horticulturae

MDPI

Review

Sustainable Water Management in Horticulture: Problems, Premises, and Promises

Carla S. S. Ferreira [1,2], Pedro R. Soares [2,3,*], Rosa Guilherme [2,4], Giuliano Vitali [5], Anne Boulet [2], Matthew Tom Harrison [6], Hamid Malamiri [7], António C. Duarte [8,9], Zahra Kalantari [10] and António J. D. Ferreira [2,*]

1 Polytechnic Institute of Coimbra, Applied Research Institute, Rua da Misericórdia, Lagar dos Cortiços—S. Martinho do Bispo, 3045-093 Coimbra, Portugal; carla.ferreira@ipc.pt
2 Research Centre for Natural Resources Environment and Society (CERNAS), Polytechnic Institute of Coimbra, Bencanta, 3045-601 Coimbra, Portugal; rosa.guilherme@ccdrc.pt (R.G.); anne.karine@esac.pt (A.B.)
3 Soil Physics and Land Management Group (SLM), Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands
4 Comissão de Coordenação e Desenvolvimento Regional do Centro, Polo de Inovação de Coimbra, Quinta de N. Senhora do Loreto, 3020-201 Coimbra, Portugal
5 Department of Agri-Food Science and Technology, University of Bologna, 40127 Bologna, Italy; giuliano.vitali@unibo.it
6 Tasmanian Institute of Agriculture, University of Tasmania, Newnham Drive, Launceston, TAS 7248, Australia; matthew.harrison@utas.edu.au
7 Department of Geography, Yazd University, Yazd 89158-18411, Iran; hrghafarian@yazd.ac.ir
8 School of Agriculture, Polytechnic Institute of Castelo Branco, 6001-909 Castelo Branco, Portugal; acduarte@esa.ipcb.pt
9 Research Center for Natural Resources, Environment and Society (CERNAS), Polytechnic Institute of Castelo Branco, 6001-909 Castelo Branco, Portugal
10 Department of Sustainable Development, Environmental Science and Engineering, Sustainability Assessment and Management, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden; zahrak@kth.se
* Correspondence: pedro.soares@esac.pt (P.R.S.); aferreira@esac.pt (A.J.D.F.)

check for updates

Citation: Ferreira, C.S.S.; Soares, P.R.; Guilherme, R.; Vitali, G.; Boulet, A.; Harrison, M.T.; Malamiri, H.; Duarte, A.C.; Kalantari, Z.; Ferreira, A.J.D. Sustainable Water Management in Horticulture: Problems, Premises, and Promises. *Horticulturae* **2024**, *10*, 951. https://doi.org/10.3390/horticulturae10090951

Academic Editor: Rossano Massai

Received: 1 August 2024
Revised: 27 August 2024
Accepted: 29 August 2024
Published: 6 September 2024

Abstract: Water is crucial for enduring horticultural productivity, but high water-use requirements and declining water supplies with the changing climate challenge economic viability, environmental sustainability, and social justice. While the scholarly literature pertaining to water management in horticulture abounds, knowledge of practices and technologies that optimize water use is scarce. Here, we review the scientific literature relating to water requirements for horticulture crops, impacts on water resources, and opportunities for improving water- and transpiration-use efficiency. We find that water requirements of horticultural crops vary widely, depending on crop type, development stage, and agroecological region, but investigations hitherto have primarily been superficial. Expansion of the horticulture sector has depleted and polluted water resources via overextraction and agrochemical contamination, but the extent and significance of such issues are not well quantified. We contend that innovative management practices and irrigation technologies can improve tactical water management and mitigate environmental impacts. Nature-based solutions in horticulture—mulching, organic amendments, hydrogels, and the like—alleviate irrigation needs, but information relating to their effectiveness across production systems and agroecological regions is limited. Novel and recycled water sources (e.g., treated wastewater, desalination) would seem promising avenues for reducing dependence on natural water resources, but such sources have detrimental environmental and human health trade-offs if not well managed. Irrigation practices including partial root-zone drying and regulated deficit irrigation evoke remarkable improvements in water use efficiency, but require significant experience for efficient implementation. More advanced applications, including IoT and AI (e.g., sensors, big data, data analytics, digital twins), have demonstrable potential in supporting smart irrigation (focused on scheduling) and precision irrigation (improving spatial distribution). While adoption of technologies and practices that improve sustainability is increasing, their application within the horticultural industry as a whole remains in its infancy. Further research, development, and extension is called for to enable successful adaptation to climate change, sustainably intensify food security, and align with other Sustainable Development Goals.

Keywords: horticulture; water use efficiency; irrigation technologies; IoT; artificial intelligence; precision agriculture

1. Introduction

Horticultural crops include fruits, vegetables, and ornamental, aromatic, and medicinal plants [1]. Horticultural crops are grown across most latitudes in the world, including temperate, tropical, subtropical and Mediterranean regions [2]. Horticulture is an important sector of agriculture, playing a vital role in the global economy due to high returns [3] and employment (e.g., twice higher than the number of jobs generated with cereal production [4]), extensive applications (e.g., medicine), and contribution to food security [5]. Over the last decades, economic growth in horticulture has far exceeded that in most agricultural commodities [6]. The increasing demand for horticultural products has been driven by growing population and changes in consumers' lifestyles, associated with increasing consumption of fruit and vegetables, given their low levels of fat and high levels of several nutritional compounds (e.g., vitamins, minerals, fibers, antioxidants), favored by the increasing awareness of the relationship between diet and health [7]. The average daily per capita intake of fruit and vegetables should be above 200 g and 250 g, respectively [1]. The rise of horticulture products production was also favored by the spread of supermarkets and the accelerated market demand for exotic food products [8].

Since 1960, accelerated global horticultural production has been associated with increases in land areas devoted to these crops, intensive use of agrochemicals (e.g., fertilizers, pesticides), new disease-resistant crops, and agrarian technologies [9,10]. From 2000 to 2021, the global production of fruit and vegetables increased by 59% and 64%, respectively [11]. In 2021, from the 9.5 billion tons of global primary crop production, 12% comprised vegetables and oil crops, and 10% included fruit [12]. Bananas, watermelons, apples, oranges, and grapes were the most produced fruits (representing 13.7%, 11.2%, 10.2%, 8.3%, and 8.1% of global fruit production), whereas tomatoes, onions, cucumbers, cabbages, and eggplants were the most produced vegetables (representing 16.4%, 9.3%, 8.1%, 6.2%, and 8.1% of global vegetable production) [11]. In 2021, vegetables and fruits represented 19% and 17% of the total value of primary crops production, respectively [12].

Horticultural crops are facing increasing challenges, driven by climate change (e.g., increasing frequency and intensity of droughts and floods), land and groundwater degradation (e.g., salinization, pollution), and the spread of new diseases, which have detrimental impacts on plant development and crop productivity [13]. Water is a fundamental requirement for horticultural production, given its impact on critical crop growth stages such as flowering, reproduction, fruit development and ripening, and bulb maturity [1,2]. Most horticultural crops demand high levels of water compared to other crops such as cereals [7]. However, increasing water scarcity is a global concern [14]. Water deficit conditions are present in all continents of the world [6] and affect countries and regions with extensive horticulture areas such as China, southern Europe, southeastern Australia, and western USA, with extensive horticulture areas [9]. In several regions, especially the arid and semiarid ones, the water requirement of horticultural crops is far higher than that provided by effective rainfall. Particularly in these areas, irrigation has been widely adopted to maximize crop yield and quality, secure harvest dates, and enable marketing plans [2]. Globally, there has been an increase in the area equipped for irrigation, which represented ~7% of the agricultural land area in 2021, corresponding to an increase of 22% since 2020 and more than twice the area equipped for irrigation in the 1960s [12]. Although rain-fed systems tend to be more vulnerable to climate changes than irrigated crops, irrigated horticulture faces water shortage challenges in areas with expected reductions on water availability, given the projections of rainfall decreases and evapotranspiration increases, and reductions in winter snow accumulation and lower snowmelt runoff in colder regions [2]. Furthermore, horticulturalists will face increasing competition of water resources from other sectors, such as domestic and industry [15]. In addition to changes in water availability and accessibility, crop water requirements are expected to increase under global warming conditions [16]. Climate change is expected to impact all agricultural enterprises, but more noticeably the high value horticultural production [15]. Currently, agriculture accounts for about 70% of global freshwater withdrawals [17], and with the predicted 70% increase in food demand by 2050, the global agricultural water consumption is estimated to rise by nearly 20% in 2050 [18]. This places even greater pressure on water resources.

Minimizing water use in horticulture while maintaining production (including both yield and quality) has become a critical issue [9]. Traditional irrigation methods (e.g., flood irrigation) are associated with unacceptable water losses [19]. Additionally, farmers usually decide on irrigation based on their own experience, field observations of plant canopy [20], water availability, and/or generalized regional evapotranspiration tables, leading to excessive irrigation to maximize yields and economic returns [21]. However, over recent decades, various approaches have been developed to provide irrigation water savings and improve water use efficiency. Strategies based on enhancing soil water retention, more efficient irrigation technologies (e.g., drip irrigation, subsurface irrigation) and emerging decision support systems utilizing, e.g., sensor technologies to improve and automate data collection of soil water status and physiological stress have been useful in implementing water conservation approaches and increasing the productivity per area [14]. Recent advancements in technology have led to the development of artificial intelligence and data-driven and sensor-based irrigation, offering the opportunity to meet the current challenges in horticulture [22]. Previous studies have provided a literature review on water management strategies to enhance water savings in agriculture, but they tend to focus on specific strategies (e.g., agronomic practices [23], drip irrigation [24], precision irrigation technology [25], transformative technologies in digital agriculture [26], and IoT wireless communication [27]) or in specific regions (e.g., drylands [28], arid and semiarid areas [29]). A limited number of review manuscripts focused on horticulture has a subset of agriculture, and tend to concentrate on specific water management strategies (e.g., nanotechnology-based approaches [8] and adaptive microbial inoculants for alleviation of water stress [6]) rather than providing a broader overview of the topic.

This paper aims to provide a comprehensive overview of past and current developments and improvements in water management in horticultural crops. Based on a review, this paper summarizes the scientific literature to (i) comprehensively elucidate the water requirements for different horticultural crops and associated impacts on water resources, in terms of both water availability and water quality; and (ii) identify available water management techniques and tools, including irrigation technologies and decision support systems based on sensors, use of unconventional water resources and nature-based solutions, and discuss their potential in supporting the sustainable development of horticulture. This study provides an up-to-date overview of the state of the art regarding different types of water management strategies in all types of horticultural crops, including flowers and ornamental crops not mentioned in previous review papers [30]. The paper is structured into three main sections. Section 2 summarizes knowledge on horticulture crop water requirements and discusses the impact of horticulture on water resources, including both quantity and quality. Section 3 presents measures and strategies to improve water management in horticulture, focusing on the use of nature-based solutions, unconventional water resources, emerging technologies (e.g., microirrigation, IoT, and artificial intelligence), and other methods (i.e., drought tolerant cultivars and nanotechnology, and excess water management). Section 4 presents concluding remarks and future recommendations.

Sustainable water management in horticulture involves using water efficiently to minimize wastage [31]. Ensuring the efficient use of water is important to prevent water scarcity, especially in arid and drought-prone regions, and to avoid overextraction and pollution of freshwater. This is essential for ensuring the long-term availability of water resources, protecting ecosystems and supporting human wellbeing. Its importance spans environmental, economic, and social dimensions both now and in the future. Farmers' adoption of improved water management practices and technologies can help support adaptation to climate change, contribute to food security, and support the achievement of several Sustainable Development Goals (e.g., SDGs 1, 2, 13, 14).

2. Horticulture and Water Resources

2.1. Crop Water Requirements

Water is a basic resource for plant life, playing a crucial role in several biochemical and physiological processes essential for plant growth and health. Water is involved in triggering seed germination, facilitating the uptake of minerals and nutrients from the soil, and subsequently transporting them throughout various plant organs [32,33]. Water also assumes a vital role in sustaining turgor pressure, providing rigidity to plant cells, maintaining their shape/vigor, and preventing wilting [32]. Adequate turgor pressure will additionally contribute to opening stomata [34], enabling gases exchange needed for basic physiological processes, such as plant transpiration, photosynthesis, and respiration [35], as illustrated in Figure 1. These processes contribute to preventing plant overheating, producing carbohydrates, and generating energy in the form of adenosine triphosphate (ATP), respectively [13].

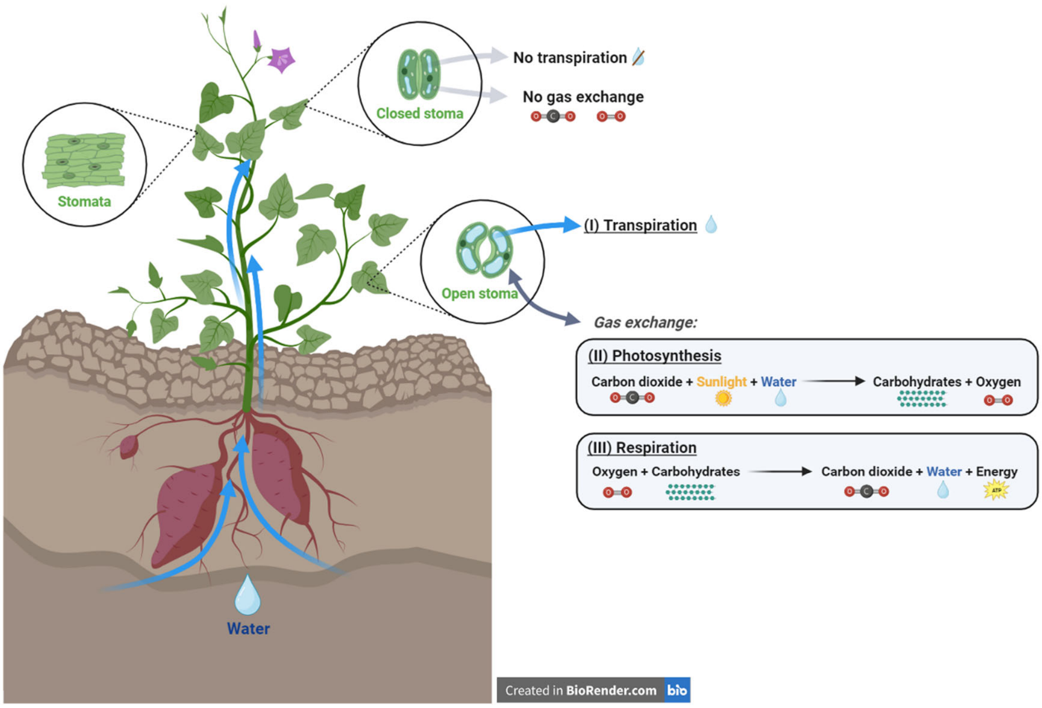

Figure 1. Conceptual representation of water impact on stomata functioning and subsequent plant physiological processes (transpiration, photosynthesis, and respiration).

In light of the critical role that water plays in the plant cycle, understanding and addressing the specific water requirements of different crops become imperative for sustainable horticulture. Each horticultural crop demands adequate availability of water over its lifecycle to avoid development constraints and decreasing yields. Table 1 synthesizes the optimal water requirements for different horticultural crops, which vary depending on prevailing climate system, soil type, farm management practices, and crop cultivar [6]. Horticultural crops are cultivated in open-field and indoor areas (e.g., greenhouse, hydroponics), with variable plant density and height (determined by, e.g., pruning practices). These cultivation differences affect the aerodynamic properties of the area with implications on, e.g., evapotranspiration and, thus, water requirements [36]. Greenhouse horticulture establishes a more favorable environment for plant growth than open-field farming, by artificially controlling temperature and air humidity, thus extending the growing season and enhancing yields [37]. In northern Europe, soil-less (i.e., on cultivation substrates) horticulture in glasshouses has shown minimal soil evaporative losses [36].

Table 1. Optimal water requirements for horticultural crops (adapted from [38]).

