Evaluation of growers' efforts to improve the sustainability of olive orchards: Development of the hydroSOStainable index

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Abstract

Sustainability is a feature that most companies adopt in order to improve their profits, even when their activity is not sustainable or the definition in their sector is not clear. This concept actually relates to the management of natural resources. Agriculture, and particularly irrigation scheduling, is strongly linked to a sustainable management; however, it is not clear what defines a sustainable management. Several efforts have been made to improve the conservation of water resources, but most of them have not involved growers at the orchard level; and consequently, they have lost their opportunity to create a real improvement in terms of sustainability. The aim of this work was to design a "hydroSOStainable index" (or "hydroSOS index") that evaluates different aspects at orchard level to improve the sustainability of the water resources. The hydroSOS index considers 16 indicators grouped in 4 areas: (i) hydraulic indicators, (ii) horticultural indicators not related to irrigation scheduling, (iii) horticultural indicators related to the moment when deficit irrigation is applied (when?), and (iv) horticultural indicators related to the way deficit irrigation is applied (how?). Each indicator provides different marks or scores, and their sum allows classifying orchard management into four labels. The weight of each indicator and each group is not in itself enough to obtain a maximum label. Groups allow to easily identify the main limitations for the orchard to achieve a sustainable irrigation management. This index was used to evaluate water management of two cases of study.

Keyword: hydroSOS products, irrigation, RDI, water saving.

INTRODUCTION

The concept of sustainability has been used since the second half of the 20th century. Initially, it was related to natural resources, but in the last years it has been associated with a wide range of economic activities. "Sustainability" is probably one of the most common words in the advertisement of different products. But these products do not involve a sustainable process or, at least, the process is not clearly defined (i.e. Dow Jones sustainability index (Foweler and Hope, 2007)). The consequence is that these strategies limit real and demonstrable uses of the concept and then the possible economic benefits. The United Nations (UN) defined sustainability as a development that covers present needs without compromising future generations' needs (UN, 1987). Such definition does not necessarily mean that the quantity and quality of natural resources should be maintained. In agriculture, the meaning commonly accepted is that of conserving the amount of natural resources in the long term to maintain a certain level of production indefinitely (Villalobos and Fereres, 2016). Although more recently, the definition of sustainable agriculture has included management styles that are viable from an economic point of view and acceptable from a social point of view (Villalobos and Fereres, 2016).

Sustainable irrigation is not clearly defined either. Gleick et al. (1995) considered that sustainable irrigation means that the hydrologic cycle and ecological systems are not being damaged. A more precise definition included concepts such as quantity and quality of water resources in the long term (i.e. Wichelns and Oster, 2006; Khan et al. 2004) and water productivity (Khan et al. 2004). According to Khan et al. (2004), the target to improve irrigation sustainability in an agricultural area could be associated with the increase of water productivity. Such increase in water productivity has been commonly supported with public policies that focused on improving water drainage or water conduction before farm level. However, these great investments did not involve growers and the water saving before farm level was lower than the water waste at farm level (Van Schilfgaarde, 1994; Wichelns and Oster, 2006). In fact, farm level is the most important part in the definition of the water productivity in a hydrological basin because crops (Azad et al. 2015) and the growers' water management (Herald et al. 2013) are the main sources of variation.

In addition, drought-resistant fruit species, such as olive trees, could improve water sustainability within a basin if an accurate irrigation management was applied. However, deficit irrigation, even for these species, is not definitely linked to a sustainable management. The reduction in water availability could turn into poor economic profits (even null) or an unclear yield response (i.e. in very low density orchards (Moriana et al. 2007)). Additionally, adequate water management at farm level means an increase of costs, but not necessarily of profits. In these conditions, growers will not support a sustainable irrigation approach at farm level. Noguera-Artiaga et al. (2016) suggested the definition of "hydroSOStainable products" as fruits and vegetables cultivated under regulated deficit irrigation. These authors reported that Spanish consumers were willing to pay an extra amount of €1.0kg^{-1} for pistachio with such trade name (Noguera-Artiaga et al., 2016). The implication is that, if a price increase can be obtained, changes in the water management will be easily promoted. Then, the question turns into how this effort of improving the sustainability of irrigation at farm level could be evaluated. There are a few approaches to assess water management at orchard level. Sustainable wine growing in New Zealand presented a protocol in which the topic of irrigation only considered a few management options (irrigation scheduling, water productivity and amount of water applied) (SWNZ, 2013). The water footprint is an approach that considers the entire production process until the product reaches the end consumer. Although the farm level is the most variable component in the cycle, this approach only considers the amount and type of water used, and not the real effort of growers to improve their management in their particular environmental and water availability conditions. An orchard receiving a high amount of rain and with low water needs could have a low-water footprint, even if the water management was very inefficient (some vineyards in New Zealand, Herath et al. (2013)). The aim of this work is to suggest an approach for olive trees that quantify the grower's effort to save water in olive orchards. in a way that could improve the sustainability of the system. This index would be based on scientific knowledge about deficit irrigation and other management techniques,

MATERIAL AND METHODS

Main concepts to consider for the hydroSOS index.

