WPS4135

Climate Change, Irrigation, and Israeli Agriculture: Will Warming Be Harmful?

Aliza Fleischer[1], Ivgenia Lichtman[2] and Robert Mendelsohn[3]

Abstract

This paper utilizes a Ricardian model to test the relationship between annual net revenues and climate across Israeli farms. The study finds that it is important to include the amount of irrigation water available to each farm in order to measure the response of farms to climate. With irrigation water omitted, the model predicts climate change is strictly beneficial. However, with water included, the model predicts that only modest climate changes are beneficial while drastic climate change in the long run will be harmful. Using the AOGCM Scenarios we show that farm net revenue is expected to increase by 16% in 2020 while in 2100 farm net revenue is expected to drop by 60% to 390% varying between the different scenarios. Although Israel has a relatively warm climate, a mild increase in temperature is beneficial due to the ability to supply international markets with farm products early in the season. Our findings lead to the conclusion that securing water rights to the farmers and international trade agreements can be important policy measures helping farmers adapt to climate change.

Acknowledgement: We would like to thank Dubi Wolfson from the Israel Ministry of Agriculture for sharing his knowledge with us. The work leading to this paper was funded in part by the German Federal Ministry of Education and Research (BMBF) in collaboration with the Israeli Ministry of Science and Technology (MOST) in the framework of the project GLOWA Jordan River and by the Research Committee of the World Bank under the study 'Climate Change and Rural Development' that was tasked managed in the Agriculture and Rural Development Department of the World Bank by Ariel Dinar.

World Bank Policy Research Working Paper 4135, February 2007

---

[1] 1Corresponding author: Department of Agricultural Economics and Management, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot 76100, Israel. Tel. +972-8-9489144; Fax: +972-8-9466267; email: fleische@agri.huji.ac.il.

[2] Department of Agricultural Economics and Management, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot 76100, Israel.

[3] School of Forestry and Environmental Studies, Yale University, 230 Prospect Street, New Haven, CT 06511, USA. Tel. +1-203-432-5128; email: robert.mendelsohn@yale.edu

Climate Change, Irrigation, and Israeli Agriculture: Will Warming Be Harmful?

Introduction

The eastern Mediterranean region, like the rest of the world, is expected to undergo changes in rainfall patterns and temperature over the next several decades due to Global Climate Change (Houghton et al 2001). Climate models for the region predict an increase in winter temperature combined with changes in rainfall amount and distribution (Ben-Gai et al., 1998). According to agronomic research, these climatic changes are likely to affect agricultural production (Gitay et al 2001). This study evaluates the economic impact of climate change on Israeli agriculture.

There are different approaches in the literature to evaluate the impacts of climate conditions and agriculture. The agro-economic approach developed by Adams et al. (1989; 1995) begins with agronomic models that predict how climate change will affect yields of specific crops. Mathematical programming is then used to predict which crops farmers will want to plant and what will happen to aggregate production and prices. This approach captures adaptation behaviors including crop switching, but only in a partial and arbitrary fashion. By contrast, the Ricardian approach includes all adaptation behaviors implicitly in the model.

We rely on the Ricardian method (Mendelsohn Nordhaus and Shaw 1994) (MNS) to measure the economic impacts of climate change on Israeli agriculture. Annual net revenues are regressed on climate, soils, and other socio-economic control variables. By using net revenues and not individual crop yields, we allow farmers to adapt to climate change by choosing different crops, crop mixes, technologies and management practices under different climate conditions.

Previous work on adaptation to climate change in agriculture suggests that there are a variety of adaptation measures that can be initiated at the private and public levels (see review of literature in Kurukulasuriya and Rosenthal 2003).It became evident that in order to address the complicated nature of climate change impact on the agricultural sector, a joint private-public and dynamic adaptation is needed (Mendelsohn 1999). As such, technological development and knowhow measures related to various aspects of the production process, including irrigation, where water is available, could be considered.

A major criticism of early Ricardian method applications is that it does not address irrigation water (Cline 1996). Mendelsohn and Dinar (2003) use surface withdrawal data in their re-estimation of the Ricardian model but actual withdrawals are endogenous. Mendelsohn and Dinar (2003), Schlenker et al. (2005), and Kurukulasuriya et al. (2006) also address the irrigation issue by estimating Ricardian models for dryland separately from irrigated land. In Israel, water supplies are determined exogenously by administrative and historic mechanisms. This specific situation allows us to explore what difference exogenous flows of irrigation water have on farm performance and on its climate sensitivity.

