Technical Note

Improvement of Strawberry Irrigation Sustainability in Southern Spain Using FAO Methodology

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Abstract: Irrigation sustainability is particularly important in the vicinity of Doñana National Park (Huelva, Spain), where Europe's most important wetland area coexists with a profitable strawberry irrigation activity. In this paper, an innovation and technology transfer project was laid out. The project was promoted by the Institute of Agricultural and Fisheries Research and Training (IFAPA), belonging to the Regional Government of Andalusia. The main objective of the project was to contribute to the sustainability of the complex ecological, productive, and social system of this region. The project was focused on the rational use of water resources. Experimentation, demonstration, technology transfer, and training activities were carried out, involving public administrations, companies, and private farms. The project was carried out in collaboration with strawberry companies covering a total surface area of 1900 hectares. Irrigation application efficiency and irrigation water productivity increased by 66% and there was also a significant increase in water saving (44%), without resulting production losses. The success of the activity was based on the implication of farmers in experimentation assignments. During a five-year time span, irrigation trials took place on several farms. This fact allowed a progressive improvement of irrigation management by farmers based on confidence in the experimental work results.

Keywords: soil water balance; evapotranspiration; irrigation efficiency; water productivity; agricultural extension

1. Introduction

Irrigation is essential to ensure suitable production and adequate crop quality in regions with a Mediterranean climate [1]. However, social pressure centered on the use of water in agriculture has not ceased in recent years, with special reference in semi-arid areas dedicated to intensive horticulture. This increase in public concern is mainly due to the population´s general perception that agricultural water use is far from efficient [2]. The negative image of surface irrigation, the loss of water in canals and ditches as well as the idea that low water prices cause both a lack of interest and effort in increasing the efficiency of its use have all contributed to this idea.

The introduction of technological innovations implies economic advantages and improvements in the efficiency of the use of water, energy, and productive resources [3]. Thus, the introduction of new irrigation infrastructures in distribution networks and microirrigation has had a notable impact on the potential improvement of the use of irrigation water. Notwithstanding, technologies and methodologies associated with irrigation management

have not had the level of acceptance that might be expected despite the benefits they provide. In fact, the absence of rational irrigation management can even lead to irrigation systems with a high potential for saving water actually having the opposite outcome due to bad management [4].

The soil water balance method is probably the most widely used in irrigation scheduling [5]. Soil water balance method has proven to be robust enough for a wide range of climatic. Nevertheless, its use is still rare in many regions of the world. A methodology for irrigation scheduling based on soil water balance method combined with estimations of crop water requirements was proposed by FAO more than 40 years ago [6,7]. It was demonstrated that using FAO methodology can produce potential water savings of 40% compared to traditional irrigation [8].

Other irrigation scheduling methods are based on monitoring the soil moisture and plant water status. The most important limitation of soil moisture monitoring is the difficulty in coping with the spatial variability of soil properties and distribution of irrigation water [5]. There exist several methods to evaluate plant water status, but their measurements are difficult to use in irrigation scheduling [9]. Nevertheless, the soil water balance method allows adequate irrigation with less need for external resources. In this sense, the economy of means is fundamental when opting for the FAO methodology. The main means currently available in the farm to promote the use of the FAO methodology are the increasing availability of technicians on farms, the availability of local meteorological and ET_o data from public meteorological networks and the expansion of microirrigation, where water balance is most easily implemented. Finally, the widespread use of Smartphones and Apps allow the visualization of meteorological data and irrigation schedules in real time [10].

In Spain, the Agroclimatic Information System for Irrigation (SIAR) [11] has been one of the greatest advances in the last 20 years in order to improve irrigation management (Figure 1). The SIAR network, with 468 automatic weather stations, provides daily evapotranspiration reference (ET_o) and precipitation data for irrigation scheduling based on FAO methodology. In Andalusia, Southern Spain, the SIAR network has more than 100 automatic weather stations [12].
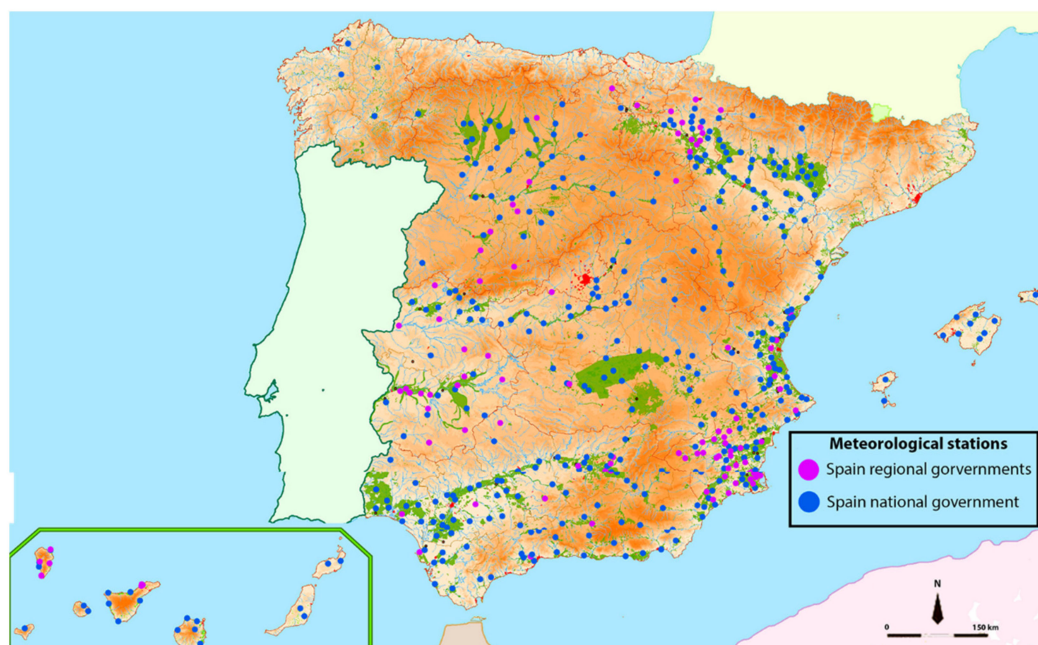

Figure 1. Meteorological stations of the Agroclimatic Information System for Irrigation (SIAR) in Spain (www.siar.es).

The economic profitability of horticulture in Andalusia is linked to the use of intensive production systems. These intensive production systems have high investment costs in infrastructure (greenhouses and microirrigation systems), inputs (fertilizers and energy), and labor. Therefore, they are productive systems where the high added value of production is achieved from a high investment. The objective of farmers in intensive agricultural systems is usually to maximize net margins and not the irrigation water productivity [3]. Faced with this situation, farmers tend to overirrigate crops like strawberry, even if they use localized irrigation systems which have the potential to be very efficient [1,13]. Overirrigation occurs primarily because most irrigators take intuitive or qualitative approaches to scheduling their irrigations, based on his previous experience and not on information concerning current growing methods and/or weather conditions [5]. On the other hand, it appears unlikely that greenhouse farmers will adopt this method of irrigation scheduling, as water represents only 2–4% of total crop cost [14].

