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Water stress as a critical issue for Mediterranean viticulture: economic evidence from the Montepulciano d'Abruzzo PDO grape based on a case study in central Italy

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Abstract. Climate change has impacted viticulture in almost all of the Mediterranean area, mainly because of temperature rises and changes in precipitation patterns, thus influencing yield, quality, and the management of grape production. One of the measures to mitigate these effects is the adoption of irrigation strategies. This has environmental and economic implications. Thus, it seems essential to evaluate if irrigation is economically and environmentally justified to ensure the sustainability of the vineyard by preserving the water resource. The aim of this research is to compute water-use indicators such as Water Productivity and Economic Water Productivity using field data obtained and to assess the economic impact of supplemental irrigation expenses through the analysis of a single case study. Since the results are heavily influenced by pedoclimatic conditions, vineyard structure, and economic decisions, the generalizability of our findings is not conceivable. However, our findings are valuable in determining when supplemental irrigation is or is not viable. Nonetheless, the findings might shed light on how water is managed in an Italian vineyard. Future supplemental irrigation plans ought to be developed using precision viticulture technologies to monitor the intricate soil-plant-environment system.

Keywords: vineyard, irrigation, climate change, economic analysis, water use indicators.

1. INTRODUCTION

Increasing water scarcity and precipitation variability attributable to climate change pose a major threat to the agriculture sector [1]. According to the Organisation for Economic Co-operation and Development (OECD), the agricultural sector is the largest user of water of any sector globally, accounting for 70% of the total consumption. As in most agricultural sectors, grape and wine production are affected by these changes, and water scarcity is becoming one of the main risks for grape, so wine, production in the Mediterranean area [2]. Although grapevine is a drought-tolerant species, water availability has impacted viticulture in the last decades [3]. Therefore, the increasing episodes of water scarcity, combined with climate change and the rising temperatures, make viticulture more difficult, forcing the modification of the cultivation practices for grapes to make the vineyards more resilient and sustainable [4-6]. In fact, climate change affects the entire physiology of vines, with strong effects on yield and quality, making it difficult to produce berries of optimal and consistent oenological quality over the forthcoming decades [7]. Currently, some measures of adaptation to climate change that could be taken in highly vulnerable regions are the selection of varieties and rootstocks that are more tolerant to drought and high temperatures, the reduction of the density of plantations, the adaptation of training system, the reduction of canopy changes in soil management practices, and the performance of irrigation with water-efficient training systems [8-11]. Even considering these strategies, adjustments to climate change could be slower for a perennial crop like grapevines, where the twenty-year productive lifetime and the implantation on marginal land restrict mitigation options and increase short-term adaptation costs [12,13]. Although many Mediterranean vineyards are currently cultivated in dry conditions, one of the main measures of adaptation will be the introduction of irrigation, with substantial changes in water management through the implementation of water-saving irrigation strategies, techniques, and technologies to improve efficiency in the use and application of irrigation water [14]. Although the percentage of irrigated land used for vineyards in Europe is less than 10% of the total area, irrigation is becoming more popular to counteract the impacts of climate change and an increasingly hostile environment. As a result, irrigation is growing across France, Spain, Portugal, and Italy's arid regions [15]. In the literature, some studies have already investigated the efficiency of the use of water in viticulture from an agronomic standpoint. Texeira et al. [16] determined the water parameters related to evapotranspiration for wine and table grapes growing under different training and irrigation systems. Salvador and colleagues [17] performed an assessment of seasonal on-farm irrigation performance in the Ebro basin (Spain), considering the differences between crops and irrigation systems and determining the water productivity where yields and production costs were available. Phogat et al. [18] performed an estimation of the water balance and transpiration and evaporation in the case of an irrigated Chardonnay vineyard, as the accurate estimation of water parameters, like evapotranspiration, is fundamental for correct water management. The objective was to calculate the water productivity of grapes for wine production under different deficit irrigation conditions. These works allowed for evaluating the performance and implications of water application in viticulture, assessing its needs, and considering the necessity to minimise and limit water consumption to sustainable levels. However, irrigation is not a marginal adaptation, as it requires substantial investments and changes in practices [19]. In fact, water should be supplied in a sustainable manner, at the right time, in the calibrated quantity, to ensure profitability, quality, and longevity of the production [20]. Thus, economic evaluation is crucial to ensuring that the wine sector remains economically sustainable. The introduction of irrigation as a productive factor in the vineyard will have economic and environmental implications, and it seems essential to evaluate if irrigation is economically and environmentally justified to ensure the sustainability of the vineyard by preserving the water resource both now and in the future [21,22]. As reported by Azorin and Garcia Garcia [14], the conflict between quantity and quality is still driving wine production. Unusual factors, such as water use, may bring higher quality but at the expense of higher management costs. To obtain the best combination of productive and economic indexes and berries' quality, it is fundamental to put in place supportive policies to allow vine growers to invest in suitable and sustainable agronomic practices, also considering the use of supplemental irrigation. Romero et al. [23] reported a similar outcome, with long-term deficit irrigation techniques improving wine quality but at the expense of decreased financial efficiency. Therefore, determining the ideal irrigation water level is essential to developing supplemental irrigation systems that are long-lasting, effective, and financially rewarding. Although the specific circumstances in which grapes are grown have a significant impact, the profitability of irrigation practices is also heavily reliant on the extent of irrigated land, hence water prices. Aparicio et al. [24] stated that a financially successful project requires a minimum area of 1 hectare in the unique situation of Maltese vineyards. A rationalisation of water inputs might be possible with the use of precision viticulture systems, given the current technological capabilities. Bellvert et al. [25] state that, when accounting for net energy and water savings, the use of smart irrigation systems that deliver the appropriate amount of water at the appropriate time may also enable monetary savings of thousands of euros. Finco et al. [22] combined the economic analysis of grape production with two water use efficiency indexes, Water Productivity (WP) and Economic Water Productivity (EWP). Their findings indicate that a lower EWP indicates worse management of the supplemental irrigation, even while a larger WP implies a stressful condition of the plant that should be considered from a negative point of view depending on which phase the vine is stressed in. However, including the evaluation of different indexes of socio-economic efficiency could support decision-making. The contribution of this article is to evaluate, through the analysis of a case study, the economic impact of supplemental irrigation costs and calculate, using field-collected data on yield values, production costs, water costs, commodity prices and irrigation performance, efficiency, and productivity of irrigation water-use indicators such as WP and EWP. In detail, the analysis concerned Montepulciano d'Abruzzo (Protected Designation of Origin - PDO) grapevine cultivar production for four productive years, from 2018 to 2021, comparing two different training systems: tent roofs and vine rows with the simple Guyot method. Out of the four years that were taken into consideration, supplemental irrigation was only put into place in 2021. This is because the year was marked by unfavourable weather conditions for the vineyards, which were among the hottest in the Mediterranean basin. The wine company in question, aware of the environmental issues that are surfacing, has chosen to invest in precision technologies for real-time water balance monitoring and in a supplemental irrigation system for the vineyard. This is the rationale behind the selection of just one case study. It is important to emphasise that the pedoclimatic conditions, vineyard structure, and company decisions all contribute to the limited generalizability of the results [24]. Indeed, the indexes to assess water use efficiency may vary between regions and countries, making it difficult to compare "companies/farms" performance [20]. On the other hand, this study offers significant proof about the prevalence of irrigation expenses in a particular case. The paper is structured as follows: Section 2 describes the methodology employed in the analysis; Section 3 shows and discusses the main results. Finally, Section 4 concludes.

2. METHODOLOGY

In this section, the selected case study (2.1) and the methodology applied in the economic analysis (2.2) will be described.

2.1. Case study description

The selected case study vineyard is in Abruzzo (Central Italy) (Figure 1).

The cultivated surface is 23 ha with two training systems, tent roof (16.5 ha) and vine rows with simple the Guyot method (6.5 ha), dedicated exclusively to Montepulciano d'Abruzzo grapevine cultivar production under organic and PDO quality schemes (Figure 2).

The density of the vines is 5000 plants/ha in the rows and 1600 plants/ha in the tent roof. Conversely to the tent roof, where the grapes are harvested by hand, the harvesting is done mechanically in the vine rows. Due to climate change, rainfall reduction, and the rise in temperatures, the winery decided to invest in a drip irrigation system to try to maintain a constant production yield. However, during the four years considered in

Figure 1. Geographical context of the case study.

