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Determining Irrigation Requirements of Extensive Crops Using the Typical Meteorological Year Adjusted to the Growing Cycle Period

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Abstract: In the Castilla-La Mancha (CLM, Spain) region, most of the irrigated area is managed by two different strategies in which the previously defined irrigation requirements of crops affect both the distribution of crops and the sustainable management of groundwater resources. Thus, in the western Mancha system, the amount of irrigation water per farm is limited, while in the eastern Mancha system the irrigable area per farm is limited. Therefore, the use of average irrigation requirements in these areas may cause yield drops in dry years and the overuse of groundwater. Consequently, the main aim was to achieve a better approach to the irrigation requirements of the main extensive crops in CLM (maize (*Zea mays* L.), onion (*Allium cepa* L.), garlic (*Allium sativum* L.), and barley (*Hordeum vulgare* L.)) to help farmers and water authorities achieve higher yields and a more sustainable use of water resources. The typical meteorological year (TMY) methodology combined with the MOPECO model were used to: (1) determine the distribution of wet, intermediate, and dry years during the growing cycle of the four selected crops; (2) determine the average (AVE) and typical irrigation requirements of these crops for the complete 70 years series (TMY_G) or the duration of the crop cycle (TMY_C), and under wet (TMY_W), intermediate (TMY_I), and dry (TMY_D) year conditions; and (3) recommend the irrigation depths to be used for the management of farms and water bodies. The results show that the number of wet, intermediate, and dry years depends on the growing cycle of the crop considered, with wet years being unusual, although they notably increase the average rainfall in the area. The irrigation requirements for the average year were between 20.4 and 9.0% lower than the average irrigation requirements calculated for the four studied crops during the 70 years of the series. For western Mancha farmers the recommended irrigation depth for dry years and most profitable crops (garlic and onion) is the one calculated for the driest year of the series, while for the rest of the years and crops is that estimated by the global dry TMY (TMY_{GD}). For eastern Mancha farmers the recommended irrigation depths are also those estimated by the TMY_{GD}.

Keywords: climatic series; typical meteorological year; average year; MOPECO; garlic; barley; onion; maize

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1. Introduction

The growing competition for water, due to the increase in demand for different uses, has led to greater limitations on its availability for irrigation. In addition, the agricultural policies of the European Community seek to eliminate the possible negative environmental impact caused by its use. Moreover, climate change may decrease the availability of water for irrigation due to extreme drought periods and temperature rises, which also may affect the crop growth duration and final yield. Consequently, in water-scarce areas, such as the Castilla-La Mancha (CLM) region located in the middle of Spain (Figure 1), farmers are limited in the use of water so as to safeguard the sustainability of the water sources.

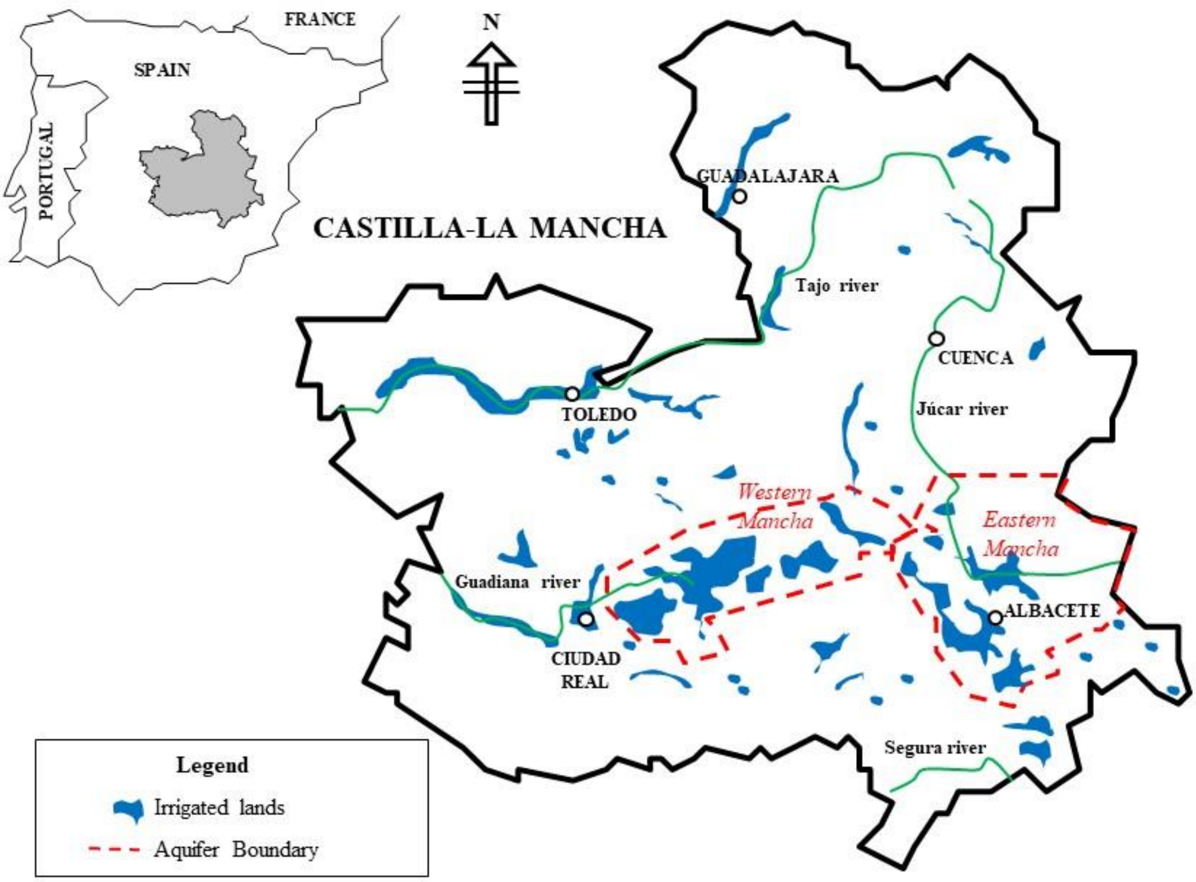

Figure 1. Distribution of the irrigated lands in Castilla-La Mancha.

The use of irrigation in CLM is the result of a low average annual precipitation (around 400 mm year^{-1}) and high reference evapotranspiration (>1100 mm year^{-1}), characterizing the area as semi-arid [1]. In addition, water endowments are below the national average (2700 vs. 4000 m^3 ha^{-1}) [2] and are clearly insufficient to fulfill the irrigation requirements of most of the crops in the area (between 2600 and 7000 m^3 ha^{-1}) [3], forcing farmers to leave a portion of the irrigable area as fallow or to cultivate it with rainfed crops.

