water

MDPI

Article

Distribution Uniformity in Intensive Horticultural Systems of Almería and Influence of the Production System and Water Quality

Juana Isabel Contreras [1,*], José Roldán-Cañas [2], Maria Fatima Moreno-Pérez [2], Pedro Gavilán [3], David Lozano [3] and Rafael Baeza [1]

[1] Institute of Research and Training in Agriculture and Fishery (IFAPA), Junta of Andalucia, La Mojonera, 04630 Almería, Spain; rafaelj.baeza@juntadeandalucia.es
[2] Department of Agronomy, Campus de Rabanales, University of Córdoba, 14003 Córdoba, Spain; jroldan@uco.es (J.R.-C.); mfatima@uco.es (M.F.M.-P.)
[3] Institute of Research and Training in Agriculture and Fishery (IFAPA), Junta of Andalucia, Alameda del Obispo, 14003 Córdoba, Spain; pedrod.gavilan@juntadeandalucia.es (P.G.); david.lozano@juntadeandalucia.es (D.L.)
* Correspondence: juanai.contreras@juntadeandalucia.es; Tel.: +34-950-156-453

Abstract: The high productivity and efficiency of the use of irrigation water that characterizes greenhouse horticultural crops can be affected by poor irrigation distribution uniformity. The objective of this work was to estimate the average irrigation distribution uniformity (DU) of the greenhouses in Almería, determining the influence of the irrigation water quality as well as the production system on this uniformity. A prospective study was carried out in which commercial farms were selected that used different water qualities (groundwater vs. reclaimed) with different production systems (organic vs. conventional/integrated). The average irrigation distribution uniformity in the greenhouses of Almería was 80%. The farms with organic production systems presented a drastic DU reduction with respect to conventional farms (48% vs. 88%). The DU of the irrigation water presented in commercial farms irrigated with reclaimed water presented a lower DU than those irrigated with groundwater (76% vs. 86%). The distribution of irrigation depth of water in the greenhouses showed slight variations (from 3.2 to 2.9 mm) depending on the emitter position, with the highest values being at the head of the sub-main pipe and dripper line and the lowest at the end of the sub-main pipe and dripper line. The depth of water values was very close to the theoretical average of 3 mm. Water quality affects the distribution pattern of the depth of water in greenhouses. Installations irrigated with reclaimed water showed greater oscillation of the water depth within the sub-unit, varying from 3.6 to 2.0 mm, although the average depth was located close to the theoretical depth (3 mm). The production system affected the distribution of the depth of water—in the organic system, the depth underwent greater variation depending on the position of the emitter in the sub-unit, ranging from 1.7 to 3.3 mm. In addition, within this production system, the median depth of water was close to 2.5 mm, lower than the theoretical depth (3 mm), which denoted a certain generalized filling that was accentuated at the end of the dripper line and sub-main pipe.

Keywords: greenhouse; organic production system; conventional/integrated production system; depth of water; groundwater; reclaimed wastewater

check for updates

Citation: Contreras, J.I.; Roldán-Cañas, J.; Moreno-Pérez, M.F.; Gavilán, P.; Lozano, D.; Baeza, R. Distribution Uniformity in Intensive Horticultural Systems of Almería and Influence of the Production System and Water Quality. *Water* **2021**, *13*, 233. https://doi.org/10.3390/w13020233

Received: 23 December 2020
Accepted: 12 January 2021
Published: 19 January 2021

1. Introduction

Agriculture is by far the main user of water in the world. Irrigated agriculture accounts for 69% of water withdrawals, which can rise to more than 90% in some regions. Around 20% of total water used globally is from groundwater sources (renewable or not), and this share is rising rapidly, particularly in dry areas [1]. Drip irrigation, also called trickle irrigation or micro-irrigation, is a localized irrigation method that slowly and frequently provides water directly to the plant root zone [2]. Due to limited water resources and environmental consequences of common irrigation systems, drip irrigation technology has received more attention and played an important role in agricultural production. Therefore, the use of drip irrigation systems is rapidly increasing around the world. Moreover, irrigation management also needs to be efficient in order to help reduce the environmental impact and to promote the sustainable use of resources [3–5].

One of the main problems that localized irrigation systems present and that can affect water use efficiency and crop productivity is the low uniformity of irrigation distribution, fundamentally associated with the clogging of drippers. Some research showed the importance of flow distribution uniformity on growth, productivity, and the quality of different crops, such as cotton [6], maize [7], onion [8], and zucchini [9], among others. However, other studies have shown irrigation system uniformity does not have a significant influence on the yield of some crops [10,11]. In any case, the decrease in uniformity is associated with greater water consumption, since water is irrigated above the needs of the crop in order to ensure that the most unfavorable points receive the necessary water.

Since the beginning of 1990, organic farming in Spain has been on the increase, both in terms of surface area as well as the number of operators. According to official figures, in 2016 there were more than 2,000,000 ha dedicated to this activity and almost 40,000 registered operators [12].

These numbers place Spain at the head of organic production in Europe. In Andalusia, growth has been even more significant, monopolizing almost 50% of the total national surface dedicated to organic farming. Greenhouse horticultural crops have not remained on the sidelines of this trend. In the province of Almería, about 2000 producers are currently registered as organic farmers [13]. In the process of conversion to organic farming, producers adapt their cultivation techniques. Soil fertility management and fertilization is one of the most modified aspects. The contributions of organic fertilizers in soil have increased and in fertigation the synthetic fertilizers have been replaced by natural nutrients, normally organic and of low solubility. The low solubility of these products can affect irrigation facilities, generating emitter plugging and low distribution uniformity [14].

Another factor that can affect distribution uniformity is the source of the irrigation water. Specifically, when surface water and reclaimed urban wastewater are used, it is possible that they also generate emitter clogging in the localized irrigation systems, since these waters can cause clogging of a physical, biological, and chemical type [15]. The situation of structural water deficit that affects the intensive agriculture of southeastern Spain has forced the incorporation of new water sources that complement the traditional underground water used in these areas, with desalinated sea water being the most widespread alternative source. In the Bajo Andarax region in Almería, reclaimed water obtained from purified urban waste from the city of Almería has been used during many years for the irrigation of horticultural crops [16–18] and a noticeable area of greenhouses (2500 ha) are sustained almost exclusively with this type of water.

Greenhouse horticultural crops are characterized by high levels of efficiency and productivity of irrigation water and nutrients applied [3,19], and practically all the farms have irrigation systems. However, these indices may be affected by poor distribution uniformity of fertigation. Different previous prospective studies show that there is a significant percentage of facilities with a low distribution uniformity (DU) level [20,21]. This low uniformity may be associated with different factors, such as water quality [15], terrain slope [22,23], and production systems [3].

The objective of this work was to determine distribution uniformity of average irrigation within greenhouses in Almería, determining the influence of the irrigation water quality and the production system on this uniformity.

2. Materials and Methods

A prospective study was carried out in which commercial greenhouses that used different water qualities (underground vs. reclaimed) with different production systems (organic vs. conventional) were selected.