Figure 2. Montepulciano grapevine cultivar in Abruzzo: a - vine rows with simple Guyot; b - tent roof.

this study, the winery carried out four supplemental irrigations, two to the *veraison* and two to the fruit set, on the entire area planted with vines only in 2021. Supplemental irrigation is an adaptable measure in current scenarios. The distributed volume of water is 200 m^3/turn.

2.2. Economic analysis

The economic analysis aims to evaluate the impact and incidence of irrigation on the total costs of Montepulciano d'Abruzzo PDO vineyard management. In addition, the costs and returns of various items were used to calculate two water-use indicators, WP and EWP; these indices are considered useful parameters for analysing the economic efficiency of irrigation. For the purpose of the study, the costs of all the cultivation operations carried out in the field, including those related to the irrigation of the vineyards, and the grape yields and prices of four reference years (2018, 2019, 2020, and 2021), were collected with the use of a questionnaire and in-depth interviews with the winery's agronomist. Considering this timeframe, it was possible to compare the costs in the vineyard without (2018, 2019, 2020) and with (2021) irrigation.

The first evaluation was made on variable costs, including the expenses that the company incurs annually for cultivation operations. The number of cultivation operations, as well as the working hours, vary from year to year based on the different seasons. The expense items that make up the variable costs of the winery under study are listed below:

- Pruning
- Branch removal
- Binding
- Green pruning
- Thinning
- Phytosanitary treatments
- Agricultural processing
- Fertilization and weeding
- Harvest
- Vineyard maintenance
- Machine maintenance
- Other
- Irrigation

Each variable cost item is made up internally of the costs for labour and technical means (when required). The irrigation item includes expenses for energy, labour, and maintenance of the drip system (i.e., for the damages caused by hunters).

The fixed costs of the winery include depreciation, administrative and management costs, and overheads. For the drip irrigation system, the fixed costs consist of depreciation and the annual water-providing consortium fee. The turnover, the production trends, and the prices in the four considered years were evaluated to identify the factors affecting the profit and the possible influence of irrigation. The wineries' efficiency structure is explained by two key performance indicators (KPIs): the operating profit margins and the cost-revenue ratio. The first indicator represents how efficiently a company can generate profit through its core operations and is expressed by Equation 1:

$$\textit{Operating profit margin} = \frac{operating\ profit}{revenue} \tag{1}$$

where the operating profit corresponds to Earnings Before Interest and Taxes (EBIT).

High operating profit margins show that a company is managing its operating costs well [26]. The second KPI is a measure of efficiency that compares a company's expenses to its earnings (Equation 2):

$$Cost\ revenue\ ratio = \frac{total\ costs}{revenue} \tag{2}$$

A lower cost-revenue ratio means that a company can produce more using fewer resources.

Finally, the data collected for the cost analysis were also useful to estimate the WP and EWP for the assessment of water use efficiency. The concept of WP was introduced by Molden in 1997 [27] to support water-related studies, helping identify opportunities for water saving. Productivity, in general, is a ratio referring to the unit of output per unit of input, but depending on how the terms in the numerator and denominator are expressed, WP can be expressed both in physical and economic terms [28]. The water productivity is expressed as the ratio between the crop productive yield and the actual evapotranspiration (Et) (Equation 3):

$$WP = \frac{yield\ (kg\ ha^{-1})}{Et\ (m^3 ha^{-1})} \tag{3}$$

Generally, the estimation of Et is not easy to achieve, but an accurate evaluation is essential for WP definition. For the scope of the study, the Et values were retrieved from an experimental smart platform that collects data from remote and non-remote sensors in real time with a site-specific approach. The Et is determined by a combination of several factors, like environmental conditions, plant canopy size, and water stress. However, it is worth remembering that an improvement in WP does not necessarily lead to water savings. A better management of the water resource is fundamental not only for environmental sustainability but also for the economic sustainability [29]. The water productivity approach alone is not enough to identify the best option for irrigation; hence, economic profit must be considered [30]. Indeed, replacing the numerator of Equation 3 with the profit, the EWP is defined by Equation 4:

$$EWP = \frac{Profit\ (€\ ha^{-1})}{Et\ (m^3 ha^{-1})} \tag{4}$$

In this specific case, the profit is given by summing the gross income (yield multiplied for the market price) with the European contributions (deriving from the Common Agricultural Policy and the organic certification) minus variable and fixed costs (Equation 5):

$$Profit = ((Y*Pr)+E-V-F) \tag{5}$$

Y = Yield (kg/ha)
Pr = Grape market price (€/kg)
E = European funds (CAP and organic) (€/ha)
V = Variable costs (€/ha)
C = Fixed costs (€/ha)

EWP is particularly useful to take decisions on how to manage irrigation in the most profitable way. A precise calculation of EWP, however, can be made only at the end of the season, when the revenue and costs are known. It is, however, important to note that the EWP is very sensitive to market prices, which may vary and lead to a substantial increase in production due to market and supply-demand economics. A negative value of EWP means that the costs of production exceed the benefits of production [31].

