1st Teaching Workshop on Environmental Economics

for the Middle East and North Africa

December 5-16, 2005 - ICTP, Trieste, Italy

Economic Assessment Of Climate Change Impacts On Agriculture

A sub-project of GLOWA-Jordan River Project

M. Shechter, I. Kan, D. Haim, & M. Rapaport-Rom

University of Haifa

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ECONOMIC ASSESSMENT OF CLIMATE CHANGE IMPACTS ON AGRICULTURE

A sub-project of *GLOWA-Jordan River Project*

M. Shechter, I. Kan, D. Haim, & M. Rapaport-Rom

Natural Resource & Environmental Research Center

University of Haifa

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Road Map of Economic Analyses under GLOWA-JR *I*

- Research Objectives
- Some Relevant Background Data on Israel
- Underlying Economic Approaches
- Two Earlier Exploratory Studies
- Crop Level Analysis of Impacts
- Farm & Regional Level Analyses of Impacts
- Further Extensions – GLOWA-JR *II*

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1. Research Objectives

Investigate and evaluate the socioeconomic impacts of regional climate change on water resources and-use changes, with a focus on agriculture and natural vegetation.

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Climate Change Impact on Agriculture

- Changes in plant productivity due to altered levels of temperature, precipitation, global radiation and relative humidity
- Direct effect of increased atmospheric CO_2 concentration on photosynthesis rates

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2. Some Relevant Data on Israel

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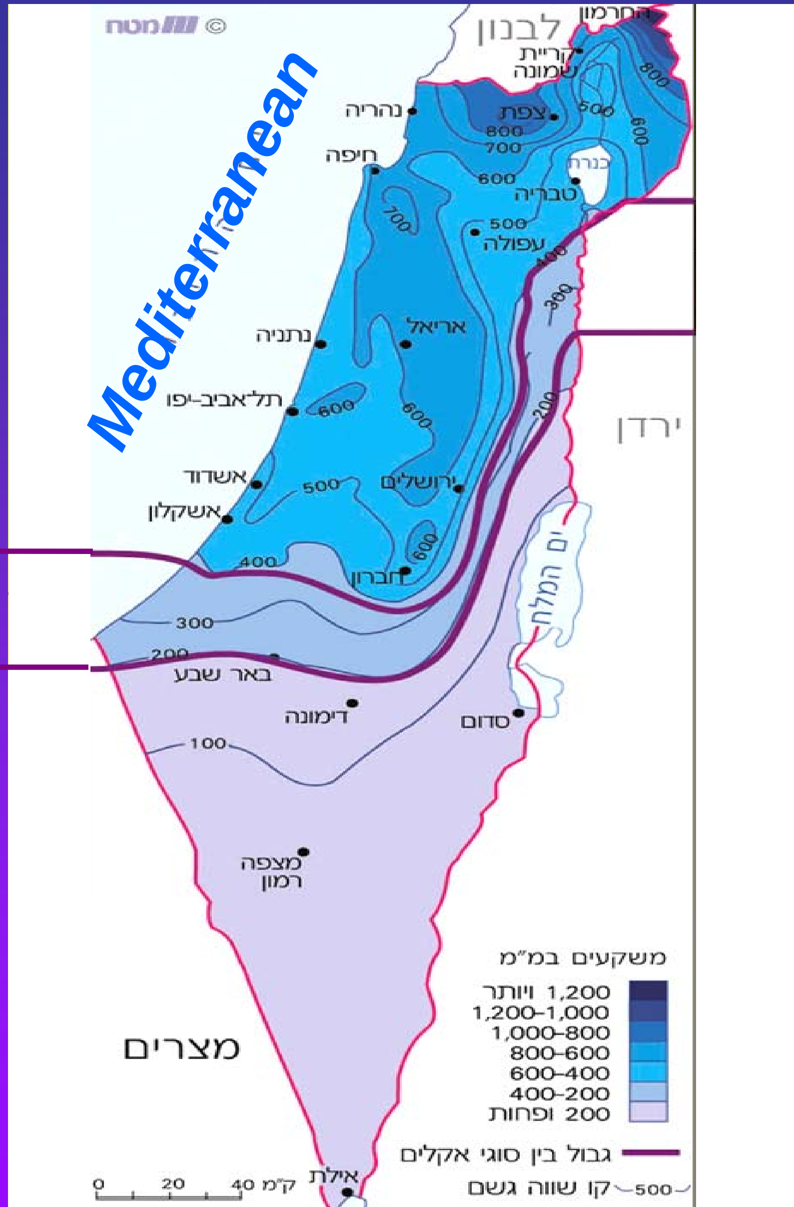
Climatic Gradient - Precipitation