2.1. Area Description

The study area was located on the coast of the Almería province, in southeastern Spain, within the 3 main production sub-areas for greenhouse horticultural crops in the province (Figure 1).

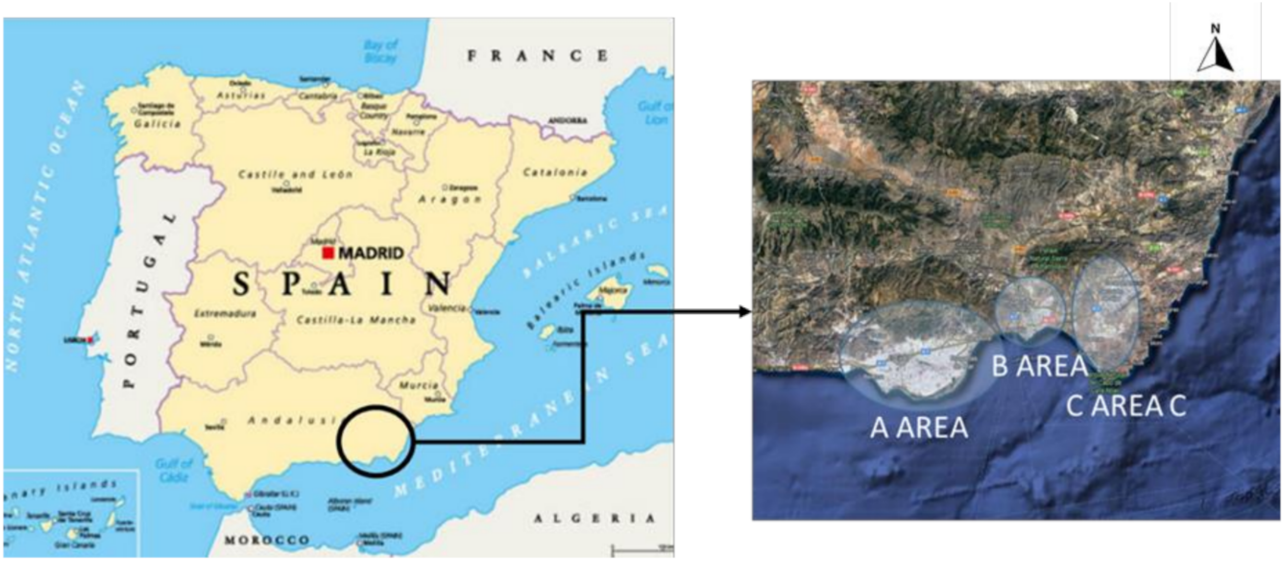

Figure 1. Study areas included in the trial.

The 3 study sub-areas included in the trial cover a total of 29,800 ha of greenhouses out of the total of 32,000 ha in the province of Almería [24]. Sub-area A is the so-called Campo de Dalías region, the largest and oldest greenhouse area on the Spanish Mediterranean coast, concentrating 21,300 ha. Sub-area B is called Bajo Andarax and in this area 3000 ha is concentrated; it has the peculiarity that almost all reclaimed water is used for irrigation. Sub-area C is the denominated Campo de Nijar where 5500 ha is concentrated, and it is where the highest percentage of greenhouses in an organic production system is concentrated. The organic production system is regulated by the European regulation of organic farming (REGULATION (EU) 2018/848).

In the study area the climate is Mediterranean with mild winters and low annual rainfall; the average annual temperature and rainfall are 18 °C and 220 mm, respectively. The greenhouses are Almería-type (low-cost structures covered with plastic film, without active climate control systems, sand-mulched soil, and a drip irrigation system with non-compensating emitters) located on practically flat plots. The average surface area of the greenhouses is 7500 m^2 in sub-area A and 7900 m^2 in sub-areas B and C [25].

2.2. Experimental Design

A stratified random sampling was carried out, classifying the greenhouse surface (number of hectares) into 2 groups according to the production system (conventional/integrated or organic), and in another 2 groups according to the quality of irrigation water used (groundwater or reclaimed water). In both cases, a stratification with proportional allocation was carried out (the number of sample elements of each stratum was directly proportional to the size of the stratum within the population).

To determine the size of each stratum both for the production system and for water quality, we used updated data on the greenhouse surface area in Almería, registering a total of 32,000 ha [24]. This area is distributed according to the production system, with 3000 ha in organic production and 29,000 ha in conventional/integrated. Furthermore, it depends on the type of irrigation water used, with 2500 ha irrigated with reclaimed water and 29,500 ha irrigated with groundwater.

The sample size was determined in order to achieve a confidence level of 95% and a margin of error of 10%. The 32,000 ha of greenhouses with an average individual greenhouse area of 7500 m^2 [25] were considered, resulting in a total of 42,000 sites. In addition, it was considered that each greenhouse should have an average of 1.5 irrigation units with an average surface of 5000 m^2 per unit [26]. In each unit, the average number of sub-units was 5, with an average area of 1000 m^2 per sub-unit [26], which is the common and representative size, resulting in a total of 320,000 irrigation sub-units.

The average length of drip lines was 25 m, and 90% of the greenhouse irrigation system had a pressure variation coefficient of less than 0.12, with 62% of the installations having a pressure variation coefficient of less than 0.06 [26]. Regarding the filtering system, 95% of the greenhouses had screen filters, with 105 µm filtration level [26].

A total of 88 greenhouses were sampled depending on the production system (80 conventional/integrated and 8 organic), and 88 greenhouses on the basis of the type of irrigation water used (81 with groundwater and 7 with reclaimed water). The choice of greenhouses was carried out randomly with random distribution within the production areas.

Sampling was performed during 4 summer seasons, after the end of the growing cycles, once the harvest remnants were removed from the greenhouse. The last season was fulfilled in the summer of 2018. Due to the large number of greenhouses sampled, it was necessary to distribute it over 4 summer seasons.

The greenhouses chosen are Almería-type (described above) and they had the standard irrigation framework of the greenhouse horticultural production system, 2 emitters m^{-2} of 3 L h^{-1}, and a drip irrigation system with non-compensating emitters.

The reclaimed water used was provided by the "Cuatro Vegas" Irrigation District, distributor of reclaimed urban wastewater of the city of Almeria. The water source came from the urban wastewater reclaiming plant in the city of Almería (Southern Spain) (36°50′ N, 2°27′ W). It has been estimated that this plant treats 15 hm^3 $year^{-1}$. In this plant, the primary treatment of wastewater is carried out by decanting the solids and breaking down the fatty emulsions. The next stage is the secondary treatment (biological) by activated sludge. After these treatments, the water is sent to the tertiary treatment plant, located 6 km away from the first plant. In this second treatment plant, the water undergoes a treatment using sodium hypochlorite, followed by a treatment a filtration system composed of 20 sand and anthracite filters of 2500 mm diameter that decreases the concentration of suspended solids and turbidity of the water. The chemical characteristics of the reclaimed water were suitable for irrigation (HCO_3^-: 6.6 mM, Cl^-: 8.9 mM, N–NO_3^-: 0.3 mM, $H_2PO_4^-$: 0.4 mM, N–NH_4^+: 3.3 mM, Ca^{2+}: 4.8 mM, Mg^{2+}: 4.2 mM, Na^+: 9.1 mM, K^+: 0.6 mM). The water had low concentrations of inorganic contaminants (Cr: 14.22 µg L^{-1}, As: 4.84 µg L^{-1}, Cd: 0.04 µg L^{-1}, Pb: 1.79 µg L^{-1}, Ni: 3.08 µg L^{-1}, Mn: 13.17 µg L^{-1}, Cu: 9.82 µg L^{-1}, Zn: 37.76 µg L^{-1}). The average values of the physical and chemical parameters of the reclaimed water during the evaluation seasons are shown in Table 1.