Horticultural Crops	Family	Crop Name	Optimal Water Requirements (mm)
Vegetables	Amaranthaceae	Spinach (*Spinacia oleracea* L.) Beetroot (*Beta vulgaris* L.)	800–1200 600–800
	Amaryllidaceae	Onion (*Allium cepa* L.) Garlic (*Allium sativum* L.)	350–600 750–1600
	Apiaceae	Carrot (*Daucus carota* L.)	600–1200
	Asteraceae	Lettuce (*Lactuca sativa* L. var. capitata)	1100–1400
	Brassicaceae	Mustard (*Brassica juncea* (L.) Czern.) Broccoli (*Brassica oleracea* L. var. botrytis) Cabbage (*Brassica oleracea* L. var. capitata)	 600–1100 500–1000
	Cucurbitaceae	Pumpkin (*Cucurbita pepo* L.)	600–1500
	Fabaceae	Bean (*Phaseolus vulgaris* L.)	500–2000
	Solanaceae	Pepper (*Capsicum annuum* L.) Eggplant (*Solanum melongena* L.) Tomato (*Lycopersicum esculentum* Mill.)	600–1250 1200–1600 600–1300
Fruits	Anacardiaceae	Mango (*Mangifera indica* L.)	600–1500
	Cucurbitaceae	Watermelon (*Citrullus lanatus* (Thunb.) Matsumura & Nakai)	500–700
	Lauraceae	Avocado (*Persea americana* Mill.)	500–2000
	Rosaceae	Apple (*Malus domestica* Borkh.) Pear (*Pyrus communis* L.)	700–2500 600–900
	Rutaceae	Orange (*Citrus sinensis* (L.) Osbeck)	1200–2000
Aromatic and medicinal plants	Apiaceae	Parsley (*Petroselinum crispum* (Mill.) Nym. ex AW Hil)	900–1500
	Lamiaceae Lamiaceae Lamiaceae Lamiaceae Lamiaceae Lamiaceae	Lemon balm (*Melissa officinalis* L.) Sage (*Salvia officinalis* L.) Rosemary (*Rosmarinus officinalis* L.) Oregano (*Origanum vulgare* L.) Spearmint (*Mentha spicata* L. var. crispa) Basil (*Ocimum basilicum* L.)	800–1000 500–1000 600–1400 700–1300 900–1200 1000–1600

Water stress, defined as the share of freshwater withdrawal in available freshwater resources, after taking into account environmental water requirements [12], is one of the most concerning issues for agricultural productivity [6], including horticulture. Water stress interferes with plant physiology and the normal metabolic activities, such as closure of stomata on aboveground organs to avoid water losses through transpiration [39]. However, these adaptations can lead to reduced photosynthetic activity, due to stomatal closure, membrane damage, disruptions in enzyme activity, particularly those involved in carbon dioxide fixation and ATP synthesis, decreased cell division, and reduced growth [39,40]. Though some fruit seem to benefit from deficit irrigation (e.g., sugar content) [41], in the majority of case water stress has negative impacts on plant morphology (e.g., elongated stems, reduction in root length and surface area which affects the nutrient uptake and transport to the shoots, smaller leaves, reduces fruit size), reduced crop yield [6], and poor fruit quality (e.g., poor color in tomato, decrease in total soluble sugars in melons), which is a relevant parameter in horticultural crops [5].Over the last decade, the increasing frequency of drought due to climate change has affected various critical crop growth stages such as flowering, reproduction, fruit development and ripening, and physiological maturity, leading to a 10–87% yield reduction in horticultural crops [1]. A summary of the most affected growth stages from drought in different horticultural crops and the implication for yield is provided in [1].

2.2. Impact of Horticulture on Water Resources

Irrigation is a common practice in horticulture, especially for high-value horticultural products, such as vegetables and fruit [15]. Typically, it includes water from freshwater resources and/or groundwater, depending on water availability and existent technology and/or hydraulic infrastructures to exploit the actual water resources. The expansion of horticultural activities and associated water requirements can exert substantial pressure on water resources, including both quantity and quality. Increasing water demand for irrigation has contributed to the depletion of water resources [14], and to conflicts in scarce water regions [41]. Irrigated agriculture accounts for 85–90 % of global water consumption [42]. Specific water consumption for horticulture alone is difficult to point out due to varying methods of measurement and regional practices, and the significant differences in crop requirements (e.g., tomatoes, lettuce, and citrus fruits are particularly water-intensive, whereas ornamental plants require less but frequent watering), but is estimated to represent 20–30% of the agricultural water use [43]. Surface water resources support 62% of global irrigated land, while groundwater provides the remaining 38% [44]. Overextraction of groundwater can lead to the depletion of aquifers, lowering water tables, and affecting water availability for other uses [45]. Additionally, irrigation can reduce the flow of surface water bodies (e.g., rivers), with impacts on downstream water availability for ecosystems and other anthropogenic uses [46]. Although several studies have focused on the impact of agriculture irrigation on water resources availability (including marine salty water intrusions in onshore areas), less is known about the specific impact of horticulture. Nevertheless, in countries with high horticulture production, such as China and India, water consumption is high and may represent a relevant threat to the available water resources. In the Mediterranean region, the intensive fruit and vegetable production requires significant irrigation and represents a major threat to local water resources [47]. In this region, as well as other arid and semiarid areas, water demand for horticulture is expected to increase due to climate change and associated decreasing precipitation and increasing temperatures [42].

The intensification of horticulture has been often associated with the increasing use of agrochemicals (e.g., fertilizers, pesticides, and herbicides), and the adoption of some nonconservative soil management practices (e.g., intensive tillage), with repercussions on both surface and ground water resources quality [10]. Surface runoff and leaching from horticulture croplands can transport many pollutants derived from the agrochemicals used. Previous studies have reported high loads of nutrients, such as phosphorus and nitrogen [48], heavy metals (e.g., cadmium and zinc) caused by using phosphate fertilizers and copper-based agrochemicals [10,49,50], and herbicide residues [51], posing a significant risk of contamination for water resources [14,49]. In Argentina, for example, glyphosate and aminomethylphosphonic acid (AMPA) in soluble and suspended-particulate-matter fractions were detected in 67% and 83% of surface water samples collected over three years nearby a 5000 ha horticulture cropland [52]. Furthermore, surface water quality impairments can result from soil erosion driven by intensive soil management practices. This has been a major concern, e.g., in new citrus plantations in Spain [47]. Due to cultivation on slopes, vineyards and orchards are among the crops with highest soil erosion rates [53,54]. The sediments transported in surface runoff can reach water bodies (e.g., rivers and lakes) and increase turbidity, thus reducing the penetration of sunlight and causing detrimental impacts on aquatic plant growth and affect the overall aquatic ecosystem [55]. Water turbidity may also reduce fish resistance to disease and alter egg and larval development [56]. Sediments may also transport several pollutants, such as phosphorous [57], heavy metals [58], organic pollutants (e.g., persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs)) [59], and pathogens like bacteria, viruses, and parasites from manure applications [60]. The overuse of fertilizers coupled with intensive irrigation practices and poor drainage in horticultural plantations can also lead to salinization, i.e., the accumulation of soluble salts in the soil to levels that negatively impact water quality and agricultural productivity [47]. Salinization caused by horticultural practices is a major problem in countries like Australia [61], Pakistan, and India [62].

Pollutants derived from intensive management practices can also penetrate through the soil profile and reach the groundwater. Intensive horticulture has led to significant groundwater contamination by nitrate and pesticide residues leaching [63,64]. In intensive olive grove orchards in the south of Portugal, about 70% of the nitrogen applied via fertilization is lost through leaching, resulting in a high risk for groundwater contamination [65]. In La Rioja, Spain, 30 compounds associated with pesticide residues (15 fungicides, 7 insecticides, and 3 herbicides) were identified in groundwater-driven contamination from vineyards [66], a type of horticulture. Fungicides were detected at the highest concentrations because they are applied more frequently. Twenty-six residues of pesticides were also identified in the groundwater of a wine region in southeast of Spain [67]. In Almeria, Spain, 80% of the water wells had to be abandoned due to pollution caused by leaching of agrochemical substances used in agriculture [49]. Here, more than 30,000 ha of land are occupied by greenhouses, the largest concentration of greenhouse in the world, visible even from space [49]. Greenhouse horticulture faces the challenge of ensuring crop yields while reducing the environmental impacts. This is crucial to support achieving European goals, such as the zero-pollution ambition of the Green Deal and the Farm to Fork Strategy [68].

3. New Opportunities for Improving Water Management in Horticulture

3.1. Nature-Based Solutions to Improve Water Management

Nature-based solutions are increasingly explored in horticulture to reduce water-irrigation requirements, within the context of climate change. These solutions often involve the use of organic and inorganic mulches and also other agronomic techniques to enhance soil properties and water retention and support plant growth. Mulching, as a layer of material on the soil surface, is a technique used to conserve soil moisture by improving the quantity of water accessible to plants and decreasing direct soil water evaporation [29]. It has received increasing application in horticulture [69]. Organic mulches, such as straw, bark, wood chips, and compost, have been demonstrated to improve soil physical properties (e.g., reducing soil bulk density and increasing porosity), favoring water infiltration and increasing soil organic matter content, which further aids in water retention [70]. Organic mulches contribute to regulating soil temperature, thus reducing evaporation [71]. The use of mulch can reduce 20 to 50% of evapotranspiration from soil when compared with unmulched soils [72–76]. Various organic mulches have been investigated in ornamentals [77], fruits (e.g., strawberry, apple) [78], vegetables (e.g., pepper) [79], and aromatics (e.g., turmeric, basil) [80,81]. Inorganic mulches, made from materials like plastic, landscape fabric, gravel, and rocks, do not require replacement as often as organic mulches [82]. Impervious plastic mulches have a short lifetime (up to two years) and can lead to soil contamination [83]. In horticulture, plastic mulches are the most widely used, including in fruits (e.g., strawberry) [84], vegetables (e.g., pepper) [85], herbs [86], and ornamentals [87], but gravel mulches [88] and geotextiles [76] have been also applied. For example, in a commercial adult mandarin orchard located in southeastern Spain, the black polypropylene raffia geotextile mulch reduced the intensity of water stress by 18% [76]. Some studies have revealed that inorganic mulches may be more effective in increasing soil water content than organic mulches [89]. The choice of mulch material depends on several factors, including availability, climate, durability, cost-effectiveness, and environmental impact [64,82]. Given the wide number of variables affecting soil water retention (e.g., soil type, rainfall patterns, evaporative demands), it is challenging to generalize about the efficiency of mulching in reducing water requirements in horticulture [29].

Other crop management practices such as organic amendments, reduced tillage, and cover crops have been used in horticulture, e.g., to improve water holding capacity [90–99]. In horticulture, the annual application rates of compost typically range from 20 to 40 t/ha in vegetable crops [29], 10 to 30 t/ha in orchards and vineyards [93], and 10 to 20 t/ha in both ornamental [94] and aromatic [99] cultivations, depending on the type of compost, crop nutrient requirements, soil properties, and local practices [91]. Horticulture plants, however, have been increasingly grown on soilless media, with compost being used as a substitute of soil in greenhouse crops [96]. Soilless systems, i.e., cultivation on substrates such as peat moss, perlite, vermiculite, and expanded clay pellets, provide a supportive environment for plant roots and have higher water use efficiency than soil cropping, given the better water retention properties of substrates compared to soil [68]. Soilless media are widely used in horticulture, particularly in controlled environments like greenhouses, vertical farms, and hydroponic systems. In hydroponic systems, water recirculation provides enhanced water use efficiency [97]. Various types of horticultural crops are successfully grown in soilless media, such as lettuce, tomatoes, blueberries, roses, and orchids. Savvas and Gruda [98] provided a literature review on the application of soilless technologies in greenhouse industry. Biochar, a carbon-rich solid byproduct with a porous structure obtained from pyrolysis [99], is a soil amendment with high potential to increase water storage by improving soil structure (e.g., reducing soil bulk density) [100,101]. It can also mitigate the negative impacts of horticulture on water quality by immobilizing nutrients and contaminants [100,101]. The impacts on soil properties are widely variable, depending on the feedstock material, the pyrolysis production system, and the properties of the soil where it is applied [102]. However, little is known about its impact on soil microbiome, which mediates nutrient cycle [101]. Biochar has been applied in fruit (e.g., strawberry, citrus, apple) [103–105], vegetable (e.g., tomato and pepper) [106], herbs (sweet basil, mint, and oregano) [107], and ornamental (e.g., calendula, marigold, petunia, and geranium) [108] production.

Cover crops, planted between the growth cycles of main crops or during fallow periods, can improve water infiltration and retention by enhancing soil structure and increasing organic matter content [109], although they are mainly used for soil erosion mitigation, weed control [2], and fixing atmospheric nitrogen, thus reducing fertilization requirements [110]. Cover crops have been used, e.g., in orchards and vineyards [111], ornamentals [112], and herbs [113], but knowledge on their contribution to reducing water-irrigation requirements is very limited. Intercropping has been shown to increase the water use efficiency of horticulture crops (e.g., moth bean between paired rows of pearl millet and green gram between paired rows of pigeon pea) because of higher yields in intercropping systems [29]. Reduce tillage improves soil water retention by maintaining soil cover and promoting better water infiltration [114]. It has been applied in different horticulture crops (e.g., tomato, strawberry) [115,116], but studies do not specify water savings.

Hydrogels, hydrophilic polymer networks that absorb and retain large amounts of water forming a gel-like substance, have been used to improve soil water retention in horticulture [117]. Different types of hydrogels, made from, e.g., methylcellulose and hydroxypropyl methylcellulose blended with potassium sulphate, have been demonstrated to improve water holding and water retention capacities on, e.g., sandy soils [118]. Chitosan-based hydrogels with urea can retain soil water content by up to 154% and reduce nitrogen leaching, enhancing plant growth by 70% [119]. Superabsorbent polymers, a type of hydrogels designed to absorb and retain extremely large amounts of water, can absorb up to 600 times their dry weight due to their three-dimensional structure, acting as water reservoirs that release stored water when the soil starts to dry [69]. Hydrogels have been applied, e.g., in tomato [120], lettuce [121], rain-fed peach trees [122], and ornamentals [123].

The use of nature-based solutions has been identified as innovative solutions to improve water resources management under climate change [124]. The abovementioned agriculture best management practices lead to improved soil structure and water holding capacity, relevant to decreasing irrigation water demand [109], but also providing improvements to soil health (e.g., fertility), reduced nutrient losses [14], and soil erosion [46], relevant to mitigate the environmental impacts of horticulture on water resource quality. However, generalizations on their effectiveness in reducing horticultural water irrigation are difficult, given the several factors affecting water availability and crop requirements in different regions. Future studies should focus on the effectiveness of different nature-based solutions in horticulture water savings to support water management.

3.2. Use of Unconventional Water Resources

The increasing demand for water in agriculture and other economic sectors and increasing water scarcity, which already affects 45 countries worldwide [125], have triggered a shift to the utilization of nonconventional water sources for irrigation [126]. The reuse of treated wastewater and desalination are considered promising solutions to ensure global food security in water-scarce regions [127].

Treated wastewater generally contains higher nutrient content when compared to natural water resources, meaning that these nutrients can directly be assimilated by crops, boost crop yield, and decrease the need for chemical fertilizers [126,128]. The quality of treated wastewater is of paramount importance for agriculture irrigation [129]. This is particularly challenging for horticulture due to tight requirements (e.g., *E. coli* contamination), involving, e.g., water disinfection, which increases the treatment cost. There are also increasing concerns regarding the presence of various emerging pollutants in treated wastewater, and their intake through the food chain and impacts on public health [129,130]. Conventional wastewater treatments are not prepared to remove contaminants such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), pharmaceuticals, personal care products, microplastics, pathogens, and antibiotic-resistant bacteria and genes, virus, or organic micropollutants [131–134]. These contaminants are not considered in the European Water Reuse Directive [135]. Nevertheless, studies to assess the long-term implication of reusing treated wastewater on crops are highly recommended [125,136]. The use of treated wastewater also poses environmental risks, such as salinity in the root zone, decreasing soil porosity due to changes in soil cation exchange driven by sodium absorption [136], and leaching of nutrients to aquifers [137]. These problems can be mitigated with appropriate agronomic strategies, such as irrigation-leaching strategies and crop selection [138]. Water reuse for agriculture irrigation is established in regions facing water scarcity, such as Israel (75%), Egypt (70%), California (46%), and Florida (44%) [139–141]. Although we do not know the exact numbers for the application of treated wastewater in horticulture, regions like the Mediterranean basin [142], East Asia [143], and the Middle East [144] have been reported in the literature.

