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Dealing with drought in irrigated agriculture through insurance schemes: an application to an irrigation district in Southern Spain

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Abstract

Hydrological drought is expected to have an increasing impact on both crop and fruit yields in arid and semi-arid regions. Some existing crop insurance schemes provide coverage against water deficits in rain-fed agriculture. The Prevented Planting Program in the USA covers against drought for irrigated agriculture. However, drought insurance for irrigated agriculture is still a challenge for companies and institutions because of the complexity of the design and implementation of this type of insurance. Few studies have attempted to evaluate the risk of loss due to irrigation water scarcity using both stand-alone production functions and crop simulation models. This paper's contributions are that it evaluates the suitability of AquaCrop for calculating drought insurance premiums for irrigated agriculture and that it discusses contract conditions and insurance design for hydrological drought risk coverage as part of a traditional insurance product, with on-field loss assessment in combination with a trigger index. This method was applied to an irrigation district in southern Spain. Our insurance premium calculation showed that it is feasible to apply this method provided that its data requirements are met, such as a large enough set of reliable small-scale yield and irrigation time series data, especially soil data, to calibrate AquaCrop. The choice of a trigger index should not be underestimated because it proved to have a decisive influence on insurance premiums and indemnities. Our discussion of the contract conditions shows that hydrological drought insurance must comply with a series of constraints in order to avoid moral hazard and basis risk.

Additional key words: crop insurance; hydrological drought; AquaCrop; trigger index.

Abbreviations used: ASI (April Status Indicator); CAP (Common Agricultural Policy); CV (Coefficient of Variation); ET_0 (Potential Evapotranspiration); EU (European Union); GGRBS (General Guadalquivir River Basin System); ID (Irrigation District); NPK (Nitrogen, Phosphorus, Potassium); WAPA (Water Availability Policy Analysis); WTO (World Trade Organization); WUE (Water Use Efficiency).

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Introduction

Drought-induced water scarcity is a recurring issue in some regions of the world. During drought periods, farmers resort to different management strategies, mostly aimed at increasing the amount of water available to crops: development of terraces, soil bunds or small catchments; mitigation of evaporation through crop residue management, intercropping and cover cropping; construction of water storage structures ranging from farm ponds to dams (Rockström, 2003). However, water harvesting and irrigation are not always a definitive solution because drought sometimes affects irrigated agriculture, too. Hydrological drought is an event that inflicts significant losses on farmers. Its effects are potentially exacerbated by water managers over-allocating water to irrigators in years of plenty (Iglesias *et al.*, 2003). Moreover, it is predicted that climate change may aggravate water scarcity and drought events in some regions by changing the frequency, intensity and distribution of precipitation (IPCC, 2012).

A tool with the potential for dealing with this important risk is crop insurance. Despite the fact that several experts consider crop insurance an inefficient management tool (Glauber & Joseph, 2013; Wright, 2014), it has expanded in recent years into many developed and developing countries (Bielza *et al.*, 2008). Meteorological drought risk has traditionally been considered as a non-insurable risk because of its systemic character, which means that large losses are registered contemporaneously over vast areas (Pérez & Gómez, 2014). Nevertheless, rainfed crops have recently been covered against drought by private insurance, owing to public sector support (*e.g.*, Spain, Austria, Canada and the USA) (Bielza *et al.*, 2008).

On the contrary, existing agricultural insurance typically does not provide coverage against hydrological drought in irrigated agriculture (Maestro & Bielza, 2011; Pérez & Gómez, 2014). In the USA drought is covered by the Multiple Peril Insurance Coverage (MPCI) program. The program covers against damage caused by natural hazards including drought. In the case of irrigation, if farmers expect to receive less water than their usual allotment before coverage begins, they often decrease planted acreage under irrigation. The remainder of their acres can either be planted but reported as non-irrigated, or not planted and compensated for under the Prevented Planting Program[1] (Rejesus *et al.,* 2003; RMA-Topeka, 2013).

Pérez & Gómez (2012) mention two main problems with insurance coverage for hydrological drought risks in irrigated agriculture: (1) institutional decisions about water availability are very tentative, and (2) insurance generally costs much more than the alternative of illegal abstractions. Whereas the second problem varies from one case to another depending on groundwater availability, the first issue can be considered as the main reason why there are still so few drought insurance products for irrigated agriculture. The possibility of managing and redistributing water stocks means that hydrological drought is not a purely random risk. These problems could be solved if strict rules were applied to water stock allocation. Pérez & Gómez (2012) mention that if the Mediterranean countries of the European Union (EU) would enforce existing rules established in river basin management plans and drought management plans (DMPs), they would increase the cost of illegal abstractions and, if strictly adhered to, eliminate discretionary management decisions as well.

In spite of the complexity of insuring drought in irrigated agriculture, researchers are studying this issue. For some time now, in addition to the Prevented Planting Program, the USA has been trying to develop a methodology to implement successfully an insurance contract option for irrigated agriculture. This methodology attempts to cover farmers who, due to the lack of water, are obliged to apply limited irrigation to their crops (corn and soybean). It is based on yield adjustment tables calculated by the University of Nebraska on the basis of limited irrigation, but an agreement has not been reached with producers on the proposed yield tables (Waechter, 2012).

Other authors have estimated the potential cost of hydrological drought insurance. Quiroga *et al.* (2011) have estimated farmers' willingness to pay for hypothetical hydrological drought insurance for maize in the Ebro River Basin of Spain. Pérez & Gómez (2012, 2014) have calculated pure premiums of hydrological drought insurance for ligneous crops[2] in southern Spain (La Campiña, Guadalquivir) and in south-eastern Spain (Campo de Cartagena, Segura).

The main objective of this study was to estimate the cost of hydrological drought insurance for irrigated arable crops. We tested a developed methodology by comparing premiums estimated from AquaCrop simulated yields with premiums estimated from actual yield data provided by an irrigation district (ID). Based on data availability, we selected the Genil-Cabra ID in the Guadalquivir River Basin (southern Spain). While some existing studies have estimated the cost of hydrological drought insurance for irrigated agriculture, none has offered a comprehensive discussion of insurance design and contract conditions. Thus, a second objective of this paper was to look at the cost of commercial premiums and discuss product design and contract conditions.

