Research Article

Effects of Irrigation and Field Management Practices within Water Resources Systems

Sulama ve Arazi Yönetimi Uygulamalarının Su Kaynakları Sistemlerindeki Etkileri

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Abstract

The world population is foreseen to increase up to 9.8 billion people toward 2050, and global food and water demands can also be predicted to rise accordingly. Regarding these future demands, climate change and depletion in water resources; new approaches, management strategies, and models are needed. In this study, the AquaCrop model was used as an analytical tool to predict the effects of management practices within winter wheat, spring wheat, winter barley, and maize in a specific location, middle Guadiana sub-catchment, Spain. The primary drivers from the model were designated as actual evapotranspiration, crop yield, and water productivity. Model runs were executed within three different management strategies: irrigation technologies, irrigation strategies, and mulching practices. Thereafter, yield gaps and water productivity gaps were analyzed, and water scarcity/shortage degrees were compared. The results showed that the AquaCrop model is a versatile model to estimate actual evapotranspiration, crop yield, and water productivity parameters. Yield productions in deficit irrigation were found higher than supplementary irrigation. Full irrigation showed the highest crop yield within non-limited water conditions. However, some negative impacts of the full irrigation strategy such as salinity should be considered. Mulching practices positively affected the actual evapotranspiration reduction. Full irrigation and no mulching scenario showed the worst results on the water resources systems. Supplementary irrigation and synthetic mulching practices depicted the least deterioration of surface water resources. Deficit irrigation and synthetic mulching practices resulted in considerable water savings with fewer yield losses compared to the scenario with the highest yield production levels.

Keywords: *AquaCrop model, management practice, water productivity, yield gap, water scarcity/shortage degrees*

Öz

Dünya nüfusunun 2050'de 9,8 milyar kişiye ulaşacağı ve bu artışla eş zamanlı olarak küresel ölçekte gıda ve su taleplerinin de artacağı öngörülmektedir. Gelecekteki bu taleplere ek olarak iklim değişikliği ve su kaynaklarının tükenmesi durumları da dikkate alındığında; yeni yaklaşımlar, yönetim stratejileri ve modellerin geliştirilmesine ihtiyaç duyulmaktadır. Bu çalışmada, belirlenen bir bölgede (orta Guadiana alt havzası, İspanya) üretilen kış buğdayı, bahar buğdayı, kışlık arpa ve darıdaki yönetim uygulamalarının etkilerini tahmin etmek için AquaCrop modeli, bir analitik araç olarak kullanılmıştır. Modeldeki birincil sürücüler gerçek evapotranspirasyon, mahsül verimi ve su verimliliği olarak belirlenmiştir. Model çalışmaları sulama teknolojileri, sulama stratejileri ve malçlama uygulamaları olmak üzere üç farklı yönetim stratejisinde yürütülmüştür. Daha sonra, mahsül verimi açığı ve su verimlilik açığı analiz edilmiş, su kıtlığı/yokluğu dereceleri karşılaştırılmıştır. Bu çalışma, gerçek evapotranspirasyon, mahsül verimi ve su verimliliği parametrelerini tahmin etmek için AquaCrop modelinin kullanışlı bir model olduğunu göstermiştir. Kısıntılı sulamada mahsul üretimi, tamamlayıcı sulamaya kıyasla genellikle daha verimli bulunmuştur. Tam sulama, sınırlandırılmamış su koşullarında en yüksek verimi göstermiştir. Ancak, tam sulama stratejisinin tuzluluk gibi diğer olumsuz etkileri de dikkate alınmalıdır. Malçlama uygulamaları, gerçek evapotranspirasyon azalmasını olumlu yönde etkilemiştir. Tam sulama ve malçlama uygulanmayan senaryo, su kaynakları sistemleri üzerinde en olumsuz etkiyi göstermiştir. Tamamlayıcı sulama ve sentetik malçlama uygulamaları, yüzeysel su kaynağı üzerine en düşük etkiyi göstermiştir. Kısıntılı sulama ve sentetik malçlama uygulamaları, en yüksek üretim seviyelerine sahip senaryoya göre daha az mahsül üretimi kaybıyla dikkate değer su tasarrufu sağlamıştır.

Anahtar kelimeler: AquaCrop modeli, yönetim uygulaması, su verimliliği, verim boşluğu, su kıtlığı/yokluğu dereceleri

Introduction

The world's population is expected to reach 9.8 billion people in 2050, which is 2.2 billion more people than 2020 according to the United Nations (UN), and global food and water demands can also be foreseen to increase accordingly. The agricultural sector has a substantial water use dimension amongst other sectors with nearly 70%, and global warming originates crucial impacts on crop water productivity (Patel et al., 2017; Kang et al., 2009). Due to the increased population of the world, food demand and water use have been dramatically increasing for over several decades. Therefore, crop yields must be higher to eradicate issues on food security to ensure adaptation to different drivers like socioeconomic developments, climate change, and water resources depletion (Van Ittersum et al., 2013). Several studies have focused on irrigation management strategies to increase either crop yield or water productivity under limited available water for sustainable productions (Chukalla et al., 2015). Crop yield response to water was described by Food and Agriculture Organization of the United Nations (FAO) as optimizing rainfed and irrigated agriculture at field levels. Because of costly management practices and experiments on the field, crop

development models are needed within different factors such as irrigation techniques, soil types, crop types, climatic conditions, and management strategies. Hence, a dynamic model is needed, such as AquaCrop, which provides simplicity, robustness, and accuracy including climatic, soil characteristics, and management practices for agricultural irrigation.

Crop yield (**Y**) can be described as the harvested production per harvested area unit for crop commodities (OECD, 2015). Regarding crop yield, due to increased food demand and other abovementioned reasons, water resources systems can be considered. Yield gap **(Y_g)** is an important parameter that can be described as a calculation of the differences between actual farmers` yield and potential yield without limitation from water and management practices. Yield gap analysis can be done by field experiments or simulation models to estimate yield gap at different scales (i.e. regional, national, or global) (Wart et al., 2013). According to Global Yield Gap Atlas (**GYGA**) (2017), yield gap (Y_g) analysis is one of the methods that can be applied ranging from local to a regional extent for agricultural sustainability, and described as a difference between potential yield (Y_p), water-limited yield potential (Y_w) or partially-irrigated yield potential (Y_{pi}), and actual yield (Y_a) (GYGA, 2017). In addition to this analysis, impacts of different adaptation pathways in agricultural irrigation on the water balance may have a momentous benefit for the future.

Water productivity (**WP**) is a measure of the efficiency of water resources that support rainfed and agricultural irrigation, and can be defined as how much yield output is obtained per cubic meter of fresh water abstracted (Smakhtin et al., 2004). Water productivity calculation may provide the efficiency with which water is converted to food, and which resource can be used effectively (GYGA, 2017). Besides, Water Footprint (WFP) concept is an inverted version of WP (m^3/kg). According to Hoekstra et al. (2011), the water footprint is an indicator of freshwater use that looks at both direct and indirect water uses by consumer or producer. Irrigation Water Use Efficiency can be defined as the ratio of the net irrigation water requirement and the total amount of water that needs to be withdrawn from the source (Döll & Siebert, 2002). Harvest Index (**HI**) is explained as the plant capacity to allocate biomass (**B**) into the formed reproductive parts (Wnuk et al., 2013).

Water Balance is another significant analysis which can be affected either positively or negatively by results of different artificial applications. A general equation can be described for sub-catchment scale regarding surface water body as the accumulation of the stream flow (**Q**), evaporation (**E**), abstractions and storage changes per time equal to return flows **(ΔS)**, precipitation on the Earth system (**P**) (Uhlenbrook & Savenije, 2017). After changing the agricultural management

practices, irrigation water requirements might be more or less, and the effects on the systems may show differences.

Water scarcity can be described as a lack of sufficient available water resources to meet the demands of freshwater to produce food, to supply industries, and to sustain inhabitants in the world within different specific scales (i.e. regional, national or global) (Hoekstra et al., 2012). Water Scarcity Index **(WSI)** is one of the indicators that ensure assessing the water scarcity/shortage/stress degrees (Falkenmark et al., 1989). Water scarcity analysis is crucial to understand the stress on the water resources systems and might help to select the proper adaptation pathways to assess not only the climate change impacts, also to assess the yield and water productivity for specific locations.

In this study, the aim was to investigate the soil and plant interactions regarding yield and water productivity in the agricultural sector for selected locations (sub-catchments) and certain crop productions within different irrigation technologies, irrigation strategies, and mulching practices by using AquaCrop model.

Method

Study Area

The research area is sub-river basins of Guadiana river basin, the middle Guadiana and Portugal area Guadiana. The Guadiana river basin indicates the starting point of the border between Spain and Portugal, and it becomes an international river basin between two countries. According to Chukalla et al. (2015), dominant soil profiles in Badajoz are loam, sandy loam, and silty clay loam. The main reason for selecting middle Guadiana as study area was that agricultural activities were the second highest water user in this region, and it is also the starting point of the delineation of the Spain-Portugal border.

In addition to those parameters, station-specific data was collected from an online database (Tank et al., 2002) regarding meteorological data from weather station, and also data related with hydrological and water use sectors was provided from specific studies on the Guadiana river basin (GuaSEEAW, 2015). The study area in the Guadiana river basin is illustrated in Figure1 (partly taken from Camacho et al., 2014 and modified).