The main irrigable areas in CLM depend on groundwater resources that belong to western and eastern Mancha aquifers (Figure 1). These hydrogeological systems are controlled by the water authorities called the *Confederación Hidrográfica del Guadiana* (CHG) and *Confederación Hidrográfica del Júcar* (CHJ) to avoid the overexploitation problems that arose during the transformation from rainfed to irrigated farms more than 40 years ago [4–6]. In the case of the irrigation area of the western Mancha aquifer, each year, CHG (www.chguadiana.es) (accessed on 16 February 2022) determines the volume of water that can be extracted and the amount each farm can use. This is regulated by means of meters installed on every farm, which are read by technicians from the Association of Groundwater Users (CUAS, in its Spanish acronym), who transmit the data to the CHG in order to check user compliance. This is an efficient way to control the water extracted from bodies of groundwater and to ensure its sustainability, if combined with monitoring of the piezometric levels of the aquifers, as specified in the hydrologic plan of the basin. In the case of eastern Mancha, the CHJ (www.chj.es) (accessed on 16 February 2022), in conjunction with the *Junta Central de Regantes de la Mancha Oriental* (irrigation board) (www.jcrmo.org) (accessed on 16 February 2022), is responsible for administering the available water resources. The difference between this area and western Mancha is that, instead of using meters to regulate water use, the farmers are required to present an exploitation plan (crops and area of their farm to be cultivated), where, after determining the mean consumption of irrigation water per crop, the estimated total = Σ (irrigated area per crop x mean irrigation volume applied to each crop) must not exceed the theoretical amount of water allocated to the farm. The advantage of this methodology is that the farmers' use of water is not limited, which allows them to meet the irrigation requirements of crops when climate conditions are unfavorable. In this case, it is the land to be cropped that is limited. However, if they wish, farmers can install a meter and operate as in western Mancha.

Therefore, in both areas, accurately determining crop irrigation water requirements is essential for the proper management of the farms and the water bodies. In western Mancha, farmers use these values to determine the crop distribution that maximizes the profitability of the farm. In this area, drier years than those considered to determine the irrigation dose may exhaust the available irrigation water at the farm before the end of the growing period, causing a yield drop or even the death of the crop due to water deficit. However, in humid years, farmers will save water even when the total available amount is low, decreasing the potential profitability of the farms in those years. In the case of eastern Mancha, accurate irrigation requirements are mainly necessary to avoid a decrease in piezometric levels in dry years, when farmers will extract more water than expected. This usually forces CHJ to reduce the availability of irrigation water for all the area in the following years to offset the decrease in piezometric levels. In addition, crops with higher than estimated actual irrigation requirements may cause a chronic overuse of resources in the area. On the other hand, crops with overestimated irrigated requirements cause a higher restriction in the total cultivated area of the farms where they are cropped.

Therefore, an accurate determination of the irrigation requirements of crops is required by both farmers and water authorities to improve the profitability of the farms and achieve a sustainable use of water resources. In areas with low climatic variability, the use of the average year to determine the average irrigation requirements of crops may be a suitable solution. Nevertheless, in areas where the inter-annual climatic variability is high, as is the case of CLM, the use of the average irrigation requirements may decrease the efficient use of available resources if most of the years are significantly different to average conditions. Tools that estimate the volume of water to be applied according to the development crop stage, climatic conditions, and irrigation water availability may be useful to advise farmers and technicians in determining the most suitable irrigation depths [7–9].

MOPECO (model for the ECOnomic OPtimization of irrigation water) [10] is a decision support model whose purpose is to maximize the gross margin of an irrigated farm through the optimal use of available irrigation water and irrigable land, as well as to determine the most suitable distribution of crops on the farm. MOPECO, among other features, calculates the irrigation requirements of crops under different climatic conditions and generates optimal irrigation schedules, under both non-deficit and regulated deficit irrigation conditions, thus improving the management and efficiency of water use on farms. This model can be used in many irrigable areas by calibrating a small number of crop parameters. Indeed, MOPECO has already been calibrated for the main crops in CLM, namely, maize [11], onion [12], garlic [13], and barley [14], and in other areas of the world.

The contribution of CLM to the national production of these four crops Is significant. CLM is the main producing region for garlic and onion and the second largest producer of barley and the fifth largest producer of maize. Thus, 22% of total barley grain and 5% of total maize grain produced in Spain is cultivated in this region [15]. Similarly, in the case of onion and garlic, the percentage is much higher, with CLM accounting for 54 and 60% of the national total, respectively [15].

To optimize irrigation scheduling and determine the typical irrigation requirements of crops by using MOPECO, [13] adapted the methodology proposed by [16] for the generation of the "Typical Meteorological Year" (TMY). A TMY consists of 12 months statistically selected from individual years and concatenated to form a complete year, resulting in a perfect correlation across the daily values of the climatic variables (i.e., temperature, rainfall, and radiation). This methodology may be used to enhance the management of irrigable areas through a better design of irrigation systems, the estimation of the typical irrigation requirements of crops, or the determination of the irrigation demand peak of an irrigators association. To determine the irrigation requirements of crops, it would be possible to establish the TMY for the months of the growing cycle of the crop, as well as to differentiate between different types of years, according to the water demand generated for the crops. This methodology was also combined with the MOPECO model to develop the ORDIL (optimized regulated deficit irrigation for limited volumes of irrigation water) methodology [17], which allows the yield to be maximized for a certain volume of irrigation water that is lower than irrigation requirements.

The main aim of this work was to achieve a better approach to the typical irrigation requirements of the main extensive crops in CLM (maize, onion, garlic, and barley) to help farmers and water authorities achieve higher yields and a more sustainable use of water resources. To meet this aim, the following partial objectives were proposed: (1) to determine the distribution of wet, intermediate, and dry years during the growing cycle of the four selected crops; (2) to determine the average and typical irrigation requirements of these crops under wet, intermediate, and dry years conditions; and (3) to recommend the typical irrigation depths to be used by farmers and water authorities for the management of farms and water bodies in the western and eastern Mancha irrigation systems.

2. Materials and Methods

2.1. Site Description

The agricultural area of CLM consists of 3,546,960 ha, 546,576 ha of which are irrigated land [15]. Although the percentage is only 15.4%, compared to the national average of 23% [15], irrigated land plays an important social and economic role in the region, as this activity generates 40% of the regional agrarian income [18]. For this reason, 1523 hm^3 of water were used for irrigation in 2018 [19], making up more than 83% of regional water consumption. This provides insight on the importance of water productivity in this sector.

Approximately 70% of the irrigable areas of CLM are located close to groundwater sources, given that mostly surface water resources are used in other regions on the borders. The most common crops in these areas are grapes, cereals (maize, barley, and wheat), garlic, onion, melon, watermelon, pepper, and other crops such as sunflower, potato, and alfalfa, while the irrigation systems used in the area are drip irrigation (18.03% of the area) for tree crops and solid set system (16.65% of the area) and center pivot (24.22% of the area) for annual crops [20].

2.2. Determination of the Typical Meteorological Years (TMY) and Average Year (AVE_Y)

A typical meteorological year (TMY) consists of a year constructed from daily data from 12 months selected from individual years and concatenated to form a complete year [16]. For this purpose, [13] focused on the following parameters:

- ETo (daily reference evapotranspiration) and precipitation (P), due to their importance in irrigation requirements.
- T_{min} (daily minimum temperature) and T_{max} (daily maximum temperature) due to their effects on ETo and crop phenological development.

In addition to a single (global) TMY calculated for the entire climatic data series, the methodology developed by [13] and extended by [17] allows several types of TMY to be generated, depending on the climatic conditions of each year of the series. In this way, years in the series can be classified into three large groups: dry, intermediate, and wet, and a representative TMY for each group can thus be generated.

The characteristics of these three types of TMY are:

- Dry TMY: Rainfall is lower and ETo higher than that of an average year, so irrigation requirements should be higher. If the amount of available irrigation water on the farm is limited, under dry conditions, it is considered that this volume may be exhausted prematurely, which could lead to severe water deficits in crops with the corresponding losses in yield and/or profitability for the farmer.

- Intermediate TMY: ETo and precipitation should be close to those in an average year. Consequently, crop irrigation requirements under these conditions would be the reference.
- Wet TMY: ETo is lower, and precipitation is higher than those in an average year. Crop irrigation requirements under these conditions should be lower than in the average year. In contrast to a dry TMY, if there is a limited volume of irrigation water, farmers may save some irrigation water without causing water deficit to crop.