Material and methods

Insurance design and contract conditions

During the design of an insurance product, insurance companies usually have to set some contractual condi-

[1] The prevented planting provision is a standard element of crop insurance contracts offered by the Risk Management Agency (RMA) of the USA. This provision allows an insured producer to receive an indemnity payment if, due to a valid cause of loss (including drought), the producer fails to plant an insured crop before a designated planting date. The cause of loss must be 'general' in the surrounding area and must have prevented similar producers in the area from planting their crops. [US-GAO, 1999; USDA/OIG, 1999].

[2] Fruit trees including citrus, olive trees and grapevine in La Campiña; fruit trees including citrus, almond trees and grapevine in Campo de Cartagena.

Table 1. Insurance design and main characteristics of the insurance contract

Characteristic	Description
C1. Farm eligibility	For a farm to be insurable, farm water allotment information should be supplied to the insurer by the ID managers and non-monitored water transfers between farms should not be technically possible
C2. Loss assessment: on field- *vs*. index	On-field loss adjustment
C3. Crop-specific *vs*. whole-farm insurance	Whole-farm insurance: it is compulsory to insure all crops on the farm and it is limited to farms with eligible crops only
C4. Guarantee or insured value	Historical-average crop production value of the insured farm
C5. Trigger-index	Potential use of status indicators from drought management plans, where indicator and water allotment must be correlated
C6. Coverage	50-100% coverage of guarantee or insured value
C7. Deductibles	Franchise deductible of 5% of guarantee or insured value
C8. Purchase period	Before the rainy season
C9. Duration of the contract	In case of inertial systems, a multiannual contract
C10. Limitation on insurable crop surface mix	The sum of each crop surface multiplied by the average historical water allocation to each crop cannot exceed the farmer's water rights

ID: Irrigation District.

tions to avoid asymmetric information problems, but additional circumstances need to be taken into account in the case of hydrological drought. Each of these contractual conditions (C1 to C10) are explained below and summarized in Table 1.

Farmers can typically manage water stocks by either selling them to a neighbor or redistributing them between crops. We analyzed the implications of these two possibilities. The option of selling water to a fellow farmer could cause severe moral hazard, because a farmer who buys insurance will have an incentive to sell the water to a non-insured farmer and claim an indemnity. Thus, one condition for farmers to be eligible for insurance should be that the irrigation system infrastructure prohibits or monitors these transactions by some control mechanism, such as water meters.

In any case, irrigation districts should inform insurance companies of the water supplied to all farmers (C1). If this is not possible, only index insurance (which depends on an index value rather than actual farm yields) would be viable. This is why many authors have proposed index insurance against drought in irrigated agriculture[3]. Index insurance has a lot of potential because it avoids moral hazard and adverse selection problems. Under non-homogeneous farming conditions, however, it can fail due to low correlation between the index and actual farm losses, which results in a high 'basis risk'. Bielza *et al.* (2012) have shown that indexes are not closely correlated to the relevant risks in some areas of Spain. This is why we propose a combination of an index-based and traditional insurance scheme, where an index value triggers the right to file a claim, but indemnities are calculated from actual farm losses directly observed during on-field loss assessments (C2). Therefore, in the proposed methodology, the use of the drought index differs from index insurances where the indemnity or compensation amount is directly estimated from the index value. In our case the index just determines if there is a drought but not its intensity. On-field loss assessment has the additional advantage that it is deeply rooted in Spain and in general in the Mediterranean European countries despite the fact that it increases administrative costs significantly (Hyde & Vercammen, 1997; Wright, 2014). Thus farmers and Spanish insurance companies are used to it.

Regarding water redistribution between crops, in the case of water shortage, economists would expect farmers to allocate all the available water to certain crops and not to others in such a way that they minimize economic losses. If insurance was crop-specific, this behavior would lead to adverse selection (*i.e.*, farmers might insure only crops that typically receive less water) and moral hazard (*i.e.*, reallocating all water to non-insured crops). This means that crop-specific insurance with traditional on-field loss assessment is not an option for hydrological drought. It is only viable for farms that grow only one crop. Otherwise all crops on a farm should be insured. Given that whole-farm insurance has been shown to be more efficient than the sum of crop-specific insur-

[3] Leiva & Skees (2008) have proposed irrigation insurance based on a river flow index in Mexico. Zeuli & Skees (2005) proposed a rainfall index as a tool for improving drought management in Australia.

ance (Bielza & Garrido, 2009), the insurance premium rates should be personalized according to the percentage of each eligible crop present on the farm. This implies, however, that a farm can only be insured when it grows only insurable crops (*i.e.*, crops whose drought risk can be calculated by the insurer) (C3). This constraint could potentially discourage farmers from trying new crops within their rotation, as an adaptation to climate change.

The insurance product's guarantee should be the farm production value, calculated as the weighted average of crop production value. This is obtained from all available past crop yields multiplied by a fixed crop price; therefore, it will not cover price or market risks. Premium rates will depend on the historical variability of farm yields due to a shortage of irrigation water (C4).

Loss adjusters should single out the loss caused by drought from the losses caused by other factors. However, this might not always be evident. To increase the certainty that a loss is caused by drought, insurance indemnities would be linked to a drought index that acts as a trigger in years of water shortage (C5). Only when the indicator value falls below a trigger value (specifically chosen to correspond to a drought situation for each farmer or ID) are farmers entitled to file a claim to the insurance company. The insurance company will then send an independent expert to evaluate the losses and establish an indemnity if applicable (this step differentiates our insurance scheme from strictly index-based schemes, which do not involve a loss adjustment process). Combined, the drought index and on-field loss adjustment reduce moral hazard associated with insured farmers attributing losses to water shortages when losses are due to other reasons.

