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Physical and Economic Water Productivity in Agriculture between Traditional and Water-Saving Irrigation Systems: A Case Study in Southern Italy

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Abstract: Water scarcity is a growing social, economic, and political issue, especially in Southern European countries that are becoming even more arid and where different crops can be cultivated only if irrigation is possible. In this context, strategies to enhance water use efficiency are regarded as critical from both an economic and an environmental standpoint. The present work aims to analyse water use efficiency and productivity of processing tomato in Apulia region of Southern Italy. Specifically, the study examines the potential enhancements in economic and physical water productivity through the simulation of the fully coupled FEST-EWB-SAFY model, a hydrological crop model that estimates the optimal water requirements for irrigation using satellite and ground data. The model's estimates suggest that plants require significantly less water than that provided by conventional irrigation systems. The simulations also suggest that information technology, when combined with irrigation water-saving techniques, can lead to a reduction in water waste, an increase in water productivity, and lower incidence of water costs. Policy interventions should integrate water efficiency into existing regulatory measures and promote better water usage planning through the adoption of smart delivery systems aimed at supplying water only when necessary and at optimal volumes.

Keywords: physical water productivity; economic water productivity; hydrological crop model; FEST-EWB-SAFY; processing tomato; Southern Italy

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Citation: Perelli, C.; Branca, G.; Corbari, C.; Mancini, M. Physical and Economic Water Productivity in Agriculture between Traditional and Water-Saving Irrigation Systems: A Case Study in Southern Italy. *Sustainability* **2024**, *16*, 4971. https://doi.org/10.3390/su16124971

Academic Editors: Anastasia Angelaki and Paraskevi Londra

Received: 29 April 2024
Revised: 31 May 2024
Accepted: 4 June 2024
Published: 11 June 2024

1. Introduction

The growing water scarcity is becoming an increasing social and economic issue for policymakers and competitive water users. Over the last 50 years, the global demand for fresh water has increased by more than 40% due to socio-economic development, rapid global population growth, and the demand for food associated with it [1]. Although the primary source of stress on freshwater resources is human activity, climate change affects the water cycle and causes devastating events like droughts and floods. The constant reduction in water quality and scarcity have put unprecedented pressure on arid and semi-arid regions, as well as humid areas. [2]. Irrigated agriculture is considered one of the largest users of water globally [3]. It represents 20% of the total cultivated land, contributes to 40% of the total food produced worldwide [4] and make up about 87% of global water consumption [5]. Approximately 60% of global freshwater withdrawals are devoted to irrigation. In Europe, the agricultural sector accounts for around 24% of total water use, peaking at 80% in the southern regions [6], where the balance between water demand and water availability has reached critical levels [7]. In this area, climate change-induced impacts, including reduced river flows, lower lake and groundwater levels, and wetlands drying up, are posing significant threats to freshwater ecosystems. The reductions in water availability and reliability in Southern Europe will be combined an increase in water demand due to population growth, which will trigger higher use across economic sectors. In particular, it is expected that agricultural water use will intensify to satisfy increased food demand. This means that more rural areas would need to be irrigated in the future, putting an additional strain on Europe's already stressed water bodies [8].

Since irrigation water is becoming an increasingly scarce resource for the agricultural sector [9], strategies to improve water use efficiency and productivity are considered determinant from both economic and environmental perspectives. In this regard, the use of crop growth models, that take into account crop growth dynamics and yield response to climatic conditions, could be very beneficial for planning and improving irrigation practices. In recent years, numerous models based on physical or semi-empirical equations have been combined with satellite data, whose availability has been enabled thanks to the rapid development and availability of remotely sensed data at various geographical and temporal resolutions [10]. They represent a reliable tool for describing and examining biomass evolution, and monitoring irrigation water needs while taking into account the relative effects of weather patterns, land surface temperature, and the cycles of water-energy fluxes. To quantify the impact of such models in terms of irrigation efficiency, several indicators have been developed over the years. Some of them take into account crop yields on evapotranspiration or irrigation volumes, while others consider the effect on water loss by drainage or soil degradation [6]. However, it is also critical to understand the economic component associated with the ability of such models to improve agricultural productivity, generate profits, and reduce costs. Since water is considered a productive factor with an economic value, potential savings in its use should be assessed and evaluated, considering both environmental and economic perspectives. The aim of this study is to analyse the physical and economic water productivity of agricultural production in Apulia region of Southern Italy, with a specific focus on the potential improvements connected with the simulation of the fully coupled FEST-EWB-SAFY model, an engineering instrument capable of estimating the amount of water required for irrigation purposes through the combination of the following elements: (i) the FEST-EWB model (flash flood event-based spatially distributed rainfall-runoff transformation-energy water balance model), an energy-water balance scheme that allows to compute continuously in time and distributed in space soil moisture and evapotranspiration fluxes; (ii) the irrigation optimisation strategy (SIM); and (iii) the simple algorithm for the estimation of crop yields (SAFY) [11].