For example, treated mixed industrial and domestic wastewater has been used to grow lettuce and silver beet [128], and agro-industrial effluent subject to purification was used for irrigation of broccoli and tomatoes [145] and lettuce and radish [146]. Cost-related concerns, however, have raised interest in seeking more cost-effective treatment technologies for the reuse applications of wastewater [128,147]. The reuse of water from aquaculture systems in horticulture has also received increasing attention due to the high content of nutrients [148]. Schoor et al. [149] provided a literature review on the use of aquacultural water in horticultural irrigation systems.

Seawater desalination represents an abundant source of water to effectively overcome water shortage constraints. Although it can provide a durable water supply, the energy-intensive nature of the process poses a significant obstacle for the widespread adoption of this technology in crop irrigation [150]. The cost of desalination is very high, ranging from EUR 0.7 to EUR 3.5 to produce 1 m^3 of water in large and small plants, respectively [151]. Additionally, the disposal of the concentrated waste brine, a byproduct of desalination, poses environmental challenges that must be addressed [150]. Desalinated water has been mainly used for irrigation of high-value crops, such as fruits, vegetables, and ornamental plants, and indoor horticulture (e.g., greenhouse, aquaponic, and hydroponic) [152]. Desalination for crop irrigation in horticulture has been used in countries like Spain (e.g., strawberries and lettuce), Israel (e.g., tomatoes, cucumbers, and peppers), Florida and California, and is under consideration in Chile, China, and Australia [153]. Water quality is a major concern for irrigation, since desalinated water is characterized by a chemical composition distinct from natural water sources, due to the predominance of sodium and chloride ions, and very low concentration of other minerals, such as calcium, magnesium, and sulphate, considering the nutritional requirements for horticultural crops [153]. There is limited knowledge on how to supplement these nutrients effectively and economically in horticultural systems [150]. There is also a lack of information on crop yields irrigated with desalinated water. Furthermore, there is limited understanding of the long-term effects of using desalinated water on soil health, particularly regarding soil structure, salinization, microbial activity, and nutrient availability.

3.3. Emerging Technologies and Tools for Water Management

3.3.1. Irrigation Technologies and Methods

Irrigation is a technical measure used to replenish water necessary for crop growth [14]. It has been used for thousands of years to maximize the performance, efficiency, and profitability of crops, and it is a science that is constantly developing [154]. The global irrigation efficiency is low, with crops using less than 65% of the applied water [44]. Several authors advocate for water use efficiency as a crucial aspect to decrease water demand [155,156], which can be achieved using efficient irrigation methods [157]. Generally, drip irrigation has a water application efficiency of 65–95%, whereas sprinkler and furrow irrigation methods have efficiencies of 50–90% and 50–70%, respectively [25].

Traditionally, both flood and furrow irrigation have been used in vegetable, fruit, ornamental, and herb crops. Generally, flood irrigation is used in areas with abundant water resources for the cultivation of, e.g., leafy greens (e.g., spinach and lettuce), citrus trees, flower beds, and mint [158,159]. Furrow irrigation has been used in different horticulture crops, including vegetable (e.g., tomatoes, cucumbers, and lettuce), fruit (e.g., melons, strawberries), ornamental (e.g., shrubs and hedges), and aromatics (e.g., mint, thyme) [158,159]. Both flood and furrow irrigation are easy to implement and require relatively low initial investment, but they tend to overwater and are less efficient in water use compared to other irrigation systems, thus contributing to the depletion of water resources. Overirrigation using these systems is quite common and can result in nitrogen leaching and pollution of water resources, low fertilizer use efficiency, and increased production costs [20].

Environmental, economic, and social drivers have been placing great pressure on horticultural systems to improve water use efficiency [160], which has led to the application of a range of irrigation technologies and methods, such as drip irrigation systems, subsurface irrigation systems, and controlled drainage [15]. Sprinkler irrigation systems have been used in horticulture, e.g., in apples [161], blueberries [162], lettuce [163], and basil [164]. Sprinkler technology uses stationary sprinklers, moving sprinklers, or center-pivot systems to spray water over the crops. However, part of the water is retained by the canopy and can induce diseases due to the wetting of foliage, which creates a favorable environment for the growth and spread of pathogens [165].

In small-acreage irrigation, methods such as microirrigation are commonly used [1]. The use of microirrigation systems, such as drip irrigation, is a key factor in achieving higher yields and better-quality product in open-field [166] and greenhouse [167] vegetable cultivation. Drip irrigation diverts water near the root zone through a network of pipes, tubes, and emitters. It has been proposed as a potential alternative to traditional methods as it can significantly increase yield and water use efficiency due to lower water loss through seepage and evaporation [168,169]. For example, a literature review focused on crops irrigated in China revealed that for the same amount of water applied, drip irrigation increases crop yields by 29%, 8%, 5%, and 2% comparing to the yields from flooding, furrow, microsprinkler, and two-sprinkler irrigation, respectively [14].

Numerous horticulture farmers use drip irrigation technologies [2]. Several forms of automated microirrigation systems, including drip irrigation, have been used in water management methods such as deficit irrigation [170]. Deficit irrigation methods are based on the reaction of signaling molecules transported by xylem tissue, since water is first sent by the roots and provides the signal to leaves to retard the standard development and prevent water loss [1]. Based on this principle, water-management techniques such as partial root-zone drying (PRD) and regulated deficit irrigation (RDI) have been successfully used to improve yield and quality in horticulture [171]. PRD involves alternately wetting and drying different parts of the root zone, effectively exposing only half of the root system to water stress at any given time [172]. In PRD, irrigation is applied to one side of the plant's root system while the other side is allowed to dry. After a certain period, typically one to two weeks, irrigation is switched to the previously dry side. This alternation helps to stimulate physiological responses in the plant that improve water use efficiency and can lead to benefits such as improved drought-tolerance mechanisms and reduced transpiration rates [1]. PDR has been successfully applied in various horticulture corps, leading to a 30–50% reduction in irrigation in, e.g., tomato [173], potato [174], and citrus [175]. RDI is a method that intentionally reduces the amount of water applied to crops during specific growth stages. By applying water deficits at noncritical growth stages, plants can be conditioned to use water more efficiently, leading to considerable reductions in water use with minimal impacts on yield and quality [176]. However, RDI requires detailed understanding of crop-specific growth stages and water needs to identify the timing of water deficits that would minimize the impact on crop growth [9], precise monitoring of soil moisture content, and high management complexity for the precise timing and application of water deficits [1]. RDI has led to water savings of up to 20–30% in horticultural crops such as tomato [177], grapes [178], and bean [179]. Water savings in horticulture are particularly relevant in arid and semiarid areas [29]. Nevertheless, both RDI and PDR are strategies that could be further explored in some horticultural cropping regimes [2].

Research on subsurface irrigation for open-air horticulture crops has shown promising results. In subsurface irrigation, water is delivered into the crop root zone, through a pipe network system laid below the surface layer. This method reduces deep seepage and soil evaporation and improves water use efficiency [14]. Oron [180] found that a subsurface drip system can be used for years without failure, with increased yields compared to surface microirrigation systems. Ayars [181] reported significant yield and water use efficiency increases in various crops, including tomato, cotton, and cantaloupe, when using subsurface drip irrigation. Brown [182] demonstrated the practical advantages of subsurface drip irrigation for multiple cropping, with higher yields in cantaloupe and dry onion. Lamm [183] highlighted the increased usage of subsurface drip irrigation in the USA, particularly for cotton, tomato, and onion production.

Controlled drainage is a water management practice that involves the regulation of the water table to enhance water availability during dry periods and prevent waterlogging during wet periods, thereby optimizing growing conditions to improve crop performance [184]. It has been used to avoid waterlogging in horticulture crops like strawberries and tomatoes, and to prevent both waterlogging and drought stress in orchards [185,186]. Controlled drainage is mainly used in countries like the Netherlands and Denmark. Nevertheless, its impact on water quality is not clear, with some studies reporting a reduction in nitrogen and phosphorus loss [164], while others show an increase in total phosphorus concentration [187]. Therefore, while controlled drainage can be a valuable tool in water management, its limitations and potential trade-offs should be carefully considered in horticultural crops.

Recent research in horticulture irrigation methods has focused on improving water and nutrient management in greenhouse vegetable crops [188]. This includes the use of fertigation and advanced technologies such as hydroponics [189]. Water and nitrogen shortage are some of the most limiting factors for crop production and they often occur together [20]. Fertigation, i.e., the application of fertilizers through irrigation systems, provides an efficient method to optimize water and nutrient management in intensive horticultural systems, such as strawberries, lettuce, roses, and mint [190,191]. Hydroponic is a soilless farming technique using mineral nutrient solutions in an aqueous solvent, with minimum evaporative losses. It is gaining attention in horticulture for its potential to provide increased yields, higher growth rates, efficient use of water and nutrients, higher plant density and allowing for vertical farming, thus addressing food demand and environmental challenges [192]. Examples of hydroponic applications in horticultural crops include strawberries [193], cucumbers [194], and mint [195]. However, hydroponic also presents challenges, including high initial investment, technical knowledge requirements, and reliance on consistent electricity and water supply [196]. Despite these limitations, the future of hydroponic farming looks promising, with the potential to provide high-quality, locally grown products [197].

The challenge of adapting water management to a changing climate, including the need to reduce water consumption and improve water quality, involves improving irrigation efficiency [198]. The best irrigation practice to implement, however, can vary with crop morphology, land availability, and soil type [2]. In addition to water use efficiency, the selection for the irrigation technology and method should consider the water accessibility and availability and the associated costs for both technology and water abstraction [199]. Previous studies focusing on economic aspects of irrigation have shown that low-cost and moderate- to high-efficiency irrigation infrastructures may best suit farmers targeting area-based income [200].

3.3.2. The Potential of IoT and Artificial Intelligence in Supporting Water Management

The most recent technological advances in irrigation involve smart irrigation and precision irrigation, based on the adoption of a new generation of technology and information tools, such as Internet of Things (IoT) and artificial intelligence (AI). Smart irrigation is more focused on time aspects (scheduling), involving the automation and optimization of irrigation processes using real-time data [201], whereas precision irrigation is more focused on the spatial distribution of water supply, targeting the precise application of water based on detailed analysis of field variability [202]. Furthermore, IoT sensors can be used to detect leaks in irrigation systems [197], thus supporting improved water management. The rapidly evolving fields of IoT and AI hold immense promise for addressing the crucial challenge of water management in horticulture [203]. These tools can support precision irrigation by using IoT sensors for real-time data collection (e.g., soil moisture content, weather conditions, and plant water needs) and transmitting the collected data to data centers [204]. IoT includes actuators (e.g., to operate valves and pumps) and connected electronic devices (nodes) to support smart irrigation [201]. Apart from this hardware side, IoT comprises cloud computing for system feedback, based, e.g., on the water budget approach for personalized and farm-directed alerts [205,206]. Remote control of the irrigation system allows farmers to control irrigation and other water management systems from anywhere (especially considering the 6G wireless systems), providing timely interventions by farmers, flexibility, and efficiency [207].

Advancements in the field of horticulture include, e.g., the design of intelligent drip irrigation network control systems, which can monitor soil humidity, air temperature, and light and provide feedback through wireless sensor networks [208–218]. Several studies have used soil moisture sensors for real-time optimization of irrigation systems (scheduling) in both open-field and indoor horticulture [21,206]. Soil moisture monitoring to support drip irrigation scheduling has been performed using sensors such as tensiometer and a standard evaporating dish [209–211], time domain reflectometry [212], and neutron probes [213]. Pardossi [215] used a new generation of dielectric sensors that can also measure electrical conductivity and nutrient microenvironment for controlled fertigation [197]. Kumar et al. [218] provided a literature review on the application of IoT technologies in agriculture, including irrigation in some horticultural crops.

Automation based on the use of wireless sensor network technologies has provided a relevant increase in water use efficiency of horticultural crops [21]. Tang et al. [27] provided a literature review on the application of wireless communication technologies (e.g., 5G, WiFi, and ZigBee) in agricultural irrigation management. Emerging decision support systems utilizing sensor technologies to improve and automate data collection of soil water status, screen for drought tolerance within specialty cropping systems, and implement responsive, climate-smart, irrigation programs have been increasingly used in horticulture [21,197]. Sensor technology has been used to optimize water savings and crop yields in, e.g., tomato [216], lettuce, and cabbage [217]. Figure 2 provides a summary of variables and processes considered in data analytics used to support smart improved irrigation in horticulture.

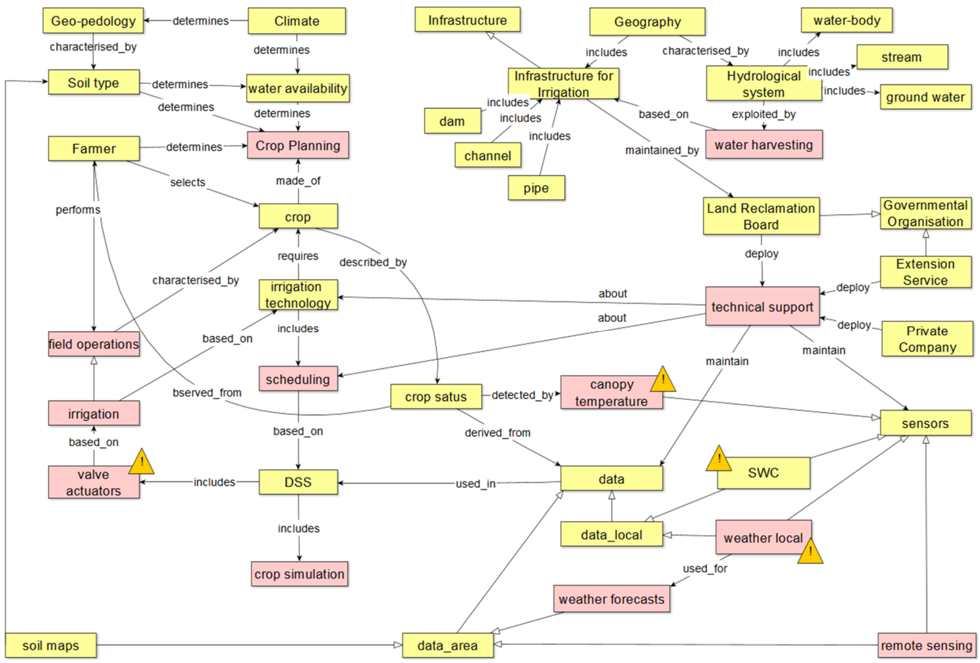

Figure 2. Ontographic representation of most relevant structural (yellow) and dynamical (pink) entities involved in IoT-based horticulture smart irrigation; entities are linked by relation arrows and (open head) subclassing arrows; warning triangles show where IoT devices are commonly in use (SWC: Soil Water Content).