The berry crops have transformed the province of Huelva, turning it into a prosperous area of Andalusia, in the Southern of Spain. Strawberries have led the process, although in the last four years crops such as raspberries, blueberries and blackberries have increased their surface area. In the 2019/2020 season, the cultivated areas were 6217 ha of strawberries, 2363 ha of raspberries, 3089 ha of blueberries and 145 ha of blackberries (data provided by Freshuelva). The province of Huelva (Spain) is the main strawberry producer in Europe and the sixth in the world after China, United States, Mexico, Egypt, and Turkey. Nevertheless, since the 1990s, there has been a debate in the region about the harmonization of agricultural production with the preservation of the environment. 75% of strawberry production is located in the vicinity of the Doñana National Park, a natural area of high ecological value classified by UNESCO as World Heritage since 1994. The main source of water supply for agriculture, tourism, and the Doñana National Park itself is the Almonte-Marismas Aquifer. In the last 30 years the piezometric levels of the Almonte-Marismas Aquifer have decreased. In fact, a part of the aquifer has even been declared to be in "poor condition" by the basin authority [15].

The first work about irrigation efficiency and strawberry productivity in the province of Huelva was carried out in 2008. The information was obtained from 75 surveys carried out with technicians and farmers from companies and cooperatives. According to this work, farmers said apply between 4300 and 10,800 $m^3\ ha^{-1}$ of fertigation for irrigation season (Gavilán et al., not published data). [16] obtained applied irrigation values between 5200 and 7500 $m^3\ ha^{-1}$ from farmer surveys in Huelva. Later, [17] using data from the irrigation times applied by the farmers of Huelva, estimate that the average values of irrigation efficiency and seasonal irrigation volume were 81% and 7000 $m^3\ ha^{-1}$, respectively. However, it should be noted that the use of irrigation time for estimating irrigation volume produces an overestimation of irrigation volumes of up to 15%. Considering these data, similar values of yields were obtained using a wide range of applied irrigation volumes. In addition, most of the farmers claimed to irrigate above the provision of 4500 $m^3\ ha^{-1}$ established in the Hydrological Plans of the Guadalquivir and Tinto-Odiel-Piedras basin authorities.

Faced with this scenario of the restriction of water allocations and uncertainty about the local strawberry irrigation requirements, the Institute for Agricultural and Fisheries Research and Training of the Regional Government of Andalusia (IFAPA) launched a long-term project. The project was aimed improving the irrigation sustainability of strawberry irrigation in the surroundings of the Doñana National Park (Huelva), in Southern Spain. The project included experimentation, training, and extension. The objective of the project was to contribute to the sustainability of the complex ecological, economic, and social system of the region by promoting the rational use of water resources. We hope that this paper will serve other worldwide Institutions as a guide to face similar challenges of economic and environmental sustainability in agriculture.

2. Methodology of Irrigation Sustainability Project in the Vicinity of Doñana National Park

We proposed a project to improve irrigation sustainability in the vicinity of the Doñana National Park in which agriculture should be part of the solution to the problem of the scarcity of water resources. The objective of the project was to facilitate the transition from traditional irrigation, based mainly on the farmer's experience, towards sustainable intensive agriculture based on rational criteria for water use. To do this, all agents (public administrations, companies, cooperatives, and farmers) were involved from the beginning of the project. The first step was to capture the interest of producers. In this sense, a basic principle of the project methodology was to do trials in the own fields of the farmers. Farmers have more confidence in the results of the trials obtained on their own farms which favor the transfer of results. Irrigation monitoring applied by farmers was the first task to be carried out. The objective of monitoring the farmer's irrigation was to know the starting point before taking action.

2.1. Experimental Site Description

Between 2012 and 2015, eight irrigation trials were carried out in Almonte (Huelva) (southern Spain), on two commercial strawberry (Fragaria × ananassa) farms with Sabrina, Antilla, Fortuna and Victory cultivars [13,18] (Figure 2). Sabrina was the most planted cultivar in Huelva in the study season with 34.75% of the total cultivated area. On the other hand, Antilla is a classical cultivar in Huelva with a 5.05% of total cultivated area in this season. The farms are near the village of El Rocío (longitude 6°29′ W, latitude 37°07′ N, at an altitude of 75 m above sea level). The climate is Csa (Köppen-Geiger classification) with rainfall annual mean value of 467 mm. Average, maximum and minimum temperatures annual mean values are 17.8, 36.5 and 14.1 °C, respectively. The soils of the two studied areas are classified as sandy (USDA classification), with 92% sand, 4% silt, and 4% clay.
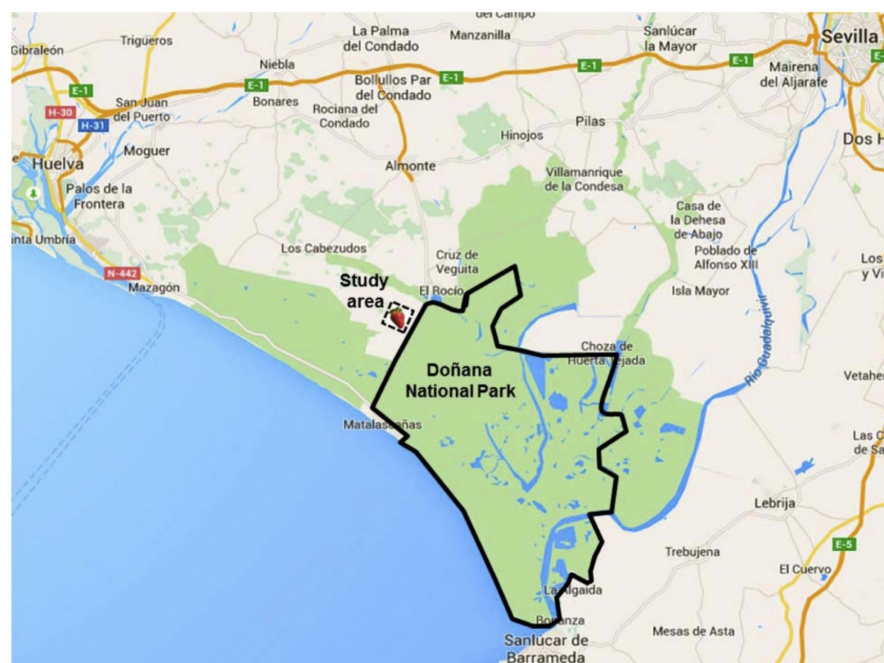

Figure 2. Location of the Doñana National Park and the study area (trials).

Farm managers carried out all the necessary tasks for strawberry cultivation in the trials except drip irrigation. They contributed building the beds, maintaining their structure before planting and ensuring plant establishment after transplanting. The strawberry plants were transplanted in mid-October, with planting densities ranging of 66,000 to 72,000 plants per ha. The differences in crop systems for cultivars are due to different farmer habits. The

plastic tunnels were set up in mid-November. Hence, strawberries were grown outdoor until the second or the third week of November, and then strawberries were covered by plastic tunnels. Strawberries were planted in trapezoidal raised beds measuring 0.60 m at the base, 0.50 m at the top, with a height of 0.50 m. Beds were 1.1 m or 1.2 m apart, and were covered with black plastic mulch. Two rows of plants were placed along the bed with a subsurface drip irrigation tape in the center installed during bed construction. Plants were spaced 0.25 m apart. Each tunnel had six beds. Fruit harvest started in early January and all experiments ended in early June. Mature strawberry fruits were harvested twice a week from January to March and three times a week from March to June. In these studies, we only consider market category which is of great economic importance to growers.

