

A comparative estimate of climate change impacts on cotton and maize in Greece

Dimitrios Voloudakis, Andreas Karamanos, Garyfalia Economou, John Kapsomenakis and Christos Zerefos

ABSTRACT

The impact of climate change on cotton and maize was estimated on the basis of three IPCC Emission Scenarios (A1B, A2, B2) for seven main agronomic areas during three periods, 1961–1990, 2021–2050 and 2071–2100. All climate models were assessed for their ability to identify the yield differences through the standardized discriminant function coefficients. Discriminant analysis was performed for each period. For cotton, using the A1B scenario, areas of Western Greece exhibited the most favourable results in terms of yield increase, compared to other regions, ranging up to the maximum value of +24%. This tendency became more pronounced towards the end of the century reaching an increase of +31%. In the A2 scenario, all the areas had a positive impact on their yield change rising up to 30% in areas of central Greece. A positive change for all regions was observed for scenario B2 ranging from +10% to +25%. In maize, the scenario A1B produced small changes in yields, not exceeding 5%. For A2 scenario, yield change varied from –5.7% to +3.6%. Scenario B2 gave more optimistic estimates of yield changes towards the end of the century, in some cases exceeding 5%.

Key words | AquaCrop, climate change, cotton, discriminant function analysis, Greece, maize

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INTRODUCTION

Arable crops in Greece cover almost 55% of the cultivated land (ELSTAT 2014). Greek cotton (*Gossypium hirsutum* L) represents more than 80% of the total EU production while maize (*Zea mays* L) accounts for 17% of the arable crops cultivated area in Greece (ELSTAT 2014).

An integrated national study regarding the impacts of climate change on agriculture showed that in some cases arable crops yields are significantly vulnerable to water stress, temperature increase and soil degradation (CCISC 2011). Previous research regarding the impact of the A1B scenario on cotton yields in the same areas indicated a differentiation of yield change between western-southern areas and the others (Voloudakis *et al.* 2015).

Both cotton and maize are intensively irrigated in Greece. However, there is a lack of information regarding the comparison of these crops reaction under climate

change conditions. There is a concrete demand for further knowledge on how the different photosynthetic mechanisms of these crops – cotton is a C3 and maize a C4 plant – affects their reaction to climatic variation. This study investigates the impact of three basic IPCC scenarios not only in cotton but also in maize.

MATERIALS AND METHODS

Study sites

Greece is located at the southern end of the Balkan Peninsula and 80% of the country consists of mountains and hills. Continental plains in the Greek mainland are of great importance for the agricultural production. Seven

areas (from north to south: Alexandroupoli, Mikra, Karditsa, Arta, Agrinio, Yliki and Pyrgos) representing the most important cotton and maize cultivation zones of the Greek mainland were selected for this study (Figure 1).

Climate change scenarios and climate models

For the projection of climate change conditions, three emission scenarios (A1B, A2, B2), as developed in the third IPCC report, were used (Nakićenović et al. 2000). Each emission scenario was simulated by several climate models providing information for minimum and maximum temperature (°C), air relative humidity (%), precipitation (mm/day), solar radiation (W/m²) and wind speed (m/sec) on a daily basis for the periods 1961–1990 (reference period), and 2021–2050, 2071–2100 for the A1B scenario. For the scenarios A2 and B2 only, the period 2071–2100 was considered. The comparison of these periods was based on the report of WG I of the fourth IPCC Assessment Report in which the main differences among climate scenarios are identified for the second half of the 21st century (Randall et al. 2007).

Eight climate models (HadRM3, C4I, REMO-MPI, ETHZ, CNRM, DMI-HIRHAM, KNMI, SMHI) derived from the ENSEMBLES project (Hewitt & Griggs 2004) were used for the analysis of the A1B scenario, while the

models HadRM3, DMI-HIRHAM and SMHI, provided by the PRUDENCE project (Christensen & Christensen 2007), were applied to the A2 and B2 scenarios. Wind speed was adjusted from 10 m to 2 m above ground surface using the ETo calculator software (v3.2) by means of the FAO Penman–Monteith equation according to the reference manual of the ETo calculator (Raes 2012). All models were selected because of their ability to project all the necessary climatic parameters, described above, on a daily basis.

Crop growth model

The AquaCrop crop growth simulation model (Raes et al. 2009; Steduto et al. 2009) was used to project the yield productivity taking into account the variability of the climatic parameters of the climate models and the increase in CO₂ concentration of each emission scenario. AquaCrop simulates final crop yield in four steps that are easy to understand, which makes the modelling approach transparent. The steps consist of the simulation of development of the green crop canopy cover, crop transpiration, above-ground biomass and final crop yield. Temperature and water stresses directly affect one or more of the above processes. The effect of CO₂ concentration on biomass is simulated by altering the normalized water productivity. The model requires a relatively small number of explicit parameter values and mostly intuitive input variables (Vanuytrecht et al. 2014). AquaCrop has been used extensively in the case of cotton (García-Vila et al. 2009) and maize crop simulations (Hsiao et al. 2009).

Methodology

In order to proceed with crop model calibration and validation procedure, past experimental field data (Kotoulas 2010; Voloudakis 2015) were used as the data source due to absence of analytical information for all the areas mentioned above. This method has been used previously to study climate change impacts on cotton (Traore et al. 2013) and maize (Ruane et al. 2013).

The model was calibrated using data derived from a 3 year experiment (2005, 2006, 2007) for cotton (Kotoulas 2010) and a 2 year experiment (2010, 2011) for maize (Voloudakis 2015).

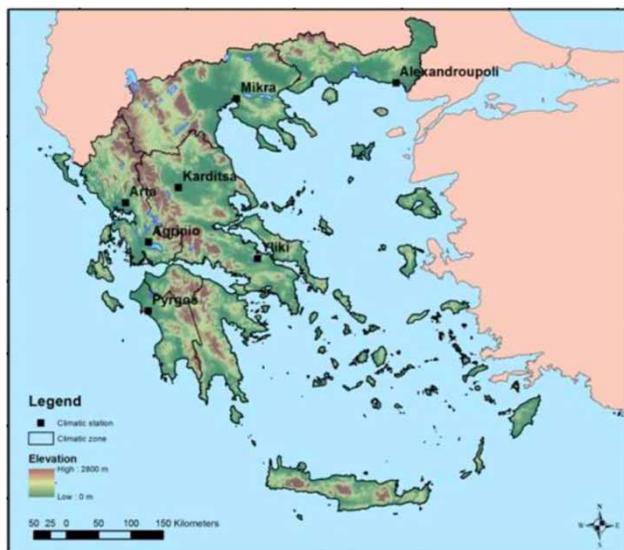


Figure 1 | The seven study areas (1: Alexandroupoli, 2: Mikra, 3: Karditsa, 4: Arta, 5: Agrinio, 6: Yliki, 7: Pyrgos).