Table 1. Physical and chemical parameters of reclaimed water. Seven samples analyzed during the irrigation evaluations.

Parameter	Average Value	Range
Turbidity (NTU)	4.2	3.8–4.4
Suspended solids (mg L^{-1})	3.8	3.5–4.0
pH	7.8	7.7–7.9
Biochemical oxygen demand—BOD5 (mg O_2 L^{-1})	<5	<5
Chemical oxygen demand—COD (mg O_2 L^{-1})	22.1	20.1–25.3
Electrical conductivity—EC (dS m^{-1})	1.89	1.80–1.93

The emitters presented a manufacturing variation coefficient of less than 0.05, complying with the ISO 9261: 2004 standard that establishes that the emitters must have a manufacturing variation coefficient of the analyzed sample that does not exceed 0.07. For this reason, the influence on uniformity is very low.

2.3. Determinations

2.3.1. Uniformity Distribution (DU)

The data were obtained by direct measurement of the flows emitted by the irrigation installation drippers in the selected greenhouses (Figure 2). Experimental data were collected at approximately 9 a.m.

Figure 2. Image of data collection in a greenhouse.

The established procedure for the estimation of DU was:

- Selection of the greenhouse.
- Selection within the greenhouse installation of the most representative irrigation unit (in the case where there were more than 1) being considered as the most representative the one that met the average values (size closest to 5000 m^2).
- Selection of the most representative sub-unit within that unit (size closest to 1000 m^2) (Figure 3).
- Performing flow measurements at the 16 established points according to the Merriam and Keller [27] methodology.

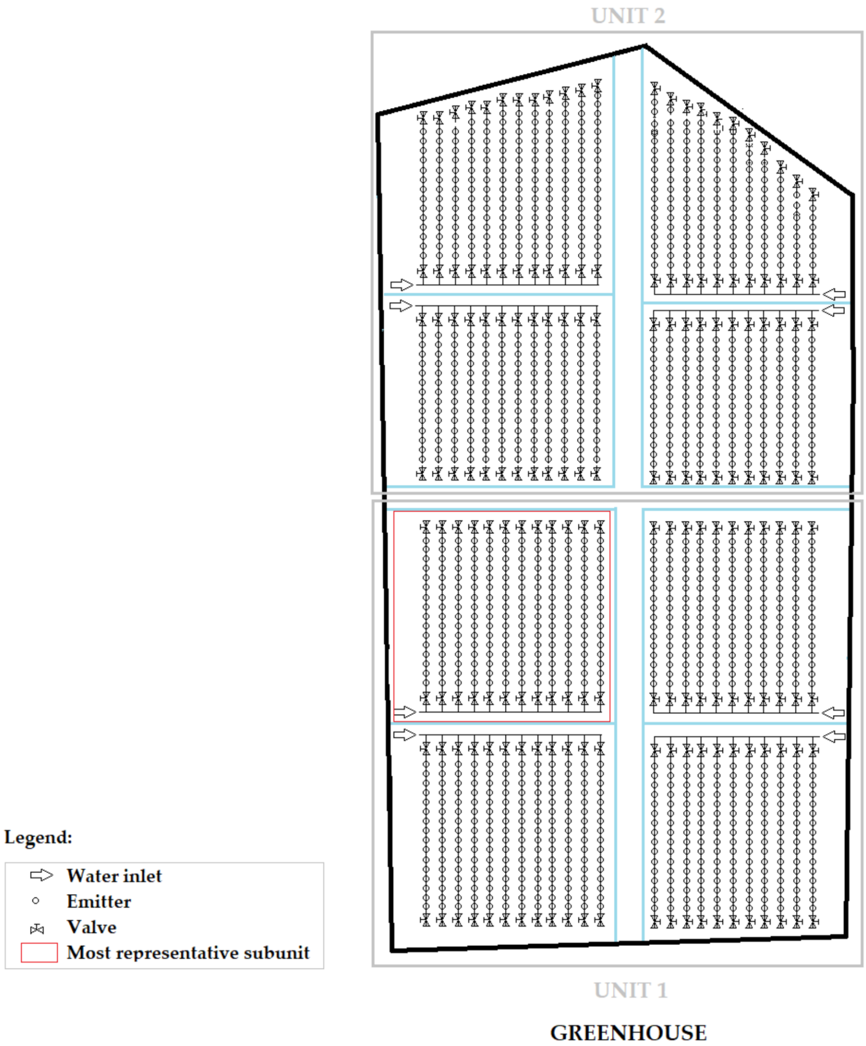

Figure 3. Choosing the most representative irrigation sub-unit in a greenhouse (size closer to 1000 m^2). The blue lines represent the sub-units.

The DU was estimated by using the classical methodology proposed by Merriam and Keller [28], who proposed the following Equation (1):

$$DU = (q25\%/qm) \times 100 \tag{1}$$

where q25% is the average discharge of the 25% of the emitters with the lowest flow rate (L h^{-1}), and qm is the average discharge of all emitter tested (L h^{-1}).

The classification of the distribution uniformity coefficient (DU) by Merriam and Keller [28] is shown in Table 2.

Table 2. Classification of distribution uniformity (DU) coefficient by Merriam and Keller [28].

DU	Classification
>95%	Excellent
85%–95%	Good
80%–85%	Fair
70%–80%	Poor
<70%	Unacceptable

2.3.2. Distribution of Irrigation Water (DW)

The flow data obtained directly in the greenhouse were transformed to describe and model spatial patterns of the depth of water applied in the greenhouses during a 30 min irrigation period, which is the average irrigation applied in the study area. A geostatistical analysis including the spatial autocorrelation and the interpolation of values at unsampled locations is performed in this study.

2.4. Statistical Analysis

The DU data were analyzed by a randomized uni-factorial design, considering the production systems and the water quality used for irrigation (one-way ANOVA). For production systems, 2 treatments (organic and conventional-integrated) were considered, with the farm's DU being the repetition. For water quality used for irrigation, 2 treatments (groundwater and reclaimed water) were considered, with the farm´s DU being the repetition. The data were also analyzed using a geostatistical analysis for the distribution of irrigation water. Kriging techniques were used to describe and model spatial patterns. With this procedure, we estimated the value of the variable studied in a two-dimensional region that was sampled in 16 locations. For each variable studied, the sample variogram was determined, as well as the estimated model variogram, along with the semi-variance in each lag. Statistical analyses were performed with Statgraphics 18 (2020 Statgraphics Technologies, Inc. The Plains, VA, USA).