Another advantage of establishing this drought index (with a trigger value) is that it assures the scheme is compliant with EU legislation and with the World Trade Organization (WTO, 1995) green box condition for subsidies to crop insurance. Specifically, the 2006 EU Regulation (EU, 2006) has one necessary condition for state subsidies to agricultural insurance to be exempt from the notification requirement: the climatic event causing a loss should be attributable to a natural disaster and must be formally recognized as such by public authorities. Similarly, the 2009 Regulation of the EU Common Agricultural Policy (CAP) (EU, 2009) allows EU CAP funds to be used for crop/animal/plant insurance; however, that insurance "shall only be available where the occurrence of an adverse climatic event or the outbreak of an animal or plant disease or pest infestation has been formally recognized as such by the competent authority of the Member State concerned. Member States may, where appropriate, establish in advance criteria on the basis of which such formal recognition shall be deemed to be granted". One criterion that could be established to officially categorize a drought as a natural disaster is that a public drought index reaches a specific trigger value. Therefore a valid drought index should be public, easy to understand, transparent and impossible to manipulate.

Other contract conditions attempt to avoid potential problems of moral hazard or adverse selection. This is the case for enforcing a deductible. We suggest that the insurance contract should at least include a small franchise deductible[4] equaling for example 5% of the insured amount (C7). This means that losses will only be considered when they are higher than 5% of the insured amount. The reason is that it is not worthwhile to claim losses under that level for either the insurance company, which has to incur the cost of the loss assessment for a relatively small loss, or the farmer, who according to the Spanish insurance regulation has to keep not less than a 5% sample surface unharvested to allow for loss adjustment (BOE, 1996).

Given that hydrological drought can usually be foreseen at the time spring-planted crops are sown, farmers might buy insurance only when a drought is expected, generating adverse selection. For this reason, the purchase period for insurance should be before the rainy (or snowfall) season (C8). In some areas with a large reservoir capacity, hydrological drought can be foreseen months before the start of the rainy season (inertial systems). This encourages farmers to buy insurance only when a dry season is expected. To avoid this risk, we proposed offering farmers a multiannual contract whereby they would be committed to buy insurance for a certain number of years, and the premium would be modified every year according to the yearly farm crop surface distribution (C9). Additionally, to avoid that a farmer purposely shifts his crop mix towards crops that are both more valuable and water demanding in order to increase the probability and value of an indemnity, the maximum insurable surface of each crop must be limited by farmer water rights (C10). It must not be feasible to insure a crop surface mix that multiplied by the crops historical

[4] Franchise deductible is a minimum amount of loss that must be incurred before insurance coverage applies. A franchise deductible differs from an ordinary deductible in that, once it is met, the entire amount of the loss is paid, subject to the policy limit (IRMI, 2014).

average water allocation is above the water rights of the farmer.

Finally, another situation specific to hydrological drought insurance is the possibility of a farmer who, having bought insurance at the beginning of the crop season (fall time) for a specified planted crop acreage, faces at spring time a drought that is more severe than expected. Often, the farmer still has the option, during the spring, to plant different crops to minimize their losses. In this case, the farmer will have to inform the insurance company of changes in crop surface areas (and therefore, the insurance premium should be rectified in this second period), and indemnities will have to be paid based on the success or failure of the new crop surface areas. This is not a fair solution, especially if the new surface areas are dominated by fallow land where the farmer would not receive any compensation. In this point the prevented planting program used in the USA could be applied if there is forecasted an extremely severe drought that could prevent crop success.

Calculation of pure premium rates

The estimation of pure (actuarially fair) hydrological drought insurance premiums involves two main steps: (i) quantifying the risk associated with irrigation water allocations received by farmers, and (ii) quantifying the impact of water allocations on farmers' revenue or income.

Pérez & Gómez (2014) quantify the risk associated with irrigation water allocation by taking an approach similar to index insurance. They estimate water delivered to farmers from two stochastic variables (water stored in reservoirs and annual runoff), which is then combined with decision rules used by reservoir water authorities. In practice, however, these rules are not always followed. In the future, however, water allocation rules should be strictly adhered to if insurance is to be feasible. Quiroga *et al.* (2011) used the Water Availability and Policy Analysis (WAPA) model to simulate the joint operation of all reservoirs in a basin to satisfy a set of demands. We propose to simply quantify the risk associated with irrigation water allocation directly from historical values of water allocation to each crop, which are annually reported by the IDs to the river basin hydrographic confederations. These water allocation data can be used for risk calculation only if they have not been distorted to get insurance payments.

Impact of water allocation on farmers' revenue during a shortage is often quantified using stochastic models that relate crop yields —and indirectly, farm revenue— to different variables, including irrigation water allocation. For example, Quiroga *et al.* (2011) have statistically estimated a crop production function for maize yield response to various bio-physical and socio-economic explanatory variables. Pérez & Gómez (2012, 2014) used agronomic production functions for ligneous trees that are based on the percentage of evaporation satisfied.

One challenge to modeling the impact of hydrological drought on crop yields is data. Quiroga *et al.* (2011) use provincial data to calibrate their model. From our point of view, a province, which includes land belonging to different irrigation districts or different watersheds, is too large and heterogeneous a surface area. Smaller-scale data should be used to properly estimate the impact of irrigation water on crop yields. Agronomic production functions, such as those used by Pérez & Gómez (2012, 2014), are potentially a good alternative but they are not always easy to find for a particular site. When unavailable, production functions from other regions have been modified to fit yields characteristic of the case study area (assuring that they maintain their elasticity and marginal productivity properties). But it has not been verified that yield response to water is the same across regions. Moreover, we have observed that these models have sometimes been calibrated only for a specific range of water allocations and are not suitable for out-of-sample values.

We proposed an alternative method, which is the use of a crop growth simulation model. Only aggregate (provincial) yield data are available in Spain, so crop production is calculated from a set of daily climatic and irrigation parameters used as input to the FAO's AquaCrop model (Heng *et al.*, 2009; Hsiao et *al.*, 2009; Raes *et al.*, 2009; Steduto *et al.*, 2009). AquaCrop was chosen because yields depend not only on the water they receive, but also precipitation and local conditions, such as weather, soil, crop variety and agronomic techniques.

Yields simulated with AquaCrop take into consideration only differences in water application and weather variability, whereas actual yields obtained by farmers may have suffered from other eventualities like disease or pests. We therefore calculated insurance premiums from actual yields provided by the ID in order to validate the yields and premiums calculated using AquaCrop. We also conditioned the indemnities on the existence of a drought episode, as identified by a drought indicator, to limit yield variability to that caused by hydrological drought.

