PREDICTION OF CLIMATE CHANGE IMPACTS ON COTTON YIELDS IN GREECE UNDER EIGHT CLIMATIC MODELS USING THE AQUACROP CROP SIMULATION MODEL.

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Abstract: The impact of climate change on cotton yields in seven main arable crop sites in Greece (Agrinio, Alexandroupolis, Arta, Karditsa, Mikra, Pyrgos, Yliki) was investigated. The FAO AquaCrop (v.4) water driven model was used as a crop development simulation tool under eight climatic models (HadRM3, C4I, REMO-MPI, ETHZ, CNRM, DMI-HIRHAM, KNMI, SMHI) based on IPPC's A1B Climate Change scenario. The mean values of the models ensemble for temperature and precipitation were +1,8˚C until 2050 and +4 ˚C until the end of the century. The respective values for precipitation were -11% and -24%. The research was applied over three periods, 1961-1990, 2021-2050 and 2071-2099. AquaCrop validation for yield, biomass and canopy cover in respect to field data obtained from experiments carried out in Karditsa (Central Greece) from 2005 to 2007 was satisfactory on the account of Root Mean Square Error (0.17 to 0.49) and Index of Agreement (0.93 to 0.94). AquaCrop model was run using the Growing Degree Day mode in order to account better for the temperature variations. However, it gave erratic results for some specific climatic models (SMHI, KNMI, CNRM) in some years within the period 1961-1990. The predicted yields were highest in locations of western Greece (Agrinio, Arta, Pyrgos), whereas north-eastern Greece (Alexandroupolis) appeared to be less favoured by climate change. A tendency towards increasing yields by the end of the century was detected for the majority of the models. The efficiency of the eight models for yield predictions in the seven sites was assessed by means of a discriminant function analysis. On the account of their function coefficients over the seven sites, it was found that the models DMI and C4I explained consistently a great proportion of variation among the three time periods whereas the models ETHZ, SMHI and KNMI were more efficient in the periods 1961-1990, 2021-2050 and 2071-2099 respectively.

Key words: AquaCrop, climate change, cotton, climate model classification, Greece

1. INTRODUCTION

Cotton is a crop of high importance for Greek agricultural production. Greece is the biggest cotton producer in the European Union accounting for almost 80% of its total production (European Commission, 2013). In addition, cotton exports are in the fourth place of the total Greek exports with an added value of 426 million euro (El.Stat, 2012).

According to the last IPCC report for climate change (IPCC, 2007), the Mediterranean Basin will be among the areas to be most adversely affected in terms of a rise in temperature, a decrease in overall water balance and a higher frequency of extreme climatic events. Evidently, agricultural production will also be decisively affected. If these predictions wiil be confirmed, it is really important to develop an integrated view of the future cotton yield trends, since one of the aims of Climate Change research is to aid decision making by reducing future uncertainties (Lobell and Burke, 2008).

In the case of cotton, Reddy et al (1999), concluded that a rise in atmospheric CO_2 concentration under optimal temperatures produced more fruiting structures and cotton bolls, although, boll retention was severely curtailed when air temperatures exceeded 28˚C. In a more recent research, the same authors predict an overall decrease in cotton yield by 9% for the Mississippi cotton zone caused by the negative effects of projected changes in climatic variables other than CO_2 (Reddy et al, 2002). Yoon et al (2009) reported that an elevated CO_2 concentration could increase both the above ground biomass and boll weight of cotton, although seed and lint yield could also increase only when plants were not exposed to temperatures above the optimum. According to Bange et al. (2008) the restriction of water resources induced by climate change in Australia will adversely affect cotton production in respect to other crops and make imperative a continuous effort for improvement in whole farm and crop water use efficiency. In a recent interdisciplinary study funded by the Bank of Greece, it was predicted that cotton yields were going to increase in the climatic zones of Northern and Western Greece, but to decline in Central-Eastern Greece under the A1B and A2 emission scenarios (Karamanos et al., 2011).