Semi Arid

Arid

800 mm

50 mm

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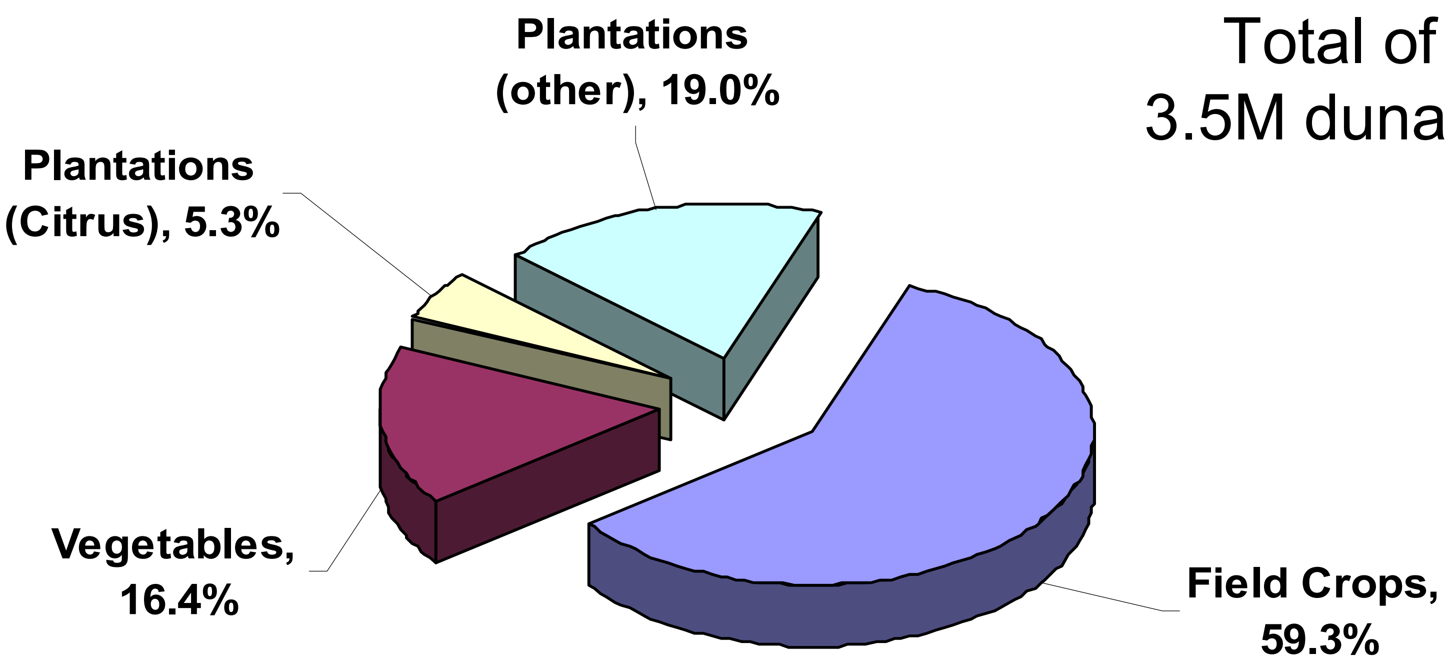
Agricultural Crop Land