The engineering and economic approaches used in the present study look at agricultural water use efficiency (WUE) and productivity (WP). WUE is a concept introduced by Briggs and Shantz [12] and refers to a relationship existing between plant productivity and water use. Specifically, it is defined as the ratio of biomass accumulation to water used [13]. Considering the use of water in irrigation systems, WUE is strongly related to the water losses that occur when water, moving from reservoirs, is conveyed to the farm, applied in the fields, stored in the soil, and finally utilised by horticultural products [14]. With reference to the computation of WUE, there is a debate in the literature on the conceptual framework underlying the existing indicators and how they should be used [15,16]. Indeed, WUE indicators can be defined based on different perspectives. Specifically, while Perry et al. [17] define WUE as a ratio between evapotranspiration and the total water applied by irrigation and precipitation, Osmond et al. [18] pay attention to the physiological processes of plants and obtain WUE by dividing the net CO_2 assimilation rate, or net photosynthesis, by the stomatal conductance. On the other hand, Flexas et al. [19] consider WUE as a ratio between the biomass produced by a plant and the total amount of water transpired or used. The theory of WUE is strongly connected with the concept of water productivity (WP), which was proposed by Kijne et al. [20] as a robust measure of the ability of an agricultural system to convert water into food. In a broad sense, it reflects the objectives of producing more food, income, and ecological benefits at less social and environmental cost per unit of water used [14].

In the present study, the analysis of water use efficiency and productivity focuses on the production of processing tomatoes, a high-water-demanding crop for which Italy is one of the current world-leading producers [21]. Tomato is considered one of the most intensive users of agricultural inputs in general and water in particular. Indeed, it is a long-season crop with irrigation water requirements estimated between 400 and 600 mm [22]. This crop needs a constant and adequate supply of water, especially during the flowering period, in order to prevent a reduction in fruit growth and size [23]. While a prolonged water deficit limits growth and reduces yield, excessive use of water may determine a reduction in fruit quality and yields due to the fruit's susceptibility to cracking and negative environmental impacts, such as nitrogen leaching [23]. Despite the availability of some on-farm irrigation schedules based on smart technologies, most tomato growing methods adopted in Italy use predefined intervals between irrigation supplies without taking into account the real crop water needs [24]. This irrigation scheme leads to water use inefficiencies, which may also have repercussions in the economic sphere of the farm.

The paper is innovative from different points of view. First of all, it was developed using a unique dataset that reports detailed information at the plot level over time. Furthermore, it combines an economic approach with an experimental engineering model with the aim of addressing the inefficient use of water across different dimensions. It also illustrates the performance of hydrological-crop models and water-saving technologies in an integrated manner.

The results obtained can support policymakers in the definition of effective water policy instruments; additionally, they can provide water suppliers and farmers with useful information for enhanced resource management and improved irrigation techniques.

Regarding the study's limitations, it is necessary to emphasise that the work is based on engineering simulations whose results are adapted within economic models that do not take into account elements related to human, social, and institutional contexts. This means that the findings of this study are only intended to highlight potential inefficiencies in irrigation systems that are currently in use, providing a point of reflection on possible interventions and improvements that certainly need to be tailored to the local agricultural contexts.

The paper is structured as follows. Section 2 describes the study area, illustrates the data used, and presents the methodologies applied. Results are illustrated and discussed in Section 3. Conclusions and policy implications are provided in Section 4.