Sensors, however, provide point-based data and might fail to capture field heterogeneity and associated spatial variation of, e.g., soil moisture and plant water stress [20]. Determining the optimum number of soil sensors for automation of irrigation in different crops is complex, since it depends on many factors such as soil type and soil profiles [203]. To overcome point-based data problems, other methods have been also applied in horticulture. For example, crop water status monitoring can be performed using plant-canopy-based methods, including both contact (e.g., pressure chamber for measuring stomatal conductance and water potential, and leaf diffusion porometers) [218] and non-contact (e.g., infrared thermometers and remote sensing) [219] methods. Low-altitude remote sensing techniques use different spectral bands from multispectral and hyperspectral sensors [20]. Hyperspectral cameras have been used to detect water stress in, e.g., tomato, citrus, and tea crops ([220,221]). Khormizi et al. [222] monitored the water stress of a pistachio orchard by using an unmanned aerial vehicle (UAV). They used images from a drone to quantify evapotranspiration and assess drought stress in individual trees, based on the Normalized Difference Vegetation Index (NDVI). Other vegetation indices, such as Green Normalized Difference Vegetation (GNDVI) and Optimized Soil Adjusted Vegetation Index (OSAVI)), have been used to assess water in horticultural crops, such as lettuce, tomatoes, and spinach, under different climatic conditions [222–224]. However, the spectral behavior of crops used to calculate the indices differs with crop type and climatic conditions [225,226]. Enhanced monitoring of soil moisture content and more efficient irrigation scheduling strategies can decrease irrigation water demand up to 30 % [36]. Brajović [227] introduced the concept of smart irrigation software, which utilizes data fusion to optimize irrigation scheduling and system design. Irrigation scheduling programs should be based on estimating crop water requirements from measurements of soil moisture, deep drainage, and crop water stress, with weather forecasts [2,210].

Data from IoT sensors and remote sensing can be used in AI algorithms for data analysis to determine the optimal irrigation schedule and amount, enhancing water use efficiency [22]. Adjustments on irrigation can be refined through AI integration of data, achieved by learning from past data and predicting future water needs, for more precise and efficient water usage [197]. AI models can be used for predictive analytics to forecast weather conditions (e.g., rainfall patterns) and crop water demand (based on analysis of historical data and current conditions), simulating the effects of preventive and/or corrective actions [228,229]. Predictive analytics can support farmers in assessing the impact of climate change on irrigation [197]. Digital twins, virtual replicas of real-world entities, rely on sophisticated data analytics such as prediction models and machine learning [230]. Advancements in smart and data-driven greenhouse horticulture have been achieved with digital twins [231]. Ariesen-Verschuur et al. [231] presented a systematic review on the application of digital twins in horticulture. Ahmed et al. [28] provided an overview of the use of AI, deep learning, and predictive models in supporting water use efficiency in water-scarce agricultural regions, including a few examples of application in greenhouses.

The use of digital applications and technology to monitor crops and the environmental conditions provides relevant inputs to improve irrigation management, reduce water losses, and improve water use efficiency [157,210]. A recent literature review on precision irrigation water-saving technology suggested that enhancements in irrigation efficiency alone can fulfil 50% of the anticipated rise in water demand, and that only by using IoT and AI tools it would be possible to achieve the long-term viability of global food production [25]. Previous studies have shown that the use of new technologies and tools improved water savings of 19% in coffee [232], and 46% [25] and 59% [233] in tomato comparing to traditional irrigation methods. Additionally, AI and IoT can also support the improvement of other management practices (e.g., optimizing fertilization and pest control) relevant to reducing the pollution of water resources [26]. AI and IoT have been mainly used to support greenhouse management, including water and other resources, to create ideal growing conditions, especially in greenhouses [22].

In the future, it will be vital to know how to harness and maximize the potential of new technologies to irrigate horticultural crops efficiently and manage a scarce resource such as water. Despite the relevant opportunities provided, the adoption rates of new technologies and practices in agriculture has been slow [15]. Generally, only the more added-value crops, such as the majority of those included in horticulture, have been using IoT and AI [203]. The use of IoT and AI in agriculture can be challenging, since the initial cost of IoT devices and AI systems may represent barrier for small-scale farmers [21]. This can be particularly relevant to horticulture since it is dominated by small- and medium-sized business [203]. Furthermore, data management can be also challenging, since collecting, storing, and analyzing large amounts of data require robust infrastructure and expertise [204].

3.4. Other Methods

3.4.1. Drought-Tolerant Cultivars and Nanotechnology

To minimize the harmful effects of water stress, various approaches have been used to boost horticultural production and quality. They include, for example, growing plants with low water requirements by selecting crops, varieties, and rootstock [1]. Advances in crop improvement to develop drought-tolerant cultivars in horticultural crops have been achieved, involving, e.g., progress in molecular breeding and genome editing to induce various physiological, morphological, and biochemical modifications [1]. These advances involve, for example, genetic improvements by stimulating gene activity through nanotechnology (e.g., zinc oxide nanoparticles), adjusting levels of hormones to produce growth regulators, enhancing water uptake, improve root hydraulic conductance, and preventing oxidative damage [1,13]. Recent studies on physiological phenotyping have monitored water relations in the soil–plant-atmosphere continuum of multiple horticultural crops under dynamic environmental conditions [220]. Physiological phenotyping is a tool used to identify and select plant traits that enhance water-use efficiency and reduce water requirements in horticultural crops. This approach involves assessing various physiological parameters of plants, such as their ability to maintain growth under water-limited conditions, their water uptake and transport mechanisms, and their overall response to drought stress [234]. By integrating these phenotypic traits into breeding programs, water-scarcity-resilient horticultural crops can be developed. Breeding programs have used physiological phenotyping to select for traits such as improved water use efficiency, leading to tomato, lettuce, and grape varieties that require less water [235].

Nanotechnology offers innovative solutions for managing water stress in horticulture, such as hydrogel nanocomposites, materials that significantly enhance soil water retention and slowly release depending on plants need, silver nanoparticles to enhance plant growth under oxidative stress associated with drought, and silicon nanoparticles to improve drought tolerance by enhancing water uptake and reducing transpiration [236]. Manzoor et al. [8] presented a literature review on nanotechnology-based approaches in horticulture, including for water stress tolerance. Hayat et al. [13] presented a literature review on the use and potential of nanoparticles for improving drought stress resistance of plants. As research progresses, these technologies are likely to become increasingly integrated into sustainable agricultural practices, helping to mitigate the effects of climate change and water scarcity on horticulture.

Adaptive microbial inoculants are increasingly recognized as effective tools for mitigating water stress in horticultural crops. These inoculants consist of beneficial microorganisms, such as bacteria, fungi, or a combination of both, that enhance plant resilience to drought. Examples of microbial inoculants include (i) arbuscular mycorrhizal fungi, widely used to enhance drought tolerance in tomatoes, peppers, and strawberries [237]; (ii) plant-growth-promoting rhizobacteria for promoting root growth, enhancing nutrient uptake, and inducing systemic tolerance to drought in crops like lettuce, carrots, and cucumbers [1]; and (iii) phosphate-solubilizing bacteria and rhizobium inoculation, used to improve water use efficiency in crops such as chickpea [29]. Kour et al. [6] provided a literature review on adaptive microbial inoculants for alleviation of water stress in horticultural crops. As research advances, the development and application of tailored microbial consortia could become a key strategy in sustainable horticulture, particularly in regions prone to drought.

Grafting has been also successfully used to mitigate water stress in horticultural crops [238]. It involves joining the tissues of two plants so that they grow as one. This well-established technique often involves the use of rootstocks resilient to drought, and scions selected for specific fruit or vegetable production characteristics. Grafting has been used, e.g., in *Cucurbitaceae* and *Solanaceae* families and grapevines [238,239]. The success of grafting in mitigating water stress lies in its ability to improve water uptake, regulate water loss, enhance root-to-shoot communication, and provide resilience against drought-induced oxidative stress. This approach is increasingly important in the context of climate change and water scarcity, making it a critical tool for sustainable horticulture [240].

3.4.2. Managing Excess Water Due to Flooding

Although water management has been largely focused on water scarcity stress, flooding is also a substantial environmental challenge that significantly decreases crop yield and has become a global issue [13], expected to be exacerbated by climate change [16]. More than one-third of the world's irrigated land is affected by flooding, whether commonly or infrequently [13]. Several factors can contribute to this issue, including heavy rainfall, unlevelled land, poor drainage, and overirrigation [13]. Excess water in the soil reduces gas exchange and diffusion between plant roots and the atmosphere, leading to restricted respiration, hypoxia, and anoxia in plants due to excessive water filling air spaces [13], and can deter efficient root function, thus hindering nutrient uptake [2,5]. Overirrigation leads to low fertilizer use efficiency, reduced productivity, and increased production costs, and may also result in nitrogen leaching and consequent pollution of water bodies [20]. Such environmental challenges require adaptive cultivation techniques to ensure that plants meet their nutritional requirements [5]. The impacts of flooding on horticultural crops can be mitigated using drainage systems, including both surface (e.g., drains, such as ditches or shallow trenches, to quickly convey water from the field) and subsurface (tiles or pipes installed to remove excess water from the root zone, preventing prolonged waterlogging) systems [241]. Other agronomic practices include planting crops on raised beds to elevate the root zone above the saturated soil, reducing the risk of root hypoxia and improving aeration [242]. In fields with gentle slopes, installing ridges can help channel excess water away from the plant roots. This technique is particularly effective for crops such as strawberries, tomatoes, and peppers [242]. Selecting or breeding crop varieties that are more tolerant to waterlogging or temporary flooding can help mitigate losses. Some rootstocks or cultivars have better tolerance to low-oxygen conditions [243]. Nanotechnology has been used to alleviate the harmful effects of flooding stress on plants by limiting root cell death, reducing O_2 deprivation stress, shifting from aerobic to anaerobic energy metabolism, regulating protein synthesis, and detoxifying toxic products [244,245]. However, there is a lack of studies that specifically investigate the role of nanoparticles against flooding stress tolerance in horticultural plants [13].

4. Concluding Remarks and Prospects

Horticulture is a crucial sector for food security and the global economy. Horticultural crops, including fruits, vegetables, aromatic herbs, and ornamental plants, have noticed an increasing social demand over the last few decades. These types of crops require considerable amount of water, often necessitating irrigation, especially in arid and semiarid regions. Increasing water scarcity due to climate change, population growth, and competing demands from other sectors (e.g., industry, urbanization) is a critical challenge for horticulture. Inefficient irrigation practices also represent a major challenge for water management in horticulture. Traditional irrigation methods such as flood irrigation are often associated with overirrigation, nutrient leaching, and soil degradation (e.g., salinization).

The expansion of horticulture has raised environmental concerns due to impacts on water resources, such as overextraction of groundwater and pollution driven by the intensive use of agrochemicals, but the extent and magnitude of the impacts are not known. Further studies to assess the real impact of large-scale horticulture on both quantity and quality of the water resources are needed. This will require monitoring programs to assess the impacts on water resources availability, and chemical and biological status, at the basin scale. Particular attention should be provided to emerging contaminants (e.g., herbicides and microplastics).

To cope with water shortages and improve water use efficiency, a holistic approach combining sustainable agriculture practices and technological innovation to improve water management in horticulture is required. However, one of the primary challenges for water management in horticulture is the lack of knowledge among farmers regarding the water requirements of their crops. Farmers often rely on their perception of crop status and the availability of water, rather than actual crop water needs. Several horticulture crops have been well investigated regarding water needs in distinct growth stages (e.g., tomato and lettuce), but there is limited information about many crops, especially some perennials, ornamentals, and aromatics. Additionally, studies on crop water demands are developed in specific environments, and information for varying regions is still lacking (e.g., the Mediterranean). A global database about crop water requirements in different environments, easily accessible to farmers, would be useful.

The implementation of nature-based solutions based on best agricultural practices, such as mulching, organic amendments, and cover crops, can enhance soil moisture by improving the water holding capacity and reducing losses by evaporation, and, thus, decrease water irrigation requirements. The use of hydrogels, for instance, can reduce evaporation losses up to 50%. However, there is a lack of comprehensive knowledge on the effectiveness of different measures in distinct horticulture crops and environments. For example, the impact of several mulches and application rates are highly variable. Other techniques to reduce irrigation requirements, such as nanotechnology-based approaches for water stress tolerance, are promising, but studies of large-scale application are still lacking. The development of drought-resistant crop varieties can reduce the dependency on water and maintain productivity in challenging conditions. Breeding and genetically engineering crops that are more resistant to drought and can thrive in low-water conditions is a critical research area.

The use of unconventional sources of water, comprising an important aspect of water management in horticulture, have been increasingly explored. Water sources such as treated wastewater and desalination provide sustainable alternative to freshwater resources, especially in water-scarce regions. However, these sources are more expensive than natural water resources, and inappropriate management can lead to the accumulation of salts, causing soil degradation and decreases in crop yields. This is a major issue for horticulture, especially in arid and semiarid regions. The quality of treated wastewater is another major concern for horticulture, given the risk of food contamination and impact on public health. The extent of soil degradation and food safety problems have not been sufficiently investigated. Future research should focus on developing cost-effective technologies to improve the water quality of alternative sources.

Improved irrigation techniques are of the utmost importance to enhance water use efficiency in horticulture. The adoption of more efficient technologies, such as drip irrigation, can optimize water use by delivering water directly to the root zone in appropriate amounts. Nevertheless, innovative technologies and tools are necessary to effectively optimize water management. Automation and remote sensing are emerging research fields to improve irrigation. The real-time integration of data from sensors (providing information about the water status of crops) and weather forecasts enable farmers to optimize irrigation. Precision irrigation and smart irrigation have high potential to improve water use efficiency by tailoring irrigation schedules and spatial variability, respectively, to the specific needs of crops. The use of IoT with 6G wireless systems has the potential to revolutionize horticulture, given the high capacity of 6G to support large-scale operations with numerous IoT devices. Other innovative tools, such as data analytics, predictive modeling, and digital twins, provide remarkable improvements in decision support systems. The practical implementation of these technologies, however, has been limited. The high cost of the technology and the complexity of implementation are barriers to the widespread adoption of these water-efficient tools. Additionally, farmers are often resistant to change their established practices. Efforts to develop more cost-effective and user-friendly technologies and tools and to educate and engage farmers will be crucial in driving the widespread adoption of water-efficient practices. Smart irrigation and the safeguarding of water resources are essential to adapt to climate change, ensure food security, and achieve some of the Sustainable Development Goals.

Although this paper is focused on demand-driven water management by controlling and reducing the demand for water through more efficient use, conservation practices, and drought-tolerant crops to meet growing demands for horticulture crops, other demand-driven strategies are also available (e.g., water pricing policies). Effective water management in agriculture also involves supply-driven strategies and measures, such as the development of infrastructure like dams, reservoirs, and irrigation canals to store and deliver water to horticulture when it is needed. A holistic approach involving both supply-driven and demand-driven strategies is required to cope with increasing water scarcity, exacerbated by both growing societal demand and climate change, and to ensure sustainable water management required for food security.

Author Contributions: Conceptualization, C.S.S.F., G.V., and M.T.H.; formal analysis, C.S.S.F., P.R.S., R.G., G.V., H.M. and A.B.; writing—original draft preparation, C.S.S.F., P.R.S., R.G., G.V., and A.J.D.F.; writing—review and editing, C.S.S.F., M.T.H., A.C.D., H.M. and Z.K.; supervision, A.J.D.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Portuguese Foundation for Science and Technology, P.I., through the research project PTDC/EEI-ROB/2459/2021, and by the Carbo2Soil project—Strengthening the complementarity between agriculture and livestock to increase soil fertility and its carbon sequestration capacity. PRR–ID140–PRR-C05-i03-I-000030, and the SoloC+ project—Development of solutions to increase the resilience of agricultural soils to climate change in the Centre Region. PRR–ID150–PRR-C05-i03-I-000032, the institutional scientific employment program-contract CEECINST/00077/2021 of Carla Ferreira, and the doctoral fellowship 2022.10290.BD allocated to Pedro Soares.

Data Availability Statement: The data used in this study are available on the Internet and can be found by following the references section.

