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Climate Change Effects on Spatial Distribution of Cotton Irrigation in Thessaly Plain

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Abstract: Gradual warming of the global atmosphere, and regional changes in precipitation by three consecutive periods until the end of 21st century, as greenhouse gases mount, is expected. A composite model predicts the effects on the spatial distribution of cotton irrigation in Thessaly Plain. Irrigated percentages of cultivated area are projected for 45 defined regions. Predictions of actually irrigated area, which would depend on economic conditions and availability of new water supplies, are not made. All climate transient scenarios resulted from HadCM2GGa general circulation model predicted increase in potential net irrigation requirements for cotton. The irrigated percentages increased for the cotton crop. Concerning the crop of cotton, the greatest impact of climate change on the agricultural economy would occur in the Central and East Plain. In the Central-East areas this would occur because of decreases in totally cultivated area. In the other regions, irrigation would increase, accompanied by some decrease in cultivated areas. Improved use of technologies could help meet increasing evapotranspiration needs, but large new surface supplies would generally be required to maintain or increase present levels of irrigation.

Key words: Gradual warming of atmosphere, potential net irrigation requirements, agriculture rainfall, percentages of irrigated areas, crop of cotton.

1. INTRODUCTION

The prospect of a global greenhouse warming has introduced major new uncertainties and challenges for irrigators, farmers, and water users establishing a new era for irrigation (US National Research Council, 1996; Panagoulia, 2000). A warmer climate would accelerate the hydrological cycle, increasing both the rates and patterns of precipitation and evapotranspiration and hence affecting the irrigation demands and cropping patterns (Arnell, 1996).

An increase in demands from irrigated crops could have great significance because crop yield and quality can be dependent on demands for water being met. Allen *et al.* (1991), Peterson and Keller (1990), and Cohen (1991) investigated potential changes in irrigation demand and the length of the growing seasons in the USA and Canada. In these studies the increase in temperature and the percentage change in precipitation were arbitrarily taken or were the mean values of General Circulation Model (GCM) outputs for doubling of equivalent atmospheric CO_2 concentrations considering an equilibrium climate (IPCC, 1990).

More recent climate experiments (Murphy and Mitchell, 1995) have simulated the effects of a gradual increase in CO_2 concentrations. Because transient experiments provide more realistic projections of change in climate, they are adopted in the present study. Unfortunately, they have the problem of coarse spatial resolution that it is also the problem of equilibrium projections. This problem could be overcome by using downscaling procedures, which have been widely applied (e.g. Wigley *et al.*, 1990; Bardossy et Plate, 1992; Hay *et al.*, 1992). However, little is known about the 'value-added' of downscaled versus raw GCM outputs, especially when applied to non-linear impact models (Wilby *et al.*, 1999).

With this in mind, as well as the additional effort required to generate downscaled climate scenarios, seven sets of mean monthly increases in temperature and changes in precipitation for three consecutive periods (from 2010 until 2099) were extracted from the transient HadCM2 general circulation model (IPCC, 1996) in order to investigate the raw outputs' effects on present irrigation of cotton in Thessaly Plain. Subsequently, the used irrigation methodology and obtained results are described. Finally, the need and possibility for increased irrigation water supplies, as well as the potential of technology for reducing adverse effects are discussed.

2. STUDY REGION AND DATA

The Thessaly Plain was selected for the purposes of the study because it is the largest unified cultivated area of Greece. The Thessaly Plain lies in Central Greece and occupies about 514.000 ha including the counties of Karditsa, Larissa, Magnissia and Trikala. The Plain is divided into large subregions, the eastern that includes the Larissa basin with an area of 495 km^2 and mean elevation 45-90m and the western one that includes the Trikala basin with an area of 1267km^2 and mean elevation 90-170m. The eastern boundary of the Plain (Magnissia' county) is watered from the Agean sea.

According to the requirements of the study the selected data were: (1) the mean monthly temperatures collected from 7 available stations, (2) the sunshine (hour/day) collected from 2 available stations, (3) the minimum daily relative humidity collected from 8 available stations, (4) the mean daily wind speed collected from 2 available stations, and (5) the mean monthly rainfall height collected from 7 available stations. Forty five cultivated areas with cotton were determined within the Plain, while the potentially irrigated area was provided from the Ministry of Agriculture for each community (numbered 505 in total).

The selected crop occupied the largest land cover. Because there was not a symmetric distribution between meteorological stations and cultivated areas, there was need for distribution of these areas to the nearest stations by using a mapping process between stations and cultivated areas. For this distribution, the latitude and longitude of cultivated areas and meteorological stations, as well as some geographical features, such as the mountainous series, were considered.