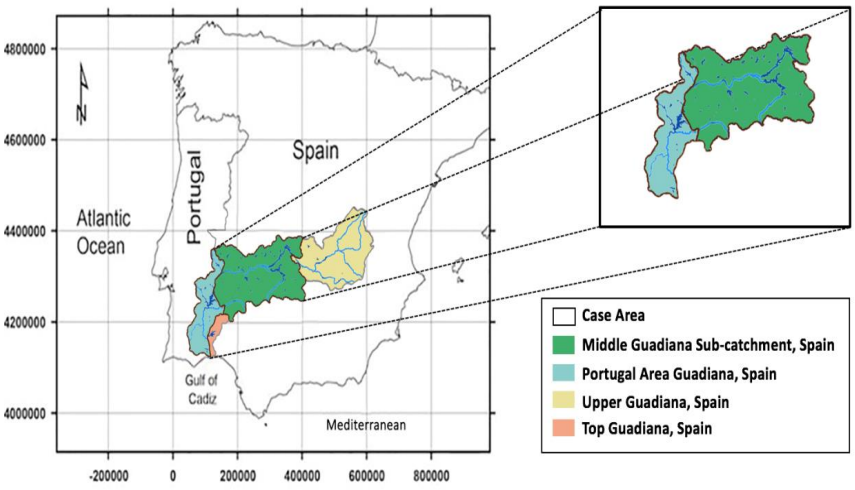

Figure 1. The study area in Guadiana river basin.

In selected area, irrigation technology was divided into three sections: sprinkler irrigation with 22%, localized irrigation with 23%, and surface flood irrigation with 54% (Aldaya and Llamas, 2008). Furthermore; dry, normal, and wet climates of the last ten years from the year of the study were found as 2015, 2009, and 2010, respectively; and model runs were executed for the normal year, 2009. According to the Spanish Ministry of Agriculture, Fisheries and Food (MAPAMA, 2010), on one hand, wheat and barley cultivations were based on rainfed irrigation (83% of the total selected area), only 2% was irrigated in 2009. On the other hand, 15% of the study area was irrigated for maize production without rainfed irrigation. In addition to this, while groundwater is dominant in the water system in the upper Guadiana, the middle Guadiana has surface water dominated areas (Aldaya and Llamas, 2008). Hence, in this study, we focused on surface water bodies more than the others while making water balance analysis. Table 1 shows the selected herbaceous crops such as maize, wheat, and barley, and irrigated crop calendars for the selected crops.

Table 1

Irrigated Crop Calendar (FAO, 2017)

	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec
Winter Wheat	■	■	■	■	■						■	■
Spring Wheat					■	■	■	■	■			
Maize					■	■	■	■	■			
Winter Barley	■	■	■	■							■	■

Step-1: AquaCrop Model

In this study, AquaCrop model (version 6) was used. AquaCrop is a dynamic model providing a simulation on the interaction between soil and crop, which is mainly divided into two sections regarding location- and user- specific parameters (Steduto et al., 2012). Location-specific parameters are climate and soil features, and user-specific settings are crop cultivar perception, the timing of crop cycle, water management, and agronomic practices. AquaCrop model performs the simulation robustly for herbaceous crops within a single growth cycle by the calculation of biomass production and final crop yield, which is to predict the crop yield at a field (point simulations). Herbaceous crops are a strong side of AquaCrop model. The field is presumed to be uniform. Solely vertical incoming such as precipitation, irrigation, and capillary rise and outgoing (evaporation, transpiration, and deep percolation) water fluxes can be taken into account. AquaCrop uses Penman-Monteith method to calculate reference evapotranspiration (ET_0). Furthermore, water productivity was normalized in the model for air CO_2 concentrations and atmospheric demand (WP*).

The main equations of the model parameters can be seen below:

$$B = WP^* \times \Sigma(Tr/ET_0) \quad (1)$$

$$Yield = B \times HI \quad (2)$$

$$WP = Y/ET \text{ (kg (yield)/m}^3 \text{ (ET))} \quad (3)$$

$$WP = B/\text{water applied (kg (biomass)/m}^3 \text{ (Tr))} \quad (4)$$

where B= Biomass; WP= Water Productivity; WP*= normalized WP; HI= Harvest Index; Y= Yield; Tr= Transpiration; ET_0=reference evapotranspiration.

Irrigation techniques.

Irrigation is an artificial way to provide water for crop production. Irrigation methods can be varied depending on energy or pressure requirements, or the specific techniques regarding wetted areas (Chukalla et al., 2015). The AquaCrop model has different options for users, for example, irrigation technologies within their efficiency and wetted area rates, which can be adjusted in accordance with the technology. Irrigation technologies were chosen as sprinkler, drip, and furrow irrigation in this study. Some of the rates of the irrigation efficiency and wetted area can be seen in Table 2 for different irrigation techniques.

Table 2

Efficiency Rates (IE) and Wetted Areas for Different Irrigation Techniques

Techniques	Çakmak et al. (2008)		FAO (2012)[1]	Aldaya &Llamas (2008)
	IE	IE	Wetted Areas	IE
Sprinkler	70%	75%	100%	70%
Drip	90%	90%	30%	90%
Surface (Furrow)	40%	60%	80%	50%

Note. [1] Retrieved from http://www.fao.org/docrep/t7202e/t7202e08.htm

From these efficiency rates for specific techniques, distribution of the irrigation technologies was given as 23% of the irrigation for drip, 22% for sprinkler, and 54% for furrow irrigation within the middle Guadiana. Thus, the water balance analysis was conducted according to assumptions of these distributions.

Irrigation strategies.

Full irrigation **(FI)** is the application of the irrigation during plantation applying water into the system for ensuring evaporative demand to increase yield within a no water stress condition (Chukalla et al., 2015). Irrigation can be applied to a certain amount periodically or after water depletion on a certain readily available water (RAW%) depletion. The AquaCrop model helps to users for choosing RAW% threshold. When a certain crop type is selected in the model, which guides its users for selecting the correct thresholds among affected canopy expansion, stomatal closure, and senescence acceleration.

Deficit irrigation **(DI)** can be explained as when the water is limited in the area of agricultural activities; optimal water application can provide efficient amount of water according to the research and technology innovations based on optimal yield and water productivity (Hamdan et al., 2006). Unlike FI strategy, DI strategy can be applied less than evaporative demand within limited water applications among less water shortage sensitive periods of the crop development.

Supplementary irrigation **(SI)** is a method that the certain amount of water applied to increase yield and water productivity when the crop growth under insufficient rainfed conditions. During the critical stages, such as lack of soil moisture within dry periods, SI can be applied to ensure important improvements in the yield and water productivity. SI can ensure to achieve good performance when the timing is selected correctly. According to Pereira et al. (2012), SI provides irrigation which

does not provide to reach crop water requirements as much as FI during insufficient rainfed conditions. At this point, less crop water is provided compared to FI and DI. When the water is limited, DI strategies can be more effective for farmers to increase WP rather than yield increase. At that point, more water can be available for more lands to be cultivated. SI is a kind of managed DI, and irrigation events can be done less than others among the stress conditions especially during the critical crop development stages to eradicate stress effects on the crop (Ewans et al., 2008). SI is a method to provide water when the dry spell occurs, and the water stress is observed during the development stage. Irrigation can be applied to increase soil moisture during dry periods for rainfed lands. Thus, SI is a remarkable strategy to increase water productivity and yield.

Mulching practices.

Using mulches in the crop cultivations provides decreases soil evaporation; besides, fewer impacts on transpiration occurs through plants. Organic, synthetic, and no mulching applications with a different surface coverage rates were considered in the study. The decrease in soil evaporation can be seen in Figure 2 by Zhang et al. (2002). Hamdan et al. (2006) refer to mulching agronomic practices as one of the evaporation reduction methods in addition to select correct timing for planting or drip irrigation. In the AquaCrop model runs, organic mulching with 100%, and synthetic mulching with 80% surface coverage were assumed for all the practices (Chukalla et al., 2015).

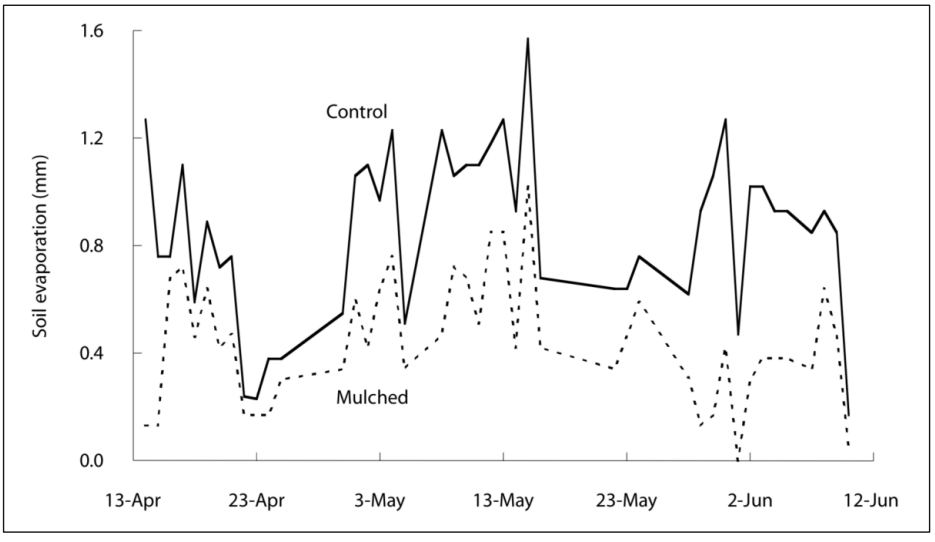

Figure 2. Effect of mulching on soil evaporation for winter wheat cultivation.

