Effect of Global Warming on the Secondary Factors Affecting Water Use Efficiency and Irrigation Management

Israel Sub-Group

Jiftah Ben-Asher [1] , Pinhas Alpert [2] and Moti Shechter [3]

[1] *Jacob Blaustein Institute for Desert Research , the Ben Gurion University of the Negev.Israel*

Beer Sheva 84993, Israel

[2] *Dept. of Geophysics and Planetary Sciences, Tel Aviv University. Israel.*

[3] *Natural Resource and Environmental Research Centre, University of Haifa.Israel*

Abstract

The major factor affecting crop production in semi-arid environment is certainly water availability. However, according to Liebig's law of the minimum, agricultural productivity is controlled only by one or two environmental properties that are the scarcest resource. When water is available crop growth is affected by the secondary factors. Therefore, quantitative estimate of environmental properties such as temperature, CO2 concentration in the air , salinity relative humidity and dew formation can be useful to determine optimal growth conditions.
In this presentation we describe experimental and theoretical results that were obtained during the years of ICCAP project. Productivity data , evapotraspiration and photosynthetic rates (PN) were collected in the Chukuva basin Turkey. Nine different summer and winter crop, orchards and natural habitats were studied using unique measuring systems and analyzed from a biophysical and economical points of view.

Temperature effect: The steep decline in PN with temperature above 24-25 °C for winter wheat or 34-36 for summer crops means that small increases in ambient temperature can then lead to significant decreases in net CO2 uptake ability and it indicate that irrigation then may lead to only small enhancements in net CO2 uptake.

Relative Humidity (RH) and Dew formation: Contrary to expectations, photosynthesis in the early morning hours was not linked to transpiration (or weakly linked). This weak link resulted from the presence of dew on the leaves which caused a temporary reduction in leaf to air VPD followed by increased stomatal conductance and improved water use efficiency (WUE).

Salinity: Agroproductivity of the saline soils in the Chukurova basin is reduced to half the productivity of the non-saline soils but the optimal temperature remain the same.

Climate model: The outputs of the global climate model HadCM3 was adjusted to the specific research locations, we generated projections for 2070-2100 temperatures and precipitations for two climate change scenarios. These data were used to support the economic analysis.

Economic analysis: Net revenues from wheat become negative under the severe scenario (A2), but may increase under the moderate one (B2), depending on the fertility of the soils. By contrast, under both scenarios cotton evinces a considerable decrease in yield, resulting in significant economic losses.

Interactive effects: Increase of CO2 concentration in the air increased NP and transpiration rates but the NP was reduced under low relative humidity at all plants species. Low RH increased the transpiration rates and hence reduced WUE. Contrarily, dew formation on the leaves increased

NP but reduced transpiration rate to result in improved WUE.

Concluding remarks This study was aimed to predict the effect of climate change on natural and managed vegetation and contribute to strategy to conserve them. It's unique approach was that with the appropriate field instrumentation it provided increased understandings of the complex interactions between crops and their environment. For example elevated CO2 humidity, and temperature changes. From the standpoint of irrigation management the consequenses are that we established a tool to control the crops environment even under global warming. Undoubtedly the models for predicting effect of climate change are constantly modified as knowledge increases but this study with the understanding of the interactive effects was a step to minimize the economic damage of global warming. Goal: Investigation of crop factors that are influenced by global warming

Reasearch objectives

A. Global warming effect on biomass production and water requirements.(BGU)

1. Quantification and development of models to predict the effect of extreme GCC scenarios on biomass production

B. Socio-Economic impact of GCC. (HU)

2. Assessment of Damage and Adaptability to Regional Climate Change.
3. To determine how farming would change with the expected changes in precipitation patterns.

C. Regional climate change (TAU)

4. Analysis of the global warming models over the Mediterranean.
5. Daily classification of synoptic systems for 1948-2000 including : change of seasons,

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J.Ben-Asher[1], A Genis[1], F. Evrendilek[2] M. Aydın[2] R.Kanber[3], K Dogan[3]

[1] The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Beer Sheva 84993, Israel
[2] Department of Landscape Architecture, Mustafa Kemal University, Antakya-Hatay, 31034,
[3] Cukurova University Faculty of Agriculture Adana Turkey

Goal: Investigation of crop factors that are influenced by global warming

1. Irrigation as a Major Factor Affecting Crop Production.
2.Water Use Efficiency:
3.The Secondary Factors Affecting Productivity.