The evaluation of the model simulation under real conditions was performed using the root mean square error (RMSE)

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n (S_i - O_i)^2}$$

where S_i and O_i are the simulated and observed values, respectively, and n is the number of observations (the model's fit improves as RMSE approaches zero), and the index of agreement (d) is calculated as:

$$d = 1 - \frac{\sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (|S_i - MO| + |O_i - MO|)^2}$$

where MO is the mean of the n observed values. The value of d ranges from 0 to 1.0 and the model's fit improves as d approaches unity.

Both statistical tools have been used previously to estimate the goodness of AquaCrop's fit to observed data (Stricevic et al. 2011).

For the projection of future yields, the present experimental full irrigation schedule was applied to all crop simulations. In addition, no fertility stress was taken into consideration for the estimation of cotton and maize yields.

Finally, the stepwise discriminant function analysis (SDFA) (Jennrich 1977) was used to assess the climate model's ability to differentiate the simulated cotton and maize yields among the study areas.

Discriminant functions were calculated for groups of samples according to the different simulated cotton and maize yields (simulated from the eight climate models) derived from the seven study areas. The stepwise procedure was applied using the Wilks' lambda method as a criterion for entry of variables into the final equations. At each step, the variable that minimized the overall Wilks' lambda was

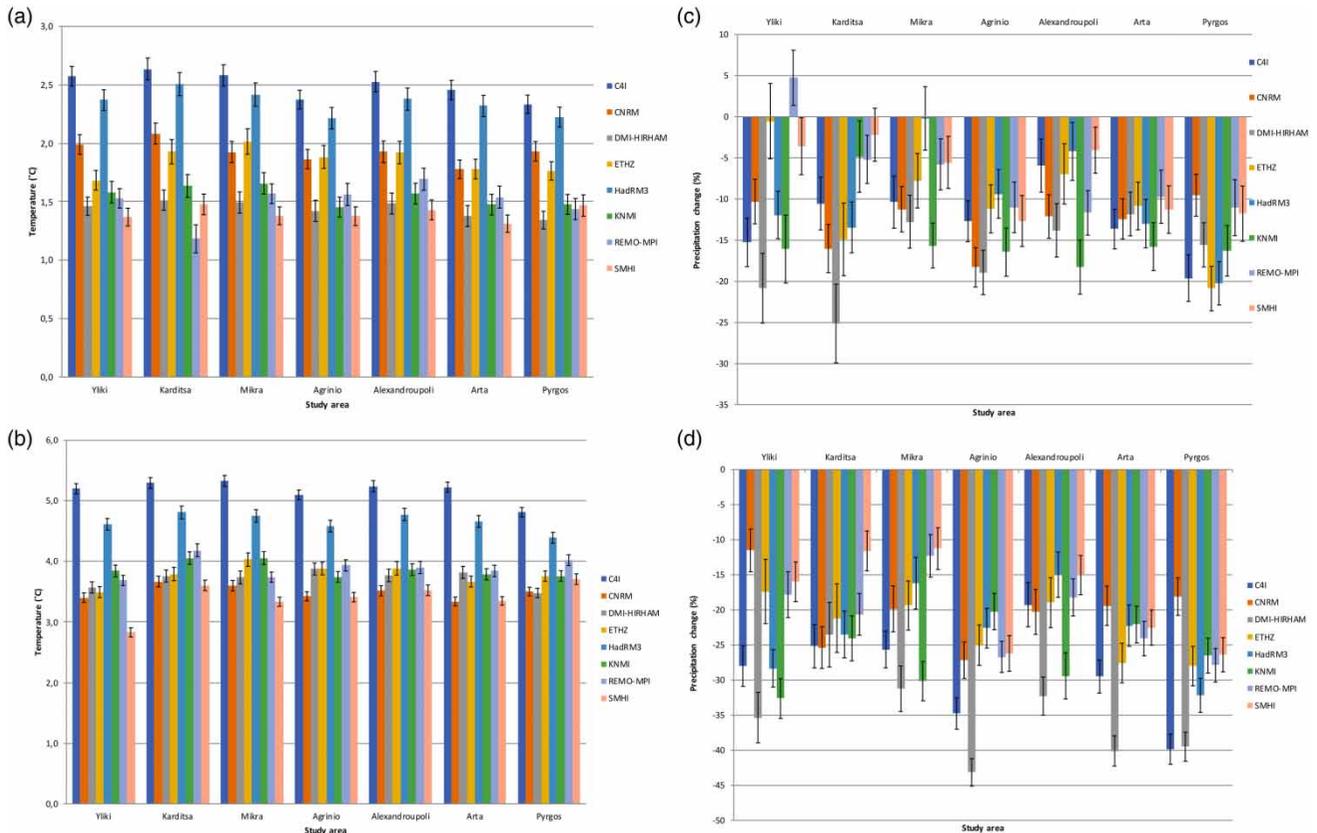


Figure 2 | The A1B scenario changes in temperature for 2021–2050 (a) and 2071–2100 (b), and in precipitation (%) for 2021–2050 (c) and 2071–2100 (d).

entered. Further investigation on the ability of each of the eight climate models to identify the actual seed cotton and maize yield differences among the areas of study according to the differentiation of the climatic conditions was assessed through the standardized discriminant function coefficients. Discriminant analysis was performed for the periods 1961–1990, 2021–2050 and 2071–2100 using the statistical software package SPSS version 17 (SPSS Inc., Chicago, IL).

Discriminant analysis has been used previously in the framework of climate change research in agriculture. Kueppers *et al.* (2005) used the discriminant analysis in their research on the impacts of climate change on endemic oak in California and Jaradat & Boody (2011) to model agroecosystem services.

RESULTS AND DISCUSSION

AquaCrop's calibration and validation procedure

AquaCrop was firstly calibrated and validated for both cotton and maize using experimental data from fields in Karditsa

(2005, 2006, 2007) and the Agricultural University of Athens (2010, 2011) (Voloudakis 2015). In both cases, the crop yield and biomass derived from the model were close to the observed values. For cotton yield the RMSE and d values were 0.17 and 0.94 respectively. For maize yield the corresponding values were 0.34 and 0.79. The statistical comparison between observed and simulated biomass in the case of cotton was 0.49 (RMSE) and 0.93 (d) and for maize 0.70 (RMSE) and 0.81 (d). Similar results were reported for previous simulation works using the AquaCrop model for cotton (García-Vila *et al.* 2009) and maize (Hsiao *et al.* 2009; Stricevic *et al.* 2011).