3. Results

3.1. Distribution Uniformity (DU)

3.1.1. Average Distribution Uniformity (ADU)

The DU in the greenhouses of Almería was 79.8% (Table 3). The average uniformity of the Almería greenhouses was poor according to the Merrian and Keller classification (Table 1). Table 3 shows the distribution of the greenhouses according to the DU that they presented. More than 56% of the greenhouses presented a DU greater than 85%. To explain whether the influence was from the production system or the type of water, we analyzed them both separately.

Table 3. Average distribution uniformity (%) in Almería greenhouse and distribution (%) of greenhouses according to the DU and according to the Merrian and Keller classification.

		DU (%)	Classification
	Average	**79.8**	
Greenhouse Distribution (%)			
9.1		>95	Excellent
47.2		85–95	Good
7.4		80–85	Fair
14.2		70–80	Poor
22.2		<70	Unacceptable

Confidence level of 95% and a margin of error of 10%.

3.1.2. Distribution Uniformity According to the Production System

The DU values according to the production system are shown in Table 4. There was a statistically significant effect of the production system, with the greenhouses with the conventional system showing a much higher uniformity than those presented by organic systems (88% vs. 48%). The average uniformity of the greenhouses with conventional systems was good (88%) according to the Merrian and Keller classification (Table 1). Nevertheless, greenhouses with an organic production system presented an unacceptable uniformity (48%) according to the Merrian and Keller classification (Table 1).

Table 4. Distribution uniformity (%) depending on the production system.

	DU (%)	Standard Deviations
System	*	
Conventional/integrated	87.8 a	17.0
Organic	48.0 b	24.5

* Significance for $p \leq 0.05$; Different letters describes significant differences between production system.

3.1.3. Distribution Uniformity According to the Water Quality

The DU in terms of the type of water used is shown in Table 5. There were no statistically significant differences associated with the water quality, although the greenhouses with groundwater showed a higher uniformity than those presented by greenhouses irrigated with reclaimed water (86% vs. 76%). The average uniformity of the greenhouses that use reclaimed water was poor (76%) according to the Merrian and Keller classification (Table 1). However, greenhouses that used groundwater presented a good uniformity (86%) according to the Merrian and Keller classification (Table 1).

Table 5. Distribution uniformity (%) depending on the water quality.

	DU (%)	Standard Deviations
Quality water	ns	
Groundwater	86.3 a	15.5
Reclaimed	76.4 a	20.4

ns: no significance for $p \leq 0.05$; different letters describe significant differences between water quality.

3.2. Distribution of Irrigation Water in the Greenhouse (DW)

3.2.1. Average of Irrigation Water in the Greenhouse (ADW)

The average distribution of irrigation water in the greenhouses of Almería (Figure 4) presented a variation of 12% depending on the position of the emitter in the sub-main pipe and the dripper line, varying from 3.26 to 2.88 mm for a 30 min irrigation events with 2 drippers m^{-2} and 3 L h^{-1} emitter^{-1}. Most of the surface receive a 3 mm irrigation depth, however, the emitters located near the water inlet receive a greater volume than those further away from it. The differences in flow were greater in the dripper line than in the sub-main pipe.

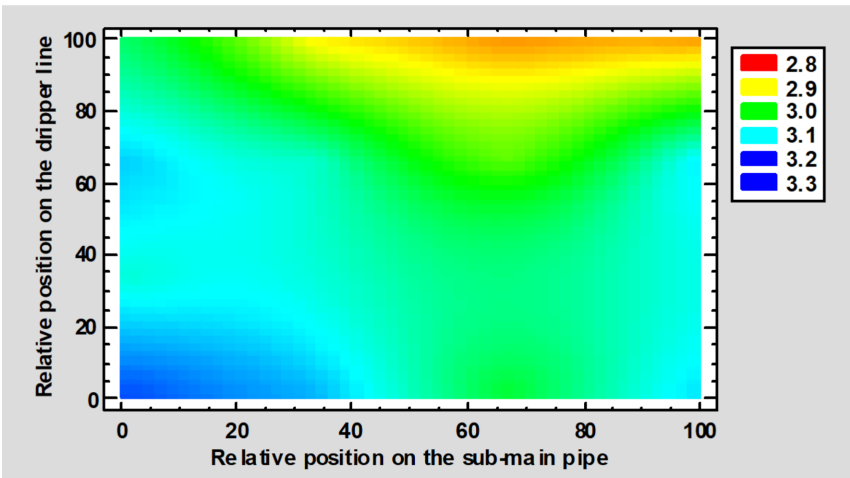

Figure 4. Kriging map for distribution of irrigation water (mm) in two dimensions in the greenhouses of Almería, where 0 corresponds to of the dripper line or sub-main pipe and 100 corresponds to the last emitter of the dripper line or sub-main pipe. Exponential adjustment with R^2 = 98.38%, root mean square error (RMSE) = 0.00107, and $p \leq 0.05$.

3.2.2. Distribution of Irrigation Water in the Greenhouse According to the Production System

Figure 5 shows the depth of water in conventional-integrated (a) and organic (b) production systems. In the conventional production system (Figure 5a), the irrigation sheet underwent less variation, ranging from 3.3 to 2.9 mm. The highest flow rates were registered at the head of the sub-unit and drip holders and the lowest at the tail of the sub-unit and drip holders. In the organic system, the sheet underwent great variation depending on the position of the emitter in the sub-unit, ranging from 2.0 to 2.9 mm. In addition, in this production system, the median depth was close to 2.5 mm, less than the theoretical plate (3 mm), which denoted a certain generalized water filling that was accentuated in the tail of the drip holders and gate holders (Figure 5b).