Total of 3.5M dunams

Central Bureau of Statistics, Israel, 2002

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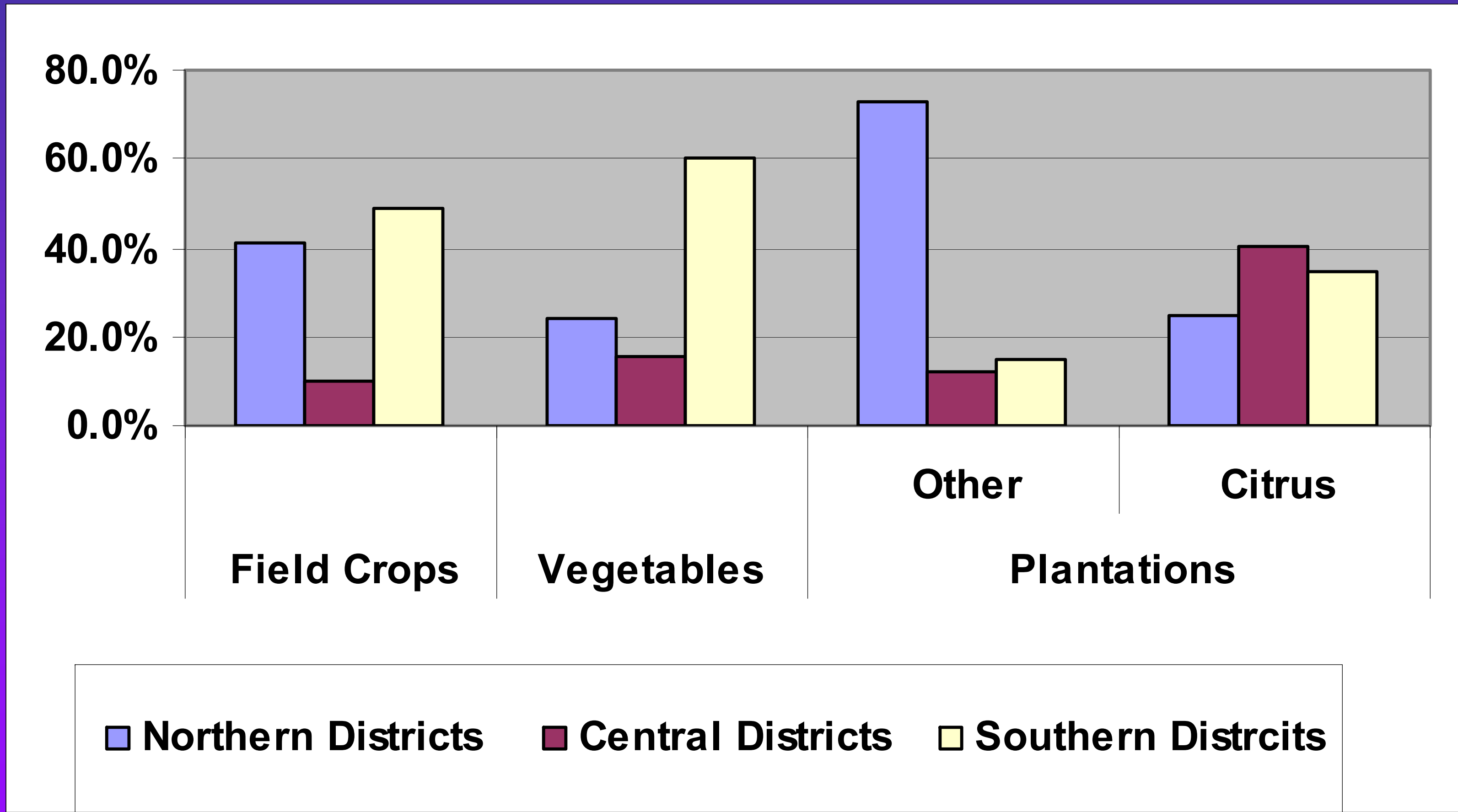
Agricultural Crop Land – National Regions



Central Bureau of Statistics, Israel, 2002

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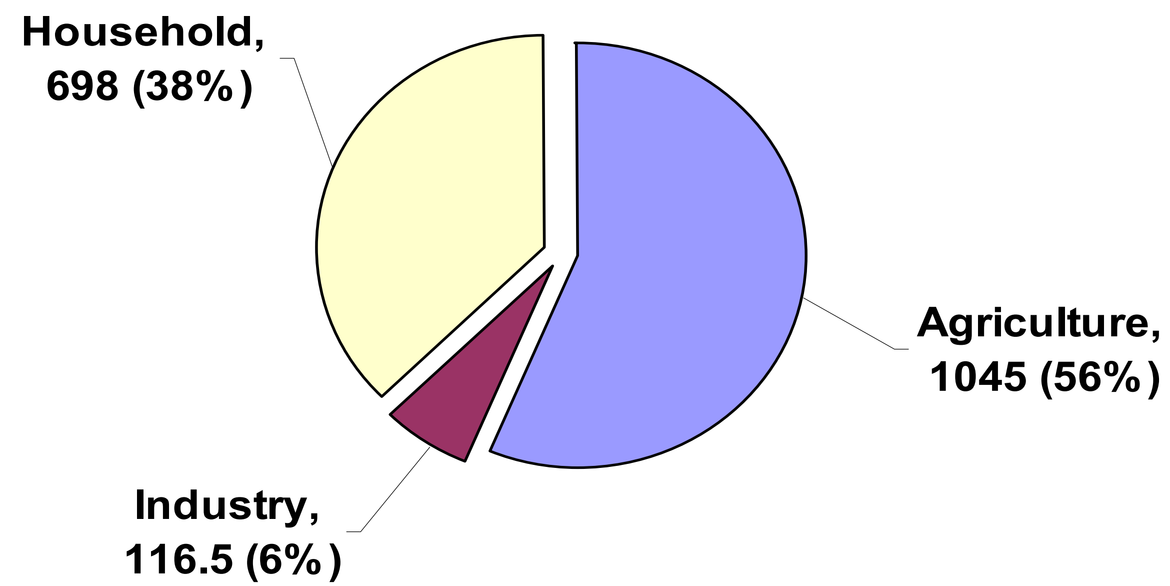
Water Consumption by Sectors (Million cu.m.)