Due to the fact that Israeli agriculture depends heavily on water, there have been significant efforts of the public sector to provide incentives to farmers for efficient water use. Using diversified water availability levels across the country, the paper offers a unique opportunity to investigate the role of irrigation water as an adaptation strategy of farmers to climate change in Israel.

Israeli agriculture is also unique in its investment in capital to substitute for water and land. Farmers use combinations of advanced irrigation technologies, such as drip irrigation and cover technology in order to adapt specialized farming techniques to local climate. Israeli farmers have consequently been able to shape their agricultural system to the climate of their country and take advantage of heat rather than be a victim of it. We consequently see that Israeli agriculture is relatively more heat tolerant than, for example, the United States (Mendelsohn and Dinar 2003). Having observed that, an investigation of the impact of climate change on the Israeli agriculture is still needed to address the question in the title of the paper.

The next section will provide the background information on climate and water quotas in Israel—two essential resources that shape the nature of the Israeli agriculture. Then section three of the paper spells out the model applied, followed in section four by the data sources and data preparation procedures. The results of the sensitivity surface estimates are presented and discussed in section five. A set of forecasts of impacts is detailed in section six, followed by a conclusion section. The paper ends with a section on possible extensions and policy implications.

Israeli Climate Conditions and Water Quotas

Israel's total area is about 22,000 square kilometers. The northern part is characterized by a Mediterranean climate while the southern part is a hot dessert. In between there is a narrow transitional strip of semi-arid climate. The rainy season extends from around mid-October to early May, with the rainfall peaking from December through February. Rainfall varies considerably from the north to the south. The highest rainfall is observed in the North and center parts of the country and the lowest in the southern part. The average annual precipitation range is between 151.94 mm to 772.6 mm and the average annual temperature ranges between 15.92 ^{0}C to 23.91 ^{0}C. A more detailed classification of the climatic zones in Israel can be delineated by 12 geo-climatic zones (Goldreich 2003). This classification is based on comprehensive climatic data and adjustment for physiographic conditions. This classification expresses the synthesis between regional similarity by climatic parameters and the special physiographic characteristics of the various regions. We base our data sampling on the geo-climatic zones since they reflect better the climate zones relevant for agriculture.

Israel's agricultural sector is characterized by an intensive system of production stemming from the need to overcome a scarcity in natural resources, particularly water and arable land. The country's varied climate and seasonal temperatures have stimulated the development of unique agro-technological solutions. The climate conditions enable especially the warmer regions to produce vegetables, fruits and flowers during the winter off-season, particularly for export markets in Europe (Sheskin and Regev, 2001). This ability to be the first to the market affords them high prices in the European markets as well as in the local market. In this case warm temperatures are an advantage.

About half of the 282 thousands hectares of crop area are allocated for growing field crops. On about a quarter of this area farmers grow vegetables, potatoes and melons. About 16 percent of the crop land is used for fruit orchards, 7 percent for citrus orchards and 2 percent for flowers and other garden plants (Israeli Central Bureau of Statistics, 2005). Almost all the crops excluding field crops are irrigated. Field crops are grown on large plots of marginal lands and depend partially on rainfall. The agricultural sector is the main water user in Israel. About 60% of the water supply (from wells, reservoirs, effluent water, etc.) is used for irrigation.

Underground and surface water are state property by the Israel water law. Each year the Israel water commissioner allocates for each village an annual water quota for irrigation. Historical initial quotas were determined according to factors such as: total land suitable for irrigation, soil type, population size, location, water usage prior to 1959 and political affiliation of the village. Water quotas are adjusted periodically in order to take into consideration new water sources and new villages. The price of water is determined by the commissioner using a three-tier price system. These price levels are determined according to historical quotas (Bar Shira, Simhon and Finkelstein, 2006). Thus, the allotment of irrigation water and water prices are assumed to be exogenous to the farmers.

Model

A production function of a farm can be expressed as a function of exogenous and endogenous inputs and managerial skills variables. The exogenous input variables include climate and soils conditions and, in the Israeli case, the irrigation water quota. The endogenous variables include labor, capital, seeds and fertilizers and other inputs. The characteristics of the farmers may also have an important contribution to the production process.

The profit function for a farmer growing *n* crops receives the following form:

$$(1)\ \pi = \sum_{j=1}^{n}[p_j Q_j(z,m,x_j) - wx_j],\ j=1,2,\ldots n \text{ crops}$$

where: p_j are crop prices, Q_j production functions, *z* is a vector of climate variables, *m* is a vector of exogenous farm characteristics, x_j is a vector of crop's *j* inputs and *w* is a vector of input prices.

