CAMBIO CLIMÁTICO Y ADAPTACIÓN DE LA AGRICULTURA MEDITERRÁNEA: EVALUACIÓN DE ALGUNAS INCERTIDUMBRES

ADAPTATION OF MEDITERRANEAN AGRICULTURE TO CLIMATE CHANGE: EVALUATION OF SOME UNCERTAINTIES

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RESUMEN

El cambio climático resulta en variaciones regionales de los riesgos y oportunidades para la mayoría de los agricultores del Mediterráneo en las próximas décadas. La identificación de políticas y acciones adaptación, políticas y acciones por parte de los agricultores, es difícil puesteo que es difícil comprender la incertidumbre asociada a los impactos en distintas zonas y en distintos cultivos. En este estudio evaluamos algunos aspectos relacionados con esta incertidumbre en la agricultura mediterránea. El resultado final es una evaluación del nivel de riesgo que tienen distintos cultivos en distintas zonas para apoyar la toma de decisiones relacionadas con la adaptación. Utilizamos proyecciones múltiples de impactos basados en 16 escenarios de cambio climático y modelos respuesta del cultivo para evaluar la probabilidad de los impactos proyectados en sistemas agrícolas tradicionales del mediterráneo. Los resultados muestran la amplia variabilidad de la incertidumbre según el cultivo y su ubicación y nos dejan concluir que la prioridades de adaptación dependerán en el enfoque de riesgo de los planes de adaptación.

Palabras Clave: Agricultura, Mediterráneo, incertidumbre, cambio climático, adaptación

ABSTRACT

Climate change inevitably results in large regional variations of risks and opportunities and will be felt by most farmers in the Mediterranean in the next decades. The interpretation of results to determine appropriate policy response is troubled with difficulties, such as understanding the local uncertainty and the interpretation of specific crop responses. Here we provide an analysis of the impact of climate and likelihood for Mediterranean agriculture. We generate multiple projections of impacts based on different models of climate change and crop response in order to capture uncertainties. We use statistical models of yield response and projections of climate change generated from 16 climate scenarios to address the likelihood of projected impacts on traditional Mediterranean farming systems. Results show that uncertainty varies widely with crop and location, and therefore adaptation priorities will depend on the risk focus of adaptation plans.

Keywords: Agriculture, Mediterranean, uncertainty, climate change, adaptation

1 INTRODUCTION

Communicating uncertainties is a challenge. The potential impacts of climate change and their likelihood are main factors for developing mitigation and adaptation policy. Impacts and likelihood are determined by a wide range of assumptions about future society, choice of climate model, analytical tools, and data (Fronzek, Carter 2007). Many argue that it is possible to reduce uncertainty by making clear assumptions (Hulme et al. 1999). But future predictions are inherently uncertain and therefore even the application of scientific rigor will not be able to completely eliminate this aspect of the projections and must therefore be dealt with. Characterisation of uncertainty is difficult due to its several determinants and local system specificity. Understanding the impact and likelihood of climate change is complicated due to inconsistencies of inputs across geographical and time scales and changes in physical and social variables that often derived using different assumptions. As result, some of the most profound consequences of climate change may be more difficult to project than the future climate itself. In this paper we address some of these challenges.

Here we focus on Mediterranean agriculture, a well studied region from the climate and the agricultural point of view (Giorgi, Lionello 2008; Parry et al. 2007; Iglesias et al. 2007; Olesen, Bindi 2002; Eurpean Environment Agency 2008). The Mediterranean region has the world's largest area of olives, grapevine and citrus, as well as extensive cereal production. These crops are an important part of the history and diet of the region and their future will determine the socio-economic and environmental development of many rural areas.

