agriculture

Editorial

Future of Irrigation in Agriculture in Southern Europe

Iván Francisco García-Tejero [1,*] and Víctor Hugo Durán-Zuazo [2]

[1] IFAPA "Las Torres", Ctra. Sevilla-Cazalla km 12.2, Alcalá del Río, 41200 Sevilla, Spain
[2] IFAPA "Camino de Purchil", Camino de Purchil s/n, 18004 Granada, Spain; victorh.duran@juntadeandalucia.es
* Correspondence: ivanf.garcia@juntadeandalucia.es; Tel.: +34-67-153-2878

Citation: García-Tejero, I.F.; Durán-Zuazo, V.H. Future of Irrigation in Agriculture in Southern Europe. *Agriculture* **2022**, *12*, 820. https://doi.org/10.3390/agriculture12060820

Received: 31 May 2022
Accepted: 6 June 2022
Published: 7 June 2022

Water is the most limiting natural resource in many Mediterranean areas of southern Europe, and this, together with the actual scenario of climate change (CC), promotes a framework of uncertainty and creates major challenges concerning the sustainability and viability of the current agro-ecosystems. Spain is one of the main agricultural producers in the EU, and it has one of the largest areas of irrigated land in the EU, which is used to grow several crops (annual and perennial); these crops require different levels of water supply to meet the crop water requirements and ensure profitable yields. In this regard, the preservation of the agricultural sector will largely depend on its capability to adapt to current and future conditions and its ability to ensure viable and high-quality products within sustainable and environmentally friendly management systems.

The main impacts of CC on Mediterranean irrigated agriculture have been evaluated by identifying adaptation measures and sustainable intensification strategies for use in irrigated crops under drought conditions. The initial focus of research in this sector was the fact that the current management of agroecosystems in southern Europe was not sustainable [1,2]. In this context, CC will not only promote substantial changes in the management of natural resources, but also in the phenological evolution of crops, with a shortening in the phenological cycles and earlier flowerings as responses to higher ambient temperatures, water resource depletion, and a higher frequency of extreme climatic events [3–5]. In the case of Mediterranean countries in southern Europe, the anticipated increases in air temperature during the winter months will induce earlier flowering in woody crops, affecting the fruit growth trends and ripening, as it has been proved in citrus fruits [6], olives [3], and vineyards [7]. In agreement with this, flowering requires a period of cool conditions to release dormancy, followed by a period of warm conditions with enough water availability to induce budburst [8,9]. Thus, early flowering is expected under warmer conditions, affecting the final yield if cool conditions do not occur during the dormancy period [10].

Among annual and perennial crops, the most relevant Mediterranean woody crops (olives, vineyards, almonds, stone fruits, or citrus, among others) will be particularity sensitive to CC, not only to increases in air temperature and less rain, but also to extreme weather events such as heatwaves and long periods with negligible precipitation. To a large extent, higher ambient temperatures during the flowering and fruit setting periods could promote widespread flower-dropping, with significant reductions in the final yield, as suggested by other authors [11,12]. In this regard, it is essential to define those physiological changes related to fruit yield losses in order to minimize the agronomic effects and maximize the water savings and irrigation water productivity.

Out of all of the expected conditions in CC scenarios, the rise in [CO_2] is perhaps one of the most significant. Depending on the scenarios, this concentration could increase from 470 to 940 mmol CO_2 mol^{-1} (air) by 2100, which could lead to a mean surface global warming of 1.4–5.8 °C [13]. Several authors have suggested that an increase in [CO_2] could be accompanied with a reduction in crop transpiration levels, and hence, higher intrinsic water-use efficiency (WUE_i), because of the increase in the stomatal and mesophyll conductance [14–17]. Even though higher [CO_2] levels could be considered a positive factor in relation to improvements in WUE_i, there is little information regarding the physiological interactions promoted by the increase in [CO_2] and air temperature and water stress situations. According to this, if water stress conditions extend over time and coincide with high radiation rates, oxidative stress can be promoted, generating reactive oxygen species (ROS) [18]. The increase in ROS can be accompanied by a synthesis of enzymes with antioxidant activity (catalase, dismutase superoxide, or peroxidase, among others), and if the water stress is very severe, it may promote lipidic peroxidation [19]. Thus, it is necessary to clarify this mechanism in order to understand the interactions in current and future CC scenarios and the yield response of irrigated crops in sensitive agricultural areas.