Central Bureau of Statistics, Israel, 2002

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3. Economic Approaches

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A. The *Ricardian* Approach

Examines how climate affects the net value of agricultural land (a direct function of expected revenues), to account for the impact of climate on yields, as well as the indirect substitution of different inputs, introduction of different activities, and other potential adaptation to climate.

Weaknesses:

– Based on the assumption of well-functioning land markets, often distorted due to governmental intervention. **In Israel, most lands owned by the state; therefore, land prices are significantly affected by administrative regulations and national policies**

Advantages:

– Incorporates adaptation efforts

B. The Production Response Approach

Evaluates the direct effect of climate change on yields, and thereby incomes; then employs a land-use optimization model, based on the response functions of specific crops to changes in climatic variables

Weaknesses:

– Overestimation of Climate change impacts (land value is attached to a particular use)

– The need for reliable response functions for every crop

Advantages:

– Based on scientific knowledge regarding crops' responses to climate and agronomic conditions

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4. Earlier Exploratory Studies

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I: "Naïve" Assessments of Regional CC Impacts on Israeli Agriculture

Main assumptions:

- One limiting factor: precipitation (water)
- All water shortage absorbed by agriculture
- No structural change due to adaptation
- Real prices (including water!) remain constant
- IPCC Average Scenario ("IS92a"): CO_2X2 **2060**

See: Shechter, M. & Giupponi, C. (eds.), 2003. *Climate Change in the Mediterranean: Socio-economics Perspectives of Impacts, Vulnerability and Adaptation*. Edward Elgar

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Scenarios & Results

- Scenario I: Naive Scenario
- Scenario II: Economic adaptation – farm level
- Scenario III: Economic adaptation – Macro level

Scenario	**I**	**II**	**III**
Economic Welfare Losses (mil. $, annual)	*208*	*101*	*125*