2. Materials and Methods

2.1. Study Area

The study focuses on Puglia, an Italian region that exhibits a Mediterranean climate characterised by warm to hot, dry summers and mild to cool, wet winters. The agricultural sector is mainly based on the cultivation of permanent crops such as olives and grapes, as well as fresh-cut vegetables. The case study here considered is the Sud Fortore Area of the 'Capitanata Irrigation Consortium', which is located in the Apulia region (Southern Italy). In this area, tomato is one of the most important cultivated crops [25]. This crop's production relies on a wide range of growth practices connected with varied cropping sites (greenhouse or open field), fertiliser inputs (mineral or organic), and energetic requirements (electricity and fossil fuel) [26]. The growth season, which runs from May to August, is marked by high temperatures (sometimes above 40 °C) and little precipitation (180 mm, on average, between 1981 and 2010). This exposes the tomato plant to recurrent heat stress and water stress throughout critical phenological phases [27]. The case study here considered is characterised by a general scarcity of natural water resources [28]. The irrigation systems adopted are mainly based on groundwater, whose increasing exploitation risks to exceed the natural recharge rate of such a freshwater source. This is causing water table drawdown, well depletion, increased pumping costs, and severe seawater intrusion in coastal areas [29].

The study area's irrigation water distribution is centralised, with river basin authorities managing water allocation and local authorities (irrigation Consortia) handling water withdrawals and distribution, as well as infrastructure management [7]. The water pricing criteria adopted in the area consists of a binomial and block-rate tariff, which includes a fixed fee farmers pay to the Consortium per hectare of farmed area and a variable (low) tiered fee based on consumption [30]. Such systems do not promote efficient water use and often lead to water-intensive agricultural systems characterised by over-irrigation [7].

2.2. Data

Data used in the present analysis are extracted from the Farm Accountancy Data Network (FADN). This Accountancy Data Network is a European system of sample surveys conducted every year to collect accountancy data from farms, with the aim of monitoring the income and business activities of EU agricultural holdings. For the purpose of the present study, databases for the period 2011–2018 were selected. In order to evaluate the efficiency and productivity of irrigated crop production in the study area, 73 farms were selected from each dataset, with a subset identified that had grown processing tomatoes during each reference period. They were selected inside the territorial borders of the Capitanata Consortium test-area using the National Information System for Water Management in Agriculture (SIGRIAN) (Figure 1).

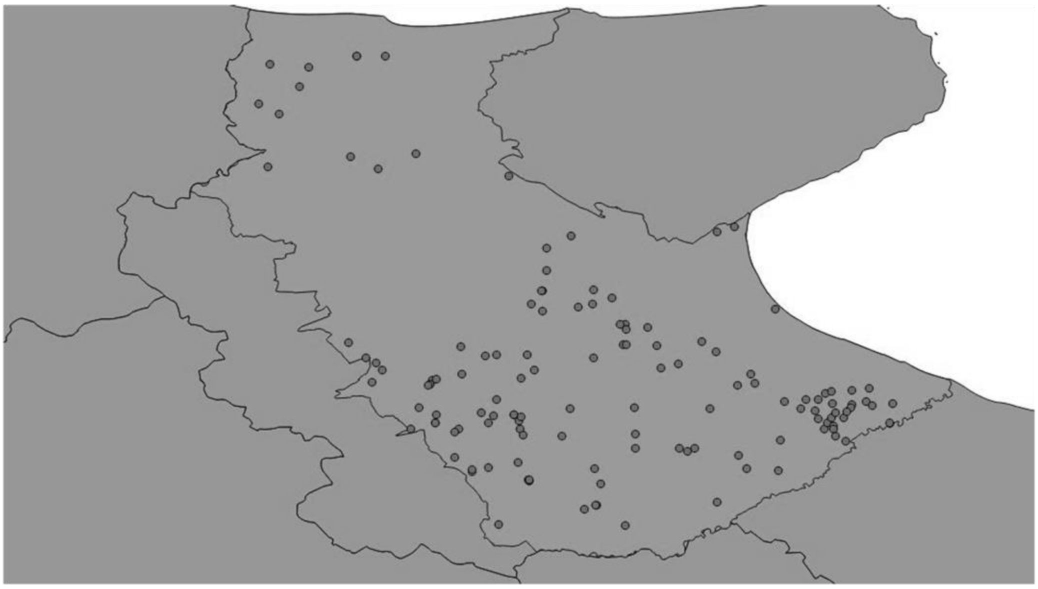

Figure 1. FADN farms located inside the Capitanata Consortium area.