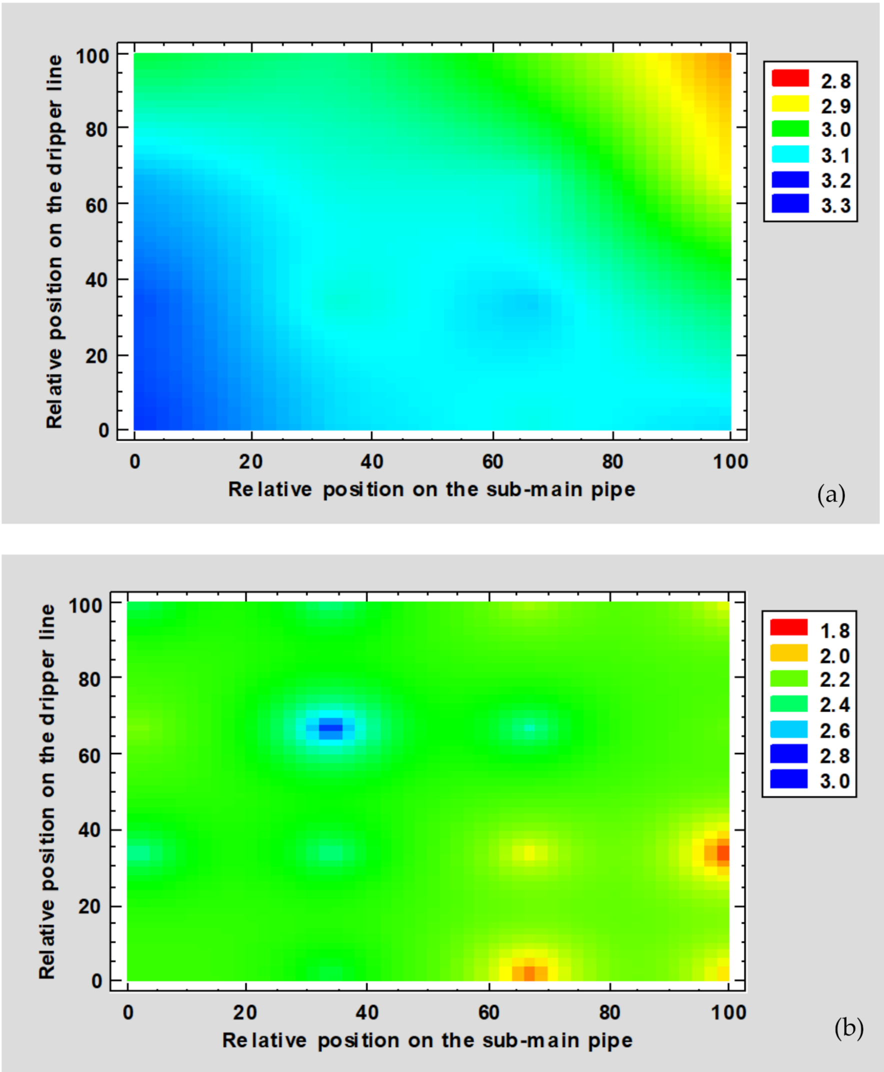

Figure 5. Kriging map for distribution of irrigation water (mm) in two dimensions in conventional/integrated (**a**) and organic (**b**) production systems of the greenhouses of Almería, where 0 corresponds to of the dripper line or sub-main pipe and 100 corresponds to the last emitter of the dripper line or sub-main pipe. Exponential adjustment with R^2 = 96.70%, root mean square error (RMSE) = 0.00122, and $p \leq 0.05$ for (**a**), and R^2 = 79.65%, root mean square error (RMSE) = 0.01879, and $p \leq 0.05$ for (**b**).

3.2.3. Distribution of Irrigation Water in the Greenhouse According to the Water Quality

Figure 6 shows the sheet of water as a function of the type of water used for irrigation: groundwater (a) and reclaimed water (b). In greenhouses that used groundwater, the irrigation sheet varied within the sub-unit between 3.25 and 2.95 mm (Figure 6a), registering the highest values at the head of the sub-unit and drip holders and the lowest at the tail of the sub-unit and drip holders. A similar pattern was registered with the use of reclaimed water, although the oscillation in the water layer was greater within the irrigation sub-unit, varying from 3.6 to 2.0 mm (Figure 6b), although the average depth was located close to the theoretical depth (3 mm).

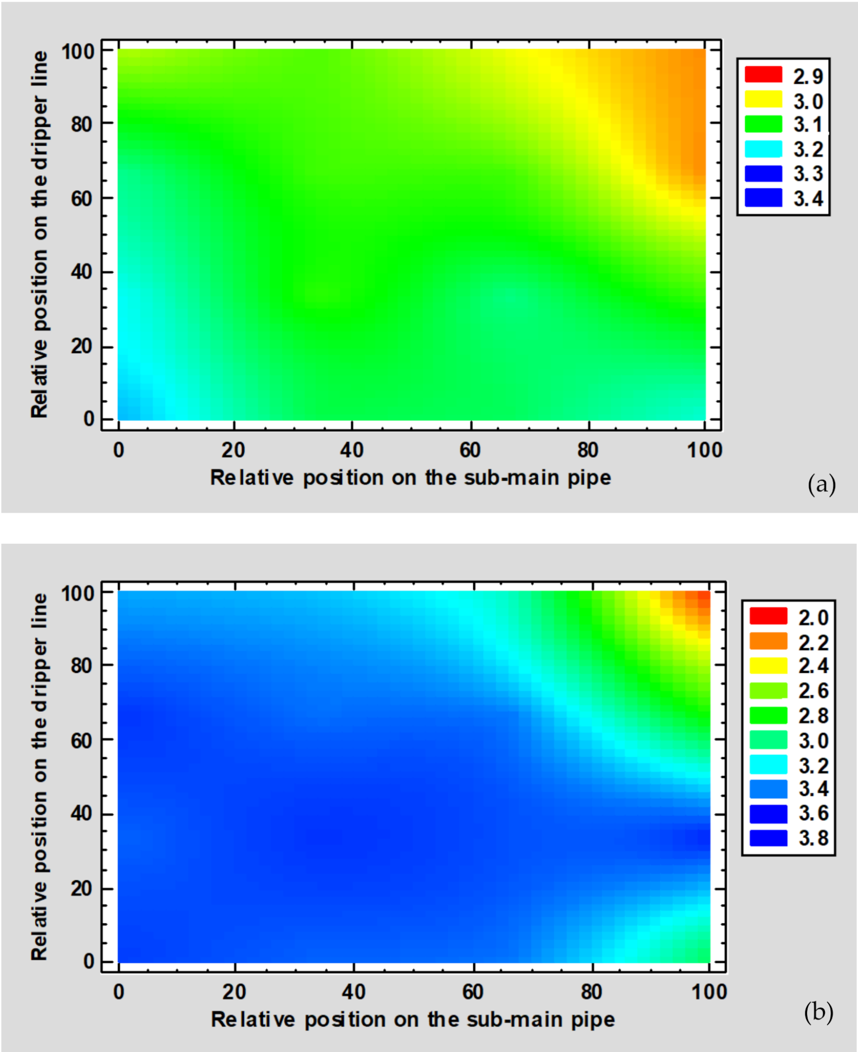

Figure 6. Kriging map for distribution of irrigation water (mm) in two dimensions in systems that use groundwater (**a**) and reclaimed (**b**) irrigation water of the greenhouses of Almería, where 0 corresponds to of the dripper line or sub-main pipe and 100 corresponds to the last emitter of the dripper line or sub-main pipe. Exponential adjustment with R^2 = 94.14%, root mean square error (RMSE) = 0.00102, and $p \leq 0.05$ (**a**), and R^2 = 96.78%, root mean square error (RMSE) = 0.01742, and $p \leq 0.05$ for (**b**).

4. Discussion

4.1. Distribution Uniformity (DU)

The average uniformity of the greenhouses in Almería was fair according to the Merrian and Keller classification, amounting to nearly 80%. The greenhouses that use groundwater, which occupy a significant surface area (29,500 ha), presented good uniformity (86%), as well as those that use the conventional or integrated production system (88%). However, greenhouses that use reclaimed water showed poor uniformity (76%) and those with an organic production system presented unacceptable uniformity (48%). The surface area of greenhouses in organic agriculture is still small in Almería (being 3000 ha) compared to the area of greenhouses in conventional and integrated production (29,000 ha) [24]. In some quality certifications for horticultural crops under shelter, such as integrated production, a minimum uniformity of 85% is required [27]. The average uniformity of the greenhouses evaluated in the conventional and integrated production system exceeded 85%.