3. RESULTS AND DISCUSSION

Costs and profits for each season and for the two training systems, including irrigation costs, are shown in Table 1. The variable costs include human labour and the input costs (when required). The machineries costs are included in depreciation and other costs (fixed costs). Supplemental irrigation was performed only in 2021 with four interventions, distributing 800 m^3/ha in total on all the surface (23 ha).

In detail, Table 1 shows that in the tent roof the total variable costs are always higher than those in the simple Guyot (+ 42% on average). In detail, in the tent roof, the cost items that influence the more the variable costs are the green pruning (on average 26%), the harvest (on average 21%), the branch removal (on average +12%), and the phytosanitary treatments (on average 11%). Instead, in the Guyot method, the main variable cost items are the mechanical harvest (on average 19%), the green pruning (on average 15%), the phytosanitary treatments (on average 14%), and the vineyard maintenance (on average +12%). The training system (tent roof vs. Guyot) and the input availability seem to have an impact on the production costs. Appropriate agronomic practices, such as water management and cultivation techniques, may bring higher costs, especially due to the intensification of plant protection treatments, but they may reduce the negative impacts on yields [32].

Concerning the variable costs of irrigation, these are only present in 2021 and correspond to 160.00 €/ha for both management methods. These costs include expenses for energy (40.00 €/ha), labour (20.00 €/ha),

Table 1. Costs for Montepulciano d'Abruzzo grape production in 2018, 2019, 2020, and 2021(€/ha).

	2018		2019		2020		2021	
	Tent roof	Vine row	Tent roof	Vine row	Tent roof	Vine row	Tent roof	Vine row
Variable Costs	*9,260.07*	*6,543.65*	*8,952.39*	*6,117.49*	*9,130.46*	*6,163.69*	*10,563.06*	*7,816.26*
Pruning	232.52	220.61	313.67	297.61	234.24	222.25	269.38	272.57
Branch removal	1,186.53	750.53	895.77	566.61	1,140.95	721.69	1,035.75	698.94
Binding	364.89	351.13	169.21	160.55	334.96	317.82	299.38	302.92
Green pruning	2,018.42	820.75	2,417.27	982.94	2,417.27	982.94	2,597.00	1,126.20
Thinning	362.01	343.48	0.00	0.00	282.59	268.12	171.25	173.28
Phytosanitary treatments	907.68	838.85	1,073.55	967.62	1,071.65	966.14	987.75	921.58
Agricultural processing	598.91	464.93	808.46	627.60	793.90	616.30	867.63	718.29
Fertilization and weeding	589.97	513.92	591.87	515.39	503.24	446.59	679.69	605.73
Harvest	1,916.55	1,212.29	1,726.62	1,092.15	1,926.91	1,218.84	2,075.25	1,399.91
Vineyard maintenance	903.02	856.79	865.61	821.30	260.72	247.37	1,296.88	1,312.25
Machine maintenance	37.99	36.04	33.96	32.22	50.07	47.51	52.50	53.12
Other	141.58	134.33	56.40	53.52	113.96	108.12	70.63	71.46
Irrigation	0.00	0.00	0.00	0.00	0.00	0.00	160.00	160.00
Fixed Costs	*2,550.00*		*2,550.00*		*2,550.00*		*2,550.00*	
Depreciation	1,000.00		1,000.00		1,000.00		1,000.00	
Administration and management	150.00		150.00		150.00		150.00	
Overheads	800.00		800.00		800.00		800.00	
Irrigation	600.00		600.00		600.00		600.00	
Total costs	11,810.07	9,093.65	11,502.39	8,667.49	11,680.46	8,713.69	13,113.06	10,366.26

and maintenance (100.00 €/ha) of the drip system. It also emerges that, in the tent roof, the variable irrigation costs weigh 1.2%, while in Guyot 1.5%.