Future projections of some climatic parameters

The development of the mentioned climate models for the eight areas provided a general view of the projected climate variabilities. The A1B scenario is associated with an increase of CO₂ level close to 720 ppm on 2100. A deeper analysis of the climate models showed that C4I and HadRM3 projections were the warmest among the eight models predicting temperature increase close to or higher

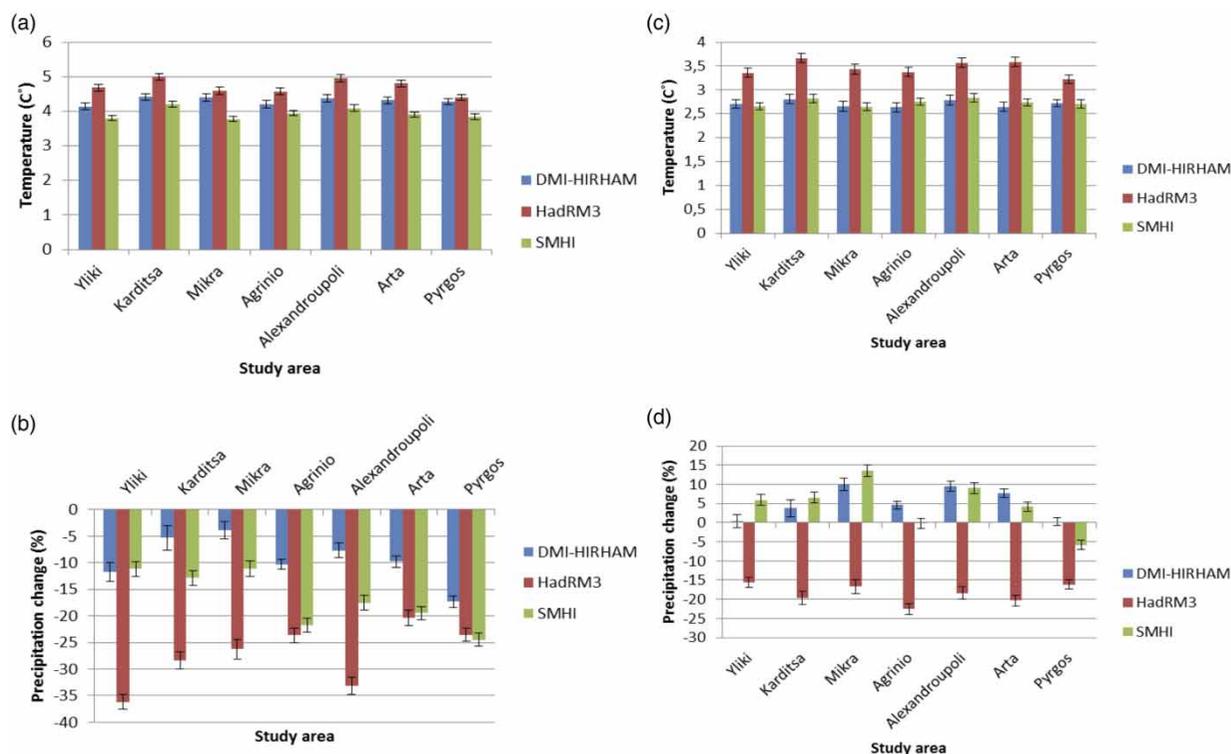


Figure 3 | The A2 scenario changes for temperature (a) and precipitation (b) and B2 scenario changes for temperature (c) and precipitation (d) for 2071–2100.

than 2.5 °C for 2050 and 5 °C for 2100, respectively, in some cases (Figure 2(a) and 2(b)). On the other hand, the SMHI model projection was the coolest, producing temperature values lower than 1.5 °C for 2050 and 3.5 °C for 2100 (Figure 2(a) and 2(b)).

In terms of precipitation, almost all climate models predicted a decrease for both 2021–2050 and 2071–2100 periods. In the first case, the vast majority of the climate models predicted a decrease ranging between –0.5% to –25% depending on the area with the exception of REMO-MPI model for Yliki that produced a 5% precipitation increase (Figure 2(c)). For 2100, the precipitation decrease was almost 15% higher than that of 2050, predicting a reduction from –20% up to –43% for the DMI-HIRHAM model in Agrinio (Figure 2(d)).

The A2 climate scenario is associated with a CO₂ increase close to 850 ppm for 2100. As in the case of A1B, the HadRM3 model was the one producing the higher temperature increase close to +5 °C while the SMHI predicted an increase close to +4 °C. The higher temperature increase was predicted in the areas of Alexandroupoli and Karditsa (Figure 3(a)). In terms of precipitation, the HadRM3 model produced the highest mean values of reduction (about –27%), while SMHI produced –17% and DMI-HIRHAM –9%. Yliki was the driest area for HadRM3 and Pyrgos for DMI-HIRHAM and SMHI models (Figure 3(b)).

The B2 scenario, the lowest emission scenario, refers to a CO₂ increase close to 620 ppm on 2100. In this case, the HadRM3 model produced a temperature increase of 3.5 °C, whereas SMHI and DMI-HIRHAM produced an increase of 2.7 °C. The areas of Karditsa, Alexandroupoli and Arta exhibited the higher values (Figure 3(c)).

In contrast with the A1B and A2 scenarios, the DMI-HIRHAM and SMHI models predicted an increase in precipitation for almost all areas except Pyrgos. The HadRM3 model produced a decrease in precipitation close to –20% for Agrinio and Arta (Figure 3(d)).