1.1 Introduction

The Chukurova basin provides a good case study for analyzing the impact of global climate change on a regional basis. The predicted increase in temperature by 2-4˚C and the expected decrease in precipitation by 30% may adversely affect crops productivity and water availability by the year 2050. Computer crop models and intensive field measurements in the Chukurova basin in Turkey, the Negev Desert and the Jordan River basin in Israel were used to evaluate possible yield changes caused by climate change including the beneficial effect of increasing CO2 levels on crop growth. Results showed that wheat yield may increase by 20-25% for respective increase of 2˚C and 4˚C. But, the associated increase in water consumption is 18% and 40% and the water cost for increased productivity may be too high. (Fig.1).There is no need to emphasize the importance of irrigation and water availability as the major factor for agricultural production but availability of water resources is not necessarily affected by global warming because water resource are unlimited especially if one considers sea water desalination technology which may be improved to a point of feasibility. Thus water availability is only a problem of "money" as opposed to the secondary factors which are uncontrollable and depend on climate variations / change. In our study the selected non-conventional factors affecting irrigation policy were temperature , salinity, relative humidity and dew formation.

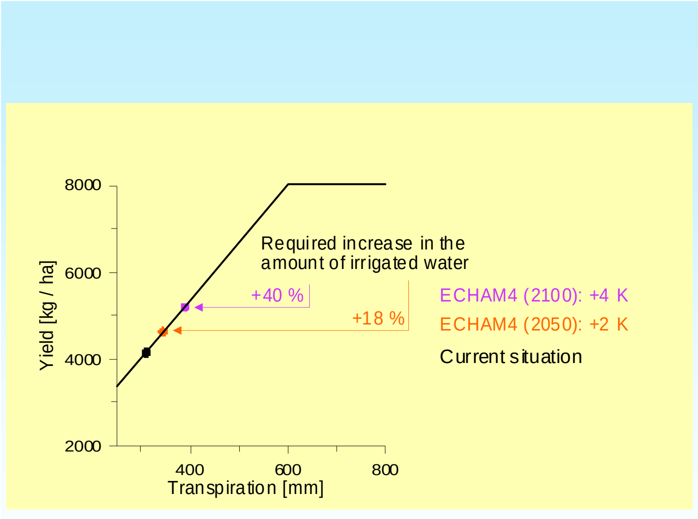

Fig. 1. Preliminary results from ECHAM4 climate change scenarios Simulated effects for wheat production

1.2 Methodology

Study region: Study sites (37o04´-36o46´N, 35o20´-35o25´E) are located in the Çukurova region, a southern Mediterranean region of Turkey, at an altitude 6 to 150 m above sea level. A typical Mediterranean climate prevails in the study region with the long term mean annual temperature18.7 oC (Minimum and maximum air temperatures are -8.1 oC in January and 45.6 oC in August), 647 mm precipitation, 1320 mm potential evapotranspiration and incident PAR of 284 MJ m-2.. About 87% of precipitation falls during the winter (November to May). Maximum incident PAR occurs in August (415 MJ m-2 month-1) and the minimum in December (141 MJ m-2 month-1).

he surface soils (0-30 cm) with different proportions of sand, silt, and clay fractions in the study locations were predominantly fine-textured soils. The soils of the wheat sites displayed a wide range of variation with respect to field capacity and permanent wilting point which corresponded to -0.03 MPa and -1.5 MPa, respectively, in matric potential. Soil dry bulk densities ranged between 1.22 and 1.35 g cm-3. The soils had no salinity problem, and total soluble salt contents were under 0.1%. Soils of the study sites had slightly alkaline pH values of 7.5 to 7.7 and were determined to be poor in soil organic matter (1.18 to 2.37 %).

Measurements: The coupled dynamics of net photosynthetic rate (PN), transpiration rate (ET), water use efficiency (WUE), light use efficiency (LUE), stomatal conductance (gs), photosynthetically active radiation (PAR), air temperature (T), relative humidity (RH), and atmospheric CO2 concentration (Catm) were quantified at five rainfed wheat sites with the same stages of development (midflowering) along south-to-north and east-to-west transects for eight days in April.