A profit maximizing farmer will choose vector *x* satisfying the following condition for all the endogenous inputs:

$$(2)\quad p_j \frac{\partial Q}{\partial x_j} = w \qquad j = 1,\ldots n$$

Optimal x_j can be denoted as follows: $x_j = x_j(z,m)$. Following MNS (1994) it is assumed that the climatic variables enter in a quadratic functional form in *z*. We can also assume that *p* and *w* are uniform across the country. Under these assumptions and by substituting $x_j = x_j(z,m)$ in equation (1) the farm profit function can be expressed as a function of *C* climate conditions and *L* farm characteristics:

$$(3)\ \pi = \alpha_0 + \sum_{i=1}^{C}\alpha_i z_i + \sum_{i=1}^{C}\beta_i z_i^2 + \sum_{l=1}^{L}\gamma_l m_l + u \quad i = 1,2\ldots C \quad l = 1,2\ldots L$$

where: α, β, and γ are coefficients of the climate and exogenous variables respectively and *u* is and error term $u \sim N(0,1)$.

One of the exogenous variables under the prevailing conditions in Israel is the allotted irrigation water. We hypothesize that a larger supply of water leads to increased farm revenue and reduced climate sensitivity. Due to the extensive use of technology and access to markets our hypothesis is that the response of farm revenue to annual temperature should be hill-shaped (convex).

Data

Most of the farmland in Israel is publicly owned by the Land Authority. The land is leased on a long term basis and its price is not determined in the free market. Thus, the prices of agricultural land in Israel cannot be used for the Ricardian approach. In order to conduct the analysis linking profits to climate conditions, we rely on annual net farm income and not land values as in MNS (1994).

Farm data were collected by conducting a face-to-face survey among a representative sample of farmers. The sampled farmers were chosen according to their location in the geo-climatic zones and type of village. Rural communities vary in their organization. There are 863 rural villages which can be subdivided to 3 types: kibbutz (collective communities, 36%), moshav (cooperative communities, 47%) and other private villages (17%). The kibbutz and moshav today account for 80 percent of the country's fresh agricultural produce. The kibbutz being collective communities are much larger farms than the moshav farms whose ownership is on a per family basis. Thus we account for the size of the farm in the analysis.

The different types of rural villages define three strata, which were represented proportionally in the sample. Three maps were created, each showing the geoclimatic zones of Israel: the first one denotes the location of each kibbutz, the second one the location of each moshav, and the third one the location of the other types of villages. The dispersion of each type of village in the different geoclimatic zones can be observed using these maps.

In the next stage we ordered the villages in each map from north to south in stratums of 4 km each. All the villages in such a stratum received a number identifying the stratum and were ordered according to their stratum number from north to south. The most northern stratum received number 1, the one south of it number 2, and so on. Sampling within each stratum was done by systematic sampling. A number between 1 and 10 was chosen randomly. Each village receiving this chosen number was included in the sample, as was every 10th village thereafter.

A total of 86 rural villages out of 863 potential villages were sampled: 41 moshav, 31 kibbutz, and 14 other villages. Five farmers were chosen randomly and interviewed from each moshav and "other village" for the sample. In each kibbutz, we analyzed five questionnaires, one from each agricultural branch. These branches were randomly selected and the manager for that activity was interviewed for the survey.

A total of 381 farmers were interviewed out of which 230 grow crops and the rest have animal husbandry farms. In this paper, we concentrated on crop farms only and thus most of the analysis is conducted on the 230 crop farms observations. 95% of the farmers in our sample irrigate at least part of their land. There were a few mixed farms but we decided to concentrate on crops growers only. The mixed farms will be analyzed in the future with the livestock farms.

Climate data on temperature and precipitation were taken from Bitan and Rubin (2000). Average annual temperature calculations are based on data collected in 38 meteorological stations over the period 1965-1979 while average annual precipitation were calculated on data collected from 32 meteorological stations over the years 1961-1990. The periods and the stations for the temperature and precipitation calculations are slightly different because precipitation were not measured in all of the 38 stations and in some stations data for temperature were not available for all the years.

Following MNS (1994) we used an extrapolation of physical data of each village location to predict climate data for 230 farms based on data from 32 meteorological stations. Annual average temperature and precipitation were described by a polynomial function of the altitude, longitude, and latitude of each village. The models' OLS coefficients appear in Table 2. The R^2 values are high in both models: 95% for temperature and 89% for precipitation. This means that the model can predict quite accurately the variation in climate data and thus predictions of these models can be used for climate data at the village level.