Yield change prediction

Impacts on cotton

When studying the impacts on cotton yields according to the A1B scenario, some quite erratic results for some

Table 1 | Estimation of cotton yield change (%) for A1B scenario from 1961–1990 to 2021–2050 and 2071–2100

	Agrinio			Alex/lis			Arta			Karditsa			Mikra			Pyrgos			Yliki		
	1961–1990	1990–2021	2021–2100	1961–1990	1990–2021	2021–2100	1961–1990	1990–2021	2021–2100	1961–1990	1990–2021	2021–2100	1961–1990	1990–2021	2021–2100	1961–1990	1990–2021	2021–2100	1961–1990	1990–2021	2021–2100
HadCM3	–3.48	–8.71	–137.81	–109.41	12.38	36.49	47.19	19.99	–30.14	–69.66	–24.03	–63.75	–31.35	–102.88							
C4I	–0.54	22.56	27.26	–23.84	16.8	7.04	3.38	–11.09	8.01	–18.02	7.69	25.52	20.28	9.57							
REMO-MPI	na	na	43.75	43.1	45.84	51.19	7.45	31.16	11.63	38.17	25.33	30.75	8.39	32.2							
ETHZ	17.14	20.07	72.2	70.39	12.27	18.67	14.86	25.49	36.04	47.9	7.89	17.87	19.37	27.9							
CNRM	–21.54	–3.85	76.94	51.51	na	na	–71.27	–8.53	–10.67	–3.51	–0.73	–37.78	49.31	43.28							
DMI-HIRHAM	19.22	28.49	–15.5	–5.06	24.08	31.59	–2.75	28.37	–11.56	7.1	4.48	10.18	7.82	19.81							
KNMI	8.83	13.58	na	na	6.61	19.77	16.34	24.94	4.4	–4.57	13.32	19.28	21.27	36.58							
SMHI	na	na	na	na	na	na	–14.79	46.93	na	na	na	na	35.73	40.5							

na: value not available.

climate models and areas are evident (Table 1). For example, in the case of Yliki the yield prediction ranged from -102% to $+43\%$, while in some other areas the crop model could not even proceed to a yield estimation (na, not available). This dysfunction is mainly attributed to the very low yields during the reference period 1961–1990 due to the lack of the necessary growing degree-days for the AquaCrop simulation procedure that some climate models produced.

On the other hand, there were no erratic results in AquaCrop predictions for the A2 and B2 scenarios. For the A2 scenario, the DMI-HIRHAM model produced the highest yield increase. The HadRM3 model predicted reduced yields of -34% and -2% for Alexandroupoli and Yliki respectively. In contrast, Agrinio, Arta and Pyrgos, all three areas in the western part of the Greek mainland, seemed to be more favoured. The SMHI model produced positive effects on cotton yields, ranging from $+11.9\%$ to $+27.6\%$.

For the B2 scenario, an important positive impact of climate change was estimated for the period 2071–2100, except Alexandroupoli for the HadRM3 model. The highest increases were predicted in Agrinio for HadRM3, in Karditsa for DMI-HIRHAM and in Yliki for SMHI.

In order to overcome some of the problems mentioned above, all climate models were assessed using the SDFA. In the case of A1B scenario, the analysis retained six out of the eight climate models for the period 1961–1990, that contributed significantly to the discrimination of the areas

on the base of AquaCrop simulations. Higher values of function coefficients were associated with a greater discriminant ability of the climate model. For this reason, the DMI-HIRHAM and the C4I models discriminated the eight areas more effectively by providing a range of minimum and maximum values of cotton yield change (Table 2).

For the A2 and B2 scenarios the SDFA did not confirm the ability of the three climate models to significantly differentiate the eight areas. In that case, the range of minimum and maximum values of cotton yield change was estimated taking into account all the three climate models.

According to this procedure, the calculation of the impact of climate change on cotton yields for the A1B scenario showed a positive trend especially for the western and southern areas. For 2021–2050 (Figure 4(a)), in Yliki, Pyrgos and Arta, maximum and minimum yield change ranged from $+4.5\%$ (Pyrgos) to $+24\%$ (Arta). In Agrinio, Alexandroupoli, Karditsa and Mikra, the maximum change was positive and the minimum was negative, whereas the highest ($+27\%$) and lowest (-15%) changes were predicted for Alexandroupoli. Therefore, Alexandroupoli, followed by Mikra, both in northern Greece, are characterized by the highest level of uncertainty.

These findings were reinforced when observing the relevant findings for the period 2071–2100 (Figure 4(b)): all the western and southern areas (Yliki, Pyrgos, Arta, Agrinio) were projected to become more favoured than the areas of central and northern Greece (Karditsa, Mikra, Alexandroupoli). The same positive impact of climate change on cotton

Table 2 | Standardized discriminant function coefficients (func1 and func2) for the three different periods of the A1B scenario application on cotton

Models	1961–1990		2021–2050		2071–2100	
	Standardized		Standardized		Standardized	
	func1	func2	func1	func2	func1	func2
HadRM3						
C4I	0.569	-0.504	0.556	0.01	0.648	0.018
REMO-MPI	0.328	0.608	0.383	0.821	-0.258	0.38
CNRM	0.176	0.527	-0.36	0.344	0.223	0.221
DMI-HIRHAM	0.454	-0.118	0.456	0.105	0.474	-0.162
KNMI	0.397	0.185	0.383	-0.535	0.483	-0.584
SMHI			0.598	-0.24	0.187	0.869
ETHZ	0.526	0.161				