Adaptation is a key factor that will determine the future severity of climate change impacts on agriculture and food production (Lobell et al. 2008; Brooks et al. 2005; Burton, Lim 2005; Howden et al. 2007). Prioritizing climate change policies in the agricultural sector requires information on: (a) assumptions about the future climate; (b) characterisation of the regional disparities and local realities; and (c) sources of uncertainty in the assessment. Here we characterize impacts and likelihood by addressing the uncertainty of the scenario choice, the uncertainty of the local conditions (locations and type of agricultural system), and the evaluation of probabilistic impacts. Our methodology incorporates a number of strengths: it links climate and agricultural uncertainty aspects in a common and consistent framework, uses a range of emission scenarios to provide insights into the effects of climate change policy, and uses a range of crops that have future social and environmental implications. The second section of this article provides information on the methodological approach. The third section describes the results of the estimates of climate impact based on 16 climate scenarios, four locations and four types of crops. The final section presents the conclusions

2 METHODS

2.1 Approach

The study includes four components. A multi-scenario framework addresses the climate uncertainty, a range of crop choices and contrasting locations addresses the uncertainty derived from the agricultural system, and the probabilistic risk level is derived from Monte Carlo analysis. Finally we derive an impact to risk index that allows comparison of uncertainty across the regions and choice of crops in the evaluation of informed decisions. The study sites are located in the Mediterranean region, Spain, which exemplifies other drought and water scarcity areas, with likelihood of drought intensification in the future. The crops selected are the major crops in the region: cereals, citrus, grapevine, and olives. The methodology addresses some uncertainty questions relevant for policy development in the region (Table 1).

Uncertainty question addressed	Methodological approach	Policy implications
Are there differential risks to crop production arising from different socio-economic and climate scenarios?	Multi scenario approach	Boundaries of possible futures Benefits of mitigation action
How does location and crop type affects uncertainty of projected impacts?	Regional and crop analysis	Choice of the crop and diversification of the farming system
What risk are farmers willing to accept?	Monte Carlo probabilistic analysis; risk factor	Selection of threshold levels for insurance protection to extreme events Define risk attitude

Table 1. Uncertainty questions, methodological approach in the study and implications to address adaptation decisions

2.2 Climate change scenarios

Climate change is characterised from a range of global change scenarios. Since no single projection is a prediction, scenarios represent alternative futures. Here we use 16 climate change scenarios that allow comparison between the four SRES socio-economic drivers of greenhouse gas emissions (Nakicenovic and Swart, R., 2000), general circulation models (four GCMs), for the period 2071 to 2100 (Table 2). The source of the data is the IPCC DDC and the Tyndall Centre (Mitchell et al., 2004).

Scenario	model	description	Driving socio economic scenario (SRES)	Precip change mm/day for period 2071-2100 (Average in Spain)	temp change (C) for period 2071-2100 (Average in Spain)
1	CGCM2A1	Canadian Centre for Climate Modelling and Analysis, coupled model version 2	A1	-0.3033	4.7
2	CGCM2A2		A2	-0.2447	3.8
3	CGCM2B1		B1	-0.0732	2.1
4	CGCM2B2		B2	-0.0893	2.5
5	CSIRO2A1	Australian Commonwealth Scientific and Research Organisation CSIRO-Mk2	A1	0.0263	3.7
6	CSIRO2A2		A2	-0.0912	3.9
7	CSIRO2B1		B1	-0.0315	2.9
8	CSIRO2B2		B2	-0.0400	3.1
9	HadCM3A1	Hadley Centre, UK, Coupled Model Version 3	A1	-0.4268	5.8
10	HadCM3A2		A2	-0.3773	4.4
11	HadCM3B1		B1	-0.3287	2.9
12	HadCM3B2		B2	-0.1712	3.3
13	PCMA1	National Center for Atmospheric Research, USA, NCAR PCM	A1	-0.1890	3.1
14	PCMA2		A2	-0.1537	2.5
15	PCMB1		B1	-0.1208	1.5
16	PCMB2		B2	-0.1490	1.9

Table 2. Summary of the 16 climate scenarios used in the study. Source of data: IPCC DDC and Tyndall Centre (Mitchell et al. 2004)

2.3 Crops and agricultural models

To understand the components of yield variability in a range of agro-climatic conditions we use econometric models of yield response with climatic data as explanatory variables

(Quiroga, Iglesias 2009; Iglesias, Quiroga 2007). The models also consider the effect of technical progress, incorporating several management indicators as input variables. Technological change, represented by farm machinery and fertiliser application, results in yield increases for all crops; while irrigation is the main factor responsible for yield increase in olives. To take into account this effect, a percent of irrigated area index was introduced (Quiroga, Iglesias 2009). The models include autoregressive terms in order to correct the autocorrelation of the residuals and to capture the dynamics of the data. Finally, some impulse dummy variables (with a value of 1 in a selected year) have been added to the model in order to isolate the effects of some anomalous drought years.