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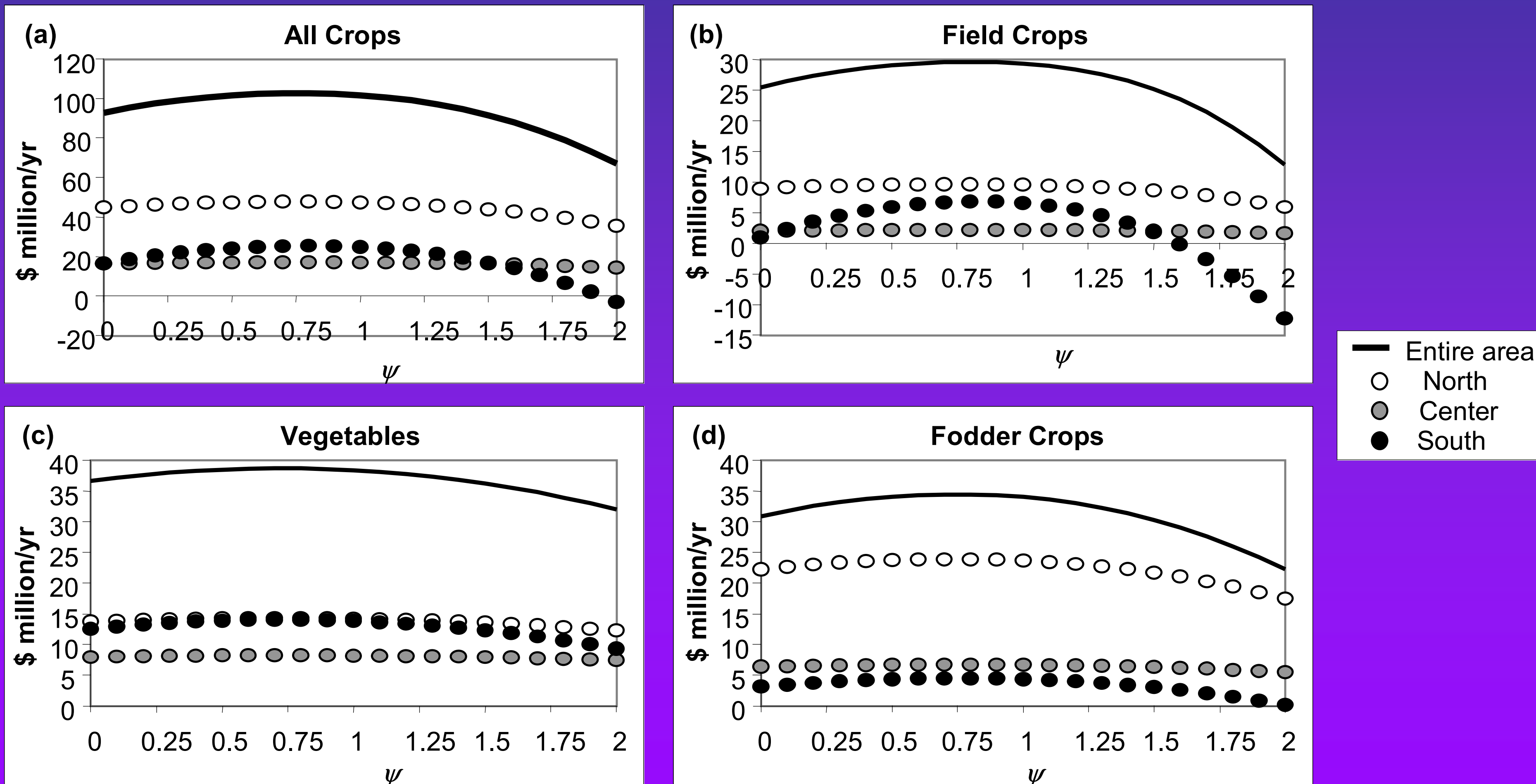
II. Farm level Assessments – Impact of Precipitation Changes

- This paper explores the effects of changes in annual rainfall patterns on the profitability of crop production in Israel
  - Period I covers the winters from 1931/2 to 1960/1, with a median of 1945/6 (ψ=0)
  - Period II covers the winters from 1961/2 to 1990/1 with a median of 1975/6 (ψ=1)
  - Period III - prospective future Period (ψ=1.75)

Precipitation Distribution: North, Center & South of Israel



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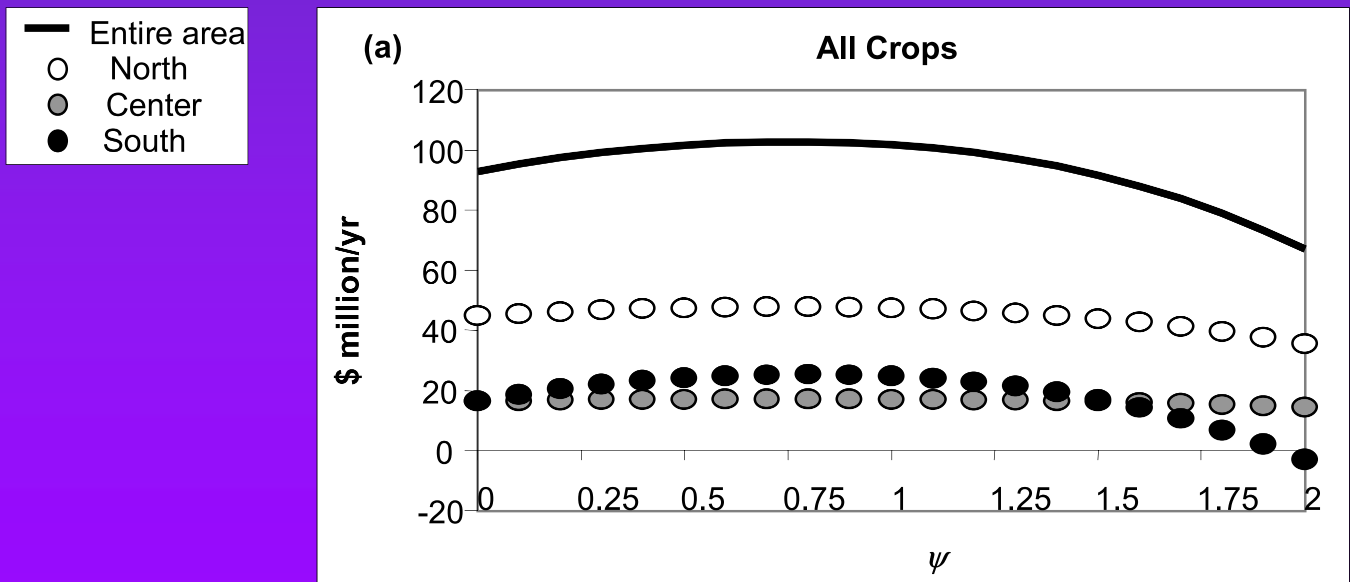
Results: Total Annual Net Profit