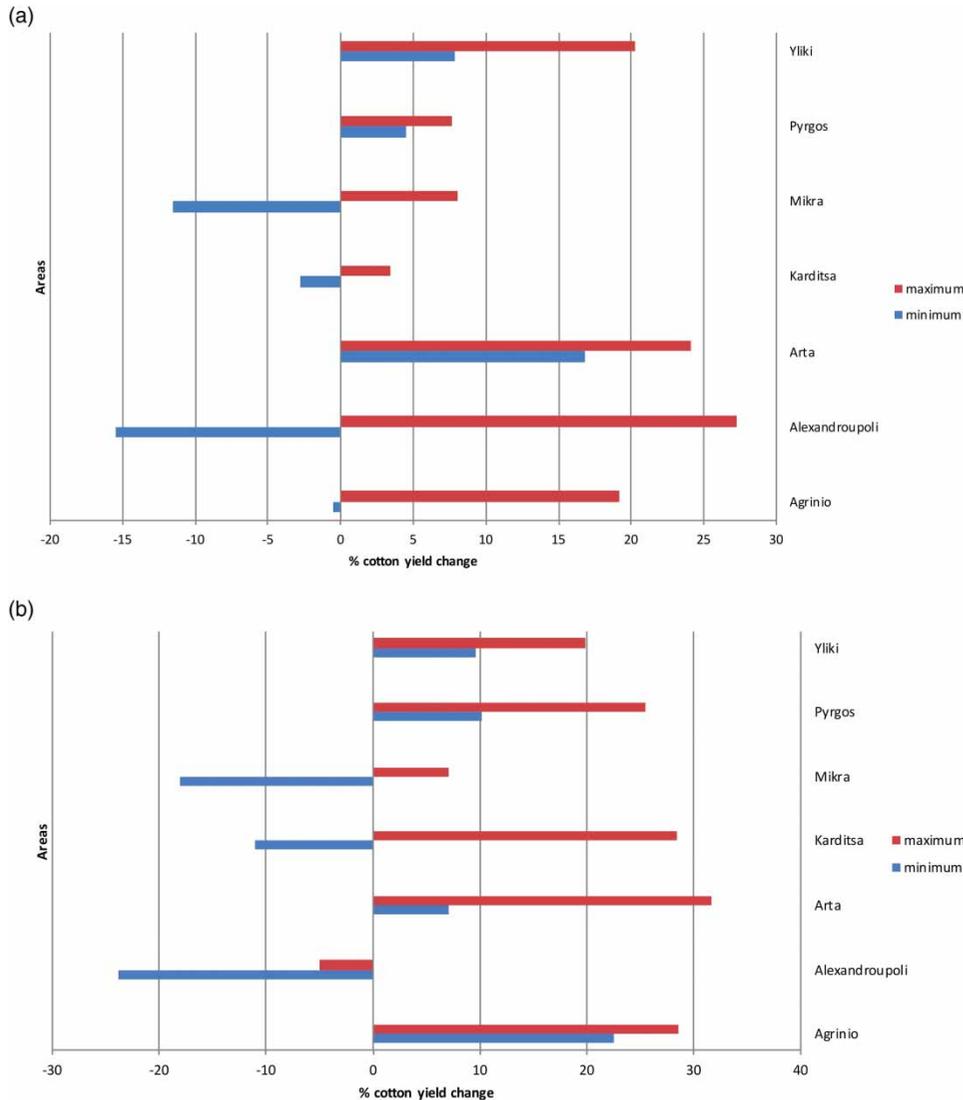


Figure 4 | The range of climate change impact on cotton yield for the A1B scenario between the periods 1961–1990 and 2021–2050 (a) and between the periods 1961–1990 and 2071–2100 (b).

yields was observed in a recent study of the A1B scenario using a different crop model in Greece (Georgopoulou et al. 2017).

This kind of differentiation between western-southern and central-northern areas was not observed for the A2 scenario, where AquaCrop yield simulation showed a clear beneficial impact for almost all the areas during 2071–2100 (Figure 5(a)). In this scenario, areas of central Greece like Yliki and Karditsa were characterized by yield increase higher than 35%. In addition, Alexandroupoli continued to be a zone of high uncertainty

because of the extreme negative minimum yield change of -34% .

Similar findings were observed when the B2 scenario was used for crop simulation (Figure 5(b)). However, in this case the minimum values of yield change were clearly higher than in the A2 scenario. Even in Alexandroupoli, the minimum value was calculated as -4.4% for B2, instead of the corresponding -34% for the A2 scenario.

Higher yield changes for B2 scenario against A2 were suggested by the CCISC (2011) for the same periods when compared using AquaCrop.

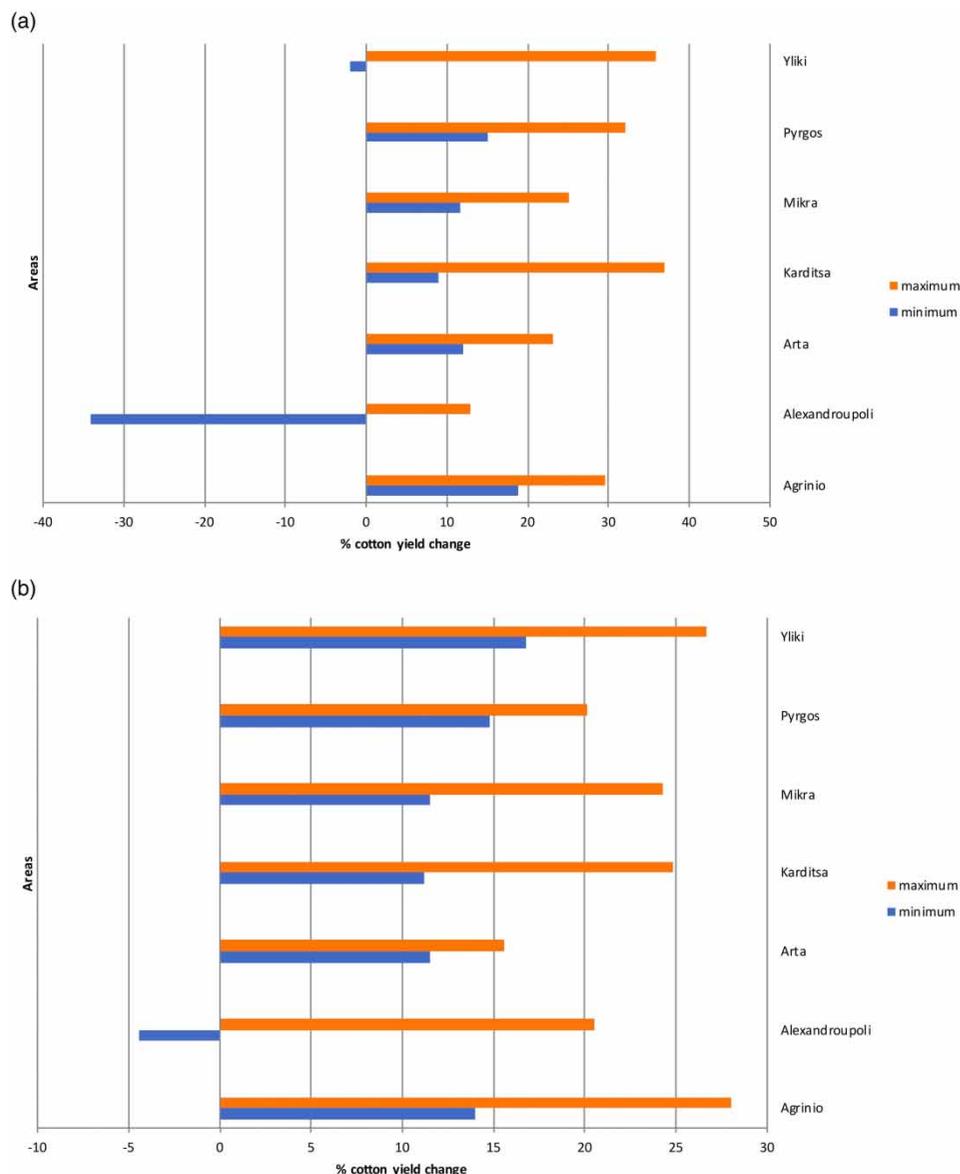


Figure 5 | The range of climate change impact on cotton yield between the periods 1961–1990 and 2071–2100 for the A2 scenario (a) and for the B2 scenario (b).