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

References

1. Kaldate, R.; Singh, S.; Guleria, G.; Soni, A.; Aikwad, D.; Kumar, N.; Meshram, S.; Rana, M. Current approaches in horticultural crops to mitigate the effect of drought stress. *Stress Toler. Hortic. Crop.* **2021**, *13*, 213–240. [CrossRef]
2. Webb, L.; Darbyshire, R.; Goodwin, I. Climate Change: Horticulture. *Encycl. Agric. Food Syst.* **2014**, *2*, 266–283. [CrossRef]
3. Staritz, C.; Reis, J.G. Global Value Chains, Economic Upgrading, and Gender. Case Studies of the Horticulture, Tourism, and Call Center Industries. The World Bank. 2013. Available online: https://documents1.worldbank.org/curated/en/912761468337873624/pdf/832330WP0GVC0G0Box0382076B00PUBLIC0.pdf (accessed on 18 March 2024).
4. USAID. Global Horticulture Assessment. USAID. 2005. Available online: https://pdf.usaid.gov/pdf_docs/pnadh769.pdf (accessed on 18 March 2024).
5. Touil, S.; Richa, A.; Fizir, M.; García, K.; Gómez, A. A review on smart irrigation management strategies and their effect on water savings and crop yield. *Irrig. Drain.* **2022**, *71*, 1396–1416. [CrossRef]
6. Kour, D.; Khan, S.; Kaur, T.; Kour, H.; Singh, G.; Yadav, A.; Yadav, A. Drought adaptive microbes as bioinoculants for the horticultural crops. *Heliyon* **2022**, *8*, e09493. [CrossRef]
7. USDAID; ISHS. *Global Horticulture Assessment*; International Society for Horticultural Science: Leuven, Belgium, 2005; ISBN 9066053674.
8. Manzoor, M.; Xu, Y.; Iv, Z.; Xu, J.; Shah, I.; Sabir, I.; Wang, Y.; Sun, W.; Liu, X.; Wang, L.; et al. Horticulture crop under pressure: Unraveling the impact of climate change on nutrition and fruit cracking. *J. Environ. Mang.* **2024**, *357*, 120759. [CrossRef] [PubMed]
9. Stefanelli, D.; Goodwin, I.; Jones, R. Minimal nitrogen and water use in horticulture: Effects on quality and content of selected nutrients. *Food Res. Int.* **2010**, *43*, 1833–1843. [CrossRef]
10. Wilson, M.M.; Michieka, R.W.; Mwendwa, S.M. Assessing the influence of horticultural farming on selected water quality parameters in Maumau stream, a tributary of Nairobi River, Kenya. *Heliyon* **2021**, *7*, e08593. [CrossRef]
11. FAO. Agricultural Production Statistics 2000–2021. FAOSTAT Analytical Brief 60. 2022. Available online: https://openknowledge.fao.org/server/api/core/bitstreams/58971ed8-c831-4ee6-ab0a-e47ea66a7e6a/content (accessed on 22 April 2024).
12. FAO. FAO's Global Information System on Water and Agriculture 2024. 2023. Available online: https://www.fao.org/aquastat/ (accessed on 22 April 2024).
13. Hayat, F.; Khanum, F.; Li, J.; Iqbal, S.; Khan, U.; Javed, H.U.; Razzaq, M.K.; Altaf, M.A.; Peng, Y.; Ma, X.; et al. Nanoparticles and their potential role in plant adaptation to abiotic stress in horticultural crops: A review. *Sci. Hortic.* **2023**, *321*, 112285. [CrossRef]
14. Guo, J.; Zheng, L.; Ma, J.; Li, X.; Chen, R. Mata-Analysis of the effect of subsurface irrigation on crop yield and water productivity. *Sustainability* **2023**, *15*, 15716. [CrossRef]
15. Bogdan, A.M.; Kulshreshtha, S.N. Canadian horticultural growers' perceptions of beneficial management practices for improved on-farm water management. *J. Rural Stud.* **2021**, *87*, 77–87. [CrossRef]
16. Ferreira, C.S.; Seifollahi-Aghmiuni, S.; Destouni, G.; Ghajarnia, N.; Kalantari, Z. Soil degradation in the European Mediterranean region: Processes, status and consequences. *Sci. Total Environ.* **2022**, *805*, 150106. [CrossRef] [PubMed]
17. FAO. Water for Sustainable Food and Agriculture: A Report Produced for the G20 Presidency of Germany [WWW Document] Food Agric. Organ. 2017. Available online: http://www.fao.org/3/a-i7959e.pdf8.7.18 (accessed on 18 March 2024).
18. WWAP. The United Nations World Water Development Report 4 Vol 1: Managing Water under Uncertainty and Risk. *UNESCO, Paris.* 2012. Available online: http://unesdoc.unesco.org/images/0021/002156/215644e.pdf (accessed on 18 March 2024).
19. Huang, X.; Zhang, J.A.; Liu, R.P.; Guo, Y.J.; Hanzo, L. Airplane-aided integrated networking for 6G wireless: Will it work? *IEEE Veh. Technol. Mag.* **2019**, *14*, 84–91. [CrossRef]
20. Mwinuka, P.R.; Mourice, S.K.; Mbungu, W.B.; Mbilinyi, B.P.; Tumbo, S.D.; Schmitter, P. UAV-based multispectral vegetation indices for assessing the interactive effects of water and nitrogen in irrigated horticultural crops production under tropical sub-humid conditions: A case of African eggplant. *Agric. Water Manag.* **2022**, *266*, 107516. [CrossRef]
21. Bierer, A.M. Development of an open-source soil water potential management system for horticultural applications, "Open_Irr". *HardwareX* **2023**, *15*, e00458. [CrossRef]
22. Singh, R.; Singh, R.; Gehlot, A.; Akram, S.; Priyadarshi, N.; Twala, B. Horticulture 4.0: Adoption of Industry 4.0 Tecnologies in Horticulture for meeting Sustainable Farming. *Appl. Sci.* **2022**, *12*, 12557. [CrossRef]
23. Bhinde, H.; Shukla, A. A Review of Sustainable Agricultural Practices for Water Conservation and Efficient Farming. *Anveshak Int. J. Manag.* **2019**, *8*, 9–18. [CrossRef]

24. Yang, P.; Wu, L.; Cheng, M.; Fan, J.; Li, S.; Wang, H.; Qian, L. Review on Drip Irrigation: Impact on Crop Yield, Quality, and Water Productivity in China. *Water* **2023**, *15*, 1733. [CrossRef]
25. Lakhiar, I.; Yan, H.; Zhang, C.; Wang, G.; He, B.; Hao, B.; Han, Y.; Wang, B.; Bao, R.; Syed, T.; et al. A Review of Precision Irrigation Water-Saving Technology under Changing Climate for Enhancing Water Use Efficiency, Crop Yield, and Environmental Footprints. *Agriculture* **2024**, *14*, 1141. [CrossRef]
26. Fuentes-Penailillo, F.; Gutter, K.; Vega, R.; Silva, G.C. Transformative Technologies in Digital Agriculture: Leveraging Internet of Things, Remote Sensing, and Artificial Intelligence for Smart Crop Management. *J. Sens. Actuator Netw.* **2024**, *13*, 39. [CrossRef]
27. Tang, P.; Liang, Q.; Li, H.; Pang, Y. Application of Internet-of-Things Wireless Communication Technology in Agricultural Irrigation Management: A Review. *Sustainability* **2024**, *16*, 3575. [CrossRef]
28. Ahmed, Z.; Gui, D.; Murtaza, G.; Yunfei, L.; Ali, S. An Overview of Smart Irrigation Management for Improving Water Productivity under Climate Change in Drylands. *Agronomy* **2023**, *13*, 2113. [CrossRef]
29. Alharbi, S.; Felemban, A.; Abdelrahim, A.; Al-Dakhil, M. Agricultural and Technology-Based Strategies to Improve Water-Use Efficiency in Arid and Semiarid Areas. *Water* **2024**, *16*, 1842. [CrossRef]
30. Pan, Q.; Lu, Y.; Hu, H.; Hu, Y. Review and research prospects on sprinkler irrigation frost protection for horticultural crops. *Sci. Hortic.* **2024**, *326*, 112775. [CrossRef]
31. Russo, T.; Alfredo, K.; Fisher, J. Sustainable Water Management in Urban, Agricultural, and Natural Systems. *Water* **2014**, *6*, 3934–3956. [CrossRef]
32. Sevik, H.; Cetin, M. Effects of Water Stress on Seed Germination for Select Landscape Plants. *Pol. J. Environ. Stud.* **2015**, *24*, 689–693. [CrossRef] [PubMed]
33. Scharwies, J.D.; Dinneny, J.R. Water transport, perception, and response in plants. *J. Plant Res.* **2019**, *132*, 311–324. [CrossRef] [PubMed]
34. Ali, O.; Cheddadi, I.; Landrein, B.; Long, Y. Revisiting the relationship between turgor pressure and plant cell growth. *New Phytol.* **2023**, *238*, 62–69. [CrossRef] [PubMed]
35. Jones, H.G. Stomatal control of photosynthesis and transpiration. *J. Exp. Bot.* **1998**, *49*, 387–398. [CrossRef]
36. Orgaz, F.; Fernández, M.; Bonachela, S.; Gallardo, M.; Fereres, E. Evapotranspiration of horticultural crops in an unheated plastic greenhouse. *Agric. Water Manag.* **2005**, *72*, 81–96. [CrossRef]
37. Shen, J.; Zhang, P.; Chang, Y.; Zhang, L.; Hao, Y.; Tang, S.; Xiong, X. The environmental performance of greenhouse versus open-field cherry production systems in China. *Sustain. Prod. Consum.* **2021**, *28*, 736–748. [CrossRef]
38. FAO. *The Ecocrop Database*; Food and Agriculture Organization of the United Nations, Ed.; FAO: Rome, Italy, 2000.
39. Gupta, A.; Rico-Medina, A.; Caño-Delgado, A.I. The physiology of plant responses to drought. *Science* **2020**, *368*, 266–269. [CrossRef] [PubMed]
40. Farooq, M.; Hussain, M.; Wahid, A.; Siddique, K.H.M. Drought stress in plants: An overview. In *Plant Responses Drought Stress*; Springer: Berlin/Heidelberg, Germany, 2012; pp. 1–33.
41. Lanari, N.; Schuler, R.; Kohler, T.; Liniger, H. The Impact of Commercial Horticulture on River Water Resources in the Upper Ewaso Ng'iro River Basin, Kenya. *Mt. Res. Dev.* **2018**, *38*, 114–124. [CrossRef]
42. Qin, Y.; Mueller, N.D.; Siebert, S.; Jackson, R.B.; AghaKouchak, A.; Zimmerman, J.B.; Tong, D.; Hong, C.; Davis, S.J. Flexibility and intensity of global water use. *Nat. Sustain.* **2019**, *2*, 515–523. [CrossRef]
43. Molden, D. *Water for Food, Wate for Life: A Comprehensive Assessment of Water Management*; Routledge: London, UK, 2007; ISBN 978-1-84407-397-9.
44. Frimpong, F.; Asante, M.; Peprah, C.; Yeboah, P.; Danquah, E.; Ribeiro, P.F.; Aidoo, A.K.; Agyeman, K.; Asante, M.O.O.; Keteku, A.; et al. Water-smart farming: Review of strategies, technologies, and practices for sustainable agricultural water management in a changing climate in West Africa. *Front. Sustain. Food Syst.* **2023**, *7*, 1110179. [CrossRef]
45. Thomas, B.F.; Famiglietti, J.S. Identifying climate-induced groundwater depletion in GRACE observations. *Sci. Rep.* **2019**, *9*, 4124. [CrossRef]
46. Eekhout, J.; Delsman, I.; Baartman, J.; Van Eupen, M.; Van Haren, C.; Contreras, S.; Martínez-López, J.; De Vente, J. How future changes in irrigation water supply and demand affect water security in a Mediterranean catchment. *Agric. Water Manag.* **2024**, *297*, 108818. [CrossRef]
47. Harrison, M.; Cullen, B.; Rawnsley, R. Modelling he sensitivity of agricultural systems to climate change and extreme climatic events. *Agric. Syst.* **2016**, *148*, 135–148. [CrossRef]
48. Shrivastava, P.; Kumar, R. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi J. Biol. Sci.* **2015**, *22*, 123–131. [CrossRef]
49. Ferreira, C.; Keizer, J.; Santos, L.; Serpa, D.; Silva, V.; Cerqueira, M.; Ferreira, A.; Abrantes, N. Runoff, sediment and nutrient exports from a Mediterranean vineyard under integrated production: An experiment at plot scale. *Agric. Ecosyst. Environ.* **2018**, *256*, 184–193. [CrossRef]
50. Garcia-Caparros, P.; Contreras, J.I.; Baeza, R.; Segura, M.L.; Lao, M.T. Integral Management of Irrigation Water in Intensive Horticultural Systems of Almería. *Sustainability* **2017**, *9*, 2271. [CrossRef]
51. Muriithi, F.K.; Yu, D. Understanding the Impact of Intensive Horticulture Land-Use Practices on Surface Water Quality in Central Kenya. *Environments* **2015**, *2*, 521–545. [CrossRef]