In many cases, a number of available crop models (CropSyst, AquaCrop, CERES, etc.) were used to simulate crop productivity under different climatic conditions. The AquaCrop is a crop water productivity model developed by the Land and Water Division of the Food and Agricultural Organisation (FAO) of the United Nations (Doorenbos and Kassam, 1979). In comparison with other models, it is more effective for areas where water is a limiting factor, it requires fewer parameters, it is user-friendly, it is more accurate, with lower error probabilities (Raes et al., 2009). Furthermore, it accounts for the expected rise in atmospheric CO_2 concentration through a flexible response of the water productivity parameter to elevated CO_2, which captures the variation in crop responsiveness associated with crop sink strength (Vanuytrecht et al, 2011). For all these reasons the AquaCrop is considered as a suitable tool for crop simulation studies in Greece. Its suitability, however, needs to be assessed through field experimentation.

Among the existing emission Scenarios, a moderate one, the A1B, can be used for the projection of climatic changes. According to this scenario, a very rapid economic growth is expected accompanied by a global population reaching its maximum in the mid-century and declining thereafter. In addition, a rapid introduction of new and more efficient technologies and a balanced use of fossil and non-fossil energy sources are anticipated. Small changes in land use and a considerable increase in CO_2 concentration reaching up to 720ppm by 2100 are expected (Nakicenovic et al., 2001). Different Regional Climate Models (RCMs) are suggested for the generation of future climate data within the A1B Scenario.

The prediction of cotton yields in Greece for the middle (2021-2050) and the end (2071-2100) of the running century is the main aim of this work. The predictions will be extended to all major cotton cultivating areas in Greece and will be based on the implementation of AquaCrop under different RCMs of the A1B Scenario for each area. In addition, an effort to validate the AquaCrop model using field data and to assess the performance of the different RCMs for their reliability in cotton yield predictions in the different areas using techniques of multivariate analysis will be made.

2. MATERIALS AND METHODS

2.1 ***Study areas***

Greece is transversely divided by the mountain range of Pindos into a western and eastern part, giving a unique natural terrain and important climatic diversity. Seven areas in the Greek mainland covering almost the total range of cotton producing habitats all over Greece were selected for the study (Fig. 1). The areas belong to distinct climatic zones within the Greek territory according to Zerefos et al. (2011), namely: Alexandroupoli to Eastern Macedonia and Thrace, Mikra to Western and Central Macedonia, Karditsa and Yliki to Central and Eastern Greece, Arta and Agrinio to Western Greece and Pyrgos to Western Peloponnese.

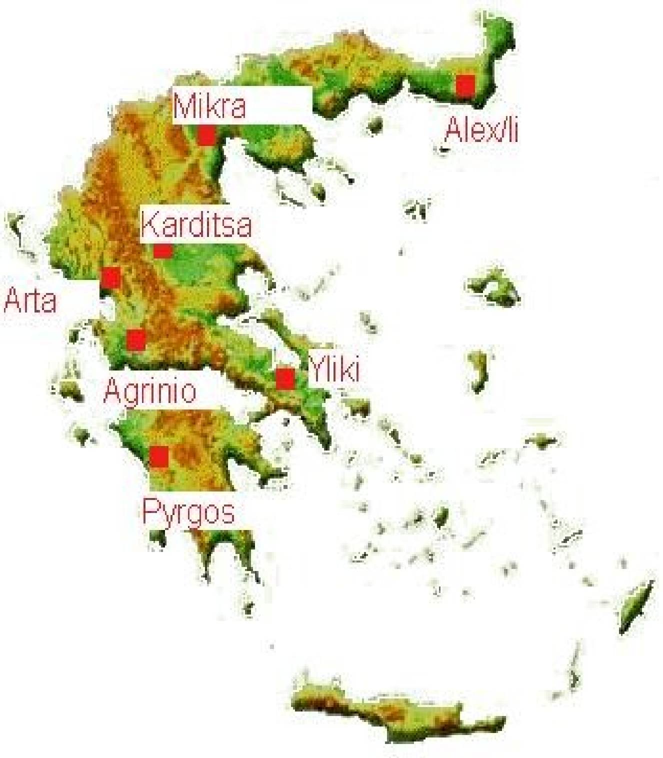

Fig.1. The seven sites of the study

Table 1 shows the average cotton yields recorded in the seven areas between 1961 and 1990 by the Hellenic Statistical Authority (Agricultural Statistical Survey 1961 to 1990).