The irrigation trials had four treatments with four repetitions with a randomized block design. The experimental unit was a complete greenhouse. Therefore, each trial consisted of 16 greenhouses. In the first season (2012/2013), the first treatment (T1) was set up to apply the crop water requirements, based on ETo and estimated crop coefficients. T2 and T3 were designed to apply 25% and 50% more water respectively than T1. In the second season, experiments were carried out for estimating the effect on the distribution uniformity and irrigation application efficiency of pulse irrigation duration and different flow-rate emitters. In the third season, trials were carried out to study the effect on yield of different doses of fertigation (Table 1). In all cases, a treatment (T4) was irrigated according to the farmer's criteria based on his own experience. In all treatments, the total volume of irrigation applied by treatment was measured by flowmeters. The experimental plot was a complete tunnel of 70×6.6 m^2 approximately. The tunnels were covered with 0.15 mm thick thermal polyethylene plastic film. Using the entire tunnel as the experimental unit allowed the farmer to compare the results of the trials with the results in the rest of the farm. The irrigation systems consisted of drip irrigation laterals, capable of applying between 5 and 2.5 L h^{-1} m^{-1} at a working pressure between 0.55 and 1 bar. Yield data were statistically analyzed using analysis of variance (ANOVA), according with the experimental design in which the experiment was carried out. LSD test was used to identify treatments that were statistically different at a level of significance of 0.05. Statistix Sx.9 software (Analytical Software, 2105 Miller Landing Rd, Tallahassee, FL, USA) was used in the analysis.

Table 1. Trials and irrigation demonstration carried out by IFAPA in Almonte, Lepe and Rociana del Condado fields (Huelva) between the 2012 and 2017.

Irrigation Season	Cultivar	Irrigation Treatments		
		T1	T2	T3
2012/13 [1]	Sabrina	100% ET$_c$	125% ET$_c$	150% ET$_c$
2012/13 [1]	Antilla	100% ET$_c$	125% ET$_c$	150% ET$_c$
2013/14 [2]	Sabrina	5′ irrigation pulse	10′ irrigation pulse	15′ irrigation pulse
2013/14 [2]	Sabrina	5′ irrigation pulse	10′ irrigation pulse	15′ irrigation pulse
2013/14 [3]	Antilla	2.5 l/h/m	3.8 l/h/m	5 l/h/m
2014/15 [4]	Fortuna	Farmer fertilization	1.25 T1	1.5 T1
2014/15 [5]	Victory	Weekly forecast	Daily forecast	Historical ET$_o$
2014/15 [5]	Victory	Weekly forecast	Daily forecast	Historical ET$_o$
2014/15	Victory, Fortuna	Measurement of the uniformity of distribution (UD) and analysis of the factors that affect UD		
2015/16 2016/17	Victory, Rociera Primoris	Demonstration trials of irrigation scheduling in commercial farm		

[1] Trials for estimating crop water requirements and crop coefficients; [2] Trials for estimating the effect of pulse irrigation duration on the distribution uniformity and irrigation application efficiency; [3] Trial for estimating the effect of using different flow-rate emitters on the distribution uniformity and irrigation application efficiency; [4] Trial to study the effect of different doses of fertigation on the yield; [5] Trial for estimating the effect of different irrigation schedules on the yield.

During the 2015/16 and 2016/17 irrigation seasons, experiences of efficient irrigation application were carried out on a commercial scale (40 ha) in farms from Almonte, Rociana del Condado, and Lepe. Furthermore, more than 100 evaluations of irrigation systems were carried out in strawberry, raspberry, and blueberry crops for estimating irrigation distribution uniformity [19].

2.2. Crop Water Requirements

The proposed method by FAO for computing consumptive use of water by crops (crop evapotranspiration or ET_c) is a two-step approach. Crop evapotranspiration quantifies the atmospheric demand through the calculation of the reference evapotranspiration (ET_o) and the surface characteristics through a crop coefficient (K_c). The product of ET_o and K_c provides an estimation of the crop evapotranspiration:

$$ET_c = ET_o \times K_c \qquad (1)$$

Typically, the reference crop refers to an extensive surface of green grass of uniform height -8–15 cm tall, actively growing, completely shading the ground, and not short of water [7]. Crop coefficient depends on several factors including the crop type, stage of growth of the crop, canopy cover, and density and soil moisture. The Penman–Monteith [7] or Hargreaves [20] equations are used to estimate the evapotranspiration reference (ET_o) from measurements of meteorological variables readily available nowadays.

Most crop coefficients can be found in the FAO Irrigation and Drainage Paper No. 56 [7] and more recent publications [21]. For greenhouse horticultural crops, ET_c values for the main vegetable crops in southeast Spain were determined by [22] using the worldwide K_c-ET_o method as proposed by the FAO. In southwest Spain, several works determined crop coefficients for strawberry under greenhouse [13,23] and evaluates water relations and physiological and growth response to water shortage of different strawberry cultivars [24]. [25,26] proposed strawberry crop coefficients for southern coast of California.

Before plastic tunnel was setup, ET_o was estimated according to standardized Penman–Monteith equation [7]. The ET_o into the greenhouse was estimated using the methodology proposed by [27]. It was developed on the Southeastern Mediterranean coast, at similar latitude than Doñana National Park. A weekly ET_o forecast was used in the scheduling for estimating the irrigation time of the next week. ET_o forecast was estimated from weather forecast of the Spanish Meteorological Agency (AEMET). During the first two irrigation seasons, the ET_o was estimated according to the methodology proposed by [18]. From the third irrigation season, a variant was introduced in the forecast of solar radiation according to [28]. Likewise, two automatic weather stations were installed inside two greenhouses of the IFAPA irrigation trials. These weather stations measured the temperature and relative humidity of the air (HMP 45C probe, Vaisala, Vantaa, Finland) and solar radiation (CM3 pyranometer, Kipp and Zonen B.V., Delft, The Netherlands), storing the data in a CR10X datologger (Campbell Scientific, Logan, UT, USA). Both meteorological stations were included in the SIAR Network and their data could be consulted online [11]. With the data measured in the meteorological stations, the ET_o was calculated to compare it with the ET_o forecasted from the AEMET meteorological data. Thus, a quality control of the method used in the irrigation scheduling was carried out throughout the irrigation season.

The crop coefficient (K_c) was estimated as proposed [25] during the first two irrigation season. From the third season, local crop coefficients obtained by [13] were used. Both methodologies are based on the relationship between the crop coefficient and the coverage. Green canopy coverage is the fraction of the soil surface covered by green canopy cover. The values of green canopy coverage were measured using digital photography techniques. Irrigation application efficiencies from 60 to 90% were used in the irrigation scheduling along the season. The lowest values were used for the first weeks following the transplantation to ensure a proper crop establishment. Irrigation application efficiency was increased throughout the season.

