

Response to the comments provided by Luis Pereira

Title: " Risk of water scarcity and water policy implications for crop production in the Ebro Basin in Spain"

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AR: Authors responses

1. The paper could be of interest for HESS but probably it would fit better in a journal related with water management. The difficulty with the paper is that supporting concepts are not clear, including they may be wrong, and material and methods are insufficiently described and include wrong assumptions.

AR: We are very interested in this journal because it is a multi-disciplinary approach that enables a broadening of the hydrologic perspective and the advancement of hydrologic science through the integration with other cognate sciences.

In this case, our paper has an economic vision of hydrological processes and their interactions with human activity. The subject area of our paper is Water Resources Management and the Technique and Approach is: Modelling Approaches

2. Page 5897 lines 17-18: there is confusion on the use of the terms water use, consumption and demand: water demand corresponds to water use and therefore includes non-consumptive uses. In the Ebro Basin, which is a highly populated and industrial area, agriculture cannot reach up to 90% or more of water demand; may be authors pretend to refer to water consumption. 90% or more of water demand for agriculture only occurs in non-industrial areas with low population.

AR: We agree with the comment, it was our mistake to mention water demand instead of water consumption. We have changed it in to the text as follows: "In Spain, irrigated agriculture accounts for 80% of national consumption of water (Gómez-Limón and Riesgo, 2004) and only 40% of the land area is suitable for cultivation (Iglesias et al. 2000). This paper focuses on the Ebro basin, where agriculture can reach up to 90% or more of water consumption."

3. Page 5897 line 19: I suppose that the National Irrigation Plan (2001) is deeply changed in the last years, thus such a tremendous increase is not likely to occur. However it is of interest to assess what could happen if it would be applied.

AR: The National Irrigation Plan "Horizon 2008, (In Internet: <http://www.mapa.es/es/desarrollo/pags/pnr/principal.htm> elaborated by the Spanish Ministry of Environment, rural affairs and marine affairs (Ministerio de medio

ambiente, y medio rural y marino) in 2001. It includes long term objectives (2008-2015) and hasn't been revised by now. We agree with the reviewer in a future revision of this plan such a huge increase on irrigated land is not likely to be maintained and we add the following paragraph into the text to clarify this point: "Although some efforts are being made to make the irrigation systems more efficient, trying to reduce water consumption for agriculture, such a huge increase on irrigated land is not likely to occur in a climate change context since more and more severe drought events are expected to happen. In addition, it will be difficult to make this compatible with the water framework directive environmental restrictions. So we have consider three policy scenarios where irrigated area is reduced"

4. Introduction. The considerations in the introduction suggest a inter-sector conflict for water. Something could be added about non-agricultural water use sectors.

AR: We have added some consideration about water conflicts. However, it is not the focus of the paper. We added the following paragraph to the Introduction section: "Although that, it is important to consider factors affecting water availability such as the increase of urban demands and the energy consumption and the environmental restrictions by the Water Framework Directive, among others."

5. More important, the introduction lacks i) a formulation of objectives of the study (independently of what already said in the abstract) and ii) review/discussion of methodological approaches that support methods used in this paper, as well as show possible advances relative to current knowledge.

AR: We have added the following paragraph in the introduction section formulating the objectives of the study and the organization of the sections in the paper: "In this paper, we focus on the evaluation of hydrological risk and water policy implications for agricultural production in the Ebro basin in Spain. We link bio-physical and socio-economic factors by the introduction of environmental, hydrological, technological, geographical and economic variables to characterize crop yield for the main Mediterranean crops in this basin. The results provide information about the best crop to minimise risk. Later, these models are used to address a simulated policy to assess some policy scenarios with irrigated area adjustments that could cope in a context of increased water shortage. We observe how a reduction in irrigated land results in moderate or significant losses of crop productivity. The response is crop specific and may serve to prioritise adaptation strategies.

The article is organized as follows: The second section provides general and detailed information on the methodological steps. The third section describes the results of the estimates crop-water production functions for 8 main crops in the basin. This section shows also the estimates of agricultural added value function, Montecarlo risk analysis and virtual policy scenarios. The final section presents the conclusions of the paper."

6. In the Material and Methods section there is some but limited review; however in this section methods should be described in a focused way and references should be used just to support further information for readers. Section 2.1 is written as it is usual for an introduction and not for material and methods

AR: We have reorganized all the Section 2 to better explain the steps on methodology.

7. Page 5898 lines 12-14: Authors write: “we estimate linear regression models by ordinary least squares (OLS). Statistical models of yield response have proven useful to estimate the water requirements” Unfortunately it is totally unclear what kind of models are referred and, of course, if they were calibrated and/or validated and how this was performed. two pages later, El Jamal – should be El Jamal et al. - is called but it is not clear how this model applies to Ebro, and how was it parameterized/calibrated for crops and climates different of those by the developers.

AR: Our paragraph was not entirely clear, so we have rewritten it to clarify why we mention each of the studies: “Statistical models of yield response have proven useful to estimate the water requirements at different locations for selected crops and have also proven useful to evaluate the effects of extreme contingencies and other socioeconomic variables. Extensive literature exists about the estimation of crop production functions to compute the climate effects over crop production (Lobell et al., 2005; Lobell et al. 2006; Parry et al. 2004; Iglesias et al., 2000; Hussain and Mudasser, 2007). Some papers focus specifically on the crop-water relationship for irrigated yields (Al-Jamal, 2000; Alcalá and Sancho-Portero, 2002; Echevarría, 1998; Acharya and Barbier, 2000). Socio-economic factors have also been included as explanatory variables (Iglesias and Quiroga, 2007; Quiroga and Iglesias, 2009; Griliches, 1964). In this paper, we have linked bio-physical and socio-economic factors introducing environmental, hydrological, technological, geographical and economic variables to characterize crop yield for the main Mediterranean crops in the Ebro river basin.”

8. Page 5898, eq.2: i) why the Solow-Stiglitz model was selected? The question is raised because it has more than 30 years when there are many others more recently developed? I do not say it is inappropriate but I ask a short discussion and justification be given in the paper

AR: We have added the following discussion in to the text: “Estimation of production functions is always controversial and each approach has strengths and limitations. In order to put our work in the viewpoint of the productivity literature we used the Solow-Stiglitz perspective. We follow Solow (1956) in the sense that we are modelling a production technology in order to identify productivity change. Some experts have criticized this function because of the assumption that R and K are substitutes, what is not true, since, they are complementary (Daly, 1997). However, nowadays it is extensively used to represent production processes (Stiglitz, 1997). Our approach differs from Solow’s initial model from that we use more than two factors of production to obtain output. It is good to say that based in this model we specifically use the usual Cobb-Douglas specification, as it allows a simple estimation and the coefficients obtained have a very intuitive interpretation in terms of elasticities. There are empirical studies that have shown that in agriculture, statistical models of yield response have been proven useful to estimate input requirements at different locations for selected crops (Lobell et al., 2005; and Lobell et al., 2005, 2007; Parry et al. 2004.”

9. Page 5898, eq.2: ii) the variables are not identified nor units are given.

AR: The variables have been clarified as follows:

$$Y = K^{\alpha_1} L^{\alpha_2} R^{\alpha_3} \quad \text{with } \alpha_1 + \alpha_2 + \alpha_3 = 1 \text{ y } \alpha_i > 0$$

Where: K is capital, L is labour, R is natural resources and $\alpha_1, \alpha_2, \alpha_3$ are parameters and represent the elasticity of substitution among the factors. Eq. 2 is a general theoretical specification of the original model, but later, in section 2.3 we showed the extended empirical model and Table 1 shows the full specification of each one of the variables including the units.

10. Page 5900 line 11: “Crop yield is defined as the ratio between production (T) and agricultural total area (ha)”. Is this referring to each crop?? Please be more specific. Why a T is used when the common symbol for yield is Y?

AR: Crop yield is referring to each crop. In the section “Results” we show the results by each crop. The notation has been clarified: “Crop yield (Y) is defined as the ratio between production (t) and agricultural total area (ha) and data were obtained from the Spanish Ministry of Environment (MARM)”

11. Page 5900 lines 24-26: It is written that “The crop-water production function is linear in the deficit irrigation section because all the applied water is used for evapotranspiration, and the production function is equal to the evapotranspiration production function.” This is not true because ET is water consumption and applied water is water use, which includes provision for inevitable water wastes or operational losses, and for leaching (the Ebro basin has salinity problems in various locations that require leaching). Moreover, it is necessary to specify if the analysis is done only at parcel level or if it is up-scaled to the farm, where distribution water wastes also occur, or up-scaled to the system level, where more water wastes need to be considered. Anyway, equalling water application to ET is an absolutely unacceptable assumption.