Table 1: Seedcotton yields (tn/h) in the seven study areas for the period 1961-1990.

	AGRINIO	ARTA	YLIKI	ALEX/LI	PYRGOS	MIKRA	KARDITSA
mean	1,87	1,96	2,00	1,41	2,24	2,12	2,21
Standard error	±0,06	±0,05	±0,06	±0,06	±0,06	±0,04	±0,06

Tables 2 and 3 show the monthly averages of temperature and precipitation for the growth period of cotton (April to November) in the seven study areas during the period 1961 to 1990. It appears that the areas belonging to the northern climatological zones, like Alexandroupoli and Mikra, are characterized by lower temperatures, while the area of Karditsa (Central Greece) is warmer during spring and summer.

Table 2: Monthly averages of mean daily temperature in the seven study areas for the period 1961-1990.

	April	May	June	July	August	September	October	November
Agrinio	15,2	20,3	24,5	27,0	26,6	23,1	17,9	13,0
Alex/li	13,2	18,3	23,0	25,7	25,2	21,0	15,5	11,0
Arta	15,3	20,0	23,9	26,5	26,4	23,0	18,3	13,4
Mikra	14,2	19,5	24,2	26,5	25,8	21,8	16,1	10,9
Pyrgos	15,4	19,8	23,8	26,4	26,3	23,4	18,9	14,7
Yliki	14,6	20,0	25,1	27,3	26,4	22,5	17,1	12,9
Karditsa	15,4	20,7	25,4	27,5	26,7	22,8	16,4	11,2

Table 3: Monthly averages of the precipitation in the seven study areas for the period 1961-1990

	April	May	June	July	August	September	October	November
Agrinio	67,8	45,1	27,4	9,9	18,7	23,9	78,5	107,7
Alexandr	65,6	46,0	26,9	10,5	19,7	23,0	79,2	107,0
Arta	67,8	46,3	25,2	10,7	18,3	23,6	80,8	107,4
Mikra	67,2	46,9	25,5	10,6	17,0	24,7	80,5	108,9
Pyrgos	69,0	49,0	26,2	10,3	17,6	23,7	83,6	111,7
Yliki	68,4	50,4	26,9	10,9	18,1	18,8	83,0	115,0
Karditsa	66,5	48,8	25,9	10,9	17,9	19,7	78,9	113,8

2.2 *Climate scenario and models*

The A1B emission Scenario, as it was developed in the third IPCC report (Nakicenovic et al., 2001,) was used for the projection of climatic changes in this work. Eight Regional Climate Models: HadRM3, C4I, REMO-MPI, ETHZ, CNRM, DMI-HIRHAM, KNMI and SMHI, derived from adjustments developed by the Research Center for Atmospheric Physics and Climatology of the Academy of Athens, were used for the A1B Scenario. Results from the application of these models are extracted for the seven study areas giving a large spectrum of climatic variability. The climatic parameters used from each model were, on a daily scale, maximum and minimum temperature (˚C), air relative humidity (%), wind speed at 2m above ground surface (m/sec), solar irradiance (W/m^2), and precipitation (mm/day).

2.3. Crop simulation model

The AquaCrop crop growth simulation model (version 4, 2013) was used to assess the response of cotton to climate change. Detailed descriptions of the model have been given by Raes et al. (2009) and Steduto et al. (2009). The functional components of the model are: soil and its balance with water, the plant and its processes, the atmosphere and its thermal regime and rainfall. Other components include: evaporative demand, carbon dioxide concentration and management practices (e.g. planting date, fertilizer use, irrigation, etc). The model uses input variables that require simple methods for their determination, but it does not take into consideration factors like pests, diseases and weeds (FAO, 2009).