2.3. Irrigation Scheduling

The proposed method by FAO for irrigation scheduling is soil water balance [6]. Soil water balance was the methodology used by authors for irrigation scheduling. Irrigation requirements can be determined by measuring or estimating the various components of the soil water balance. The method consists of assessing the incoming and outgoing water flux into the crop root zone over some time period. Irrigation (I) and rainfall (R) add water to the root zone. Part of I and R might be lost by surface runoff (RO) and by deep percolation (DP) that will eventually recharge the water table. Water might also be transported upward by capillary rise (CR) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SF_{in}) or out of (SF_{out}) the root zone. In many situations, however, except under conditions with large slopes, SF_{in} and SF_{out} are minor and can be ignored. Soil evaporation and crop transpiration deplete water from the root zone. If all fluxes other than irrigation (I) can be assessed, the irrigation can be deduced from the change in soil water content (ΔSW) over the time period:

$$I = ET_c - R + RO + DP + CR \pm \Delta SF \pm \Delta SW \tag{2}$$

Under greenhouse rainfall (R) can be disregarded. Greenhouses have no slope and, therefore, RO and subsurface flow may not be considered. In sandy soils the capillary rise is also negligible. DP is difficult to estimate and it can be considered zero when daily irrigations are applied. Microirrigation makes the frequency of irrigation issue irrelevant because the primary concern is to match applications to crop water requirements daily. Therefore, irrigation is applied every day to replace ET_c and maintain non-limiting soil water content. In this case, the soil water balance method is very easy to apply when microirrigation is used [5]. Irrigation depth (I) was estimated from the ET_c and the irrigation application efficiency (E_a):

$$I = \frac{ET_o \times K_c}{E_a} \tag{3}$$

2.4. Measurement of Crop Evapotranspiration and Estimation of Local Crop Coefficients

To measure crop evapotranspiration and to estimate local crop coefficients a soil water balance was made within a confined soil volume using drainage lysimeters. For this, it was necessary to measure the volumes of irrigation water applied (I) and drained (D), as well as to monitor the soil moisture to estimate the variation of water storage (ΔSW). The irrigation water inlet was measured with volumetric flowmeters. To measure water drained, drainage lysimeters were used. Drainage lysimeters were constructed of polyester reinforced with fiberglass. The dimensions of the lysimeters were $1.40 \times 0.60 \times 0.60$ m. The drainage lysimeters fulfilled a double function: to measure the drained water as well as the farmers visualized water losses. For monitoring soil moisture, FDR probes EasyAG (Sentek Ltd., Stepney South Australia) and ECH2O, (Decagon Devices, Pullman, WA, USA) were used. Humidity probes measured volumetric soil moisture every 10 cm, up to 50 cm depth. Finally, crop evapotranspiration (ET_c) was estimated through a water balance in the lysimeters. In this case, rainfall was not taken into account because strawberries are cultivated under plastic tunnels and there was no runoff:

$$ET_c = I - D \pm \Delta SW \tag{4}$$

3. Results

3.1. Yield vs. Irrigation Depth

Irrigation depths of 57 plots were measured, ranged from 3700 to 12,400 m^3 ha^{-1} throughout five irrigation seasons. Similar yields were obtained for similar strawberry varieties in spite of the difference between irrigation depths (Figure 3). The differences in yields were not only due to different duration of the growing seasons, but also the degree of intensification (planting density) and the productive characteristics of the different

cultivars. Similar strawberry cultivars had similar productions with different volumes of irrigation applied for the same density of plantation and the same duration of the season (Figure 3). Therefore, it can be concluded that no deficit fertilization or irrigation occurred in any of the 57 plots.
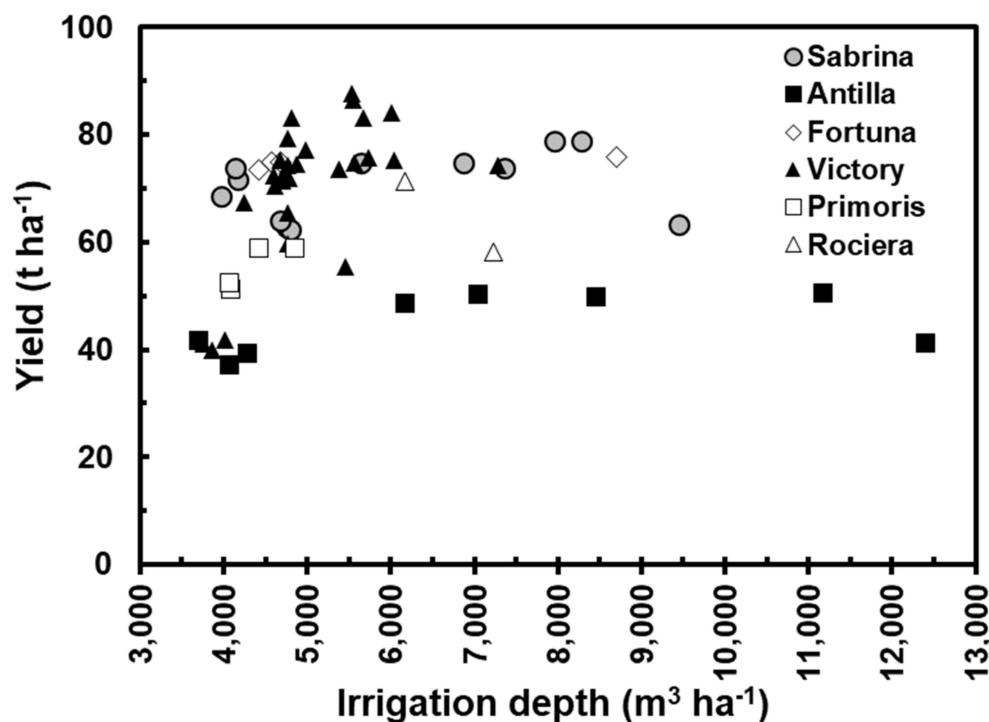

Figure 3. Applied irrigation depths and yields in 57 strawberry plots between 2012 and 2017 for six strawberry cultivars (Sabrina, Antilla, Fortuna, Victory, Primoris and Rociera) in the province of Huelva.

3.2. Farmer vs. Scheduled Irrigation Based on FAO Methodology

The reduction of the irrigation volume after IFAPA applying an irrigation schedule based on water balance, FAO methodology, included using weather forecast for estimating ET_o, was 44%. The average irrigation depth applied by the farmers in all the trials and commercial plots was 7622 m^3 ha^{-1}. The average irrigation depth applied by IFAPA was 4252 m^3 ha^{-1} (Table 2). During 2013/2014 season, there were no differences between yields of farmer and irrigation scheduled by IFAPA, despite the fact that the farmer's irrigation applied almost twice the amount of irrigation than IFAPA (Figure 4). Strawberry productivity was similar both for traditional farmer irrigation and IFAPA irrigation, around 1000 g $plant^{-1}$ in the most productive varieties. The average irrigation water productivity was 8.9 kg m^{-3} for the farmer irrigation and 14.5 kg m^{-3} for the scheduled irrigation, reaching maximum values close to 18 kg m^{-3} (Figure 5). Therefore, similar yields with very different water applied imply that saving water did not cause yield losses.

