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EDITORIAL

Using water for best product quality in fruit and nut trees and vines

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Abstract
Perennial vine and tree crops are increasing in production due to market demand for fruit and nut products. These crops are often grown in (semi) arid regions where irrigation is needed to increase production. However, the presence of these crops hardens water demand in increasingly water-scarce regions, thus reducing flexibility to respond to drought. In addition, poor irrigation management can reduce crop quality, thus potentially increasing wastage and reducing farmer profitability. Therefore, careful management of these crops to optimize irrigation water use, yield, and crop quality is needed. In this special issue of *Irrigation Science*, ten studies are presented on different approaches to irrigation management with a wide array of crops and strategies to improve water productivity and maximize crop quality.

Introduction

In recent decades, there has been a major expansion of consumption of fruits, nuts, and fruit-derived products (e.g. olive oil, wine) that come from perennial trees and vines (Johnson 2016; Asci and Devadoss 2021) due both to population increases and changing diets to an increasing proportion of consumption coming from fruits, vegetables and nuts (Schmidhuber and Traill 2006). Despite their status as "specialty crops" grown on smaller amounts of land, tree and vine crops management is critical. First, these crops have great importance for human nutrition. Second, tree and vine crops often have greatly increased input costs and economic yields on a per-area basis compared to forage and grain costs (Klonsky 2012). Third, these crops result in hardened water demand (e.g. you cannot usually remove irrigation without causing a major, multi-year, loss of investment) (Feinerman and Tsur 2014; Mall and Herman 2019). Thus, these crops' relative increase in cultivation area can greatly reduce a region's capacity to adapt to drought. This is particularly relevant as much specialty crop production occurs in regions with Mediterranean-type climates (e.g. Western United States, Southern Europe, Southern Africa, and Australia) that are seeing increased water scarcity (Feng et al. 2019).

Along with the issues mentioned above, crop quality is critical for the economic value of tree and vine crops along with yield (Fereres and Evans 2006). Factors affecting crop price include fruit size (Lötze and Bergh 2004), color (Ranasingha et al. 2019), uniformity (Calderon-Orellana et al. 2014), sugar content (brix) (Kajikawa 1998), flavor and firmness (Marsal et al. 2010; Diehl et al. 2015), and others. While these factors can vary in importance depending upon the specific crop (Diehl et al. 2015), they share major commonalities across most crops. Irrigation has been shown to affect these properties across a wide range of crops (Zekri et al. 2003; Girona et al. 2006; Zegbe et al. 2007; Pérez-Pastor et al. 2007; Behboudian et al. 2010; Lopez et al. 2012; Laribi et al. 2013; Falagán et al. 2015; Gucci et al. 2019; Suarez et al. 2019; Carrasco-Benavides et al. 2020; Palai et al. 2022a, b). Given the need to optimize irrigation water use, finding and disseminating practices that improve and maintain fruit quality while increasing water productivity in

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tree and vine crops is imperative. Irrigation practices which degrade fruit size or quality are not likely to be adopted by growers. In this special issue of *Irrigation Science*, we focus on this crucial challenge.

Papers in this special issue

Papers in this special issue were split closely between those focusing on vines and those on tree crops, with four papers focusing on grapes and six focusing on fruit and nut trees. Papers on vine crops spanned a wide range of topics. Caruso et al. (2022) evaluated the impact of pre and post-veraison deficit irrigation on Sangiovese grapes with differing rootstocks. Among the key findings were that pre-veraison deficits reduced fresh berry weight and acidity. Additionally, the 1103P rootstock showed greater sensitivity to irrigation deficits, particularly pre-veraison. Martínez-Moreno et al. (2022) evaluated the impact of irrigation with brackish water with different anions (chloride versus sulphates) in full season and post-veraison treatments compared to no added salinity and no irrigation (rainfed only). Over three seasons, salinity did not have a major effect on crop quality compared to the no-irrigation treatment in their well-drained soils, thus suggesting that brackish water (EC of 5 dS/m) could be a useful short and medium-term substitute in the absence of higher quality water. However, chloride and sodium accumulation in the leaves in the third year indicate this strategy may not be sustainable in the longer term. Bianchi et al. (2023) examined the impact of a multifaceted irrigation system that applied water through both drip irrigation and mini-sprinklers, with the sprinklers designed to provide protection against frost and extreme heat waves. They found that the mini-sprinklers increased bud temperature by 1 °C during frost events, suggesting protection. Sprinkler operation during the summer increased malic and titratable acids and reduced soluble solids in the must. Finally, Oliver-Manera et al. (2023) evaluated how summer pruining (forcing) may reduce heat stress on berries via delay of veraison under different irrigation strategies. While veraison was successfully delayed with forcing and must acidity increased, forced vines showed greater sensitivity to deficit irrigation both in yield and must quality.

