*horticulturae*

Technical Note

# Water Use and Leaf Nutrient Status for Terraced Cherimoya Trees in a Subtropical Mediterranean Environment

**Victor Hugo Durán-Zuazo [1,*], Dionisio Franco Tarifa [2], Iván Francisco García-Tejero [3], Saray Gutiérrez Gordillo [3], Pedro Cermeño Sacristan [3] and Juan José Pertiñez Roldan [1]**

1. IFAPA Centro "Camino de Purchil". Camino de Purchil s/n, 18004 Granada, Spain; juanj.pertinez@juntadeandalucia.es
2. Ayto. de Almuñécar, Plaza de la Constitución 1, 18690 Almuñécar, Spain; dionitarifa@yahoo.es
3. IFAPA Centro "Las Torres-Tomejil", Carretera Sevilla-Alcalá del Río km 12,2, 41200 Alcalá del Río, Spain; ivanf.garcia@juntadeandalucia.es (I.F.G.-T.); saray.gutierrez@juntadeandalucia.es (S.G.G.); pedro.cermeno@juntadeandalucia.es (P.C.S.)

* Correspondence: victorh.duran@juntadeandalucia.es; Tel.: +34-671-532-861

Received: 26 April 2019; Accepted: 20 June 2019; Published: 23 June 2019

**Abstract:** Water scarcity in many semi-arid agricultural areas, in particular for the Mediterranean basin, is promoting changes in irrigated agriculture, with alternative strategies being introduced for water-use optimization. The coast of Granada and Malaga (Southeast Spain) is an economically important area for subtropical fruit cultivation. This intensively irrigated agriculture is characterized by requiring extra amounts of water and the adoption of sustainable practices to improve agricultural water management. A two-season experiment was conducted to assess (1) the water use in terraced cherimoya (*Annona cherimola* Mill. cv. Fino de Jete) orchards under conventional and organic production systems with drainage lysimeters, and (2) the impact on fruit yield and nutritional effects between the two considered production systems. Crop coefficient (*Kc*) values for cherimoya were 0.60–0.66, 0.64–0.71, and 0.48–0.62 at flowering, fruit set, and fruit growth, respectively. Fruit yield was similar in both systems, ranging from 47.1 for conventional to 44.1 kg tree$^{-1}$ for organic farming, averaging 13.2 and 12.3 t·ha$^{-1}$, respectively. No differences between these systems were observed in terms of leaf nutrient status, with variations in the N, P, and K contents during the different phenological stages. The N, P, and K lessen during flowering and fruit growth; the highest levels of these nutrients were fixed at harvest. These patterns were the opposite in Ca and Mg, ascribable to the antagonism between K and both Ca and Mg. Thus, these findings highlight the need to establish the optimal use of irrigation water with respect to crop requirements, thereby encouraging sustainable subtropical farming in terraces.

**Keywords:** *Annona cherimolia* Mill.; subtropical farming; water scarcity; leaf-nutrient content

## 1. Introduction

The reduction of available water resources has become a global problem, aggravated by climate change [1]. The problems arising under this scenario will be accentuated in the countries of the Mediterranean basin, where the increase in temperature will be even more pronounced, and rainfall will be reduced, both characterized by greater temporal and spatial variability [2]. These changes in climate, together with an increase in the atmospheric concentration of $CO_2$, will have direct adverse effects on ecosystems and agricultural production [3], especially regarding the availability and distribution of irrigation water [4,5]. In addition to temperature and rainfall, relative humidity is also expected to have a great influence on the water-use efficiency [6].

The Spanish government has promoted a change in water use based on a scenario that guarantees its availability and quality, and involves sustainable water management, support of reuse formulas, and modernization of irrigation, through the promotion of research into new technologies [7]. In this context, and according to the latest data from Encuesta sobre Superficies y Rendimientos de Cultivos (ESYRCE) [8], the irrigated area in Spain increased to 3,663,990 ha in 2017.

In Andalusia (South Spain), the total irrigated area amounted to 1,043,181 ha, and from this, a large part was surface water [8]. The average cost of water was about 0.12 €·$m^{-3}$, which is an average consumption per hectare of approximately 492 €·$ha^{-1}$. According to the Proyecto del Plan Hidrológico Nacional (PPHN) [9], the current water consumption for irrigation in the Mediterranean hydro-graphic basin is 814.8 $hm^3 \cdot y^{-1}$ (cubic hectometers per year), with an irrigation system efficiency of 74% and an unmet demand of 42.08 $hm^3 \cdot y^{-1}$. Thus, by 2027, consumption will be 846.3 $hm^3 \cdot y^{-1}$ with an incomplete demand of approximately 72.5 $hm^3 \cdot y^{-1}$. The last global update regarding water balances conducted in the framework of the Hydrological Plan indicates for the Mediterranean Hydrological Basin (MHB) highlighted an important deficit between the demands to be served and the available resources. This water shortage is even more serious if it considers the overexploitation of aquifers in such areas, and the limited margin available to increase the availability of surface water flows. This scenario causes a clear imbalance between the real possibilities of supply and demand, where the average consumption exceeds the water availability and, therefore, the optimization of irrigation will be crucial to attain the sustainability of agricultural systems.