Moreover, it is necessary to consider the fact that most of the crops produced by agriculture in southern Europe are exported to countries where the consumer is increasingly demanding a more efficient use of water in agriculture. This improvement in water efficiency means one must go a step further than simply saving natural resources [20]. Thus, the Strategic Plan for the Implementation of the EIP Agriculture (European Innovation Partner-ships) on "Agricultural Productivity and Sustainability" [21] argues that the concept of sustainability must encompass not only an efficient use of natural resources but also that these result in an economic benefit for farmers (economic sustainability) and a response to social concerns (social sustainability), such as, for example, the generation of healthy products.

Therefore, not only is it important to define the response of crops to CC scenarios, but also to continue those experiments related to the improvement in water management under drought conditions and the interactions between deficit irrigation (DI) strategies and final yield and fruit-quality improvements. Water-saving strategies regarding perennial crops in semi-arid areas of southern Europe are not optional but mandatory under water scarcity scenarios. Obviously, these strategies are going to limit the maximum yield potential, but what would happen if these economic losses were compensated by reducing the production costs and increasing some bioactive compounds in the fruit, generating an added value to the final product? To answer these questions, recently, a novel, new type of research, focused on food production under hydro-sustainable strategies (hydroSOS products), was successfully developed [22,23]. The advantages of DI in different Mediterranean crops are also remarkable, with significant improvements in the fruit quality, healthy composition, sensory attributes, and consumer acceptance. In this context, research should focus on studying characteristics or parameters of fruits related to their marketability and consumer acceptance that could be affected by DI strategies. Thus, it is peremptory to redesign irrigation programs in areas where water is scarce, adjusting the DI strategies not only to save water, boost WUE, and stabilize productivity, but also to yield fruits with enhanced quality. As reported by Rincón-Leon [24], many Mediterranean crops are considered functional foods because they are important sources of bioactive compounds such as flavonoids, carotenoids, anthocyanins, essential oils, pectins, vitamins A, E, or C, organic acids, sugars, or mono- and poly-unsaturated fatty acids. In addition, their concentration is highly determined not only by genomic differences or industrial extraction systems, but also by the agronomic practices involved in the final production [25–27]. For example, vitamin C is considered as the major antioxidant in citrus, and its content is largely influenced by cultural practices, maturity, climate, or processing factors [28,29]. In the case of flavonoids, these help to supplement the body's antioxidant defenses against free radicals, and their presence contributes to the appearance, taste, and nutritional value of products from plants. A similar phenomenon occurs with carotenoids, which have different biological functions and actions, contributing to antioxidant activity, reducing the risk of cancer and bone and cardiovascular diseases, and protecting against age-related macular degeneration [30,31].

Several authors have demonstrated the advantages of DI strategies when they are properly applied, promoting increases in the synthesis of bioactive compounds under controlled water stress situations [32–35]. Considering all of these questions, it is possible to define irrigation strategies that are able to maintain sustainable yield values, enable significant irrigation water savings, and ensure improvements in the physical and chemical properties of fruit and their functional and sensory characteristics.

Moreover, when a DI strategy is applied, it is necessary to monitor the crop water status to ensure minimum yield losses and maximize the water savings and the irrigation water productivity. Traditionally, this assessment is conducted using manual measurements, which are both labor-intensive and time-consuming. As a response, Internet of Things (IoT) and Machine Learning processes are being widely applied in smart cities, industry, intelligent buildings, and agriculture [36]. By implementing these techniques, together with the use of new, low-cost sensors, we can obtain adequate information regarding crop water statuses, which will ultimately help in decision-making processes when water resources are scarce.

Finally, we cannot ignore the importance of the management of cover crops under water scarcity conditions. Cover crops play an increasingly important role in the enhancement of soil quality, reductions in agricultural inputs, and the enhancement of environmental sustainability. Additionally, cover crops have attracted greater interest because of their potential to provide additional eco-system services in agricultural systems, reducing erosion, improving water quality, and enhancing biodiversity. Moreover, cover crops can also increase soil organic carbon stocks in agricultural soils [37], as higher C and N contents are added to soil pools as cover crop residues decompose [38]. However, several questions should be considered, especially those focused on the most appropriate cover crop management to avoid hypothetical competition with the main crop for water resources, and how a cover crop could help increase soil water retention during the period with the highest evapotranspiration levels.