Step-2: Yield Gap (Y_g) and Water Productivity Gap (WP_g) Analysis

Yield gap (Y_g) is the difference between potential (Y_p) or water-limited yield (Y_w), and actual yield (Y_a). Y_p is the yield during the cultivation of a crop by a cultivar when the crop development is achieved by the proper climatic conditions, non-limited nutrients, and well-controlled biotic stress (Van Ittersum et al., 2013). Y_a is observed yield from the actual amounts in the field (GYGA, 2017). Y_w is more relevant to the benchmark for rainfed crops. Both Y_p and Y_w can be used as benchmarks for supplementary irrigated crops. The only difference between Y_p and Y_w is that Y_w is also dependent on soil characteristics and limited water for irrigation applications. Y_p and Y_w information can be obtained from models. In this study, the results from GYGA and AquaCrop showed the difference between two models, which have different management strategy categories and modelling characteristics. Besides, harmonization of both Y_p and Y_w could be better for yield gap analysis (GYGA, 2017). Furthermore, the difference between Y_p and Y_a came from precipitation and soil profile. To estimate WP_g, the methodology was used as same as the Y_g analysis. Furthermore, exploitable yield is defined as the difference between 80% of Y_p (or Y_w) and Y_a (Van Ittersum et al., 2013).

Step-3: Water Balance on Water Resources Systems

Water balance analysis begins with the calculation of the field level water balance within the soil water balance. The consumptive water uses (CWUs) within green (rainfed) and blue (irrigated) CWUs were upscaled among the upstream part to see impacts on both upstream and downstream later with WSI. This first step was executed through the AquaCrop model output. Reference data for hydrological information was taken from GuaSEEAW (2015) and Automatic System of Hydrological Information (SAIH) (2017). The next step was the upscaling of the field level CWUs for a sub-catchment level within harvested area-based calculations. Lastly, upstream changes in the water balance and the pressures on the downstream scale can be investigated within available data from the stations or reference sources. A visualization example of the water balance for current study at catchment level can be seen in Figure 3. Other sectoral water uses (such as domestic and industrial) were kept constant as in today`s world (GuaSEEAW, 2015). The strategies were chosen by different management practices according to the larger to smaller effects on the water resources system. Both withdrawal and consumptive water uses were considered in this study. Water withdrawal based calculations indicate uncertainties regarding the water losses in water distribution for the sectoral water demands. For this reason, the methodology was updated to use model results more accurately through CWUs. Water losses have significant importance on the estimations regarding the impacts

on the defined water balance. According to Aldaya and Llamas (2008), water losses during the water distribution were assumed as approximately 30%. Instead of this average value, CWUs were assumed in this section, and WSIs were calculated by a water consumption-based analysis. Assumptions to execute water balance part are briefly given below:

- The contributions of the selected strategies to the water balance were based on the reference. The representation of the current cultivation types (rainfed winter wheat, rainfed winter barley, irrigated maize) were calculated within the consideration of other agricultural activities (i.e. olive trees, vegetables, industrial crops) among the middle Guadiana regarding the CWU. Two types of the CWUs were calculated as green CWU and blue CWU through ET_a values from AquaCrop simulations. To analyze the water resources systems, blue CWU parameters were mainly used.

- Aldaya and Llamas (2008) stated the usage of different irrigation technologies for sprinkler with 22%, furrow with 54%, and drip with 23%. Those proportions were assumed in this study, and the combinations of the different mulching (NM, OM, SM) and irrigation strategies (FI, DI, SI) were used to illustrate impacts into the water balance. The calculated and changed outflow from the upstream part was accepted as additional inflow for the downstream region.

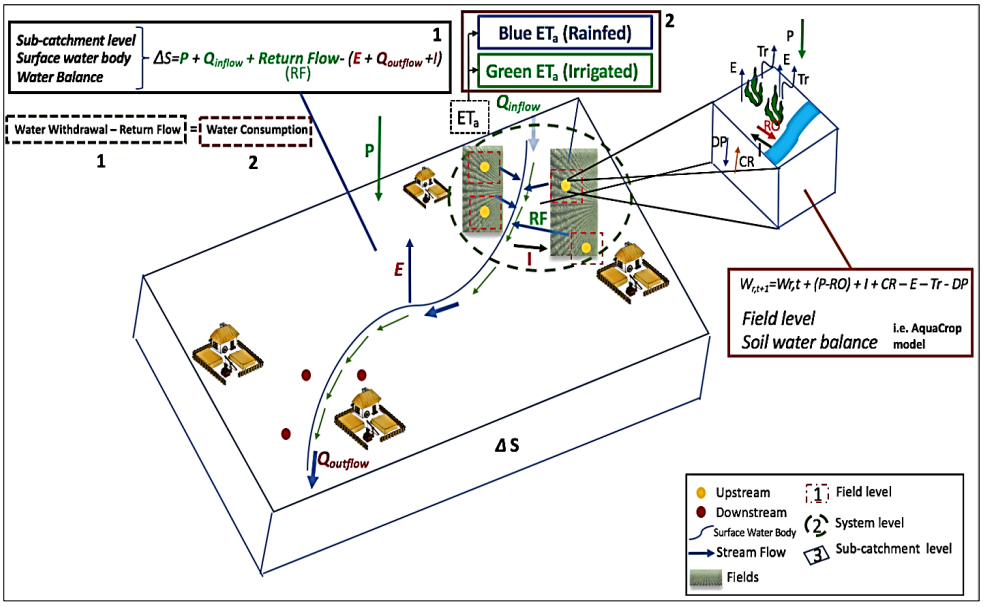

Figure 3. A visualization example of the water balance for study area at catchment level (ΔS= net change in storage; P= precipitation; E = Evaporation; Q= surface water flow; RF= Return Flow; I= Irrigation; Tr = Transpiration; ET_a= actual evapotranspiration; CC = Capillary rise; DP = Deep percolation).

Step-4: Water Stress/Scarcity Index (WSI)

Water stress/scarcity degree can be calculated within the available data for different management strategies in the agricultural system and their impacts on the water resources systems (equations 5 and 6). The illustration of the WSI application for the selected sub-basins and key flow parameters can be seen in Figure 4. It is precise that the WSI variation can be smaller regarding projections for a small proportion of the selected crops amongst all sectoral activities in the middle Guadiana. However, this analysis gives an idea regarding how different practices could depict various consequences on the water resources systems` stress degrees. The reference data in the study area was from different sources regarding other sectoral water uses and water dimensions (stream inflows) (GuaSEEAW, 2015).

Water Scarcity Index (WSI) was implemented by the equations below for upstream and downstream to compare different strategies, respectively:

$$WSI_{Spain} = \frac{\text{Water Consumption} - \Delta\ \textbf{Blue ETa,Spain}}{\text{Stream Inflow ,upstream}} \quad (5)$$

$$WSI_{Portugal} = \frac{\text{Water Consumption}}{\text{Stream Inflow ,downstream} + \Delta\ \textbf{Blue ETa,Spain}} \quad (6)$$

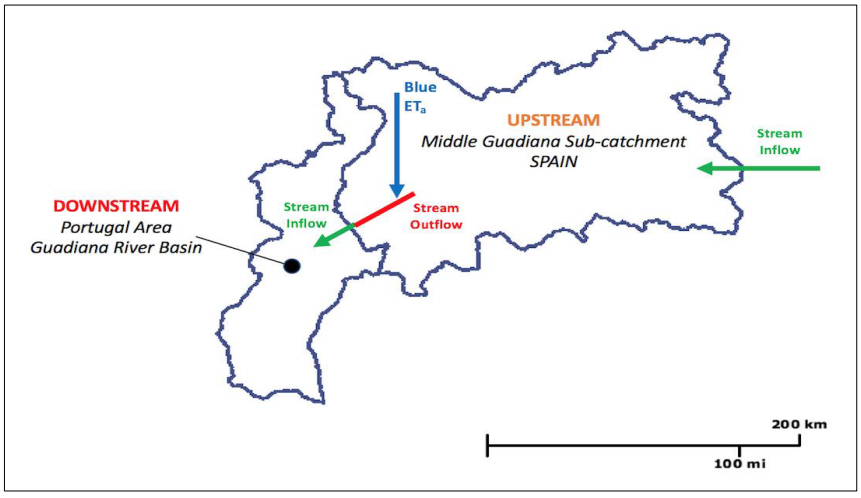

Figure 4. The illustration of the WSI application for the study area and key flow parameters.

Stepwise Approach

The stepwise approach of the study can be seen in Figure 5 including initial and main implementation phases of the research including above-stated steps.