Unlike similar studies we use annual climate data only and not monthly or seasonal data. The main reason for this is the small size and geographical location of the country in our study and thus the lack of significant variation in climate conditions over a year period. The use of monthly or seasonal climate data led to high multicolinearity in the regression analysis. As a result almost all the monthly or seasonal climate variables were not found to be significantly different than zero.

Data for water quotas were obtained from the annual water consumption report of the Water Commissioner 2001 (Israel Water Commissioner, 2001).

Results

Table 3 presents the results of the two models. In the first model, linking farm profits to farm exogenous variables, the irrigation water quota was omitted. The second model in Table 3 includes irrigation water in a linear form. A third model was also estimated that included irrigation water in a quadratic form but it was not significant and so it is not shown. All models were estimated using heteroskedasticity- robust standard errors.

Comparing the Israeli results to MNS reveals that the value of R^2 is low. There are several reasons for this: 1) farm profits for one year tend to fluctuate more than farmland value, 2) Israel is a small country which means low variance in climate conditions, and 3) this data set has individual farms as observations whereas MNS relied on county averages for observations.

Examining the significant coefficients of the control variables in Table 3 reveals that they have the expected sign. Soil type 'sand2' has a positive significant effect on farm profit level. Profits increase with the age of the farmer. Age reflects experience and thus managerial skills of farmers. It should be noted that we tried to include the age variable in a squared form but it was not significant.

Soil type ‘Sand2’ and level of salinity do not a have a significant effect on profit level of farmers. The variable ‘hectare’ (farm size) which is considered in the regression in order to account for economies to scale and the farm system is also not significant. The reason that a variable reflecting farm type does not appear separately in the regression analysis is the high correlation it has with farm size. The collective farm system, Kibbutz, is much larger than private farm systems. Adding a dummy variable for the Kibbutz farm system to the analysis not only does not increase the R^2 but it also increases the variance of the coefficient of ‘Hectare’ due to the multicolinearity.

The estimated second order climate coefficients in Table 3 imply that the farm profit function is u-shaped (convex) in temperature and hill-shaped (concave) in precipitation. The coefficient of the water quota variable is positive and significant. This means that an increase in yearly water quota to the farmer leads to an increase in the annual profits per hectare. The assumption that the water quota is exogenous to the farmer was tested by running a regression of the water quota on the climate variables, i.e., annual temperature, annual temperature squared, annual precipitation and annual precipitation squared. The R^2 was found to be 0.08 and all the coefficients were not significant. These results confirm our assumption that the water quota does not depend strongly on climate conditions and thus can be considered exogenous.

Comparing the two models in Table 3 reveals that including the availability of irrigation water affects the climate coefficients. Consequently, Ricardian models of regions with irrigation that fail to include water availability may be biased. Including the water quota variable in the second model led to a decrease in the level of significance and magnitude of the two temperature coefficients. The temperature coefficients which were significant at the 5% level in the first model are significant only at the 10% level in the second model. It also should be noted that the optimal temperature is higher in the model with a water quota than that without the water quota. There was little effect on the precipitation coefficients.

Figures 1 and 2 illustrate how the predicted climate sensitivities of the two models differ. The predicted values of profits with and without the water quota were calculated at the average values of all the variables except for precipitation in Figure 1 and temperature in Figure 2. In Figure 1 we can see that the inclusion of the water quota variable shifts the profit curve with respect to precipitation to the left and in Figure 2, with respect to temperature, to the right. More importantly, though, the temperature function with water included is much flatter implying a lower temperature sensitivity compared to the regression with water omitted.

The marginal effects of climate predicted by both models are also calculated in Table 4. The marginal effects of temperature are negative up to about the current average annual temperature for Israel. As expected in a relatively warm region, an increase in temperatures leads to a decrease in profits. However, at high temperatures, profits rise. The region that is mostly characterized by these high temperature levels is the Jordan valley where it is warm all year round. Irrigation, cover, and other technologies enable farmers in the region to adjust to the high temperatures. Moreover, they are the first to bring their produce to both the local and European markets and thus enjoy high prices before their competitor's outputs reach the markets.

In the case of precipitation the inverse is true, up to about the average precipitation level in Israel, the marginal effect of more rainfall is positive (Table 4). For Mediterranean and Arid climates where almost all the crops are irrigated it is expected that profits will increase with precipitation. However, more rain above the average reduces profits. The significant negative marginal effects in the high precipitation levels indicate that too much rain disturbs the farmers. For example, it prevents them from working the fields, the crops get less sunlight, access to the field might be blocked and so on.