In this deficit context, Spain is a unique country in Europe, hosting a significant amount of subtropical irrigated fruit crops. This sector has gradually been expanding in Andalusia, particularly along the Mediterranean coast since the first cherimoya trees (*Annona cherimolia* Mill.) were planted in the 1950s [10]. Spain is one of world's leaders in cherimoya fruit production (80%), with about 3200 hectares of land used and 40,000 tons being harvested. The largest areas of irrigated cherimoya plantations are located on the coasts of Granada (94%) and Malaga (5%), with 3102 ha and an average yield of 14.4 $t \cdot ha^{-1}$ [11].

These coastal areas are the exclusive commercial-scale producers in Europe and, therefore, irrigation is essential to guarantee their productivity. Most cherimoya plantations are distributed in flat areas. However, they are also in orchard terraces. The production using this latter method is more expensive due to pumping the irrigation water to higher levels in hilly areas. In this sense, the pressure on water resources has increased due to the competition with other sectors such as tourism. Within this context, understanding crop evapotranspiration ($ET_C$) is essential for optimization of water management, as precise predictions are needed to adjust irrigation volume and frequency to real crop water demand. Reported measurements of evapotranspiration and crop coefficients from mature cherimoya trees are scarce. In this line, from plant physiology and water-use perspectives, the impact of climate change on cherimoya trees will be significant [12,13].

Conventional intensive subtropical fruit production requires fertilization, often applying more plant nutrients than required by crops. Such excesses create a high risk of environmental pollution. Therefore, remedial strategies should begin with the long-term objective of augmenting efficiency in nutrient use by focusing on balancing N, P, and K inputs with outputs, while simultaneously improving management of soils and mineral fertilizers. Shifting from conventional to organic farming has positive environmental impacts in terms of avoiding the excessive application of synthetic pollutants as was stated by Lorenz and Lal [14], although it remains a controversial topic [15]. The transition from conventional to organic system production implies several changes in management practices and the adoption of new strategies and techniques. These changes are not only related to the prohibition of using synthetic chemicals and fertilizers, but farmers should manage their orchards according to observation, anticipation, and prevention to create an effective and sustainable organic system.

In the present study, during two growing seasons, drainage lysimeters were used to assess the water-use performance for irrigated and terraced cherimoya trees by determining the crop coefficients

($K_C$), fruit yield, and mineral nutrition throughout the production cycle under conventional and organic production systems in a subtropical Mediterranean environment.

## 2. Materials and Methods

*Experimental Area and Drainage Lysimeters*

The experiment was conducted on orchard terraces of cherimoya located in the Mediterranean coast near Almuñécar (Granada, Southeast Spain) (36°48′00″ N, 3°38′0″ W) at an elevation of 150 m above sea level (a.s.l.). The study terrace was a reverse-sloped bench-terrace type with a toe drain measuring 150–180 m long, with a platform of 2–3 m wide, and the talus 3–5 m high (Figure 1A).


**Figure 1.** (**A**) Terraced cherimoya plantation, (**B**) cherimoya fruit *Annona cherimola* cv. Fino de Jete, and (**C**) drainage lysimeters used for the study.

The soil was characterized by 684 $g \cdot kg^{-1}$ of sand, 235 $g \cdot kg^{-1}$ of silt, and 81 $g \cdot kg^{-1}$ of clay, containing 9.4 $g \cdot kg^{-1}$ of organic matter, and 0.7 $g \cdot kg^{-1}$ of total N, 14.6 $mg \cdot kg^{-1}$ total P, and 178.7 $mg \cdot kg^{-1}$ available K [16]. For the soil profile from 0.10 to 0.90 m, the soil water content at field capacity $\theta_F$ (0.33 atm) and at permanent wilting point $\theta_W$ (15 atm) had average values of 0.23 and 0.11 $cm^3 \cdot cm^{-3}$, respectively.

Cherimoya (*A. cherimola* cv. Fino de Jete) trees, twenty years old, were planted in single rows spaced 7 m × 5 m apart (approx. 280 $trees \cdot ha^{-1}$; Figure 1A,B). In all studied trees, about 100–120 flowers were hand pollinated with pollen from the same cultivar in both conventional and organic plantations. Cherimoya flowers were pollinated in the morning after storing pollen overnight to pollinate newly opened flowers.

The whole experimental orchard, as well as the trees studied with the lysimeters, was managed according to commercial practices in the area, using conventional and organic fertilization and routine cultivation techniques. The mineral fertilizer application rate ($N:P_2O_5:K_2O$ 1:0.40:0.70) was 680, (190 kg $N \cdot ha^{-1}$), 272 (174 kg $P_2O_5 \cdot ha^{-1}$), and 476 (160 kg $K_2O \cdot ha^{-1}$) g $tree^{-1}$, respectively, to simulate the contributions made by farmers in the area, who usually used $KNO_3$, $KH_2PO_4$, $NH_4NO_3$, $HNO_3$, and $H_3PO_4$. Similar rates of different organic amendments were applied in another experimental cherimoya plantation, using poultry (2.85% N, 3.54% $P_2O_5$, and 3.2% $K_2O$), sheep (2.37% N, 1.14% $P_2O_5$, and 1.25% $K_2O$), and cattle (1.19% N, 0.94% $P_2O_5$, and 0.56% $K_2O$) manures (Table 1).