Pure premium rates were calculated for individual crops and also for an average farm, with the same crop distribution as that typically observed in the ID (referred to as *ID/whole-farm* insurance). ID/whole-farm insurance pure premiums are calculated according to Eq. [1]:

$$Premium = PR(\%) \times \overline{R} \qquad [1]$$

With

$$\overline{R} = \frac{1}{n}\sum_{t=1}^{n}\overline{R}_t$$

$$\overline{R_t} = \frac{\sum_{c=1}^{k} P_c \times S_{ct} \times \overline{Y}_c}{\sum_{c=1}^{k} S_{ct}};$$

$$\overline{Y}_c = \frac{1}{n}\sum_{t=1}^{n}\overline{Y}_{ct}$$

$$PR(\%) = \frac{1}{n}\sum_{t=1}^{n}\begin{cases}\dfrac{\left(C\times\overline{R}_t - r_t\right)}{\overline{R}_t} & \text{if } \left(\overline{R}_t - r_t\right) > FD\times\overline{R}_t \text{ and if } i_t < I_{Tr}\\ 0 & \text{otherwise}\end{cases}$$

and

$$r_t = \frac{\sum_{c=1}^{k} P_c \times S_{ct} \times y_{ct}}{\sum_{c=1}^{k} S_{ct}}$$

where PR is the premium rate (as a percentage), $\overline{R}$ is the farm's average crop revenue (ha^{-1}), n is the number of years, $\overline{R}_t$ is the insured value of a farm's crop production (ha^{-1}) in year t, r_t is the farm's actual average crop revenue (ha^{-1}) in year t, FD is the franchise deductible, i_t is the drought index in year t, I_{Tr} is the drought index trigger level, C is the coverage level, k is the number of crops on the farm, P_c is the average crop price for crop c in the studied time series, S_{ct} is the surface area of crop c in year t, $\overline{Y}_c$ is the average yield for crop c, y_{ct} is the actual yield for crop c in year t. If a significant trend was observed for yields, we detrended it before taking the average to isolate natural variability in yield from technology-driven changes in yield.

When the farm only has one crop, crop-specific insurance is possible, and premiums are also calculated according to Eq. [1], where k=1, $\overline{R}_t = P_c \times \overline{Y}_c$, and $r_t = P_c \times y_{ct}$.

Commercial premiums

Commercial premiums are calculated by increasing pure or actuarially fair premiums through multiplication by a number of factors to account for uncertainty about the estimated indemnity, administrative and operating (A&O) expenses, loss-adjustment costs, and profit for the insurance company (Agroseguro, 2003; Smith & Watts, 2009). Based on data from a wide review of agricultural insurance systems in several European countries, Bielza *et al.* (2008) suggested that the ratio of the pure premium to the commercial premium is approximately 70%[5]. According to Agroseguro (2003), the commercial premium equals the pure premium multiplied by 1.406. Given these two values are almost equal, we multiplied our pure premiums by 1.4 to obtain commercial premiums.

For comparison purposes, actual commercial premiums charged by insurance companies in the study area have been obtained from Agroseguro (2013). However, these 'real' commercial premiums are for multi-risk crop insurance, covering irrigated crops against all natural hazards whose effects are verifiable and measurable (such as hail, fire, wildlife or excess rainfall), but not drought.

Application to the Santaella Irrigation District (Genil-Cabra, Guadalquivir)

Our case-study is the Santaella ID (*Colectividad de Santaella*), located in the Guadalquivir River Basin in the Andalusian province of Córdoba (southern Spain). This ID is a part of the Genil-Cabra Irrigation System (*Zona Regable del Genil Cabra).* This system is fed mainly by the Iznájar and the Cordobilla dams through the Genil-Cabra channel, which has a mean flow rate of 40 m^3/s. Water supplied by the channel is mostly used for irrigation; only 1% of it is allocated to industrial uses. The Genil-Cabra Irrigation System is managed as part of the larger General Guadalquivir River Basin System (GGRBS), between which water exchanges take place according to needs. There is no irrigation from underground water in Santaella ID.

Indexes with the desirable characteristics for index insurance (being public, easy to understand, transparent and impossible to manipulate) have been used in recent years to officially indicate different drought levels in all of the Spanish river basins. They are called *Indices de Estado* (status indicators) and were published by the river basin hydrographic confederations in the 2007 special plans of action in drought warning and potential drought situations (EC, 2007; Estrela & Vargas, 2012). These plans of action define the "status indicators", which are calculated from reservoir stock levels, in-

[5] The ratio of pure premium to commercial premium can be assimilated to the long-term loss ratio or ratio of average indemnities to average premiums.

flows and, in some cases, also from groundwater levels. The plans also establish thresholds defining the system's drought status (normal, watch, warning and emergency). These indicators and thresholds are often taken into account by ID water managers when they determine water allotments. So, these indicators can be used as a trigger index, provided that they are positively correlated with the water allotments given to farmers.

In our study area, April is the month that best represents the upcoming irrigation season (CHG, 2007), so the GGRBS April Status Indicator (ASI) is a potential candidate to be used as a trigger index i_t for our insurance scheme. This indicator is based on GGRBS water reservoir stocks at the end of April and is used by water management authorities to determine water allocations. Even though the status indicators have shown a good correlation with water allocations in other Spanish river basins (*e.g.*, Bardenas in the Ebro River Basin), we found that the correlation was surprisingly low for Genil-Cabra. We chose it anyway because it is the indicator that behaves better among other available indicators (we also tried the Standardized Precipitation Index, water inflows, and different combinations of water inflows with previous year stocks in the GGRBS reservoir system and in the Iznajar-Cordobilla reservoirs). Moreover, we have certainty that when it indicates a drought, water allocations suffer cuts (to a greater or lesser extent) because water authorities use it as a reference to determine annual allocations. The ASI takes values between 0 (no water available in reservoirs) and 1 (full water availability). For ASI below 0.5 the water authorities consider the system in warning status and water allocations may be cut back. Therefore, we set the trigger level at =0.5. Thus, whenever ASI is below 0.5, the status for the crop season is considered to be drought.