$\psi = 0$ (Period I)	$\psi = 0.75$	$\psi = 1$ (Period II)	$\psi = 1.75$ (Period II)	$\psi = 2$
$93.0 million	$102.8 million	$101.7 million	$80.0 million	$67.1 million



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II. Farm level Assessments – Impact of Precipitation Changes

Past Climate Impacts:

Wheat:

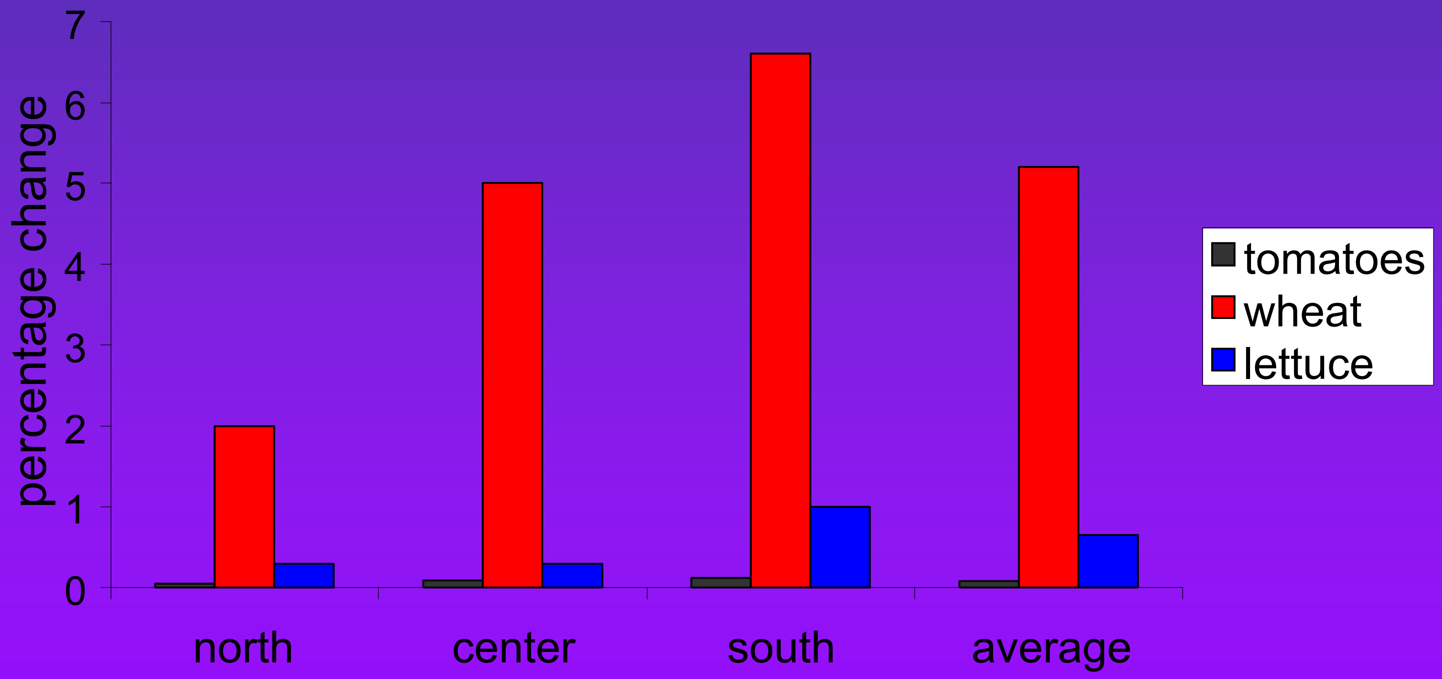
+ 5% p.a.

Tomatoes:

+ 0.08% p.a.

Lettuce:

+ 0.65% p.a.