The historical year selected for the study's purposes was 1995 due to the completeness of the required data and the highest harvested areas (Ministry of Agriculture, 1997).

3. IRRIGATION MODEL

To estimate irrigation requirements for changed climate, one needs to compute a new value of crop evapotranspiration, growing seasons, etc, for the new climatic conditions and crop patterns. Knowing the effective rainfall, new values of irrigation requirement (IR) can be compared to the present ones. The process needs to be repeated at all cultivated areas (representative sites) to obtain a spatial distribution of changes in IR.

To avoid variations in local economic and farm practice procedures for the various sites the potential net irrigation requirement (NIR) was adopted. Having mapped present NIR, correlation with spatial distribution of irrigation was sought. Percentages of cultivated areas were found to correlate well with NIR, and the correlation equation was used to predict future percentages under climate change. This section presents quantitatively the projections made using this model.

3.1 Potential Net Irrigation Requirement

Potential net irrigation requirement, NIR, is the depth of irrigation water needed to maximize crop production at a particular location. It equals the required crop evapotranspiration minus effective rainfall. The NIR concept assumes that the farmer would explore the crop potential production, regardless of economics, by maintaining optimal soil moisture and maximum multiple cropping and using optimal non-water inputs such as fertilizer. Although this is not what farmers actually would do, the NIR is a comparable measure for all sites and scenarios, and it is economically neutral.

The NIR was calculated for the cotton cropping patterns of the 45 determined areas. The cropping patterns were correlated with latitude, longitude, and mean annual temperature and precipitation. These four parameters explain 95% of the variation in the distribution of the standard patterns, thus providing a predictor of cotton cropping patterns for the scenarios of climate change.

Planting and harvesting dates were obtained from Ministry of Agriculture (1992). Although the length of crop growing seasons could be expected to increase with a warming climate, the crop scheduling under the future climate scenarios was assumed to be the same as this at present. Values of NIR were estimated for the historical and seven transient scenarios using a soil-crop-water simulation model. The monthly average precipitation and temperature for the appropriate climate region (present and HadCM2GGa climates) were used for cotton cropping pattern. Reference evapotranspiration was estimated by Doorenbos and Pruitt version of Blaney-Criddle method (Doorenbos and Pruitt, 1977). Although the annual distribution of temperature and precipitation might also change, lacking further information, monthly averages were simply changed by the scenario amounts.

The crop growth stage was determined by accumulating growing degree-days (Wright 1982). This means that a crop growing stage could accumulate days from two successive months. The crop coefficients, K_C, for each stage were calculated on the basis of the best available information of Ministry of Agriculture (1992) and FAO (1986) according to relative humidity and wind speed of the determined area. The reference evapotranspiration was multiplied by K_C for cotton crop growing stage to determine crop evapotranspiration.

The effective rainfall was assessed according to the crop pattern, the crop growing stage, the study site, the crop evapotranspiration, and the rainfall station that recorded the rain of the site during this season (Bili, 2001). Isograms of NIR for the historical cases were plotted using the visualization computer program Arc View GIS (Version 3.0) and the Spline contour methodology (Bili, 2001).

3.2 Percent of Irrigated Area

For any single year, statistics for areas of cultivated and irrigated land vary depending on the source and how the usage is defined. Census of agriculture for 1995 year (Ministry of Agriculture, 1997; National Statistical Service, 2000) was used for the study. The Census reports total and irrigated cropland, total and irrigated harvested cropland, total and irrigated pastured cropland and other cropland (cover crops, summer fallow, etc.). The areas harvested category was found to provide the most consistent data and the 1995 percentages were selected for the case for this study.

For present conditions, the percentage of cotton harvested irrigated area was correlated with the NIR that was assumed as the mean value for the four crop growing stages to predict the change in percentage of irrigated area. The resulted prediction equation for the crop of cotton is: irrigated (%) = 0.373 NIR + 25.22. To allow for the random variation among the defined areas, the irrigated percentage predicted by the correlation equation for each defined area and crop was adjusted by multiplying by the ratio of the current irrigated percentage to the current percentage projected by the correlation equation. The resulted percentages for the irrigated crop were plotted as pie slices (Bili, 2001).