Impacts on maize

In the case of the A1B scenario, AquaCrop projected smaller ranges of yield changes for maize (Table 3) than in cotton. For the period 2021–2050, all models produced yield increases compared to the period 1961–1990 in Yliki and Arta. The same applies for Pyrgos, except for the CNRM model. In Agrinio, the REMO-MPI and CNRM models produced small reductions in yields of

–2.36% and –4.5%, respectively. The highest increase in yields, close to 6%, was produced by the DMI-HIRHAM model for Arta. On the contrary, the largest decrease, –6.27%, was observed in Mikra for the HadRM3 model. The picture differs for 2071–2100. For the Alexandroupoli area, all climate models predicted negative effects on maize yields. In Mikra, Karditsa and Agrinio, seven of the eight models gave negative values compared to 1961–1990, with a maximum –22.19% reduction in

Table 3 | Estimates of maize yield change (%) for the A1B scenario in 2021–2050 and 2071–2100 as compared to 1961–1990

	Agrinio		Alex/li		Arta		Karditsa		Mikra		Pyrgos		Yliki	
	2021–2050	2071–2100	2021–2050	2071–2100	2021–2050	2071–2100	2021–2050	2071–2100	2021–2050	2071–2100	2021–2050	2071–2100	2021–2050	2071–2100
HadRM3	4.57	−0.44	−2.04	−13.51	0.06	−10.98	0.53	−15.03	−6.27	−17.08	1.70	−2.69	3.26	−1.68
C4I	1.82	−0.19	−2.34	−11.75	1.83	0.04	−2.94	−19.27	−0.72	−11.06	2.32	0.27	5.78	3.70
REMO-MPI	−2.36	−0.48	2.48	−0.24	2.96	0.22	0.12	−1.55	3.15	1.52	3.99	0.97	3.22	2.41
ETHZ	3.17	−7.07	1.29	−8.25	3.67	2.94	2.07	−6.75	−2.48	−22.19	2.56	2.89	2.45	−7.72
CNRM	−4.50	−1.20	−0.01	−8.80	0.02	−7.56	−5.07	−6.36	−6.21	−4.53	−0.21	1.43	2.76	−6.23
DMI-HIRHAM	5.12	0.75	0.18	−4.47	6.06	2.04	0.32	1.73	−6.48	−5.71	3.80	1.76	3.16	0.78
KNMI	3.12	−0.56	1.80	−3.66	3.52	−0.99	1.05	−3.13	2.25	−4.71	1.14	0.66	3.12	−0.56
SMHI	2.78	−0.92	1.54	−3.67	2.18	−1.94	2.46	−3.18	0.62	−2.78	3.02	−2.09	2.30	−0.48

Mikra. In Arta and Yliki, however, there were either marginal increases or reductions reaching up to 11% (HadRM3 for Arta). Pyrgos seems to be less vulnerable to climate change as for most models a positive effect on yields was estimated, while for HadRM3 and SMHI there were reductions of 2–3%.

In conclusion, yields in most areas for the period 2021–2050 were predicted to increase in comparison to the reference period. For the period 2071–2100, however, negative estimates were produced for most areas, with some exceptions showing marginal increases. Only Pyrgos exhibited a rising trend in yields in six out of the eight models.

Both the A2 and B2 scenarios exhibited small values of yield change, as the A1B scenario.

As regards the A2 scenario, it was found that in most areas there was a decrease in yields. According to the HadRM3 model, the largest decreases were projected in the areas of Alexandroupoli and Karditsa, −23% and −34% respectively. A decrease was also observed in Yliki, Pyrgos and Agrinio. On the other hand, AquaCrop produced marginal increases in Mikra and Arta. The HadRM3 model produced marginal increases in Alexandroupoli, Arta and Mikra and reductions in other areas. Finally, the SMHI showed marginal reductions in all areas with a minimum peak of −5.7%.

As for the B2 scenario, percentage comparison of yields per area and climate model showed marginal differences between the two periods. However, there was a differentiation among climate models: HadRM3 for all regions except Pyrgos showed decreases in yields between the

Table 4 | Standardized discriminant function coefficients (func1 and func2) of the used climatic models for the three periods of the A1B scenario applied to maize

Models	1961–1990		2021–2050		2071–2100	
	Standardized		Standardized		Standardized	
	func1	func2	func1	func2	func1	func2
HadRM3	0.013	0.093	0.413	0.074		
C4I	0.08	0.363	0.423	0.132	0.478	0.243
REMO-MPI	1.116	0.601	0.633	−0.06	1.016	−0.654
CNRM	0.587	−0.743	0.132	0.418		
DMI-HIRHAM	−0.329	0.266	0.514	0.216		
KNMI	−0.417	−0.459	−0.117	0.536		
SMHI			0.115	−1.006	−0.235	1.083
ETHZ					0.226	0.527

reference period and the last 30 years of the century, the maximum occurring in Alexandroupoli and Karditsa. For DMI-HIRHAM yield increases ranged from 1.9% in Mikra to 5.2% in Karditsa. For SMHI, the corresponding increases ranged from 2.4% in Alexandroupoli to 4.3% in Yliki.

As described for cotton, all climate models were assessed for their area discriminant ability of maize yields using the SFA.

In the case of A1B scenario, only the REMO-MPI model succeeded in the discrimination of the areas with the highest coefficient during the three periods (Table 4). Among the other models, only C4I succeeded in the discrimination of the areas but the coefficient in the first period was almost zero. Consequently, in line with the procedure followed also in cotton, the performance variation was estimated based on the selected REMO-MPI and C4I models, as shown in Figure 6.