The DU in greenhouses was affected by the production system. Greenhouses with the conventional system displayed a much higher uniformity than those presented by organic systems (88% vs. 48%). This difference in uniformity could be fundamentally associated with the products used in fertigation, which in the case of organic systems are of organic origin and mostly not soluble. These types of products are liable to produce greater seals in the irrigation emitters, since the physical and biological ones are added to the possible chemical seals [29–34]. Moreover, the restriction of the use of nitric acid in this production system for the cleaning of emitters and the scarce implantation of authorized substitutes has aggravated the problem.

Therefore, in organic production systems, it is necessary to find solutions that increase the DU. Applying fertilizers in depth so that they do not have to go through the irrigation system could be a solution. Moreover, the use of irrigation systems that are replaceable in each season could solve the problem. For example, the use of irrigation tapes that present high uniformity [35,36]. Thus, the study of the effectiveness of authorized products in organic agriculture that are effective in cleaning emitters, as well as the optimal doses, would be another possible line to develop. A preliminary study shows that the combination of citric acid and hydrogen peroxide can be effective in cleaning emitters that have been used in organic greenhouse production systems [37].

To solve this problem is of the utmost importance, because uniformity levels of that range (DU of 48%) can produce a reduction in crop productivity [6–9]. In fact, a study carried out recently in greenhouse cultivation of zucchini [9] showed that a DU of 50% greatly reduced production (between 44 and 45% reduction compared to a DU of 75 and 100%, respectively). In addition, a DU of 50% not only affected the production of the zucchini crop, but also reduced vegetative growth and modified the harvest index (determined as the ratio between generative dry biomass and total shoot dry biomass), significantly reducing it from 0.40 to 0.30 g g^{-1}, as well as the water use efficiency and the efficiency of the use of nutrients that were reduced in about 30% [9].

With respect to the type of water used, there were no statistically significant differences associated with water quality, although the greenhouses with groundwater showed a higher uniformity than those presented by greenhouses irrigated with reclaimed water (86% vs. 76%). This difference in uniformity could be associated with greater clogging produced by the composition of the irrigation water, since reclaimed water presents a higher concentration of suspended solids and organic components than water of from an underground origin. The results obtained are in accordance with the interest shown in recent worldwide investigations that study the effect of the use of reclaimed water on emitter obstruction from different approaches, analyzing the effect of water quality [15], emitter type [15,38], the effects on the variation of the microbial population on the bio-obstruction in the emitters [39], as well as the effect of the chlorination treatments of the reclaimed water on the bio-obstruction of the emitters [40]. However, 75% DU shows no effect on production according to different investigations [6,7,9].

4.2. Distribution of Irrigation Water in the Greenhouse (DW)

Regarding the average distribution of irrigation water in the greenhouse (ADW), the most common emitter and flow frame in the greenhouses of Almería is 2 drippers m^{-2} and 3 L h^{-1} $emitter^{-1}$ respectively [41]. For its part, the irrigation pulse usually oscillates between 20 and 40 min, which translates into theoretical water depths of 2 to 4 mm, the most common being 30 min (3 mm), which is the one used by the selected greenhouses in this experiment. The distribution of irrigation water in the greenhouses of Almería presented a slight variation (12%, corresponding to 0.36 mm) depending on the position of the emitter in the sub-main pipe and in the position of the dripper line, varying from 3.26 to 2.88 mm for a 30 min irrigation and 2 drippers m^{-2} and 3 L h^{-1} $emitter^{-1}$. Most of the surface receives 3 mm irrigation, however, the emitters located near the water inlet receive a greater volume than those at a further distance. The differences in flow were greater in the dripper line than in the sub-main pipe. These small differences were associated with the slight pressure differences (90% of the greenhouse irrigation installations had a pressure variation coefficient of less than 0.12, with 62% of the installations having a pressure variation coefficient of less than 0.06) that translate into a change in flow rate in the non-compensating emitters [42], which are those evaluated in the experiment, since the pattern it describes is similar to those that occur with the theoretical pressures in a greenhouse sub-unit.

The cultivation system also had an influence on the water distribution pattern in the greenhouse (Figure 5). Greenhouses with a conventional/integrated production system presented a fairly homogeneous water depth distribution, varying from 2.9 to 3.3 mm, when the theoretical depth to be applied was 3.0 mm. However, the organic production system showed a generalized reduction of the water layer, reducing it to 2.5 mm, also registering a great variation, from 2.0 to 2.9 mm. The irregular distribution that was observed in greenhouses with an organic production system was not only associated with pressure losses, as if it were, the water depth would be decreasing in both pipes, as observed in the case of integrated conventional production systems. This reduction and the great variation in organic production systems were associated with severe problems of partial clogging of emitters associated with the use of organic fertilizer products in fertigation [43]. It is assumed that in both cases the variations due to errors in dripper manufacture were the same.

The type of water used also had an influence on the pattern of water distribution, registering greater variation in irrigated greenhouses with reclaimed water. Greenhouses that used groundwater presented a very homogeneous water depth distribution, varying from 2.95 to 3.25 mm, when the theoretical depth to be applied was 3.0 mm. However, the greenhouses that used reclaimed water showed a great variation, from 3.6 to 2.0 mm, although the average depth of water was 3.0 mm. This greater variation could be associated with the partial clogging registered with this type of water at the ends of the pipes [16,38–40].

5. Conclusions

The average uniformity of greenhouses in Almería that do not use reclaimed water was good (86% DU), as was that of greenhouses with a conventional/integrated production system (88% DU). However, greenhouses with an organic production system presented a very low DU (48%), which is a significant problem to be solved since these uniformity values would drastically reduce the productivity of greenhouse horticultural crops. Greenhouses using reclaimed water also reduced DU (76%) but to a lesser extent.

The distribution of the depth of water of greenhouses in Almería with a conventional/integrated production system and those that use groundwater showed slight variations (from 3.2 to 2.9 mm) depending on their position, with the highest values being at the head of the tube holder and drip holders and the lower ones at the tail of the tube holder and drip holders. The water depth values were found to be very close to the theoretical average of 3 mm. Nonetheless, installations irrigated with reclaimed water showed greater oscillation of the water sheet within the sub-unit, varying from 3.6 to 2.0 mm, although the middle sheet was located close to the theoretical sheet (3 mm). In the organic system, the depth underwent greater variation depending on the emitter position in the sub-unit, ranging from 1.7 to 3.3 mm. In addition, in this production system, the median depth was close to 2.5 mm, lower than the theoretical plate (3 mm), which denotes a certain generalized filling that is accentuated in the end of the dripper line and sub-main pipe.