**Table 1.** N, P, and K application rates for cherimoya trees under conventional and organic treatments.

| Application Rate | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| | | (kg·ha$^{-1}$) | |
| Conventional inorganic | 190 | 174 | 160 |
| Organic manure | | | |
| 3.5 t Poultry | 100 | 124 | 112 |
| 2.8 t Sheep | 66 | 32 | 35 |
| 2.5 t Cattle | 30 | 24 | 14 |
| Total | 196 | 179 | 161 |

The lysimeters were located on the terraces as a part of the orchard with mature cherimoya trees at full production (Figure 1C). The drainage lysimeters were replicated twice for each system production, containing one tree and 7.5 m$^2$ in area (3.0 m × 2.5 m), 1.0 m deep, bounded on the sides by nylon-reinforced polyethylene, and 35 m apart. Irrigation was applied by a combination of self-regulating emitters (4 L·h$^{-1}$) in a double-line system and controlled automatically by a head-unit programmer and electro-hydraulic valves.

Reference evapotranspiration ($ET_0$) is the amount of water lost by evapotranspiration from a hypothetical reference crop with an assumed crop height, fixed surface resistance, and an albedo that is maintained under optimal water and nutrient conditions. $ET_0$ was estimated by the Penman–Monteith equation [17], and climatic data were obtained from a meteorological station 80 m from the drainage lysimeters. The $ET_C$ was estimated weekly with the soil-water balance (SWB) [18], which is as follows:

$$\mathrm{ET_C} = \mathrm{P_{EF}} + \mathrm{I} + \mathrm{U} + \mathrm{R} - \mathrm{D_W} - \Delta\mathrm{S} \tag{1}$$

where $P_{EF}$ is the effective precipitation (mm) [19,20], I is the irrigation amount (mm), U is the upward capillary flow into the root zone (mm), R is the runoff (mm), $D_W$ is the downward drainage out of the root zone (mm), and ΔS the volumetric change in soil water stored in the 0–90 cm soil layer (mm).

The downward flow ($D_W$) was determined using the drainage lysimeter. Soil water content (ΔS) was measured twice weekly using the Frequency Domain Reflectometry (FDR) system, at 10, 20, 30, 50, 70, and 90 cm soil depth in the lysimeters. The FDR used was a commercial device with a hand-held capacitance probe (Diviner-Sentek Pty Ltd., Sentek Sensor Tecchnologies, Stepney, South Australia, Australia). This instrument comprises a data display connected by cable to a portable probe rod with one sensor attached. The upward movement of water (U) was evaluated in agreement with Darcy's law [21,22], which could be considered negligible in the water balance equation. The surface runoff (R) was also negligible because the lysimeters were placed within the platform of terraces with 0% slope.

Finally, the crop coefficient ($K_C$) was weekly calculated with the following equation:

$$K_C = ET_C/ET_0. \tag{2}$$

The water-use efficiency (WUE) was adjusted by the equation

$$\mathrm{WUE} = Y/ET_C \tag{3}$$

where $Y$ is the fruit yield (kg·ha$^{-1}$) and $ET_C$ is the total actual evapotranspiration over the growing season (mm).

Finally, throughout the study period in both conventional and organic plantations, foliar samples were collected for chemical analyses [16], and at the end of each survey, the yield of seven trees was determined, and weight and size of 15 fruits per tree were measured using calipers.

## 3. Results and Discussion

### 3.1. Crop Coefficients (Kc)

Figure 2A displays the reference crop evapotranspiration ($ET_0$) throughout the study period for both production systems, showing a typical Mediterranean pattern. The *ETc* increased in agreement with the crop water demand, especially during development of fruits in the tree (Figure 2B). Overall, *ETc* was higher during the summer months, especially in July, with the maximum monthly average *ETc* for cherimoya being 4.6 mm day$^{-1}$ or 164.7 L·tree$^{-1}$ day$^{-1}$ during the fruit-set phenological stage.