AR: We totally agree with the reviewer in this point. It has been a mistake. We have not made such an assumption. Our variable to represent water factors is net water needs of crops as it is shown in Table 1. We have not used evapotranspiration. We used it in a first step of our modelling process (following Al Jamal, 2000), but then we did not found a significant relationship and changed our analysis. (We forgot to remove this paragraph). We have now removed this paragraph that describes something we have not used.

12. Model of page 5901: it is not enough to send the reader to a table but it is necessary: i) to identify all variables when an equation is presented, ii) to give units, iii) to explain how parameters are obtained, iv) to evidence the goodness of model parameterization (in results section)

AR: We think the use of a table is good to show clearly and concisely the meaning of the variables and the units in which they are expressed. Table 1 includes all the information related to the variables. In pp. 5901 line 15-21 explain how parameters are obtained and the goodness of model parameterization.

13. Page 5902 lines 5-7: ” To date, it is difficult to characterize droughts because of their spatial and temporal properties and the range of indicators required”; this is a wrong sentence because there are various good papers by Spanish colleagues identifying droughts in the Ebro basin

AR: We agree that there are several good studies that estimate the drought in the Ebro basin, but the difficulty comes from the fact that there is no universally accepted definition of drought. We rewrite this sentence like: “To date, it is difficult to characterize droughts because of their spatial and temporal properties and the lack of a universally accepted definition (Tsakiris et al., 2007)”.

Tsakiris, G., Loukas, A., Pangalou, D., Vangelis, H., Tigkas, D., Rossi, G., and Cancelliere, A. (2007). Drought Characterization in Drought Management Guidelines Technical Annex”. Cap. 7. Pp 85 – 102.

14. Page 5902 lines 20-21: Authors assumed “a dummy variable that equals 1 if the year t is a drought year (with SPI smaller than -1) and 0 in other cases” for their modelling approach. This is totally inappropriate because the lack of water affects crops differently according the intensity of water shortage and periods when timing of water shortage. The approach is therefore too much rough. Literature has numerous examples how to deal with water scarcity impacts on yields.

AR: We disagree with the reviewer on this comment. How to deal with water scarcity on yields is a very interesting topic addressed from different approaches and we do not think there is a unique way to deal with it. We are not assuming that water affects crops equally as seem to suggest the reviewer. Introducing a dummy variable to characterize drought we estimate a different response for each crop. Some previous works using this approach in Spain includes Garrote et al., 2007; Moneo, 2005; Iglesias et al 2007; Quiroga and Iglesias, 2009.

15. Page 5903 lines 2-15: This text is written as for a summary and any reader may have extreme difficulties in understanding. For instance, writing “to help in the choice of appropriate models, we have used Akaike (1973) and Schwarz (1978) and adjusted R squared criteri\” is not all sufficient for a reader to understand what was performed. The basic information on the approaches by these authors, eventually the fundamental equations used, should be given. In addition R2 refer to which kind of relations? Which are the observed variables that could be related with simulated ones? In addition, the VIF equation, includes a R2; it refers to which regression? Since you have k variables, thus k VIF values, which are the criteria for evaluation and elimination of variables?

AR: All the tests were conducted for each of the regressions, as can be found in the results (Table 5). We inserted some sentences to clarify the paragraph:

“Finally, to help in the choice of appropriate models, we have used Akaike (1973) and Schwarz (1978) and adjusted R squared criteria, which are widely used to describe the goodness of model parameterization. A full description of the methods can be found in Greene (2003). To complete this process of variable selection, we observe a strong relationship between some of the explanatory variables which might be a source of collinearity problems. To detect a potential problem in each regression, we calculated the variance inflation factor (VIF) for each of the explanatory variables:

$$VIF(x_k) = \frac{1}{1 - R_k^2}$$

VIF represents the squared standard error (or sampling variance) of $\hat{\beta}_k$ in the estimated model divided by the squared standard error that would be obtained if x_k were uncorrelated with the remaining variables (Chatterjee and Hadi, 2006). So we have a VIF factor for each variable. Then, we follow the following criteria: (i) values larger than 10 give evidence of collinearity and, (ii) a mean of the VIF factor considerably larger than one suggests collinearity. We then proceed to eliminate variables which have a VIF value larger than 10. The criteria for elimination of variables when collinearity exists have been to eliminate the variable presenting lower impact on the goodness of model. We proceed in an iterative way when collinearity persists.”

16. Eq. lnGAV: the beta values are the same as for the model presented before? However, if the model is crop specific and various beta are used, in this equation beta refer to each crop and can not be the same. But it is not clear at all how these beta are obtained. The epsilon use to be residuals; in this case they are residuals of what? Which are the observed values, i.e., nothing is said about what is observed?

AR: The parameters in Eq lnGAV are not the same. To clarify this, we have renamed it as follows:

$$\ln GAV_t = \alpha_0 + \alpha_i \ln Y_{it} + \varepsilon_t$$

We have added the following sentences: “Where the dependent variable ($\ln GAV_t$) is the natural logarithm of agricultural gross added value for a site in year t and the subscript i refers to the different crops considered and α_0, α_i are parameters.” and “The coefficients have been estimated by OLS and diagnostic tests were conducted as in the crop-water production function estimation process”

The observed data has been clarified as follows: “We have included observed historical data about crop yield, water and climate requirements and socio-economic and geographic characterization of eight representative crops in the 18 regions in the Ebro basin from 1976 to 2002.”

17. page 5904 lines 3-4: authors say: “Diagnostic tests were conducted as in the cropwater production function estimation process.” However it is essential to explain what kind of tests were used and which criteria were used to accept results.

AR: See comments 15 and 16

18. Section 2.5. Montecarlo risk analysis this section is insufficiently described. It is not necessary that the article explains montecarlo approach but that be more clear about how it was used.

AR: We have clarify how Montecarlo has been used in the paper: “In this paper, the probability distribution of production functions for each crop is estimated using the Montecarlo method, which is a key component of uncertainty and probabilistic risk evaluation, since it allows us to generate random samples of statistical distributions to measure risk (Robert and Casella, 2004; Iglesias and Quiroga, 2007; Hammersley and Handscomb, 1975). The approach consists of generating a synthetic series of yield variables using the Monte Carlo method and Latin Hypercube sampling (Just, Weninger 1999; Atwood et al. 2003.).”

Crop yields response to water pressures in the Ebro basin in Spain: risk and water policy implications

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Abstract

The increasing pressure on water systems in the Mediterranean enhances existing water conflicts and threatens water supply for agriculture. In this context, one of the main priorities for agricultural research and public policy is the adaptation of crop yields to water pressures. This paper focuses on the evaluation of hydrological risk and water policy implications for food production. Our methodological approach includes four steps. For the first step, we estimate the impacts of rainfall and irrigation water on crop yields. However, this study is not limited to general crop production functions since it also considers the linkages between those economic and biophysical aspects which may have an important effect on crop productivity. We use statistical models of yield response to address how hydrological variables affect the yield of the main Mediterranean crops in the Ebro river basin. In the second step, this study takes into consideration the effects of those interactions and analyzes gross value added sensitivity to crop production changes. We then use Montecarlo simulations to characterize crop yield risk to water variability. Finally we evaluate some policy scenarios with irrigated area adjustments that could cope in a context of increased water scarcity. A substantial decrease in irrigated land, of up to 30 % of total, results in only moderate losses of crop productivity. The response is crop and region specific and may serve to prioritise adaptation strategies.

Keywords: crop productivity, water production function, water policy, Montecarlo simulations

1 Introduction

Water conflicts in the Mediterranean have been extensively reported, and many of the studies have analysed the costs for governments to maintain or even increase water supply (Smith, 2002). In the past, studies have focused on the supply side through cost-benefit analyses. However, with the new water-related problems, such as climate change, droughts and floods, focus on the demand side is needed. For this kind of analysis physical, political and socioeconomic components must be integrated for an optimal management of activities to increase the basin's output.