In summary, the future of irrigation lies in determining the limitations of agroecosystems and natural resources, adapting new production strategies based on competitiveness without forgetting sustainability, and making proper use of new technologies and scientific knowledge. In addition to all of this, we should not forget the critical role that agriculture is playing in CC scenarios and how proper activities development can help to mitigate its effects and turn irrigation agriculture into a sustainable and profitable sector within a sustainable environmental equilibrium.

Author Contributions: I.F.G.-T. and V.H.D.-Z. had an equal contribution in the different actions for the Editorial redaction, review and editing, supervision, project administration and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the research Project entitled "Sustainable Intensification of Almond (*Prunus dulcis* Mill.). Cultivation in a Context of Climate Change (ISACLIMA)" (SG1.SG12020.005, PY20_00999).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Garrote, L.; Granados, A.; Iglesias, A. Strategies to reduce water stress in Mediterranean river basins. *Sci. Total Environ.* **2015**, *543*, 997–1009. [CrossRef] [PubMed]
2. Ruiz-Ramos, M.; Ferrise, R.; Rodríguez, A.; Lorite, I.J.; Bindi, M.; Carter, T.; Fronzek, S.; Palosuo, T.; Pirttioja, N.; Baranowski, P.; et al. Adaptation response surfaces for managing wheat under perturbed climate and CO_2 in a Mediterranean environment. *Agric. Syst.* **2018**, *159*, 260–274. [CrossRef]
3. Gabaldón-Leal, C.; Ruiz, R.M.; de la Rosa, R.; León, L.; Belaj, A.; Rodríguez, A.; Santos, C.; Lorite, I.J. Impact of changes in mean and extreme temperatures caused by climate change on olive flowering in southern Spain. *Int. J. Climatol.* **2017**, *37*, 940–957. [CrossRef]
4. Lizaso, J.I.; Ruiz, R.M.; Rodríguez, L.; Gabaldon, L.C.; Oliveira, J.A.; Lorite, I.J.; Sánchez, D.; García, E.; Rodríguez, A. Impact of high temperatures in maize: Phenology and yield components. *Field Crops Res.* **2018**, *216*, 129–140. [CrossRef]
5. Lorite, I.J.; Gabaldón-Leal, C.; Ruiz-Ramos, M.; Belaj, A.; de la Rosa, R.; León, L.; Santos, C. Evaluation of olive response and adaptation strategies to climate change under semi-arid conditions. *Agric. Water Manag.* **2018**, *204*, 247–261. [CrossRef]
6. Fitchett, J.M.; Grab, S.W.; Thompson, D.I.; Roshan, G. Spatiotemporal variation in phenological response of citrus to climate change in Iran: 1960–2010. *Agric. For. Meteorol.* **2014**, *198*, 285–293. [CrossRef]