The marginal effects differ between the models with and without the water quotas. Including the water quotas reduces the absolute values of all the significant marginal effects of precipitation in the model. The reverse is true for almost all the absolute values of the temperature marginal effects. Including the water quota reduces the sensitivity of farm profits to precipitation but increases the sensitivity to temperature. Similar results were found by Mendelsohn and Dinar (2003) in their estimation of the Ricardian model in the USA.

Forecasts

We then apply three climate scenarios from Atmospheric Oceanic Global Circulation Models (AOGCM) for Israel (Mendelsohn and Williams 2004). We use the 2020, 2060, and 2100 forecasts of the Parallel Climate Model (PCM) (Washington et al. 2000), Center for Climate System Research (CCSR) (Emori et al. 1999), and Canadian Climate Centre Model (CCC) (Boer et al. 2000) to forecast percent changes in average annual farm profits in each of those decades. The models predicted an absolute change in temperature and a percentage change in precipitation for the country which was then applied to each farm. The climate coefficients in Table 3 are then used to predict the change in net income per hectare for each new climate. The forecasts in Table 5 demonstrate the importance of specifying the model correctly. The two models, with and without irrigation water, show different results. The forecasts with irrigation water quota in the model show lower absolute welfare effects. That is, by omitting water quota, the Ricardian model overstates both losses and gains from climate change scenarios.

Comparing scenarios over time reveals that the models are highly sensitive to temperature. According to the model with irrigation water quota, farm profits tend to increase at first with small changes in temperature across all three climate scenarios. Over time, as temperatures climb even higher, farm profits decline in all three climate scenarios. A very different picture, however, emerges with the model that omitted irrigation water quota. In this case, higher temperatures lead to increasing farm profits over time. The biased model predicts global warming is strictly beneficial to Israeli agriculture.

Conclusions and Policy Implications

This paper estimates the economic effect of climate on Israeli agriculture using the Ricardian technique. An economic survey of farms throughout Israel was conducted for this study. Net annual income is regressed on climate and other control variables across farms. Because this region depends heavily on irrigation, the study examines the importance of water supply on the Ricardian results by comparing regressions with and without irrigation water quotas. Higher allotments of irrigation water clearly increase profits (\$1500/m^3). However, including irrigation water quotas also affects the estimated climate coefficients. The study finds that including irrigation water quotas reduces the marginal impact of the temperature variables. In other words, Ricardian models that omit irrigation water (or quotas) in regions with irrigation, as in the MNS (1994) paper, will tend to over predict the benefits and losses of warming.

Despite the fact that Israel has a relatively warm climate, the study found that increases in temperature above $20^{\circ\ C}$ would actually increase net income. The level of technology plays an important role in Israeli farms and affects the impact of climate on farmers' profits. Israeli farmers use irrigation, cover, and marketing arrangements with European markets. The warmer temperatures coupled with these technological advances and marketing arrangements allow Israeli farmers to reach these markets early in the season with precisely monitored fruits, vegetables and flowers. The Israeli farmers thus turn hot climates into an advantage that yields them additional profit. Of course, these results may not continue to apply if other hot regions duplicate the Israeli investments in technology. Increased supply early in the season would reduce prices and thus profits.

Examining alternative climate scenarios suggests that the marginal changes in climate that one might see over the next twenty years are likely to be beneficial to Israeli agriculture. The existing technology including irrigation, cover, and early market products will likely cope with small warming. However, according to the model with water quotas included, climate change scenarios for 2100 are likely to result in reductions in farm profits. In contrast, the model that did not include water allotments predicted that warming over the next century would be strictly beneficial no matter how severe. The difference in these results demonstrates the importance of including irrigation water allotments in models of farms that depend on irrigation.

An important caveat to the results concerns the assumption that water supply would not change with climate change. In practice, higher temperatures would reduce flows and increases/decreases in precipitation would increase/decrease flows. A complete model would treat these hydrological changes endogenously. As climate changes, the model would predict changes in available aggregate water supply. The water should then be reallocated to the farms with the greatest marginal productivity for water. The change in net productivity of each farm can then be calculated given the change in irrigation water as well as climate that it faces. For example, an endogenous hydrologic-agriculture model was recently constructed for California (Lund et al. 2006 and Howitt et al. 2006). The use of technology such as irrigation and cover are also a function of climate conditions and needs to be investigated further.

Climate change is likely to affect agriculture in many countries. The impact level depends on location, level of development and technological advancement, and institutional setting in the countries. Approaches to adapt to climate change may also differ based on the same set of variables. Whether or not the findings from one country may be applicable to other countries is not easy to determine. Probably some findings could be adapted in part to conditions in some countries. In that respect we would like to particularly touch upon several issues that are more relevant for such extrapolation.