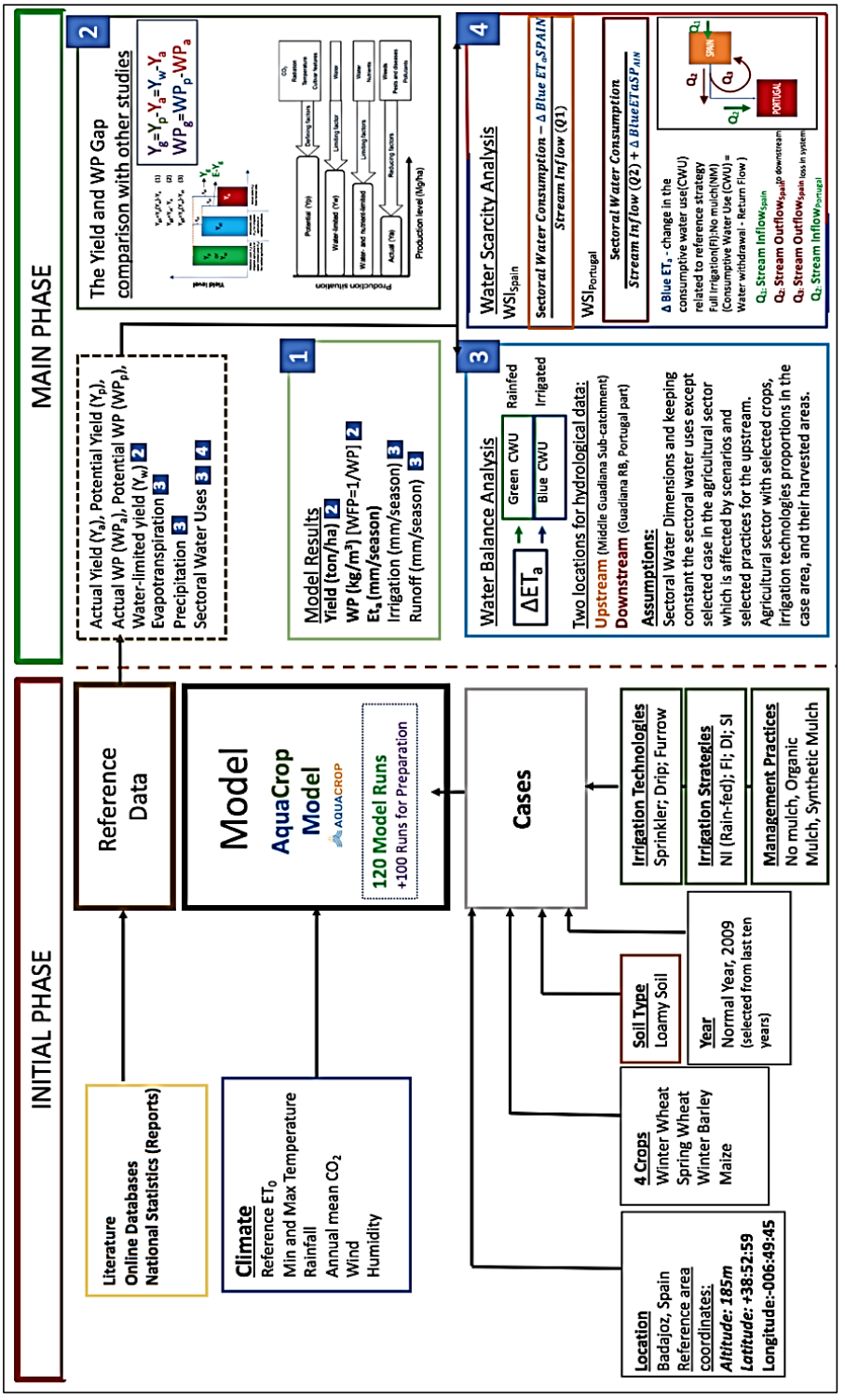

Figure 5. An overall flow diagram of the research and key parameters.

Results and Discussion

Model Results Regarding ET_a, Y, and WP within Different Management Practices by Using AquaCrop Model

In this section, actual evapotranspiration (ET_a), yield (Y), and water productivity (WP) model results were given with different illustrations according to the various purposes for selected crops which are winter wheat, spring wheat, winter barley, and maize. Y&ET_a and WP&ET_a for four crops were compared within all different management practices and significant correlations were found (Appendix). WP and ET_a results for four crops showed that the ET_a results lower than 300 mm were related to the rainfed cultivation for spring wheat and maize. The results higher than 500 mm were related to irrigated agriculture for the same crops. A total ET_a for wheat production can differ between 200-500 mm (Chukalla et al., 2015), and it was found that the range of ET_a production was in the simulated results with this scope (Appendix). The relationship between Y and ET_a showed a production curve that is increasing and leveling off with a high correlation value (0.99 R^2) for spring wheat and maize. Furthermore, the relationship between Y and ET_a; and WP and Y were found weak in winter wheat and winter barley production compared to maize and spring wheat production. Figure 6 depicts that a declining linear trend on ET_a for selected crops. Increasing trend of WP and main ordinal ranking was found as a following trend of NM, OM, SM, respectively. The effects of mulching practices depicted a decreasing trend on ET_a due to the increase of surface areas and a decrease in mainly soil evaporation values.

The reduction of transpiration values was found less affected compared to soil evaporation changes. Winter wheat and winter barley results showed less ET_a amounts compared to spring wheat and maize. The main reason of that these cultivations were rainfed based and mulching practices showed more impacts than other strategies (irrigation strategies did not exist in rainfed). However, when we look at the ranking of WP from smaller to larger, irrigated crops (maize and spring wheat) did not show a trend as found under rainfed conditions. It can be seen that leading drivers of the increasing in the WP is caused by mulching and irrigation strategies. The most significant ET_a deviations were found in the maize and spring wheat applications, whereas winter barley and winter wheat had fewer variations. Management practices without mulches depict higher ET_a values compared to organic and synthetic mulching practices as expected. The lowest ET_a value was seen in the synthetic mulching. The lower ET_a and WP values (extreme values) in both figures are related to rainfed cultivations for maize and spring wheat (Figure 6). There was an increasing trend on

WP which has less increasing trend in spring wheat, and other crops show similar increasing rates. The most substantial deviation among the mulching practices related to the WP changes was found in the rainfed maize.

As it is stated in the AquaCrop model manual (Steduto et al., 2012), yield values depict the preference of the cultivation types either rainfed or irrigated ones. It is clear that rainfed conditions were not appropriate for maize and spring wheat which illustrate extremely low yield productions under rainfed conditions. However, when we compared irrigated maize and irrigated spring wheat for a selection of more profitable options for farmers, maize production as modern producers` choices in the area, gives approximately double yield amounts. Hence, rainfed winter barley and rainfed winter wheat productions were better options as in the current situation. When any selection is needed to be done between irrigated maize and irrigated spring wheat, maize appears as an optimal selection because of its higher yield values. Different irrigation strategies had different yield responses because of the fewer water applications, from highest to lowest amounts by FI, DI, and SI, respectively, during the irrigation period. While rainfed maize was not applicable in the study area, yield from the irrigated maize was substantially more than other considered crops within the study. Spring wheat trials showed that the spring wheat production was not an efficient way for crop production compared to maize, but it still can be considered as an option for farmers whether they would like to cultivate their fields when there is an available time in addition to the present cultivations in the basin. Spring wheat might also provide strategy options in the future. It is not only for spring wheat; other crop types can be simulated in further studies for additional crop pattern alternatives.

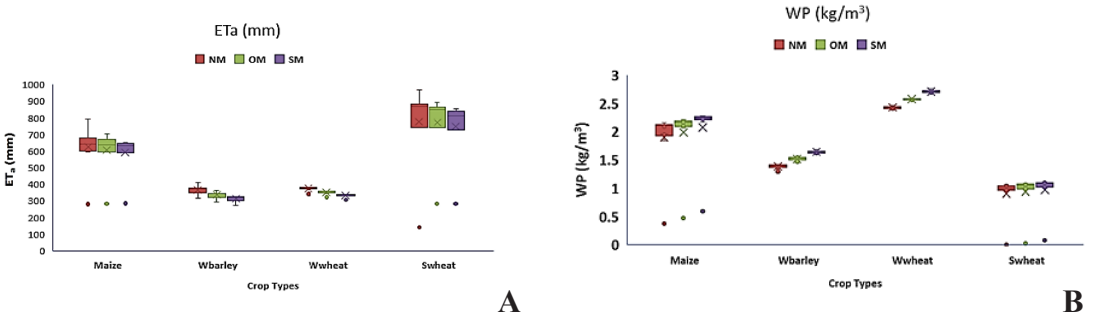

Figure 6. The actual evapotranspiration (ET_a) changes (A) and water productivity (WP) changes (B) for four crops within different mulching practices.

Figure 7 shows the different trends regarding ET_a, Y, WP, irrigation amount (I), and harvest index (HI). The highest difference between rainfed and irrigated agriculture was found for maize and spring wheat. On the other hand, there is no significant difference on yield parameter for winter barley and winter wheat. HI values showed insufficient rainfed conditions for maize and spring wheat; therefore, irrigated agriculture for those crops was inevitable. HI values were found nearly 0.5 for maize (0.5 in Steduto, 2012), 0.30-0.35 for winter barley (0.45-0.5 for modern producers in in Steduto, 2012), and 0.45-0.50 for winter wheat in this study (0.2-0.55 in Steduto, 2012). Due to the insufficient environmental conditions, lower amounts can be seen compared to literature information regarding the HI of certain crops which shows the comparability of the productions (Steduto et al., 2012). Different irrigation strategies have different yield responses because of the less water applications during the irrigation period. It is clear that fewer irrigation amounts were implemented by FI, DI, and SI in the simulations, and taken order from highest to lowest amount with FI, DI, and SI, respectively. In later sections, different strategy impacts on the water resources systems were given with selected strategies for current applications in the selected location.

The Comparison of the Yield Gap (Y_g) and Water Productivity Gap (WP_g) with Other Studies

Rainfed yield gap comparisons.

Figure 8 illustrates the yield gap comparisons of the model results with GYGA, and water-limited yields (Y_w) from the AquaCrop model and actual yields (Y_a) comparisons given to depict differences between yield gaps according to overall Y_g for a certain area in GYGA and different Y_g performances within different strategies. Only rainfed winter wheat and winter barley comparisons were given because of insufficient rainfed conditions for spring wheat and maize cultivations. For rainfed winter wheat, due to declining trend of Y_g in parallel with the estimated potential yield. According to the MAPAMA (2010), the same situation for Badajoz in modern cultavitions do exist, and only the irrigated maize production was carried out in 2009 among selected crops. When the simulated (AquaCrop) Y_ws results were compared to GYGA results (both Y_w, Y_a from GYGA), a significant decrease was found on Y_g. Synthetic mulching (SM) based field studies depict higher Y_ws for both crops, therefore, yield gap increased due to the more efficiently crop yield production from SM compared to NM.

