, by a clear preference for the Lyre in terms of wine quality based on sensory analysis while chemical analysis were not able to separate the GDC from the Lyre (Carbonneau, 1980, 1990). *Experiments comparing the Lyre to different trellis systems under different situations, which are performed by INRAE or Institut Agro Montpellier, are unique for demonstrating the quality advantage of Lyre wines through analytical sensory analysis (based on series of basic sensory elements and not only on overall preferences).*

The implication of wine analysis as the final judge of viticulture experiments appeared more and more necessary (Cargnello, 1983; Cargnello et al, 2001). Grape berry sensory analysis can also be useful (Cargnello, 1986.4).

Anyway we learned a lot from Nelson Shaulis in terms of methodology and knowledge of vine biology.

Research then developed in a fundamental direction on the basis of the descriptor 'Exposed Leaf Area' (Carbonneau, 1995) and extended to the model of a 'biological triptych' including Exposed Leaf Area, yield and vigor (Carbonneau, 1996).

Other vine architectures based on the concept of canopy division and where berry microclimate was also a major criterion were designed, such as the 'Lys (Lily)' for vigorous vines trained on a single vertical divided-canopy trellis (de Castro et al, 1996).

Different environments were evaluated, particularly dry terroirs where the Lyre architecture performed well due to better root development than classical training (Carbonneau et al, 2006).

Innovative pruning methods were also achieved: winter cordon pruning using the 'alternating crenel' method more balanced than classical ones; Half Pruning Before Harvest or 'Passerillage sur souche' for facing lack of berry maturity; Second Pruning Adjusted in Spring for facing too early maturity and delaying it by several weeks. Most of our results are published in Carbonneau and Torregrosa (2020) and in Carbonneau and Cargnello (2023).

Nelson Shaulis retired around 1978, just before we launched the study group GESCO (Groupe d'Étude des Systèmes de COnduite de la Vigne) in Montpellier/Bordeaux, France 1979, which developed as a full international and multidisciplinary group G*i*ESCO (Group of *international* Experts of vitivinicultural Systems for CoOperation) with 22 international meetings held to date; during the 2023 meeting at Cornell University, Ithaca NY special tribute was given to Professor Nelson Shaulis.

Giovanni Cargnello. The first meeting in Conegliano with Prof. Nelson Shaulis occurred in 1974 prior to a visit to North-East of Italy in the region of Veneto, Friuli-Venezia Giulia and Trentino. Shaulis was interested in the traditional forms variously divided in vine rows, and those covering the land surface in a horizontal or inclined manner.

After we made modifications to the structure of existing vines, by adding secondary short cordons named 'Spalle' (Shoulders). Thus we create three-dimensional shapes of the R5C, R100C, R 800C, R3000C series (Carbonneau and Cargnello 2023; Cargnello, 1980.3, 1986.2) in which leaf position and cluster location are affected and achieved through the 'Spalle'. We applied this method to the Geneva Double Curtain and to the Single Curtain-Cortina Semplice (Baldini and Intrieri 1972, Intrieri 1978), to different classical training systems as well, in order to improve their adaptation to Italian viticulture (Cargnello, 1986.2, 1986.3).

We still concentrate on adaptation of mechanization techniques to different canopies (Cosmo and Cargnello, 1974; Cargnello and Piccoli, 1977; Cargnello, 1978, 1980.1, 1980.2, 1990).

We also invested in controlled non-natural ripening of the grapes on the plant in the vineyard (see before 'Passerillage sur souche') with reasoned pruning of the shoot and harvesting before or even much later than the traditional harvest (Cargnello, 1992), in trellising design and canopy management for steep slope vineyards in small terraces, developing a family of 'Harp' architectures (Cargnello, 1987, 1990; Cargnello et al, 1989), and more generally in EcoMetaEthics in Viticulture (Cargnello 1986.1, 2021; Carbonneau and Cargnello 2023), as a cooperation Cargnello/Carbonneau.

That is our tribute to Nelson Shaulis who opened new ways in vine Biology and canopy management.

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