It is crucial for the Mediterranean region, where irrigation represents as much as 90% of total water consumption (Gómez-Limón and Riesgo, 2004), to measure the risks associated with climate variability in agriculture and to implement water demand policies that promote an efficient allocation and use of resources in the region's farms. According to the OECD, agriculture is the major user of water in most countries, since about 70% of total available water is used for irrigation. It also faces the enormous

challenge of producing almost 50% more food by 2030 and doubling production by 2050. This will likely need to be achieved with less water, mainly because of growing pressures from urbanisation, industrialisation and climate change (OECD, 2010). Agriculture is also the main user of other environmental and natural resources and therefore has an important role to play in global ecosystem sustainability. Therefore, small changes in agricultural water use (in planting, crop management or crop production) can have significant economic and hydrological impacts. In Spain, irrigated agriculture accounts for 80% of national consumption of water (Gómez-Limón and Riesgo, 2004) and only 40% of the land area is suitable for cultivation (Iglesias et al. 2000). This paper focuses on the Ebro basin, where agriculture can reach up to 90% or more of water consumption. In fact, more than 354,245 ha of irrigated land are projected to be added according to the National Irrigation Plan (2001) for the nine regions in the Ebro basin. This represents an increase of 2,110 hm³/year of water demand and an expected increase of 44% in the irrigated area, raising the total mean to 1,128,653 hectares. This increase imposes significant additional pressure on aquatic ecosystems and has serious environmental implications, such as the maintenance of environmental flows and water quality in rivers. Although some efforts are being made to make the irrigation systems more efficient, trying to reduce water consumption for agriculture, such a huge increase on irrigated land is not likely to occur in a climate change context since more and more severe drought events are expected to happen. In addition, it will be difficult to make this compatible with the water framework directive environmental restrictions. So we have consider three policy scenarios where irrigated area is reduced.

The Ebro Basin is located in the Northeast of the Iberian Peninsula with a total area of 85,362 km². This watershed is the largest in Spain, accounting for 17.3% of the total national area. It is made up of 347 major rivers, including the Ebro River, which drains the basin. It rises in the Cantabrian Mountains and ends in the Mediterranean and has a total length of 910 km and 12,000 km of main river network (CHEBRO, 2009). The climate in the Ebro basin is primarily Continental Mediterranean, with hot, dry summers, cold, wet winters and short, unstable autumns and springs. In the middle of the basin, the climate is semi-arid and in the northwest corner it is oceanic. Consequently, there is a wide heterogeneity in temperature. In 2007, for example, the province of Tarragona reached a maximum temperature of 43 °C, while Burgos had a minimum of -22 °C. Our methodological approach deals with these differences since links bio-physical and socio-economic factors.

In this paper, we focus on the evaluation of hydrological risk and water policy implications for agricultural production in the Ebro basin in Spain. We link bio-physical and socio-economic factors by the introduction of environmental, hydrological, technological, geographical and economic variables to characterize crop yield for the main Mediterranean crops in this basin. The results provide information about the best crop to minimise risk. Later, these models are used to address a simulated policy to assess some policy scenarios with irrigated area adjustments that could cope in a context of increased water shortage. We observe how a reduction in irrigated land results in moderate or significant losses of crop productivity. The response is crop specific and may serve to prioritise adaptation strategies.

The article is organized as follows: The second section provides general and detailed information on the methodological steps. The third section describes the results of the estimates crop-water production functions for 8 main crops in the basin. This section shows also the estimates of agricultural added value function, Montecarlo risk analysis and virtual policy scenarios. The final section presents the conclusions of the paper.

2 Methods

2.1 Steps on methodology

The methodology developed in this study is applied to selected crops in Ebro basin. Models are obtained for each of 8 crops in order to estimate the risk of water variability and policy scenarios. The methodology includes the following 4 steps: [1] we estimate linear regression models by ordinary least squares (OLS). Statistical models of yield response have proven useful to estimate the water requirements at different locations for selected crops and have also proven useful to evaluate the effects of extreme contingencies and other socioeconomic variables. Extensive literature exists about the estimation of crop production functions to compute the climate effects over crop production (Lobell et al., 2005; Lobell et al. 2006; Parry et al. 2004; Iglesias et al., 2000; Hussain and Mudasser, 2007). Some papers focus specifically on the crop-water relationship for irrigated yields (Al-Jamal, 2000; Alcalá and Sancho-Portero, 2002; Echevarría, 1998; Acharya and Barbier, 2000). Socio-economic factors have also been included as explanatory variables (Iglesias and Quiroga, 2007; Quiroga and Iglesias, 2009; Griliches, 1964). In this paper, we have linked bio-physical and socio-economic factors introducing environmental, hydrological, technological, geographical and economic variables to characterize crop yield for the main Mediterranean crops in the Ebro river basin. The goal was to analyse economic component (labour and capital) as opposed to the natural component (water for irrigation and irrigated area components of the production function) together. Literature on this specific area includes Acharya and Barbier, 2000; Alcalá and Sancho-Portero, 2002; Echevarría, 1998; and Hussain and Mudasser, 2007. [2] In a second step, we try to understand the interactions between agricultural production and profit functions focusing on water demand. To do so, we analyze the total agricultural gross added value (GAV) of the region and its interaction with the aggregate crop yield. [3] We use the Montecarlo method to characterize statistical properties of crop yield in response to water patterns or policy adjustments. This method is a powerful and commonly used technique for analyzing complex problems and conducting experiments to evaluate probabilistic risk (Rubinstein, 1981). In agriculture, this method is used to characterize statistical properties of crop yield in response to climatic variables and other inputs (Lobell & Ortiz-Monasterio, 2006; Iglesias and Quiroga, 2007). [4] Finally, we simulate the structural adjustments, in this case a decrease in irrigated area (ha) that could allow the agricultural sector, to cope with increased water restrictions for the agricultural sector. See Figure 1.

[FIGURE 1 NEAR HERE]

In our approach, the estimation of the crop production function plays a fundamental role, since it is then used to evaluate the added value as well as the risk and policy implications. Estimation of production functions is always controversial and each approach has strengths and limitations. Here we have followed the Solow-Stiglitz perspective (Solow, 1974; Stiglitz 1979, 1997), as specified below. According to Solow (1956), there are two factors of production to obtain output, capital (K) and labour (L). Where its technological possibilities are represented by a production function:

$$Y = F(K, L)$$

[1]

It is assumed that production shows constant returns to scale. Therefore the production function is homogeneous to the first degree. This is equivalent to assuming no scarcity of non-augmentable resources such as land. If we assume scarce-land, this would lead us to decreasing returns to scale in capital and labor and the model would become more Ricardian. Nowadays, it is well known that natural resources are very important to economic growth and environmental sustainability. In this context we find an extended production function named the Solow-Stiglitz model (Solow, 1974; Stiglitz 1979), which includes natural resources (R).

$$Y = K^{\alpha_1} L^{\alpha_2} R^{\alpha_3} \quad \text{with } \alpha_1 + \alpha_2 + \alpha_3 = 1 \text{ y } \alpha_i > 0$$

[2]

Where: K is capital, L is labour, R is natural resources and $\alpha_1, \alpha_2, \alpha_3$ are parameters and represent the elasticity of substitution among the factors.

Estimation of production functions is always controversial and each approach has strengths and limitations. In order to put our work in the viewpoint of the productivity literature we used the Solow-Stiglitz perspective. We follow Solow (1956) in the sense that we are modelling a production technology in order to identify productivity change. Some experts have criticized this function because of the assumption that R and K are substitutes, what is not true, since, they are complementary (Daly, 1997). However, nowadays it is extensively used to represent production processes (Stiglitz, 1997). Our approach differs from Solow's initial model from that we use more than two factors of production to obtain output. It is good to say that based in this model we specifically use the usual Cobb-Douglas specification, as it allows a simple estimation and the coefficients obtained have a very intuitive interpretation in terms of elasticities. There are empirical studies that have shown that in agriculture, statistical models of yield response have been proven useful to estimate input requirements at different locations for selected crops (Lobell et al., 2005; and Lobell et al., 2005, 2007; Parry et al. 2004).

2.2 Data

To characterize our model we use regional, national and international sources of data. Table 1 describes the variables included in this study and the source of data. We have included observed historical data about crop yield, water and climate requirements and socio-economic and geographic characterization of eight representative crops in the 18 regions in the Ebro basin from 1976 to 2002. Crop yield (Y) is defined as the ratio between production (t) and agricultural total area (ha) and data were obtained from the Spanish Ministry of Environment (MARM). Economic and geographic variables were mainly obtained from the Spanish Institute of Statistics (INE) while technological variables were taken from FAOSTAT and Food and Agriculture Organization (FAO). To build a proxy variable for irrigation, we used Ebro basin management authority local data, (CHEBRO, 2004) about net water needs of crops. Finally, climatic data such as total precipitation, maximum and mean temperatures, and number of days below 0°C degrees were taken from the Spanish Meteorological Agency (AEMET) to characterize the impact of climate.