Concerning tree crops, each of the papers in this special issue evaluated a different crop. There was maximum ecosystem water use efficiency in the fall but relatively little sensitivity to the deficit irrigation. Sperling et al. (2022) evaluated the impact of plant mineral status on transpiration in almonds. Low nitrogen and phosphorus and very high nitrogen limited plant transpiration to below 3 mm/day. The results indicate that fertilizer status could be used to predict almond water demands. Calvo et al. (2022) conducted a mini-review of irrigation, growth, and crop quality in walnuts. Their synopsis reported that most walnut groves have yearly ET between ~ 1000 and 1200 mm. Moderate water deficits (midday stem water potential greater than − 0.8 MPa) had little impact on production, but there is concern about kernel and oil quality. Panigrahi (2023) presented the results of a deficit irrigation experiment in mandarin using different irrigation levels and triggers using the Crop Water Stress Index (CWSI). This study found that irrigation at 60% of calculated crop ET (ETc) with a CWSI trigger of 0.4 resulted in superior quality fruits and the highest water productivity. Plavcová et al. (2023) assessed the water-yield relations of two apple cultivars grown under rainfed conditions and with supplemental irrigation in Czechia. They found that the yields were similar between rainfed and irrigated conditions, but the irrigated treatments had larger sized fruits. Finally, Ahumada-Orellana et al. (2022) presented the yield, leaf-gas exchange, and water status of olive orchards subjected to two lengths of irrigation cutoff and water stress. They found that the oil yield of the most severe treatment was slightly greater than 60% of the control treatment, thus indicating considerable susceptibility of olives to deficit irrigation and irrigation cutoff.

Concluding thoughts

Proper irrigation management will be increasingly vital for the production of specialty crops, given the increasing area of tree and vine crops and decreasing availability and consistency of irrigation water. This special issue of *Irrigation Science* presents ten studies across a wide array of crops and strategies to increase water productivity while maintaining yield and crop quality. With the advancement of sensor technologies and data analysis tools (e.g. artificial intelligence) and increasing prevalence of drip and micro-sprinkler irrigation systems, there will be increased opportunities to precisely control the timing, rate, and amount of irrigation water applied to tree and vine crops to maximize water productivity and crop quality.

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References

Ahumada-Orellana L, Ortega-Farias S, Searles PS, Zúñiga M (2022) Leaf gas exchange, water status, and oil yield responses to rewatering after irrigation cut-off periods in a superintensive drip-irrigated olive (cv. Arbequina) orchard. Irrig Sci. https://doi.org/10.1007/s00271-022-00817-8

Asci S, Devadoss S (2021) Trends and issues relevant for the US tree nut sector. Choices Mag Food Farm Resour Issues 36:1–7

Behboudian MH, Marsal J, Girona J, Lopez G (2010) Quality and yield responses of deciduous fruits to reduce irrigation. Horticultural reviews. John Wiley & Sons Inc., pp 149–189

Bianchi D, Bolognini M, Brancadoro L et al (2023) Effect of multi-functional irrigation on grape quality: a case study in Northern Italy. Irrig Sci. https://doi.org/10.1007/s00271-022-00837-4