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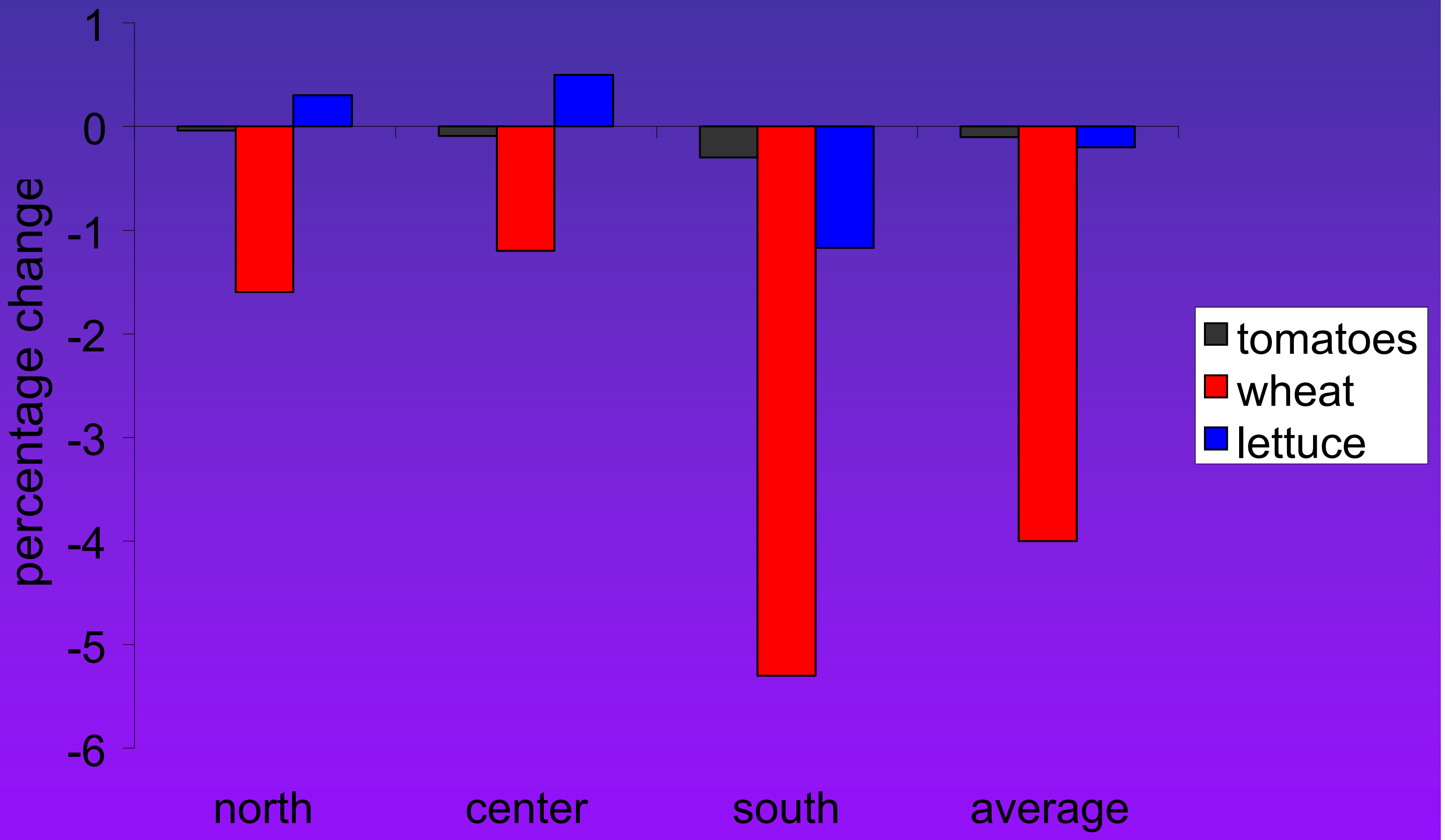
Future Climate Impacts:

Wheat:
- 4% p.a.
Tomatoes:
- 0.12% p.a.
Lettuce:
- 0.2% p.a.