The four study sites and four crops are representative of Mediterranean agriculture (Table 3). Data of observed crop yields at province level were taken from MAPA (2004) for the selected crops and sites. In each site, series of maximum and minimum temperatures, number of days per month with temperature bellow 0ºC, and precipitation for the 1959-2000 period were obtained from the National Meteorological Service (Spain). These four sites show differences in seasonal temperature and the amount and distribution of precipitation, and also are characterised by different crop management practices and levels of production.

	Lat ºN	Long ºW	Altitude (m)	Tavg (C)	Pavg (mm)	Simulated crops cereals	citrus	grapevine	olives
Burgos	42.37	-3.63	894	10.2	630	x			
Logroño	42.45	-2.33	353	13.4	383	x		x	x
Murcia	38.00	-1.10	0	17.6	305	x	x	x	x
Cordoba	37.85	-4.83	92	17.9	674	x	x	x	x

Table 3. Representatives sites and crops

2.4 Risk level

The probability distribution of production changes for 2080s for each crop and location is estimated using the Monte Carlo method. Monte Carlo simulations are widely used to derive large size samples from short time series observed data (Robert, Casella 1999). The Monte Carlo method is used in agriculture to characterize statistical properties of crop yield prices, as well as crop yield as response to rainfall or other inputs . Here we apply Monte Carlo methods to derive probability distribution functions of yield risk levels. The approach consists of generating synthetic series of yield variables using the Monte Carlo method and Latin Hypercube sampling (Just, Weninger 1999; Atwood et al. 2003.)

2.5 Impact to risk index

A standardised impact to risk index (SIR) is proposed to quantify the magnitude and likelihood of having an impact in each location and crop. This diagnostic probabilistic measure of uncertainty is useful for proposing the most appropriate adaptation strategy in each case. The SIR is computed as the ratio between the risk measured as the average probabilistic impacts and standardised kurtosis of the impact distribution. The kurtosis is a measure of the relative concentration flatness or peakedness of the probability distribution of a real-valued random variable. Distributions having higher kurtosis have fatter tails or more extreme values, as opposed to the lower kurtosis that means fatter middles or fewer extremes. Kurtosis values are always positive since it is defined as: μ_4 / σ^4, where μ_4 is the fourth moment of the mean and σ is the standard deviation. Therefore the sign of the SIR is derived from the sign of the impacts. Negative values of SIR indicate negative impacts and positive values of SIR indicate positive impacts. Since the SIR index is standardized, it is a 0, 1 normal and 90% of the values are between -2 and +2. The SIR index ponders the impacts and their associated likelihood. A positive or negative impact hat has associated large uncertainty, is more difficult to address with adaptation measures, and therefore the "real" risk will be even more negative. Table 4 provides an interpretation of the values of the SIR index.

SIR values	
+2 and more	Positive impact (opportunity), highly unlikely
+0.5 and more	Positive impact (opportunity), likely to occur
-0.5 to 0.5	Likelihood of little or no deviation from current
-0.5 and less	Negative impact (risk), likely to occur
-2 and less	Negative impact (risk), highly unlikely

Table 4. Interpretation of the values of the SIR index.

3 RESULTS AND DISCUSSION

3.1 Uncertainty derived from the choice of scenarios

In Mediterranean agriculture, precipitation determines a large proportion of the observed and projected crop yield change. Therefore this variable is of key importance for estimating impacts and likelihood. Fronzek and Carter (2007) hint at a systematic difference from downscaling the output of the global climate models only in the temperature but not the precipitation. Therefore, we have not included in the analysis downscaled scenarios, to broaden the possible choice of climate and emissions models for the analysis. Projections of annual mean changes in temperature and annual changes in precipitation from the 16 scenarios are summarized in Figure 1.