The evaluation of the orchard management is very difficult because there are many factors that could affect the final results. Although the present work will focus only on the irrigation management, there are several factors more that could be involved in the sustainability of irrigation at orchard level. The present approach will describe and rate each factor in order to evaluate water management. This approach will have a similar structure to the "Seattle Green Factor" (Seattle Department of Construction and inspections, 2018). Briefly, the "Seattle Green Factor" was designed to evaluate green urban zones. This approach describes elements that could be evaluated, such as surface covered with plants, type of plants, how they are growing and so on. Each element is rated according to their importance and a final score is obtained for the evaluated zone. The approach followed in this document (hereinafter, the "hydroSOS index") will identify, describe and rate different indicators which improve irrigation sustainability in the orchard. The quantification of these indicators will allow identifying weakness and strengths of the orchard.

The key concept in the hydroSOS index is the irrigation scheduling based on regulated deficit irrigation. According to Goldhamer (1999), the irrigation reduction during pit hardening in olive trees allows saving water with no effect on the yield. Such results have been confirmed in other works using different cultivars (i.e. Moriana et al. 2003; Iniesta et al., 2009). Although there are a few works with different recommendations (i.e. Lavee et al., 2007), such differences could be explained by the level of water stress reached in comparison with the Goldhamer paper (Girón et al., 2015a). Fernández et al. (2018) in a recent review suggested more accurate periods of water restriction for olive trees than those traditionally considered. However, in order to simplify the orchard evaluation, we will use the original suggestion in Goldhamer's work. Therefore, the highest marks will be obtained when this irrigation strategy (water stress during pit hardening period) is applied to the orchard. The hydroSOS index includes different indicators that allow applying the strategy and improve water saving. These indicators are grouped into hydraulic and horticultural. Hydraulic indicators are related to the irrigation design. Horticultural indicators are the most important in the evaluation and include all different orchard managements which could be involved in the increase of irrigation sustainability. The aim of the index is not to improve water productivity or even water saving, because in arid climates, the available water could be very limited and both criteria would not be associated with a good water management.

Indicators definition for hydroSOS index. Hydraulic Indicators

The irrigation design is the key point in the orchard for an efficient water management. But the correct design implies a great investment. Then, sometimes, no adequate hydraulic design are installed to reduce the costs. Efficient hydraulic designs are very important for deficit irrigation management because fast recoveries are typically necessary at the end of the water stress period. Low amounts of water applied during rehydration reduce the recovery of midday stem water potential (i.e. Moriana et al., 2007) and have been associated with a slow recovery of gas exchange in olive trees (Pérez-López et al., 2008). Hydraulic indicators include the type of irrigation, number and flow of the drips, irrigation interval and uniformity of the water distribution (Table 1).

- **Type of irrigation.** All irrigation types could be efficient in an olive orchard if an accurate management is applied. However, drip and micro-sprinkler irrigation will provide more uniformity in the water distribution and a better control of the water applied. Moreover, the reduction of humidity at crown level will improve the health of the crops. Therefore, only these two irrigation types will be assigned a top mark (Table 1). In this case, as several types were present at the orchard, marks will be given to the ones installed over a greater surface.
- **Number and flow of drips/micro sprinklers.** The distribution of olive tree roots in irrigated orchards takes place on the surface and near the water source (Fernández et al., 2001), so maximum water uptakes are measured in the first 60cm (Girón et al., 2015a). The amount of humid soil volume affects the water relations in olive trees (Torres-Ruiz et al., 2013). Therefore, the number of water points in the orchard is very important for the management of the irrigation water. In addition, a low number of drips per tree would increase the irrigation time and it could even hinder the application of the maximum rates during the recovery

period. In order to evaluate these indicators, a minimum of humid soil surface of around 35-40% in the crown surface should be considered (Gispert Folch, 2003). According to the daily crop evapotranspiration commonly reported in mature olive orchards (between 4-5mm day^{-1}), a hydraulic system which provided around 1mm h^{-1} (between 0.8 to 1.2mm h^{-1}), would be acceptable. Other types of irrigation with different drip or micro-sprinkler will not be considered for this indicator.

- **Irrigation frequency.** Only a high-frequency system will be considered. Therefore, only 1 to 3 days will be the correct values. That is the frequency that the hydraulic system could use according to the orchard/ irrigation community organization. This is not the current frequency in the orchard; instead, it could be lower according to the current water management.
- **Water distribution uniformity in the orchard.** Design and maintenance of irrigation system are related to distribution uniformity. A great heterogeneity in the way water is applied in an orchard means that some areas could be overirrigated in order to provide an adequate irrigation scheduling for others receiving a smaller amount of water. According to the type of irrigation considered (drip or micro sprinkler), the current approach considers only values higher than 95% or between 90-95% as adequate.

Horticultural Indicators

These indicators include all types of horticultural management related to water management at the orchard level. This group is the most important in the hydroSOS approach and growers could change easily most of the components in their orchards. These indicators are grouped in three: indicators not directly related with irrigation scheduling, indicators of the moment when the water stress occurs and indicators of the level of water stress.