[TABLE 1 NEAR HERE]

2.3 Crop-water production function

We have estimated a crop-water production function that establishes the relationship between crop yield and water applied for a range of crops that represent irrigated agriculture in the Ebro basin. The crop-water production function is linear in the deficit irrigation section because all the applied water is used for evapotranspiration, and the production function is equal to the evapotranspiration production function.

Nevertheless, non-linear responses indicate that not all water is used by the crop, since some goes to deep drainage and the evapotranspiration production function is really a production function. The function becomes curvilinear as more of the applied water goes to deep drainage. Generally, a curvilinear function is expressed as a second order polynomial (Al-Jamal, 2000). This function is not unique and varies among crops and zones.

The specified model is:

$$\ln Y_t = \alpha \ln Y_{t-1} + \beta_0 + \beta_1 L_t + \beta_2 Mac_t + \beta_3 Mac_{t-n} + \beta_4 Altitude_t + \beta_5 Area_ebro_t + \beta_6 Irrig_area_t + \beta_7 Irrig_t + \beta_8 Irrig_t^2 + \beta_9 Pr ec_{it} + \beta_{10} T_Max_{it} + \beta_{11} T_Mean_{it} + \beta_{12} Fr_{it} + \beta_{13} Dro_t + \varepsilon_t$$

[3]

Where the dependent variable ($\ln Y_t$) is the natural logarithm of the crop yield for a site in year t . The explanatory variables were described on Table 1. The subscript i on climate and some water variables refers to the three months periods ($i = def$ (Dec, Jan, Feb), mam (Mar, Apr, May), jja (Jun, Jul, Aug) and son (Sep, Oct, Nov)).

Agricultural time series are nonstationary since they always present a trend. When variables are nonstationary, normal regression analysis requires a transformation of the data. When there is not enough information about the causes of a such trend, the transformation needed to generate a stationary variable may be attained by simply removing deterministic trends (that is by directly subtracting the trend value from the observations or “detrending”); by taking first-differences (that is the variable in year t (Y_t) minus the variable in year $t-1$ (Y_{t-1}); or by introducing and autoregressive term as a the independent or explanatory variable. (Iglesias, Quiroga, 2007). In our case, we assume that there is a causal relationship between yield increase and technological change, and therefore we consider a management variable, the farm equipment power (Mac), to explain yield trend. A range of management indicators such as farm equipment power (Mac), tractors (Trac), nitrogen fertilizer (Fert), pesticide consumption (Pest), or seeds improvement (Seed) have a high correlation (Quiroga, Iglesias, 2009) since they can be considered as a proxy variable for technology and investment in a farm or in the farming sector of a district or country. (See Figure 2).

We used OLS to estimate the coefficients. To facilitate the improvement of particular model estimation for each crop, 95% confidence intervals were estimated assuming normality of the residuals, and significant relations were considered into the estimated model. White’s general test (White, 1980) was used to check conditional heteroscedasticity under null hypothesis (H_0) of homoscedasticity (Johnston and Dinardo, 2001). Durbin-Watson statistics are used to check autocorrelation existence (Durbin and Watson, 1950).

When the parameters β_i are estimated, the marginal effect of a change in the explanatory variables is given by:

$$\frac{\partial E[\ln Y|X_i]}{\partial X_i} = \beta_i$$

[4]

The signs and magnitude of the marginal effects indicate the effect of a particular input variable X_i over the crop yield. In this case, the coefficients of the model have to be interpreted as semi-elasticities because the model presents a semi-logarithmic transformation. The interpretation is that semi-elasticity is responsible for the percent increase of yields produced by a unit change in the input variable.

In the Ebro basin there exists a very high variability in precipitation and it is common to observe that recurrent drought periods affect agricultural production. To date, it is difficult to characterize droughts because of their spatial and temporal properties and the lack of a universally accepted definition (Tsakiris et al., 2007; Hayes 2002, Keyantash and Dracup 2002; Bradford 2000). In this work, we use the frequently used Standardized Precipitation Index (SPI, McKee et al 1993). This index, based on the probability of precipitation for any time scale, calculates the difference in accumulated precipitation between a selected aggregation period and the average precipitation for that same period, it is an index. The calculation of the SPI for any location is based on the long-term precipitation record for a desired time. This long-term record is fitted to a probability distribution, and is then transformed into a normal distribution, implying values that vary around 0. This allows areas with different climates to be relatively compared (McKee et al 1993; Steinmann et al., 2005). We have selected 12 months as the aggregated period for calculation. To define the criteria for a drought event we follow McKee et al.'s (1993) table where a drought event occurs when SPI values are -1.0 or less (see Table 2). This criterion was followed in previous detailed works in Spain (Iglesias et al 2007; Garrote et al., 2007). We, then, construct a dummy variable that equals 1 if the year t is a drought year (with SPI smaller than -1) and 0 in other cases.

[TABLE 2 NEAR HERE]

Due to the large number of correlated variables the selection of explanatory variables for model specification is important. Greene (2003) shows two alternatives to follow: (a) an inductive approach, which consists in starting with a reduced model and amplifying it by including more variables to a general model. The main problem associated with this approach is that the computed statistics can be biased and inconsistent if the hypothesis is incorrect. (b) A deductive approach, which consists in starting with a given general model to set up a correct fitted model. This approach is frequent in recent analyses since, although inefficient, the estimates and test statistics computed from this over-fitted model are not systematically biased. We therefore, we use the second approach in this paper. As usual the choice of the explanatory variables to include in the final specification follows a deductive approach based on the Akaike (1973) and Schwarz (1978) criteria and adjusted R squared criteria, which are widely used to describe the goodness of model parameterization. A full description of the methods can be found in Greene (2003). To complete this process of variable selection, we observe a strong relationship between some of the explanatory variables which

might be a source of collinearity problems. To detect a potential problem in each regression, we calculated the variance inflation factor (VIF) for each of the explanatory variables:

$$VIF(x_k) = \frac{1}{1 - R_k^2}$$

[5]

VIF represents the squared standard error (or sampling variance) of $\hat{\beta}_k$ in the estimated model divided by the squared standard error that would be obtained if x_k were uncorrelated with the remaining variables (Chatterjee and Hadi, 2006). So we have a VIF factor for each variable. Then, we follow the following criteria: (i) values larger than 10 give evidence of collinearity and, (ii) a mean of the VIF factor considerably larger than one suggests collinearity. We then proceed to eliminate variables which have a VIF value larger than 10. The criteria for elimination of variables when collinearity exists have been to eliminate the variable presenting lower impact on the goodness of model. We proceed in an iterative way when collinearity persists.

2.4 Agricultural added value

Agricultural added value variations are characterized as a function of crop yields as follows:

$$\ln GAV_t = \alpha_0 + \alpha_i \ln Y_{it} + \varepsilon_t$$

[6]

Where the dependent variable ($\ln GAV_t$) is the natural logarithm of agricultural gross added value for a site in year t and the subscript i refers to the different crops considered and α_0, α_i are parameters.

In this case, the coefficients of the model can be understood as elasticities because the model presents a logarithmic transformation. The interpretation is that elasticity is responsible for the percent increase of yields produced by a one percent increase in the input variable.

The coefficients have been estimated by OLS and diagnostic tests were conducted as in the crop-water production function estimation process.

2.5 Montecarlo risk analysis

Risk analysis bridges the gap between impact evaluation and policy formulation by focusing policy's interest on consequences (i.e. crop yield) rather than agents (i.e. rainfall or irrigation). There are many definitions of risk but, in a wide sense, risk can be defined as the capacity of a system to suffer losses when it is exposed to an external stressor.

In this paper, the probability distribution of production functions for each crop is estimated using the Montecarlo method, which is a key component of uncertainty and probabilistic risk evaluation, since it allows us to generate random samples of statistical distributions to measure risk (Robert and Casella, 2004; Iglesias and Quiroga, 2007; Hammersley and Handscomb, 1975). The approach consists of generating a synthetic

series of yield variables using the Monte Carlo method and Latin Hypercube sampling (Just, Weninger 1999; Atwood et al. 2003.).

In agriculture, Montecarlo simulation offers a flexible and accurate approach for investigating and understanding statistical properties of crop yield in response to inputs like irrigation and rainfall (Lobell & Ortiz-Monasterio, 2006). In terms of water policy, we analyze marginal effects on the statistical model to calculate how a reduction in irrigated area could affect crop yield (Iglesias and Quiroga, 2009; Llop, 2008). Using Montecarlo simulations we obtain 10,000 random values of statistical distributions of every crop yield and then analyze the distribution of probabilities to obtain a certain yield (risk level).