Calderon-Orellana A, Mercenaro L, Shackel KA et al (2014) Responses of fruit uniformity to deficit irrigation and cluster thinning in commercial winegrape production. Am J Enol Vitic 65:354–362. https://doi.org/10.5344/ajev.2014.13135

Calvo FE, Silvente ST, Trentacoste ER (2022) A mini review of the impacts of deficit irrigation strategies for walnut (*Juglans regia* L.) production in semiarid conditions. Irrig Sci. https://doi.org/10.1007/s00271-022-00815-w

Carrasco-Benavides M, Espinoza Meza S, Olguín-Cáceres J et al (2020) Effects of regulated post-harvest irrigation strategies on yield, fruit quality and water productivity in a drip-irrigated cherry orchard. N Z J Crop Hortic Sci 48:97–116. https://doi.org/10.1080/01140671.2020.1721544

Caruso G, Palai G, Gucci R, D'Onofrio C (2022) The effect of regulated deficit irrigation on growth, yield, and berry quality of grapevines (cv. Sangiovese) grafted on rootstocks with different resistance to water deficit. Irrig Sci. https://doi.org/10.1007/s00271-022-00773-3

Diehl DC, Sloan NL, Brecht JK et al (2015) What factors do retailers value when purchasing fruits? Perceptions of produce industry professionals. J Food Distrib Res. https://doi.org/10.22004/AG.ECON.212992

Falagán N, Artés F, Artés-Hernández F et al (2015) Comparative study on postharvest performance of nectarines grown under regulated deficit irrigation. Postharvest Biol Technol 110:24–32. https://doi.org/10.1016/j.postharvbio.2015.07.011

Feinerman E, Tsur Y (2014) Perennial crops under stochastic water supply. Agric Econ 45:757–766. https://doi.org/10.1111/agec.12120

Feng X, Thompson SE, Woods R, Porporato A (2019) Quantifying asynchronicity of precipitation and potential evapotranspiration in mediterranean climates. Geophys Res Lett 46:14692–14701. https://doi.org/10.1029/2019GL085653

Fereres E, Evans RG (2006) Irrigation of fruit trees and vines: an introduction. Irrig Sci 24:55–57. https://doi.org/10.1007/s00271-005-0019-3

Girona J, Mata M, del Campo J et al (2006) The use of midday leaf water potential for scheduling deficit irrigation in vineyards. Irrig Sci 24:115–127. https://doi.org/10.1007/s00271-005-0015-7

Gucci R, Caruso G, Gennai C, Esposto S, Urbani S, Servili M (2019) Fruit growth, yield and oil quality changes induced by deficit irrigation at different stages of olive fruit development. Agric Water Manag 212:88–98

Johnson R (2016) The US trade situation for fruit and vegetable products. Congressional Research Service

Kajikawa C (1998) Quality level and price in Japanese apple market. Agribusiness 14:227–234. https://doi.org/10.1002/(SICI)1520-6297(199805/06)14:3%3c227::AID-AGR5%3e3.0.CO;2-2

Klonsky K (2012) Comparison of production costs and resource use for organic and conventional production systems. Am J Agr Econ 94:314–321

Laribi AI, Palou L, Intrigliolo DS et al (2013) Effect of sustained and regulated deficit irrigation on fruit quality of pomegranate cv. 'Mollar de Elche' at harvest and during cold storage. Agric Water Manag 125:61–70. https://doi.org/10.1016/j.agwat.2013.04.009

Lopez G, Hossein Behboudian M, Girona J, Marsal J (2012) Drought in deciduous fruit trees: implications for yield and fruit quality. In: Aroca R (ed) Plant responses to drought stress. Springer Berlin Heidelberg, Berlin, Heidelberg, pp 441–459

Lötze E, Bergh O (2004) Early prediction of harvest fruit size distribution of an apple and pear cultivar. Sci Hortic 101:281–290. https://doi.org/10.1016/j.scienta.2003.11.006