For measuring various environmental and plant parameters the PM-48M Photosynthesis Monitor (PhyTech Ltd., Israel) was used (Fig. 2A).

The system contains: four self-clamping leaf chambers LC-4A(Fig 2B) which successively close for two minutes for monitoring CO2 exchange of leaves, infrared CO2 analyzer and a built-in data logger. The monitor also has eight inputs for additional sensors.

The additional sensors used in the current experiment included:

- PIR-1 Photosynthesis Radiation Sensor
- ATH-2 Air Temperature and Humidity Sensor
- Four SMS-2 Soil Moisture Sensors
- SF-4M Sap Flow Relative Rate Sensor

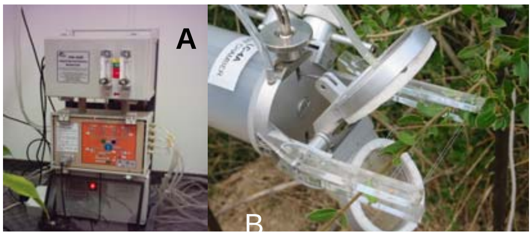

Fig. 2. The PM-48M Photosynthesis Monitor (Fig. 2A).and the self-clamping leaf chambers LC-4A(Fig 2B)

Photosynthesis data from four leaf chambers as well as data from the 8 additional sensors were automatically recorded every 30 minutes around-the-clock. Soil temperature was recorded at two points of the soil profile every 30 seconds using two CR10XTCR thermocouples (Fig. 3), attached to CR10X Measurement and Control Module (Campbell Scientific Inc., USA).

Crops: Summer measurements were taken throughout 24 hours taken from June 16 to June 22,2003.. The plants were: forty days old Cotton (Gossypium hirsutum) and Soybean (Glycine max), mature Maize (Zea mays) representing field crops. Lemon (Citrus limon,) representing perennial groves. Three typical Mediterranean trees were tested on the Taurus mountains (Turkey): Pine (Pinus pinea), Pistachio (Pistacia terebinthus) and Oak (Phyllyrea media). From April 9 to 16 of 2005 measurements of photosynthesis and transpiration rates of wheat leaves (Triticum aestivum L.) were carried out automatically at 30 min intervals.

Statistical considerations : We analyzed the standard deviation of three leaf chambers per plant while the forth chamber was used to measure soil respiration. Ambient CO2 was detected with four probes including the probe attached to soil respiration. The dimensionless data are average of actual values from three dew affected plants with three replications such that each data point represent a population of 9 samples Average standard deviation of the normalized values was 0.13 for both photosynthesis and transpiration.

Fig. 3. a) thermocouples; b)datalogger; c) digital thermometer.

1.3 Key results

Effect of dew and relative humidity

The measured dew point temperature and associated climatic conditions are given in table 1. According to Table 1 dew was formed in four nights each for a different crop (Cotton, Soybean and Corn). In the early morning hours of the 16,17,18,and 19 of June the canopy temperature was below the dew point temperature of the surrounding air and leaves were covered with dew. It was formed between 3:30 and 5:30 am. (Local time) whereas dew formation was not detected on the mornings of 20 and 21st of June when leaf temperature was slightly higher than the dew point temperature.

The results in Fig.1a display the lag time between peak photosynthesis and peak transpiration

Table 1. measured dew point temperature and associated climatic conditions

Date	Occurrence Time	Crop	Dew point Temperature	Leaf temperature	Air temperature	Relative Humidity (%)
16/6/03	3:30	Cotton	20.2	20.0	21.3	93.2
17/6/03	4:00	Cotton	21.1	19.8	21.7	96.2
18/6/03	5:30	Corn	20.4	20.1	21.5	93.3
19/6/03	5:30	Soybean	20.9	20.6	21.7	95.4
20/6/03	5:30	Lemon	20.6	20.8	21.4	95
21/6/03	5:30	Oak, Pine&Pistachio	20.4	20.7	22.9	85.6