For the purpose of the present study, the following information was extracted from the FADN dataset: (i) total gross production expressed in kilogrammes (kg); (ii) irrigated land measured in hectares (ha); (iii) water used for irrigation measured on a volume basis (m^3/ha); (iv) crop's selling price; (v) variable production costs associated with agricultural products produced; (vi) gross margin. With reference to the economic analysis, the following additional indicators were computed: (i) average crop yield (ACY), computed by dividing the total gross production by hectares (kg/ha); (ii) average gross sales production (AGSP), obtained by multiplying the selling price with average crop yield; (iii) average variable costs, generated by the ratio between total variable costs and hectares (EUR/ha); and (iii) average gross margin (AGM), computed by dividing gross margin by hectares (EUR/ha). Considering water use related variables, we computed the following indicators: (i) average water used (AWU), obtained by dividing the total amount of irrigation water by the number of hectares of land (m^3/ha); and (ii) the average water expenses paid to the Consortium per hectare of land (AWEXP). As mentioned previously, this last variable was computed following the "binomial pricing system", a method widely used in Puglia to compute water tariffs to pay. Specifically, it is based on a fixed quota paid to cover general expenses (i.e., ordinary maintenance) and a variable contribution that accounts for the effective water quantity (m^3) used. The following formula is applied:

$$C = Q_f + VC_u$$

where C is the contribution paid by water users; Q_f is the fixed contribution per hectare of irrigated land for the maintenance of the Consortium system (it is paid also if the land is not cropped and the water is not used) and amounts to EUR 30; V is the volume (expressed in m^3) of water distributed; and C_u is the unitary contribution by m^3. The latter parameter is determined based on the amount of water used: it amounts to EUR 0.12 for every m^3 of water used below the volume of 2050 m^3/ha; EUR 0.18 for every m^3 of water used between 2050 and 4000 m^3/ha; and EUR 0.24 for every m^3 of water used above 4000 m^3/ha.

2.3. Methodology

The analysis here proposed aims to assess and compare physical and economic water productivity considering two distinct approaches for calculating irrigation water supply: (i) the traditional scheduling based on predefined intervals between irrigation supplies; and (ii) the simulation of an integrated hydrological crop model (FEST-EWB-SAFY) which enables the estimation of crop water requirements and irrigation based on the actual demands of the plant. The generated findings are supplied with statistics that describe the variables utilised (i.e., mean and standard deviation) as well as the statistical significance of the acquired parameters (through the use of *t*-tests).

2.3.1. Water Productivity Indicators

Water productivity can be expressed in physical and economic terms [31,32]. Specifically, while physical water productivity is the ratio of agricultural output (crop yields) to the amount of water utilised [33], economic water productivity represents the economic value derived from each unit of water used. [34].

The physical water productivity is defined as the ratio of the crop yield achieved (kg per hectare) to the quantity of water used (m^3 per hectare). It can be computed based on the total water use (TWU) or, alternatively, the irrigation water use (IWU) [15,20]. For the purpose of the present study, the denominator of such an indicator refers to irrigation water use (IWU) and does not consider the amount of precipitation:

$$\mathrm{PWP} = \frac{\mathrm{Yield\ (kg)}}{\mathrm{IWU}}$$

Economic water productivity refers to the ratio between outputs and inputs in monetary terms [16]. With reference to the formula, while some authors consider the gross margin as the numerator, some others use the net margin (particularly in those cases where crops need huge initial investments) or the profits [16]. The economic water productivity (EWP) is here obtained by dividing the gross margin by the irrigation water used (IWU):

$$\mathrm{EWP} = \frac{\mathrm{Gross\ margin\ (EUR)}}{\mathrm{IWU}}$$

Finally, in order to estimate the incidence of water expenses on the agricultural budget, and then quantify the economic importance of efficient irrigation water systems in terms of costs, the water cost incidence was computed as the ratio of the costs of water used for irrigation and the total variable production costs:

$$\text{water cost incidence} = \frac{\text{cost of IWU}}{\text{Variable cost}} * 100$$