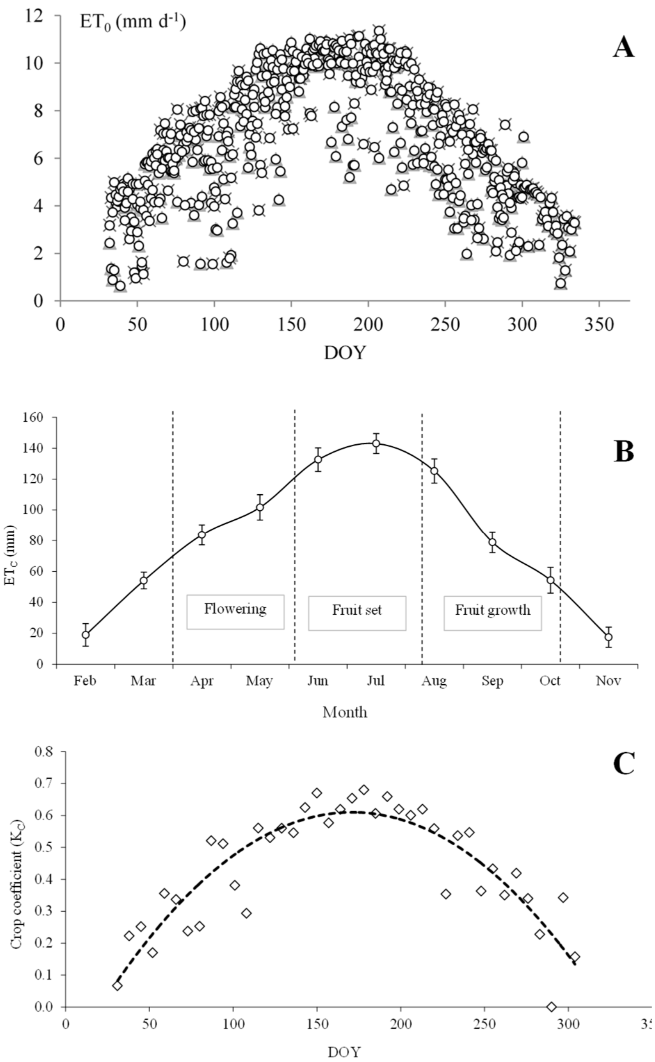


**Figure 2.** Average reference crop evapotranspiration ($ET_0$) (**A**), crop evapotranspiration ($ET_C$) in relation to main phenological stages (**B**), and crop coefficient as a function of day of the year (DOY) for cherimoya trees (**C**) throughout two monitoring seasons in the study zone. Bars represent the standard deviation.

Figure 2C shows the changes in the average *Kc* for cherimoya over the two monitoring seasons estimated by the water balance from experimental lysimeters for both productions systems. The *Kc* at three main growing stages (flowering, fruit set, and fruit growth) was fitted by a polynomial function (*Kc* vs. Julian days). During the phenological stages of flowering, fruit set, and fruit growth, average *Kc* values were 0.63, 0.68, and 0.55, respectively.

After fruit harvest, the *Kc* for cherimoya trees decreased quickly to 0.23. The *Kc* is closely related to crop type and management practice, which may influence the plant development rate and ground coverage throughout vegetative growth [17,23]. The average annual *Kc* value for the cherimoya trees during the irrigation period (May–October) was 0.55. The pooled *Kc* values for cherimoya trees for both systems was the highest in summer 0.57, and intermediate in spring and autumn at 0.48 and 0.39, respectively. These values provide a useful base for designing the irrigation timetable in drip-irrigation systems for terraced cherimoya plantations.

Until now, *Kc* values for cherimoya trees have not been defined, especially for orchard terraces. According to the findings, the amounts of water required for the fruit production period increased from the initial stage to the mid-season and decreased at the end of the late season. The most water was required at the flowering and fruit setting stages and comparatively less was required in the initial and maturity (harvest) stages, with evapotranspiration being the dominant factor governing crop water requirements. The *Kc* is a widely used parameter in the estimation of water consumption by plants. Therefore, it is essential to determine this value for the local conditions in which it will be used since the water flow dynamics are a joint function of local climatic factors [17,24]. In this context, the phenological stage, cultivar, local climate, and soil conditions resulted in different *Kc* values that maintained the amount of water within the capacity level for absorption and utilization by the plant root system.

### 3.2. Irrigation, Fruit Yield, and Water-Use Efficiency

Table 2 shows the impact of irrigation on cherimoya fruit yield for both production systems during the monitoring period. The average irrigation water applied in the orchard terraces for conventional and organic treatments during the first and second seasons were 3970 and 4124 $m^3 \cdot ha^{-1}$, respectively. Although the average fruit yield under the conventional (47.1 $kg \cdot tree^{-1}$) system was higher than the organic (44.1 $kg \cdot tree^{-1}$) system, these differences were not significantly different during the two monitoring seasons ($p > 0.01$). The yield in the organic plots during the first season could be attributed to the residual effect of the conventional fertilizer applied in previous years, as the plant nutrients from organic manures need time to be available for uptake by the trees. Therefore, the average fruit yield for conventional and organic farming in terraced chirimoya plantations (~280 $trees \cdot ha^{-1}$) were 14,308 and 13,468 $kg \cdot ha^{-1}$, respectively. The water-use efficiency for conventional and organic production systems was 3.6 and 3.3 $kg \cdot m^{-3}$, respectively.

**Table 2.** Impact of irrigation (100% $ET_C$) on fruit yield and water-use efficiency for the two production systems.

| Production System | Irrigation | Fruit | | | | WUE |
|---|---|---|---|---|---|---|
| | | Yield | FW [Z] | L | W | |
| | (mm) | ($kg \cdot tree^{-1}$) | (g) | (mm) | (mm) | ($kg \cdot ha^{-1}$ $mm^{-1}$) |
| Conventional | 397.0 | 47.1 | 398.8 ± 86 | 86.6 ± 15.5 | 91.6 ± 10.4 | 33.2 |
| Organic | 412.4 | 44.1 | 390.5 ± 90 | 84.7 ± 17.1 | 87.2 ± 11.8 | 29.9 |

[Z] FW, Fruit weight; L, fruit length; W, fruit width; WUE, water-use efficiency; ± standard deviation.

In relation to fruit size, we found no significant differences, although the fruits from conventional systems seemed to be larger.