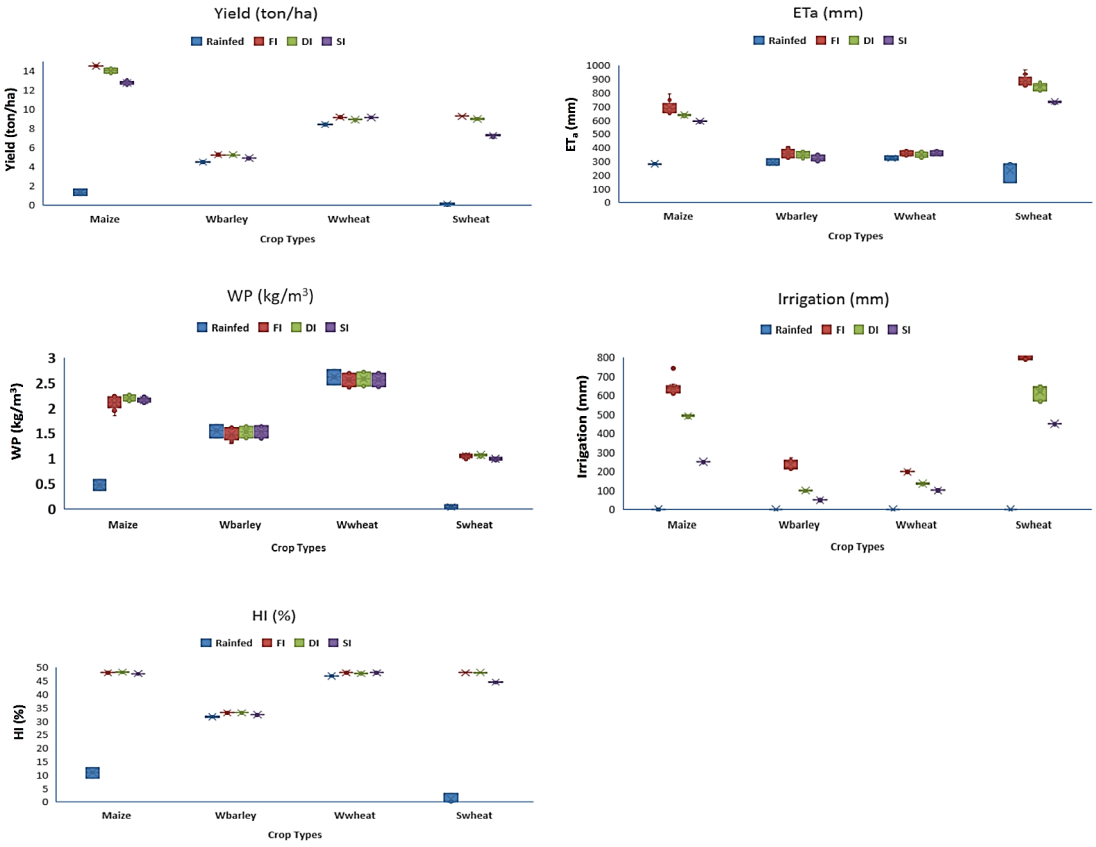

Figure 7. The yield (Y), actual evapotranspiration (ET_a), water productivity (WP), irrigation (I), and harvest index (HI) comparisons for selected crops within different irrigation strategies.

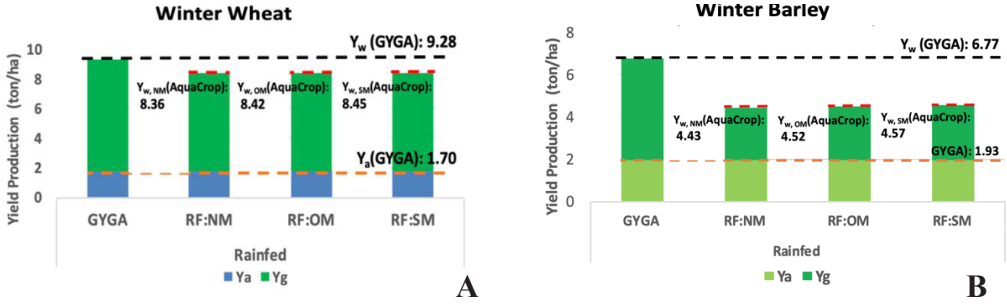

Figure 8. Changes in yield gap (Y_g) compared to GYGA within the comparison of GYGA for rainfed winter wheat (A) and winter barley (B) with different mulching trials.

Irrigated yield gap comparisons.

Figure 9 shows the yield gap changes according to different simulated management strategies for irrigated agriculture. Y_a was taken from GYGA regarding the reference column given as GYGA, and the remaining parts using the simulated yields which were selected as strategy-specific potential yields by different management applications. Potential yield (Y_p-GYGA) was taken from GYGA portal. It was found that more significant yield deviations found in the irrigated maize and irrigated spring wheat which are currently better options compared to rainfed agriculture (including only the yield quantity, economical and quality perspectives were not studied). Due to the higher proportion of the irrigated maize application, with approximately 15% highest yield decrease was found with SI application. As it is defined in the GYGA protocol, both GYGA (WOFOST model) and the findings of the current study (AquaCrop) describe the potential yields. However, Y_gs were smaller within the deficit irrigation strategies because of their less potential yield productions compared to full irrigation. Besides, large differences between AquaCrop and GYGA were because of the different model mechanisms and the data used during both studies. According to the exploitable yield gap results, SI strategy based simulations depicted a lower exploitable yield than modern maize cultivations; however, it provides savings for water resources through less water requirements in terms of crop productions.

Yield gap comparisons showed that FI strategy applied production had the highest Y_g because of its more massive potential (Y_p) compared to deficit water conditions (DI, SI, respectively, from larger to smaller yield production). As it was expected, Y_g decreases when the irrigation strategy changes from FI to SI. If yield production decreases for farmers and industrial producers like approximately 10%, the efficient use of water resources within the tendency towards less water demanded irrigation strategies (i.e. DI or SI) is inevitable. Irrigated maize yield production was in the range of 12.5-14.6 ton/ha, whereas it showed an insufficient amount of yield production under rainfed conditions with less than 0.6 ton/ha. An impressive result from this research was that yield production in irrigated maize production was almost three times higher than winter barley, and almost 0.5 times more than irrigated wheat. Hence, it is possible to reach more yield productions within maize cultivation. The critical point is that maize has less crop growth time length with five months (spring period) than other plantings with seven months (winter period). Thus, it makes possible to get benefit from those lands more, and food security issue might be undertaken more from this perspective to manage potential management opportunities.

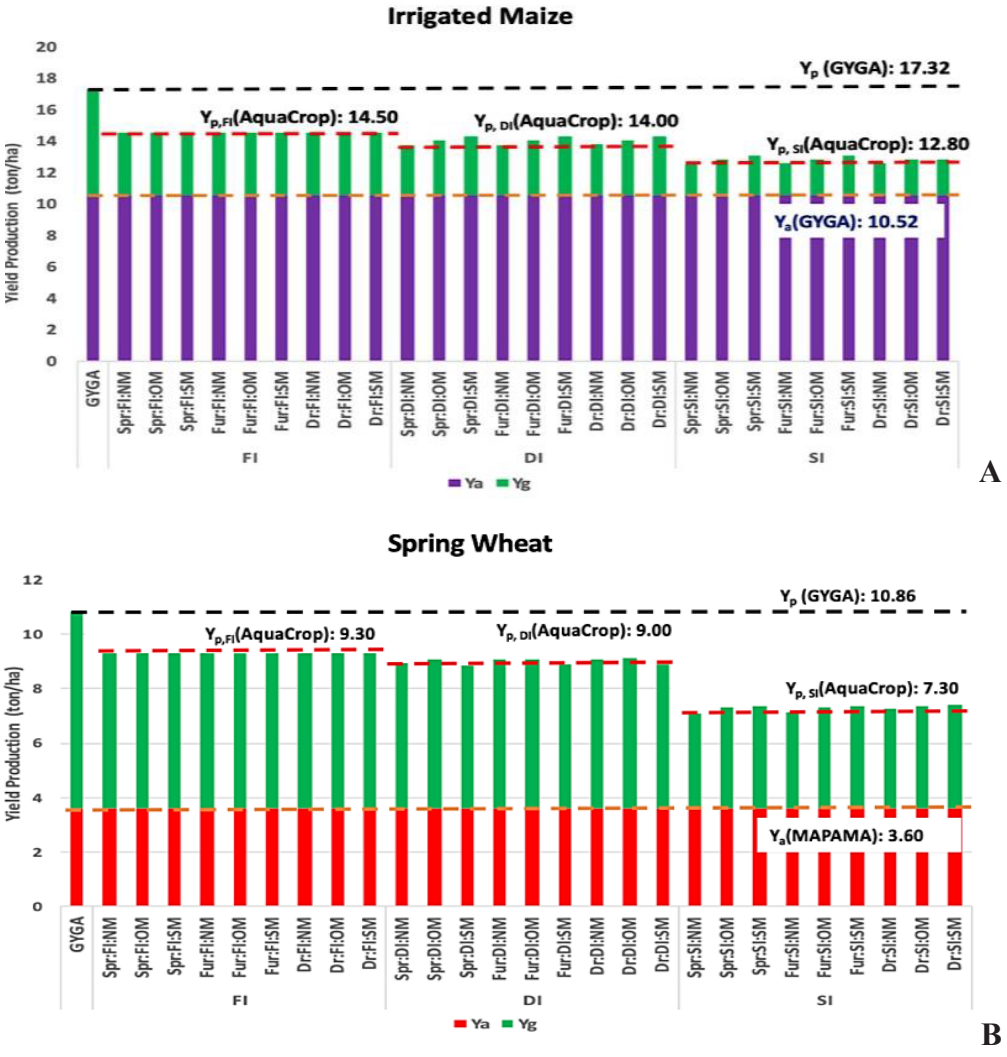

Figure 9. The yield gap changes within the comparison with GYGA (WOrld FOod STudies [WOFOST] model) for irrigated maize (A) and irrigated spring wheat (B).

To sum up, some strategies were selected considering the results from model. It was found that yield gap increases when the irrigation water uses increases because potential yields increases concurrently. Besides, no mulching had the highest consumption due to its least fruitful impact on water resources use efficiency. Furthermore, water is not the most limiting factor especially about water-limited yield formations for having fewer yield gaps also other factors like improvements on management practices would bring significant declines on yield gaps (Van Ittersum et al., 2013).