52. Atucha, A.; Merwin, I.A.; Brown, M.G.; Gardiazabal, F.; Mena, F.; Adriazola, C.; Lehmann, J. Soil erosion, runoff and nutrient losses in an avocado (Persea americana Mill) hillside orchard under different groundcover management systems. *Plant Soil* **2013**, *368*, 393–406. [CrossRef]
53. Loughlin, T.; Peluso, M.; Aparicio, V.; Marino, D. Contribution of soluble and particulate-matter fractions to the total glyphosate and AMPA load in water bodies associated with horticulture. *Sci. Total Environ.* **2020**, *703*, 134717. [CrossRef]
54. EC. Proposal From the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions for a Directive of the European Parliament and of the Council Establishing a Framework for the Protection of Soil and Amending. Directive 2004/35/EC. *Eur. Comm. Bruss.* **2006**, *232*. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32004L0035 (accessed on 18 March 2024).
55. Verheijen, F.G.; Jones, R.J.; Rickson, R.J.; Smith, C. Tolerable versus actual soil erosion rates in Europe. *Earth-Sci. Rev.* **2009**, *94*, 23–38. [CrossRef]
56. Straffelini, E.; Pijl, A.; Otto, S.; Marchesini, E.; Pitacco, A.; Tarolli, P. A high-resolution physical modelling approach to assess runoff and soil erosion in vineyards under different soil managements. *Soil Tillage Res.* **2022**, *222*, 105418. [CrossRef]
57. Häder, D.-P.; Kumar, H.; Smith, R.; Worrest, R. Effects of solar UV radiation on aquatic ecosystems and interactions with climate change. *Photochem. Photobiol. Sci.* **2007**, *6*, 267–285. [CrossRef] [PubMed]
58. Sharpley, A.; Wang, X. Managing agricultural phosphorus for water quality: Lessons from the USA and China. *J. Environ. Sci.* **2014**, *26*, 1770–1782. [CrossRef]
59. Han, Y.; Zhao, W.; Ding, J.; Ferreira, C.S.S. Soil erodibility for water and wind erosion and its relationship to vegetation and soil properties in China's drylands. *Sci. Total Environ.* **2023**, *903*, 166639. [CrossRef]
60. Rügner, H.; Schwientek, M.; Milačič, R.; Zuliani, T.; Vidmar, J.; Paunović, M.; Laschou, S.; Kalogianni, E.; Skoulikidis, N.T.; Diamantini, E. Particle bound pollutants in rivers: Results from suspended sediment sampling in Globaqua River Basins. *Sci. Total Environ.* **2019**, *647*, 645–652. [CrossRef]
61. Williams, J. Salinity: A major environmental issue in Australia. *Int. J. Environ. Stud.* **1999**, *56*, 507–521.
62. Qureshi, A.S.; McCornick, P.G.; Qadir, M.; Aslam, Z. Managing salinity and waterlogging in the Indus Basin of Pakistan. *Agric. Water Manag.* **2008**, *95*, 1–10. [CrossRef]
63. Bradford, S.A.; Morales, V.L.; Zhang, W.; Harvey, R.W.; Packman, A.I.; Mohanram, A.; Welty, C. Transport and fate of microbial pathogens in agricultural settings. *Crit. Rev. Environ. Sci. Technol.* **2013**, *43*, 775–893. [CrossRef]
64. Melo, A.; Pinto, E.; Aguiar, A.; Mansilha, C.; Pinho, O.; Ferreira, I.M. Impact of intensive horticulture practices on groundwater content of nitrates, sodium, potassium, and pesticides. *Environ. Monit. Assess.* **2012**, *184*, 4539–4551. [CrossRef]
65. Marchi, E.; Zotarelli, L.; Delgado, J.; Rowland, D.; Marchi, G. Use of the Nitrogen Index to assess nitrate leaching and water drainage from plastic-mulched horticultural cropping systems of Florida. *Int. Soil Water Conserv. Res.* **2016**, *4*, 237–244. [CrossRef]
66. Cameira, M.; Pereira, A.; Ahuja, L.; Ma, L. Sustainability and environmental assessment of fertigation in an intensive olive grove under Mediterranean conditions. *Agric. Water Manag.* **2014**, *146*, 346–360. [CrossRef]
67. Manjarres-López, D.P.; Andrades, M.S.; Sánchez-González, S.; Rodríguez-Cruz, M.S.; Sánchez-Martín, M.J.; Herrero-Hernández, E. Assessment of pesticide residues in waters and soils of a vineyard region and its temporal evolution. *Environ. Poll.* **2021**, *284*, 117463. [CrossRef] [PubMed]
68. Herrero-Hernández, E.; Simón-Egea, A.B.; Sánchez-Martín, M.J.; Rodríguez-Cruz, M.S.; Andrades, M.S. Monitoring and environmental risk assessment of pesticide residues and some of their degradation products in natural waters of the Spanish vineyard region included in the Denomination of Origin Jumilla. *Environ. Poll.* **2020**, *264*, 114666. [CrossRef]
69. Gava, O.; Antón, A.; Carmassi, G.; Pardossi, A.; Incrocci, L.; Bartolini, F. Reusing drainage water and substrate to improve the environmental and economic performance of Mediterranean greenhouse cropping. *J. Clean. Prod.* **2023**, *413*, 137510. [CrossRef]
70. Gholami, R.; Hoveizeh, N.; Zahedi, S.; Arji, I. Effect of organic and synthetic mulches on some morpho-physiological and yield parameters of 'Zard' olive cultivar subjected to three irrigation levels in field conditions. *S. Afr. J. Bot.* **2023**, *162*, 749–760. [CrossRef]
71. Liao, Y.; Cao, H.-X.; Liu, X.; Li, H.-T.; Hu, Q.-Y.; Xue, W.-K. By increasing infiltration and reducing evaporation, mulching can improve the soil water environment and apple yield of orchards in semiarid areas. *Agric. Water Manag.* **2021**, *253*, 106936. [CrossRef]
72. Hale, R.; Stewart, A. The effect of mulch on soil temperature and moisture in vegetable crops. *HortScience* **2008**, *43*, 473–479.
73. Bowers, S.; Gossard, J. Mulch effects on soil moisture and evapotranspiration in ornamental plant beds. *Landsc. Urban Plan.* **2005**, *71*, 197–205. [CrossRef]
74. Kuehny, J.S.; Bowers, R. Mulch effects on evapotranspiration and growth of herbs in container production. *J. Plant Nutr.* **2006**, *29*, 585–600.
75. Chai, Q.; Gan, Y.; Zhao, C.; Xu, H.-L.; Waskom, R.M.; Niu, Y.; Siddique, K.H. Regulated deficit irrigation for crop production under drought stress. A review. *Agron. Sustain. Dev.* **2016**, *36*, 3. [CrossRef]
76. Bai, Z.; Caspari, T.; Gonzalez, M.R.; Batjes, N.H.; Mäder, P.; Bünemann, E.K.; de Goede, R.; Brussaard, L.; Xu, M.; Ferreira, C.S.S. Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agric. Ecosyst. Environ.* **2018**, *265*, 1–7. [CrossRef]
77. Berríos, L.R.; Nielsen, K.F. Crop response to irrigation—Vegetables. *Irrig. Agric. Crop.* **2006**, *33*, 791–820.
78. Wavhal, E.; Giri, M. Intelligent Drip irrigation system using linear programming and interpolation methodology. *Int. J. Comput.* **2014**, *2306*, 1–11.

79. Hossain, M.D.; Ryu, K.N. Effects of mulching on yield, quality and soil properties in strawberry. *Sci. Hortic.* **2009**, *124*, 282–286. [CrossRef]
80. Wang, Q.; Klassen, W.; Li, Y. Influence of cover crops and organic mulches on soil properties and the growth of bell pepper. *HortTechnology* **2009**, *19*, 58–64. [CrossRef]
81. Agyarko, K.; Asiedu, E.K.; Tachie-Menson, J. Effect of mulching materials on soil temperature, nutrient concentration, growth and yield of turmeric (*Curcuma longa*). *Int. J. Plant Prod.* **2006**, *2*, 63–75.
82. Khan, F.A. A review on hydroponic greenhouse cultivation for sustainable agriculture. *Int. J. Agric. Environ. Food Sci.* **2018**, *2*, 59–66. [CrossRef]
83. Kader, M.; Singha, A.; Begum, M.; Jewel, A.; Khan, F.; Khan, N. Mulching as water-saving technique in dryland agriculture: Review article. *Bull. Natl. Res. Cent.* **2019**, *43*, 2–6. [CrossRef]
84. Teuten, E.L.; Saquing, J.M.; Knappe, D.R.; Barlaz, M.A.; Jonsson, S.; Björn, A.; Rowland, S.J.; Thompson, R.C.; Galloway, T.S.; Yamashita, R. Transport and release of chemicals from plastics to the environment and to wildlife. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2009**, *364*, 2027–2045. [CrossRef] [PubMed]
85. Lamont, W.J. Plastics: Modifying the microclimate for the production of vegetable and small fruit crops. *Hort. Technol.* **2005**, *15*, 477–481. [CrossRef]
86. Díaz-Pérez, J.C.; Batal, K.D.; Granberry, D.M. Plastic mulches and row covers on growth and production of bell pepper. *Hort. Sci.* **2005**, *40*, 1315–1320.
87. Materechera, S.A.; Mkhabela, T.S. Influence of inorganic mulches on soil moisture retention and temperature, and growth of cowpea (*Vigna unguiculata* L. Walp.) in a semi-arid environment. *Soil Tillage Res.* **2001**, *58*, 31–40.
88. Svenson, S.E.; Davies, F.T. Growth of Liriope muscari under different light regimes and mulch colors. *J. Environ. Hortic.* **1992**, *10*, 21–24.
89. Montague, T.; Kjelgren, R.; Rupp, L.; Allen, R. Tree growth and aesthetics for different mulch types in a landscape setting. *Arboric. Urban For.* **2007**, *33*, 343–349.
90. Ren, A.-T.; Zhou, R.; Mo, F.; Liu, S.-T.; Li, J.-Y.; Chen, Y.; Zhao, L.; Xiong, Y.-C. Soil water balance dynamics under plastic mulching in dryland rainfed agroecosystem across the Loess Plateau. *Agric. Ecosyst. Environ.* **2021**, *312*, 107354. [CrossRef]
91. Braun, M.; Mail, M.; Heyse, R.; Amelung, W. Plastic in compost: Prevalence and potential input into agricultural and horticultural soils. *Sci. Total Environ.* **2021**, *760*, 143335. [CrossRef] [PubMed]
92. Ketterings, Q.M.; Bigham, J.M. Soil organic matter: Definition and measurement in agronomy. *Soil Sci. Soc. Am. J.* **2003**, *67*, 2020–2028. [CrossRef]
93. Ronga, D.; Francia, E.; Allesina, G.; Pedrazzi, S.; Pane, C.; Francia, M.; Lovelli, S. Using compost in horticulture: A tool to increase sustainability. *Agroecol. Sustain. Food Syst.* **2016**, *40*, 1–23.
94. Glover, J.D.; Reganold, J.P.; Andrews, P.K. Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. *Agric. Ecosyst. Environ.* **2000**, *80*, 29–45. [CrossRef]
95. Diacono, M.; Montemurro, F. Long-term effects of organic amendments on soil fertility. *Sustain. Agric.* **2011**, *2*, 761–786.
96. Singh, R.; Sharma, R.R. Effects of various organic soil amendments on growth, yield and quality of strawberry. *Biol. Agric. Hortic.* **2003**, *21*, 37–48. [CrossRef]
97. Carotti, L.; Pistillo, A.; Zauli, I.; Meneghello, D.; Martin, M.; Pennisi, G.; Gianquinto, G.; Orsini, F. Improving water use efficiency in vertical farming: Effects of growing systems, far-red radiation and planting density on lettuce cultivation. *Agric. Water Manag.* **2023**, *285*, 108365. [CrossRef]
98. Savvas, D.; Gruda, N. Application of soilless culture technologies in the modern greenhouse industry—A review. *Eur. J. Hortic. Sci.* **2018**, *83*, 280–293. [CrossRef]
99. Corato, U.D. Agricultural waste recycling in horticultural intensive farming systems by on-farmcomposting and compost-based tea application improves soil quality and plant health: A review under the perspective of a circular econom. *Sci. Total Environ.* **2020**, *738*, 139840. [CrossRef]
100. Gökalp, Z.; Bulut, S. Potential use of biochar in wastewater treatment operations and soil improvement. *Curr. Trends Nat. Sci.* **2022**, *11*, 161–169. [CrossRef]
101. Kavitha, B.; Reddy, P.V.L.; Kim, B.; Lee, S.S.; Pandey, S.K.; Kim, K.-H. Benefits and limitations of biochar amendment in agricultural soils: A review. *J. Environ. Manag.* **2018**, *227*, 146–154. [CrossRef] [PubMed]
102. Chiomento, J.; Nardi, F.; Filippi, D.; Trentin, T.; Dornelles, A.; Fornari, M.; Nienow, A.; Calvete, E. Morpho-horticultural performance of strawberry cultivated on substrate with arbuscular mycorrhizal fungi and biochar. *Sci. Hortic.* **2021**, *282*, 110053. [CrossRef]
103. Ortiz-Liébana, N.; Zotti, M.; Barquero, M.; González-Andrés, F. Biochar + AD exerts a biostimulant effect in the yield of horticultural crops and improves bacterial biodiversity and species richness in the rhizosphere. *Sci. Hortic.* **2023**, *321*, 112277. [CrossRef]
104. Álvarez, J.; Pasian, C.; Lal, R.; López, R.; Díaz, M.; Fernández, M. Morpho-physiological plant quality when biochar and vermicompost are used as growing media replacement in urban horticulture. *Urban For. Urban Gree.* **2018**, *34*, 175–180. [CrossRef]
105. Akhtar, S.S. Biochar stimulates plant growth but not fruit yield of processing tomato in a fertile soil. *Sci. Hortic.* **2015**, *264*, 109184.
106. Genesio, L.; Miglietta, F.; Baronti, S.; Vaccari, F.P. Biochar increases vineyard productivity without affecting grape quality: Results from a four years field experiment in Tuscany. *Agric. Ecosyst. Environ.* **2015**, *201*, 20–25. [CrossRef]
107. Graber, E.R.; Meller Harel, Y.; Kolton, M.; Cytryn, E.; Silber, A.; Rav David, D.; Tsechansky, L.; Borenshtein, M.; Elad, Y. Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. *Plant Soil* **2010**, *337*, 481–496. [CrossRef]

108. Rowland, L.; Smith, H.; Taylor, G. The potential to improve culinary herb crop quality with deficit irrigation. *Sci. Hortic.* **2018**, *242*, 44–50. [CrossRef]
109. Arif, M.; Jan, M.T.; Khan, M.Q.; Saeed, M.; Khan, N.U. Biochar improves growth, physiology, and ornamental quality of Calendula (*Calendula officinalis* L.). *J. Plant Nutr.* **2017**, *40*, 272–281.
110. Barão, L.; Alaoui, A.; Ferreira, C.; Basch, G.; Schwilch, G.; Geissen, V.; Sukkel, W.; Lemesle, J.; Garcia-Orenes, F.; Morugán-Coronado, A. Assessment of promising agricultural management practices. *Sci. Total Environ.* **2019**, *649*, 610–619. [CrossRef]
111. Boulet, A.K.; Alarcão, C.; Ferreira, C.; Kalantari, Z.; Veiga, A.; Campos, L.; Ferreira, A.; Hessel, R. Agro-ecological services delivered by legume cover crops grown in succession with grain corn crops in the Mediterranean region. *Open Agric.* **2021**, *6*, 609–626. [CrossRef]
112. Steenwerth, K.; Belina, K. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Appl. Soil Ecol.* **2008**, *40*, 359–369. [CrossRef]
113. Hartwig, N.L.; Ammon, H.U. Cover crops and living mulches. *Weed Sci.* **2002**, *50*, 688–699. [CrossRef]
114. Mohammed, A.; Oloyede, F.M.; Adeniran, O.M. Effect of cover cropping on soil properties and growth performance of basil (*Ocimum basilicum*) in a derived savanna ecology. *Acta Hortic.* **2020**, *1273*, 341–348. [CrossRef]
115. Ferreira, C.S.S.; Veiga, A.; Caetano, A.; Gonzalez-Pelayo, O.; Karine-Boulet, A.; Abrantes, N.; Keizer, J.; Ferreira, A.J.D. Assessment of the Impact of Distinct Vineyard Management Practices on Soil Physico-Chemical Properties. *Air Soil Water Res.* **2020**, *13*, 1–13. [CrossRef]
116. Wang, Q.; Klassen, W.; Li, Y. Cover crops and tillage systems influence tomato growth and yield via influencing soil health. *HortScience* **2004**, *39*, 1163–1166.
117. Steinmaus, S.J.; Elmore, C.L.M.; Smith, R.J. Reduced tillage and cover cropping impacts on soil conditions and yields in a California strawberry production system. *HortScience* **2008**, *43*, 2089–2094.
118. Narjary, B.; Aggarwal, P.; Singh, A.; Chakraborty, D.; Singh, R. Water availability in different soils in relation to hydrogel application. *Geoderma* **2012**, *187*, 94–101. [CrossRef]
119. Chen, Y.-C.; Chen, Y.-H. Thermo and pH-responsive methylcellulose and hydroxypropyl methylcellulose hydrogels containing K2SO4 for water retention and a controlled-release water-soluble fertilizer. *Sci. Total Environ.* **2019**, *655*, 958–967. [CrossRef]
120. Iftime, M.M.; Ailiesei, G.L.; Ungureanu, E.; Marin, L. Designing chitosan based eco-friendly multifunctional soil conditioner systems with urea controlled release and water retention. *Carbohydr. Polym.* **2019**, *223*, 115040. [CrossRef]
121. Islam, M.R.; Xue, X.; Mao, S.; Zhao, X.; Eneji, A.E.; Hu, Y. Superabsorbent polymers (SAP) enhance efficient water use and reduce soil erosion in the Loess Plateau of China. *Agric. Water Manag.* **2011**, *98*, 1297–1306. [CrossRef]
122. Naderi, R.; Ahmadi, S.H.; Zarebanadkouki, M.; Meunier, F. Hydrogel application to sandy soil reduces the water stress of lettuce under deficit irrigation. *J. Agric. Food Chem.* **2016**, *64*, 8381–8390. [CrossRef]
123. Zhanga, X.; Kangb, S.; Lia, F.; Zhang, L. Effects of soil hydrogels on soil moisture and performance of rain-fed peach trees. *Sci. Hortic.* **2007**, *116*, 164–169. [CrossRef]
124. Ciampittiello, M.; Marchetto, A.; Boggero, A. Water Resources Management under Climate Change: A Review. *Sustainability* **2024**, *16*, 3590. [CrossRef]
125. Silva WTL da Oliveira FL de Silva MM da Lima, L.A.; Lima, M.A.C. Hydrogels increase the survival and water status of landscape plants under drought conditions. *Agric. Water Manag.* **2018**, *202*, 119–126. [CrossRef]
126. Christou, A.; Beretsou, V.G.; Iakovides, I.C.; Karaolia, P.; Michael, C.; Benmarhnia, T.; Chefetz, B.; Donner, E.; Gawlik, B.M.; Lee, Y.; et al. Sustainable wastewater reuse for agriculture. *Nat. Rev. Earth Environ.* **2024**, *5*, 504–521. [CrossRef]
127. Keilmann-Gondhalekar, D.; Hu, H.-Y.; Chen, Z.; Tayal, S. The Emerging Environmental Economic Implications of the Urban Water-Energy-Food (WEF) Nexus: Water Reclamation with Resource Recovery in China, India, and Europe. *Environ. Sci.* **2021**, *12*, 56–61. [CrossRef]
128. Ofori, S.; Puškáčová, A.; Růžičková, I.; Wanner, J. Treated wastewater reuse for irrigation: Pros and cons. *Sci. Total Environ.* **2021**, *760*, 144026. [CrossRef]
129. Amori, P.; Mierzwa, J.; Bertelt-Hunt, S.; Guo, B.; Saroj, D. Germination and growth of horticultural crops irrigated with reclaimed water after biological treatment and ozonation. *J. Clean. Prod.* **2022**, *336*, 130173. [CrossRef]
130. Mishra, S.; Kumar, R.; Kumar, M. Use pf treated sewage or wastewater as na issigation water for agricultural purposes—Environmental, health and economic impacts. *Total Environ. Res. Themes* **2023**, *6*, 100051. [CrossRef]
131. Zheng, Y.; He, J.; Huang, G.; Zhou, Z.; Miao, B. The effects of irrigation and fertilization on the growth and yield of culinary herbs in a controlled environment. *Agric. Water Manag.* **2013**, *123*, 20–30.
132. Oliveira, M.; Nunes, M.; Barreto Crespo, M.T.; Silva, A.F. The environmental contribution to the dissemination of carbapenem and (fluoro)quinolone resistance genes by discharged and reused wastewater effluents: The role of cellular and extracellular DNA. *Water Res.* **2020**, *182*, 116011. [CrossRef] [PubMed]
133. Murrell, K.A.; Teehan, P.D.; Dorman, F.L. Determination of contaminants of emerging concern and their transformation products in treated-wastewater irrigated soil and corn. *Chemosphere* **2021**, *281*, 130735. [CrossRef] [PubMed]
134. Leitão, I.A.; Van Schaik, L.; Iwasaki, S.; Ferreira, A.J.D.; Geissen, V. Accumulation of airborne microplastics on leaves of different tree species in the urban environment. *Sci. Total Environ.* **2024**, *948*, 174907. [CrossRef]
135. Kötke, D.; Gandrass, J.; Bento, C.P.M.; Ferreira, C.S.S.; Ferreira, A.J.D. Occurrence and environmental risk assessment of pharmaceuticals in the Mondego River (Portugal). *Helyion* **2024**, *10*, e34825. [CrossRef]