The average year (AVE_Y) was calculated by averaging the daily climatic variables of the data series. In the case of rainfall, the average daily value involves a very little amount of water for every day of the month, which is not realistic, but the total amount coincides with the average monthly value. In consequence, the average monthly precipitation was first calculated for the whole series. In a second step, for each month, a year of the series was sought when a similar rainfall to monthly average occurred in the same month. Third, the real daily rainfall distribution during that month was used for the average month, fitting the daily values if necessary to reach the calculated monthly average value.

For this study, we used a daily climatic series for a 70-year period (1951–2020) from the weather station "Los Llanos" (latitude: 38°57′15″ N; longitude: 1°51′23″ W; altitude: 704 m a.s.l) belonging to the National Meteorology Agency network located 5 km away from Albacete town (Figure 1).

2.3. Determination of Typical Meteorological Year Adapted to Crop Cycles (TMY$_{-C}$)

The climatic characterization of years is based on the precipitation deficit (PD = P − Eto; where P is accumulated rainfall and Eto accumulated the reference evapotranspiration) index [21,22]. This index provides a simple way to determine how dry, intermediate, or wet a year was, but does not consider the temporal distribution of rainfall during the year or the real soil moisture availability for plants. Therefore, being a cumulative amount for the whole year can "disguise" the climatic characteristics of the months in which a crop is to be grown. Thus, in addition to the calculation of the different TMY with the climatic values of the 12 months of the year, the same types of TMY were also calculated but adjusted to the crop cycle, i.e., with the climatic values of the months corresponding to the cycle of each crop.

The nomenclature, followed to differentiate the different TMYs, follows the structure TMY-xy where:

- x: G (for the 12 months) or C (for the months involved in crop cycle).
- Y: W (for wet year), I (for intermediate year), or D (for dry year).

2.4. "MOPECO" Irrigation Water Economic Optimization Model

In irrigated agriculture, irrigation scheduling is one of the most complex processes to be performed by the farmer due to the multitude of factors involved in water management, requiring technical information for accurate knowledge on applied water and crop yield [23,24].

In this sense, the aim of MOPECO is to maximize the economic gross margin (GM) through the efficient use of irrigation water. A set of data (Figure 2) is required for the simulation of the optimal "Yield vs. Total Net Water" (Y vs. TWN), a function for each crop under the climatic conditions of a certain year. In this function, TWN = net irrigation (IN) + effective rainfall (Pe). To obtain Y vs. TWN, the model simulates a range of deficit irrigation schedules using the optimized regulated deficit irrigation (ORDI) methodology [17–25], considering the effects of irrigation uniformity [26] and electrical conductivity of water [27] on yield. The Y vs. TWN function is translated into "Yield vs. Total Gross Water" (Y vs. TWG), where TWG = gross irrigation (IG) + Pe, to include efficiency of applying the irrigation system (in this case "solid set system"). The GM vs. TWG function is then calculated using economic data on the crop. Finally, the model calculates the optimal distribution of crops that meets the restrictions imposed by the user (Figure 2).

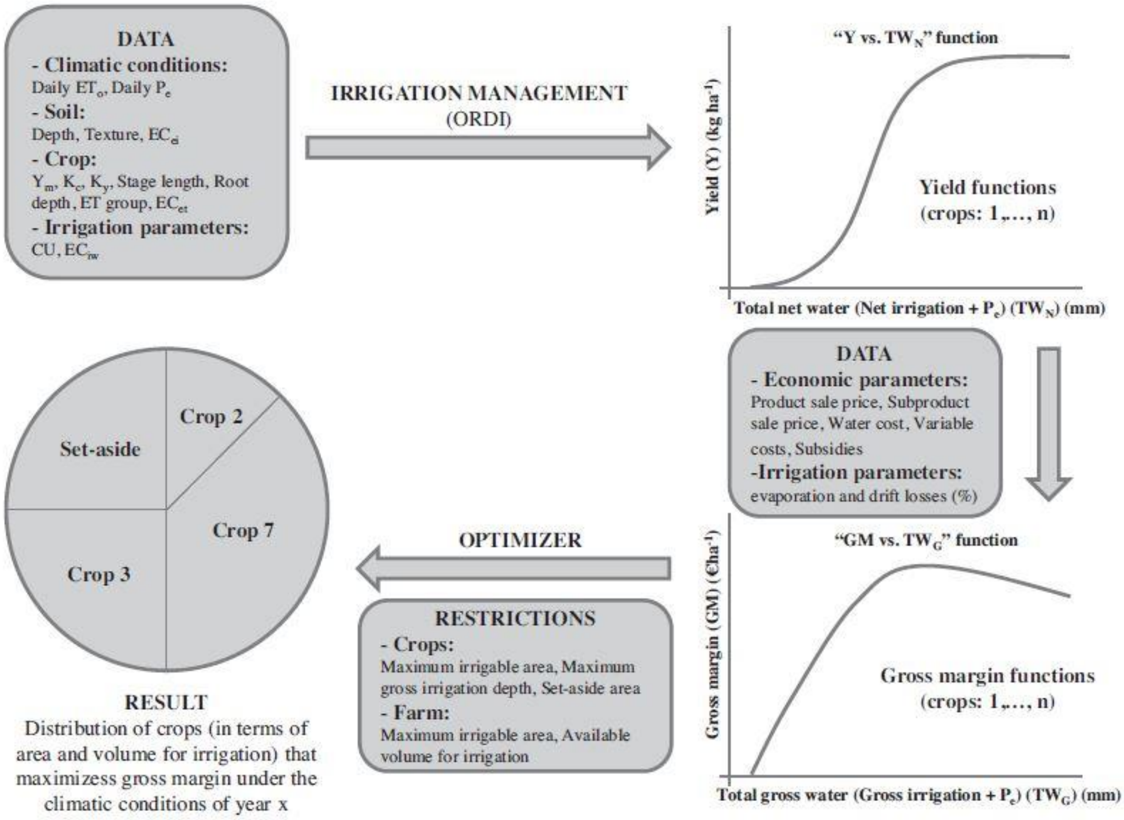

Figure 2. ETo: daily reference evapotranspiration (mm); Pe: daily effective rainfall (mm); ECei: water conductivity of the saturated soil extract at the beginning of the irrigation season (dS m^{-1}); Ym: potential yield of the crop in the area (kg ha^{-1}); Kc: crop coefficient (dimensionless) [28]; Ky: crop yield response factor by growing stage (dimensionless) [29]; ECet: water conductivity of the saturated soil extract that decreases the evapotranspiration capacity of a crop (dS m^{-1}); ET group: this conditions the daily value of the fraction of the total available water (TAW) that a crop can extract without suffering water stress [30]; CU: uniformity coefficient of the irrigation system; and ECiw: electrical conductivity of the irrigation water in the area (dS m^{-1}).

MOPECO uses the equation proposed by [31] and modified by [32] for estimating crop yield as a function of the actual versus maximum evapotranspiration ratio (ETa/ETm) in the different growth stages. [29] considered four growth stages, according to the different sensitivity of crops to water deficit (vegetative, flowering, yield formation, and ripening period). The crop yield response factor (K_y) expresses how sensitive the crop is to water deficit at each growth stage. When ETa < ETm, the plant suffers from water deficit stress, which may cause a loss in yield (actual yield (Y_a) < maximum yield (Y_m)).

$$Y_a = Y_m \prod_{k=1}^{4} \left(1 - K_{y_k}\left(1 - \frac{ET_{a_k}}{ET_{m_k}}\right)\right) \quad (1)$$

where Y_a = actual harvested yield (kg ha^{-1}); Y_m = agronomic maximum yield that can be achieved in a given area when crop development is not limited by water availability or other factors (kg ha^{-1}); K_y = yield response factor, which shows the sensitivity of the crop to water stress (Table 1); ET_a = actual crop evapotranspiration (mm); ET_m = crop evapotranspiration for maximum yield (mm); and i = the developmental stages of the crop.