Indicators not directly related with irrigation scheduling

These indicators will contribute to save water but they are not involved in the irrigation scheduling of the olive orchard (Table 2). Therefore, growers could obtain top marks in these indicators without a regulated deficit irrigation strategy.

- **Source of irrigation water.** Irrigation with re-used water (i.e. from urban uses) or desalinated water could improve the hydrologic budget at a basin level because less ground water will be consumed. The use of a structure to store rainfall and use in the orchard irrigation also improves the sustainability of the system. This indicator considers 4 levels based on the irrigated surface of the orchard that uses only re-used or desalinated water (100%, 75-100%, 50-75%, 25-50%). In addition, positive marks are given if the farm includes damns to store rainfall water (Table 2).
- **Soil management.** Soil management could reduce evaporation and runoff in olive orchards, thus improving the hydrologic budget. Covering the soil with crops or weeds during the rainfall period reduces runoff in olive orchards (Pastor et al., 2001). In addition, a lack of tillage management increases infiltration and reduces evaporation (Pastor, 1989). Therefore, only living covers (with top marks) or no tillage will be considered as positive in this topic (Table 2).

- **Water quality.** Water quality could affect sustainability in two ways. First, some works considered sustainable irrigation when the water quality did not decrease with the agricultural use (Khan et al., 2004; Wichelns and Oster, 2006). On the other hand, a low-quality water means an increase of the leaching requirements, hence an increase of water consumption. The hydroSOS approach will mark positively the annual analysis of salinity in the irrigation water (Table 2). In addition, the leaching requirements (LR) will also be considered in the evaluation. First, LR are estimated according to Rhoades (1974) for low-frequency irrigation (Eq. 1) and according to van Schilfgaarde (1974) for high-frequency irrigation (Eq. 2)

$$LR = \frac{ECiw}{13.5 - ECiw} \qquad (1)$$

$$LR = \frac{ECiw}{28} \qquad (2)$$

Where:

LR is the leaching requirements

ECiw is the electrical conductivity of irrigation water

Values of threshold electrical conductivity (2.7dS/m; Eq 1) and electrical conductivity for zero yield (14 dS/m; Eq 2) for olive trees have been included in the formulas according to Villalobos et al. (2002).

The seasonal rainfall excess was calculated for the period when rainfall is greater than ETc, as the difference between rainfall and the sum of crop evapotranspiration and water soil stored capacity. When the seasonal rainfall excess was lower than LR, this meant that irrigation should include additional water to maintain the soil salinity within adequate values. Therefore, these additional requirements should not penalize the evaluation and they will be deducted from the seasonal water applied.

- **Water use efficiency (WUE).** Water saving increases the irrigation sustainability but improving the water productivity is the target of several definitions of sustainable irrigation (Khan et al., 2004). Water productivity can be estimated as the ratio between yield and applied water (hereinafter water use efficiency, WUE). Although this definition is not widely accepted (Fernández et al., 2018), it is the easiest way to evaluate the irrigation productivity at orchard level. The WUE is related to irrigation scheduling, but in the case of olives trees it is mainly related to yield because this fruit tree is very efficient in its water use. For this reason, the indicator is included in this group. The influence of cultivars in WUE has not been reported in olive trees (Goldhamer, 1999; Moriana et al., 2003; Lavee et al., 2007; Moriana et al., 2007; Iniesta et al., 2009; Gomez del Campo, 2011; Moriana et al., 2013; Fernández et al., 2013; Girón et al., 2015a). HydroSOS index will consider: values higher than 6kg m^{-3} and values between 3 and 6kg m^{-3} (Table 2). In general, values below 3kg m^{-3} will not be considered. However, the alternate bearing pattern could dramatically reduce the WUE. Almost zero yields have been reported in olive orchards (i.e. Moriana et al., 2013) and such values are not necessarily associated to an unsuccessful irrigation management. In order to include this possibility, the annual relative irrigation supply (ARIS) is calculated using Eq. 3 (Lorite et al., 2012):

$$ARIS = \frac{Irrigation}{(ETc - R)} \qquad (3)$$

Where:

ARIS: annual relative irrigation supply

Irrigation: seasonal amount of irrigation

ETc: evapotranspiration during irrigation period

R: rainfall during irrigation period

ARIS values lower than 1 mean deficit irrigation. In these conditions, low values of WUE could be related to very low yield and the orchard will received the same mark than when WUE is in the interval 3-6 kgm^{-3} (Table 2). Irrigation amount is this equation will be reduced with the leaching requirements when the excess rainfall was not higher than the leaching requirements. Moreover, an additional point will be given when orchards have several water meters delimiting irrigation zones (Table 2).

Indicators related to irrigation scheduling. When.