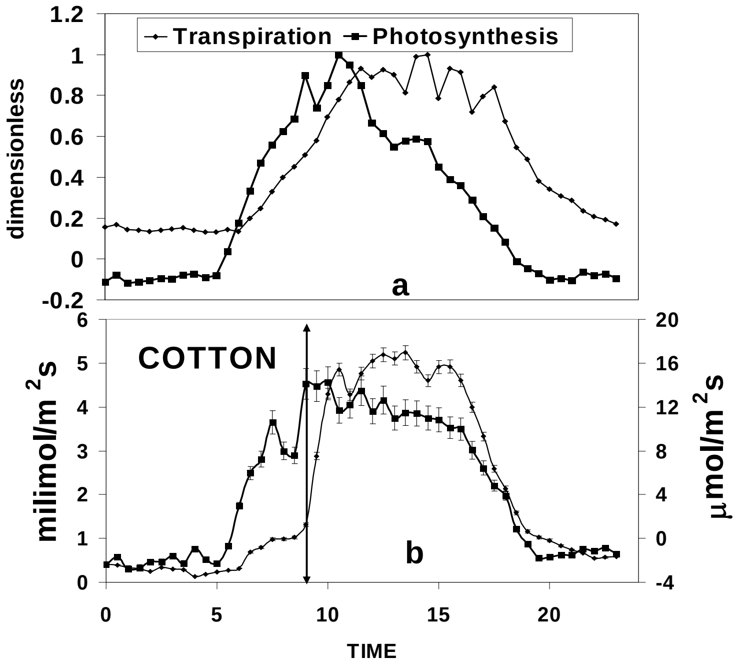

Fig. 4. The effect of dew formation on the diurnal course of photosynthesis and transpiration. (a) Normalized values for the three dew affected plants. (b) Example of actual data of photosynthesis in the right ordinate and transpiration in the left ordinate for cotton. In both displays maximum photosynthesis preceded maximum transpiration due to the combined effect of wide stomatal aperture under dew formation and high CO2 gradient at sun rise. The double arrows line indicates 9:00 am at which the largest difference and ratio between photosynthesis and transpiration was obtained. It thus indicates the time of maximum WUE.

of the dew affected crops (3 crops with 3 replications n=9, 1 standard deviation, s.d. = 0.13). From Fig.4a , maximum photosynthetic rates were measured several hours earlier than maximum transpiration rate. Fig 4b shows the same trend with actual fluxes of H2O and CO2 .

Separated, early peaks of photosynthesis and late peaks of transpiration are contrary to expectations because the pathway for diffusion of CO2 into leaves is similar to the pathway for diffusion of H2O out of leaves. Both are linearly affected by stomatal conductance and solar radiation. Thus the two processes are expected to be in phase.13-14. In Fig 4 however, photosynthesis in the early morning hours was weakly linked to transpiration or not linked at all.

We argue here, and later demonstrate it experimentally that, thanks to the dew, this weak linkage is an inherent part of strategy aimed at maximizing water use efficiency (WUE) which is most important in habitats where water supply is limited.

The practical consequences of the above relate to irrigation methodology and irrigation timing. It implies that production of "artificial dew" by sprinkling a crop shortly before sunrise may improve water use efficiency and crop productivity as shown in Table 2

We now turn to the question of how much can the "artificial dew" improve the productivity and WUE in dry environments. . In particular, in Table 2 and figure 5 we examined the concept of photosynthetic WUE .

Table 2 The effect of dew on CO_2 and H_2O uptake

Dew	gr. CO2 m^{-2} (leaf) h^{-1}		
	Corn	Cotton	Soybean
Production with dew	3.2	2.2	2.2
Production without dew	1.4	1.7	1.2
	gr. H2O m^{-2} (leaf) h^{-1}		
Production with dew	116.9	112.3	103.5
Production without dew	151.2	291.6	227.5