Table 1. Calibrated parameters for MOPECO for the crops studied in CLM.

Crop	Stage	K_c	GDD (°C)	Stage	K_y	GDD (°C)	Other Parameters	Value	Sowing Date
Maize	I	0.3	353.4	i	0.35	789.3	ET group	4	1 Apr.
	II	0.30–1.10	902.3	ii	1.05	1206.6	Y_m (kg ha^{-1})	19,700	
	III	1.1	1381.2	iii	0.40	1519.3	T_L (°C)	8	
	IV	1.10–0.65	1802.8	iv	0.20	1802.8	T_U (°C)	30	
Onion	I	0.65	458.5	i	0.45	926.5	ET group	1	15 Mar.
	II	0.65–1.20	926.5	ii	0.80	1805.2	Y_m (kg ha^{-1})	100,000	
	III	1.2	1805.2	iii	0.20	2283.4	T_L (°C)	5	
	IV	1.20–0.75	2283.4	iv	-	2283.4	T_U (°C)	45	
Garlic	I	0.15	468.5	i	0.45	1021.5	ET group	1	1 Jan.
	II	0.15–1.00	1021.5	ii	0.75	1615.2	Y_m (kg ha^{-1})	17,800	
	III	1.00	1615.2	iii	0.30	2044.0	T_L (°C)	0	
	IV	1.00–0.60	2044.0	iv	-	2044.0	T_U (°C)	45	
Barley	I	0.3	290.3	i	0.20	645.3	ET group	3	3 Jan.
	II	0.30–1.15	744.5	ii	0.55	981.2	Y_m (kg ha^{-1})	9000	
	III	1.15	1087.2	iii	0.30	1186.1	T_L (°C)	2	
	IV	1.15–0.45	1149.5	iv	0.15	1149.5	T_U (°C)	28	

Kc: crop coefficient; Kc (I): initial; Kc (II): crop development; Kc (III): mid-season; Kc (IV): late season; GDD: growing-degree-days; Ky: crop yield response factor; Ky (i): vegetative period; Ky (ii): flowering period (not in the case of onion during the marketable development); Ky (iii): yield formation; Ky (iv): ripening; ET group: it conditions the daily value of the fraction of the total available water (TAW) that a crop can extract without suffering water stress [30]; Ym: potential crop yield fitted to the cultivars used in this study; TU is the upper developmental threshold temperature or the temperature at and above which the rate of development begins to decrease; and TL is the lower developmental threshold temperature or the temperature at and below which development stops.

Daily ETm is calculated by multiplying the daily crop coefficient (K_c) by the daily reference evapotranspiration (ETo) [28]. ETo was calculated by using the equation proposed by [33] due to that not enough climatic data are available in the area before year 2000 for using Penman–Monteith FAO equation [28]. Daily ETa requires a daily soil water content balance based on FAO-56 [28], which is calculated as the difference between inputs (precipitation and irrigation, capillary ascent not being considered in this case) and outputs (ETa and deep percolation) [27].

For crop simulation, the duration of the K_c and K_y stages in cumulative degree days (GDD) is also needed. MOPECO uses the double triangulation method, which requires two parameters for GDD calculation [34], T_L (minimum threshold temperature for development) and T_U (maximum threshold temperature at which the development rate starts to decrease).

Therefore, to implement the MOPECO model in an irrigable area, it is necessary to obtain the climatic data (ETo, precipitation, and maximum and minimum temperatures), basic edaphic data (texture and depth), calibrated crop parameters for simulation (potential yield, threshold temperatures for development, K_c and K_y coefficients, as well as the duration of the stages in cumulative degree days) (Table 1).

For the simulation of the four crops using MOPECO, the following other parameters were considered, which are representative of the studied area: (a) soil: clay–sandy loam texture, 0.40 m depth; (b) irrigation interval: min and max equal to 2–6, 2–8, 2–5 and 2–5 days for garlic, barley, onion, and maize, respectively; (c) min and max irrigation depths: 4 and 36 mm, respectively, for solid set system; and (d) average drift and evaporation losses equal to 12% in the area [35,36].

It must be advised that MOPECO was not designed for simulating the effect of extreme climatic conditions on the development of crops. Therefore, the results offered by this model using climatic data (real or simulated) distant from the usual in the pilot area must be considered with caution.

3. Results and Discussion

3.1. Determination of Wet, Intermediate, and Dry Years

Using complete years to determine whether a crop was developed under wet, intermediate, or dry years may cause confusion, as the same year may include periods over or under average conditions (Table 2). Thus, only 27 of 70 years were considered in the same deficit index class (wet, intermediate, or dry), regardless of the five temporal periods considered (full or global year “12 months”, and growing period of garlic, barley, onion, and maize). Consequently, 53 years of the series show different climatic conditions with regard to the considered period. Moreover, the amount of accumulated rainfall (in this case the excess of precipitation) may significantly affect the precipitation index of a certain year, considering that a year is an outlier in some periods. This is the case of 5 years in the series analyzed, which must be dropped from the series to avoid results that are too far removed from the typical conditions.

Table 2. Classification of years (wet, intermediate “Int.”, or dry) for different growing periods.

Period		**12 Months**			**Garlic and Barley**			**Onion**			**Maize**	
Type	**Wet**	**Int.**	**Dry**	**Wet**	**Int.**	**Dry**	**Wet**	**Int.**	**Dry**	**Wet**	**Int.**	**Dry**
	1957	1951	1952	1962	1951	1952	1951	1955	1952	1951	1952	1953
	1960	1955	1953	1967	1954	1953	1969	1956	1953	1969	1955	1954
	1962	1956	1954	1969	1955	1961	1971	1957	1954	1971	1956	1958
	1971	1958	1964	1974	1956	1964	1972	1960	1958	1972	1957	1961
	1972	1961	1966	1976	1957	1965	1974	1962	1961	1974	1960	1964
	1974	1963	1970	1978	1958	1966	1975	1963	1964	1975	1962	1965
	1975	1965	1973	1980	1960	1973	1976	1967	1965	1976	1963	1970
	1976	1967	1981	1988	1963	1983	1979	1968	1966	1979	1966	1973
	1979	1968	1983	1989	1968	1987	1989	1977	1970	1980	1967	1982
	1984	1977	1985	1992	1970	1994	1993	1978	1973	1988	1968	1983
	1988	1978	1994	1993	1972	1995	1996	1980	1982	1989	1977	1985
	1989	1980	1995	2004	1977	1999	2013	1981	1983	1992	1978	1987
	1993	1982	1999	2010	1979	2000	-	1984	1985	1993	1981	1991
	1996	1986	2001	-	1981	2001	-	1986	1987	1996	1984	1994
	1997	1987	2003	-	1982	2003	-	1988	1994	1997	1986	1999
Years	2010	1990	2005	-	1984	2009	-	1990	1995	1998	1990	2000
	-	1991	2006	-	1985	2012	-	1991	1999	-	1995	2001
	-	1992	2007	-	1986	2014	-	1992	2000	-	2002	2003
	-	1998	2009	-	1990	2015	-	1997	2001	-	2004	2005
	-	2002	2011	-	1991	2016	-	1998	2003	-	2008	2006
	-	2004	2014	-	1996	2017	-	2002	2005	-	2010	2007
	-	2008	2015	-	1997	-	-	2004	2006	-	2013	2009
	-	2012	2017	-	1998	-	-	2008	2007	-	2018	2011
	-	2013	-	-	2002	-	-	2010	2009	-	2019	2012
	-	2016	-	-	2006	-	-	2018	2011	-	-	2014
	-	2018	-	-	2007	-	-	2019	2012	-	-	2015
	-	2019	-	-	2008	-	-	2020	2014	-	-	2016
	-	2020	-	-	2011	-	-	-	2015	-	-	2017
	-	-	-	-	2013	-	-	-	2016	-	-	2020
	-	-	-	-	2018	-	-	-	2017	-	-	-
	-	-	-	-	2019	-	-	-	-	-	-	-
	-	-	-	-	2020	-	-	-	-	-	-	-
Total	16	28	23	13	32	21	12	27	30	16	24	29
	24%	42%	34%	20%	48%	32%	17%	39%	43%	23%	35%	42%