The selected coverage level is 100%; this enables us to capture the whole risk in the premium. However, the more common 70% coverage is also used to compare our calculated commercial premiums (for drought) with real commercial premiums for an existing multi-risk insurance product.

The crop season in Santaella ID starts in November with the sowing of winter cereals. The rainy season occurs from October to April. Therefore the insurance purchase period could be October-November at the latest, to prevent adverse selection. Looking at the correlation coefficient between the ASI and the previous year's October Status Indicator (cc=0.8, p=0.00), we can deduce that this case-study represents an inertial system, thus requiring a multiannual contract.

We analyzed crops with the largest irrigated surface area in Santaella ID: wheat, maize, sunflower, cotton, and olive tree (IFAPA, 2009). The main agronomic parameters needed to define yield simulations in AquaCrop are: the most common crop varieties, crop life-cycle reference dates, and planting density. All of these parameters were obtained from García-Vila & Fereres (2012) for all crops, except wheat, which were not available. Wheat was simulated using AquaCrop's default parameters. The simulated sunflower yields were too high with respect to actual yields, so fertilization was adjusted to 50% of potential need. In fact, there is a tendency to under-fertilize sunflowers with NPK in the south of Spain, partly because of the crop's capacity to absorb residual fertilizers from deep soil layers (Urbano, 2010). Another issue possibly influencing under-fertilization of sunflower in the region is that the crop has lower water use efficiency (WUE) than maize. At the same time, sunflower is not very sensitive to water scarcity; its WUE is more adaptive in response to available moisture (Green & Read, 1983). Therefore, it is one of the first crops to suffer water constraints in favor of more profitable crops.

Olive tree is one of the most important crops in the Genil-Cabra ID (36.6% of total crop area in 2012). In view of its importance, and because AquaCrop is unable to simulate ligneous crops, a crop production function was used instead. In this function, final yield depends solely on the annual amount of water received by the tree, taking into account both rainfall and irrigation. The following explicit production function was validated for the neighboring province of Jaén with a R^2 =0.72 (Pastor *et al.*, 2002).

$$Y = -5477.8 + 30.8x - 0.01x^2 \qquad [2]$$

where Y is the yield (kg/ha) and x is the amount of water applied to the tree via rainfall and irrigation (mm).

Weather variables collected for AquaCrop simulations included precipitation, potential evapotranspiration (ET_O), and temperature from 1999 to 2012. These data were sourced from the Agriculture and Fisheries Research and Training Institute, of the Andalusian Regional Government Department of Agriculture, Fisheries and the Environment.

Soil characteristics such as type, depth and underground water salinity were also included in AquaCrop simulations. Average soil type was taken from Coelho *et al*. (2000); it is classified – according to the FAO classification system (FitzPatrick, 1980) – as sandy loam *Typic Xerofluvent* (USDA, 1975) or *Eutric Fluvisol* soil. It imposes clear constraints on root growth at depths of 3 m. Irrigation water salinity was calibrated according to Rodriguez (2005), who found an average salinity close to 2 dS/m in the Santaella ID.

Irrigation water is supplied to the Santaella ID by a modern pressurized irrigation-delivery system, which allows farmers to irrigate on demand with variable frequency, rate and duration. Sprinkler irrigation accounts for 60% of the area; the remaining 40% is under drip irrigation. Yields were simulated for each water application method, and subsequently weighted according to the area under each irrigation method. Data regarding irrigation was sourced from the Santaella ID annual reports, which record the annual amount of water allocated to each crop and the amount of water employed monthly throughout the whole district. These data were used to estimate the distribution of actual irrigation events for each season and each crop, taking into account different crop calendars. Irrigation records cover the 2000-12 period, excluding the year 2009, when no reports were published by the ID. Figure 1 shows the annual volume of water applied in the entire ID in each irrigation season (from April to September), and the average volume of water applied per hectare on the secondary axis. All parameters and variables used to calibrate AquaCrop for the Santaella ID's agronomic and climatic conditions are summarized in Table 2.

Figure 1. Santaella ID total irrigation water application.

Results

Yield simulations

AquaCrop simulations were carried out for the period 2000-01 to 2011-12, except for the 2008-09 season because irrigation data were not available for it. Table 3 shows average yields (ha^{-1}) and coefficients of variation (CV) for simulated *vs* actual crop data (as reported by the ID), along with provincial yields for reference purposes. Average simulated yields are slightly higher than reported yields (except for maize) but are very close on the whole to both reported and provincial yields. The difference is due to the difficulty of calibrating AquaCrop without on-field agronomic data. Specifically, it might be due to an overestimation of the irrigation system efficiency.

Analysis of the CV shows that simulated yields are consistently less variable than reported yields, except for olive trees. A possible explanation for this lower variation in Aquacrop simulated yields is that actual yields depend on more factors, such as surface use changes (including soil quality changes) and a number of perils other than drought. Figure 2 shows the influence of surface area on per hectare yields. When maize area increases, its average yield decreases and vice versa. Other crops did not show this effect, suggesting that better quality soils are always assigned to maize. While there is a high correlation between simulated and actual reported wheat yields, the correlation of sunflower and cotton is much lower. Actual reported sunflower yields (ha^{-1}) decreased sizably in the 2004-07 period, which is consistent with a shrinkage in sunflower surface area, thereby suggesting that poorer quality soils were assigned to this crop. Cotton followed a particular trend, reflected in surface area and in reported yields, as a

Table 2. Parameters used in AquaCrop to define the Santaella Irrigation District.

	Variable	Units	Sources
Weather	Precipitation	mm	IFAPA (1999-2012)
	Temperature	°C	
	ET_0	mm	
Soil and underground water	Depth	cm	Coelho *et al.* (2000)
	Texture	USDA	
	Soil salinity	dS/m	
	Underground water salinity	dS/m	Rodriguez (2005)
Crop	Variety	Species	IFAPA (2009)
	Crop cycle reference dates	Date	Garcia-Vila & Fereres (2012)
	Seeding rate	Plants/m^2	
	Weight of 1000 grain seed	g	
	Yield	ton/ha	ID Annual Reports[1]
Irrigation	Annual water allocation per crop	hm^3	ID Annual Reports[1]

[1] Unpublished. ID: Irrigation District.