The irrigation application efficiency (the ratio between ET_c and irrigation depth) varied between 52 and 80% for scheduled irrigation and from 18% to 55% for the farmer irrigation (Figure 6). The value of 80% was the upper limit of the irrigation application efficiency throughout the whole irrigation season without producing yield losses. This upper limit of the efficiency is mainly due to two factors. The first factor is very sandy soils, sometimes with percentages of sand above 95%. Very sandy soils have very high hydraulic conductivity and low storage capacity. This produces quick water losses due to deep percolation if irrigation management is not adapted to these conditions. In these cases, irrigation by pulses is necessary. The second factor is the growing period, from October to May. This growing period is relatively cold, as it does not include the summer

months, which are the ones with the highest water demand. In addition, in these conditions of very sandy soils, a daily frequency of irrigation is required to maintain an adequate level of soil moisture in the root zone. On the other hand, the minimum irrigation pulse duration to achieve a water distribution uniformity higher than 85% is 15 min, assuming a standard flow of 5 L h^{-1} m^{-1} [19]. However, the daily irrigation time required from October to January was less than 15 min of irrigation per day. The daily irrigation frequency of minimum 15 min implies that the upper limit of irrigation application efficiency in a strategy that avoids loss of yield was 60% between the months of October and January. Since February, this efficiency limit increased because crop water requirements were higher than 15 min of irrigation per day. At the end of the irrigation season (May–June) it was possible to reach irrigation application efficiencies higher than 90%. Therefore, with these limitations in the irrigation-soil system and for maximum production conditions, the upper limit of irrigation efficiency for the entire campaign was 80% (Figure 6).

Table 2. Comparison of irrigation scheduled by farmer and IFAPA between 2012/2013 and 2016/2017 irrigation seasons (coefficient of variation in percent were indicated in parentheses).

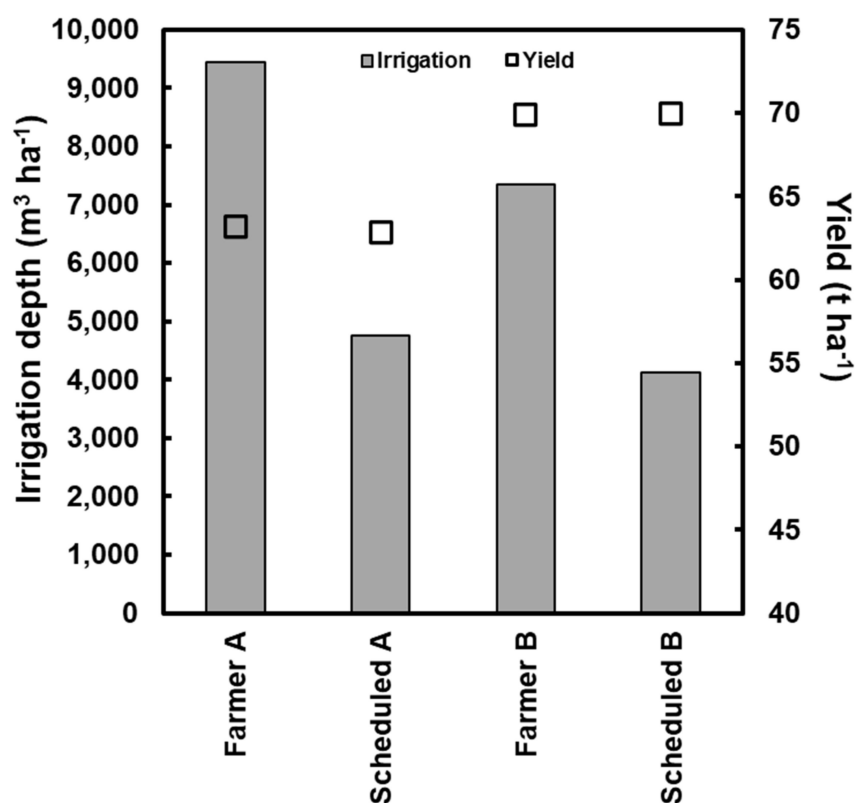|		Irrigation	Irrigation Application Efficiency	Crop Yield	Irrigation Productivity
		$(m^3 \ ha^{-1})$	(%)	$(g \ plant^{-1})$	$(kg \ m^{-3})$
IFAPA irrigation	Avg	4252 (13)	65 (11)	986 (17)	14.5 (17)
	Max	5554	80	1215	17.9
	Min	3332	52	558	7.9
Farmer irrigation	Avg	7622 (30)	40 (33)	998 (18)	8.9 (74)
	Max	11,163	55	1231	14.0
	Min	5015	18	613	3.3

Figure 4. Irrigation depth and yield in two strawberry trials during the 2013/14 season.
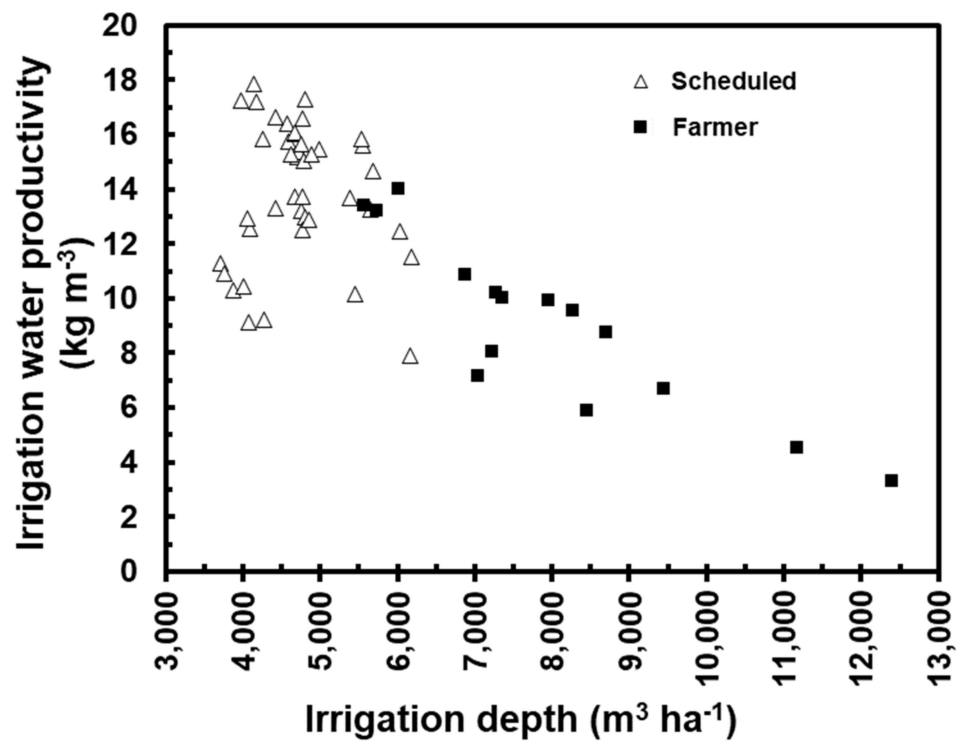
Figure 5. Irrigation water productivity as a function of the irrigation depth applied according to the irrigation scheduled by IFAPA and the farmer irrigation in 38 strawberry plots.
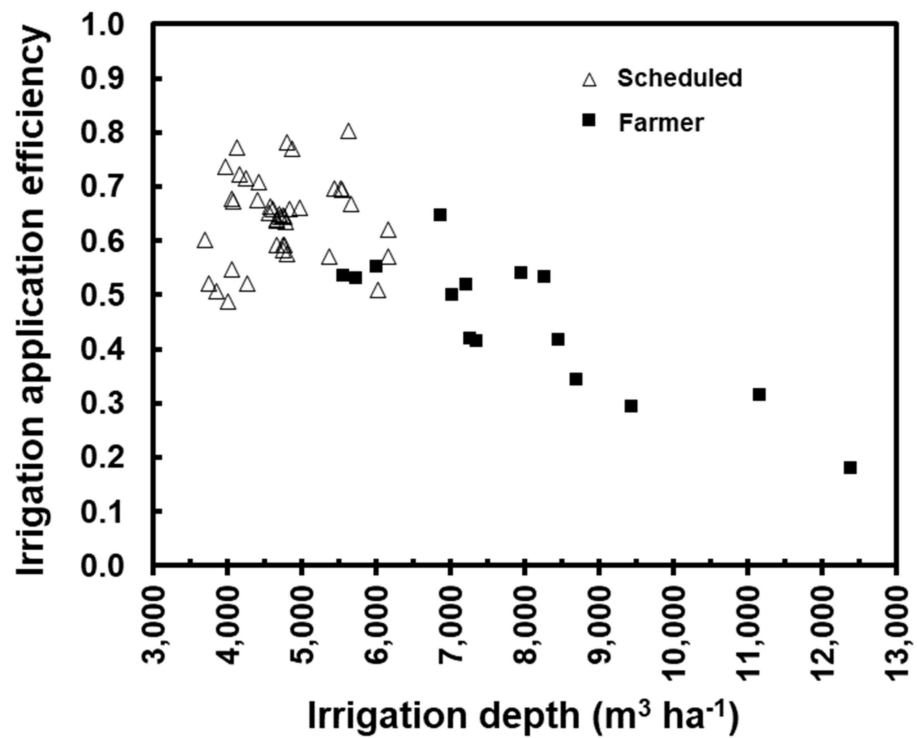