Note: A white cell means that the year was included in the same class in the five periods considered (i.e., 1955 was classified as intermediate in all the periods); a grey cell means that the year was considered in different classes, depending on the period considered (i.e., 1957 was classified as wet in “12 months” and intermediate in the rest of periods); a black cell means the year was dismissed in some periods after being considered an outlier (i.e., 1971 in “garlic” and “barley” periods).

In addition, the number of years included in each precipitation index classification is also dependent on the period. According to the global year period (12 months), most of the years in the area can be considered as intermediate (42%), while the number of wet years is lower than that of dry ones. A similar distribution of wet, intermediate, and dry years was observed for the growing period of garlic and barley crops. Evidently, for these crops, the classification distribution is the same due to both being sown and harvested on similar dates. Nevertheless, in the case of onion and maize, most of the years are dry (43% and 42%, respectively), caused by the almost complete absence of rainfall during the summer months (July and August).

The years of each deficit index class were used to determine the typical meteorological year of the different growing periods (Table 3). The comparison between the accumulated ETo values for the same growing period shows differences of up to 80 mm for maize between wet and dry, being lower for the rest of crops. However, the differences in P were higher, reaching up to 195 mm for garlic and barley, showing the great interannual variability of rainfall during winter and spring months. As expected, the accumulated ETo values for the average year (AVE_Y) and the TMY calculated using all the years of the series (TMY_G) are between the values for the intermediate and dry conditions. Furthermore, for AVE_Y the accumulated P is higher than for TMY_G and TMY intermediate (TMY_{GI}). Consequently, considering the average P of the series involves overestimating, for most of the years, the amount of water the crops will receive from rainfall (Table 2). In this sense, the TMY calculated for the growing period of the four considered crops without differentiating the deficit index (Table 3) shows ETo and *p* values between intermediate and dry conditions in all the cases, which seems more realistic according to the number of wet, intermediate, and dry years in each growing period (Table 2).

Table 3. Years comprising each typical year by using the 1951–2020 series, and the total accumulated reference evapotranspiration (ET_o) and rainfall (P) for the growing period considered.

Crop	TMY	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	ET_o (mm)	P (mm)
	AVE_Y	-	-	-	-	-	-	-	-	-	-	-	-	1234.9	339.1
	TMY_{-G}	2014	2008	1992	2003	2011	1980	1968	1979	1968	2015	1955	1952	1250.1	265.6
	TMY_{-GW}	1960	1975	1974	2010	1957	1993	1962	2010	1984	1984	1972	1997	1194.0	517.4
	TMY_{-GI}	2013	2008	1992	1963	2016	1980	1968	1965	1992	1980	1978	2004	1227.6	282.6
	TMY_{-GD}	2014	1999	1995	1985	1973	1994	2017	2014	2011	2015	1970	1983	1295.0	227.3
Garlic	TMY_{-C}	2014	2008	1992	2003	2011	1980	-	-	-	-	-	-	591.6	176.0
	TMY_{-CW}	1967	1976	1993	1989	1976	1993	-	-	-	-	-	-	563.2	304.4
	TMY_{-CI}	1956	2008	1986	1963	2011	1951	-	-	-	-	-	-	580.6	191.0
	TMY_{-CD}	2003	2009	2014	2003	1965	1994	-	-	-	-	-	-	620.8	109.1
Barley	TMY_{-C}	2014	2008	1992	2003	2011	1980	-	-	-	-	-	-	591.6	176.0
	TMY_{-CW}	1967	1976	1993	1989	1976	1993	-	-	-	-	-	-	563.2	304.4
	TMY_{-CI}	1956	2008	1986	1963	2011	1951	-	-	-	-	-	-	580.6	191.0
	TMY_{-CD}	2003	2009	2014	2003	1965	1994	-	-	-	-	-	-	620.8	109.1
Onion	TMY_{-C}	-	-	1992	2003	2011	1980	1968	1979	1968	-	-	-	1024.4	136.6
	TMY_{-CW}	-	-	1974	2013	1972	1976	1969	1969	1975	-	-	-	985.4	287.6
	TMY_{-CI}	-	-	1992	2010	1962	2018	1968	2008	1957	-	-	-	1018.8	171.8
	TMY_{-CD}	-	-	1982	2003	2000	1994	2012	2000	2011	-	-	-	1048.6	123.1
Maize	TMY_{-C}	-	-	-	2003	2011	1980	1968	1979	1968	-	-	-	947.9	116.0
	TMY_{-CW}	-	-	-	1993	1993	1997	1980	1975	1971	-	-	-	897.5	192.2
	TMY_{-CI}	-	-	-	2010	1962	1955	1968	2004	1968	-	-	-	941.2	133.0
	TMY_{-CD}	-	-	-	2003	2000	1994	2005	2000	2011	-	-	-	976.4	108.3

Where: TMY means typical meteorological year; AVE means average; G and C mean full year and crop period, respectively; W, I, and D mean wet, intermediate, and dry year, respectively.

This study has not analyzed the potential effect of global warming on the progression of climatic conditions during the 70 years of the climatic series. Nevertheless, it can be highlighted how the number of "wet" years from 2000 to 2020 is very low (Table 2). Therefore, it seems convenient to determine the most suitable length of the climatic series (i.e., the full available series, or the last 30, 25, or 20 years ...) to be used for reaching the TMY that better represents the climatic conditions of the next years, under the current climatic change scenario.

The progression of the accumulated *p* values for the average year and the four TMYs (Figure 3) shows that wet years are significantly rainier than the other four categories (Table 3). The differences mainly occur during the winter and spring months, with the amount of rainfall in summer very low (close to 0 mm), in all the cases. The decrease in cloudy days justifies the increase in the accumulated ETo values for the drier TMYs, with the differences between categories being lower than in the case of P.