136. REGULATION (EU) 2020/741, "REGULATION (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on Minimum Requirements for Water Reuse. *Off. J. Eur. Union* **2019**, *177*, 32–55. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0741 (accessed on 21 March 2024).
137. Emongor, V.E.; Ramolemana, G.M. Treated sewage effluent (water) potential to be used for horticultural production in Botswana. *Phys. Chem. Earth* **2004**, *29*, 1101–1108. [CrossRef]
138. Yalin, D.; Craddock, H.A.; Assouline, S.; Mordechay, E.B.; Ben-Gal, A.; Bernstein, N.; Chaudhry, R.M.; Chefetz, B.; Fatta-Kassinos, D.; Gawlik, B.M.; et al. Mitigating risks and maximizing sustainability of treated wastewater reuse for irrigation. *Water Res. X* **2023**, *21*, 100203. [CrossRef]
139. Minhas, P.S.; Ramos, T.B.; Ben-Gal, A.; Pereira, L.S. Coping with salinity in irrigated agriculture: Crop evapotranspiration and water management issues. *Agric. Water. Manag.* **2020**, *227*, 105832. [CrossRef]
140. Abou-Shady, A.; Siddique, M.S.; Yu, W. A Critical Review of Recent Progress in Global Water Reuse during 2019–2021 and Perspectives to Overcome Future Water Crisis. *Environments* **2023**, *10*, 159. [CrossRef]
141. Rizzo, L.; Gernjak, W.; Krzeminski, P.; Malato, S.; McArdell, C.S.; Sanchez Perez, J.A.; Schaar, H.; Fatta-Kassinos, D. Best available technologies and treatment trains to address current challenges in urban wastewater reuse for irrigation of crops in EU countries. *Sci. Total Environ.* **2020**, *710*, 136312. [CrossRef] [PubMed]
142. Bahri, A. Water reuse in Tunisia: Stakes and prospects. *Water Sci. Technol.* **2002**, *45*, 25–33.
143. Jiménez, B. Irrigation in developing countries using wastewater. *Int. Rev. Environ. Strateg.* **2006**, *6*, 229–250.
144. Al-Jayyousi, O.R. Greywater reuse: Towards sustainable water management. *Desalination* **2003**, *156*, 181–192. [CrossRef]
145. Hosney, H.; Tawfik, M.H.; Duker, A.; van der Steen, P. Prospects for treated wastewater reuse in agriculture in low- and middle-income countries: Systematic analysis and decision-making trees for diverse management approaches. *Environ. Dev.* **2023**, *46*, 100849. [CrossRef]
146. Libutti, A.; Gatta, G.; Gagliardi, A.; Vergine, P.; Pollice, A.; Beneduce, L.; Disciglio, G.; Tarantino, E. Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions. *Agric. Water Manag.* **2018**, *196*, 1–14. [CrossRef]
147. Nahim-Granados, S.; Martínez-Piernas, A.B.; Rivas-Ibanez, G.; Plaza-Bolanos, P.; Oller, I.; Malato, S.; Pérez, J.A.S.; Agüera, A.; Polo-López, M.I. Solar processes and ozonation for fresh-cut wastewater reclamation and reuse: Assessment of chemical, microbiological and chlorosis risks of raw-eaten crops. *Water Res.* **2021**, *203*, 117532. [CrossRef]
148. Abdelraouf, R.E. Reuse of Fish Farm Drainage Water in Irrigation. In *Unconventional Water Resources and Agriculture in Egypt. The Handbook of Environmental Chemistry*; Negm, A., Ed.; Springer: Cham, Switzerland, 2017; Volume 75. [CrossRef]
149. Schoor, M.; Arenas-Salazar, A.P.; Parra-Pacheco, B.; García-Trejo, J.F.; Torres-Pacheco, I.; Guevara-González, R.G.; Rico-García, E. Horticultural Irrigation Systems and Aquacultural Water Usage: A Perspective for the Use of Aquaponics to Generate a Sustainable Water Footprint. *Agriculture* **2024**, *14*, 925. [CrossRef]
150. Cordeiro, S.; Ferrario, F.; Pereira, H.Z.; Ferreira, F.; Matos, J.S. Water Reuse, a Sustainable Alternative in the Context of Water Scarcity and Climate Change in the Lisbon Metropolitan Area. *Sustainability* **2023**, *15*, 12578. [CrossRef]
151. Zolghadr-Asli, B.; McIntyre, N.; Djordjevic, S.; Farmani, R.; Pagliero, L. The sustainability of desalination as a remedy to the water crisis in the agriculture sector: An analysis from the climate-water-energy-food nexus perspective. *Agric. Water Manag.* **2023**, *286*, 108407. [CrossRef]
152. Gikas, P.; Angelakis, A.N. Water resources management in Crete and in the Aegean Islands, with emphasis on the utilization of non-conventional water sources. *Desalination* **2009**, *248*, 1049–1064. [CrossRef]
153. Martínez-Alvarez, V.; Martin-Gorriz, B.; Soto-García, M. Seawater desalination for crop irrigation—A reviewof current experiences and revealed key issues. *Desalination* **2016**, *381*, 58–70. [CrossRef]
154. Gil, J.; González, R.; Sánchez-Molina, J.; Berenguel, M.; Rodríguez, F. Reverse osmosis desalination for greenhouse irrigation: Experimental characterization and economic evaluation based on energy hubs. *Desalination* **2023**, *574*, 117281. [CrossRef]
155. Carr, M.K. *Advances in Irrigation Agronomy: Plantation Crops*; Cambridge University Press: Cambridge, UK, 2012; Volume 317.
156. Nikolaou, G.; Neocleous, D.; Christou, A.; Kitta, E.; Katsoulas, N. Implementing Sustainable Irrigation in Water-Scarce Regions under the Impact of Climate Change. *Agronomy* **2020**, *10*, 1120. [CrossRef]
157. Kang, J.; Hao, X.; Zhou, H.; Ding, R. An integrated strategy for improving water use efficiency by understanding physiological mechanisms of crops responding to water deficit: Present and prospect. *Agric. Water Manag.* **2021**, *255*, 107008. [CrossRef]
158. Ferreira, C.S.S.; Kašanin-Grubin, M.; Destouni, G.; Soares, P.; Harrison, M.; Kikuchi, R.; Kalantari, Z. Freshwater: Management Principles for Sustainability under the Climate Emergency. In *Environmental Sustainability in the Mediterranean Region—Challenges and Solutions*; Ferreira, C.S.S., Destouni, G., Kalantari, Z., Eds.; Springer Nature: Berlin/Heidelberg, Germany, 2024; *in press*.
159. Singh, R.; Singh, B. Effect of different irrigation methods on growth and yield of mint (*Mentha arvensis* L.). *J. Herbs Spices Med. Plants* **1992**, *1*, 45–51.
160. Devitt, D.A.; Morris, R.L. Water use of landscape plants in an arid environment. *HortScience* **2007**, *42*, 68–74. [CrossRef]
161. Hamilton, A.; Boland, A.; Stevens, D.; Kelly, J.; Radcliffe, J.; Ziehrl, A.; Dillon, P.; Paulin, B. Position of the Australian horticultural industry with respect to the use of reclaimed water. *Agric. Water Manag.* **2005**, *71*, 181–209. [CrossRef]
162. Fereres, E.; Evans, R.G. Irrigation of fruit trees and vines: Principles and practices. *Irrig. Agric. Crop.* **2006**, *33*, 781–808.
163. Strik, B.C.; Buller, G. The impact of early cropping on subsequent growth and yield of highbush blueberry. *HortScience* **2005**, *40*, 1998–2001. [CrossRef]

164. Simonne, E.H.; Hochmuth, G.J.; Dukes, M.D.; Pitts, D.J. *Irrigation Management for Vegetable Crops in Florida*; University of Florida IFAS Extension: Homestead, FL, USA, 2005.
165. Simonne, E.H.; Hochmuth, G.J. *Irrigation Management for Culinary Herbs*; University of Florida IFAS Extension: Homestead, FL, USA, 2011.
166. McDonald, E.M.; Linde, C. The impact of sprinkler irrigation on the development of foliar diseases in horticultural crops. *Australas. Plant Pathol.* **2022**, *31*, 117–123.
167. Senapti, S.; Santosh, D.; Pholane, L. Techno economic feasibility of drip irrigation for vegetable cultivation. *Int. J. Agric. Sci.* **2021**, *17*, 636–643. [CrossRef]
168. Zhang, J.; Xiang, L.; Liu, Y.; Jing, D.; Zhang, L.; Liu, Y.; Li, W.; Wang, X.; Li, T.; Li, J. Optimizing irrigation schedules of greenhouse tomato based on a comprehensive evaluation model. *Agric. Water Manag.* **2024**, *295*, 108741. [CrossRef]
169. Sebastian, K.; Bindu, B.; Rafeekher, M. Performance of papaya variety 'Surya'under fertigation and foliar nutrition. *Plant Sci. Today* **2021**, *8*, 718–726. [CrossRef]
170. Seema Dahiya, R.; Prakash, R.; Roohi Sheoran, H.S. Drip Irrigation as a Potential Alternative to Traditional Irrigation Method for Saline Water Usage in Vegetable Crops- A Review. *Int. J. Econ. Plants* **2022**, *9*, 115–120.
171. Wen, S.; Cui, N.; Wang, Y.; Gong, D.; Xing, L.; Wu, Z.; Zhang, Y.; Zhao, L.; Fan, J.; Wang, Z. Optimizing deficit drip irrigation to improve yield, quality, and water productivity of apple in Loess Plateau of China. *Agric. Water Manag.* **2024**, *296*, 108798. [CrossRef]
172. Chen, Y.; Zhang, J.-H.; Chen, M.-X.; Zhu, F.-Y.; Song, T. Optimizing water conservation and utilization with a regulated deficit irrigation strategy in woody crops: A review. *Agric. Water Manag.* **2023**, *289*, 108523. [CrossRef]
173. Shahnazari, A.; Liu, F.; Andersen, M.N.; Jacobsen, S.E.; Jensen, C.R. Effects of partial root-zone drying on yield, tuber size, and water use efficiency in potato under field conditions. *Field Crop. Res.* **2007**, *100*, 117–124. [CrossRef]
174. Giuliani, M.M.; Nardella, E.; Gagliardi, A.; Gatta, G. Deficit irrigation and partial root-zone drying techniques in processing tomato cultivated under Mediterranean climate conditions. *Sustainability* **2017**, *9*, 2197. [CrossRef]
175. Yactayo, W.; Ramírez, D.A.; Gutiérrez, R.; Mares, V.; Posadas, A.; Quiroz, R. Effect of partial root-zone drying irrigation timing on potato tuber yield and water use efficiency. *Agric. Water Manage.* **2013**, *123*, 65–70. [CrossRef]
176. Consoli, S.; Stagno, F.; Vanella, D.; Boaga, J.; Cassiani, G.; Roccuzzo, G. Partial root-zone drying irrigation in orange orchards, effects on water use and crop production characteristics. *Europ. J. Agron.* **2017**, *82*, 190–202. [CrossRef]
177. Loveys, B.; Stoll, M.; Davies, W. Physiological approaches to enhance water use efficiency in agriculture: Exploiting plant signalling in novel irrigation practice. In *Water Use Efficiency in Plant Biology*; Wiley: Hoboken, NJ, USA, 2004; pp. 113–141.
178. Savic, S.; Stikic, R.; Zaric, V.; Vucelic-Radovic, B.; Jovanovic, Z.; Marjanovic, M.; Djordjevic, S.; Petkovic, D. Deficit irrigation technique for reducing water use of tomato under polytunnel conditions. *J. Cent. Eur. Agric.* **2011**, *12*, 597–607. [CrossRef]
179. Faci, J.M.; Blanco, O.; Medina, E.T.; Martínez-Cob, A. Effect of post veraison regulated deficit irrigation in production and berry quality of autumn royal and crimson table grape cultivars. *Agric. Water Manage.* **2014**, *134*, 73–83. [CrossRef]
180. Bourgault, M.; Madramootoo, C.A.; Webber, H.A.; Stulina, G.; Horst, M.G.; Smith, D.L. Effects of deficit irrigation and salinity stress on common bean (*Phaseolus vulgaris* L.) and mungbean [*Vigna radiata* (L.) Wilczek] grown in a controlled environment. *J. Agron. Crop. Sci.* **2010**, *196*, 262–272. [CrossRef]
181. Oron, G.; DeMalach, J.; Hoffman, Z.; Cibotaru, R. Subsurface microirrigation with effluent. *J. Irrig. Drain. Eng.* **1991**, *117*, 25–36. [CrossRef]
182. Ayars, J.; Phene, C.; Hutmacher, R.; Davis, K.; Schoneman, R.; Vail, S.; Mead, R. Subsurface drip irrigation of row crops: A review of 15 years of research at the Water Management Research Laboratory. *Agric. Water Manag.* **1999**, *42*, 1–27. [CrossRef]
183. Brown, M.; Bondurant, J.; Brockway, C. Subsurface trickle irrigation management with multiple cropping. *Trans. ASAE* **1981**, *24*, 1482–1489. [CrossRef]
184. Lamm, F.R.; Stone, K.; Dukes, M.; Howell, T.; Robbins, J.; Mecham, B. Emerging technologies for sustainable irrigation: Selected papers from the 2015 ASABE and IA irrigation symposium. *Trans. ASABE* **2015**, *59*, 155–161. [CrossRef]
185. Strock, J.S.; Dell, C.J.; Schmidt, J.P. Drainage water management for water quality protection. *J. Soil Water Conserv.* **2007**, *62*, 144A–153A. [CrossRef]
186. Ayars, J.E.; Christen, E.W.; Hornbuckle, J. Controlled drainage for improved water management in arid regions irrigated agriculture. *Agric. Water Manag.* **2006**, *86*, 128–139. [CrossRef]
187. Feset, S.E.; Strock, J.S.; Sands, G.R.; Birr, A.S. Controlled drainage to improve edge-of-field water quality in southwest Minnesota, USA. In Proceedings of the 9th International Drainage Symposium Held Jointly with CIGR and CSBE/SCGAB Proceedings, Québec City, QC, Canada, 13–16 June 2010; p. 1.
188. Drury, C.F.; Tan, C.S.; Reynolds, W.D.; Welacky, T.W.; Calder, W.; McLaughlin, N.B. Reducing nitrate loss in tile drainage water with cover crops and water-table management systems. *J. Environ. Qual.* **2009**, *38*, 1193–1204. [CrossRef] [PubMed]
189. Incrocci, L.; Thompson, R.B.; Fernandez-Fernandez, M.D.; De Pascale, S.; Pardossi, A.; Stanghellini, C.; Rouphael, Y.; Gallardo, M. Irrigation management of European greenhouse vegetable crops. *Agric. Water Manag.* **2020**, *242*, 106393. [CrossRef]
190. Koukounaras, A. Advanced greenhouse horticulture: New technologies and cultivation practices. *Horticulturae* **2020**, *7*, 1. [CrossRef]
191. García-Ruiz, J.M.; López-Bermúdez, F.; Jordán, A. The effects of soil erosion and sediment transport on soil fertility and plant productivity. *Agriculture* **2017**, *7*, 119.
192. Incrocci, L.; Massa, D.; Pardossi, A. New trends in the fertigation management of irrigated vegetable crops. *Horticulturae* **2017**, *3*, 37. [CrossRef]