Figure 6. Irrigation application efficiency as a function of the irrigation depth applied according to the irrigation scheduled by IFAPA and farmers in 38 strawberry plots.

3.3. Process of Acceptance of Technological Innovation

The adoption by farmers of the innovation in irrigation scheduling proposed by the project was progressive. During the first three season, the farmers A and B embarked on a path of reducing irrigation (Figure 7a,b). This decrease in applied irrigation led to a considerable increase in irrigation application efficiency (Figure 8) and in irrigation water productivity (Figure 9). The modification of their irrigation habits was progressive, and it was based on the confidence of the results of the irrigation trials. Farmers could verify on their own farm that the decrease in irrigation did not imply a reduction in production (Figure 10). The leap to apply the irrigation methodology proposed by the project on a commercial scale occurred from the fourth year (2015/2016). In the 2015/2016 season, it is observed how the irrigation applied by the farmers and by IFAPA were similar (Figure 7a,b). In farms A and B there was an average reduction in irrigation of 1774 m^3 ha^{-1} and 678 m^3 ha^{-1} per year, respectively throughout the project. Farmers A and B at the end of the project applied an average irrigation of 4366 m^3 ha^{-1} and 5500 m^3 ha^{-1}, respectively, on a commercial scale (Figure 7a,b). On Farm A and B there was also an average annual increase in irrigation water productivity from 2.72 kg m^{-3} and 1.28 kg m^{-3}, respectively, reaching values of 13 kg m^{-3} and 13.7 kg m^{-3}, respectively (Figure 9). However, farmers do not understand increases in the irrigation efficiency or water productivity that are not linked to the maintenance or even improvement of yield and quality. In relation to this, it is observed that it was possible to increase the water productivity of strawberry irrigation in four irrigation seasons more than 60% without affecting production. Using average data from [29], the maximum values obtained of 18 kg m^{-3} of irrigation suppose an economic water productivity value of 24.3 euros m^{-3}.
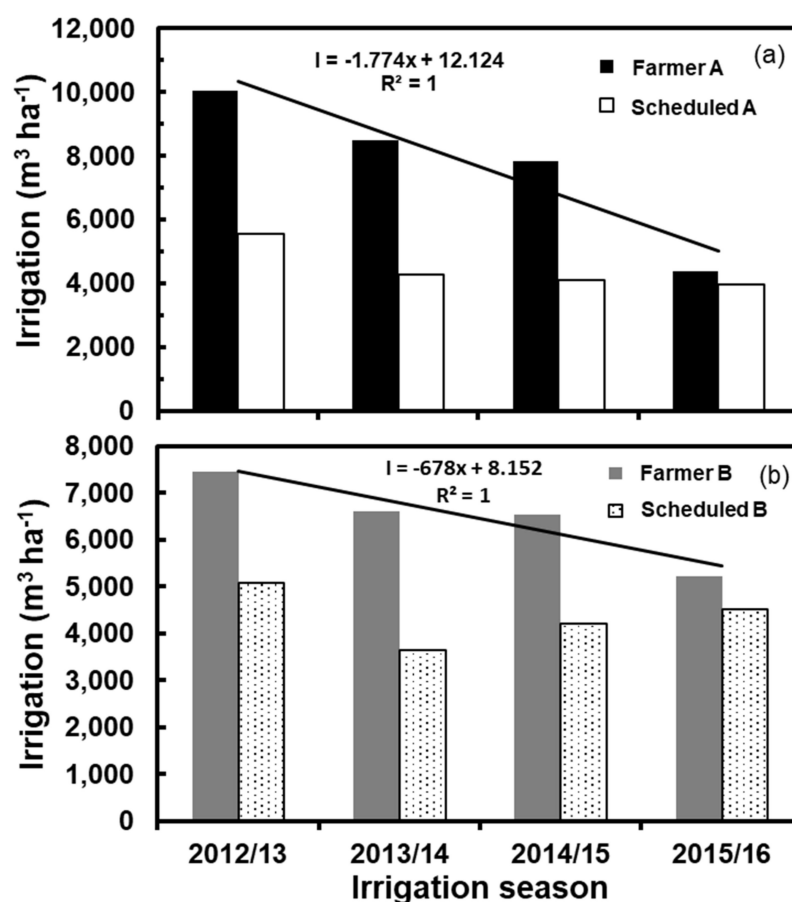