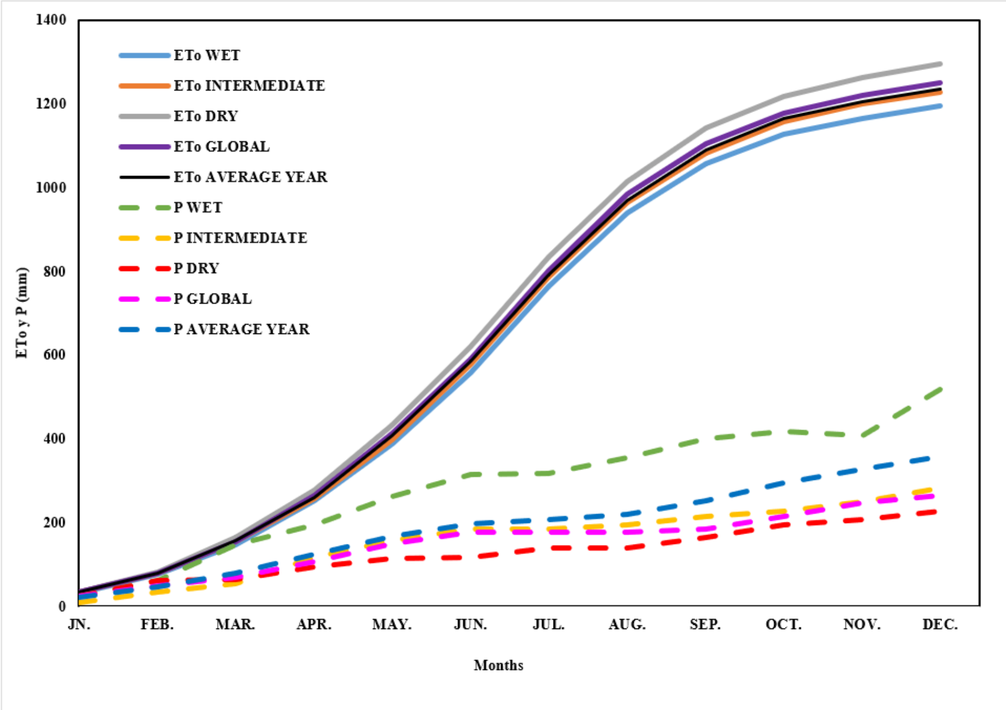

Figure 3. Cumulative daily evolution of reference evapotranspiration (ET_o) and precipitation (P) for average year and typical meteorological years (global, dry, intermediate, and wet).

3.2. Irrigation Requirements of Crops under Average, Wet, Intermediate, and Dry Conditions

Aiming to assess the effect of the differences across years with different climatic conditions, the net irrigation requirements for reaching full irrigation were calculated for each crop and the precipitation deficit index category, as well as for the climatic conditions of the AVE_Y and for each of the years of the series, obtaining the average irrigation requirements value (Ir) for the complete series (Table 4). The results show that the irrigation requirements for the AVE_Y were between 20.0 and 7.8% lower than the Ir for garlic and maize, respectively. With regard to the irrigation requirements calculated for the different growing periods and climatic conditions, the AVE was always lower, excepting for TMY_{GW} and TMY_{CW} barley and TMY_{CW} maize. In other words, AVE_Y was only higher than the irrigation requirements of these two crops for wet year conditions.

In contrast, and as expected, the highest irrigation requirements for each crop were obtained for the dry years, being just from 3.6 to 5.8% higher than the Ir for TMY_{CD} barley and TMY_{CD} maize, respectively. In this sense, and counter to our expectations, using the wet, intermediate, and dry TMY (TMY_{GW}, TMY_{GI}, TMY_{GD}) calculated from the years in the 12 months series (Table 2), higher requirements were obtained than those for the TMY calculated by using the years selected according to their precipitation deficit index for the growing period of garlic (TMY_{CW}, TMY_{CI}, TMY_{CD}). For the remaining crops, the TMY_C do not always present higher requirements. In the case of maize, for example, the three TMY_C have greater requirements than their corresponding G; for onion, the TMY_{CW} and TMY_{CI} show higher irrigation requirements than their corresponding G; and in the case of barley, TMY_{CW} is the only year with higher requirements. Thus, in this case, the irrigation requirements increased between 2.8 to 8.0% compared to the Ir for TMY_{GD} maize and TMY_{GD} garlic, respectively (Table 4).

Table 4. Net irrigation requirements (m^3 ha^{-1}).

Period	AVE_Y	TMY_G	TMY_{GW}	TMY_{GI}	TMY_{GD}	TMY_C	TMY_{CW}	TMY_{CI}	TMY_{CD}	Ir	Ir_{max}
Garlic	2696	3089	3083	3312	3637	3089	2755	3230	3561	3368	4060
Barley	2372	2657	2026	2670	3046	2657	2131	2425	2968	2864	3593
Onion	7022	7581	7056	7356	7946	7581	7259	7535	7812	7515	8486
Maize	4733	5267	4672	5087	5276	5267	4787	5270	5432	5133	5789

Where: AVE_Y is the average year calculated using the 70 years of the series; TMY_G: typical meteorological year (TMY) using the 12 months for the 70 years of the series; TMY_{GW}, TMY_{GI}, and TMY_{GD} are the TMY using the wet (W), intermediate (I), and dry (D) years, respectively, for the 12-month period; TMY_C is the TMY using the months in the growing period of each crop for the 70 years of the series; TMY_{CW}, TMY_{CI}, and TMY_{CD} are the TMY using the W, I, and D years, respectively, for the growing period of each crop; I_r is the average of 70 simulations to determine the full irrigation requirements of the crops under the climatic conditions in all the years of the series; and Ir_{max} is the maximum irrigation depth calculated for meeting the irrigation requirement in the driest year.

We calculated the number of years in which the full irrigation requirements of the crops were fulfilled by using the irrigation depths calculated in Table 4 (Table 5). As expected, Ir satisfied around 50% of the years, and those for the dry years covered the highest percentage of years. In this sense, and according to the results in Table 4, TMY_{GD} reached a higher percentage (>64.3%) than TMY_{CD} (>58.6%) for all the crops excepting maize. However, AVE_Y and wet TMY satisfied the irrigation requirements for a low number of years, varying from 1.4 (TMY_{CW} barley) to 25.7% (TMY_{GW} garlic).

Table 5. Percentage of years in which the net irrigation requirements of crops were fulfilled (%).

Period	AVE	TMY_G	TMY_{GW}	TMY_{GI}	TMY_{GD}	TMY_C	TMY_{CW}	TMY_{CI}	TMY_{CD}	Ir
Garlic	4.3	25.7	25.7	40.0	72.9	25.7	4.3	35.7	64.3	48.6
Barley	11.4	31.4	1.4	31.4	65.7	31.4	1.4	15.7	58.6	48.6
Onion	12.9	58.6	12.9	31.4	84.3	58.6	21.4	57.1	75.7	54.3
Maize	15.7	60.0	11.4	44.3	64.3	60.0	17.1	61.4	78.6	47.1

Where: AVE_Y is the average year calculated using the 70 years of the series; TMY_G: typical meteorological year (TMY) using the 12 months for the 70 years of the series; TMY_{GW}, TMY_{GI}, and TMY_{GD} are the TMY using the wet (W), intermediate (I), and dry (D) years, respectively, for the 12-month period; TMY_{CG} is the TMY using the months in the growing period of each crop for the 70 years of the series; TMY_{CW}, TMY_{CI}, and TMY_{CD} are the TMY using the W, I, and D years, respectively, for the growing period of each crop; and Ir is the average of 70 simulations for determining the full irrigation requirements of the crops under the climatic conditions in all the years of the series.