Since AquaCrop simulations respond to changes in CO_2 concentration, it is possible to evaluate the interactive effects of temperature increase, erratic rainfall and the rise in CO_2-concentration in future climates. Different scenarios may be introduced, following predictions of the regional climate change models.

The calibration of the model was performed using real data obtained from field experiments carried out during three seasons (2005 to 2007) in Karditsa, Central Greece (Kotoulas, 2010). The model was run in the Growing Degree-Days mode to account better for the important effects of rising temperatures on a warm-season crop such as cotton. The model was calibrated for canopy cover, seedcotton yield and biomass. Cotton canopy progress was monitored using a DT-leaf area meter (Delta-T Devices Ltd, Burwell Cambridge, UK), from which the Leaf Area Index (LAI) was calculated during the growth period. The conversion from LAI to canopy cover (CC), the parameter used in AquaCrop, was done using the following equation (Garcia-Vila et al, 2009):

$$CC= 1-e-LAI/1,31+e-LAI/1,3$$

(1)

The statistical parameters used to assess the fitness of the model to the real data were the Root Mean Square Error (RMSE) and the index of agreement (d). RMSE was calculated from the following equation:

$$RMSE= 1/n1n(Si-Oi)2 \qquad (2)$$

where Si and Oi are the simulated and observed values respectively, and n is the number of observations. The model's fit improves as RMSE approaches zero. The index of agreement (d) (Willmott, 1982) is given by the following equation:

$$d=1-i=1n(Si-Oi)2i=1n(Si-MO+Oi-MO)2$$

(3)

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

2.4 Assessment of the climate models

The Stepwise Discriminant Analysis (Jennrich, 1977) was used as a tool for the assessment of the examined climate models on the account of their ability to differentiate the simulated seedcotton yields among the study areas. Discriminant functions were calculated for groups of samples according to the different simulated cotton yields (simulated from the eight climatic 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 entered. Further investigation on the ability of each of the eight climatic models to identify the actual seedcotton 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 2071-2099 using the statistical software package SPSS version 17 (SPSS Inc. Chicago, IL).

3. RESULTS AND DISCUSSION

3.1 Results of AquaCrop calibration and validation

The use of AquaCrop produced output values for seedcotton yield and biomass very close to the data obtained from the field experiments in all three cultivation periods, especially in 2006 (Table 4).

Table 4. Statistical comparison between simulated and observed yield and biomass for the three experimental years. RMSE: root mean square error; d: index of agreement

		Years	
Crop characteristics	2005	2006	2007
Yield (tn/ha)			
Observed	4.05	3.65	2.97
Simulated	4.02	3.67	3.26
RMSE		0.17	
d		0.94	
Biomass (tn/ha)			
Observed	14.09	12.85	12.10
Simulated	14.25	12.86	11.20
RMSE		0.49	
d		0.93	

The close proximity between simulated and actual values in these crop characteristics is also reflected in the values of RMSE (ranged from 0.17 to 0.49, for yield and biomass respectively) and of d (ranged from 0.93 to 0.94, for yield and biomass respectively). As regards canopy cover, the simulated results were also very close to the actual observations, especially in 2006. The statistical analyses performed for each season gave excellent values for RMSE (0.14, 0.05 and 0.12 for 2005, 2006 and 2007 respectively) and d (0.92, 0.99, and 0.98 for 2005, 2006, and 2007 respectively). Similar positive results for AquaCrop application were reported by other investigators for cotton (Farahani et al, 2009; Garcia-Vila et al, 2009; Hussein et al, 2011) and other arable crops such as maize (Hsiao et al, 2009., Abedinpour et al, 2012), wheat (Salemi et al, 2011), sugarbeet (Stricevic et al, 2011), sunflower (Todorovic et al, 2009), barley (Araya et al, 2010), and quinoa (Geerts et al, 2009).

3.2 Future projections of some climatic parameters

The eight models were run for three distinct periods, 1961-1990, 2021-2050, and 2071-2100. In Figs 2-5 the changes in two main climatic parameters (mean air temperature and precipitation), derived from the use of each climatic model within each area, are depicted as proportions of differences from the reference period 1961-1990.