2.3.2. The Hydrological-Crop Model FEST-EWB-SAFY

The present work looks at the simulation of the hydrological-crop model FEST-EWB-SAFY, a new technological approach based on the implementation of a system for operative irrigation water management able to monitor crop water needs, reduce irrigation losses, and increase water use efficiency [10]. Such a system couples satellite (land surface temperature LST and vegetation information) and ground data with pixel-wise hydrological crop soil water energy balance model. Specifically, the Simple Algorithm for Yield (SAFY) crop model is applied together with the pixel energy water balance FEST-EWB model, whose main purpose is to compute continuously in time and distributed in space the soil moisture dynamic, the crop water requirements, as well as the crop yield [10]. The FEST-EWB model is based on the system of energy–water balance equations, which are written in terms of the LST, which is the land surface temperature that allows closing the energy balance equation, so that this model internal variable can be directly compared with remotely sensed LST. Thus, by solving the water balance equation, estimates of the soil moisture (SM) and evapotranspiration (ET) dynamic could be computed, according to water availability. The SAFY model is a parsimonious agronomical model that simulates the Green Area Index (GAI) and Dry Aboveground Mass (DAM) at a daily time step [35], combining the Monteith's light-use efficiency theory with a leaf partitioning function. The biomass estimates are then converted into crop yield through the harvest index. The SAFY model has been previously demonstrated to produce reliable estimates of dry biomass for wheat in semi-arid regions, as well as for over irrigated or rainfed maize, sunflower, and soybean in the southwest of France [36].

The coupled model also implements an irrigation strategy based on soil moisture and crop stress thresholds [37], which allows the triggering of irrigation only when needed and with an optimised volume [11]. This approach was defined to address water use inefficiencies, particularly in those agricultural contexts relying on irrigation systems and characterised by persistent water exploitation.

3. Results and Discussion

3.1. Evolution of On-Farm Economic Indicators over Time

Before assessing the water productivity of tomato processing, the on-farm economic indicators used in this study were analysed and described, taking into account their evolution over time (Table 1). Furthermore, in order to evaluate the influence of climate variability and water availability, a few economic variables were also combined and correlated with information related to average temperature (°C) and cumulative precipitations (mm) observed in the study area during the season April–November. Results show that, in the time period considered, the average crop yield (ACY) amounts to 95,917 kg/ha. Its trend is, however, unstable, with a minimum level registered in 2017 (68,380 kg/ha) and a peak registered in 2011 (120,086 kg/ha). Among all possible factors that may have affected changes in the volumes of output obtained, the climatic aspect should be considered. As confirmed by the Pearson's coefficient (ρ) (Table 2), the average yield for processing tomatoes is positively correlated with temperatures (ρ = 0.55). Crop growth is directly impacted by temperature, which can also significantly alter plant phenology. It has been determined that the ideal temperature range for tomato growth is between 22 and 28 °C, indicating that lower average temperatures may result in lower tomato yields. On the other hand, it is important to consider that a significant rise in temperatures, as foreseen by climate change projections, can have a dominant role in the shortening and anticipation of the tomato growing cycle, with unavoidable bad consequences in terms of plant productivity [38]. At the same time, the correlation between ACY and average cumulative precipitation was found to be weak and negative (ρ = −0.33). This implies that an increase in rainfall may result in a decrease in agricultural output, confirming that excessive water utilisation may result in worse agricultural yields. However, the lack of significance for these parameters leads us to evaluate such results with caution and deserves a more comprehensive econometric analysis that takes into account the action of many other variables potentially connected to tomato crop productivity (e.g., weed management, fertiliser, and pesticide use, distribution of precipitations during the season, etc.).

Table 1. Economic on-farm indicators of processing tomato, by year (2011–2018).

	Temperature	Precipitations	AWU	ACY	PRICE	AGSP	AVC	AGM	AWEXP
Year	**(°C)**	**(mm)**	**(m^3/ha)**	**kg/ha**	**EUR/kg**	**EUR/ha**	**EUR/ha**	**EUR/ha**	**EUR/ha**
2011	25.3	133.6	4848	120,086	0.11	13,389	4294	9095	1185
2012	17.8	501.8	2800	90,833	0.03	10,433	6455	3978	598
2013	23.4	90.6	5817	95,649	0.10	9592	3372	6219	1658
2014	21.1	214.6	7090	88,206	0.10	9015	3710	5305	1950
2015	23.9	113.3	8420	100,636	0.09	9378	3873	5505	2056
2016	22.3	150.4	3630	98,489	0,10	9691	3733	5958	2767
2017	17.5	446	3120	68,380	0.10	6569	2652	3916	622
2018	17.2	594	2919	105,059	0.11	11,626	3903	7724	819
Mean	21	281	4831	95,917	0.09	9962	3999	5963	1457
Std.Dev.	3	201	2108	14,834	0.03	1989	1102	1763	781

Source: Authors' elaboration from FADN data (2011–2018).