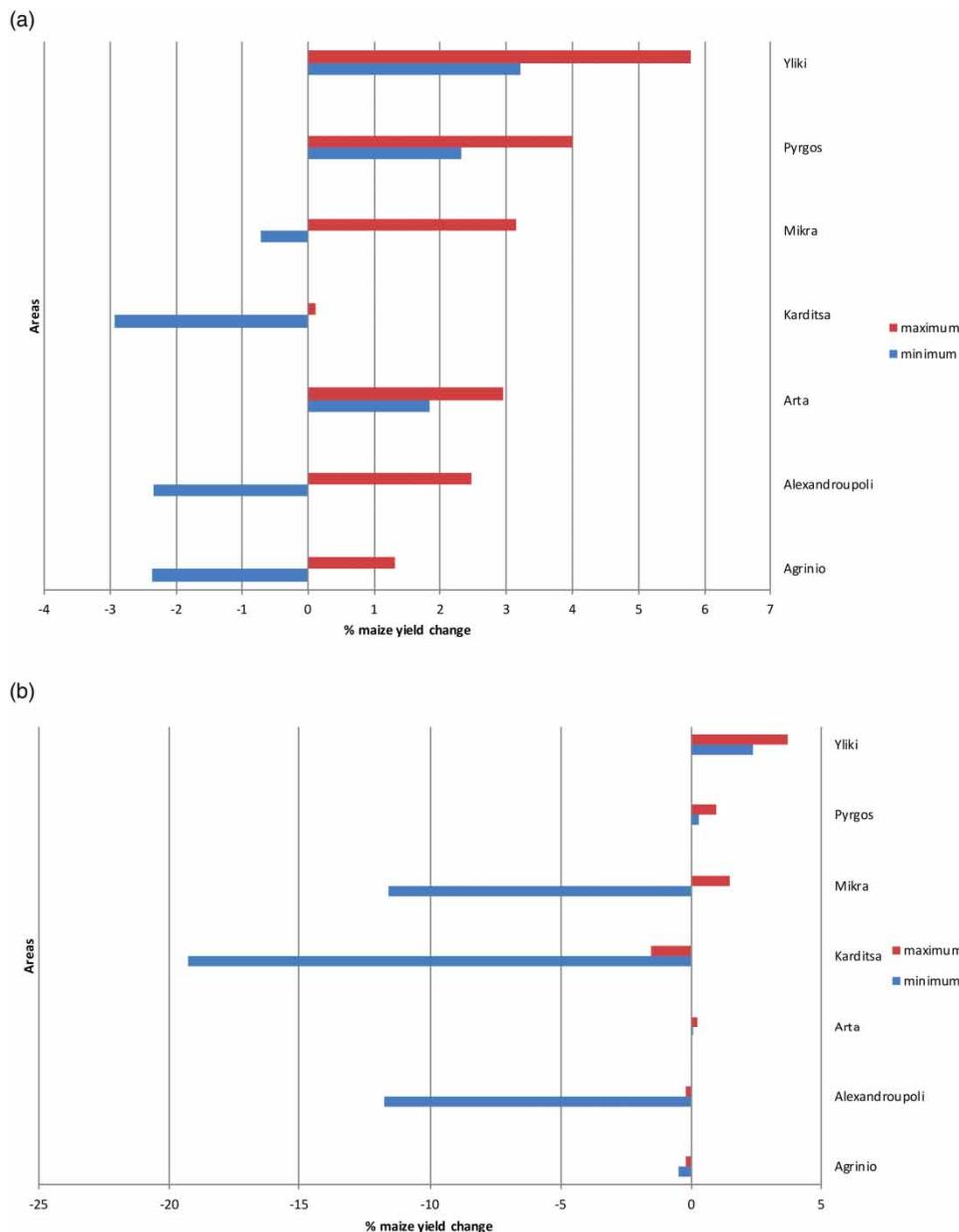


Figure 6 | The range of climate change impact on maize yield for the A1B scenario between the periods 1961–1990 and 2021–2050 (a) and the periods 1961–1990 and 2071–2100 (b).

Comparing the maize yield changes of the period 2021–2050 with those of 1961–1990 (Figure 6(a)), the most favourable areas for the cultivation of maize are Yliki, Pyrgos and Arta in descending order of magnitude. Those with the greater uncertainty are Mikra, Alexandroupoli, Agrinio and Karditsa. However, the yield differences, either positive or negative, do not exceed 5%, except for the maximum estimate of Yliki which reaches 6%. For the same period, Georgopoulou *et al.* (2017) concluded that the range of maize yield change was projected to be between -5.2% and -3.2% , with the exception of regions in Northern Greece (Anatoliki Makedonia-Thraki), which in this study is represented by Alexandroupolis, where the yield decreased by 10.1%.

As regards the yield changes in the period 2071–2100 (Figure 6(b)), the areas of Yliki and Pyrgos showed positive values. Arta and Agrinio exhibited remarkable stability, while Karditsa and Alexandroupoli showed negative forecasts. Finally, Mikra is characterized by uncertainty due to the large differences between the positive and negative estimates. In all cases, the maximum positive values do not exceed 5%, while the negative ones in Mikra, Karditsa and Alexandroupoli exceed -10% .

In the case of scenario A2, the standardized coefficients resulting from the application of the S DFA are shown in Table 5.

Of the three climate models (HadRM3, DMI-HIRHAM, SMHI), only the last two separated efficiently the areas in both periods. Consequently, and in line with the process followed in the previous cases, the range of differentiation of maize yields was based on the selected SMHI and DMI-HIRHAM models (Table 5).

The analysis of the above models revealed that for the areas of Yliki, Pyrgos, Karditsa and Agrinio, both the maximum and the minimum changes had a negative sign.

Among these, Pyrgos and Agrinio had the most negative forecasts for the minimum change, -5.7% and -4.6% , respectively (Figure 7(a)). In contrast, Arta, Mikra and Alexandroupoli exhibited positive values in respect to the maximum projections ($+0.8\%$, $+1.5\%$ and $+3.6\%$, respectively). It is concluded that the northern areas of Arta, Mikra and Alexandroupoli showed a positive sign of the yield changes, in contrast to the other areas where the whole range of estimates was negative. The negative impact of climate change on maize yield in Thessalia region, where Karditsa is located, was mentioned by Kapetanaki & Rosenzweig (1997) forecasting a reduction up to 20%.

For the B2 scenario, the stepwise discriminant analysis did not confirm the ability of the three climate models to significantly differentiate the eight areas. This means that the estimate of the change in yields was made taking into account all the models.

From the analysis of the range of yields, it seems that, with the exception of Pyrgos, where both the maximum and the minimum change were positive, in all other areas the minimum change was negative while the maximum was positive (Figure 7(b)). The areas with the largest range between minimum and maximum values were Karditsa and Alexandroupoli, due to the large negative values of the minimum change (-9% and -11% respectively). In Agrinio, Arta and Mikra, yield changes ranged from -3% to $+3\%$. The positive impact on maize of B2 scenario against A2 was also underlined by Giannakopoulos *et al.* (2009) in a more generic approach to C4 summer plants yields change due to climate change.