Fig. 2. Changes in the mean daily temperature according to the eight models in the study areas between 1961-1990 and 2021-2050

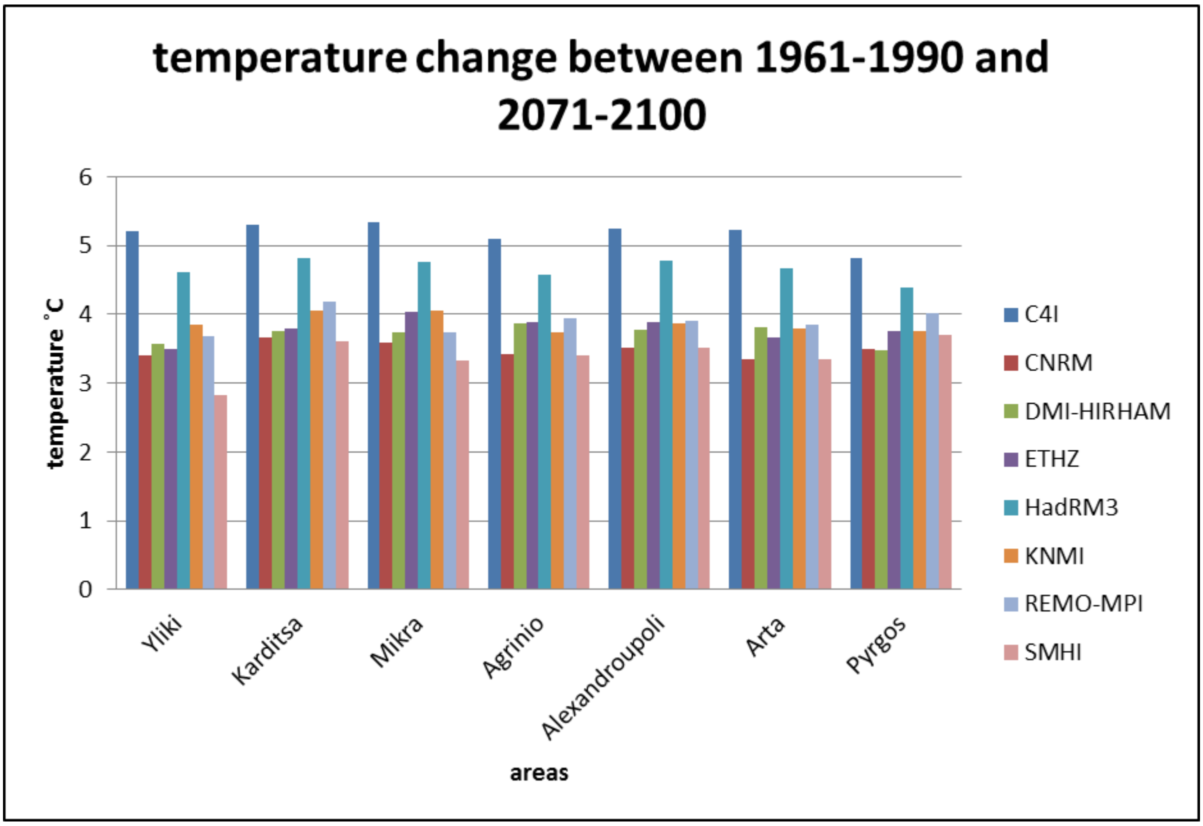

Fig. 3. Changes in mean temperature according to the eight models in the study areas between 1961-1990 and 2071-2100