Table 2. Correlation coefficients between climate variables, AWU and ACY.

Pearson's Coefficient	Temperatures	Precipitations	AWU	ACY
Temperatures	1.000			
Precipitations	−0.9455 ***	1.000		
AWU	0.6831 *	−0.7145 **	1.000	
ACY	0.5547	−0.3327	0.1669	1.000

* significant at 10%, ** significant at 5%, *** significant at 1%. Source: Authors' elaboration.

As shown in Table 1, inconstant values of ACY, together with the fluctuations registered with reference to the sell price, affected the trend of the gross sale production (AGSP), whose average amount is equal to 9962 EUR/ha. Furthermore, this variability had an impact on the value of the AGM, which was also influenced by changes in the variable costs (probably linked to changes in the quantities of inputs used and/or the underlying price dynamics). An inconstant trend is also detected considering the indicators connected with water quantity used (AWU) and the related costs (AWEXP). Results show that the average amount of water expenditure fluctuates over time. This is presumably due to the fluctuation in the quantity of average water used within the same time period, which may be related to the climate. In this regard, the correlation coefficient, computed considering AWU and cumulative precipitations, was found to be statistically significant and equal to −0.7145, indicating a strong and negative relationship. At the same time, a positive and strong correlation was detected between AWU and temperatures ($\rho = 0.68$). This means that rainfall patterns, which impact plant water availability, and temperature variations, which are primarily related to evapotranspiration and the relative soil moisture retention capacity, are usually taken into account when adjusting irrigation. However, as also illustrated by the time series here proposed, such coordination between irrigation and climate variables might not always appear to be flawless. In this regard, it should be taken into account that the climatic data here used are cumulative and do not allow us to investigate the impact of rainfall frequency and intensity on crop productivity and irrigation water consumption. They were also collected at the regional level, preventing a more accurate investigation of the microclimate effects. Moreover, another element not detected by the analysis (due to lack of data) is represented by the irrigation technology used by farmers, which certainly has a pivotal role in the amount of water used for irrigation. In fact, although 70% of farmers in Puglia use a drip irrigation system for tomato cultivation, about 30% of them adopt sprinkle irrigation, which leads to a greater dispersion of water and a consequent greater exploitation of such a natural resource.

3.2. Water Productivity under Traditional Irrigation Scheduling

Table 3 shows the fluctuations of the physical water productivity (PWP) and the economic water productivity (EWP), as well as the incidence of water cost on the total variable cost between 2011 and 2018. Results show that the trend of PWP and EWP is similar, with the lowest values reached in 2015. As previously illustrated, this year showed the highest level of m^3 of water used per hectare. This means that the denominator of both PWP and EWP has increased significantly, while the numerators have remained near the average value. Such an outcome demonstrates that greater irrigation water use (which is not always justified by reduced rainfall) does not necessarily lead to a higher productivity. Additionally, the water cost incidence recorded a high figure of 55% in the same year. However, this last parameter should be interpreted with caution, as it is also connected to the farm's general expenditures incurred during agricultural activities.

Table 3. Water productivity indicators, by year (2011–2018).

Year	Physical Water Productivity (PWP)		Economic Water Productivity (EWP)		Water Cost Incidence	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
2011	22.83	17.65	1.76	1.37	0.21	0.07
2012	32.59	2.87	1.38	0.76	0.14	0.13
2013	19.66	7.39	1.32	0.70	0.51	0.30
2014	23.68	18.41	1.25	0.81	0.64	0.73
2015	16.04	13.41	0.87	0.72	0.55	0.23
2016	40.87	32.25	2.45	2.02	0.65	0.58
2017	49.42	44.32	3.02	3.22	0.30	0.45
2018	51.26	31.65	3.32	1.43	0.24	0.28

Source: Authors' elaboration from FADN data (2011–2018).