Water saving or high water productivity is not equivalent to a correct irrigation scheduling. The RDI involves including the description of the olive phenology and the control of water stress in the scheduling. In this regard, the hydroSOS index will evaluate the water restriction period considering the duration and the effect on the water consumption (Table 3). According to the olive RDI works, the massive pit hardening is the drought-resistant phenological stage (Goldhamer, 1999; Moriana et al., 2003; Iniesta et al., 2009; Fernandez et al., 2014; Giron et al., 2015a among others). This period is broad and the beginning can be estimated according to Rapoport et al., (2103), which is actually the earliest methodology. In short, this latter work reported that the changes in the longitudinal dimensions of olive fruits modify the growth slope, and this change is coincident with the fast increase of endocarp hardening. From our knowledge, there is no phenological indicator of the end of this period. Therefore, according to the irrigation works (for example, Moriana et al., 2003; Fernández et al., 2018), the deficit period will last until the last week of August (Northern hemisphere) or February (Southern hemisphere). Maximum marks will be obtained when the period is estimated according to Rapoport et al. (2013) and ends in the last week of August/February (Table 3). However, some orchards could be strongly limited in the water availability or the amount of water. Then, they should reduce this period of water stress. In this case, mark will be lower when recovery is in the second week of August/February or in the last week of July/January.

Water saving during this pit hardening period will be also considered. Irrigation needs will be estimated with the water budget during this period of restriction. Maximum marks will be obtained when the applied water in this period represents more than 50% water saving in comparison to the water needs, but also water saving percentage of 30-50% and 10-20% will be considered (Table 3).

Indicators related to irrigation scheduling. How.

Water saving or high water productivity during the season or a particular deficit period does not mean that growers control the water applied in an accurate way. Real deficit irrigation scheduling involves olive trees being in water stress conditions at the adequate moment and growers monitoring the changes in the water status of the soil/tree. There are several indicators which could be used. HydroSOS approach will consider all of them adequate because these indicators represent a clear effort by growers to improve the irrigation sustainability. Crop models will receive the lowest mark because they are considered less accurate than sensors installed in the orchard. Several works reported that during pit hardening, water stress levels between -2 to -3.5MPa of midday stem water potential are successful if the recovery period is efficient

(Dell'Amico et al., 2012; Girón et al., 2015 a and b). Therefore, the hydroSOS approach evaluates this indicator, the management of the irrigation scheduling and the water stress level (Table 3).

- **Indicators used.** All measurements at the orchard that describe the soil-plant water status conditions will receive the maximum marks. Using the crop model will be evaluated positively, but with lower marks than the indicators used at orchard level. Climatic measurements will only be considered if they are included in crop models (Table 3).
- **Measurement frequency.** Continuous measurements (frequency lower than 2 hours) received maximum marks. Discrete measurements will be considered only if the frequency is lower than 15 days during at least the massive pit hardening period, frequencies between 15-30 days will be acceptable during the rest of the irrigation season (Table 3).
- **Sampling.** These measurements are useful when most of the orchard surface is monitored. Therefore, the surface considered and the number of measurements are key factors for an accurate sampling. Orchards will be divided in sampling zones with a maximum surface of 20ha (Shackel, 2018). The percentage sampling division of the orchard will be evaluated positively from 25-50% orchard surface, 50-75% and 75-100%. In addition, these zones will be characterized by the measured trees. Maximum marks will be obtained with methodologies that cover 100% of each zone. Positive marks will be also given to measurements covering 80-100% of the surface or using at least 10 measured trees per zone for methodologies applied to individual trees (Table 3).
- **Water stress level.** Pressure bomb techniques will be the benchmark to check the water stress level of the orchard. The midday stem water potential will be

measured in 5 to 10 trees that represent the average fruit load in the orchard. When the orchard surface is higher than 50ha or the fruit load is very different, only high fruit load zones will be considered. The orchard management will be evaluated positively if the average is between -2 to -3.9MPa. Only for young orchards, midday stem water potential values higher than -2MPa will be acceptable.

HydroSOS Labels

The sum of all the indicators considered classifies the orchard in 1 of 4 labels according to the potential sustainability of water management (Table 4). The hydroSOS index does not quantify the sustainability of the system in terms of amount of water resources or economic profits, which would be very difficult, and it is not clearly presented in the bibliography. This index evaluates the growers' efforts to optimize the water available to them and, also, can help the consumer identify the companies which are objectively more involved in the preservation of water resources. In addition, this index could highlight the main issues to improve irrigation management. The sum of all the indicators is 105 points, the highest label (A, HYDROSOS) will require obtaining more than 85 marks (Table 4). Label A means that the hydraulic indicators (25 total points) and the irrigation scheduling indicators (*when* 20 points and *how* 40 points) must be near the maximum mark, even if indicators that are not directly related to irrigation scheduling (20 points) are at maximum levels. Label B indicates an orchard where the growers' efforts are important because the marks are between 65 and 85 points. Therefore, although hydraulic indicators and indicators not directly related to irrigation scheduling were great, irrigation scheduling should be performed at least partially. Label C, between 50 and 65 points, represents an orchard with important deficiencies from the point of view of irrigation sustainability but, again, some indicators of irrigation scheduling have been positively evaluated. Finally, Label D, below 50 points, indicates an orchard where irrigation scheduling is almost null and probably management and irrigation maintenance are also very deficient.