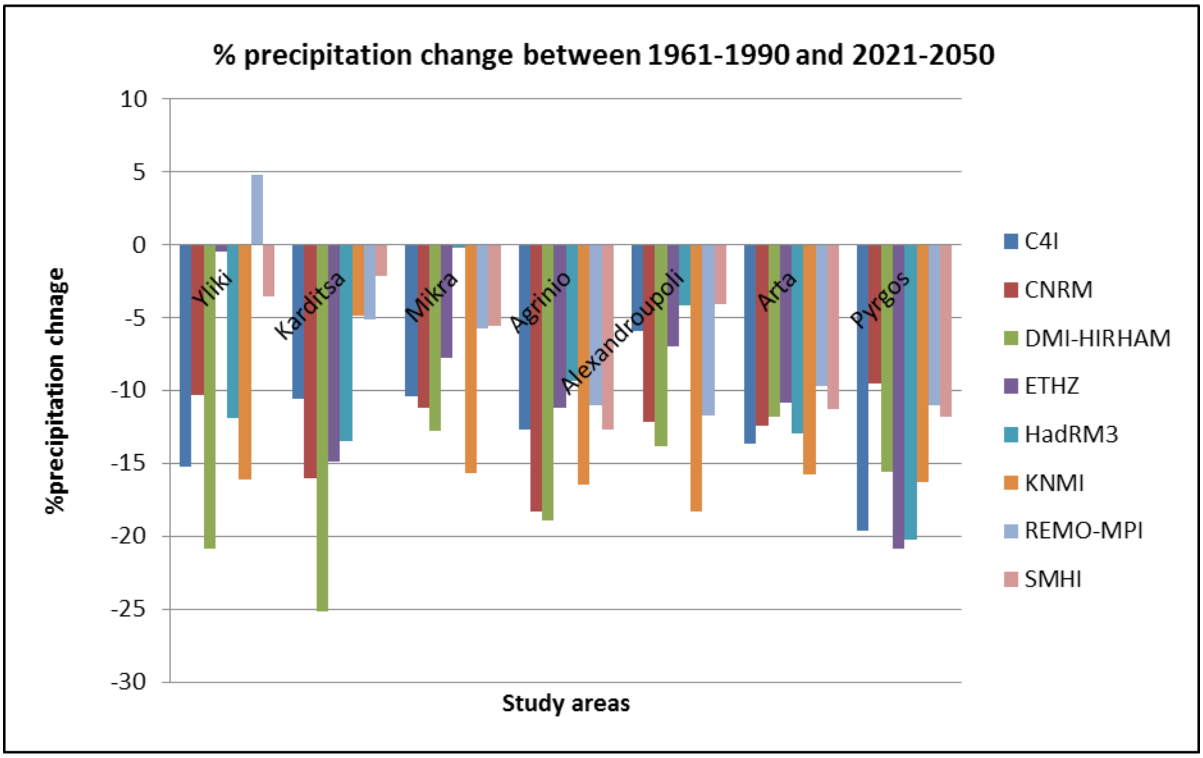

Fig. 4. Changes in precipitation according to the eight models in the study areas between 1961-1990 and 2021-2050

Fig. 5. Changes in precipitation according to the eight models in the study areas between 1961-1990 and 2071-2100

The models C4I and HaRM3 produced consistently higher while SMHI consistently lower temperatures in all areas both during 2021-2050 and 2071-2100 (Figs 2-3). The differences from 1961-1990 were as high as 2.3 to 2.6˚C and 2.2 to 2.5 ˚C for C4I and HadRM3 respectively and 1.35 to 1.48 ˚C for SMHI. As expected, the differences were higher during 2071-2100: from 4.85 to 5.20 ˚C and 4.40 to 4.80 ˚C for C4I and HadRM3 respectively and 2.80 to 3.80 ˚C for SMHI. On the average, the ensemble mean increase in temperature is approximately 1.8 ˚C for 2021-2050 and 4 ˚C for 2071-2100. Karditsa and Mikra were the areas more vulnerable in warming during the first period. During the second period, however, the projected rise in temperature from all models was similar in all areas except Pyrgos, where it was kept at slightly lower levels (Figs 2-3).

As regards the changes in precipitation, the models DMI-HIRHAM and KNMI tended to produce higher decreases ranging from 16 to 25% for most of the study areas in the period 2021-2050 (Figs 4-5). The model SMHI produced the lower decrease (2 to 12.15%) in the same period. DMI produced the higher decreases (from 23.5 to 43%) also during the period 2071-2100, followed by C4I. In this period, SMHI exhibited the lowest decreases (11 to 26%) for all areas. Pyrgos, Agrinio and Arta (Western Greece) exhibited the more intense decreases in rainfall in most of the climate models during both periods (Figs 4-5).