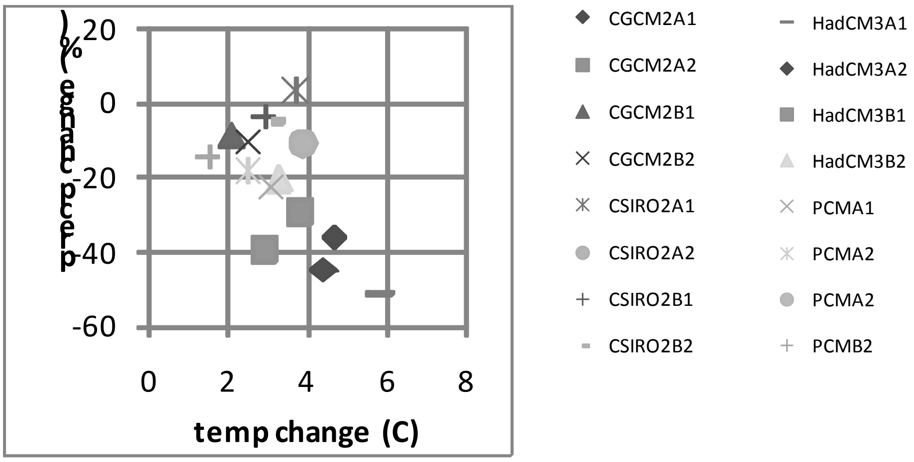


Figure 1. Changes in annual average temperature and total annual precipitation by 2071-2100 relative to 1961-1990 averaged over Spain from 4 global climate models under the A1 (AIFI), A2, B1 and B2 forcings.

3.2 Uncertainty of the agricultural system

Median projections for Mediterranean corps exhibit a very wide response to climate scenario and location (Figure 2). In general northern and southern locations show contrasting results as previously reported. Projected future climate may result in an opportunity for cereal production in the northern sites, but is very negatively affected in southern sites, where the need for supplemental irrigation is also questioned under warmer and dryer conditions. Grapevine shows the most varied response depending on local conditions. Olive production is clearly at risk at the marginal production locations (Logroño and Murcia) while climate change may not be a large threat in the main olive production region (Andalusia). The results also allow for the calculation of the effect of the socio-economic scenario assumptions on the implications of crop productivity (calculated as changes in the value of crop yield under the A2 scenario, considered as the business-as-usual projection with respect to the B2, considered as mitigation scenario that cannot be avoided even if reduction of greenhouse gas emissions are implemented). Potential benefits in crop productivity from taking action to reduce greenhouse gas emissions are possible in some locations and crops.