Case studies

The hydroSOS index was applied in two different orchards during the 2017 season (Table 5). Both orchards were very similar, with the same cultivar, distance between trees and hydraulic system (drip irrigation, one line of 2.5l h^{-1} and 0.75m between drips). Orchard-1 is a commercial olive orchard located in Ecija (Seville, Spain, 37.66ºN; -5.10ºW). This is a super-high-density olive orchard (4x1.5m) with 16-year-old trees (cv Arbequina). Two irrigation sectors of 23.5ha (A) and 15.4ha (B) were selected. In both sectors, irrigation maintenance was very unsuccessful and irrigation uniformity was considered lower than 90%. Sector A was irrigated following a regulated deficit irrigation strategy (RDI) from the beginning of pit hardening (16^{th} June). Sector B was irrigated following the decision of the growers. The second commercial orchard, "Orchard-2", is located in Marchena (Seville, Spain, 37.41ºN, -5.47ºW). This is also a super-high-density olive orchard (cv Arbequina) with 3 years-old trees. Two irrigation sectors of 12ha (A) and 29.91ha (B) were used. In both sectors, irrigation uniformity was estimated at around 95%. Sector A was irrigated following a regulated deficit irrigation strategy (RDI) from the beginning of pit hardening (16^{th} June). Sector B was irrigated following the decision of the growers. In both orchards, the RDI sectors used the same irrigation scheduling approach with the pressure bomb technique as irrigation tool, according to the Moriana et al., (2012) and Girón et al., (2015a) recommendations. The midday shade water potential was measured weekly, from pit hardening until the last week of August, and every 10-15 days thereafter until yield. Mature, healthy, shaded leaves were used for measuring the water potential using the pressure bomb technique. The target for the midday shade water potential was -3MPa during the pit hardening period (from 16th June until 24th August) and -1.4MPa thereafter until harvest. Pit hardening was estimated according to Raporpot et al., (2013). On the other hand, the growers' management was different between orchards: in Orchard-1, the water applied was almost constant during the season, while in Orchard-2, the midday shaded water potential and canopy temperature was used, with drones checking the growers' decisions. The water stress level in both orchards was checked at the end of August using measurements of midday stem water potential.

The water budget was calculated with the 10-year average rainfall obtained from the Andalusian network of agroclimatic stations (SIAR, 2018): Ecija for "Orchard-1" and Los Molares for "Orchard-2" (Tables 6 and 7). The crop evapotranspiration (ETc) was calculated according to Steduto et al., (2012) as ETc=EToxKcxKr. The reduction coefficient (Kr) was estimated according to Steduto et al. (2012) at around 1 for both orchards. The crop coefficient (Kc) was estimated also according to this latter work, considering that there was no tillage management in both orchards, with values from 0.65 during winter to 0.5 during midsummer. In order to calculate the soil water stored in both orchards, the root depth was estimated at around 0.8m, the soil texture was sandy loam (θ_{FC}=0.21 and θ_{PWP}=0.1; Villalobos et al., 2016) and the percentage of allowable depletion was fixed at 0.75 according to Orgaz and Fereres (1997). Then, the allowed depletion was estimated at 72mm and the period of irrigation from June to September, with a total irrigation needs of 354mm (Table 6) and 325mm (Table 7). Both locations are under Mediterranean conditions, with warm winters and hot and dry summer (Tables 6 and 7). The differences between ETc and rainfall data were used to determine the period of leaching, when rainfall exceeded ETc, from October to February/March. The amount of rain that could be considered as leaching was calculated as the difference between total rain in this period and the sum of ETc and soil water stored. The results were 97.77 and 111.42 mm, respectively.

RESULTS AND DISCUSSION

The evaluation of hydraulic features in both orchards are presented in Table 8. The hydraulic design is the same for both locations and the irrigation organization would allow a daily irrigation. Only the differences in irrigation maintenance lower the marks in Orchard-1 in comparison with Orchard-2, although both of them obtain great results (20 or 25 points out of 25 possible points). In this group of indicators, irrigation scheduling is not considered only hydraulic design. Problems in these indicators could limit RDI strategy in periods of no water stress condition, mainly during rehydration. Low uniformity in irrigation, the main differences between both orchards, implies that part of the orchard could be in more severe water stress conditions during deficit period or recovery. Severe water stress during pit hardening is related with yield reduction in olive trees (Goldhamer, 1999; Moriana et al., 2003; Fernández et al., 2013; Ahumada-Orellana et al., 2017) and will reduce the economic sustainability.