The irrigation system is based on economic and technical factors, the most critical of which are the cost of the facilities and availability of the required quantity and quality of water. In this line, the economic cost of installation and technical maintenance of a drip irrigation system is high, especially in orchard terraces. The cost is usually the first key aspect that influences the decision of farmers who normally use the cheapest system. However, the cost is not necessarily related to the effectiveness of the system. In this sense, irrigation by gravity through furrows or flood irrigation are the cheapest systems. However, the water distribution is rarely uniform, which means they are inefficient. On the Granada coast, flood irrigation is widespread in most cherimoya plantations in the fertile flat areas. In the Almuñécar area, the water price per $m^3$ in plantations located on terraces ranges from 0.25 to

0.30 €. Drip irrigation systems have several advantages, such as the reduction of water loss through evaporation and reduction of weed development. Economic investment for the maintenance of the system (filters and various irrigation accessories) is mandatory for proper operation, and in the same way high quality water is required to avoid any possibility of suspended materials clogging the system.

Due to the importance of subtropical crops in Andalusia and its geographical advantage in the European market, it is important to study water relationships in this particular subtropical environment, since water is scarce, and optimization of water use is essential. In this context, studies are needed to understand the impacts of the water reduction supply on yields and fruit quality.

Spain is the only cherimoya producer that can provide the European markets with high quality fruit instead of traditional temperate fruit. In this sense, fruit conservation is difficult due to the highly perishable nature of fruit and the predominance of a single cultivar, Fino de Jete, that represents almost 95% of the cultivated area. One of the most important challenges for this crop is the introduction of new cultivars that expands the varietal range. The almost absolute dependence on cv. Fino de Jete, which concentrates production during October and November, creates challenges for commercialization. The technique called "superpoda" (super pruning) has been implemented, which allows production of cherimoya in winter and spring. This involves the early defoliation of the entire tree before the natural fall of the leaves; after the old period has passed, tree flowering and harvest are slightly advanced. However, its manual execution makes cultivation more expensive and profitability is not completely ensured. An increase in pollen conservation would help produce spring fruits, which would help improve shortage of flowers.

On the other hand, organic farming perceptions are divergent, but a strong consensus exists on its eco-friendly nature and inherent ability to protect the environment in contrast to the conventional system [14]. In general, organic food production costs are higher as organic farming is labor intensive and labor is costly. However, the quality of products is also higher. Efforts have been made to encourage organic farming overall and to market organic food, including cherimoya fruits. The increasing demand for organic food products, as well as the policies adopted by many governments to encourage the export of organic agri-products, are the factors driving the increase in organic food farming, which has the potential to strengthen the local economy as well as consumer health.

### *3.3. Leaf Mineral Content of Cherimoya Trees*

The content of nutrients in relation to phenological stages throughout the production cycle for conventional and organic cherimoya trees were almost similar. In this sense, Figure 3 depicts the overall pattern of pooled leaf mineral contents for both systems, revealing similar trends with respect to N, P, and K use, with post-harvest accumulation and low levels during flowering and fruit growth, especially for N and K. These trends were the opposite for Ca and Mg. Fe, Zn, Mn, Cu, and B concentrations rose during harvest and fell during flowering. The lower energy demand of cherimoya trees during harvest presumably encouraged the accumulation of reserves. The greater foliar K (1.98%) content during this stage could provoke Mg translocation to other organs, as pointed out by Adiscott [25]. The flowering process reduces the N concentration, probably due to cell division and elongation of new spring shoots [26]. Also, the lower foliar P during flowering may be ascribed to the production of nucleic acids and coenzymes, which are fundamental for photosynthesis. K also fell during flowering, possibly because of the translocation toward new cherimoya tissues, where K is crucial to activate enzymes and regulate osmotic pressure.

The lower macro- and micro-nutrient content concentrations in some stages would also be affected by the dilution factor between foliar mass and growing fruits. The harvesting of cherimoya fruits during the harvest period activates a recovery process in foliar mineral content. In short, two clearly differentiated stages during the cycle were observed: A first stage of reduction of the foliar mineral levels during the most critical stages, followed by another of recovery once the harvesting of the fruits had begun. For some plant nutrients (P, K, and Ca), the seasonal factor was significant, with greater contents found at the harvest stage.