3.3 Cotton yield response to climate change

There were separate runs of AquaCrop for each climate model and area. In all cases fertility and irrigation were not changed, as the priority was to determine only the impacts of climatic variability.

Table 5 shows the differences in seedcotton yields in 2021-2050 and 2071-2100, expressed as percentages of the reference period 1961-1990, produced by the application of AquaCrop for each model over all areas (more than 5000 runs of the model).

	Agrinio		**Alex/lis**		**Arta**		**Karditsa**		**Mikra**		**Yliki**		
	1961-1990	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**	**1961-1990**
	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**
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
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
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
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
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
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
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
SMHI	na	na	na	na	na	na	-14.79	46.93	na	na	na	na	35.73

Table 5: Differences in seedcotton yield among the seven study areas in the periods 2012-2050 and 2071-2100, expressed as percentages to the reference period 1961-1990, according to the eight climatic models. na: no output (see text)

It seems that the HadRM3 model has the most negative impact on cotton yields. In almost all cases cotton were declining apart, apart from Arta and Karditsa, with the most negative values in Alexandroupolis and Yliki. The C4I, CNRM and KNMI models indicated a second area in northern Greece (Mikra) to be also vulnerable to climate change during 2071-2100. Conversely, KNMI, REMO-MPI and ETHZ predict, in general, a positive impact of climate change on cotton yields. For example REMO-MPI and ETHZ applications gave for the period 2071-2100 an impressive yield increase in Alexandroupolis of 43% and 70% respectively. In general, the area of Arta (Western Greece) seems to have been more positively affected from climatic modification in both periods. The same conclusion could be drawn for the area of Yliki in Central Eastern Greece (except HadRM3 model). Impressive yield decreases were observed in Karditsa (-71% for CNRM model) during 2021-2050 and Pyrgos (-38% for CNRM model) during 2071-2100.

3.4 Assessment of the used climatic models

The AquaCrop model did not function uniformly for all climate models and areas. In some cases, there were years that the crop model did not complete the necessary growing degree days (minimum GDD needed for cotton in Greece is 1450, Danalatos, 2007) and, as a result, there was not an output (na in Table 5). In some areas the change in cotton yield was extremely erratic among climate models (for example the differences in cotton yield in Alexandroupolis varied from -138% to +77% between the reference period and 2021-2050). The need of having a clearer view of the extracted values drove us into the procedure of filtering the figures produced by AquaCrop using by assessing the climate models on the base of statistical tools with a distinguishing ability. Such an assessment of the models was based on their ability to discriminate the seedcotton yields produced by the AquaCrop among the examined sites, in view of the existing real differences in yields (Table 1) due to different soil and climatic conditions prevailing in each site. Hence, the stepwise discriminant function analysis was considered as the most suitable technique for this approach. Discriminant Analysis was used in the past in investigating climate change impacts on agriculture: Kueppers et al (2005) used the discriminant analysis in their research concerning the effects of climate change on endemic oak in California and Jaradat and Boody (2011) in modeling agroecosystem services under simulated climate and land-use changes. Discriminant analysis was also extensively used in agricultural research (e.g., Slaughter et al., 2004; Piron et al., 2008; Chen, et al., 2010; Backoulou et al., 2011).

The analysis retained six out of the eight climate models for the period 1961-1990. The HadRM3 and the SMHI models were excluded from the final discriminant function model. HadRM3 was also excluded in the periods 2021-2050 and 2071-2100, together with ETHZ (Table 6).

Table 6. Standardized Discriminant function coefficients for the three different periods of the functions 1 and 2.

Models	**1961-1990**		**2021-2050**		**2071-2100**	
	Standardized		Standardized		Standardized	
	func 1	func 2	func 1	func 2	func 1	func 2
HadCM3						
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						

Based on the magnitude of standardized discriminant coefficients, C4I, ETHZ and DMI-HIRHAM had the highest contribution in function 1 and C4I, REMO-MPI and CNRM in function 2 for the period 1961-1990 (Table 6). Function 1 explained 65.5% and function 2 19.5% of the simulated cotton yields variance. Judging from the two dimensional plots of the two discriminant functions, it appears that Alexandroupolis, Mikra and Pyrgos were clearly separated by the function 1, whereas Karditsa, Yliki, Arta and Agrinio were grouped together.