Knowing what real distribution uniformity Almería greenhouses present and how both production systems and water quality are affected is essential in order to be able to provide appropriate solutions when deficient uniformity is displayed, as is currently the case within organic production systems and to a lesser extent with the use of reclaimed water.

Author Contributions: Conceptualization and methodology, J.I.C. and R.B.; validation, formal analysis, investigation, resources, and data curation, J.I.C. and R.B.; writing—original draft preparation, J.I.C.; writing—review and editing, J.I.C., J.R.-C., and R.B.; supervision, R.B.; project administration, R.B.; funding acquisition, R.B.; data acquisition, validation and supervision, J.I.C., J.R.-C., M.F.M.-P., P.G., D.L. and R.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by European Regional Development Fund (ERDF), grand number A1122062U0, and the Agricultural Research and Training Institute of Andalusia (IFAPA), under project Technological Transfer for an Irrigation Sustainable. SAR, with code PP.TRA.TRA2019.006.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We thank Nicolás Del Castillo, Gema Cánovas, Pedro Berenger, and Dolores López, students of the University of Almería for their collaboration. We thank Nicholas Andrew Davies for the English language correction.

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

Abbreviations

The following abbreviations are used in this manuscript:
DU—distribution uniformity. DW—distribution of irrigation water. ADW—average of distribution of irrigation water.

References

1. UNESCO. *The United Nations World Water Development Report 2020—Water and Climate Change. World Water Assessment Programme*; UNESCO: Paris, France, 2020.
2. Evans, R.G. *Micro Irrigation*; 24106 North Bunn Roas Prosser; Washington State University, Irrigated Agriculture Research and Extension Center: Washington, DC, USA, 2002.
3. Contreras, J.I.; Alonso, F.; Cánovas, G.; Baeza, R. Irrigation management of greenhouse zucchini with different soil matric potential level. Agronomic and environmental effects. *Agric. Water Manag.* **2017**, *183*, 26–34. [CrossRef]
4. García-Caparrós, 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]
5. Lozano, D.; Ruiz, N.; Baeza, R.; Contreras, J.I.; Gavilán, P. Effect of Pulse Drip Irrigation Duration on Water Distribution Uniformity. *Water* **2020**, *12*, 2276. [CrossRef]
6. Guan, H.; Li, J.; Li, Y. Effects of drip system uniformity and irrigation amount on cotton yield and quality under arid conditions. *Agric. Water Manag.* **2013**, *124*, 37–51. [CrossRef]
7. Wang, J.; Li, J.; Guan, H. Evaluation of Drip Irrigation System Uniformity on Cotton Yield in an Arid Region using a Two-Dimensional Soil Water Transport and Crop Growth Coupling Model. *Irrig. Drain.* **2017**, *66*, 351–364. [CrossRef]
8. Pérez-Ortolá, M.; Daccache, A.; Hess, T.; Knox, J.W. Simulating impacts of irrigation heterogeneity on onion (*Allium cepa* L.) yield in a humid climate. *Irrig. Sci.* **2015**, *33*, 1–14. [CrossRef]
9. Contreras, J.I.; Baeza, R.; Alonso, F.; Cánovas, G.; Gavilán, P.; Lozano, D. Effect of Distribution Uniformity and Fertigation Volume on the Bio-Productivity of the Greenhouse Zucchini Crop. *Water* **2020**, *12*, 2183. [CrossRef]
10. Bordovsky, J.P.; Porter, D.O. Effect of Subsurface Drip Irrigation System Uniformity on Cotton Production in the Texas High Plains. *Appl. Eng. Agric.* **2008**, *24*, 465–472. [CrossRef]
11. Zhao, W.; Li, J.; Li, Y.; Yin, J. Effects of drip system uniformity on yield and quality of Chinese cabbage heads. *Agric. Water Manag.* **2012**, *110*, 118–128. [CrossRef]

12. Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA). Agricultura Ecológica. Estadísticas 2016. 2017. Available online: https://www.mapa.gob.es/es/alimentacion/temas/produccion-eco/estadisticas_ae_2016defin_tcm30-429288.pdf (accessed on 22 December 2020).
13. Sistema de Información Sobre la Producción Ecológica en Andalucía (SIPEA). Dirección General de Calidad, Industria Agroalimentaria y Producción Ecológica. *Junta de Andalucía.* 2018. Available online: https://ws142.juntadeandalucia.es/agriculturaypesca/roae/ (accessed on 5 April 2018).
14. Contreras, J.I.; Cánovas, G.; Alonso, F.; Lao, M.T.; Baeza, R. Aspectos Limitantes en el Manejo de la Fertilización en Agricultura Ecológica de Invernadero. In Proceedings of the X Seminario Agroecología. Cambio Climático y Agroturismo; Innovación Agroecológica y Cambio Climático, Orihuela (Alicante), Spain, 19–20 October 2017.
15. Baeza, R.; Contreras, J.I. Evaluation of Thirty-Eight Models of Drippers Using Reclaimed Water: Effect on Distribution Uniformity and Emitter Clogging. *Water* **2020**, *12*, 1463. [CrossRef]
16. García-Delgado, C.; Eymar, E.; Contreras, J.I.; Segura, M.L. Effects of fertigation with purified urban wastewater on soil and pepper plant (*Capsicum annuum* L.) production, fruit quality and pollutant contents. *Span. J. Agric. Res.* **2012**, *10*, 209. [CrossRef]
17. Segura, M.L.; París, J.I.C.; Plaza, B.M.; Lao, M.T. Assessment of the Nitrogen and Potassium Fertilizer in Green Bean Irrigated with Disinfected Urban Wastewater. *Commun. Soil Sci. Plant. Anal.* **2012**, *43*, 426–433. [CrossRef]
18. Contreras, J.I. Optimización de las Estrategias de Fertirrigacion de Cultivos Hortícolas en Invernadero Utilizando Aguas de Baja Calidad (Agua Salina Y Regenerada) en Condiciones del Litoral de Andalucia. Ph.D. Thesis, Universidad de Almería, Almeria, Spain, November 2014.
19. Nederhoff, E.; Stanghellini, C. Water Use Efficiency of Tomatoes. *J. Pract. Hydroponics Greenh.* **2010**, *115*, 52.
20. Baeza, R.; Gavilán, P.; Del Castillo, N.; Berenguel, P.; López, J.G. Programa de evaluación y asesoramiento en instalaciones de riego en invernadero con uso de dos fuentes distintas de agua: Subterránea y regenerada. In Proceedings of the XXVIII Congreso Nacional de Riegos, León, Spain, 15–17 June 2010; pp. 111–112.
21. Baeza, R.; Cánovas, G.; Alonso, F.; Contreras, J.I. Evaluación de las instalaciones de riego en cultivos hortícolas intensivos del sureste de Andalucía. In *El Agua en Andalucía. El Agua, Clave Medioambiental y Socioeconómica. Tomo II*; SIAGA; Instituto Geológico y Minero de España: Málaga, Spain, 2015.
22. Lozano, D.; Ruiz, N.; Gavilán, P. *Efecto de la Pendiente en la Calidad de un Riego Localizado. Formato Digital (e-Book)*; Consejería de Agricultura, Pesca y Desarrollo Rural, Instituto de Investigación y Formación Agraria y Pesquera (Junta de Andalucia): Córdoba, Spain, 2018; pp. 1–20.
23. Gavilán, P.; Ruiz, N.; Lozano, D. Innovación y cambio tecnológico en los sistemas agrarios intensivos mediterráneos. In *El Regadío en el Mediterráneo Español. Una Aproximación Multidimensional*, 1st ed.; Garrido, A., Pérez-Pastor, A., Eds.; Cajamar- Caja Rural: Almeria, Spain, 2019; Volume 38, pp. 181–206.
24. Consejería de Agricultura, Pesca y Desarrollo Rural. Cartografía de Invernaderos en Almería, Granada y Málaga. 2017, p. 24. Available online: https://www.juntadeandalucia.es/export/drupaljda/Cartografia%20_inv_AL_GR_MA_SEE.pdf (accessed on 5 April 2018).
25. Caracterización de los Invernaderos de Andalucia. 2015- Observatorio de Precious y Mercados. Agencia. AGAPA. Consejería de Agricultura Pesca y Desarrollo Rural. p. 113. Available online: http://www.juntadeandalucia.es/agriculturaypesca/observatorio/servlet/FrontController?action=DownloadS&table=12030&element=1586185&field=DOCUMENTO (accessed on 5 April 2018).
26. Del Castillo, N. Caracterización y Evaluación de las Instalaciones de Riego Localizado en la Comarca del Campo de Dalías. Diploma Thesis, Universidad de Almería, Almeria, Spain, September 2009.
27. Junta de Andalucia. Boletin oficial de la Junta de Andalucia-BOJA. Reglamento específico Orden 10.10.2007 (Boja nº 211 de 25.10.07). ORDEN de 10 de Octubre de 2007, por la que se Aprueba el Reglamento Específico de Producción Integrada de Cultivos Hortícolas Protegidos (Tomate, Pimiento, Berenjena, Judía, Calabacín, Pepino, Melón y Sandía). Available online: https://juntadeandalucia.es/boja/2007/211/boletin.211.pdf (accessed on 22 December 2020).
28. Merriam, J.L.; Keller, J. *Farm Irrigation System Evaluation: A Guide for Management*; UTAH State University: Logan, UT, USA, 1978.
29. Gilbert, R.; Nakayama, F.; Bucks, D.; French, O.; Adamson, K. Trickle irrigation: Emitter clogging and other flow problems. *Agric. Water Manag.* **1981**, *3*, 159–178. [CrossRef]
30. Pitts, D.J.; Haman, D.Z.; Smajstrla, A.G. *Causes and Prevention of Emitter Plugging in Micro Irrigation Systems*; Bulletin 258; Florida Cooperative Extension Service Institute of Food and Agricultural Sciences, University of Florida: Gainesville, FL, USA, 1990.
31. Coelho, R.D.; Resende, R.S. Biological clogging of Netafim's drippers and recovering process through chlorination impact treatment. In Proceedings of the 2001 ASAE Annual Meeting, Sacramento, CA, USA, 29 July–1 August 2001. [CrossRef]
32. Ravina, I.; Paz, E.; Sofer, Z.; Marm, A.; Schischa, A.; Sagi, G.; Yechialy, Z.; Lev, Y. Control of clogging in drip irrigation with stored treated municipal sewage effluent. *Agric. Water Manag.* **1997**, *33*, 127–137. [CrossRef]
33. Li, J.; Chen, L.; Li, Y. Comparison of Clogging in Drip Emitters During Application of Sewage Effluent and Groundwater. *Trans. ASABE* **2009**, *52*, 1203–1211. [CrossRef]
34. Baeza, R.; Contreras, J.I. Caracterización de las instalaciones de fertirriego utilizadas en cultivos hortícolas bajo abrigo de Almería. *Actas Hortic.* **2014**, *66*, 148–153.
35. París, J.C.; Expósito, L.G.; Fernández, G.C.; Cano, R.B. EFECTO DEL NÚMERO DE CICLOS DE USO EN LA UNIFORMIDAD DE DISTRIBUCIÓN DE CAUDAL EN CINTAS DE RIEGO. *XXXIII Congr. Nac. Riegos* **2015**, 468–474. [CrossRef]

36. Cano, R.B.; Sierra, A.Z.; López, F.A.; Guerrero, A.F.; París, J.C. Comportamiento de 13 Modelos de Cinta de Riego en Condiciones de Invernadero con Agua Regenerada. In Proceedings of the XXXIV Congreso Nacional de Riegos, Sevilla, Sevilla, 7–9 June 2016. [CrossRef]
37. Baeza, R.; Cánovas, G.; Contreras, J.I. Evaluación de productos desincrustantes para la limpieza de obturaciones biológicas y químicas en emisores de riego en agricultura ecológica. In Proceedings of the X Congreso SEAE. VI Encuentro Iberoamericano de Agroecología, Albacete, Spain, 26–29 September 2012. Available online: https://www.agroecologia.net/recursos/publicaciones/actas/cd-actas-xcongresoseae/actas/comunicaciones/37-desincrustantes-baeza.pdf (accessed on 22 December 2020).
38. Zhou, B.; Zhou, H.; Puig-Bargués, J.; Li, Y. Using an anti-clogging relative index (CRI) to assess emitters rapidly for drip irrigation systems with multiple low-quality water sources. *Agric. Water Manag.* **2019**, *221*, 270–278. [CrossRef]
39. Zhou, B.; Wang, T.; Li, Y.; Bralts, V. Effects of microbial community variation on bio-clogging in drip irrigation emitters using reclaimed water. *Agric. Water Manag.* **2017**, *194*, 139–149. [CrossRef]
40. Song, P.; Li, Y.; Zhou, B.; Zhou, C.; Zhang, Z.; Li, J. Controlling mechanism of chlorination on emitter bio-clogging for drip irrigation using reclaimed water. *Agric. Water Manag.* **2017**, *184*, 36–45. [CrossRef]
41. Baeza, R.; Salvatierra, B.; López, J.G.; Gavilan, P. Líneas de trabajo para la mejora de la eficiencia del uso del agua en Andalucia. Programa de evaluación de instalaciones de riego. In Proceedings of the V Congresso Internacional Ordenamento do Território, Lisbon, Portugal, 27–28 October 2010.
42. Reyes-Requena, R.; Baeza-Cano, R.; Cánovas-Fernández, G.; López-Segura, J.G.; Roldán-Cañas, J.; Moreno-Pérez, M.F. Determinación en laboratorio de las características hidráulicas de una selección de dieciséis modelos comerciales de emisores de riego localizado. *Ibérica* **2019**, *3*, 400.
43. Liu, L.; Niu, W.; Guan, Y.; Wu, Z.; Ayantobo, O.O. Effects of Urea Fertigation on Emitter Clogging in Drip Irrigation System with Muddy Water. *J. Irrig. Drain. Eng.* **2019**, *145*. [CrossRef]