7. Wolkovich, E.M.; Burge, D.O.; Walker, M.A.; Nicholas, K.A. Phenological diversity provides opportunities for climate change adaptation in wine grapes. *J. Ecol.* **2017**, *105*, 905–912. [CrossRef]
8. Rosenzweig, C.; Phillips, J.; Goldberg, R.; Carroll, J.; Hodges, T. Potential impacts of climate change on citrus and potato pro-duction in the US. *Agric. Syst.* **1996**, *52*, 455–579. [CrossRef]
9. Srivastava, A.K.; Singh, S.; Huchche, A.D. An analysis on citrus flowering—A review. *Agric. Rev.* **2000**, *21*, 1–15.
10. Medina-Alonso, M.G.; Navas, J.F.; Cabezas, J.M.; Weiland, C.M.; Ríos-Mesa, D.; Lorite, I.J.; León, L.; de la Rosa, R. Differences on flowering phenology under Mediterranean and Subtropical environments for two representative olive cultivars. *Environ. Exp. Bot.* **2020**, *180*, 104239. [CrossRef]
11. Albrigo, L.G.; Saúco, V.G. Flower bud induction, flowering and fruit-set of some tropical and subtropical fruit tree crops with special reference to citrus. *Acta Hortic.* **2004**, *632*, 81–90. [CrossRef]
12. Iglesias, D.J.; Cercós, M.; Colmenero, F.J.M.; Naranjo, M.A.; Ríos, G.; Carrera, E.; Ruíz-Rivero, O.; Lliso, I.; Morillon, R.; Tadeo, F.; et al. Physiology of citrus fruiting. *Braz. J. Plant Physiol.* **2007**, *19*, 333–362. [CrossRef]
13. Allen, L.H.; Vu, J.C.V. Carbon dioxide and high temperature effects on growth of young orange trees in a humid, subtropical environment. *Agric. For. Meteor.* **2009**, *149*, 820–830. [CrossRef]
14. Flexas, J.; Carriquí, M.; Coopman, R.E.; Gago, J.; Galmés, J.; Martorell, S.; Morales, F.; Diaz, E.A. Stomatal and mesophyll conductances to CO_2 in different plant groups: Underrated factors for predicting leaf photosynthesis responses to climate change? *Plant Sci.* **2014**, *226*, 41–48. [CrossRef]
15. Marqués-Glavez, J.E.; Navarro-Ródenas, A.; Peguero-Pina, J.J.; Arenas, F.; Guarnizo, A.L.; Gil-Pelegrín, E.; Morte, A. Elevated atmospheric CO_2 modifies responses to water-stress and flowering of Mediterranean desert truffle mycorrhizal shrubs. *Phys. Plant.* **2020**, *4*, 537–549. [CrossRef]
16. López-Bernal, Á.; Mairech, H.; Testi, L.; Villalobos, F.J. Olive yield response to irrigation under climate change scenarios. In Proceedings of the IX International Symposium on Irrigation of Horticultural Crops, Matera, Italy, 17–20 June 2019.
17. Kizildeniz, T.; Mekni, I.; Santesteban, H.; Pascual, I.; Morales, F.; Irigoyen, J.J. Effects of climate change including elevated CO_2 concentration, temperature and water deficit on growth, water status, and yield quality of grapevine (*Vitis vinifera* L.) cultivars. *Agric. Water Manag.* **2015**, *159*, 155–164. [CrossRef]
18. Nejad, K.Z.; Ghasemi, M.; Shamili, M.; Damizadeh, G.R. Effect of Mycorrhiza and Vermicompost on Drought Tolerance of Lime Seedlings (*Citrus aurantifolia* Cv. Mexican Lime). *Int. J. Fruit Sci.* **2020**, *20*, 646–657. [CrossRef]
19. Yildiz-Aktas, L.; Dagnon, S.; Gurel, A.; Gesheva, E.; Edreva, A. Drought Tolerance in Cotton: Involvement of Non-enzymatic ROS-Scavenging Compounds. *J. Agron. Crop Sci.* **2009**, *195*, 247–253. [CrossRef]
20. GCA. *Adapt Now: A Global Call for Leadership on Climate Resilience*; Global Center on Adaptation: Rotterdam, The Netherlands; World Resources Institute: Washington, DC, USA, 2019; pp. 35–38. Available online: https://gca.org/wp-content/uploads/2019/09/GlobalCommission_Report_FINAL.pdf (accessed on 16 May 2022).
21. COM. *Communication from the Commission to the European Parliament and the Council on the European Innovation Partnership 'Agricultural Productivity and Sustainability'*; World Resources Institute: Brussels, Belgium, 2012; pp. 1–9. Available online: https://ec.eu-ropa.eu/eip/agriculture/sites/default/files/communication_on_eip_-_en.pdf (accessed on 16 May 2022).
22. Cano-Lamadrid, M.; Girón, I.F.; Pleite, R.; Burló, F.; Corell, M.; Moriana, A.; Carbonell-Barrachina, A.A. Quality attributes of table olives as affected by regulated deficit irrigation. *LWT-Food Sci. Technol.* **2015**, *62*, 19–26. [CrossRef]
23. Carbonell-Barrachina, A.A.; Calín-Sánchez, A.; Bagatar, B.; Hernández, F.; Legua, P.; Martínez-Font, R.; Melgarejo, P. Potential of Spanish sour-sweet pomegranates (cultivar C25) for the juice industry. *Food Sci. Technol. Int.* **2012**, *18*, 129–138. [CrossRef]
24. Rincón-León, F. Functional Foods. In *Encyclopedia of Food Sciences and Nutrition*, 2nd ed.; Caballero, B., Ed.; Academic Press: New York, NY, USA, 2003; pp. 2827–2832. ISBN 978-0-12-227055-0.
25. Coyago-Cruz, E.; Corell, M.; Moriana, A.; Hernanz, D.; Stinco, C.M.; Mapelli-Brahm, P.; Meléndez-Martínez, A.J. Effect of regulated deficit irrigation on commercial quality parameters, carotenoids, phenolics and sugars of the black cherry tomato (*Solanum lycopersicum* L.) 'Sunchocola'. *J. Food Comp. Anal.* **2022**, *105*, 104220. [CrossRef]
26. Lipan, L.; Cano-Lamadrid, M.; Vázquez-Araújo, L.; Issa-Issa, H.; Nemś, A.; Corell, M.; López-Lluch, D.; Carbonell-Barrachina, Á.A. "HydroSOStainable" Concept: How Does Information Influence Consumer Expectations towards Roasted Almonds? *Agronomy* **2021**, *11*, 2254. [CrossRef]
27. Sánchez-Bravo, P.; Collado-González, J.; Corell, M.; Noguera-Artiaga, L.; Galindo, A.; Sendra, E.; Hernández, F.; Martín-Palomo, M.J.; Carbonell-Barrachina, Á.A. Criteria for HydroSOS Quality Index. Application to Extra Virgin Olive Oil and Processed Table Olives. *Water* **2020**, *12*, 555. [CrossRef]
28. Paixão, T.R.L.C.; Lowinsohn, D.; Bertotti, M. Use of an electrochemically etched platinum microelectrode for ascorbic acid mapping in oranges. *J. Agric. Food Chem.* **2006**, *54*, 3072–3077. [CrossRef]
29. de Andrade, R.S.G.; Diniz, M.C.T.; Neves, E.A.; Nobrega, J.A. Determinação e distribuição de ácido ascórbico em três frutos tropicais. *Eclética Quím.* **2002**, *27*, 393–401. [CrossRef]
30. van den Berg, H.; Faulks, R.; Granado, F.; Hirschberg, J.; Olmedilla, B.; Sandmann, G.; Southon, S.; Stahl, W. The potential for the improvement of carotenoid levels in foods and the likely systemic effects. *J. Sci. Food Agric.* **2000**, *80*, 880–912. [CrossRef]
31. Aust, O.; Sies, H.; Stahl, W.; Polidori, M.C. Analysis of lipophilic antioxidants in human serum and tissues: Tocopherols and carotenoids. *J. Chromatogr. A* **2001**, *936*, 83–93. [CrossRef]