4. RESULTS: TRANSIENT CLIMATE CHANGE SCENARIOS

The grid-cell data of HadCM2GGa general circulation model with an annual gradual increase of CO_2 by 1% (Mitchell et al., 1995; Johns et al., 1995; IPCC, 1998) provided from UK Handley Center Meteorological Office were adopted in the study. The global model has a horizontal resolution 2.5°×3.75° (latitude × longitude) including a mesh of 96 × 73 cells. The mean outputs (data) of HadCM2GGaX20 and HadCM2GGaX50 gases emissions for the 2010-2039 and 2040-2069 period correspondingly, and the outputs of HadCM2GGaX80 HadCM2GGaX180, HadCM2GGaX280, HadCM2GGaX380, and HadCM2GGaX480 alternative gases emissions for the 2070-2099 period, were used for the purposes of the study. The climate outputs resulted from the above scenarios were the mean monthly increases in temperature and mean monthly changes in precipitation for the 7×21 grid-cell of the global model for the study region. The temperatures and precipitation monthly changes were added to the corresponding historical monthly data for the year 1995.

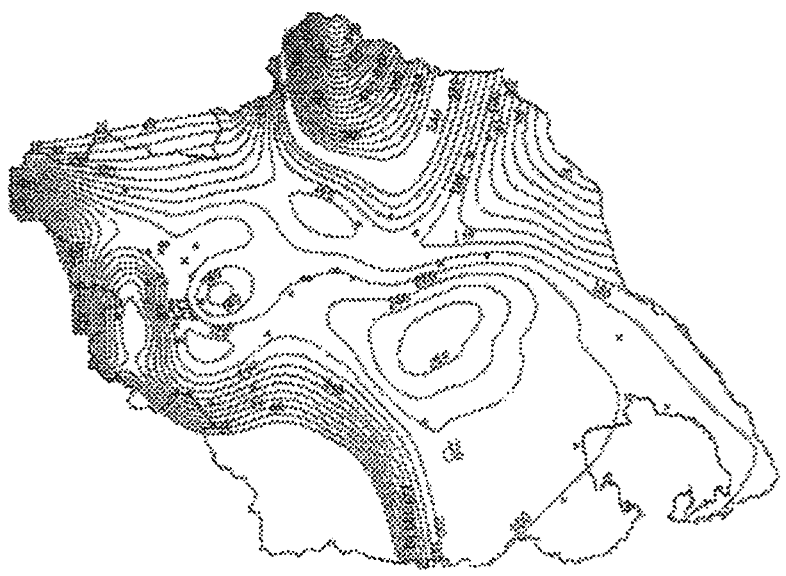

Figure 1(a). Isograms of Potential NIR (mm) for the third growing stage of cotton under present climate conditions

Isograms of NIR for the seven climate scenarios and growing stages for cotton were plotted just as for the historical conditions. Due to the large volume of generated data, only the case of historical scenario (year 1995) and HadCM2GGaX280 one, as generating the greatest increases in NIR, are shown in Figs. 1(a)-1(b) for the third growing stage due to the highest k_C and reference evapotranspiration. In all cases, NIR increased according to the applied scenario. A summarized picture of NIR increases for all scenarios and average values for the 45 cultivated areas and growing seasons is shown in Table 1.

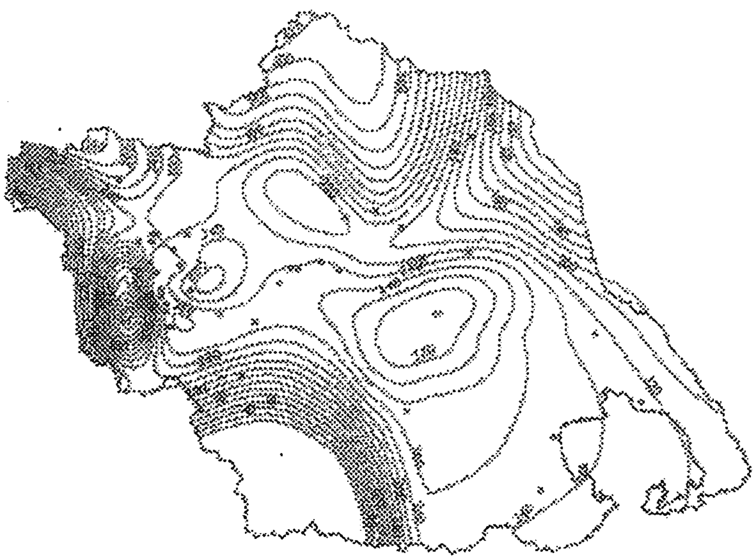

Figure 1(b). Isograms of Potential NIR (mm) for third growing stage of cotton under the HadCM2GGaX280 climate change scenario