Figure 7. Irrigation applied by Farmer A (**a**), Farmer B (**b**), and irrigation scheduled by IFAPA in both cases.
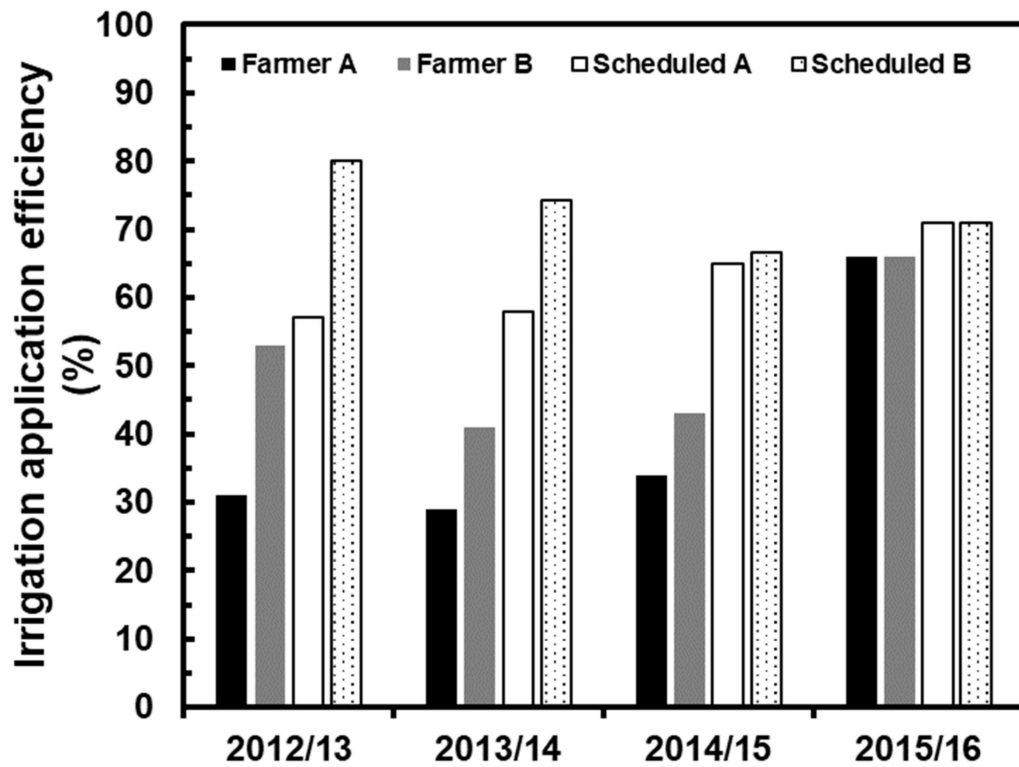
Figure 8. Irrigation application efficiency by Farmer A, Farmer B, and irrigation scheduled by IFAPA in both cases.
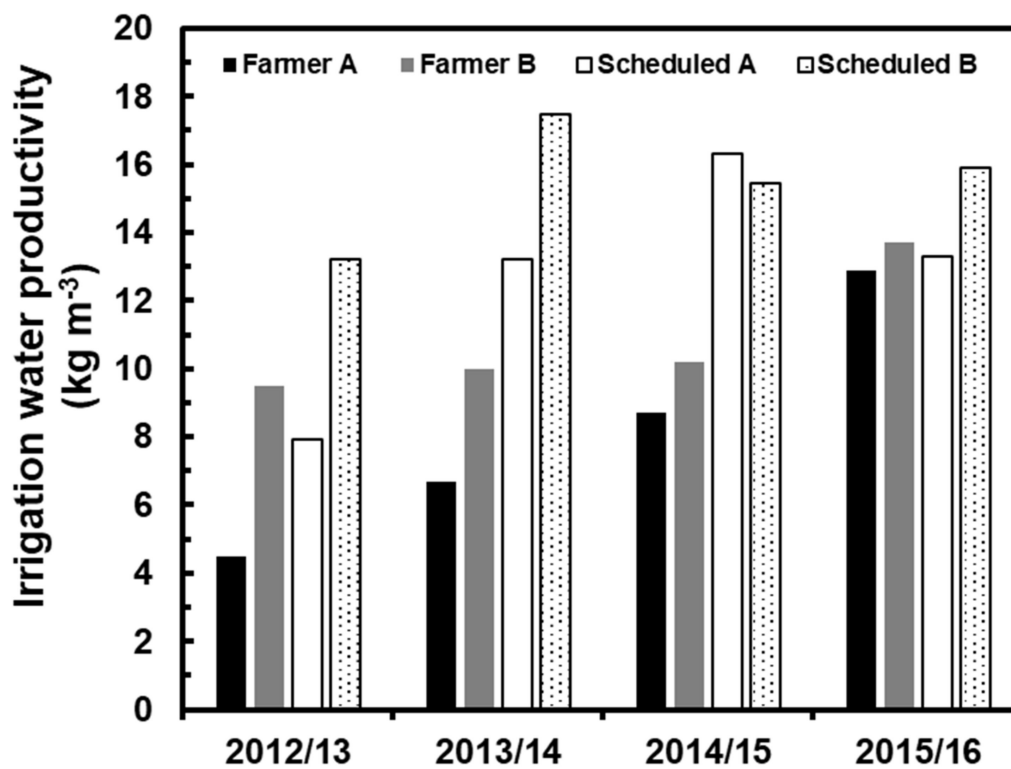

Figure 9. Irrigation water productivity by Farmer A, Farmer B, and irrigation scheduled by IFAPA in both cases.
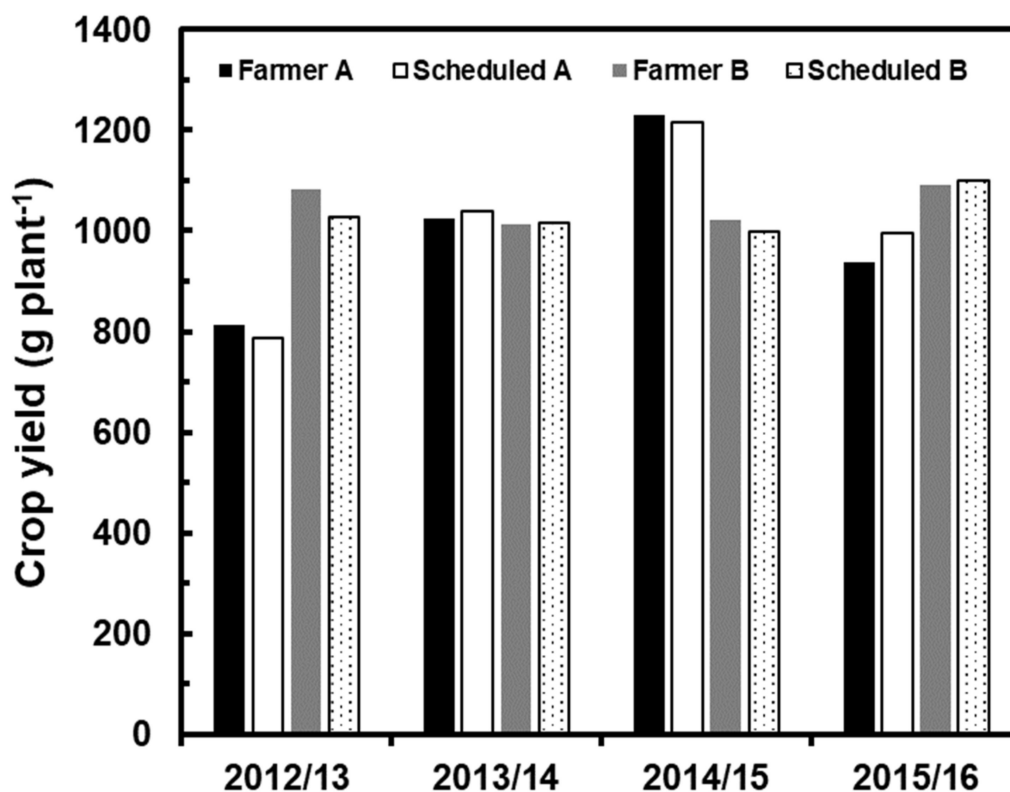
Figure 10. Crop yield by Farmer A, Farmer B, and irrigation scheduled by IFAPA in both cases.