2.6 Water policy scenarios

We have evaluated three policy scenarios considering a reduction of agricultural irrigated land of 10%, 20% and 30%. These scenarios are consistent with a perspective of increased water scarcity and reflect the policy implications of environmental concerns. The European Water Framework Directive states that it is necessary to restore and conserve the ecological health of rivers, thus the Hydrological Plan of the Ebro Basin must accommodate the irrigated land area, review current concessions and seriously consider the removal of salinised irrigated areas as well as those that consume too many resources due to their low profitability.

On the other hand, the establishment of environmental flows in some sections of the Ebro Basin Rivers means that current irrigation areas will have to be reduced. Currently, there is a provisional minimum flow of between 5% and 10% of current annual average flow which is made by sections. It is important to observe that the minimum ecological flow in the Ebro river mouth has been set at $100 \text{ m}^3 \text{ seg}^{-1}$. This amount is practically arbitrary, due to the absence of more detailed studies. At this moment, some complementary actions are being taken in order to improve the systems' basin efficiency. For instance, existing or future infrastructure needs to respect the minimum ecological flow required downstream (Herranz, 2008; CHEBRO 2004).

Also, it is well known that irrigated area is a crucial element when talking about agricultural water demand. In Table 3, we can observe a summary of irrigated areas by Community. These are grouped by large and small irrigation systems for each of the nine Autonomous Communities contained within the basin. According to the CHEBRO, the existing concessional irrigated areas' demand, in the current situation of distribution by crop, is $6310 \text{ hm}^3 \text{ year}^{-1}$ while the current concessional irrigable area is 783,948 ha. Here, Aragón and Cataluña account for more than 77% of this area. It is important to say that this demand does not coincide with the annual supplied volume, which depends on the actually irrigated area, and the actual of annual crops among other factors (CHEBRO normative).

Under a hydrologic-hydraulics point of view and according to the regulation and concessional guidelines' adaptations, the maximum possible irrigation area in the future will reach 985,999 ha, corresponding to a demand of $8,213 \text{ hm}^3$. Under the same assumptions, it would expand to a maximum irrigated area of 1,271,306 ha with a demand of $9,879 \text{ hm}^3$. This represents a partial increases of 202,051 ha and 285,307 ha for each of the two horizons. However, the effective development of these areas will depend on agricultural policy decisions taken by competent institutions. Nevertheless, the COAGRET Report (2007) says that the establishment of future environmental flows on some river sections will imply cuts in current irrigation extensions in order to follow the statements of the Water Framework Directive. It is therefore difficult to think about an increase in those ha.

[TABLE 3 NEAR HERE]

Relative to the total agricultural area in the Ebro basin, alfalfa, wheat, grapevine, olive, potato, maize and barley are the seven most representative crops in the Ebro basin since they account for almost 60% of the total agricultural area in this region. Rice does not represent a large percentage of the total cultivated area in the overall basin, but it is the most important crop in the Ebro delta area and it is an intensively irrigated crop. Alfalfa, maize, potato and rice are mainly irrigated while wheat, barley, grapevine and olive are primarily rainfed crops (Table 4).

[TABLE 4 NEAR HERE]

3 Results

3.1 Crop-water production functions and agricultural added value

The relationship between crop yields and amount of water for irrigation in the six representative crops varies with crop and location (Figure 3). The relationship between crop yield and irrigation is obviously positive in an initial phase but the marginal decrease to scale. For alfalfa, potato and maize, the most irrigated crops considered, the decreasing phase is not observed within the range of irrigated values considered in this study. For wheat, barley and grapes, optimization of the amount of water is essential. In these crops, additional water beyond a threshold results in reduced output. Rice is not shown since it is always irrigated nor are olives since the amount of irrigated land in this region is relatively small compared to the irrigated land of the other crops. Irrigated land has evolved differently for each crop and area considered (Figure 4). In the upper basin (Burgos province) the proportion of irrigated area for the cereals crops increases during the period of analysis. This increase is a result of the lack of water scarcity problems in this part of the basin during the period of analysis. In contrast, in the middle basin (Zaragoza province) and the lower basin (Tarragona province) the trend is clearly downward, except in the case of maize in Zaragoza, where the tendency is almost constant. This reflects an increased limitation of irrigation due to prioritization of water for the environment.

[FIGURE 3 NEAR HERE]

[FIGURE 4 NEAR HERE]

We estimated crop-water production functions that explain the influence of water on crop productivity and also incorporate a wide range of variables (Table 5). The increasing trend in crop productivity is explained largely by technological and management variables. We assume that yield increases due to improved varieties are linked to more intensified management. We tested the adequacy of the functions to represent crop-water production functions as outlined in the methods section; in the cases where regressions present heteroskedasticity the regressions are estimated with the White method (1980) to obtain robust estimates (following Wooldridge, 2003). In general the eight crop-water production functions present the expected signs according to the agricultural processes. Irrigation for alfalfa, wheat, rice, potato, maize

and barley present a positive impact on the crop yield but this decreases after a given amount of water. Irrigation is not statistically significant for grapevine and olive yield. This may be due to the small area of these crops under irrigation and to the fact that irrigation in these crops is “deficit irrigation” used only to maintain yield during drought periods. Irrigation area also has an important impact on alfalfa, wheat, grapevine, potato, maize and olive. For this last crop, the effect of irrigation area is the largest. In contrast, drought does not show significant impacts for all crops. Only wheat, barley, and grapevine have negative significant impacts in this variable probably because these crops are rainfed. In other words, except for olives, irrigated crops do not show evidence of significant impact of drought on their yield. The quantity of machineries has a positive effect after one period (Mac(-1)) or even two periods (Mac(-2)). That can respond to a lag in the investments on machinery. In the case of agricultural labour, the variable is at macro level and the negative effect is responding to the decreasing returns to scale when additional labour force move to agricultural sector.

Table 6 shows the estimated profit function for each crop yield. The estimation of this function has been considered for all crops; however, we only took into account those that are significant. In other words the effects may be poorly specified for crops that are not represented in the entire geographic area. We note that when yields of alfalfa, maize, potatoes and wheat increase by 1 unit, the agricultural gross added value increases. A strictly economic analysis might suggest the desirability of a stronger orientation of production towards wheat and maize, because an increase in the yield of these crops has a major impact on the region’s agricultural GAV. However, this does not take into account the cost of virtual water. Even though today the Ebro Delta does not present problems of availability of water the problems associated with the necessity of large amounts of irrigation water that are caused due to factors such as the crop’s characteristics, natural ground permeability and capillary rise of salt water should not be ignored. Therefore, an analysis of water risk management is necessary. In the next section, we analyze the water risk of the selected crops and the impacts of potential changes in water policy.

It is important to note that the contribution to the gross added value includes direct payments linked to crop productivity during the period of analysis (before 1986 from the agricultural policy in Spain and since 1986 from the EU Common Agricultural Policy). The recent decoupling of productivity and payments, since 2008, may change the relative contribution of each crop to the gross added value.

[TABLE 5 NEAR HERE]

[TABLE 6 NEAR HERE]

3.2 Montecarlo risk analysis

Statistical properties of crop yield in response to water patterns were derived using Montecarlo simulations in order to assess risk levels. Figure 5 shows the cumulative density probability functions where significant differences in risk levels between crops can be observed. According to these cumulative distribution functions, the probability of having low yields is higher for olive, barley and wheat and lower for alfalfa and potato.

[FIGURE 5 NEAR HERE]

Table 7 provides the detailed statistical properties from Figure 5. Rice and alfalfa present a low variation coefficient (CV) while olive and grapevine have a high variability. On the other hand, we observed that the skewness coefficient is above +1 in potato, olive, alfalfa and barley, indicating that they have an elevated probability of obtaining results above the mean. Also, the skewness coefficient is greater than 0, indicating that there is no large probability of having a low yield. The kurtosis coefficient for every crop yield is lower than 3, and we have a platykurtic distribution that indicates that the probability distribution functions of the crop yields have a wide peak (a lower probability than a normally distributed variable of values near the mean) and thin tails (a lower probability than a normally distributed variable of extreme values). Figure 6, presents the distribution function for rice, which is practically normal.