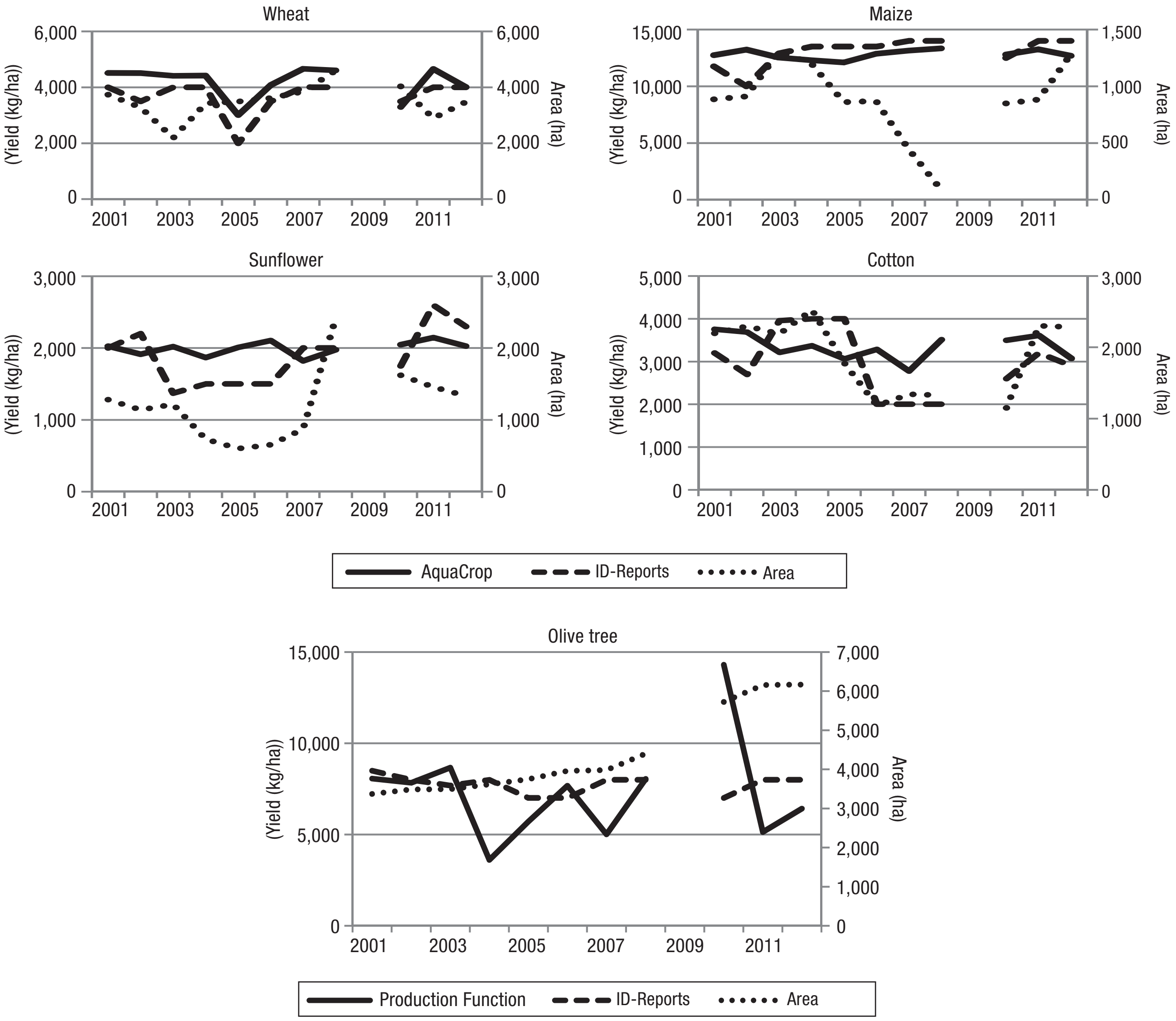

Figure 2. Actual *vs* simulated yields (kg/ha), and actual district-wide crop area (ha).

consequence of the 2005 changes in CAP subsidies (introduction of the single payment scheme), which decreased its profitability notably. Maize yields are relatively constant, although its area is constantly shifting. This is explained by the preference for allocating the best soil and consistent water to this crop.

Correlation coefficients between simulated and reported yields, between yields and the drought index, between the drought index and water allocation, and between water allocation and surface areas are shown in Table S1 [online supplement].

Pure premium rates

The pure (actuarially fair) premiums, calculated for various arable crops on a representative Santaella ID farm, assuming a 100% coverage level, are reported in Table 4 (which uses AquaCrop yields) and Table 5 (which uses actual reported yields). Both tables show the guaranteed yield (in kg/ha and €/ha), the premium amounts (in €/ha), and the premium rates (as a percentage of the guaranteed yield).

Comparing the premiums calculated from AquaCrop and ID reported yields, we found that AquaCrop premiums were smaller than ID-Report premiums, except for cotton. Another result from this comparison is that the ID premium was smaller than the premium for the area-weighted average of crop-specific insurance, due to risk management done by farmers. Farmers maximize their net income by shifting their crops' acreage distribution according to water availability, an effect that disappears when only average surfaces were considered.

Olive tree has been excluded from the ID/whole-farm insurance because, as Figure 2 and Table 3 show, yields simulated using the production function differ signifi-

Table 3. Comparison of crop yields average and coefficient of variation in Santaella ID.

Crop	Yield average (μ) (kg/ha)			Yield coefficient of variation (σ/μ) (%)		
	Simulated	ID-Reports	Province[1]	Simulated	ID-Reports	Province[1]
Wheat	4,199	3,682	4,475	13.39	16.38	3.91
Maize	12,824	13,059	12,394	3.16	9.54	5.19
Sunflower	1,996	1,884	2,008	4.87	20.90	15.95
Cotton	3,350	2,960	2,852	9.00	26.69	36.93
Olive tree	6,835 [2]	7,744	5,206	25.65 [2]	6.62	12.26

[1] Provincial yields are from annual Ministry reports (2000-2010). [2] Olive tree yield has been calculated from a production function by Pastor *et al*. (2002) instead of using AquaCrop.