Water quotas (rights) are a guarantee for farmers and secure their enterprises. How can water rights help in adaptation to climate change in developing countries? Having a, more or less, a secured resource allows farmers to invest in other water-related technologies as well and lead to stability and lower vulnerability to climate. Introducing water rights is a relatively simple institutional reform that has been adopted in many countries. Therefore, recognizing the importance of secured water rights should become a policy intervention where water is available.

Another important finding in the case of Israel is the market arrangements that have been in place to allow ‘out of season’ export of agricultural products and to reduce the impact of climate change. Indeed, as was indicated, if all countries would act in the same way vis a vis exporting their agricultural products to international markets, one would not capture the profits that have been realized by one entrepreneur country. However, regional arrangements for production of certain products and their marketing in international markets in a synchronized way over the appropriate season could be achieved via international trade agreements, as we witness already in non-agricultural markets. The policy implication is therefore, that international production and trade treaties, similar to the existing arrangements that regulate CO_2 pollution and trade, should be given a priority. The impact of the two regulatory policy interventions may be far greater than of each implemented separately.

References

Adams, R.M. (1989). Global Climate Change and Agriculture: An Economic Perspective. American Journal of Agricultural Economics, 71:5: 1272-1279.

Adams, R.M., Fleming, R.A., Chang, C., McCarl, B.A., Rosenzweig, C. (1995). A Reassessment of the Economic Effects of Global Climate Change on U.S. Agriculture. Climatic Change 30(2): 147-167.

Bar-shira Z., I. Finkelshtain and A. Simhon, (2006) "The Econometrics of Block Rate Pricing in Agriculture." American Journal of Agriculture Economics , 84(4):986-999.

Ben-Gai, T. Bitan, A. Manes, A. Alpert, P. and Rubin, S. (1998). Spatial and Temporal Changes in Rainfall Frequency Distribution Patterns in Israel. Theoretical and Applied Climatology 61:177-190.

Bitan, A. and Rubin, S. (2000). Climatic Atlas of Israel for Physical and Environmental Planning and Design. Jerusalem: Ramot.

Boer, G., G. Flato, and D. Ramsden. 2000. "A transient climate change simulation with greenhouse gas and aerosol forcing: projected climate for the 21st century", *Climate Dynamics* **16**, 427-450.

Cline, W. 1996. "The Impact of Global Warming on Agriculture: Comment" American Economic Review 86: 1309-1312.

Emori, S. T. Nozawa, A. Abe-Ouchi, A. Namaguti, and M. Kimoto. 1999. "Coupled Ocean-Atmospheric Model Experiments of Future Climate Change with an Explicit Representation of Sulfate Aerosol Scattering", *J. Meteorological Society Japan* **77**: 1299-1307.

Gitay H. Brown, S. and Easterling W. (2001) "Ecosystems and Their Goods and Services" in McCarthy, J., O. Canziani, N. Leary, D. Dokken, and K. White (eds.) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge p235-342.

Goldreich, Y. (2003). *Climate of Israel Observation, Research and Application*. Kluwer Academic Publishers Group.

Houghton, J., Y. Ding, D. Griggs, M.Noguer, P. van der Linden, X. Dai, K. Maskell, and C. Johnson (eds.) 2001. Climate Change 2001: The Scientific Basis. Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Israel Central Bureau of Statistics (CBS) (2005). Statistical Abstract of Israel No. 56.

Israel Water Commissioner (2001). Annual Water Consumption Report. Israel Water Commissioner (Hebrew).

Howitt, R. and E. Pienaar. 2006. "Agricultural Impacts" in J. Smith and R. Mendelsohn (eds.) The Impact of Climate Change on Regional Systems: A Comprehensive Analysis of California. Edward Elgar Publishing, Northampton, MA, 2006 (forthcoming).

Kurukulasuriya, P. and Rosenthal S., Climate Change and Agriculture: A Review of Impacts and Adaptations Environmental Department Papers, Climate Change Series, Paper no. 91, Washington DC: World Bank

Kurukulasuriya, P. , Mendelsohn, R. Hassan, R., Benhin, J. Deressa, T., Diop, M., Eid, H.M., Fosu, K.Y., Gbetibouo, G., Jain, S., Mahamadou, A., Mano, R., Kabubo-Mariara, J., El-Marsafawy, S., Molua, E. Ouda, S., Ouedraogo, M., Sene, I, Maddison, D., Seo, S.N. and Dinar A. (2006). "Will African Agriculture Survive Climate Change?" The World Bank Economic Review

Lund, J., T. Zhu, S. Tanaka, and M. Jenkins. 2006. "Water Resources Impacts" in J. Smith and R. Mendelsohn (eds.) The Impact of Climate Change on Regional Systems: A Comprehensive Analysis of California. Edward Elgar Publishing, Northampton, MA, 2006 (forthcoming).