3.3. Impact of FEST-EWB SAFY Model on Water Productivity and Water Costs

Considering a sub-sample of farms selected in the period 2014–2016, the FEST-EWB-SAFY hydrological-crop model was simulated on FADN data to identify potential improvements in water productivity linked to smart irrigation scheduling techniques. With reference to the computation of the irrigation water used, such simulation was carried out taking into account the estimated crop's water needs as well as the weather conditions observed during the time period considered. In order to isolate the impact that the efficient use of water has on agricultural productivity, the quantity and value of all the other agricultural inputs (e.g., labour) were assumed to be constant. As shown in Table 4, the simulated amount of water for irrigation was found to be substantially lower than that actually recorded by the same group of farms. This difference is visible in all the three years considered in the simulation. This indicates that the observed irrigation scheduling adopted by the sampled agricultural units, although strongly connected with the farm's physical characteristics and whether occurrences, is unable to guarantee a proper amount of water for the crop. What occurs is an excess in the utilisation of water resources, which does not result in proportional advantages in terms of output quantity. Indeed, as illustrated in Table 5, the yields computed through the hydrological crop model were found to be higher than those obtained by farmers sampled in the FADN database in 2014 and 2016 (despite statistically significant only in 2014), while, in 2015, they showed no substantial and significant differences. This finding is not surprising; smart irrigation solutions are designed to decrease water waste while maintaining appropriate output levels, not to boost production.

Table 4. Irrigation water used for processing tomato, by technology (2014–2016).

	m^3/ha 2014		m^3/ha 2015		m^3/ha 2016	
	FEST-EWB-SAFY	**FADN Observed**	**FEST-EWB-SAFY**	**FADN Observed**	**FEST-EWB-SAFY**	**FADN Observed**
Mean	3264.20	4708.60	2144.00	8810.00	1374.00	5666.67
St.Dev.	332.75	2274.28	221.70	978.61	280.59	2886.75
Difference	−1444.40		−6666.00		−4292.67	
t-test	−1.86		−12.99		−2.70	
p-value	0.096		0.005		0.114	

Source: Authors' elaboration from FADN data (2014–2016).

Table 5. Processing tomato yields, by technology (2014–2016).

	kg/ha 2014		kg/ha 2015		kg/ha 2016	
	FEST	**FADN**	**FEST**	**FADN**	**FEST**	**FADN**
Mean	103,427.10	82,847.60	89,366.67	90,387.33	133,100.00	116,101.00
St.Dev.	13,534.46	26,284.48	11,634.57	10,511.46	29,365.46	42,889.17
Difference	20,579.50		−1020.68		16,999.00	
t-test	3.8469		−0.451		1.6753	
p-value	0.0039		0.6964		0.2359	

Source: Authors' elaboration from FADN data (2014–2016).

Considering such estimations in the computation of water productivity indicators, it is possible to notice that, both PWP and EWP are higher with respect to what was obtained using real and observed parameters (Tables 6 and 7). These changes were less noticeable in 2014, but they became clearer and statistically significant in 2016. In that year, the average amount of water estimated by the FEST-EWB-SAFY model was about 31% less than what was actually provided. The estimated agricultural yields were instead 13% greater than those really obtained. Such findings confirm the physical and economic inefficiency of the irrigation systems actually adopted in the study area. The excess in cubic metres of water used is far greater than the real needs of the crop and does not generate any real advantage in terms of agricultural productivity and profits. An intensive use of water resources leads instead to an increase in water costs (Table 8), and, consequently, a greater impact that they have on production costs (Table 9).

Table 6. Physical water productivity, by technology (2014–2016).

	PWP_2014		PWP_2015		PWP_2016	
	FEST	**FADN**	**FEST**	**FADN**	**FEST**	**FADN**
Mean	25.93	22.59	42.14	10.33	82.54	21.93
St.Dev.	10.01	16.06	1.71	1.47	16.97	8.24
Difference	3.342		31.810		60.613	
t-test	0.7248		154.788		5.4602	
p-value	0.4870		0.0000		0.0319	

Source: Authors' elaboration from FADN data (2014–2016).

Table 7. Economic water productivity, by technology (2014–2016).