Table 4. Insurance guarantee and pure premium for Santaella ID from AquaCrop yields.

Crop	Insured value		Pure premium	
	(kg/ha)	(€/ha)	(€/ha)	(%)
Wheat	5,539	1,008	19.76	1.96
Maize	12,824	2,448	12.46	0.51
Sunflower	1,997	637	4.83	0.76
Cotton[1]	3,350	1,965	63.12	3.21
Weighted average[2]	–	1,356	27.35	2.02
ID insurance	–	1,357	16.07	1.18

[1]Simulated yields for cotton have been detrended ($y = -38.439x + 2615.3$; $R^2 = 0.34$).[2] Weighted average calculates the premium (average indemnities) per crop and weights it on the average surface of each crop for the studied period. In contrast, ID insurance calculates indemnities for the combination of crops in the ID each year.

Table 5. Insurance guarantee and premium for Santaella ID from reported yields.

Crop	Insured value		Pure premium	
	(kg/ha)	(€/ha)	(€/ha)	(%)
Wheat	3,682	670	27.83	4.15
Maize	13,059	2,492	53.08	2.13
Sunflower	1,884	561	37.15	6.18
Cotton[1]	2,960	1,906	36.28	1.90
Weighted average	–	1,181	34.41	2.91
ID insurance	–	1,199	15.61	1.30

[1]Insured cotton yield has been adapted to the structural change observed in yields and area data. It was fixed at 2.138 kg/ha for the 2001-05 and 2010-12 periods and at 1.288 kg/ha for 2006-08. Note that reported annual yields are identical during the latter period, in which the cotton growing area halved.

cantly from the actual yields taken from ID reports. Therefore, the comparison of olive's simulated yields (by means of the production function) with AquaCrop yields could be misleading. Table 6 shows the guaranteed yields and premium rates for the crop-specific olive insurance, which were calculated from the production function and from reported yields. Premium rates were much higher using the production function than reported yields, which we expected due to the higher variability of production function yields (Table 3). Recall that the olive tree production function was calculated for the neighboring province of Jaen, which does not have the same agronomic conditions as the Santaella ID. The production function also only takes into account the total annual water received by the tree, instead of daily climatic variables such as temperature, rain and evapotranspiration, which have a crucial influence over yields. Hence the use of this production function generates inaccurate estimates of yields and consequently of insurance premiums.

Commercial premiums and comparison with 2013 actual multi-risk commercial premiums

Commercial premiums for ID/whole-farm insurance calculated from AquaCrop yields and from

Table 6. Olive insurance guarantee and premium for Santaella ID.

	Crop production function	ID-Reports
Insured value (kg/ha)	7,408	7,744
Insured value (€/ha)	3,688	3,903
Premium rates (%)	4.86	1.75

reported yields are shown in Table 7, against Agroseguro multirisk commercial premiums (hereafter 'real' premiums). As Agroseguro insurance covers only 70% of the guaranteed yield, '*AquaCrop*' premiums and '*ID-Report*' premiums have also been calculated for a 70% coverage level. The premium rates are expressed as a percentage of guaranteed yield, rather than in €/ha for the purpose of comparison, given that guaranteed yield is not equal for all three premium types.

At 70% coverage, commercial premiums based on 'AquaCrop' and 'ID-Report' are zero for most crops. Only wheat yields from ID-Report suffered losses above 30% of the average yield (once in eleven years). Given that most premium rates for 70% coverage are equal to 0, they are also shown for 100% coverage (*i.e.*, no deductible) in the right-hand columns of Table 7.

Comparing the 70% coverage commercial premium rates, we found that 'real' premiums were higher than AquaCrop premiums, the only exception was cotton (see footnote to the Table 5). This is expected because 'real' premiums provide coverage for more risks than 'AquaCrop'. 'ID-Report' premiums theoretically provide coverage for the same risks as the real premiums (possibly for even more risks, such as pests and diseases). Nonetheless, they were smaller (*e.g.*, for maize, sunflower and cotton), perhaps because real premiums were calculated for the entire region where, in all probability, yields were more erratic due to a wider range of agronomic conditions. Looking at the commercial premium rates with 100% coverage, we found that ID-Report premiums were always higher than AquaCrop premiums, because the former reflect many other causes of yield variability, not just drought.

Discussion

This study has some major limitations. First, when using AquaCrop for premium calculation it should be noted that, although the model performed satisfactorily for maize in the non-water-stress treatments and mild stress conditions, it was less satisfactory in severe water-stress treatments, especially when stress occurs during senescence (Heng *et al.,* 2009). This could cause a misleading premium estimate. Second, AquaCrop is unable to simulate ligneous and forage crops, which reduces its scope of application. This could be solved in the future by extending the software to simulate additional crops. Our attempt at using a production function to overcome this limitation has shown that it will only achieve accurate results if it faithfully represents the local crop-response to water. Also, our empirical application was based on a relatively small data series. AquaCrop calibration is a key issue; it requires accurate data to define agronomic conditions. To estimate the impact of irrigation water on yields, more precise data on characteristics for the different soil types is needed. Finally, the drought index used (ASI) showed a poor correlation with water allocations and therefore with crop yields, which compromises the application of our methods to this particular case. Previous studies performed by the authors (Ruiz *et al.,* 2013) showed better correlations between the Status indicators and water allotments in Bardenas ID in Saragossa, and in El Viar ID in Seville (Spain), which shows that

Table 7. Commercial premium rates (%) for Santaella ID.

Crop	70% coverage			100% coverage	
	Real [1]	AquaCrop	ID-Reports	AquaCrop	ID-Reports
Wheat	0.48	0.00	2.00	2.74	5.81
Maize	0.31	0.00	0.00	0.71	2.98
Sunflower	0.44	0.00	0.00	1.06	8.65
Cotton	0.77	0.00	0.00	4.50	2.66
Weighted average	0.55	0.00	0.53	2.82	4.08
ID / whole-farm ins	–	0.00	0.00	1.66	1.82

[1] Multi-risk commercial premiums, Module 1 (Module 1 contract covers against all insurable perils; perils and indemnities are given for the whole farm instead of for each parcel), 70% coverage. *Source:* Agroseguro (2013). [2] Cotton premiums are highly affected by CAP subsidies, which make its yields extremely erratic along the studied period.

this weakness is strongly dependent on the study area.