Mendelsohn, R. (1999). Efficient Adaptation to Climate Change, Climatic Change 45:583-600].

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. "The Impact of Global Warming on Agriculture: A Ricardian Analysis" American Economic Review 84: 753-771.

Mendelsohn, R. and A. Dinar. (2003). "Climate, Water, and Agriculture", Land Economics **79** 328-341.

Mendelsohn, R. and L. Williams. (2004). "Comparing Forecasts of the Global Impacts of Climate Change" Mitigation and Adaptation Strategies for Global Change 9**:** 315-333.

Schlenker, W., Hanemann, M. and Fischer, A. (2005). "Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach." American Economic Review, 95(1): 395-406.

Sheskin, A. and Regev, A. (2001). *Israel Agriculture – Facts and Figures*. Ministry of Agriculture and Rural Development**.**

Washington, W., et al. 2000. “Parallel Climate Model (PCM): Control and Transient Scenarios”. *Climate Dynamics* 16: 755-774.

Table 1: Variable Description and Descriptive Statistics

Name	Description	Mean	s.d.	Min.	Max.
Age	Age of farmer or farm manager (years)	52.8	10.61	27	76
Hectare	Size of farm in hectares	81.2	206.78	0.2	1490
Irrigation water quota	Yearly average quantity of irrigation water quota per hectare (in thousands m^3)	5.59	2.95	0	14.46
Profit	Gross revenue per hectare minus variable costs and capital cost (7% of investment) ($)	1,874	25,024	-133,727	186,501
Latitude	Latitude	32.3	0.56	30.91	33.24
Longitude	Longitude	35.1	0.32	34.39	35.77
Altitude	Altitude (meters)	113.6	160.7	-326	857
Lat*long	latitude* longitude				
Lat*alt	latitude* altitude				
Long*alt	longitude * altitude				
Tan	Average annual temperature (C^0) 1965-1979	19.4	0.85	15.92	23.91
Pan	Average annual precipitation (mm) 1961-1990	526.3	129.5	152.23	772.71
Sand2	Sand with granule size 0.2 - 2 mm (% in soil)	4.3	2.54	1.05	12.55
Sand1	Sand with granule size 0.02 - 0.2 mm (% in soil)	37.1	25.01	10.96	86.12
Salinity	Dummy= 1 if soil is not salt free	0.22		0	1

Table 2: Regression of Average Annual Temperature and Precipitation over Latitude, Longitude and Altitude Data

Variable	Temperature	Precipitation
Latitude	90.07*	-1,662.37
	(35.82)	(5,248.78)
Latitude sq.	0.55*	13.53
	(0.18)	(25.45)
Longitude	-262.22*	26,304.12
	(118.5)	(16,763)
Longitude sq.	5.43*	-392.8
	(2.19)	(311.73)
Altitude	0.18*	-14.08
	(0.07)	(10.02)
Altitude sq.	-0.000002**	-0.00004
	(0.000001)	(0.0002)
Lat*long	-3.60*	29.59
	(1.27)	(182.55)
Lat*alt	0.002*	0.12
	(0.001)	(0.09)
Long*alt	-0.007*	0.30
	(0.002)	(0.35)
constant	3,140**	-432,779.4**
	(1,652)	(231,051.8)
N	38	32
R^2	0.95	0.92

Note: Standard deviations are in parenthesis, and *, ** denote significant at 5%, 10% respectively

Table 3: Regression Models Explaining Farm Profit Level

Variable	Profits per Hectare (w/o water quota)	Profits per Hectare (with water quota)
Annual Temperature	-60010*	-41650 **
	(18886)	(22224)
Temperature squared	1559*	1040**
	(524)	(621)
Annual Precipitation	342*	361*
	(105)	(105)
Precipitation squared	-0.30*	-0.33*
	(0.09)	(0.1)
Sand1	74.2	-42.7
	(89)	(121)
Sand2	3539*	3863*
	(1404)	(1448)
Salinity	6503	7242
	(5085)	(4940)
Hectare	2.21	7.68
	(4.33)	(5.1)
Age	483*	457*
	(189)	(182)
Water quota		1541*
	-	(743)
Constant	442,507*	274,606
	(149,033)	(184955)
N	230	230
R^2	0.19	0.21