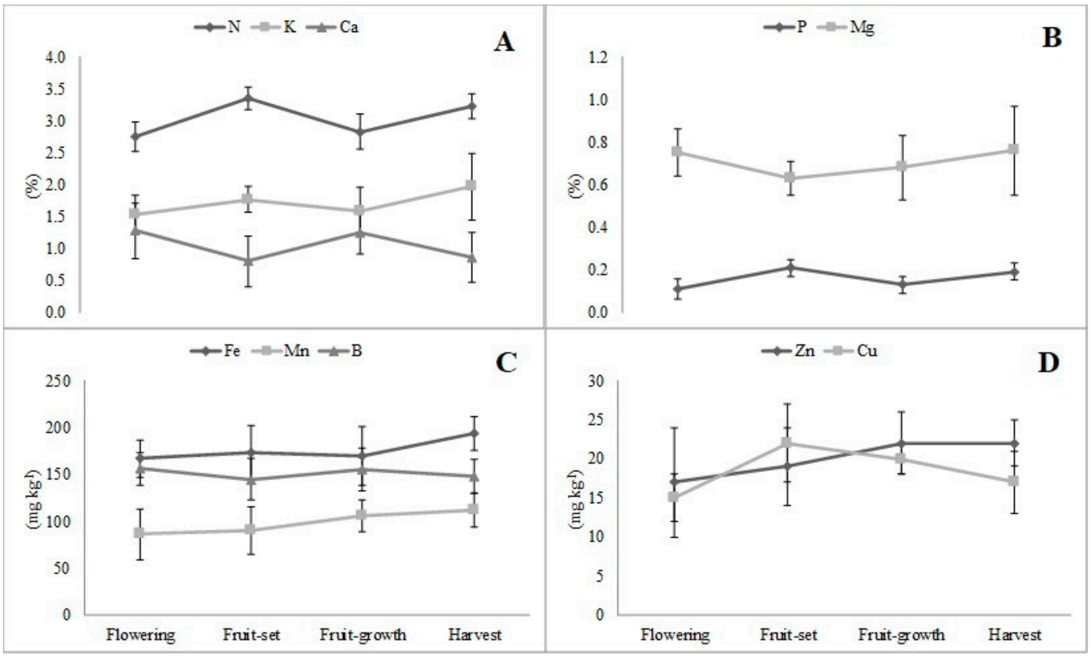


**Figure 3.** Pooled (**A**,**B**) macro and (**C**,**D**) micro leaf nutrient content in phenological stages during two monitoring seasons of terraced cherimoya trees for both systems. Bars are standard deviation ($n = 8$).

Table 3 shows the results for the analysis of the variance (ANOVA) concerning the effect of the production system and season on the average macro- and micro-nutrient leaf content; differences between individual means were tested using the LSD test at $p < 0.01$. In this sense, regarding the effects of the production systems (conventional vs. organic), no significant differences were recorded between the systems, except for Zn and Cu. However, there was a clear tendency for greater levels of NPK under conventional farming.

**Table 3.** Average macro- and micro-nutrient leaf content under conventional and organic systems.

| System | N | P | K | Ca | Mg | Fe | Zn | Mn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|
| | (%) | | | | | (kg·mg$^{-1}$) | | | | |
| Conventional | 3.06a | 0.16a | 1.82a | 0.81a | 0.74a | 185a | 25a | 85a | 16a | 150a |
| Organic | 2.98a | 0.14a | 1.75a | 0.93a | 0.78a | 180a | 21b | 97a | 19b | 145a |
| Season | | | | | | | | | | |
| 1 | 2.85a | 0.13a | 1.69a | 0.79a | 0.70a | 186a | 23a | 84a | 16a | 156a |
| 2 | 2.97a | 0.17b | 1.78b | 0.95b | 0.74a | 189a | 24a | 90a | 19a | 158a |
| ANOVA | | | | | | | | | | |
| System | ns | ns | ns | ns | ns | ns | ** | ns | ** | ns |
| Season | ns | ** | ** | ** | ns | ns | ns | ns | ns | ns |
| Interaction | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |

[Z] Values with the same letter within a column do not differ significantly at $p < 0.01$ according to the Least Significant Difference test (LSD): ns, not significant; ** Significant at $p < 0.01$.

The traditional fertilization practices in orchard terraces usually lead to excessive fertilizer applications [27]. These are unavoidable for maintaining high productivity and growth, although promoting environmental degradation and having negative impacts on crop development [28]. Under the rational use of mineral fertilizers, plant nutrients can be incorporated only when needed to endorse normal growth and productivity and an economic response to its application is generated. Although leaf nutrient analysis is the methodology used for diagnosing nutritional status in crops and the need for further mineral or organic amendments, this information is insufficient for determining the amount of nutrients that should be incorporated in the field. In this context, the reestablishment of plant nutrients removed in harvested fruits and pruning residues could be enough for the tree to maintain growth and productivity, or at least an approximation of the real requirements. However, it is crucial to consider the plant nutrients already present in the soil, and if they are in available form for uptake by root system of trees. Tree reserves in storage organs, mineralization of the soil organic matter, reuse of nutrients, nutrient supplied by the irrigation water, and other factors have to be considered.

Consequently, plant nutrient removal from orchards could be essential for estimating tree consumption and to obtain some information about to the amount of plant nutrients to be incorporated if the leaf nutrient status reveals the need for amendments.

In general, the leaf mineral content in cherimoya trees was within the ranges considered as normal by many authors [29–31]. Therefore, none of the nutrients could have acted as limiting factors.

On the other hand, recycled wastewater can provide both water and nutrients, and therefore could be an important tool to mitigate the adverse impact of climate change as was reported by Trimmer and Guest [32]. Also, slow and intermittent application of nutrients with recycled wastewater can increase nutrient-use efficiency [33]. However, there should be special attention to the water and nutrient balance according to Elliott and Jaiswal [34]. In addition, as stated by Long et al. [35], an elevated $CO_2$ concentration would result in higher yield but a lower nutritional value of food [36].