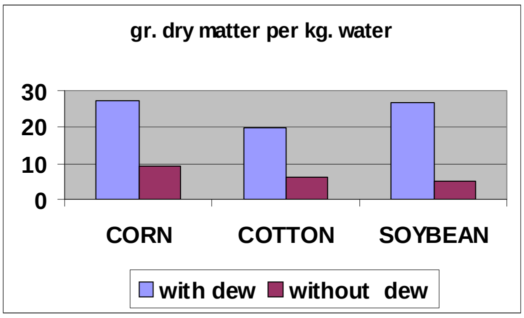

Fig. 5. The effect of due on water use efficiency of three crops

The average CO2 assimilation by wet leaves was 80% larger than dry leaves. The maximal assimilation rate was that of corn which amounted to 3.2 g CO_2m-2 hr-1 (about the potential production rate of C4 plants[17]) whereas dry leaves produced only 1.4 g CO_2m-2 hr-1 , a ratio of more than 2:1 wet:dry leaves assimilation under the same environmental conditions. In terms of WUE the results are even more convincing. Average transpiration of wet plants (covered with dew) was111 compare to 223 g H2Om^{-2} hr^{-1} transpiration from dry plants. The combination of high photosynthetic rate and low transpiration of dew affected leaves led to average WUE of 24.6 compare to 6.6 gr. CO_2 per kg. water for unaffected plants. Thus the synergistic contribution of dew or the artificial sprinkling to WUE was clearly demonstrated.

Effet of temperature

Net CO2 uptake rates (PN) were measured under relatively moderate climatic conditions in Cukurove basin Turkey (Fig 6).

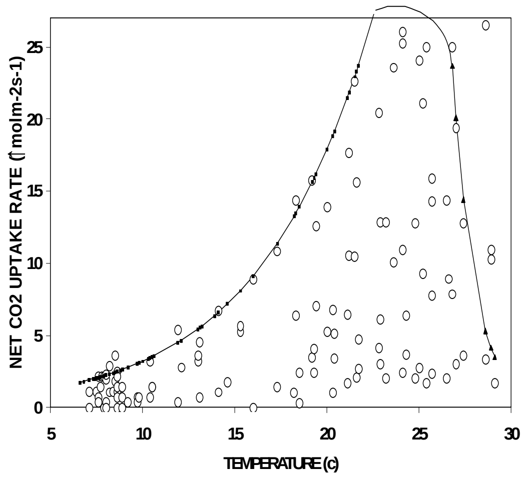

Fig.6 Temperature dependence of the net CO2 uptake rate, PN . under fresh water application.

The range of temperatures was from 7-10 C in the morning to maximum 26-28 C in the afternoon.. The Pn maximized to 27 micromolemm-2s-1 for the fresh water water. The peak was obtained at about 23-24°C. The consequences in term of irrigation policy are providing a furthere support for early morning sprinkling while irrigation during high temperatures times may be ineffective in terms of biomass production. The consequences are summarized below:

· The steep decline in PN with temperature above 24 °C for these wheat species may suggest that small increases in ambient temperature due to global warming can then lead to significant decreases in net CO2 uptake ability

· It indicate that irrigation then may lead to only small enhancements in net CO2 uptake.

· Irrigation method and timing that is cooling the canopy may be more effective.

Effect of salinity

The higher temperatures and lower relative humidity in the field led to a rapid response to salinity. The range of temperatures was from 7-10 C in the morning to maximum 26-28 C in the afternoon.. The Pn maximized to 27 micromolem/m2s for the fresh water and only 12 for the saline water (Fig.7). The peak was obtained at about the same tempersture 23-24. When looking at the data after several measuring days we could not say any thing about the tepmerature -Pn relationships . This may happen very often in our studies because there were many incidents that could not be controlled and we could not explain (For example water shortage , cloudiness etc.) but the envelope which integrates all optimal cases is complying with the known theories of van't hoff and Arrhenious model.

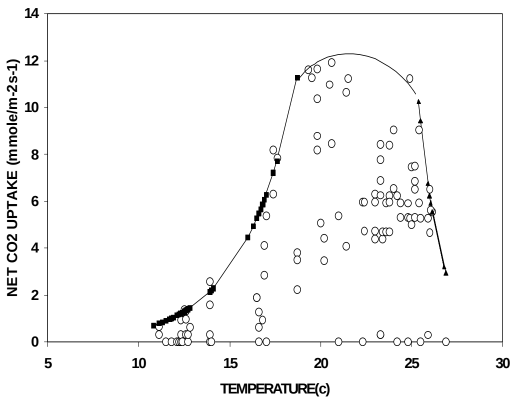

Fig.7 Temperature dependence of the net CO_2 uptake rate, P_N .of wheat on saline soil neat Karatash at the Chukurova basin. Turkey

The envelopes for the rising portions were analyzed using Arrhenius equation (Eq1), and the envelopes for the falling portions were analyzed using enzymes inactivation equation (Eq 2 and 3);

Rate=Be-A/RT (1)

where B is a constant, A is the apparent activation energy [kJ mol-1], R is the gas constant (8.314 J mol-1 K-1), and T is the absolute temperature [K]. Using an Arrhenius plot [lnPN vs. 1/T], A, which represents the minimum energy for the reaction, was estimated for both species.