Despite these limitations, the paper proposes an easy to use method to estimate insurance premiums to cover irrigation water deficits: 'a very complex and interesting issue for future research' (as described by Quiroga *et al.* (2011). The proposed method might be useful to simulate premiums under not extremely limited irrigation conditions, since Aquacrop discriminates each crop stage and faithfully replicates actual production conditions. This might be used in other studies of drought insurance to estimate yields on which insurance premiums are based, provided that crop calibration be improved through field research.

This paper also discusses insurance implementation and contract conditions, which theoretically would lead to insurance success. However, in practice, some of these contract conditions are not easy to implement. This is the case for strict delivery rules by water authorities, which is a key factor to obtaining a higher correlation between the index and water allotments. There are also some barriers to the installation of water meters on each parcel, especially in not-well-developed irrigation districts. In modern districts, such as Community V in *Los Riegos de Bardenas* in Saragossa, Spain, this could be implemented easily provided that on each parcel there is only one crop. In this Irrigation District, the amount of irrigation water applied on each parcel is requested by farmers via ATMs (automated teller machines), which are set up for this purpose, or by internet or mobile phone. The amount of water applied to each parcel is recorded automatically on the system's server.

Additional insights were gained by comparing our simulated crop yields to actual data reported by an ID, and simulated *vs* actual commercial premiums from a multi-risk insurance product. According to our results, AquaCrop premiums were mostly smaller than rates calculated from ID reports. AquaCrop yields depend mainly on the amount of water applied to the crop, whereas actual ID yields depend on more factors. Hence, ID-Report premiums included additional risks that could affect crop production, such as fire, pest damage, disease, hail or flooding, or even the effects of market and agricultural policy changes.

Our premium results can also be compared with those for olive trees by Pérez & Gómez (2012), who obtained a premium rate of 2.45% for this crop using a production function. Our production function generated some extreme and erratic values, resulting in a much higher premium of 4.86%. Premium rates from ID-Reports are lower (1.75%), even though reported yields should be exposed to more risks than our simulated yields.

Commercial premiums calculated with a 70% coverage level (the one currently used for multi-risk insurance in Spain) resulted in very low-cost insurance in comparison with current multi-risk insurance premiums. This is due to an extremely low probability of indemnity at this coverage level. Given that 100% coverage increases the premium considerably, above the customary premium levels, we recommend coverage of between 70 and 100%, or the inclusion of coverage for hydrological drought within an established insurance scheme, with an additional premium for its coverage. For the province of Córdoba, drought represented almost 24% of total indemnities for the period 2009-2011[6]. Considering that as the equivalent percentage in premiums cost, it is reasonable that Aquacrop premiums at 70% coverage level are equal to 0.

To see if irrigated-maize producers would buy drought insurance, the calculated commercial premiums for maize (0.71% for simulated yields and 2.98% for reported yields) could potentially be compared with the willingness to pay calculated by Quiroga *et al.* (2011). Unfortunately, these willingness to pay estimates – which range from 2% to 17% – were calculated for a different region, and apply only to climate change scenarios.

Regarding the implementation of hydrological drought insurance for irrigated agriculture, we proposed the use of on-field loss assessment. This not only has the potential to stabilize farmers' welfare, but also reduce incentives for illegal groundwater abstractions, therefore promoting more sustainable aquifer management. This is positive-externality specific to hydrological drought insurance with on-field loss assessment. Index insurance, without on-field loss assessment (as proposed by Leiva & Skees, 2008; or Zeuli & Skees, 2005), is much simpler to implement, but could lead to indemnity payments when crop production did not decrease, due to the use of groundwater. On the other side, on-field loss assessment might increase administrative costs. However, in the case of Spain, assessors already visit rainfed parcels when there is a drought event. It is very likely that if irrigated agriculture suffers from drought, rainfed crops suffer it as well, and that both types of parcels are closely located. Therefore assessors would only have to visit some additional parcels, particularly since irrigated agriculture represent only the 13% of the total agricultural surface (MAGRAMA, 2010).

[6] Agroseguro, 2009-2011. El seguro agrario combinado en cifras. Available at http://agroseguro.es/publicaciones/otras-publicaciones.

One of the advantages of insurance with on-field assessment is that it is not strictly dependent on a good correlation between farm production and an index. However, we agree with Pérez & Gómez (2012) that drought insurance should be associated with a trigger-value of a drought index (mainly to partially avoid the high moral hazard associated to this type of coverage). The index should be transparent and objective to avoid moral hazard problems and to ensure it is largely outside the control of the primary insurer (Doherty & Richter, 2002). The success of this type of hydrological drought insurance would require a good correlation between the index and crop yields, while at the same time strictly adhering to clear water delivery rules. As suggested by Pérez & Gómez (2012), when the annual amount of water to be delivered does not conform to strict rules, the establishment of drought insurance in irrigated agriculture may not be feasible.

To avoid asymmetric information problems, which could compromise insurance viability (Pauly, 1974), the insurance contract should include, in addition to standard contract conditions such as deductibles, a series of commitments specific to this kind of insurance, such as: provision of information about water allotments by the ID to the insurance company; use of water meters for each farm, or infeasibility of water exchanges between farms; compulsory purchase of whole-farm insurance covering all crops on the farm and limitation of insurance to farms with only eligible (insurable) crops; a fixed purchase deadline before the rainy season; and multiannual contracts in the case of inertial systems. This is the case in most irrigation systems in southern Spain, where the reservoir capacity is large relative to annual inflow. In northern Spain, though, reservoir stocks are annually renewed. A further contract condition is that farmers have no access to groundwater.

Further research should address the insurability of farms with groundwater availability. They could be entitled to an indemnity based on additional costs incurred for groundwater withdrawal during drought. However, given this would not strictly cover a loss of crop production, there could be some legal problems related to its implementation under current crop insurance legal frameworks.

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