## 4. Conclusions

Severe climatic events, combining water scarcity and droughts, are predicted to increase in intensity, frequency, and geographic extent as a result of climate change. To successfully grow crops given this adverse scenario, farmers will need to adjust to less available water. The application of efficient water management strategies is key for increasing agricultural water productivity in areas with scarce water. This is the case for subtropical Mediterranean farming, particularly terraced cherimoya orchards in Southeast Spain. In this study, conventionally applied irrigation (100% $ET_C$) could be reduced and a water-saving program could be promoted. In this sense, the *Kc* values for cherimoya offer useful information for optimizing irrigation management and adjusting irrigation volume and frequency to the crop water demand. Our findings highlight the importance of rational water use in orchard terraces to promote sustainable agricultural development for subtropical fruit trees.

Regarding the crop response to the production systems, we found no significant differences between conventional and organic farming, either in fruit yield or leaf nutrient status, at least for the studied period. Thus, subtropical fruit production is feasible under precision plant nutrition and irrigation management, and continuous efforts are needed to advise farmers about rational use of water and plant nutrients according to crop requirements.

**Author Contributions:** All authors contributed equally toward the research and the writing of the paper.

**Funding:** Part of this research was funded by the following research project: "Innovations for sustainability, productivity, and improvement of subtropical crops (mango and cherimoya)" (PP.AVA.AVA2019.38) and co-financed by the European Regional Development Fund (ERDF), Internal call for Research Projects and Technological Innovation for the period 2019-2022.

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

## References

1. Kundzewicz, Z.W.; Krysanova, V.; Benestad, R.E.; Hov, O.; Piniewski, M.; Otto, I.M. Uncertainty in climate change impacts on water resources. *Environ. Sci. Policy* **2018**, *79*, 1–8. [CrossRef]
2. Brouziyne, Y.; Abouabdillah, A.; Hirich, A.; Bouabid, R.; Zaaboul, R.; Benaabidate, L. Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios. *Agric. Syst.* **2018**, *162*, 154–163. [CrossRef]
3. Tanasijevic, L.; Todorovic, M.; Pereira, L.S.; Pizzigalli, C.; Lionello, P. Impacts of climate change on olive crop evapotranspiration and irrigation requirements in the Mediterranean region. *Agric. Water Manag.* **2014**, *144*, 54–68. [CrossRef]

4. García, T.I.F.; Durán, Z.V.H.; Muriel, F.J.L. Towards sustainable irrigated Mediterranean agriculture: Implications for water conservation in semi-arid environments. *Water Int.* **2014**, *39*, 635–648. [CrossRef]
5. García, T.I.F.; Durán, Z.V.H. *Water Scarcity and Sustainable Agriculture in Semiarid Environment: Tools, Strategies and Challenges for Woody Crops*, 1st ed.; Academic Press-Elsevier: Amsterdam, The Netherlands, 2018; pp. 1–624. ISBN 9780128131640.
6. Ort, D.R.; Long, S.P. Limits on yields in the corn belt. *Science* **2014**, *344*, 484–485. [CrossRef] [PubMed]
7. PNR. Plan Nacional de Regadíos, Ministerio de Agricultura, Alimentación y Medio Ambiente 2015. Available online: https://www.mapama.gob.es/es/desarrollo-rural/temas/gestion-sostenible-regadios/plan-nacional-regadios/texto-completo/ (accessed on 21 January 2019).
8. ESYRCE 2017. Encuesta sobre Superficies y Rendimientos de Cultivos. Available online: https://www.mapama.gob.es/es/estadistica/temas/estadisticas-agrarias/boletin2017sm_tcm30-455983.pdf (accessed on 11 February 2019).
9. PPHN. Proyecto del Plan Hidrológico Nacional. Ministerio de Agricultura, Alimentación y Medio Ambiente 2015–2021. Fase de Consulta Pública Finalizada. Available online: http://www.chminosil.es/es/chms/planificacionhidrologica/plan-hidrologico-2015-2021/proyecto (accessed on 21 December 2018).
10. Durán, Z.V.H.; Rodríguez, P.C.R.; Franco, T.D.; Martín, P.F.J. *El Cultivo del Chirimoyo (Annona Cherimolia Mill)*, 1st ed.; Imprenta Hermanos Gallego: Granada, Spain, 2006; pp. 1–105. ISBN 84-607-8627-7.
11. AEA, Anuario Estadístico de Agricultura 2016, Consejería de Agricultura Ganadería, Pesca y Desarrollo, Sostenible. Junta de Andalucía. Spain. Available online: https://www.juntadeandalucia.es/organismos/agriculturaganaderiapescaydesarrollosostenible/consejeria/sobre-consejeria/estadisticas/paginas/agrarias-anuario.html (accessed on 18 April 2019).
12. Higuchi, H.; Utsunomiya, N.; Sakuratani, T. Effects of temperature on growth, dry matter production and CO2 assimilation in cherimoya (*Annona cherimola* Mill.) and sugar apple (Annona squamosa L.) seedlings. *Sci. Hortic.* **1998**, *73*, 89–97. [CrossRef]
13. Higuchi, H.; Tetsuo, S.; Utsunomiya, N. Photosynthesis, leaf morphology, and shoot growth as affected by temperatures in cherimoya (*Annona cherimola* Mill.) trees. *Sci. Hortic.* **1999**, *80*, 91–104. [CrossRef]
14. Lorenz, K.; Lal, R. Environmental Impact of Organic Farming. In *Advances in Agronomy*; Sparks, D.L., Ed.; Elsevier BV: Amsterdam, The Netherlands, 2016; Chapter 3; Volume 139, pp. 99–285.
15. Guthman, J. *Agrarian Dreams: The Paradox of Organic Farming in California*; Volume 11 California Studies in Critical Human Geography; University of California Press: Berkeley, CA, USA, 2004; p. 328. ISBN 9780520277465.
16. MAPA. *Métodos Oficiales de Análisis de Suelos y Aguas Para Riego*; Tomo III Secretaria General Técnica del Ministerio de Agricultura Pesca y Alimentación: Madrid, Spain, 1994; pp. 205–285.
17. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements, Irrigation and Drain*; Paper no. 56; FAO: Rome, Italy, 1998; pp. 15–79. ISBN 9251042195, 9789251042199.
18. Hillel, D. *Environmental Soil Physics*; Academic Press: New York, NY, USA, 1998; pp. 588–603. ISBN 978-0-12-348525-0.
19. Kuo, S.F.; Ho, S.S.; Liu, C.W. Estimation irrigation water requirements with derived crop coefficients for upland and paddy crops in Chianan Irrigation Association, Taiwan. *Agric. Water Manag.* **2006**, *82*, 433–451. [CrossRef]
20. SCS. *National Engineering Handbook. Section 4: Hydrology*; Soil Conservation Service, USDA: Washington, DC, USA, 1972; pp. 1–55.
21. Fares, A.; Alva, A.K. Estimation of citrus evapotranspiration by soil water mass balance. *Soil Sci.* **1999**, *164*, 302–310. [CrossRef]
22. De Medeiros, G.A.; Arruda, F.B.; Sakai, E.; Fujiwara, M. The influence of crop canopy on evapotranspiration and crop coefficient of bean (*Phaseolus vulgaris* L.). *Agric. Water Manag.* **2001**, *49*, 211–224. [CrossRef]
23. Williams, L.E.; Ayars, J.E. Grapevine water use and the crop coefficient are linear functions of the shaded area measured beneath the canopy. *Agric. For. Meteorol.* **2005**, *132*, 201–211. [CrossRef]
24. Guerra, E.; Ventura, F.; Snyder, R.L. Crop coefficients: A literature review. *J. Irrig. Drain Eng.* **2015**, *142*, 06015006. [CrossRef]
25. Adiscott, T.M. Potassium and the distribution of calcium and magnesium in potato plants. *J. Sci. Food Agric.* **1974**, *25*, 1173–1183. [CrossRef]