[TABLE 7 NEAR HERE]

[FIGURE 6 NEAR HERE]

3.3 Water policy scenarios

Although irrigation contributes to social welfare in many regions, it cannot be rural development's sole concern. As we mentioned before, nowadays there are no explicit restrictions on the irrigation area in the Ebro basin. However, within the context of increases of water demands and policy developments such as the Water Framework Directive restrictions context, it is necessary that the Basin Plan consider adaptation measures such as changes in irrigated land to cope with environmental and sustainability constraints. Thus, we propose three possible scenarios, in which we assume a reduction of the irrigated area by 10%, 20% and 30%. Table 8 shows the yield changes responding to these scenarios.

[TABLE 8 NEAR HERE]

A substantial decrease in irrigated land, of up to 30 % of total, results in only moderate losses of crop productivity. The response is crop specific, wheat is the least affected and alfalfa is the most affected. These results contrast with the relative importance of the crop as measured by the gross added value (Table 6). Both indicators, the gross added

value and the changes in crop productivity, are useful to choose adaptation strategies. For example, the contribution of maize to the gross added value is large and the yield is highly reduced as result of irrigated land reduction. Therefore the economic losses of irrigated land reduction in a maize producing area are significant. In contrast, although the yield reduction of alfalfa is comparable to that of maize, the resulting economic loss due to limitation in irrigated land is smaller because alfalfa's contribution to the gross added value is low.

The reductions are consistent given the uncertainty of future policy and our purpose is to show the implications in terms of production risk. Using the models presented in Table 8, we note that these scenarios imply yield losses, ranging from 1% to more than 15%. Regardless of the extent of the reduction in irrigated land imposed by the policy, we see that wheat and grapevine do not suffer major losses in yield performance, whereas alfalfa, potato and maize would be affected considerably given that they are mostly irrigated crops. Since the irrigation area was not significant for rice (which is 100% irrigated), we cannot observe, using this technique, the amount of decrease in its yield would most likely decline. One important factor to consider is the fact that the losses are not proportional. Therefore, the loss is larger when the irrigation area is reduced from 10%-20% scenarios than when it is reduced from 20%-30% scenario. Finally, the reductions in crop yields can be used to estimate the necessary incentives for the implementation of environmental goals (Iglesias and Quiroga, 2009).

4 Conclusions

Given the pressure, mainly from agriculture, on water in the Mediterranean, this paper presents an analysis of the factors that affect eight major crops in the Ebro river basin including latent risks as well as policies that could be implemented. We analyzed the marginal effects on the statistical model to calculate the effect of a potential reduction in irrigated area on crop yield. This study was based on an analysis of demand.

Extended water production functions by crop were estimated. These show the expected signs for most of the variables. Focusing on the hydrological variables, our results show that an increase in irrigation and in the irrigated area has a positive impact on crop yields. However, the impact of irrigation is not always positive given that after a certain quantity of water supplied to the crop, yield begins to decrease (negative sign in irrigation elevated to square). The precipitation also shows a positive impact on crop yields, except for maize in the *son* quarter (Sep, Oct, Nov), which might be due to excessive water from irrigation, given the usual humidity of this time of the year.

A strictly economic analysis might suggest that production could be oriented to wheat and maize, given their impact on agricultural gross value added of the area. However, this does not consider the cost of virtual water. Maize is a major crop in the Ebro Delta, in the low basin, that could suffer a reduction on water availability. An analysis of water risk management is needed. Rice and potatoes show a low variation coefficient, implying low variability. Olive shows low yield and high variability in this area, although under a reduction in irrigated area scenario, this crop is not severely affected. Potato, maize and alfalfa are the ones most affected by a reduction in irrigated area, because they are mainly irrigated crops.

We present crop responses to different policy scenarios of reductions on irrigated area. In a climate change context, more and more severe drought events are expected to happen in the Ebro basin. This could lead to the river basin management authority to reduce water availability. Although the national irrigation plan consider increases in

irrigated land and some efforts are being made to make the irrigation systems more efficient, trying to reduce water consumption for agriculture, such an increase won't be likely to occur. Instead of this, we have considered the consequences for crop production of three policy scenarios where irrigated area is reduced. We quantify the implications on crop productivity and agricultural value added. To assess optimal water management among different crops it is necessary to know the priorities of policy-makers, since the large loss of production is not the main economic loss. Some crops are linked to rural landscapes or customs that sometimes is important to maintain, water demand is different for each crop and also economic revenues, so there is not a unique crop mix that minimize losses, since the definition of loss depends on the objectives. A multicriteria analysis can be performed in a further step, but it has not been addressed here.

Finally, the methodology presented here can be extended to examine additional factors that affect crop yield and interact with water demand, such as climate change, irrigation systems, and fertilizer application.

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Table 1. Description of variables

Type of variable	Name	Definition	Unit	Source of Data
Economic	Y_t	Crop yield at a site in year t	t / ha	MARM
	GAV_t	Gross added value of agriculture a site in year t	K€ current prices	MARM and INE
	L_t	Total employment of agricultural sector at a site in year t	People (thousands)	Labour Force Survey (LFS). INE
Water	$Irrig_{it}$	Net water needs of crops in the ith month in year t	m / month	Planning Hydrographic Office - CHEBRO
	$Prec_{it}$	Total precipitation in the ith month/ 3 month period in year t	mm / month	AEMET
Managment	Mac_t	Machinery in year t	N° (thousands)	FAO
	I_t	Irrigated area by crop type	ha	MARM
Geographic	$Altitude_t$	Variables indicating 0-600, 601-1000 and more than 1000 meters		INE
	$Area_ebro_t$	Dummy variables indicating the 3 main areas of the basin: Northern, Central and Low Ebro		Own elaboration
Climate	T_Max_{it}	Maximum temperature in the ith month / 3 month period in year t	° Celsius	AEMET
	T_Mean_{it}	Average temperature in the ith month / 3 month period in year t	° Celsius	AEMET
	Fr_{it}	No. of days with temperatures below 0° C in the ith month/ 3 month period in year t		AEMET
	Dro_t	Dummy variable indicating drought years	1 or 0 as a function of SPI critical value	SPI calculated from AEMET precipitation data

Table 2. SPI Values and drought intensities

SPI Values	
2.0 or more	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Table 3. Irrigated area by irrigation systems

Region	Irrigation Area and Percentages					
	Large systems		Small systems		Total	
	ha	%	ha	%	ha	%
Aragón	237,813	52.2	161,721	49.1	399,045	50.9
Cantabria	0	0.0	553	0.2	553	0.1
Cataluña	160,625	35.3	46,316	14.1	207,036	26.4
Castilla - La Mancha	0	0.0	241	0.1	241	0.0
La rioja	17,584	3.9	34,864	10.6	52,448	6.7
Castilla - León	0	0.0	8,913	2.7	8,913	1.1
Navarra	39,359	8.6	48,407	14.7	87,766	11.2
Valencia	0	0.0	275	0.1	275	0.0
País Vasco	0	0.0	27,277	8.3	27,277	3.5
Total land area	455,381	100.0	328,568	100.0	783,948,69	100.0

Table 4. Percentage of agricultural area for selected crops

Crop	Percentage of the total agricultural area			Total cropland (Ha)			Percentage of cropping system	
	Rainfed	Irrigation	Total	Rainfed	Irrigation	Total	Rainfed	Irrigation
Wheat	18.97	9.55	17.00	774864	102720	877584	88.30	11.70
Barley	29.90	13.04	26.38	1221483	140156	1361639	89.71	10.29
Rice	–	0.87	0.69	–	35379	35379	0.00	100.00
Maize	0.16	9.94	2.20	6700	106874	113574	5.90	94.10
Potato	0.07	1.04	0.27	2868	11191	14059	20.40	79.60
Alfalfa	0.95	13.01	4.39	38758	139837	179180	21.63	78.04
Grapevine	4.36	3.72	4.22	177957	39975	217932	81.66	18.34
Olive	5.13	2.64	4.61	209595	28413	238008	88.06	11.94
Total	59.53	53.80	59.77	2432225	604545	3037355	80.53	19.45

Table 5. Estimated coefficients of crop-water functions, robust t-statistics and R²