3.3. Irrigation Depths Recommended for the Western and Eastern Mancha Agricultural Systems

In areas where the amount of irrigation water available for the farm is limited (i.e., western Mancha), the main risk for the farmer is exhausting the irrigation depth (Table 4) before the end of the growing period and causing water deficit. In order to assess this effect on crop development, the ETa/ETm of each growing stage was simulated for each irrigation depth and year of the series. In those cases where the ETa/ETm rate was lower than 0.5 at the end of a certain growing stage (usually ripening), the crop was considered to be dead, or the harvest highly damaged [28] (Table 6). The irrigation depths that allowed the end of the growing period to be reached in all the crops but barley without attaining an ETa/ETm rate below 0.5 in ripening (or before) were TMY_{GD} and TMY_{CD}.

Table 6. Percentage of years in which the crop suffered excessive stress caused by water deficit (%).

Period	AVE_Y	TMY_G	TMY_{GW}	TMY_{GI}	TMY_{GD}	TMY_C	TMY_{CW}	TMY_{CI}	TMY_{CD}	Ir
Garlic	34.3	2.9	2.9	0.0	0.0	2.9	30.0	1.4	0.0	0.0
Barley	40.0	17.1	60.0	17.1	1.4	17.1	57.1	34.3	2.9	11.4
Onion	4.3	0.0	2.9	0.0	0.0	0.0	1.4	0.0	0.0	0.0
Maize	21.4	0.0	28.6	1.4	0.0	0.0	17.1	0.0	0.0	1.4

Where: AVE_Y is the average year calculated using the 70 years of the series; TMY_G: typical meteorological year (TMY) using the 12 months for the 70 years of the series; TMY_{GW}, TMY_{GI}, and TMY_{GD} are the TMY using the wet (W), intermediate (I), and dry (D) years, respectively, for the 12-month period; TMY_{CG} is the TMY using the months in the growing period of each crop for the 70 years of the series; TMY_{CW}, TMY_{CI}, and TMY_{CD} are the TMY using the W, I, and D years, respectively, for the growing period of each crop; and Ir is the average of 70 simulations to determine the full irrigation requirements of the crops under the climatic conditions in all the years of the series.

Barley is the most negatively affected crop for the different irrigation depths. This finding highlights the great variability of climatic conditions in the area during the growing period of this crop, which does not affect garlic in the same way. This may be justified by the fact that barley irrigation requirements are higher than those of garlic in the last stages of the growing season (from middle April to the end of June), when there are more likely to be drought periods than in the months from January to April.

In contrast, onion is the least affected crop because the higher irrigation requirements of this crop occur in the summer months (harvested at the end of August), when rainfall is close to 0 in the three classifications considered (Figure 3). Consequently, and due to ETo being highly stable regardless of the amount of precipitation (Table 3), the impact of rainfall variability on the irrigation requirements calculated for this crop and for any type of TMY is low.

In the case of maize, this crop is more affected than onion due to the high rainfall variability during the month of September, when maize reaches physiological maturity.

In addition, in areas where the amount of water used by farmers is limited by the total area they can crop, depending on an established average consumption of the crops (i.e., eastern Mancha), the main risk is farmers applying a higher volume of water to crops than that determined by the water authority to fulfill their irrigation requirements. This may cause the overexploitation of aquifers or the depletion of reservoirs. Thus, we calculated the amount of water exceeding the net irrigation depth in dry years and the volume of saved water in humid years, as well as the balance for the 70 years of the series (Table 7). As expected, the Ir irrigation depths are those with the most balanced results, showing a little positive difference of less than 2 mm year^{-1} per crop (as result of dividing the Ir value in the "balance" section of Table 7 by 70 years), which in terms of irrigation management at the farm level can be diminished. TMY_{CD} and TMY_{GD} also saved water (23.3 and 26.5 mm year^{-1} on average, respectively).

In contrast, the remaining irrigation depths would generate a great use of water in the area. TMY_{CW} and TMY_{GW} and AVE_Y are the worst, increasing 43.3, 45.4, and 45.8 mm year^{-1}, on average, the excess of water supplied to the crops.

These results highlight how using the average year for determining the irrigation depth to be assigned to the crops in the area underestimates the real irrigation requirements in a way that is close to using those for the TMY wet years, increasing the risk of overexploitation of the resources in the area. In this sense, using the Ir irrigation depth achieves the most balanced result. The main limitation of this latter methodology is the great number of simulations to be carried out (in this case, 70 per crop), while using the TMY for dry years greatly decreases this workload (determination of the TMY for dry conditions and one simulation per crop).

Table 7. Balance between the volume of irrigation water supplied in years with higher or lower irrigation requirements than assigned (mm).

Period	AVE_Y	TMY_G	TMY_{GW}	TMY_{GI}	TMY_{GD}	TMY_C	TMY_{CW}	TMY_{CI}	TMY_{CD}	Ir
Total saved volume in years with lower irrigation requirements										
Garlic	47.9	352.5	341.7	855.8	2175.5	352.5	65.6	648.0	1810.7	1026.5
Barley	126.6	547.8	28.5	576.4	1853.9	547.8	39.0	176.2	1516.7	1121.1
Onion	207.4	1379.4	238.0	648.4	3237.6	1379.4	463.8	1193.7	2476.6	1113.2
Maize	204.8	1531.7	150.0	882.7	1571.0	1531.7	264.3	1544.4	2354.5	1028.2
Total overirrigated volume in years with higher irrigation requirements										
Garlic	4280.0	2047.4	2075.6	1091.5	245.6	2047.4	3920.1	1424.9	390.0	892.6
Barley	3131.6	1728.7	5247.9	1674.1	481.8	1728.7	4586.4	2841.9	675.0	971.0
Onion	3243.9	804.3	3056.9	1547.4	176.1	804.3	1983.5	923.9	344.0	978.1
Maize	2743.1	526.5	3078.7	1101.6	504.6	526.5	2456.9	518.9	227.4	936.3
Balance for the 70 years of the series										
Garlic	−4232.1	−1694.8	−1733.8	−235.7	1929.9	−1694.8	−3854.5	−776.9	1420.7	133.9
Barley	−3005.0	−1181.0	−5219.4	−1097.8	1372.1	−1181.0	−4547.4	−2665.8	841.7	150.1
Onion	−3036.5	575.1	−2818.9	−898.9	3061.5	575.1	−1519.7	269.8	2132.5	135.1
Maize	−2538.3	1005.1	−2928.7	−218.9	1066.3	1005.1	−2192.7	1025.5	2127.1	91.9

Where: AVE_Y is the average year calculated using the 70 years of the series; TMY_G: typical meteorological year (TMY) using the 12 months for the 70 years of the series; TMY_{GW}, TMY_{GI}, and TMY_{GD} are the TMY using the wet (W), intermediate (I), and dry (D) years, respectively, for the 12-month period; TMY_{CG} is the TMY using the months in the growing period of each crop for the 70 years of the series; TMY_{CW}, TMY_{CI}, and TMY_{CD} are the TMY using the W, I, and D years, respectively, for the growing period of each crop; and Ir is the average of 70 simulations to determine the full irrigation requirements of the crops under the climatic conditions in all the years of the series.

From the perspective of a farmer located in western Mancha with a limited total volume of irrigation water [37] and who has to decide the total area to be assigned to each crop in order to avoid a lack of water at the end of the irrigation season, the most advisable irrigation depth would be TMY_{GD}. This irrigation depth guarantees achieving the harvest every season, excepting barley, although, in some years, the level of deficit could be too high in some crops. This effect can greatly impact profitable crops such as garlic or onion, whose profitability depends on the yield and quality. According to [38,39], the size of onion and garlic bulbs is significantly conditioned by the water deficit, which may cause a large reduction in the final price perceived by the farmer.