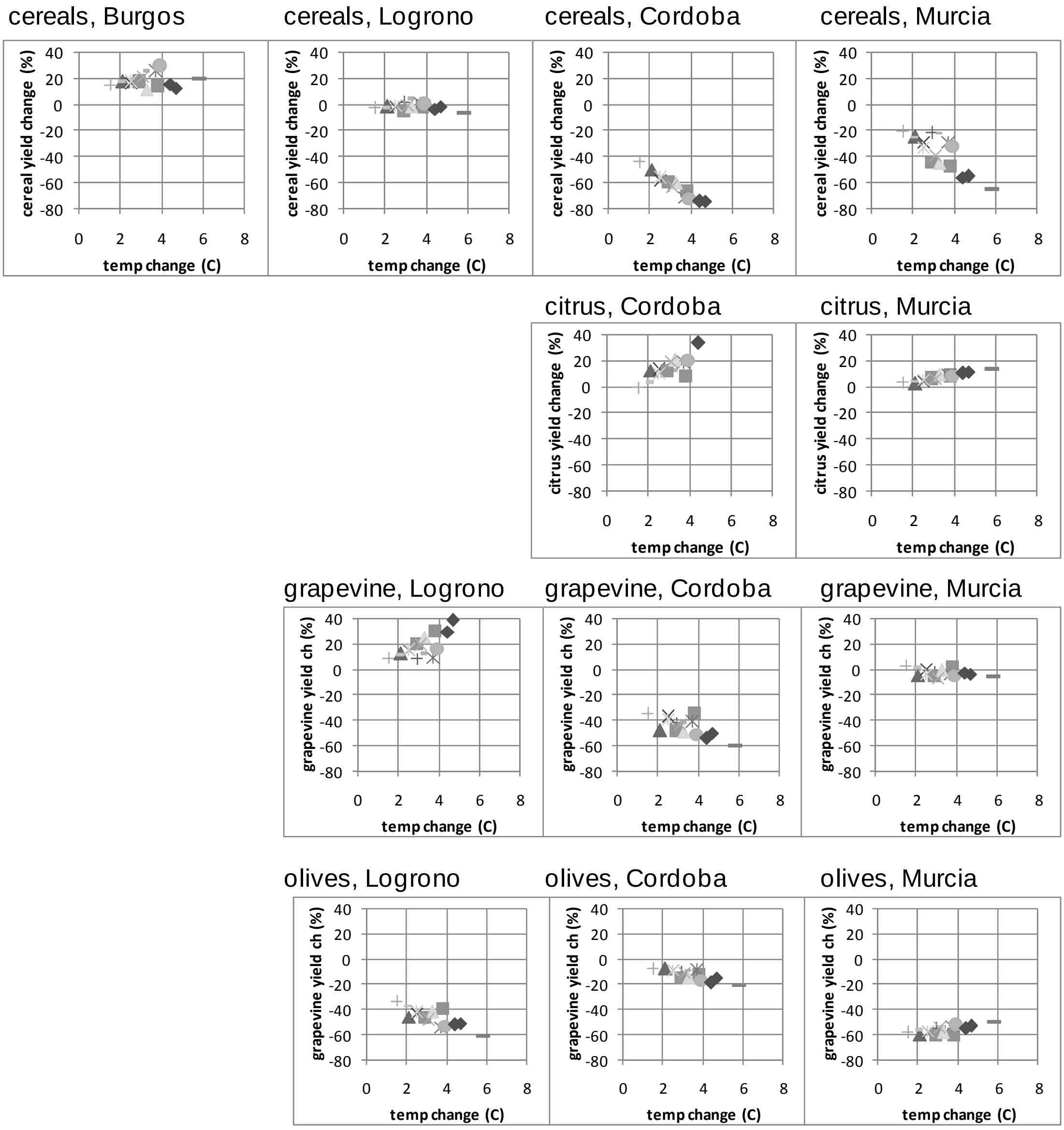


Figure 2. Crop yield changes under the 16 scenarios for the period 2071-2100 compared to baseline, plotted against the temperature change in the corresponding scenario.

3.3 Risk level

We used Monte Carlo simulations to derive random samples (10,000 values) of statistical distributions of crop yield and therefore to analyse the distribution of probabilities in order to obtain a certain yield (the risk level). Our results show large differences of impact levels on yield distribution functions across the sites and crops (Table 5 and Figure 3). Logroño has a low variance while Córdoba has the highest. In general, the skewness coefficients do not indicate a large probability of low yield, since only values below -1 indicate very negatively skewed data. Kurtosis is a parameter that describes the shape of a random variable's probability density function. High kurtosis values indicate that the distribution of impacts is closely centred around the mean; we may interpret this as meaning that the projected impact is more certain, since we have considered a high enough number of scenarios.

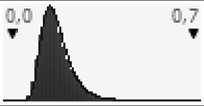
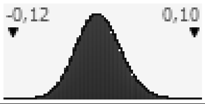
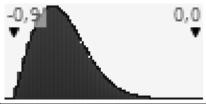
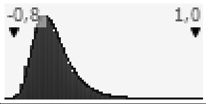
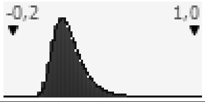
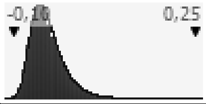
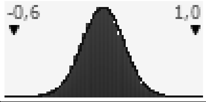
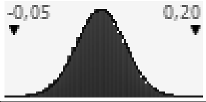
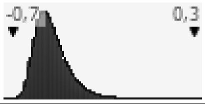
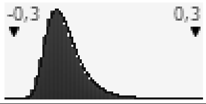
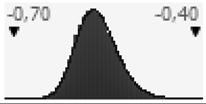
	Burgos	Logroño	Cordoba	Murcia
Cereals				
Minimum	0.07050	-0.09898	-0.85910	-0.79648
Maximum	0.63039	0.09010	-0.09528	0.96690
Mean	0.18786	-0.01353	-0.64007	-0.35982
Std Deviation	0.05288	0.02474	0.11516	0.17818
Variance	0.00280	0.00061	0.01326	0.03175
Skewness	1.15045	0.15918	0.62996	1.13662
Kurtosis	5.52180	3.03406	3.23623	5.36395
Grapevine				
Minimum		-0.04252	-0.66613	-0.09491
Maximum		0.96689	0.49367	0.21838
Mean		0.19491	-0.43926	-0.02525
Std Deviation		0.09446	0.09625	0.02986
Variance		0.00892	0.00926	0.00089
Skewness		1.14851	1.18162	1.14662
Kurtosis		5.49994	5.92001	5.47802
Citrus				
Minimum			-0.47527	-0.04624
Maximum			0.98454	0.18794
Mean			0.19664	0.07179
Std Deviation			0.16878	0.03095
Variance			0.02849	0.00096
Skewness			0.00348	-0.00025
Kurtosis			3.02124	2.99436
Olives				
Minimum		-0.65114	-0.24789	-0.65479
Maximum		0.25349	0.26682	-0.40810
Mean		-0.45989	-0.11869	-0.55977
Std Deviation		0.08592	0.05597	0.03105
Variance		0.00738	0.00313	0.00096
Skewness		1.14982	1.13018	0.39656
Kurtosis		5.51116	5.29370	3.25482