Table 9 shows the features and marks of horticultural indicators which are not related to irrigation scheduling (Table 2). In addition to the orchard, the irrigation strategy is also presented because there is an indicator which is affected. For both locations, the water source is ground water, then the mark is zero points. However, Orchard-2 has a damn which would partially recover the rainfall water, so it received 3 points. Soil management for both are no tillage and this gives them 2 points. There is no information in Orchard-1 about the water quality but Orchard-2 presented a water analysis (EC 2.12dS m^{-1}) which will be also considered later. These three latter indicators are not affected by irrigation scheduling, so both strategies are evaluated in equal terms. Finally, the WUE and even water managements were similar for both orchards (Table 5 and 9). The yield and the water applied resulted in a WUE around 6kg m^{-3} for all cases. Such results mean a high WUE, slightly higher in RDI scheduling than in growers' managements. There were no water meters in the different zones of the orchard in any of the locations. In this group of indicators, the maximum that can be achieved is 20 points (Table 2), most cases obtained less than 50% of these (Table 9). RDI scheduling got maximum marks with 8 points in comparison to growers' management at Orchard-1, just 4 points. Therefore, the hydroSOS index rated all cases with important deficiencies. The hydroSOS index penalised mainly the water source because no re-use/desalinated water was used. The consumption of ground water would potentially reduce the sustainability of the orchard, because the hydrological cycle as a basin label is more difficult to offset than if reused water were consumed, particularly in semiarid conditions. Siebert et al. (2010) estimated that ground water was consumed at a greater rate than its recharge across the world. This latter work supports that the sustainability of the system is clearly endangered, though water productivity is probably at its highest in irrigated fruit trees.

Table 10 presents the indicators data describing how growers estimate the period of irrigation restriction (described in Table 3). Irrigation scheduling for RDI, for both locations, and Orchard-2 growers' was quite similar. For the three cases, pit hardening was estimated according to Rapoport et al. (2013) and the water stress period finished at the end of August. Conversely, the growers' management at Orchard-1 did not consider any phenological stage for the irrigation scheduling. As a result, maximum marks were obtained in the three cases and none in the latter. When estimating the water saving, several data should be considered. First, the leaching requirements were estimated for Orchard-2 using the EC data and the equation 2 as 7.6%. According to the average irrigation needs (Table 7), the amount of leaching water will be 26mm. On the other hand, in the average season there will be an excess water of around 111mm (see material and methods). Therefore, in theory, leaching requirements could be offset during the rainfall period. Then, leaching water would not be subtracted from the water applied. There is no EC data in Orchard-1, so all the water applied was considered. Average irrigation needs during the period of pit hardening (from mid-June until the end of August) were obtained from Tables 6 and 7, and compared with the irrigation amount during this period (Table 5. Pit aw). As a result, water saving in the management if the grower in Orchard-1 was the lowest in comparison with the rest of cases and reached less than the 10% of the average irrigation needs (Table 10). Water saving in the other three irrigation schedules were clearly greater (39% and more than 50%). Such results clearly separated water managements in two groups, one of them clearly no sustainable in which water saving was likely more related with a mistake in the estimation of water needs and others with a regulated deficit management. Irrigation works in olive trees reported different water saving in deficit treatments. Fernández et al (2013) suggested a great restriction with only 20% irrigation needs but almost no irrigation during deficit period is also reported (Moriana et al., 2013; Girón et al., 2015a; Ahumada-Orellana et al., 2017). The percentage of reduction is also associated with the approach used for estimating water needs. Models such as Orgaz et al (2006) commonly estimated greater water needs than traditional FAO's approach (Steduto et al., 2012). The present work suggests the latter because this is a methodology easier and more widely used around the world.

Table 11 presents the results of evaluating the irrigation scheduling methodology (described in Table 3). As in the previous group, only the case of the Orchard-1 growers did not use any approach to irrigation scheduling and, consequently, the maximum level of water stress was -1.6MPa. Conversely, the other three cases used the pressure bomb technique or drone flying as part of the irrigation scheduling. In these cases, the orchard surfaces were larger than 20ha in some cases (Orchard-1 RDI, Table 5), which is the maximum surface recommended. But in these cases they represent more than 75% of the orchard. Orchard-2 growers used regular drone flying to cover almost 100% of the surface and weekly pressure bomb measurements. Such management covered maximum ranges of sampling surface and number of samples (Tables 5 and 11). As a result, in these three cases, the measured water stress levels could be considered moderate (between -2.5 and -3.9MPa, Table 5). Such level of water stress has been reported in the literature as adequate when a good rehydration is provided (Moriana et al., 2003, Iniesta et al., 2009, Moriana et al., 2012; Fernández et al., 2013). The maximum marks in this group are 40 points and only the three cases applying the RDI scheduling were near this value. Only the decrease in the percentage of the total surface representing the sampling zone lowered the evaluation in Orchard-1 RDI. This issue of the number of zones needed means that, in big orchards and in non-automatic approaches, a high investment of time and man-power is required. In fact, obtaining a high score is likely to be costly and currently not economically efficient because of the sensors price and the fact that information that they provide is not better than a cheaper, non-automatic approach such as pressure bomb.