The way to mitigate this situation is to use water initially assigned to other less profitable crops, such as barley, to fulfill the requirements of the most profitable crops. In this sense, [25] developed the ORDIL (optimized regulated deficit irrigation for limited volumes of irrigation water) methodology to maximize the final yield when the available amount of water is lower than the irrigation requirements of the crops. This methodology could be used in such cases to reduce the impact of water deficit on the less profitable crops, from which some water could be switched to other more profitable crops.

ORDIL uses the pre-sowing climatic conditions to determine the most likely climatic conditions during the growing period of the crop [25]. In this sense, we calculated the precipitation deficit index over some months before sowing (from 1 to 6 months before), in order to compare their classification (wet, intermediate, or dry) with the classification of the total growing period and assess the level of accuracy between the forecast and observed results (Table 8). Thus, depending on the crop, the highest percentage of accuracy was reached by using the PD value for the last month before sowing for garlic and barley, 3 months before sowing for onion and 4 months before sowing for maize. Moreover, 1 month could be suitable as a general recommendation, due to the level of accuracy being higher than 70% for all the crops, and the difference from the best result is of very low significance (2.9% for onion and 4.4% for maize).

Table 8. Level of accuracy between the type of growing period estimated with the months before sowing, and the type of growing period from sowing to harvest (%).

	1 Month		**2 Months**		**3 Months**		**4 Months**		**5 Months**		**6 Months**	
	H	**H + I**	**H**	**H + I**	**H**	**H + I**	**H**	**H + I**	**H**	**H + I**	**H**	**H + I**
Garlic	36.2	76.8	40.6	68.1	36.2	58.0	20.3	47.8	18.8	49.3	20.3	46.4
Barley	36.2	76.8	40.6	68.1	36.2	58.0	20.3	47.8	18.8	49.3	20.3	46.4
Onion	29.0	71.0	24.6	66.7	34.8	73.9	34.8	65.2	34.8	58.0	30.4	55.1
Maize	40.6	73.9	36.2	73.9	40.6	72.5	50.7	78.3	43.5	76.8	43.5	65.2

Where: H (hit) is the percentage of years in which the PD classification of the full growing period at harvest is equal to the PD classification before sowing; H + I (hit + improvement) is the percentage of years in which the PD classification of the full growing period at harvest is equal or better than the PD classification before sowing (from dry to dry, intermediate or wet, and from intermediate to intermediate or wet).

The main limitation of this methodology is the lack of tools specifically adapted for farmers to use it. The SUPROMED and PRODAGUA projects aim to provide farmers in the Castilla-La Mancha region and other areas in the Mediterranean basin [40] with such tools through an online platform adapted to farmers and technicians. The availability of these models would allow farmers to make more efficient use of irrigation water and increase the final income of their farms. Nevertheless, until that time, this study provides irrigation depths that allow farmers to determine the distributions of crops that present a low risk of harvests being affected by high water deficit during the final development stages.

Therefore, only in those years when the climatic classification for the month before sowing is "Dry", it is recommended to increase the irrigation depth, at least for the most profitable crops, such as onion and garlic. Thus, we calculated the maximum irrigation depth (Ir_{max}) to meet the irrigation requirements of the four crops during the driest season in the 70 years of the series (Table 5). In the case of garlic and onion, this strategy involves increasing by 15% and 8%, respectively, the amount of water assigned to these crops, forcing farmers to cultivate a smaller area of the farm mainly dedicated to barley and/or maize, the least profitable crops.

In this way, in dry years, the risk of causing water deficit to garlic and onion decreases. In contrast, reducing the considered irrigation depth when the month before sowing is considered wet can be highly risky if the year turns to intermediate or dry. Only a reduction in barley and maize irrigation depths could be manageable, but this depends on the risk tolerance of the farmer, which is typically low. Evidently, as in most of the years, the amount of water being supplied to crops should be significantly lower than required, this strategy would also help improve the ecological status of the wetlands, depending on the aquifer in the area by raising the piezometric levels of the groundwater.

In the case of eastern Mancha, the use of irrigation depths lower than those applied, on average, by farmers to determine the total area of the farm they can cultivate, involves reducing the total volume of water farmers can use when the piezometric levels in the aquifer decrease. According to the farmers' association in charge of managing the water resources in the area (*Junta Central de Regantes de la Mancha Oriental*; [41]) in coordination with the water authority (*Confederación Hidrográfica del Júcar*; [42]) the irrigation water consumption for garlic, barley, onion, and maize is 3100, 2600, 5800, and 7000 m^3 ha^{-1}, respectively [41]. These values are 14.8, 14.6, and 27.0% lower than those estimated by TMY_{GD} for garlic, barley, and onion, respectively, and 32.6% higher than that estimated for maize (Table 4). Consequently, in most years, farmers in the eastern Mancha will supply the crops with a greater amount of water than expected, causing a larger depletion of the groundwater.

This finding is partially attenuated by maize, which requires lower irrigation depths. Thus, the total amount of water assigned by the water authority to the eastern Mancha irrigable area decreased from 422 hm^3 $year^{-1}$ in 2001 to 387 hm^3 $year^{-1}$ in 2021, with 303 hm^3 $year^{-1}$ in 2010 being the minimum value reached during the series. The hydrological plan in the area aims to assign 355 hm^3 $year^{-1}$ in 2027 for irrigation [42]. Therefore, by using more accurate irrigation requirements for crops in the area, such as those proposed in this work for four crops, would avoid the progressive reduction in the total volume of water assigned for irrigation, which could lead to a lower total irrigated area and lower income for the agricultural system.

The irrigation scheduling recommendations stated in this paper can be complemented with the use of other methods and techniques for increasing the efficiency in the use of irrigation water as the previous evaluation of the irrigation systems including the installation of meters and pressure transducers for a better management of the irrigation water, the analysis of the soil properties for determining the amount of water can be stored by the soil and its monitoring by soil moisture sensors, or the use of models as MOPECO for determining the most efficient irrigation scheduling [43,44].

4. Conclusions

Using complete years to determine whether a crop was developed under wet, intermediate, or dry years may cause confusion as the same year may include periods over or under the average precipitation deficit index conditions.

The use of the average year to determine the irrigation needs of the crops in the study area can generate a great underestimation with respect to the average irrigation needs (Ir).

The irrigation requirements calculated for TMY_{GD} and TMY_{CD} were those most similar to Ir. Using the irrigation depth determined by the TMY dry for each crop instead of the average of the 70 simulations saves a great deal of time in terms of calculation and requires a lower number of climatic years.

Using the irrigation depths proposed by TMY_G for dry years will allow the end of the growing period to be reached without causing the crop to die. Nevertheless, in around 32% of the years, the crops would receive a lower irrigation depth than required, causing a certain stress and a drop in yield.

The climatic conditions of the month before sowing will be similar or even better (less irrigation requirements) from sowing to harvest in more than 71% of the years in the area. So, for dry years, the recommendation is to use the irrigation depth calculated for the driest year of the series in the case of the most profitable crops (garlic and onion), while, for the rest of years and crops, the recommended irrigation depth is that estimated by TMY_{GD}.

The official current irrigation depths in the area of study for garlic, barley, and onion are lower than those calculated by TMY_{GD}, while in the case of maize it is higher. Due to these farmers not having limitations on providing crops with as much water as they need to fulfill irrigation requirements, the water authority in the area may be obliged, every year, to decrease the total amount of water that can be extracted from the water table in the area to avoid overexploitation.

Until the development of farmer-friendly models and tools to determine the irrigable area assigned to each crop, these recommended irrigation depths may allow them to achieve suitable yields, avoiding high water deficits and making efficient use of available water.

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