Table 5. Statistical distribution of yield derived from Monte Carlo simulations and descriptive statistics for the four corps and locations.

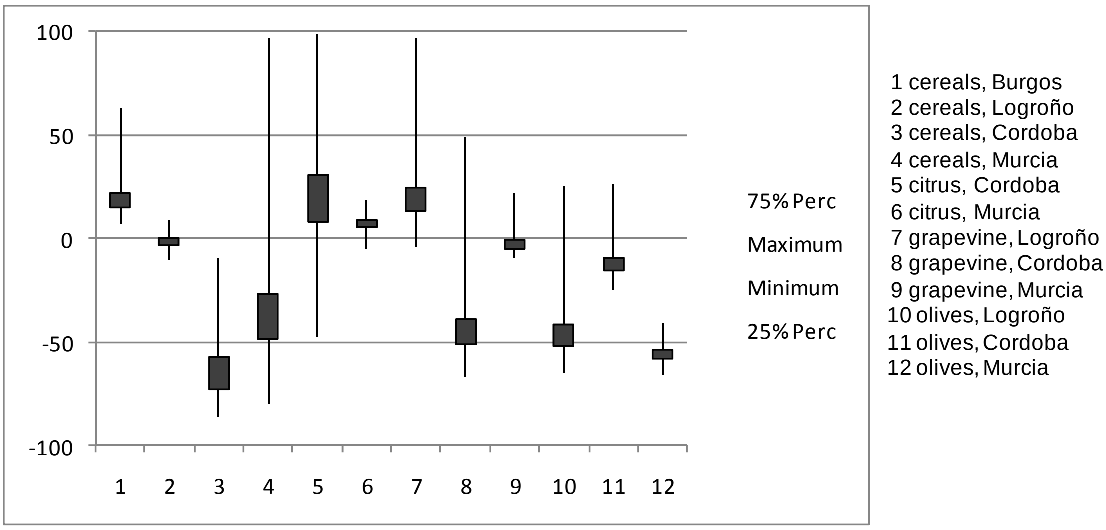


Figure 3. Summary of projected yield variation derived from Monte Carlo simulations. Boxes extend form the 25th to the 75th percentile and vertical lines extend from the max to min.

We have developed an integrating index that relates impacts to likelihood. The Standardised impact to risk index (SIR) shown in Figure 4 is calculated as the ratio between the impact and the standardised kurtosis of the impact distribution. We propose some thresholds of the SIR value to support decisions on the adaptation priorities. The results provide information about the choice of crop to minimise risk, addressing the risk at the farming system level.