	Alfalfa	Wheat	Rice	Grapevine	Olive	Potato	Maize	Barley
Ln(Y _{t-1})				0.4441 [4.73]***				
L							-0.0116 [3.66]***	-0.0118 [3.66]***
Mac	-0.0067 [2.05]**	-0.0103 [3.19]***			0.0022 [4.74]***	0.0013 [9.62]***	0.0010 [5.61]***	0.0007 [3.25]***
Mac _{t-1}	0.0069 [2.16]**	0.0109 [3.39]***		0.0010 [3.39]***				
Mac _{t-2}			0.0005 [1.73]*					
Altitude ₍₀₋₆₀₀₎		-4.80E-05 [4.24]***		-6.20E-05 [4.41]***				
Altitude ₍₆₀₁₋₁₀₀₀₎	-2.06E-05 [4.05]***	2.58E-05 [1.69]*						2.66E-05 [1.86]*
Altitude ₍₊₁₀₀₀₎	-1.49E-05 [3.36]***	-8.94E-05 [6.54]***		-6.57E-05 [4.01]***			-1.38E-05 [2.16]**	-6.53E-05 [4.89]***
Cent_ebro	-0.0412 [1.28]	-0.1006 [1.69]*		-0.0781 [1.56]			-0.2954 [6.32]***	-0.2646 [4.15]***
Northern_ebro	0.2226 [4.53]***	-0.4780 [2.97]***		-0.3589 [3.08]***			-0.3249 [5.22]***	-0.6043 [4.07]***
Irrig_area	0.8531 [9.65]***	0.5964 [3.75]***		0.9993 [4.53]***	1.6479 [4.22]***	0.5693 [11.41]***	0.7691 [9.00]***	
Irrig	0.0963 [7.10]***	0.2024 [4.73]***	0.1543 [2.08]**			0.0355 [2.08]**	0.0766 [3.35]***	0.2496 [5.19]***
Irrig ²	-0.0083 [5.69]***	-0.0447 [6.59]***	-0.0213 [1.89]*			-0.0002 [0.08]	-0.0027 [1.38]*	-0.0649 [6.24]***
Prec _{def}					0.0015 [2.41]**		0.0006 [3.49]***	
Prec _{mam}	0.0010 [6.52]***							
Prec _{jia}					0.0017 [2.58]**		0.0006 [2.88]***	
Prec _{son}		0.0005 [3.30]***					0.0000 [0.20]	0.0004 [2.33]**
Prec _{year}						0.0001 [1.80]*		
T_Max _{def}							0.0059 [2.17]**	
T_Max _{mam}		-0.0098 [3.39]***						-0.0133 [4.33]***
T_Max _{jia}				-0.0099 [3.10]***	-0.0273 [3.34]***			
T_Max _{son}		0.0092 [2.35]**					0.0069 [1.88]*	0.0187 [5.03]***
T_Mean _{year}	0.0474 [4.12]***	-0.0879 [3.00]***	0.0377 [2.24]**			-0.0685 [10.02]***	-0.0602 [2.95]***	-0.1394 [5.40]***
Fr _{def}		-0.0022 [1.67]*						-0.0019 [1.41]
Fr _{mam}		-0.0090 [1.66]*			-0.0297 [2.80]***			-0.0117 [2.53]**
Fr _{son}					0.0303 [2.79]***	-0.0120 [4.06]***	-0.0069 [2.11]**	
Dro		-0.1281 [2.22]**		-0.1328 [1.97]*				-0.1737 [3.75]***
Adj R-squared	0.65	0.63	0.17	0.84	0.41	0.62	0.77	0.55
White test: p-value	0.0008	0.4362	0.3695	0.038	0.6504	0	0.0154	0.5003

t statistics and robust t statistics in brackets, * significant at 10%; ** significant at 5%; *** significant at 1%

Table 6. Estimated coefficients of profit function (logarithm of the gross added value), robust t-statistics [in brackets] and R²

	Coefficients
Yield_Alfalfa	0.04 [4.58]***
Yield_Maize	0.11 [3.56]***
Yield_Potato	0.02 [2.49]**
Yield_Wheat	0.20 [2.80]***
Constant	9.31 [22.08]***
Observations	133
R-squared	0.31

Robust t statistics in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7. Statistical properties of yield simulations

	Alfalfa	Wheat	Rice	Grapevine	Olive	Potato	Maize	Barley
Mean	42.149	3.092	5.343	3.973	0.970	21.602	6.352	2.814
Median	40.472	3.083	5.222	3.555	0.744	20.293	6.184	2.671
SD	12.565	0.995	1.157	2.300	0.781	7.705	2.648	0.933
CV	29.810	32.196	21.661	57.893	80.457	35.668	41.692	33.171
Maximun	183.797	7.150	13.232	11.513	7.307	162.001	13.075	9.475
Minimum	8.909	0.175	2.188	0.167	0.039	4.661	0.542	0.777
Skewness	1.547	0.088	0.668	0.678	1.843	2.984	0.216	1.029
Kurtosis	9.759	2.736	3.859	2.771	7.786	28.900	2.246	4.908

Table 8. Yield changes for irrigated area policy scenarios

Decrease in irrigated land	Changes in crop productivity					
	Alfalfa	Wheat	Grapevine	Olives	Potatoes	Maize
-10%	- 4.8	- 0.7	- 1.5	- 2.2	- 4.3	- 4.8
- 20%	- 11.2	- 1.4	- 2.9	- 4.4	- 8.4	- 9.4
- 30%	- 15.5	- 2.0	- 4.3	- 6.6	- 12.3	- 13.7