The hydroSOS index classifies the four case studies with three different labels (Table 5). The lowest score was reached by Orchard-1 grower (24 points, Label D). The current management in this orchard is very deficient because RDI scheduling is not applied and the system maintenance is also poor. There is no intention in the farm to save water, although the WUE is very high, probably related to the high yields of the system. If this farm considered an RDI strategy, this score would increase (78 points, Label B). Such improvement could be achieved in one season because it is mainly related to irrigation scheduling. The change could be even made in two steps, just considering the phenology for the irrigation scheduling scores, which increase the evaluation and bring it close to Label C, almost at no cost. Orchard-2, on the contrary, was much better than Orchard-1. Growers' management (89 points, Label A) is a sustainable management and gets an optimum label (more than 85 points). Differences between grower and RDI management in this location were minimum and only related with a slightly differences in WUE. This farm is clearly involved in the improvement of water resources conservation in its basin. Although WUE were similar, slightly better in Orchard-2 than in Orchard-1, the water management in the former would increase irrigation sustainability in the basin. Therefore, from a consumer point of view, the olive oil should reach a higher price in the former than in the latter. These results show as great WUE are not necessary related with a sustainable water management. Different indicators are needed in order to an accurate evaluation.

CONCLUSIONS

The hydroSOS index evaluates objectively the growers' effort to improve the irrigation management at orchard level. This index classifies 16 different indicators in four groups: (i) hydraulic, (ii) horticultural indicators not directly related to irrigation scheduling, (iii) horticultural indicators, which define when deficit is performed, and, (iv) horticultural indicators related with how the water stress is managed. Each indicator has different scores but neither an individual indicator nor a group of indicators have enough weight in the final mark to obtain the maximum label. In addition, most of the indicators could be changed seasonally, to make possible that poor evaluations could improve fast. From the consumer point of view, the hydroSOS index provides enough information to be sure that growers work on the way to improve the sustainability of their orchards. Finally, indicators are selected according to the current knowledge about olive orchard management. But they could be changed easily and include, for instance, consideration about the olive oil features. This latter topic is very useful for commercial companies, but also very difficult to manage due to the great influence of cultivars.

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Table 1. Hydraulic indicators of the hydroSOS index. Levels and marks.

INDICATOR	LEVEL	MARK
Irrigation type	*Drip o micro-sprinkler*	5
Drips	*Correct number and flow*	10
Irrigation frequency	*1-3 days*	5
Distribution Uniformity	*>95%*	5
	90-95%	2

Table 2. Horticultural indicators of the hydroSOS index not related to irrigation scheduling. Levels and marks.

INDICATOR	LEVEL	MARK
Water Source	*100% Re-use*	5
	75-100% Re-use	4
	50-75% Re-use	3
	25-50% Re-use	1
Irrigation damn		3
Soil Management	*Plant cover*	5
	No tillage	2
Water quality monitoring	*Yes*	1
Water Use Efficiency	*>6kg* m^{-3}	5
	3-6 kg m^{-3}	2
	<3kg m^{-3}	0
Water meter at several points		1

Table 3. Horticultural indicators of the hydroSOS index which evaluate when (grey,) and how (white) the water stress is performed. Levels and marks

INDICATORS	LEVEL	MARK
Approaches to determine pit hardening	*Yes*	5
Duration of irrigation restriction	*Until last week Aug/Feb*	5
	Until second week Aug/Feb	2
	Until last week July/Jan	1
Water saving in pit hardening	*>50%*	10
	30-50%	7
	30-40%	5
	10-20%	2
Approaches for irrigation scheduling	*Plant and soil measurements*	5
	Crop models	2
Measurements frequency	*Continuous*	10
	Discrete	8
Sampling	*100% surface*	10
	75-100% surface	8
	50-75% surface	4
	25-50% surface	2
Number of data	*All surface*	10
	10 data for each zone or at least 80% surface	8
Water stress level	*Midday stem water potential between -2 to -3.9MPa*	5

Table 4. Labels of the hydroSOS index.

LABEL	POINTS	COMMENTS
A	>85	HYDROSOS
B	65-84.9	Important effort but not HYDROSOS yet
C	50-64.9	Poor management or important issues
D	50<	Water wasteful orchard. No interest in water sustainability.

Table 5. Main features of each orchard and irrigation management. GRW, growers' management; RDI, regulated deficit irrigation management. Total Surface, orchard surface considered. Total AW, water applied per season (m^3ha^{-1}). Pit AW, water applied during the pit hardening period(m^3ha^{-1}). Yield (kg ha^{-1}). EC, electrical conductivity (dS m^{-1}). %Surface, percentage of the total surface that includes a zone of 20ha. Number, number of measurements. HydroSOS, HydroSOS index final score.

	Orchard-1		**Orchard-2**	
	GRW	**RDI**	**GRW**	**RDI**
Total Surface	15.4	23.5	29.9	12.0
Total AW	3351	2389	2619	2489
Pit AW	2240	1480	1134	1081
Yield	18820	16309	15303	16389
EC	Unknown	Unknown	2.12	2.12
% Surface	NO	85%	Dron	100%
Number	NO	10	10	10
HydroSOS	24	78	89	92

Table 6. Water budget in Orchard-1. Climatic data (rain (mm) and reference evapotranspiration (ETo, mm)) are the average for the last 10 years. Crop coefficient (Kc), crop evapotranspiration (ETc) and irrigation (mm) are estimated according to Steduto et al. (2012) and Fereres and Orgaz (1997).