Note: Standard deviations are in parenthesis, and *, ** denote significant at 5%, 10% respectively

Table 4: Marginal Effects of Range of Precipitation and Temperature in Israel

Average Annual Temperature	Marginal effect without water quota	Marginal effect with water quota
16	-10129*	-8378*
17	-7012*	-6298*
18	-3894*	-4219*
19	-776	-2139
20	2341	-60
21	5459	2020
22	8576*	4099
23	11694*	6179
24	14811*	8258
Average Annual Precipitation		
175	235.6*	245.6*
275	174.8*	179.9*
375	114.1*	114.2*
475	53.3*	48.5
575	-7.5	-17.3
675	-68.2*	-83.0*
775	-129.0*	-148.7*

* significant at 5%

Table 5: Forecasts of Average Net Profits per Hectare According to AOGCM Scenarios

Climate Scenario	Change in Temperature ˚C	% Change in Precipitation	% Change in Welfare Effect (w/o water quota)	% Change in Welfare Effect (w water quota)
PCM 2020	0.8	11	59	17
PCM 2060	1.6	-4	117	22
PCM 2100	3.2	11	430	-60
CCSR 2020	1.4	-2	114	16
CCSR 2060	3.9	-23	451	-3
CCSR 2100	5.8	-23	1188	-290
CCC 2020	1.2	10	94	16
CCC 2060	2.8	-2	326	-32
CCC 2100	5.6	1	1299	-392

Figure 1: Predicted Profit per Hectare as a Function of Precipitation with and without Water Quota

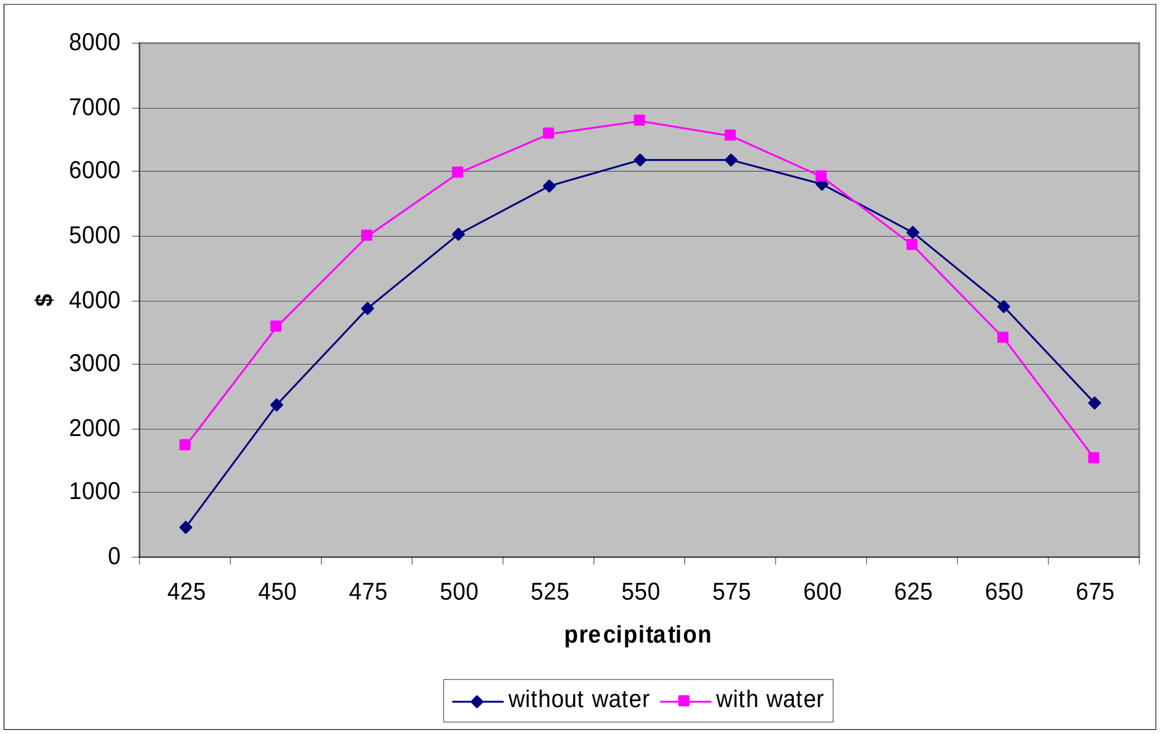

Figure 2: Predicted Profit per Hectare as a Function of Temperature with and without Water Quota