Figure 10 shows the yield gap comparisons from different studies for irrigated maize (GYGA: both Y_p and Y_a are from GYGA; for the simulated (AquaCrop): Y_p from trials within different management combinations, and Y_a from GYGA; for MAPAMA and Aldaya&Llamas (2008), Y_p from simulation runs and Y_a from sources). It can be seen that yield gap decreases from GYGA (data range for subsequent five years), MAPAMA, Simulated (AquaCrop), Aldaya and Llamas (2008), respectively. Some part of the simulated application has an overlap with GYGA (WOFOST model) estimations. Due to the larger temporal scale analysis in GYGA with 5-year, different environmental conditions (i.e. rainfall trends) show larger difference among period. In this study, year-specific actual yields were used because of the temporal scale of the research which is only for 2009. For larger temporal scale studies, using an average of 5-year actual yield was suggested by GYGA.

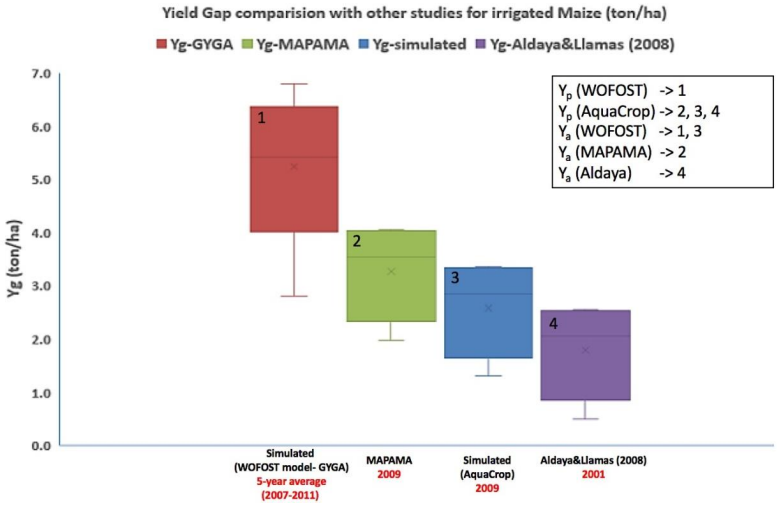

Figure 10. The yield gap comparison with other studies for irrigated maize.

Water productivity gap (WP_g).

The estimated water productivity gap (WP_g) is only available for winter wheat on GYGA. Therefore, WP_g only for winter wheat was given for various mulching practices (Figure 11). There was an increase in WP_g from no mulching to the organic and synthetic mulching due to the higher WP_p values from organic and synthetic applications by the AquaCrop model, respectively. WP_a was kept as constant from GYGA and comparisons were done with WP_p value from GYGA and possible WP values from the simulated ones. In the GYGA, only the WP_g analysis was executed for wheat production; therefore, for other crops, another reference was used (Aldaya and Llamas, 2008) from a different reference year.

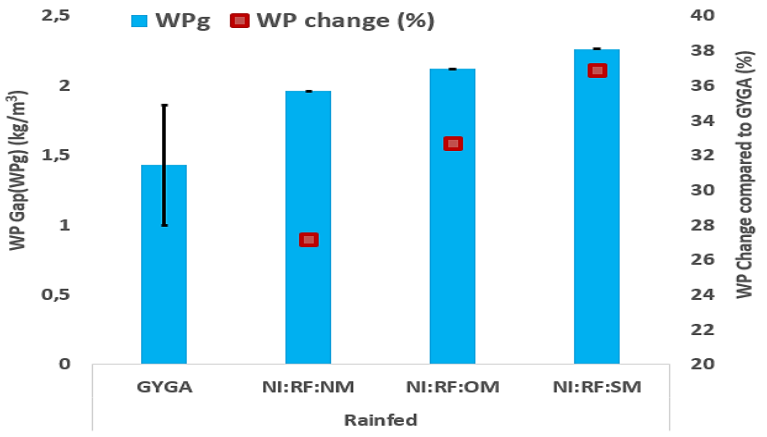

Figure 11. Strategy-specific water productivity gap (WP_g) changes over different rainfed mulching practices.

Figure 12 illustrates WP_g comparisons of the rainfed and irrigated crops. Winter wheat reachable strategy specific WP_p was calculated higher than winter barley and so the strategy specific WP_gs were higher. On the other hand, maize depicted higher WP_g for irrigated agriculture.

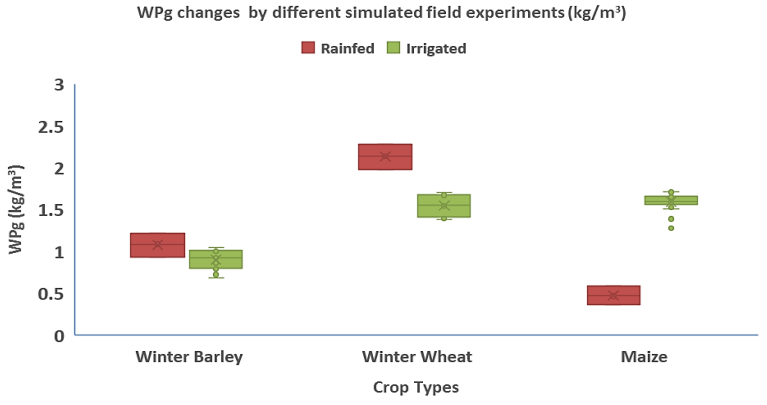

Figure 12. Water Productivity Gap (WP_g) comparisons of the rainfed and irrigated crops: winter barley, winter wheat, and maize.

Impacts of the Different Management Practices on Water Balance of the Water Resources Systems

Impacts of the different applications on the water resources systems were shown within individual strategies and then converted to the sub-catchment scale.

The reference data for this calculation was taken from GuaSEEAW (2015), which provides sub-catchment level hydrological and sectoral data among the Guadiana river basin. Besides, Portugal part was also involved in the dataset. AQUATOOL water basin management model was used by GuaSEEAW (2015), and those data were used in this research as a tool to calculate the effects of different strategies within the current case in selected sub-catchments. Stream flows were considered in this type of analysis. The order of the strategies showed a certain decrease trend from the worst-case scenario to the most efficient scenario with less water demand for agricultural production. Besides, it is necessary to consider yield changes to understand the extent of yield decreases compared to water resource efficiency increases. For irrigated maize application within strategy 9 (SI: SM), the yield decrease compared to the reference case was 12%, on the other hand, it was nearly 2% within strategy 6 (DI: SM). Integration between stakeholders is crucial to come to an agreement within a common ground. To illustrate, when it is necessary to consider both farmers' perspectives and environmentalist consideration, it might be a good scenario with less yield change and remarkable decreases in irrigation water requirements. In addition to this, mulching practices depicted an increase in yield productions for each crop.

There are two ways to interpret the analysis of water withdrawal and water consumption in water resources systems. Water withdrawal scope does also include the water conveyance losses, for instance, irrigation requirements are needed to be ensured from a water resource, and irrigation demand requires a certain amount of water conveyance line to the field from water source. However, water losses are inevitable from those water abstractions. This study was mainly focused on consumptive water uses (CWUs) as blue ET_a. Besides, CWUs were defined as ET_a which is the consumed water by a certain crop and can be derived from the AquaCrop model. The results from green CWU and blue CWU indicated that green CWU was larger than blue CWU. Due to the abstractions from surface water bodies which is the dominant water resource type in the middle Guadiana, blue CWU was selected as a critical parameter for the next steps.

Regarding sectoral water uses, it is not easy to estimate water consumptions for agricultural, domestic, and manufacturing sectors due to the substantial variabilities between soil-crop-water interactions, and water cycle complexities, human activities and different production patterns of the manufacturers. However, water consumption calculation can be executed within the use of agricultural system models (i.e. AquaCrop). These types of models are capable of simulating agricultural water demands and outflows. For example, from the manufacturing sector, recycling ratio assumption is used to estimate water consumptions as a conversion factor from water

withdrawal to water consumption for global sectoral water use models (Wada et al., 2011); however, it holds an assumption behind and having some uncertainties. Mainly, implications of studies especially in emerging countries are difficult to overcome because of data limitations and economic constraints.

In conclusion, nine strategies were selected after water balance analysis to be used in WSI analysis for comparing the strategies with a reference strategy. FI and NM application was selected as reference strategy (worst case scenario regarding water resources use efficiency), and following strategies were chosen as FI:OM (**Strategy-2**), FI:SM (**Strategy-3**), DI:NM (**Strategy-4**), DI:OM (**Strategy-5**), DI:SM (**Strategy-6**), SI:NM (**Strategy-7**), SI:OM (**Strategy-8**), SI:SM (**Strategy-9**).

Impacts of the Different Management Practices on Water Scarcity Index (WSI) of the Water Resources Systems

Figure 13 shows the difference between reference strategy (FI: NM) applications within different strategies. It can be seen that WSI changes appear to be more efficient in the way of water resources management within a different strategy. Case area-specific based WSI analysis showed significant improvements in water resources use efficiency in the upstream compared to WSI analysis including all sectors. The best management option was found as SI: SM for water resource use efficiency which illustrated that WSI compared to the reference strategy decreases five times within the case-specific calculation (Figure 13).

WSI analysis can be done by using different key drivers including water withdrawal, water consumption or population (per capita) (Kummu et al., 2016). To understand the impacts of different strategies on the WSI analysis, the worst-case scenario as the reference case (FI: NM) was chosen because of its largest water demand among other strategies. The scarcity/shortage situation was decreased significantly especially in the upstream part. Due to the differences between stream inflow to downstream part, impacts were not found significant as much as upstream part. The reason is that the nominator in the equation of the WSI analysis causes more sensivity than denominator because of tremendous amount of water availability than water uses. Therefore, case area-specific analysis was preferred for the comparison of water scarcity/shortage degrees.