Months	**Rain**	**ETo**	**Kc**	**ETc**	**Irrigation**
January	48.3	33.0	0.65	21.45	0
February	64.5	47.9	0.65	31.15	0
March	55.7	82.1	0.65	53.33	0
April	60.1	110.7	0.6	66.43	0
May	31.8	153.7	0.55	84.54	0
June	8.0	188.9	0.55	103.90	84
July	0.8	215.9	0.5	107.93	106
August	2.2	193.1	0.5	96.53	95
September	15.4	130.7	0.55	71.87	56
October	54.9	81.9	0.6	49.15	0
November	64.8	41.9	0.65	27.25	0
December	82.9	29.0	0.65	18.84	0

Table 7. Water budget in Orchard-2. Climatic data (rain (mm) and reference evapotranspiration (ETo, mm)) are the average of the last 10 years. Crop coefficient (Kc), crop evapotranspiration (ETc) and irrigation (mm) are estimated according to Steduto et al. (2012) and Fereres and Orgaz (1997).

Months	Rain	ETo	Kc	ETc	Irrigation
January	55.3	34.5	0.65	22.45	0
February	72.8	50.0	0.65	32.49	0
March	52.0	89.2	0.65	57.98	0
April	61.2	115.1	0.6	69.06	0
May	39.5	157.9	0.55	86.87	0
June	6.5	184.1	0.55	101.27	84
July	2.3	201.1	0.5	100.57	100
August	3.1	178.8	0.5	89.40	85
September	22.1	123.2	0.55	67.75	47
October	59.7	82.2	0.6	49.34	0
November	91.1	44.3	0.65	28.81	0
December	64.5	32.0	0.65	20.78	0

Table 8. Hydraulic indicators for both orchards.

Hydraulic	Features	Marks	Features	Marks
	Orchard-1		Orchard-2	
Type	Drip	5	Drip	5
Drips	0.8mm h^{-1}	10	0.8mm h^{-1}	10
Frequency	Daily	5	Daily	5
Uniformity	Lower 90%	0	95%	5
TOTAL		**20**		**25**

Table 9. Evaluation of horticultural indicators not related to irrigation scheduling (described in Table XX+1). Each feature in the orchard is marked in the line before. Irrig. means Irrigation strategies (GRW, grower; RDI, regulated deficit irrigation). Source, source of water for irrigation (Ground, ground water). Quality, water quality monitoring. Productivity, water use efficiency (kg m^{-3})

Orchard	Irrig	Source	Soil	Quality	Productivity	TOTAL
Orch-1		Ground	No Till	NO	5.6	
	GRW	0	2	0	2	**4**
		Ground	No Till	NO	6.8	
	RDI	0	2	0	5	**7**
Orch-2		Ground(1)	No Till	YES	5.8	
	GRW	3	2	1	2	**8**
		Ground(1)	No Till	YES	6.6	
	RDI	3	2	1	5	**11**

(1) Although the water source is ground water, this orchard has a damn, then 3 points are included.

Table 10. Evaluation of horticultural indicators related to irrigation scheduling (*When*, described in Table XX+2). Each feature in the orchard is marked in the line before. Irrig. Irrigation strategies (GRW, growers; RDI, regulated deficit irrigation). Pit, approaches for determining the beginning of pit hardening. Duration, duration of the irrigation restriction period. Saving, percentage of water saving during the restriction period.

Orchard	Irrig	Pit	Duration	Saving	TOTAL
Orchard-1		NO	NO	7.8%	
	GRW	0	0	0	**0**
		YES	END AUG	39.1%	
	RDI	5	5	7	**17**
Orchard-2		YES	END AUG	50.0%	
	GRW	5	5	10	**20**
		YES	END AUG	52.4%	
	RDI	5	5	10	**20**

Table 11. Evaluation of horticultural indicators related to irrigation scheduling (*How*, described in Table XX+2). Each feature in the orchard is marked in the line before. Irrig. Irrigation strategies (GRW, growers; RDI, regulated deficit irrigation). App, approaches used in irrigation scheduling. Freq, frequency of measurement of these approaches. Surface, surface of the sampling zones considered. Num, number of measurements of % of sampling zones measured. Check, midday stem water potential at the end of August (MPa).

Orchard	**Irrig**	**App**	**Freq**	**Surface**	**Num**	**Check**	**TOTAL**
Orch-1		NO	NO	NO	NO	-1.6	
	GRW	0	0	0	0	0	**0**
		Plant	Discrete	85%	10 data	-3.2	
	RDI	5	8	8	8	5	**34**
Orch-2		Plant	Discrete	Dron	10 data	-2.5	
	GRW	5	8	10	8	5	**36**
		Plant	Discrete	100%	10 data	-3.9	
	RDI	5	8	10	8	5	**36**