26. Leopold, A.C.; Kriedemann, P. *Plant Growth and Development*, 2nd ed.; McGraw-Hill: New York, NY, USA, 1975; pp. 1–75. ISBN 978-0070994317.
27. Durán, Z.V.H.; Martínez, R.A.; Aguilar, R.J. Nutrient losses by runoff and sediment from the taluses of orchard terraces. *Water Air Soil Pollut.* **2004**, *153*, 355–373. [CrossRef]
28. Ge, S.; Zhu, Z.; Jiang, Y. Long-term impact of fertilization on soil pH and fertility in an apple production system. *J. Soil Sci. Plant Nutr.* **2018**, *18*, 282–293. [CrossRef]
29. George, A.P.; Nissen, R.J.; Brown, B.I. The custard apple. *Queensland Agric. J.* **1987**, *113*, 287–297.
30. Navia, V.M.G.; Valenzuela, J.B. Sintomatologia de deficiências en chirimoya (*Annona cherimola* Mill.) cv. Bronceada. *Agric. Téc.* **1978**, *38*, 9–14.
31. Silva, H.; Silva, A.Q.; Cavalcante, A.T.; Malavolta, E. Composição mineral das folhas de algumas fruteiras do Nordeste. In *Anais do VII Congresso Brasileiro de Fruticultura*; Sociedade Brasileira de Fruticultura: Florianópolis, Brasil, 1984; pp. 320–325.
32. Trimmer, J.T.; Guest, J.S. Recirculation of human-derived nutrients from cities to agriculture across six continents. *Nat. Sustain.* **2018**, *1*, 427–435. [CrossRef]
33. Jaiswal, D.; Elliott, H.A. Long-term phosphorus fertility in wastewater-irrigated cropland. *J. Environ. Qual.* **2011**, *40*, 214–223. [CrossRef]
34. Elliott, H.A.; Jaiswal, D. Phosphorus management for sustainable agricultural irrigation of reclaimed water. *J. Environ. Eng.* **2011**, *138*, 367–374. [CrossRef]
35. Long, S.P.; Ainsworth, E.A.; Leakey, A.D.; Nösberger, J.; Ort, D.R. Food for thought: Lower-than-expected crop yield stimulation with rising $CO_2$ concentrations. *Science* **2006**, *312*, 1918–1921. [CrossRef] [PubMed]
36. Porter, J.R.; Xie, L.; Challinor, A.J.; Cochrane, K.; Howden, S.M.; Iqbal, M.M.; Lobell, D.B.; Travasso, M.I. 2014: Food security and food production systems. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the 5th Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Barros, V.R., Dokken, D.J., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 485–533.