	EWP_2014		EWP_2015		EWP_2016	
	FEST	**FADN**	**FEST**	**FADN**	**FEST**	**FADN**
Mean	1.56	1.24	2.40	0.59	3.96	1.14
St.Dev.	0.83	0.76	0.23	0.12	0.84	0.68
Difference	0.322		1.807		2.823	
t-test	1.322		25.189		29.365	
p-value	0.219		0.002		0.001	

Source: Authors' elaboration from FADN data (2014–2016).

Table 8. Average water irrigation cost for producing processing tomato, by technology (2014–2016).

	AWEXP 2014		AWEXP 2015		AWEXP 2016	
	FEST	FADN	FEST	FADN	FEST	FADN
Mean	1171.50	1491.00	809.33	2296.67	486.00	1318.00
St.Dev.	511.10	1001.67	99.08	121.82	276.17	493.13
Difference	−319.500		−1487.333		−832.000	
t-test	−1.9042		−11.836		−2.1286	
p-value	0.0893		0.0071		0.1671	

Source: Authors' elaboration from FADN data (2014–2016).

Table 9. Water cost incidence, by technology (2014–2016).

	EWPR_2014		EWPR_2015		EWPR_2016	
	FEST	FADN	FEST	FADN	FEST	FADN
Mean	0.39	0.51	0.25	0.71	0.11	0.24
St.Dev.	0.24	0.42	0.12	0.10	0.10	0.09
Difference	−0.121		−0.463		−0.130	
t-test	−1.967		−7.505		−5.629	
p-value	0.081		0.017		0.030	

Source: Authors' elaboration from FADN data (2014–2016).

4. Conclusions

The present work aims to analyse the physical and economic water productivity of agricultural production in Southern Italy, including its evolution over time and the impact of changing climatic conditions. The study also aims to highlight inefficiencies in traditional irrigation systems by simulating the FEST-EWB-SAFY hydrological crop model, a new technology that combines satellite forecasts and soil data for real-time water management. The study highlights the existence of inefficiencies related to the use of traditional irrigation systems. The FEST-EWB-SAFY hydrological crop model simulation indicates that tomato water needs are significantly lower than their actual distribution. A smart irrigation system based on this model not only saves water but also reduces production costs, maintains agricultural output, and allows greater levels of economic water productivity. This means that the hypothetical adoption of information technologies capable of predicting weather events and estimating the actual water needs of crops, when combined with water-saving techniques, can potentially lead to a more efficient use of water and significant benefits in terms of economic productivity and costs. However, it should be highlighted that, while farmers' decisions are typically based on rational behaviour aimed at maximising profits and lowering expenses, they can also be influenced by a variety of other factors, resulting in a degree of heterogeneity in the decisions made and actions taken. Irrigation practices can be explained by the association of factors directly related to the agricultural system (e.g., soil structure, irrigation technologies available, etc.), structural factors (e.g., water pricing criteria used, current regulations), and psychological elements that are not directly observable (e.g., farmer risk aversion, decision-making factors). The adoption and promotion of innovative and more efficient irrigation methods must take into account local needs as well as institutional, social, and economic circumstances.

In light of this, policy interventions should incorporate water use efficiency into regulatory measures and promote intelligent water management systems. These systems should provide water only when needed and according to crop needs, avoiding overexploitation and reducing climate-change-related uncertainty problems. They should also be tailored to local contexts and specific farmers' needs. However, further research is needed to understand the potential structural and maintenance expenses farmers may face from smart irrigation technologies, as well as the economic and regulatory barriers that may hinder this transition.

Author Contributions: Conceptualization, C.P., G.B., C.C. and M.M.; Formal analysis, C.P. and C.C.; Methodology, C.P., G.B., C.C. and M.M.; Supervision, G.B., C.C. and M.M.; Writing—original draft, C.P. and C.C.; Writing—review & editing, C.P., G.B., C.C. and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been developed under the 2018–2021 project 'RET-SIF real time soil moisture forecast for smart irrigation', ERANETMED Programme of the European Union, prot. MIUR/ERANETMED n. 0038. It was funded by the Italian Ministry of Education, Universities and Research (MIUR), Fondo per gli investimenti nella Ricerca Scientifica e Tecnologica (FIRST).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data will be made available on request.

Acknowledgments: The authors wish to thank the Handling Editor and the anonymous reviewers for their thorough reading of our manuscript and their comments that have helped us to significantly improve the work.

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

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