When we change the management practices from FI: NM to SI: SM, there were nearly five times more improvements on the system that meaning of the least negative impacts on the water resources systems. From a farmer perspective, SI does not seem

to be an optimal strategy because of the 12% less yield achievement. But the Strategy 6 (DI:SM) showed 2% yield decrease and 2 times more water resources efficiency compared to reference strategy. This finding was seen from the exploitable yield gap where SI based yield production was less than actual yield. On one hand, we look at different irrigation strategies as the most efficient ones for the water resources system were SI, DI, FI, respectively for irrigated agriculture, on the other hand, for mulching practices, the most efficient one was the synthetic one.

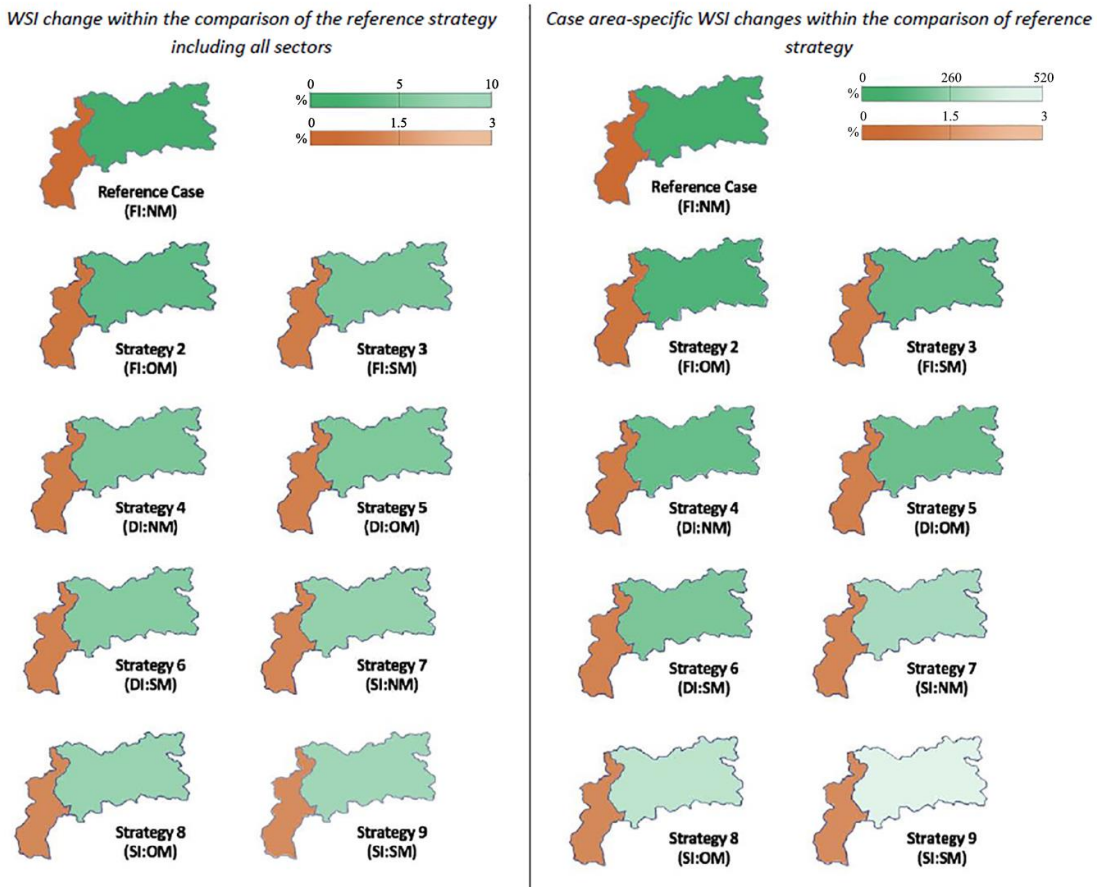

Figure 13. WSI variations of different strategies according to the reference strategy.

Conclusion

The analysis of different irrigation and management practices within the AquaCrop model indicated that model results are comparable with the particular area according to the comparisons with reported and simulated information from various sources. It was found that AquaCrop model is a sophisticated model to estimate ET_a, Y, and WP parameters. Mulching practices have positive impacts on the ET_a decreases. Besides, different irrigation strategies resulted in different yield responses, and yield productions decreased in deficit irrigation (DI) less than supplementary irrigation (SI), and full irrigation (FI) showed the highest yield within non-limited water conditions. This finding was an expected trend and decreases in water demands showed how the yields and water-related parameters are varied.

Impacts of different management practices on sub-catchment level water balance were calculated. The primary driver was selected as ET_a (CWU) change among the chosen strategies. WSI degrees were calculated by using the defined equations. The main issue regarding the water balance analysis was the scaling issues within the research and data availability concerning scales. Some assumptions were made; however, it was not possible to eradicate uncertainties entirely. To make robust and straightforward analysis, consumptive water uses from the simulated (AquaCrop) results were used to answer research questions with limited data. Water scarcity/shortage degree was estimated by water consumption amounts within including all sectors and only case-specific quantities. It is thus shown that case-specific estimations showed a clear appearance of the differences regarding the strategies compared to whole sectors. The delineation of the water scarcity/shortage degrees were more apparent in the upstream part than the downstream part because the model application was carried out for the upstream part which had the primary impacts apart from the downstream.

We address some recommendations for future studies as a next step of water resources system analysis:

1. It is possible to execute model runs for different seasons (i.e. normal, dry, wet, and future projections), in this way; results bring insights on larger temporal scales.

2. Considering grid-based soil types, other management practices (i.e. fertilizers, weed management, or salinity), and more climatic information from various meteorological stations may provide additional accuracy.

3. FI does not cause only the water resources deterioration, but also the salinity problems. Therefore, it is momentous to take into consideration quality matter too such as nonpoint source pollution (fertilizers, pesticedes etc.).

4. Although the AquaCrop model efficiency is high compared to modern observed studies, calibration and validation of the model could provide better projections for the future.

5. To calculate more detailed Y_g and WP_g estimations, data availability would bring more inputs to future studies. Such as actual yield and water productivity, potential yield and water productivity, and different management practices on the field could provide better investigations for benchmarking studies.

6. In addition to combined management practices based Y_g and WP_g analyses, strategy-specific definitions of these terms would ensure some insights on selecting the best management practices for a particular area.

7. In addition to a biophysical analysis, an integrated assessment can be done in further studies, for example, taking into consideration of economic analysis, life cycle assessment and social phenomena at the same time could be beneficial to improve integration of stakeholders and decision making process in the future.

Acknowledgements

The corresponding author would like to thank to the Turkish Ministry of National Education for getting fully-funded scholarship during this study. This study was constituted from the MSc thesis titled "*An assessment of yield and water productivity in response to different irrigation and field management practices with the AquaCrop model on a water resources system*" at Wageningen University and Research, the Netherlands. This study was carried out as a minor thesis in the Water Resources Management Chair Group (second master thesis in addition to the major thesis in the Water Systems and Global Change major track, Master of Environmental Sciences). This study was presented in the *IVth ECOCEE* (IV. Eurasian Conference on Civil and Environmental Engineering) conference on June 17-18, 2019 in İstanbul as an oral presentation, and part of this study was submitted as an extended abstract.

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Appendix

The Comparison of Yield & ET_a and WP & ET_a

First, yield (Y) and actual evapotranspiration (ET_a) results were compared with the all model results of the trials on a scatter plot diagram in Figure A1. Next, water productivity (WP) and actual evapotranspiration (ET_a) results for four crops are shown on a scatter plot diagram in Figure A2. The ET_a results lower than 300 mm are related to the rainfed cultivation for spring wheat, and maize. The ET_a results higher than 500 mm are related to irrigated agriculture for the same crops. The relationship between Y and ET_a shows a production curve that is increasing and level off with a high correlation (0.99 R^2) value for spring wheat and maize. On the other hand, there is no remarkable difference between rainfed and irrigated crop cultivation for winter wheat and winter barley. Furthermore, the relationship between Y&ET_a and WP&Y was found weaker in winter wheat and winter barley production compared to maize and spring wheat production. Figure A2 illustrates that the WP decreases after a moment reached on ET_a. It is mainly the reason for the full irrigation and no mulching strategies within different irrigation technologies. It can be seen that leading drivers of the decrease in the WP is caused by mulching and irrigation strategies.

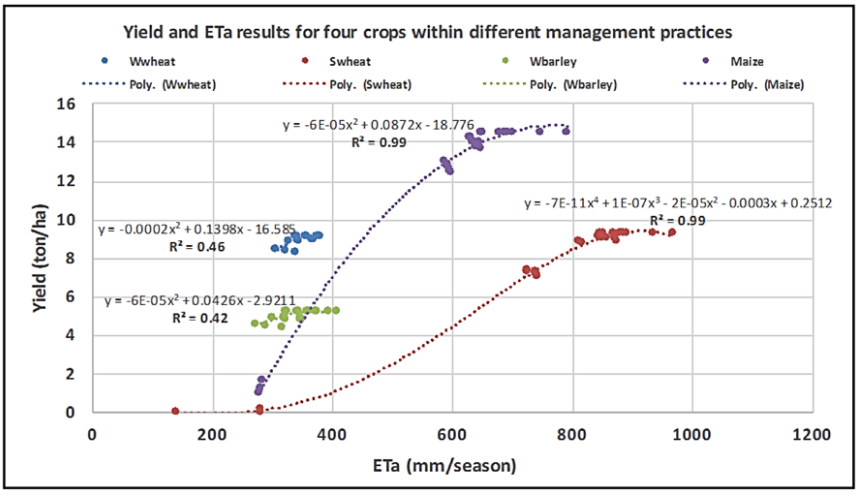

Figure A1. The comparisons of the yield (Y) and actual evapotranspiration (ET_a) for four crops (winter wheat, spring wheat, winter barley, maize) within all different management practices.