32. Mossad, A.; Farina, V.; Bianco, R.L. Fruit yield and quality of Valencia Orange trees under long-term partial rootzone drying. *Agronomy* **2020**, *10*, 164. [CrossRef]
33. Lipan, L.; García-Tejero, I.F.; Gutiérrez, G.S.; Demirbaş, N.; Sendra, E.; Hernández, F.; Durán, Z.V.H.; Carbonell-Barrachina, A.A. Enhancing nut quality parameters and sensory profiles in three almond cultivars by different irrigation regimes. *J. Agric. Food Chem.* **2020**, *68*, 2316–2328. [CrossRef]
34. Zuazo, V.H.D.; Lipan, L.; Rodríguez, B.C.; Sendra, E.; Tarifa, D.F.; Nemś, A.; Ruiz, B.G.; Carbonell-Barrachina, A.A.; García-Tejero, I.F. Impact of deficit irrigation on fruit yield and lipid profile of terraced avocado orchards. *Agron. Sustain. Dev.* **2021**, *41*, 69. [CrossRef]
35. Lipan, L.; Carbonell-Pedro, A.A.; Cárceles Rodríguez, B.; Durán-Zuazo, V.H.; Franco Tarifa, D.; García-Tejero, I.F.; Gálvez Ruiz, B.; Cuadros Tavira, S.; Muelas, R.; Sendra, E.; et al. Can Sustained Deficit Irrigation Save Water and Meet the Quality Characteristics of Mango? *Agriculture* **2021**, *11*, 448. [CrossRef]
36. Liakos, K.G.; Busato, P.; Moshou, D.; Pearson, S.; Bochtis, D. Machine learning in agriculture: A review. *Sensors* **2018**, *18*, 2674. [CrossRef] [PubMed]
37. Poeplau, C.; Don, A. Carbon sequestration in agricultural soils via cultivation of cover crops—A meta-analysis. *Agric. Ecosyst. Environ.* **2015**, *200*, 33–41. [CrossRef]
38. Ordóñez-Fernández, R.; Rodríguez-Lizana, A.; Carbonell, R.; González, P.; Perea, F. Dynamics of residue decomposition in the field in a dryland rotation under Mediterranean climate conditions in southern Spain. *Nutr. Cycl. Agroecosyst.* **2007**, *79*, 243–253. [CrossRef]