As reiterated in the previous paragraph, fixed costs of the winery include, for both methods of production, depreciation, administrative and management costs, and overheads, and correspond to 2,550.00 €/ha.

The fixed costs of irrigation make up about 24% of the total fixed costs, and they include depreciation (200.00 €/ha) and the consortium fee (400.00 €/ha). The consortium fee represents both an advantage and a disadvantage for the company. Indeed, if the entrepreneur decides not to irrigate, it must continue to sustain this cost; however, the annual fee guarantees the producer continuous access to the water resource without bothering with the actual amount used. In summary, irrigation accounts for 6–7% of the total cost of cultivation, depending on the training system. This outcome is consistent with published research [22,33].

Table 2 shows the returns deriving from the sale of the grapes at the market price set by the winery and the European contribution for organic production.

Firstly, from the analysis of the yields, it emerges that there is a consistent difference between the two-training method, and in the tent roof the yield is always higher. It is notable that, from 2018 to 2020, which are the years without irrigation, there is a continuous decrease in the yield value for all the training systems. This is particularly emphasised in the vine rows, where, for company policy, the winery is aiming at a reduction in quantity in favour of quality, as explained during the interview with the technician. On the other hand, in 2021, there has been an increase in the production quantity, especially in the tent roof. This positive result could be linked to the irrigation but also to a set of beneficial climate conditions, as declared by the agronomist of the winery [34]. Secondly, the ability of the winery company to fetch higher prices over the years, thanks to the quality policy, allowed for obtaining consistent returns [14]. In fact, increasing quantity obtained alone will not ensure higher profitability of production due to irrigation solely.

In summary, Table 3 shows the aggregates of the economic analysis and of the KPIs.

With the market prices, yield, and costs considered in this study, the vineyard generates a profit except for the vine rows in 2021. This negative value can be explained not only with the introduction of irrigation but also with an increase in variable costs relating to vineyard maintenance (+430% compared to 2020) com-

Table 2. Vineyard returns.

	2018		2019		2020		2021	
	Tent roof	Vine row	Tent roof	Vine row	Tent roof	Vine row	Tent roof	Vine row
Yield (100 kg/ha)	180.00	133.00	146.00	97.50	130.50	77.00	159.00	78.00
Grape price (€/100 kg)	86.00	86.00	102.00	102.00	105.00	105.00	110.00	110.00
Gross production (€/ha)	15,480.00	11,438.00	14,892.00	9,945.00	13,702.50	8,085.00	17,490.00	8,580.00
European funds (organic and CAP) (€/ha)	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
Total (€/ha)	16,280.00	12,238.00	15,692.00	10,745.00	14,502.50	8,885.00	18,290.00	9,380.00

Table 3. The economic costs and returns (€/ha) and the KPIs for Montepulciano d'Abruzzo grape production in the four years of the analysis.

	2018		2019		2020		2021	
	Tent roof	Vine row	Tent roof	Vine row	Tent roof	Vine row	Tent roof	Vine row
Total variable costs	9,260.07	6,543.65	8,952.39	6,117.49	9,130.46	6,163.69	10,563.06	7,816.26
Total fixed costs	2,550.00	2,550.00	2,550.00	2,550.00	2,550.00	2,550.00	2,550.00	2,550.00
Total costs	11,810.07	9,093.65	11,502.39	8,667.49	11,680.46	8,713.69	13,113.06	10,366.26
Returns	16,280.00	12,238.00	15,692.00	10,745.00	14,502.50	8,885.00	18,290.00	9,380.00
Profit/loss	4,469.93	3,144.35	4,189.61	2,077.51	2,822.04	171.31	5,176.94	-986.26
Operating margin	0.24	0.20	0.23	0.13	0.15	-0.08	0.26	-0.19
Cost revenue ratio	0.76	0.80	0.77	0.87	0.85	1.08	0.74	1.19

bined with a yield that, although increasing, is lower than in previous years. On the other hand, the irrigation practice has contributed to an increase in profit in the case of the tent roof (+84% compared to 2020). Regarding the first KPY, the operating profit margin, it emerged that, on the tent roof, this index is always higher with respect to the vine row. Thus, high operating profit margins show that a company is managing its operating costs well in this training system. This is remarked by the cost-revenue ratio that, in the vine row, is higher. As a result, the low value recorded on the tent roof indicates that the system is more efficient in managing costs and generating more money.