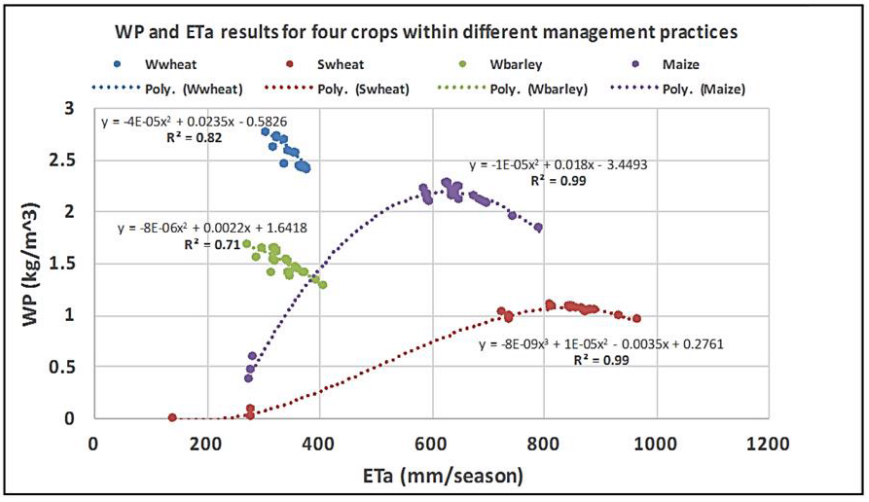

Figure A2. The comparisons of the water productivity (WP) and actual evapotranspiration (ET_a) for four crops (winter wheat, spring wheat, winter barley, maize) within all different management practices.

Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Sulama ve Arazi Yönetimi Uygulamalarının Su Kaynakları Sistemlerindeki Etkileri

Dünya nüfusunun 2050'de 2010 yılına göre yaklaşık olarak %70 oranında artacağı tahmin edilmektedir ve bu nedenle gıda talebinin giderek artacağı ve gelecek nesillerin beslenmesinin daha kritik olacağı öngörülmektedir. Bu çalışma, farklı sulama ve arazi yönetimi uygulamalarının su kaynakları sistemleri üzerinde nasıl bir etkisi olduğunu araştırmaktadır. Gerçek sistem değerlendirmelerinin karmaşıklığı nedeniyle, modeller karmaşık biyofiziksel sistemlerin analizini ve maliyetli işleri kolaylaştırmaktadır. Bu çalışmada, AquaCrop modeli (FAO), farklı sulama ve arazi uygulamalarının su kaynakları sistemlerindeki etkileri öngörmede analitik bir araç olarak kullanılmıştır. AquaCrop modeli, mahsul fenolojisini ve toprak-su-verim ilişkilerinde çevresel değişkenliklere davranışsal tepkileri simüle eder ve çiftçilere veya karar vericilere yardımcı olmaya çalışır. Daha güçlü tahminler yapabilmek ve sistemi daha iyi anlamak için Entegre Değerlendirme (Integrated Assessment - IA) yapılmasının gerekliliği kaçınılmazdır. Bu araştırmanın amacı, tarımsal sektördeki mahsül verimi ve su verimliliğine ilişkin toprak ve bitki etkileşimleri ile belirli mahsuller için seçilen alt su havzasındaki farklı yönetim stratejilerinin etkilerinin araştırılmasıdır. Bu amaç doğrultusunda aşağıdaki araştırma sorularına cevap aranmıştır:

- Gerçek evapotranspirasyon (ET_a), mahsül verimi (Y) ve su verimliliği (WP) nedir?
- Model sonuçları, diğer çalışmalarla karşılaştırıldığında mahsül verim açığı (Y_g) ve su verimliliği açığı (WP_g) analizleri bakımından nasıl sonuç vermektedir?
- Yukarı havza - aşağı havza etkileşimi ile ilgili yönetim uygulamalarından su sistemi (su dengesi) ve su kıtlığı / yokluğu dereceleri (WSI) nasıl etkilenecektir?

Araştırma adımları, bir su kaynakları sistemlerinin analizi için ayarlanmıştır. İlk olarak, AquaCrop modeli, seçilen tarım ürünlerinin (kışlık buğday, baharlık buğday, kışlık arpa ve darı) ve belirli yerlerdeki (orta Guadiana alt havzası, İspanya; Guadiana havzası Portekiz Bölümü, Portekiz) farklı yönetim uygulamalarının sonuçlarını tahmin etmek için uygulanmıştır. Modeldeki ilk adımdaki ana faktörler, tarım sektöründeki farklı yönetim uygulamalarına gerçek evapotranspirasyon (ET_a), mahsül verimi (Y) ve su verimliliği (WP)'nin tepkileridir. Bu çalışma, üç farklı yönetim stratejisinin (sulama teknolojileri (yağmurlama, karık, damla); sulama stratejileri (tam sulama, kısıntılı sulama, tamamlayıcı sulama ve yağmura dayalı sulama), malçlama uygulamaları (malçlama yapılmaması, organik malçlama, sentetik malçlama) etkilerini incelemektedir. Toplamda, farklı yönetim stratejilerinde seçilen yıl için 120 model simülasyonu gerçekleştirilmiştir. İkinci olarak, mahsül verim açığı (Y_g) ve su verimlilik açığı (WP_g) analizleri, mukayeseli değerlendirme çalışmaları bakımından önem taşımaktadır. Mahsül verimi açığı (Y_g), potansiyel olarak ulaşılabilir mahsül verimi (Y_p) ve gerçek mahsül verimi (Y_a) arasındaki farkı ifade etmektedir. Potansiyel olarak ulaşılabilir mahsul verimi (Y_p), uygun iklim koşulları, sınırlandırılmamış nütrient sağlanması ve biyotik streslerin iyi kontrol edildiği zaman elde edilen verimdir. Üçüncü olarak, mavi ve yeşil su tüketim kullanımları her bir strateji için tarla ölçeğinden alt havza ölçeğine, seçilen alandaki ekim alanları göz önünde bulundurularak hesaplanmıştır. Su çekimlerini hesaplarken, su dağıtımı için su kayıpları %30 olarak tahmin edilmiştir (Aldaya ve Llamas, 2008). Su kıtlığı/yokluğu derecelerinin (WSI) hesaplamalarında kullanılacak olması ve su iletimi – su dağıtımındaki kayıpların belirsizliği nedenleriyle su çekimleri

yerine su tüketimlerine su dengesi hesaplamalarında yoğunlaşılmıştır. Son olarak, su kıtlığı dereceleri, farklı yönetim stratejileri için karşılaştırılmıştır. Su kıtlığı dereceleri hesaplanırken su tüketimleri ve tüketimlerindeki değişimlerinin mevcut su kaynaklarının oranı ile hesaplanmış olup, bu çalışma belirli bitki deseni çeşitleri için yapıldığından ötürü, tüm sektörleri içeren WSI analizine ek olarak daha hassas sonuçları göstermesi adına çalışma özelinde hesaplamalar da gerçekleştirilmiştir.

Çalışma neticesinde elde edilen bulgulara değinilecek olursa, ilk olarak, AquaCrop modelinin ET_a, Y ve WP parametrelerini tahmin etmek için sofistike bir model olduğu bulunmuştur. Farklı sulama stratejileri farklı verim yanıtları göstermiş olup, kısıntılı sulamada (DI) tamamlayıcı sulamadan (SI) daha az mahsül verimi düşüşü gözlemlenmiştir. Tam sulama sınırlandırılmamış su koşullarında en yüksek mahsül verimini göstermiştir. Ayrıca, malçlama uygulamalarının ET_a azaltımı üzerinde olumlu etkileri gözlemlenmiştir. İkincisi, sulama ve tarla yönetimi uygulamaları Y_g'yi belirli stratejiler dâhilinde kapatmayı mümkün kılmaktadır. Bununla birlikte, bu uygulamaların olumsuz sonuçlarını ortadan kaldırmak için çevresel kaygılar dikkate alınmalıdır. Bu analizin ana bulgularından biri de tam sulama yapılan mahsullerin, kısıntılı sulama gerçekleştirilen üretime kıyasla daha yüksek potansiyel mahsül verimine ulaşmasına rağmen, mühendislik tipi modellerle su tasarrufu sağlamakla beraber mahsül eldesi düşüşlerinin minimizasyonunu hesaplamakta mümkün olmaktadır. Üçüncü olarak ise; kuvvetli ve anlaşılır bir analiz yapmak için, farklı sulama ve yönetimsel uygulamaları kullanılarak, AquaCrop modelinden elde edilen su tüketimi sonuçları ile su bütçesinin analizi ve değişikliklerin gözlemlenmesi gerçekleştirilmiştir. Son olarak, çalışılan sistemin sınırları (seçilen tarımsal ürünleri) göz önünde bulundurularak su kıtlığı derecelerinin analizi ile ilgili olarak ve tüm sektörleri içeren su kıtlığı derecelerinin farklı sulama ve yönetimsel uygulamalar bazında karşılaştırılmaları seçilen su kaynakları sistemleri için gerçekleştirilmiştir. Tam sulama (FI): Malçlama olmadan (NM) senaryosu su kaynakları üzerinde en kötü etkileri gösterirken, tamamlayıcı sulama (SI): sentetik malçlama (SM) uygulamaları çalışılan stratejiler içerisinde yüzeysel su kaynağına en düşük olumsuz etkiyi göstermiştir. Bunlara ek olarak; kısıntılı sulama (DI): sentetik malçlama (SM) stratejisinde daha az mahsül üretim kaybı ile önemli miktarda su tasarrufu gözlemlenmiştir.