CONCLUSIONS

For cotton, climate change is likely to have a positive effect on yields with variations depending on the evolving climate scenario. In the case of the A1B scenario, Aqua-Crop showed that the Pindus mountain range would act as a dividing line between the most favoured areas of Western Greece (Arta, Agrinio) and the West Peloponnese (Pyrgos) compared to the other areas surveyed. This tendency becomes more pronounced towards the end of the century, with the northern regions (Mikra, Alexandroupoli

Table 5 | Standardized discriminant function coefficients (func1 and func2) of the used climatic models for the two periods of the A2 scenario applied to maize

Models	1961–1990		2071–2100	
	Standardized		Standardized	
	func1	func2	func1	func2
HadRM3			-0.786	-0.718
DMI-HIRHAM	1.016	0.433	0.855	0.760
SMHI	-0.823	0.736	0.943	0.493

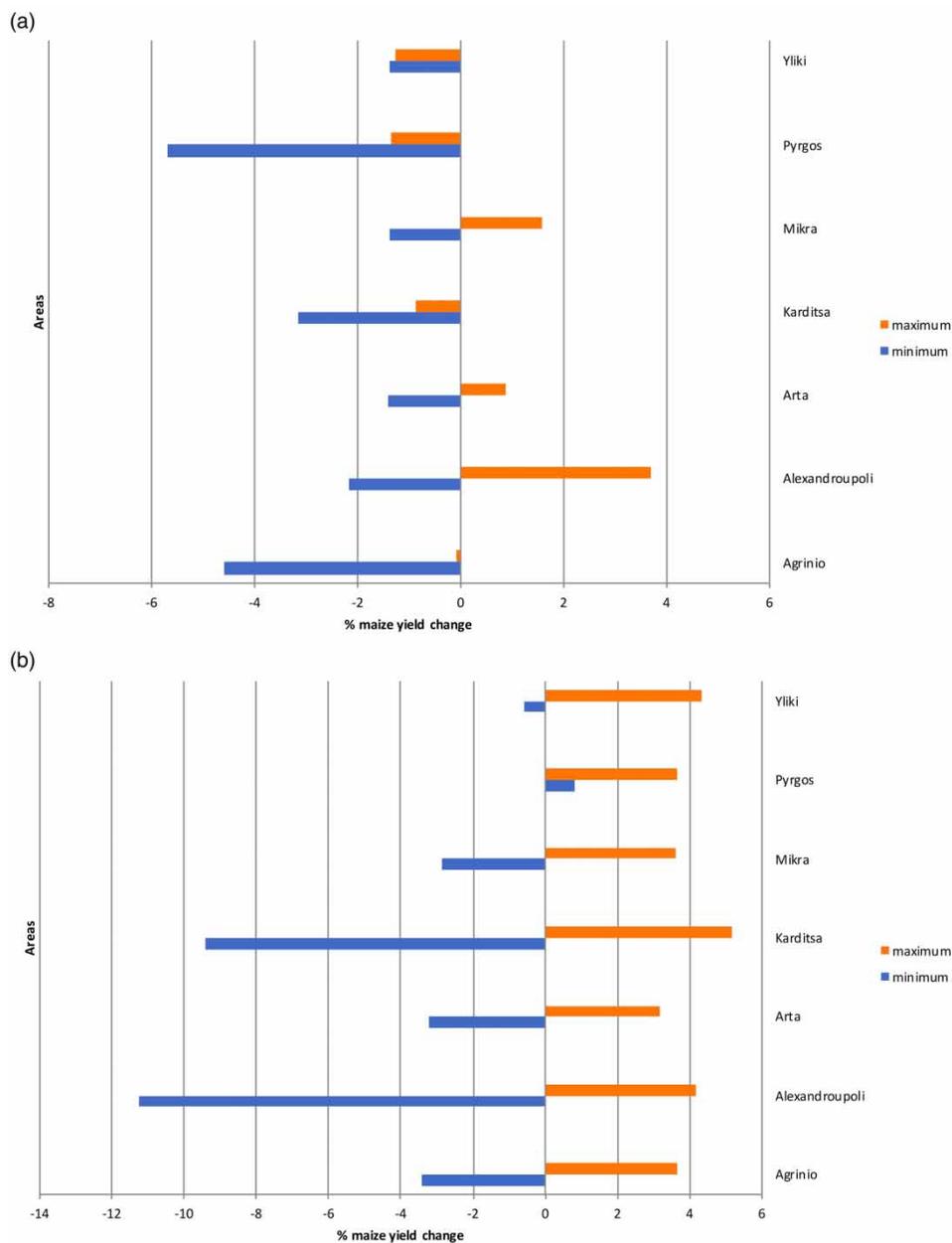


Figure 7 | The range of climate change impact on maize yield between the periods 1961–1990 and 2071–2100 for the A2 scenario (a) and for the B2 scenario (b).

and Karditsa) being characterized by a higher degree of uncertainty due to the remarkable difference between negative minimum and positive maximum yield change, while Yliki seems to be part of the potentially favoured areas. In the case of the predictions of scenario A2, the Pindus-based separation does not exist. The even greater increase in CO₂ concentration under full-scale irrigation

limits the effects of stresses such as warming. In this projection, Mikra is included in all other favoured areas, while only Alexandroupoli has a negative minimum value (–30%). In the case of scenario B2, there were more positive results for all areas, while even in Alexandroupoli the negative minimum change in yield was limited to –4%.

As regards maize, the application of the scenario A1B produced small percentage changes in yields, which did not exceed 5% for the period 2021–2050. There was no clear separation of the areas on the account of the minimum and maximum yield values. The situation changed during the period 2071–2100 as the positive values of the maximum change were reduced, while the negative absolute values of the minimum, mainly in the northern areas of Alexandroupoli, Mikra and Karditsa, increased. In scenario A2, yield variations fluctuated at very low rates. In contrast to the previous case, the aforementioned northern areas did not differ negatively. The area showing the greatest drop in the minimum change in maize yield was Pyrgos. Compared with the A1B and A2 scenarios, B2 projected a greater positive impact on yield production close to 5% for all the areas towards the end of the century. The negative values of the changes in the yields of the aforementioned areas of Alexandroupoli, Mikra and Karditsa were reduced, while in all areas the value of the maximum change increased.

The smaller range of maize yield change against that of cotton is mainly attributed to their different photosynthetic mechanisms. It seems that cotton, as a C3 plant, is taking advantage of the rising CO₂ levels at higher temperatures by increasing the photosynthetic rate, producing more yield and biomass, more effectively than maize, which is a C4 plant.

The S DFA procedure showed that C4I and DMI-HIRHAM models projecting the highest increase in temperature and rainfall reduction, respectively, contributed along with the REMO-MPI model to discrimination of the areas studied in terms of yield change.

Finally, the fact that the present irrigation management as in the field was applied to both crops, causing water stress and yield reduction in some cases, creates a demand for further research especially in the adaptation irrigation strategy that is required to be adopted under climate change conditions.

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