Above the optimum temperature, PN values declined with increasing temperature, presumably representing inactivation (or deactivation; Bernacchi et al. 2002, Sharkey 2005) of the catalytic properties of the enzymes involved. The decline in rate with increasing temperature was assumed to be proportional to the rate:

d(Rate)/dT=–C×Rate (2)

where C represents the relative fraction of inactivated molecules per unit increase in temperature. Reorganizing Eq. 2 and integrating leads to:

Rate=De-CT (3)

where D is a constant of integration that incorporates the particular units used. Eq. 3 was used to fit the upper envelopes of PN above the optimal temperatures.

Parameter values are summarized in Table 1.

Table 3. Parameters for equations describing the upper envelopes of the responses of net CO2 uptake to temperature for saline and non-saline conditions. Rising portions (below the optimal temperature) were described by Eq. 1 and falling portions (above the optimal temperature) were described by Eq. 3.

1.4 Concluding remarks:

Conditions	*A*	ln *B*	*C*	ln *D*
	[kJ mol-1]		[K]	
Saline (3dS/m)	240	101.7	0.83	250
Non saline (1dS/m)	118.4	51.2	0.83	252

How to apply the results for irrigation management?

In arid lands such as Israel irrigation is often given on a daily basis. The systems are permanent (not moving) and daily drip irrigation is applied. The system has had its revolutionary impact on agricultural productivity. However, it removed from the plant the natural effect of rain that was provided by sprinkling. That created conditions of "artificial rain" . Moreover, when sprinkling applied early in the morning it created an environment of dew formation and thus help improving WUE.

Thus with the above resultswe now have the tools to re-examine the following questions : What is the best time of the day to apply water ? What is the suitable irrigation method ?

What can we do in order to address the problems created by the response of the secondary factors to global warming ?

Ⅱ Effects of changing water availability on agricultural profits: The Israeli test case

Mordechai Shechter, David haim, Iddo Kan and Naomi Zeitouni; University of Haifa

2.1 Objectives and Methodology

The objective of this part of the research is to evaluate how the benefits of the winter agricultural production in Israel as a test case for Cukurova basin would vary with the expected changes in climatic variables in the EM.

A field-level economic model was developed, where variations in a single climate variable, annual precipitations, were considered. Given the annual precipitations, the model calculates the annual amount of irrigation water required for maximizing the field's net profits. Three winter crops were selected to represent three types of crop-groups: wheat for field crops, processing tomato for vegetables, and vetch (leguminous plant Vicia) for fodders. Profits associated with these crop-groups were considered with respect to climate conditions in the north, center and south regions of Israel. The effect of climate change on the net profit was evaluated by running the model according to various scenarios of annual recipitations.

Rainfall Gamma-distribution functions were used to describe present and future rainfall patters. Forecasts for future rainfall-distribution patterns were based on the assumption that the trend of changes in the distribution-functions found in the past for the years 1931-60 and 1961-90) will continue in the future; the estimated new distribution functions that estimated that the average rainfall will decline relative to that of 1960-1990 in 2020, 2050 and 2100 by 1.5%, 3% and 6%, respectively.

2.2 Key Results

The simulations are presented in Fig.8 .They indicate a future decline in net-benefits relative to the latter part of the twentieth century. The conditions in the past (1945-1975) have increased winter-crops profitability, but then (since 1975) there is a steady reduction. The most sensitive region is the South of Israel with a reduction of 35% in net profits in 2100 relative to 1975. The most sensitive crop-group is field crops. Although most of the effect is seen in the semi-arid southern region, some reduced profitability is detected in the Center and the North of the country as well. Concomitantly, risks for annual economic losses increase because of the larger variability in rainfall events.