Yield decrease

	0 to -5%
	-5% to -10%
	< -10%

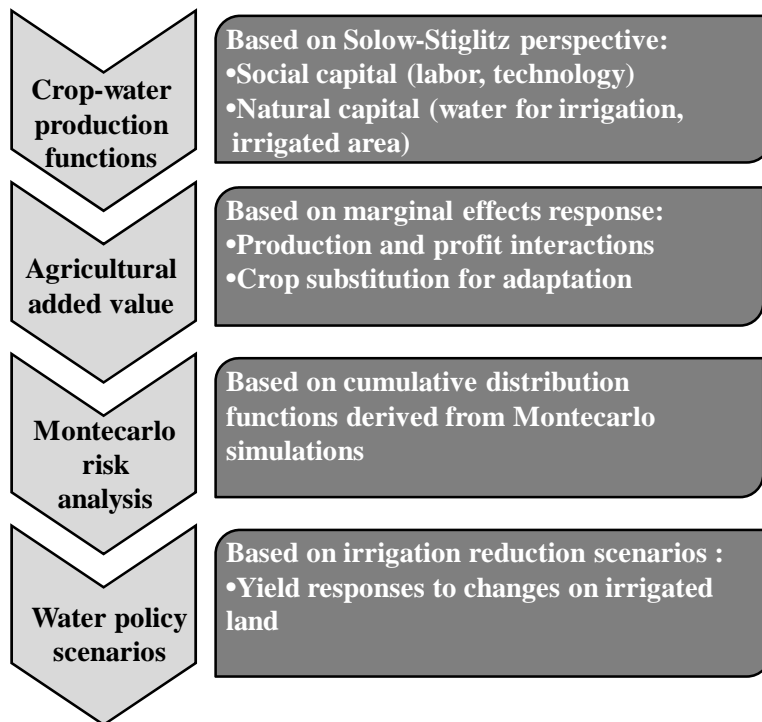


Figure 1. Steps on methodology

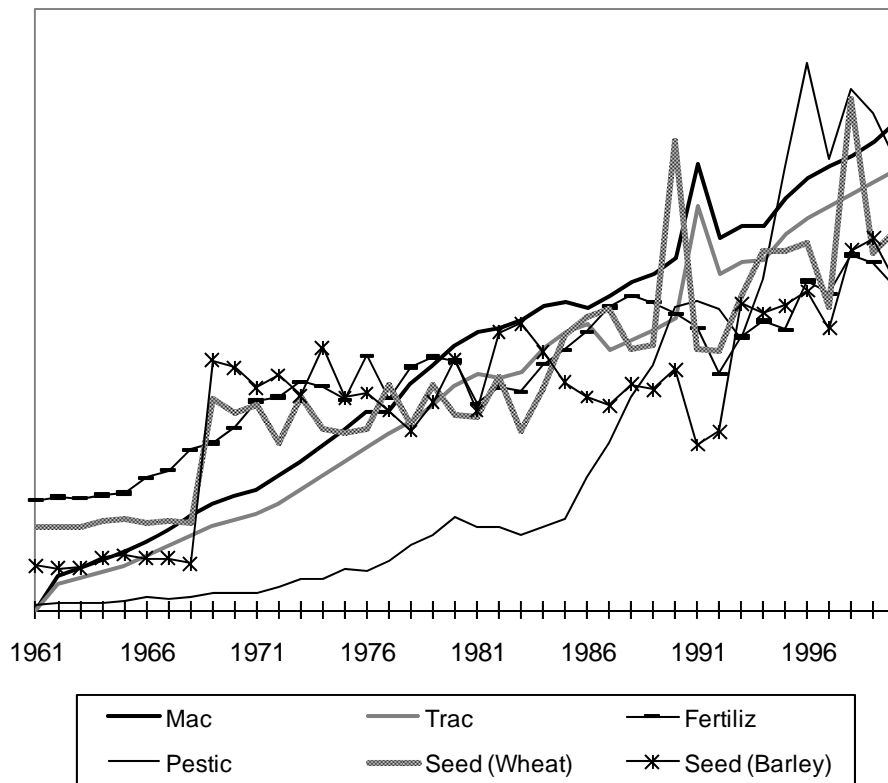
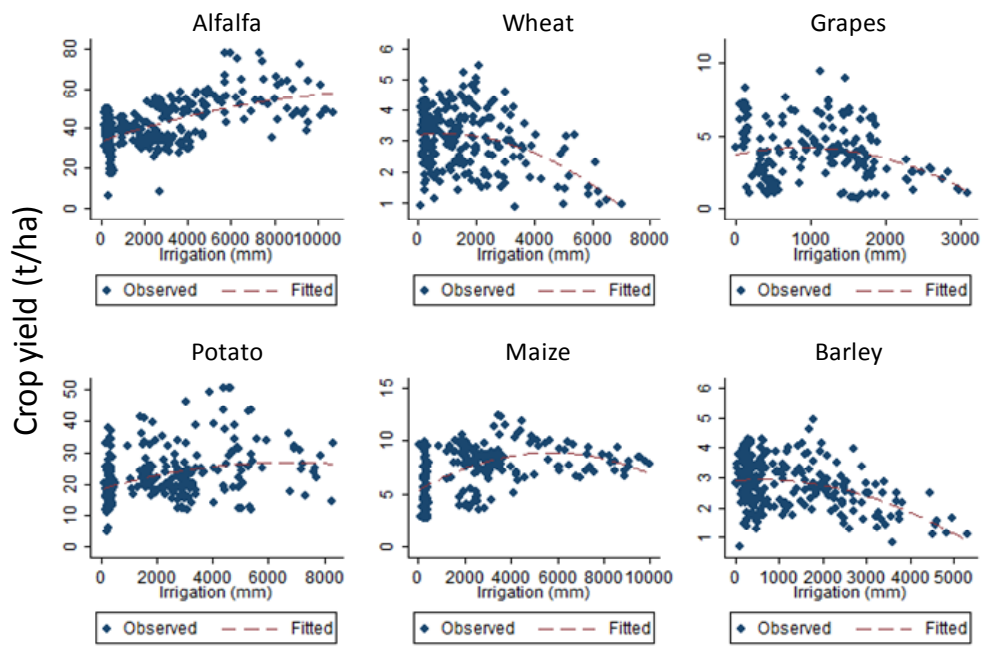


Figure 2. Evolution of management indicators: farm equipment power (Mac), tractors (Trac), nitrogen fertilizer (Fert), pesticide consumption (Pest), or seeds improvement (Seed). Source: Quiroga, Iglesias, 2009.



Source: MARM and CHEBRO databases

Figure 3. Observed crop response to irrigation water applied

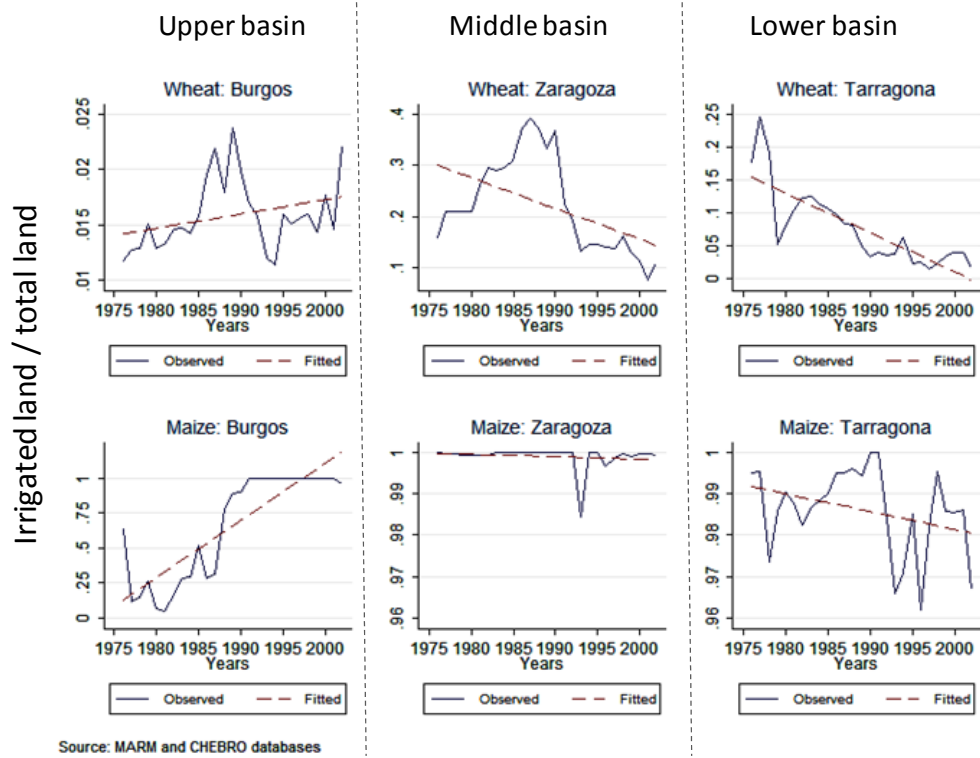


Figure 4. Irrigated land for wheat and maize at representative areas of Upper (Northern, Central and Low Ebro: Burgos, Zaragoza and Tarragona).

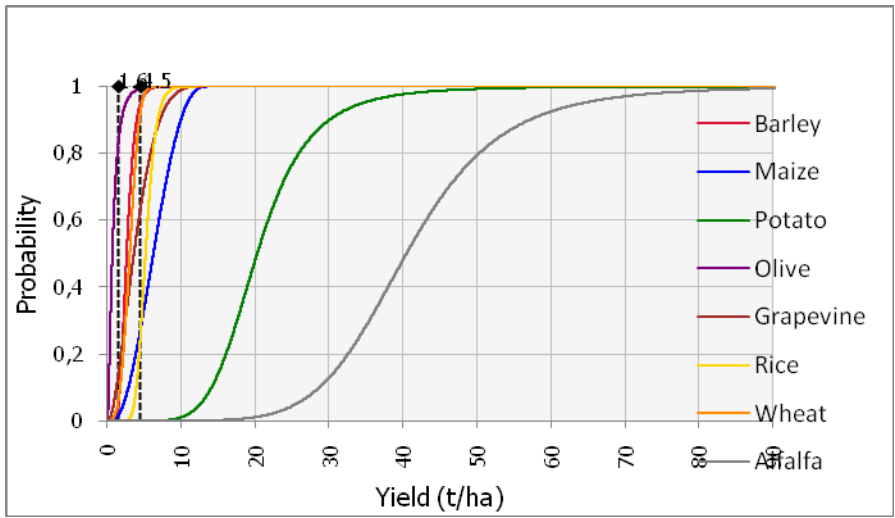


Figure 5. Cumulative density probability function of crop yield

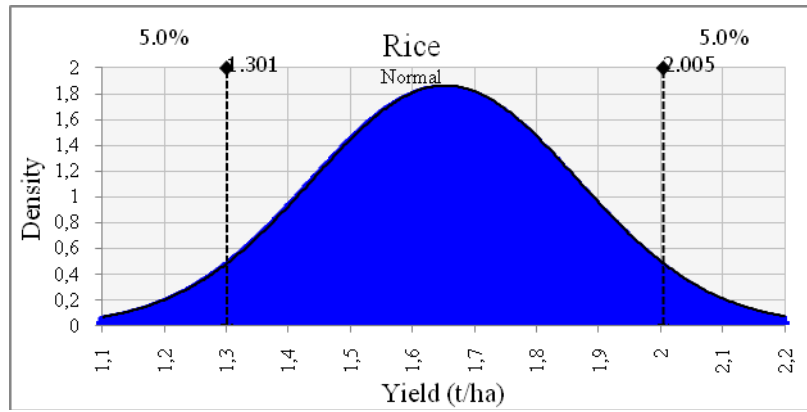


Figure 6. Distribution function of simulated rice yield in the low Ebro. Normal distribution with mean=1.62 and SD=0.21.