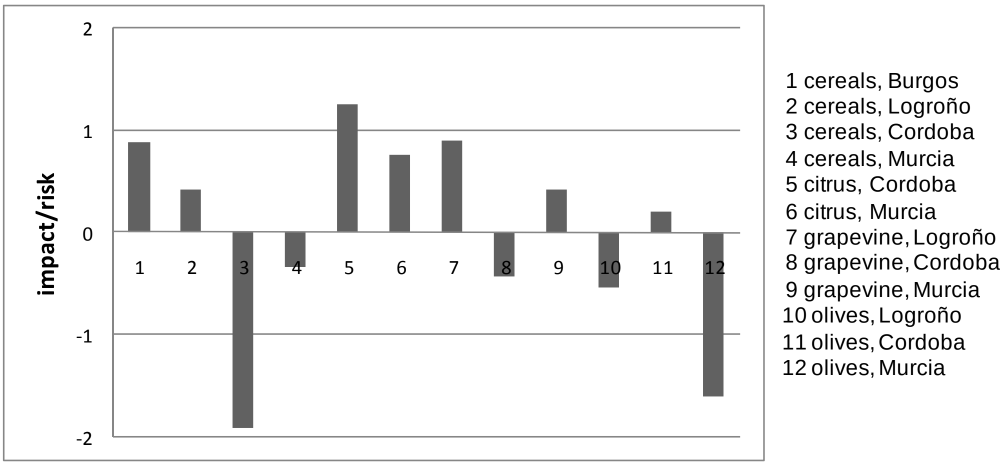


Figure 4. Standardised impact to risk index (SIR) projected for a combination of locations and crops in the Mediterranean region.

4 CONCLUSIONS

Investments and policies aimed at improving agricultural adaptation to climate change inevitably favour some crops and regions over others. (Lobell et al., 2008). Scientific uncertainty and the attitude of Institutions towards it are key factors determining these choice. There is considerable uncertainty surrounding future impacts of climate on crops and yields, derived from climate models (and underlying assumption on driving forces), crop type as well as the location. This uncertainty is increased in going from emission values to climate change, from climate change to possible impacts and finally from these driving forces to formulating adaptation and mitigation policies (Gupta et al. 2003). Furthermore, the complexity of the socio-economic system and historical and biophysical dynamics that underpin the agricultural sector condition the possible type of actions and responses and add an additional layer of complexity (Ziervogel and Zermoglio, 2009).Apart from taking into account yield differences for four crops (cereals, citrus, grapevine and olive) and locations (Burgos, Logroño, Cordoba and Murcia), we have also based our projections on 16 climate models from four different sources (CGCM, CSIRO, HadCM, PCM) and using four SRES scenarios (A1, A2, B1, B2).

The results of our analyses agree with the agronomic knowledge of crop responses to climate, but the risk ranking of the regions is not intuitive when only considering variables in isolation. For example, Murcia is a very dry region and the common perception is that the risk to crop production is higher. However, although cereals and olives are projected to experience considerable decreases in yields, citrus and grapevine, which are both irrigated in the region, are not. None of the crops offer a clear advantage over others in all of the regions; regional adverse impacts are, as can be expected, more acute in the southern study sites (Cordoba and Murcia) than in more northern location (Burgos and Logroño). This supports the argument that any policies or adaptation response needs to be location-specific and often even crop-specific in order to adequately consider and address the likely climate impacts in the region as well as the specific management and socio-economic conditions (i.e. irrigation) of the location.

The risk level that was analyzed as part of this study may provide some policy guidance, regardless of the impact and its severity. Considering the distribution of the risk level, we can deduce the likelihood of the impact occurring and thereby target policy actions to address the particular level and certainty of the impact. Therefore, although olives in Murcia are expected to decrease yields significantly, the likelihood of this occurring at the projected level is very high given the small variation between the 5^{th} and 95^{th} percentile. The impacts to risk index derived supports making informed decisions by providing an intuitive and comparable measure of the impact likelihood. Therefore, we can see that the level of impact is greatest for cereals in Cordoba and that the likelihood of this occurring is high. Ideally, this should trigger a policy or stakeholder response in order to reduce the negative impacts likely to be experienced by formers of these crops in the region.

Over the next few decades a central goal of agricultural decisions will be to decrease the risk associated with a changing climate. Future policy actions in the Mediterranean, need to be focused on helping farmers adopt strategies that are in compliance with current and developing legislation and programs, especially in view of the continued reform of the Common Agricultural Policy of the European Union (CAP) and the implementation of other policies such as the EU Water Framework Directive. Fundamental to this aim is to develop the ability to quantify climate risks associated with different geographical locations as well as different crops. Evaluating the uncertainty and risk level and analyzing the likelihood of a particular event occurring through indicators such as the impacts to risk index may serve to guide policy-makers and stakeholders as they face adverse climate impacts. Finally, scientific advances of climate change projections based on new scenarios (Moss et al 2010) will provide a clearer understanding of uncertainties .

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