For the period 2021-2050, SMHI, C4I and DMI-HIRHAM had the highest contribution in function 1 and REMO-MPI, KNMI and CNRM in function 2 (Table 6). Function 1 explained 59.7% and function 2 25.9% of the variance of the simulated seedcotton yields. Using the two dimensional plots of the two discriminant functions, it appears that Alexandroupolis was separated by the function 1 and Karditsa by function 2. Two other groups were separated, one containing the areas from Western Greece (Agrinio, Arta and Pyrgos) and another the areas of Mikra and Yliki.

For the period 2071-2099 the climatic models C4I, KNMI and DMI-HIRHAM had the highest contribution in function 1, whereas SMHI, KNMI and REMO-MPI in function 2 (Table 6). Function 1 explained 53.0% and function 2 23.1% of this variance of the simulated seedcotton yields. Using the two dimensional plots of the two discriminant functions, it appears that the simulated cotton yields from Alexandroupoli, Mikra and Agrinio are fairly discriminated by function 1, while the remaining areas were grouped together.

3.5 Comparison of cotton yield change among the study areas

To compare the future changes in seedcotton yields predicted by AquaCrop for each of the seven study areas, the climate models C4I and DMI were chosen, which appeared to play consistently the most significant role in the discriminating process for all three periods (Table 6). Figs 6 and 7 show the range of yield change in each area for the two periods of study.

Fig. 6. Comparison of seedcotton maximum and minimum yield change in the seven study areas during 2021-2050 as percentage of the reference period 1961-1990 according to the climate models C4I and DMI

Fig. 7. Comparison of seedcotton maximum and minimum yield change in the seven study areas during 2071-2100 as percentage of the reference period 1961-1990 according to the climate models C4I and DMI

It seems that during 2021-2050 cotton yields in the areas of Arta, Pyrgos and Agrinio (Western Greece) and Yliki (Central Greece) will be more favoured by climate change when compared to the other three areas. The highest benefits were observed in Arta (increases from 16.8 to 24.08%) and the lowest ones in Agrinio (-0.54 to 20%). The uncertainty was highest in Alexandroupolis (-15.5 to 27.3%) and lower in the areas of Karditsa and Mikra (-2.75 to 3.4% and -11.56 to 8% respectively) (Fig. 6).

The yields in the areas of Arta, Agrinio and Pyrgos will also be more favoured during 2071-2100 (predicted increases 7.04 to 31.59%, 22.56 to 28.5%, and 6 to 19.3% respectively) (Fig. 7). The most negative impacts of climate change on seedcotton yields will be observed in Alexandroupolis (-5 to -23.8%). Mikra, Karditsa, and Yliki exhibited a high range of yield fluctuations (-28.3 to 16.7%, -15 to 30.3% and -13.5 to 13% respectively) and, hence, a high level of uncertainty for cotton productivity.

4. Conclusion

The use of the eight climatic models in the scenario A1B for the periods 2021-2050 and 2071-2100 produced significant variations in average daily temperature and precipitation among the seven study areas. The assessment of the models was performed by the Stepwise Discriminant Analysis of seedcotton yield variations predicted by the AquaCrop simulation model in reference to the real yields observed during the period 1961-1990. The models C4I and DMI were considered as most reliable for discriminating cotton yields during 1961-1990, 2021-2050 and 2071-2100. The yields predicted by AquaCrop using these two models revealed positive impacts of climate change on seedcotton yields in the areas of Western Greece (Agrinio, Arta, Pyrgos), and negative impacts or great fluctuations in the other areas (Northern and Central Greece). The magnitude of the changes in the two periods (2021-2050 and 2071-2100) in respect to the reference period of 1961-1990 did not show a definite trend, but changed in the different areas of study.

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