Mall NK, Herman JD (2019) Water shortage risks from perennial crop expansion in California's Central Valley. Environ Res Lett 14:104014. https://doi.org/10.1088/1748-9326/ab4035

Marsal J, Lopez G, del Campo J et al (2010) Postharvest regulated deficit irrigation in 'Summit' sweet cherry: fruit yield and quality in the following season. Irrig Sci 28:181–189. https://doi.org/10.1007/s00271-009-0174-z

Martínez-Moreno A, Pérez-Álvarez EP, Intrigliolo DS et al (2022) Effects of deficit irrigation with saline water on yield and grape composition of *Vitis vinifera* L. cv. Monastrell. Irrig Sci. https://doi.org/10.1007/s00271-022-00795-x

Oliver-Manera J, Garcia-Tejera O, Mata M, Girona J (2023) Cumulative response of Tempranillo vines to the crop forcing technique and pre-forcing and post-veraison water stress in terms of yield and grape and wine quality. Irrig Sci. https://doi.org/10.1007/s00271-023-00855-w

Palai G, Caruso G, Gucci R, D'Onofrio C (2022a) Deficit irrigation differently affects aroma composition in berries of *Vitis vinifera* L. (cvs Sangiovese and Merlot) grafted on two rootstocks. Aust J Grape and Wine Res 28:590–606. https://doi.org/10.1111/ajgw.12562

Palai G, Caruso G, Gucci R, D'Onofrio C (2022b) Berry flavonoids are differently modulated by timing and intensities of water deficit in *Vitis vinifera* L. cv. Sangiovese. Front Plant Sci 13:1040899. https://doi.org/10.3389/fpls.2022.1040899

Panigrahi P (2023) Scheduling irrigation for improving water productivity and fruit quality in citrus (cv. Nagpur mandarin) under a dry tropical climate. Irrig Sci. https://doi.org/10.1007/s00271-023-00847-w

Pérez-Pastor A, Ruiz-Sánchez MC, Martínez JA et al (2007) Effect of deficit irrigation on apricot fruit quality at harvest and during storage. J Sci Food Agric 87:2409–2415. https://doi.org/10.1002/jsfa.2905

Plavcová L, Mészáros M, Jupa R et al (2023) Yield and water relations of two apple cultivars under irrigation. Irrig Sci. https://doi.org/10.1007/s00271-022-00839-2

Ranasingha RGSM, Edirisinghe JC, Ratnayake RHMK (2019) Willingness to pay for fruit attributes: a conjoint analysis. J Agric Sci 14:102. https://doi.org/10.4038/jas.v14i2.8512

Schmidhuber J, Traill WB (2006) The changing structure of diets in the European Union in relation to healthy eating guidelines. Public Health Nutr 9:584–595. https://doi.org/10.1079/PHN2005844

Sperling O, Yermiyahu U, Hochberg U (2022) Linking almond trees' transpiration to irrigation's mineral composition by physiological indices and machine learning. Irrig Sci. https://doi.org/10.1007/s00271-022-00803-0

Suarez DL, Celis N, Anderson RG, Sandhu D (2019) Grape rootstock response to salinity, water and combined salinity and water stresses. Agronomy 9:321. https://doi.org/10.3390/agronomy9060321

Testi L, Orgaz F, López-Bernal Á, Villalobos FJ (2022) Pre- and post-harvest evapotranspiration, carbon exchange and water use

efficiency of a mature peach orchard in semi-arid climate. Irrig Sci 40:407–422. https://doi.org/10.1007/s00271-022-00797-9
Zegbe JA, Behboudian MH, Clothier BE (2007) Reduced irrigation maintains photosynthesis, growth, yield, and fruit quality in 'Pacific Rose™' apple. J Sustain Agric 30:125–136. https://doi.org/10.1300/J064v30n02_11
Zekri M, Obreza TA, Koo R, Alferez F (2003) Irrigation, nutrition, and citrus fruit quality. University of Florida, Gainesville