4. Discussion

4.1. Relationship between Intensive Horticultural Systems in Southern Spain

Obtaining similar productions with very different irrigation depth (Figures 3 and 4) is very much like that which occurred in intensive greenhouse agriculture of Almería, Andalucía (Spain), during the 1990s. Application of a wide range of water volumes applied to cucumber, pepper and watermelon crops resulted in similar productions [30]. In both cases, there was a lack of knowledge with reference to the optimal supply of irrigation water to achieve maximum production without large water losses. Data from Almería in the 1990s and Huelva in the early 2010s, indicates that there were great opportunities to improve irrigation application efficiency despite the use of drip irrigation systems with a high potential for saving water. Likewise, the irrigation productivity values in the traditional farmer's irrigation were alike in strawberry, pepper, and bean crops in unheated greenhouses in Western Almería [31]. Under conditions of maximum production, the upper limit of irrigation efficiency of 80% for the entire season is comparable to that cited by [31] in bean and cucumber crops in greenhouses in western region of Almería in Southern Spain.

4.2. Barriers to Technological Innovation in Agriculture

The barriers to technological innovation in agriculture are related to the farmer's habits, the mechanisms for transferring research results from the public sector to farmer, and the role of companies that supply advice and technology services to the farmer. Human beings tend to carry out their tasks according to acquired habits. Once a work habit has been developed, changing it requires effort. To compensate for this effort, this modification has to be felt as a real improvement that makes the task easier or increases its profitability. In this sense, farmers are no exception [32]. Usually, new technologies that have reached agriculture are difficult to handle, costly to maintain, and need training for their installation, maintenance, and interpretation of the measurements [3]. All this information necessary for the success of a technological innovation is seldom readily available to farmers and

technicians [2]. Another handicap for innovation is that farmers often lack historical records of applied irrigation depth on their farms. The analysis of these historical irrigation records would allow to quantitatively evaluate the improvements made in irrigation management when a new technological innovation is used [33]. On the other hand, public research tends to perform work that never leaves the laboratory or trial fields. There is also a lack of social recognition for the work of technology transfer, in addition to the absence of public extension services. In this regard, the work that the Irrigation Advisory Services would carry out in combination with other government policies is fundamental [34]. Finally, for the most part, companies that supply technological developments to farmers lack sufficient size to contemplate their own R + D + i services. A final consideration is that these companies usually put clauses that exempt them from responsibility in the irrigation recommendations which reduces the confidence of the farmer. For these reasons, public advisory programs with improvement itineraries as that developed in this work are needed if the aim is to achieve a tangible improvement in terms of irrigation application efficiency and irrigation water productivity at field scale (Figures 8 and 9). Improvement itineraries must start from a quantitative knowledge of the initial situation if there are no historical data records related to irrigation. Only in this way is it possible to quantify the improvement that occurs as a result of the introduction of new innovation. Another important aspect in the IFAPA project was the use of economic productivity criteria to provoke a change in farmers' habits. In this sense, [35] described how the use of economic concepts helps more to change habits in the farmer than the more academic concepts related to the efficiency of the process.

4.3. Main Milestones in the Sustainability Improvement Itinerary Piloted by IFAPA

The main highlights in the itinerary to improve the sustainability of strawberry irrigation piloted by IFAPA from 2012 to 2017 were:

- Obtaining a crop development indicator adapted to the production systems of Huelva. In this sense, IFAPA generated a model that correlates the strawberry crop coefficient with the green canopy cover [13].
- Identification of two differentiated irrigation phases for optimal irrigation scheduling without loss of production. During the first phase of cultivation (October–February) the upper limit of irrigation efficiency in Huelva conditions is around 60%. From March to June (second phase) the efficiency can be progressively increased to 90%. The global irrigation application efficiency of the whole season is around 80%.
- The development of a methodology for the weekly forecast of reference evapotranspiration (ET_o) based on the climatic predictions of the public meteorological agencies as AEMET [18].
- The identification of the optimal duration of irrigation pulse for the production conditions of Huelva based on criteria of distribution uniformity, irrigation application efficiency and strategy to obtain potential production. For the most commonly used tape, $5 \text{ L h}^{-1} \text{ m}^{-1}$, the optimal duration of irrigation pulse to achieve a uniformity greater than 80% is in the vicinity of 15 min [19].
- The development of a methodology for evaluating the localized irrigation system considering the filling and emptying phases of the irrigation system [19].

In order to disseminate the innovations generated by the sustainability improvement itinerary, a wide dissemination of its benefits was carried out through specific training and demonstration to farmers and technicians. To this end, the project provided transfer and training activities in addition to experimental work in trial and farm plots. To summarize, throughout the project 12 courses and 14 field days, serving 686 farmers, with more than 600 h of teaching were carried out. Activities were carried out in 10 municipalities, two agricultural county offices, two irrigation communities, six cooperatives, and three companies.

IFAPA's advisory work on the improvement itinerary included irrigation recommendations at the beginning of the irrigation season, 475 weekly irrigation recommendations

with updating of the crop development conditions, 12 technical documents and informative articles, and nine reports to companies. The works were carried out within the framework of two contracts and three collaboration agreements with companies representing an area of 1914 ha (around 20% of the protected area). This role has traditionally been reserved for extension and advisory services promoted by the public sector [3].

5. Conclusions

The IFAPA project to improve the sustainability of irrigation in the surroundings of the Doñana National Park has been based on a holistic approach, with farmers being the main actors. The IFAPA project has achieved an increase of 66% in irrigation application efficiency and water productivity in an area of commercial strawberry farms of around 1900 ha. This improvement has resulted in an average water saving of 44% without loss of production. The new irrigation practices adopted, based on the use of irrigation calendars generated with the FAO methodology based on soil water balance, using ET_o meteorological forecasts, have assumed an economic advantage for farmers. The advantage for farmers has not only come from the reduction of the costs associated with irrigation energy and fertilizers, but also from a better positioning in the markets after demonstrating a greater sustainability of their production system.

The success of the itinerary to improve the sustainability of irrigation in the Doñana National Park has been based on the trust provided to strawberry producers. This trust has been achieved by working together with the farmers and technicians of the farms. As a consequence of this collaborative itinerary, farmers have made investments in irrigation management at commercial scale from the fourth year. Beyond the usual improvements in irrigation infrastructures, they have opted for irrigation management methodologies based on the monitoring of meteorological conditions, crop development, and soil moisture.

The acceptance by farmers of these innovations implemented in strawberry cultivation has led to a demand to carry out an itinerary to improve the sustainability of irrigation in the rest of berries (raspberry, blueberry, and blackberry). From the 2017/2018 season, IFAPA has been working with producers on a new itinerary to improve the sustainability of other berries in the province of Huelva.

The results obtained in this project have been largely due to the involvement of farmers from first phase of the project. The potential to transformation towards a more sustainable agrifood system must necessarily include the main actors, the farmers. Future work should be aimed at improving and systematizing this methodology for the active participation of farmers.

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