Table 1. Increases in NIR (%) for each climate change scenario with respect to climate of 1995

Climate scenario	Crop (Cotton)
HadCM2GGaX20	11
HadCM2GGaX50	19
HadCM2GGaX80	31
HadCM2GGaX180	27
HadCM2GGaX280	35
HadCM2GGaX380	32
HadCM2GGaX480	30

The linear correlation between NIR and the percentages of irrigated area showed a positive gradient for the crop of cotton, and consequently an increase in the percentages of irrigated area. The percentages of cotton irrigated area presented the highest increases under the HadCM2GGaX80 and HadCM2GGaX180 scenarios for the 45 cultivated areas. In several cases the percentages increases reached to 100%. An example of the increases in the percentages of cotton irrigated areas and all scenarios over two cultivated areas is shown in Fig 2 as pie slices.

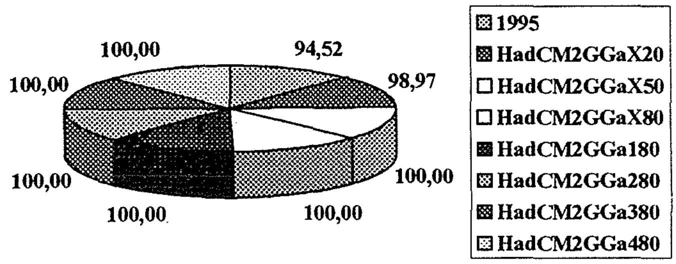

Figure 2a. Increases of irrigated areas (%) for cotton and all scenarios over cultivated region of Platykabos

The indicator NIR is a measure of the opportunity cost in terms of maximum production, but not necessarily of economics, of not irrigating. More cultivated land would be placed under irrigation as NIR increases. Increases in irrigated areas imply savings in irrigation efficiencies and development of new sources, providing additional water needed to maintain current irrigation with increased NIR. The change in irrigated percentage could occur by change in irrigated or cultivated area or both.

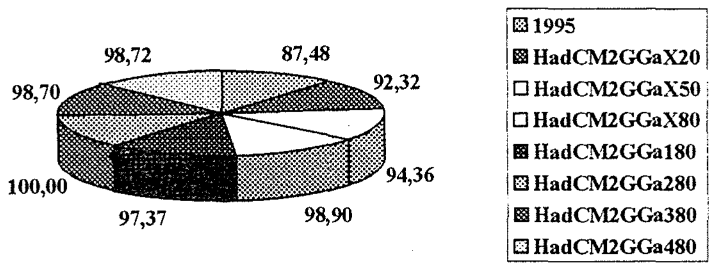

Figure 2b. Increases of irrigated areas (%) for cotton and all scenarios over cultivated region of Tavropos

The correlation equation does not specify the scenario irrigated and harvested areas. Future economics and policy, which are even less predictable than climate, would determine them. The correlation does say that optimist resources would drive agriculture toward irrigating the increased percentages.

5. CONCLUSIONS AND DISCUSSION

Given the impossibility of projecting irrigated areas under changed climatic conditions, the projected future percent of cultivated areas irrigated by defined regions is proposed as the spatial indicator of change effects on cotton irrigation.

Conclusions are quite sensitive to choice of scenario and crop growing stages under the same scenario. The increases in temperature usually obscure precipitation effects. This sensitivity to temperature is apparent in the plain of Larissa's County (Central-East Thessaly) under the used scenarios because it is tied to present values. This picture is in good agreement with Makrantonaki's study (Makrantonaki, M., 1996) referred to 22-year period water requirements of the crops for Thessaly Plain. A wide range of contrasting conclusions is possible within the range of projected regional precipitation.

The greatest impact of transient climate change scenarios on the agricultural economy would be in the Central-East Thessaly, where irrigators will be hard put to maintain even present levels of irrigation. The largest effects would occur in Larissa's County, the modest in Counties of Karditsa and Magnisia, and the minor effects in Trikala's County. Although the modest scenarios show relatively mild consequences, the resilience of agroclimatic ecologies is substantially reduced for the HadCM2GGaX280 scenario and rather modest increases in severity would trigger dramatic changes in the future of rain fed agriculture. At least part of increased NIR could be met by improved irrigation technology, some new water supplies would be needed and some would be costly. Maintenance or expansion of present irrigated areas will require development of large-scale surface storage and conveyance.

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