The continuation of this study is within the

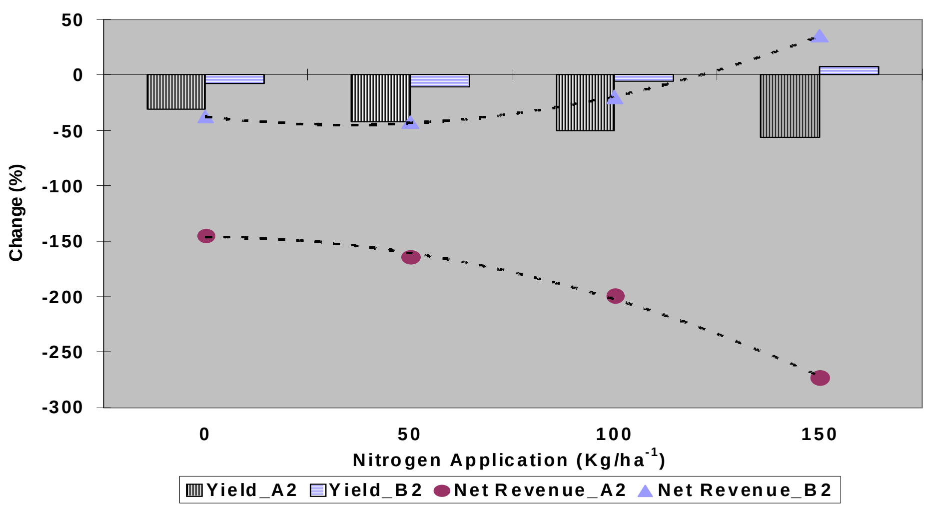

Fig. 8. Yield & net revenue changes (%) in wheat production according to A2 and B2 scenarios.

framework of socioeconomic determinants and consequences of water and land use. The aforementioned analysis focuses on the effect of one climate factor (precipitation) on a part of the agricultural activity (winter production) by a field level model in which there is only one adaptation tool (water application). The intention is to extend this model during 2006 along various directions. First, land allocation among crops as a decision variable and an additional adaptation tool will be incorporated; this requires the development of a regional scale optimization model, and application of a calibration procedure. Second, to account for the effect of variations in additional climatic and adaptation factors (e.g.temperatures and fertilizers), the appropriate response functions will be estimated.Third, summer crops will be incorporated into the model. To this end surface water constraints will be considered, where these will also be affected by climate conditions.

Ⅲ Climate analysis: regional atmospheric processes

P. Alpert, C. Price and S. Krichak – Tel Aviv U niversity

3.1 Introduction

The main goals of the research in the framework of ICCAP have been:

− To identify observed trends in climate variables over the Eastern Mediterranean.

− To evaluate the ability of climate models to capture the observed trends.

− To analyze predicted trends and compare to the observed ones. − To estimate model errors due to land-use changes over selected global regions and study the implications to the Eastern Mediterranean.

− To find out the optimal configurations of the applied regional climate model MM5 for the region.

− To perform coarse resolution dynamical downscaling for the Eastern Mediterranean using NCEP re-analyses as well as two different climate models (ECHAM4 and HadCM3) and two different scenarios (A2 and B2). − To analyse the respective results.

The characteristic behavior of global warming , may result in changes in intensity, location and frequency of occurrence of many if not all climatic parameters. Thus, it is important to pay attention to changes in synoptic disturbance characteristics -- not only to changes in the mean conditions.

3.2 Key Results

Trends in tropospheric temperatures over the EM: We analyzed 850 mb summer temperature trends over the EM from reanalysis data. A long term warming trend of 0.013 K/year was found over a 55 year period. There is an increase of both “hot” and “cool” days. The summer maximum temperature increase is 3 times greater than the increase in minimum temperatures. The increase of extended hot periods in summer was associated with severe impacts e.g. on agriculture (Saaroni et al. 2003).

Additional primary result is a significant increase in the means higher probability for flooding due to active Red-Sea trough situations.

The RCM simulations with the RegCM3 model of TAU demonstrated its ability to represent important elements of the eastern Mediterranean climate. The simulation results demonstrated a tendency for a temperature increase, precipitation decrease as well as increase in the frequency of occurrence of the extreme events in the EM according to the IPCC GHG emission scenarios A2 and B2 .