193. Khan, S.; Purohit, A.; Vadsaria, N. Hydroponics: Current and future state of the art in farming. *J. Plant Nutr.* **2020**, *44*, 1515–1538. [CrossRef]
194. Almaguer-Vargas, G.; Alcántar-González, G.; Osuna-Ceja, M. Production of hydroponic strawberry (Fragaria x ananassa Duch.) in response to electrical conductivity of the nutrient solution. *Agrociencia* **2008**, *42*, 641–652.
195. Lee, S.K.; Lee, J.H. Effect of hydroponic nutrient solution concentration on the growth and yield of cucumber in a plant factory system. *Hortic. Environ. Biotechnol.* **2015**, *56*, 33–39. [CrossRef]
196. Carrubba, A.; Militello, M. Growing peppermint (*Mentha piperita* L.) in hydroponics: A review. *J. Med. Plants Res.* **2013**, *7*, 3021–3029.
197. Pomoni, D.I.; Koukou, M.K.; Vrachopoulos, M.G.; Vasiliadis, L. A review of hydroponics and conventional agriculture based on energy and water consumption, environmental impact, and land use. *Energies* **2023**, *16*, 1690. [CrossRef]
198. Zhang, M.; Han, Y.; Li, D.; Xu, S.; Huang, Y. Smart Horticulture as an Emerging Interdisciplinary Field Combining Novel Solutions: Past Development, Current Challenges, and Future Perspectives. *Hortic. Plant J.* **2023**. [CrossRef]
199. O'Neill, M.P.; Dobrowolski, J.P. Water and agriculture in a changing climate. *HortScience* **2011**, *46*, 155–157. [CrossRef]
200. Xudayev, I.; Fazliev, J.S.; Ayusupova, A. Water saving up-to-date irrigation technologies. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *868*, 12–14. [CrossRef]
201. Muleke, A.; Harrison, M.T.; Eisner, R.; Voil, P.; Yanotti, M.; Liu, K.; Monjardino, M.; Yin, X.; Wang, W.; Nie, J.; et al. Sustainable intensification with irrigation raises profit despite burgeoning climate emergency. *Plants People Planet* **2023**, *5*, 368–385. [CrossRef]
202. Lephondo, A.; Telukdariea, A.; Muniena, I.; Onkonkwoa, U.; Vermeulena, A. The Outcomes of Smart Irrigation System using Machine Learning to minimize water usage within the Agriculture Sector Itumeleng. *Procedia Comput. Sci.* **2024**, *237*, 525–532. [CrossRef]
203. Ludwig-Ohm, S.; Hildner, P.; Isaak, M.; Dirksmeyer, W.; Schattenberg, J. The contribution of Horticulture 4.0 innovations to more sustainable horticulture. *Procedia Comput. Sci.* **2023**, *217*, 465–477. [CrossRef]
204. Keates, O. Actionable insights for horticulture supply chains through advanced IoT analytics. *Procedia Comput. Sci.* **2023**, *217*, 1631–1640. [CrossRef]
205. Singh, D.; Biswal, A.; Samanta, D.; Singh, V.; Kadry, S.; Khan, A.; Nam, Y. Smart high-yield tomato cultivation: Precision irrigation system using the Internet of Things. *Front. Plant Sci.* **2023**, *14*, 1239594. [CrossRef]
206. Bwambale, E.; Abagale, F.K.; Anornu, G.K. Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. *Agric. Water Manag.* **2022**, *260*, 107324. [CrossRef]
207. Kaburuan, E.R.; Jayadi, R. A Design of IoT-based Monitoring System for Intelligence Indoor Micro-Climate Horticulture Farming in Indonesia. *Procedia Comput. Sci.* **2019**, *157*, 459–464. [CrossRef]
208. Chen, Y. The design of intelligent drip irrigation network control system. In Proceedings of the 2011 International Conference on Internet Technology and Applications, Wuhan, China, 16–18 August 2011; pp. 1–3. [CrossRef]
209. Zhang, F.; Zhang, Y.; Weidang, L.; Gao, Y.; Gong, Y.; Cao, J. 6G-Enabled Smart Agriculture: A Review and Prospect. *Electronics* **2022**, *11*, 2845. [CrossRef]
210. Jiménez, B.; Asano, T. *Water Reuse: An International Survey of Current Practice, Issues and Needs*; IWA Publishing: London, UK, 2008. [CrossRef]
211. Zinkernagel, J.; Maestre-Valero, J.F.; Seresti, S.Y.; Intrigliolo, D.S. New technologies and practical approaches to improve irrigation management of open field vegetable crops. *Agric. Water Manag.* **2020**, *242*, 106404. [CrossRef]
212. Yao, S.; Merwin, I.A.; Bird, G.W.; Abawi, G.S.; Thies, J.E. Orchard floor management practices that build soil quality and improve tree performance. *HortScience* **2005**, *40*, 2101–2106.
213. Leão, T.; Costa, B.; Bufon, V.; Aragón, F. Using time domain reflectometry to estimate water content of three soil orders under savanna in Brazil. *Geoderma Reg.* **2020**, *21*, e00280. [CrossRef]
214. Restuccia, R. Quick Guide: Soil Moisture Sensors. 2021. Available online: https://jainsusa.com/blog/quick-guide-soil-moisture-sensors/ (accessed on 18 March 2024).
215. Pardossi, A.; Incrocci, L. Traditional and new approaches to irrigation scheduling in vegetable crops. *HortTechnology* **2011**, *21*, 309–313. [CrossRef]
216. Li, Y.; Liu, P.; Li, B. Water and fertilizer integration intelligent control system of tomato based on internet of things. In Proceedings of the Cloud Computing and Security: 4th International Conference, ICCCS 2018, Haikou, China, 8–10 June 2018; Revised Selected Papers, Part VI 4. Springer International Publishing: Berlin/Heidelberg, Germany, 2018; pp. 209–220.
217. Zhang, L.L.; Kong, G.L. Design of farmland irrigation water quality monitoring and control system based on DSP and ZigBee. *Agric. Mech. Res.* **2021**, *43*, 229–232.
218. Kumar, V.; Sharma, K.; Kedam, N.; Patel, A.; Kate, T.; Rathnayake, U. A comprehensive review on smart and sustainable agriculture using IoT technologies. *Smart Agric. Techn.* **2024**, *8*, 100487. [CrossRef]
219. Zhu, R.; Hu, T.; Zhang, Q.; Zeng, X.; Zhou, S.; Wu, F.; Liu, Y.; Wang, Y. A stomatal optimization model adopting a conservative strategy in response to soil moisture stress. *J. Hydrol.* **2023**, *617*, 128931. [CrossRef]
220. Mpakairi, K.; Dube, T.; Sibanda, M.; Mutanga, O. Remote sensing crop water productivity and water use for sustainable agriculture during extreme weather events in South Africa. *Int. J. Appl. Earth Obs. Geoinf.* **2024**, *129*, 103833. [CrossRef]
221. Zhang, M.; Xu, S.; Han, Y.; Li, D.; Yang, S.; Huang, Y. High-throughput horticultural phenomics: The history, recent advances and new prospects. *Comput. Electron. Agric.* **2023**, *213*, 108265. [CrossRef]
222. Khormizi, H.Z.; Malamiri, H.R.G.; Ferreira, C.S.S. Estimation of Evaporation and Drought Stress of Pistachio Plant Using UAV Multispectral Images and a Surface Energy Balance Approach. *Horticulturae* **2024**, *10*, 515. [CrossRef]

223. Ge, Y.; Atefi, A.; Zhang, H.; Miao, C.; Ramamurthy, R.K.; Sigmon, B.; Yang, J.; Schnable, J.C. High-throughput analysis of leaf physiological and chemical traits with VIS–NIR–SWIR spectroscopy: A case study with a maize diversity panel. *Plant Methods* **2019**, *15*, 66. [CrossRef] [PubMed]
224. Bhandari, S.; Raheja, A.; Chaichi, M.; Green, R.; Do, D.; Pham, F.; Ansari, M.; Wolf, J.G.; Sherman, T.M.; Espinas, A. Effectiveness of UAV-based remote sensing techniques in determining lettuce nitrogen and water stresses. In Proceedings of the 14th International Conference on Precision Agriculture, Montreal, QC, Canada, 24–27 June 2018; pp. 1066403–1066415. [CrossRef]
225. Klem, K.; Zahora, J.; Zemek, F.; Trunda, P.; Tůma, I.; Novotna, K.; Hodanova, P.; Rapantova, B.; Hanus, J.; Vavríkova, J.; et al. Interactive effects of water deficit and nitrogen nutrition on winter wheat. Remote sensing methods for their detection. *Agric. Water Manag.* **2018**, *210*, 171–184. [CrossRef]
226. Barros, T.; Conde, P.; Gonçalves, G.; Premebida, C.; Monteiro, M.; Ferreira, C.S.S.; Nunes, U. Multispectral vineyard segmentation: A deep learning comparison study. *Comput. Electron. Agric.* **2022**, *195*, 106782. [CrossRef]
227. Lu, Z.; Gao, J.; Wang, Q.; Ning, Z.; Tan, X.; Lei, Y.; Zhang, J.; Zou, J.; Wang, L.; Yang, C.; et al. Light energy utilization and measurement methods in crop production. *Crop. Environ.* **2024**, *3*, 91–100. [CrossRef]
228. Brajović, M.; Vujović, S.; Đukanović, S. An overview of smart irrigation software. In Proceedings of the 2015 4th Mediterranean Conference on Embedded Computing (MECO), Budva, Montenegro, 14–18 June 2015; pp. 353–356. [CrossRef]
229. Sutcliffe, C.; Pui, L.; Gush, M.; Griffiths, A. Engagement in sustainable horticulture is associated with greater perceived health benefits amongst gardeners. *Urban For. Urban Green.* **2024**, *98*, 128423. [CrossRef]
230. Katzin, D.; Marcelis, L.; van Henten, E.; van Mourik, S. Heating greenhouses by light: A novel concept for intensive greenhouse production. *Biosyst. Eng.* **2023**, *230*, 242–276. [CrossRef]
231. Ariesen-Verschuur, N.; Verdouw, C.; Tekinerdogan, B. Digital Twins in greenhouse horticulture: A review. *Comput. Electron. Agric.* **2022**, *199*, 107183. [CrossRef]
232. Zeng, Y.; Chen, C.; Lin, G. Practical application of an intelligent irrigation system to rice paddies in Taiwan. *Agric. Water Manag.* **2023**, *280*, 108216. [CrossRef]
233. Mason, B.; Rufí-Salís, M.; Parada, F.; Gabarrell, X.; Gruden, C. Intelligent urban irrigation systems: Saving water and maintaining crop yields. *Agric. Water Manag.* **2019**, *226*, 105812. [CrossRef]
234. Dalal, A.; Bourstein, R.; Haish, N.; Shenhar, I.; Wallach, R.; Moshelion, M. Dynamic Physiological Phenotyping of Drought-Stressed Pepper Plants Treated With "Productivity-Enhancing" and "Survivability-Enhancing" Biostimulants. *Front. Plant Sci.* **2019**, *10*, 905. [CrossRef] [PubMed]
235. Mir, R.; Reynolds, M.; Pinto, F.; Khan, M.; Bhat, M. High-throughput phenotyping for crop improvement in the genomics era. *Plant Sci.* **2019**, *282*, 60–72. [CrossRef]
236. Gupta, A.; Rayeen, F.; Mishra, R.; Tripathi, M.; Pathak, N. Nanotechnology applications in sustainable agriculture: An emerging eco-friendly approach. *Pant Nano Biol.* **2023**, *4*, 100033. [CrossRef]
237. Wahab, A.; Muhammad, M.; Munir, A.; Abdi, G.; Zaman, W.; Ayaz, A.; Khizar, C.; Reddy, S.P.P. Role of Arbuscular Mycorrhizal Fungi in Regulating Growth, Enhancing Productivity, and Potentially Influencing Ecosystems under Abiotic and Biotic Stresses. *Plants* **2023**, *12*, 3102. [CrossRef]
238. Grieves, M.; Vickers, J. Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. In *Transdisciplinary Perspectives on Complex Systems*; Springer: Cham, Switzerland, 2017; pp. 85–113. [CrossRef]
239. Yang, L.; Xia, L.; Zeng, Y.; Han, Q.; Zhang, S. Grafting enhances plants drought resistance: Current understanding, mechanisms, and future perspectives. *Front. Plant Sci.* **2022**, *13*, 1015317. [CrossRef]
240. Coskun, Ö.F. The Effect of Grafting on Morphological, Physiological and Molecular Changes Induced by Drought Stress in Cucumber. *Sustainability* **2023**, *15*, 875. [CrossRef]
241. Wang, S.; Xu, J. Excessive Water and Drainage Management in Agriculture: Disaster, Facilities Operation and Pollution Control. *Water* **2022**, *14*, 2500. [CrossRef]
242. Antolini, F.; Tate, E.; Dalzell, B.; Young, N.; Johnson, K.; Hawthorne, P. Flood Risk Reduction from Agricultural Best Management Practices. *J. Am. Water Resour. Assoc.* **2019**, *56*, 161–179. [CrossRef]
243. Ahmed, F.; Raffi, M.; Ismail, M.; Juraimi, A.; Rahim, H.; Asfaliza, R.; Latif, M. Waterlogging Tolerance of Crops: Breeding, Mechanism of Tolerance, Molecular Approaches, and Future Prospects. *Biomed Res. Int.* **2012**, *2013*, 1–10. [CrossRef]
244. Najeebullah, M.; Parveen, N.; Chishti, S.; Amin, E.; Shahzadi, F.; Aleem, S. Mitigation of temperature, drought and viral diseases stress in vegetable crops. *Int. J. Biosci.* **2020**, *16*, 164–172.
245. Mustafa, G.; Komatsu, S. Toxicity of heavy metals and metal-containing nanoparticles on plants. Biochim. Biophys. *Acta Proteins Proteom.* **2016**, *1864*, 932–944. [CrossRef] [PubMed]