Finally, to assess the efficiency of water management by the vineyard, WP and EWP were calculated (Table 4).

Starting from the analysis of the WP, it emerges that, in both forms of training, the values of this index are higher in non-irrigated years than in the irrigated year. Since a high WP value indicates a more stressed plant [35], it is possible to declare that supplementary irrigation, combined with efficient vineyard management, has led to a better physiological state of the plant. It is also notable that the tent roof has always had higher WP values than the vine rows. This can be explained by the different policies adopted by the winery, which aim to achieve higher yields on the tent roof while maintaining a better quality in the vine rows.

Table 4. Water use indicators.

	WP (kg/m^3)		EWP (€/m^3)	
	Tent roof	Vine rows	Tent roof	Vine rows
2018	15.74	11.63	3.91	3.49
2019	13.95	9.32	4.00	2.80
2020	14.64	8.64	3.17	1.15
2021	12.59	6.18	4.10	-0.78

Even the EWP values are always higher in the tent roof than in the vine rows, showing that the tent roof is more cost-efficient. In addition, EWP for 2021 is higher than the average value of the not-irrigated period, thus confirming the correct choice to use supplementary irrigation. Nonetheless, it is evident how the negative revenues registered in the row led to a negative index, and this demonstrates how the management of this system did not lead to a yield sufficient to cover the costs, as in the case of the tent roof. However, it is important to note that market processes, which vary largely, are very determining for the value of the EWP [36].

4. CONCLUSION

The effects of climate change on viticulture are difficult to quantify. This is because we do not know the frequency and intensity with which these phenomena will occur over time and how they will stabilize. Consequently, it is difficult even to predict the reaction of natural ecosystems and agroecosystems to change. The necessity to adopt irrigation of crops like vines, traditionally managed without water supplies, is due, on the one hand, to climate change and a reduction in rainfall, and, on the other, to the need to address production towards quality products. The key to improving the quality of the grapes is the achievement of a vegetative-productive balance through careful and rational management of resources, mainly water. Sustainable water management in viticulture aims to match water availability and water needs in quantity and quality, in space and time, at reasonable costs, and with acceptable environmental impacts. Supplementary irrigation in the vineyard could be considered a tool for improving production and reducing water stress. However, supplemental irrigation strategies should be based on the precise monitoring of atmospheric conditions, temperatures, soil characteristics, and plant water status. For this purpose, the implementation of precision viticulture technologies could be a solution and a decision-making support system [25]. The interaction between monitoring sensors to check the plant parameters and the intelligent irrigation system could be a starting point to guarantee that water is provided only when the vine requires it, in a sufficient amount, for a determined timespan, and in a specific growth phase, to ensure a profitable and high-quality yield and prolong the life of the vineyard. This should ensure that the plants are not subjected to excessive stress [37]. Climate change affects not only the yields of the grape, so the quantity of wine produced, but also the prices, thus the profit coming from the vineyard.

Our findings suggest that correct water management, combined with vineyard management, could positively influence the physiological state of the vine, leading to improved and constant quality. Indeed, the application of adaptation strategies to tackle climate change is essential to guaranteeing the resilience of the agricultural productive sector.

This study is not without limitations. It would be interesting to compare more subsequent irrigated years to understand if water consistently impacts costs, profitability, and yields. In fact, according to our findings, irrigation is not economically advantageous for the winery under consideration. However, the use of water for supplemental irrigation should be considered under the light of the fact that, with the use of water, the winery was able to maintain a high yield even during one of the hottest recent years. In this sense, water use at a certain cost may be justified to guarantee a quality product. This aspect, combined with a substantial price of grapes sold, allowed the winery to limit the loss in 2021. Water resource management that is meticulous and heavily reliant on precision technologies has the potential to optimise irrigation operations and enhance input management, which in turn can lower production costs and improve product quality. This would be useful for programming agricultural activities throughout the years. Secondly, it would be desirable to extend the concept of this study to other Italian regions to understand if there is the same struggle with water supply and propose strategies to face this problem. Our study lacks generalizability due to the different managerial choices of wineries as well as the different pedoclimatic conditions under which production occurs. However, knowledge of water use efficiency indexes may represent a good starting point for obtaining objective parameters for comparison. Therefore, our results should be considered only as a springboard for future research. Future studies could investigate different training systems and their approaches to water use in viticulture.

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