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5. Crop Level Analyses

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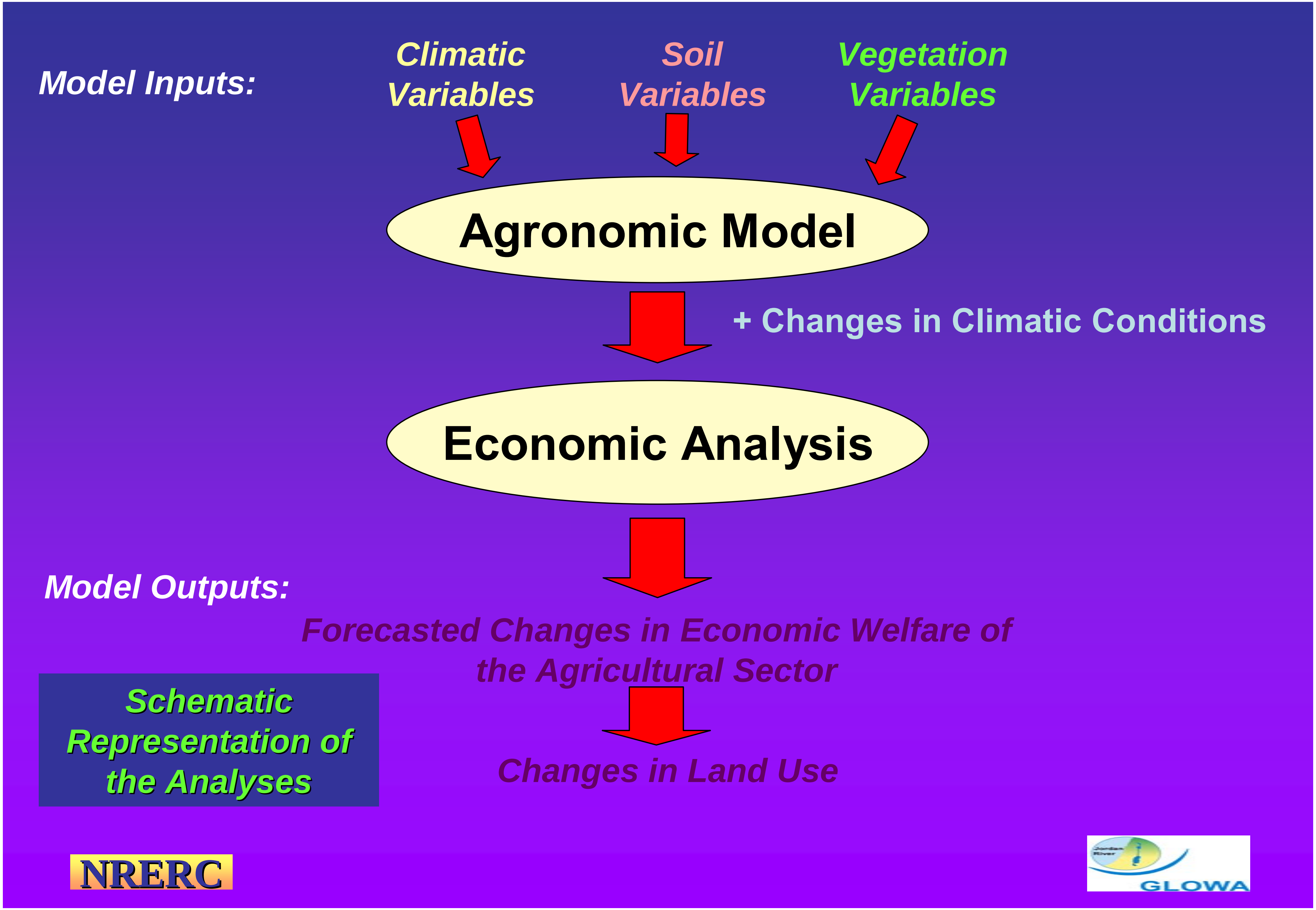
Model Inputs:
Climatic Variables
Soil Variables
Vegetation Variables
Agronomic Model
+ Changes in Climatic Conditions
Economic Analysis
Model Outputs:
Forecasted Changes in Economic Welfare of the Agricultural Sector
Changes in Land Use
Schematic Representation of the Analyses
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Focusing on two representative field crops:

Wheat

Cotton

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The Wheat Agronomic Model

$$Y = \alpha_0 + \alpha_1 S + \alpha_2 N + \alpha_{12} S*N + \beta S*N^2$$

S.t. $1 \leq S \leq 0$

N – Applied nitrogen to soil

S – Moisture stress level (calculated from a water balance model)

Water balance model: The assumption underlying the model is that the ratio ET/PET (actual to potential evapotranspiration) is a function of the total water content in the soil profile.

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Validation of the Wheat Model

I: Estimation of the production function coefficients:

Data: An experiment carried out during the winter of 1971-72 at the Gilat Experimental Center in the south of Israel.

$$Y = 104.4 + 476.3S - 13.2N + 51S \cdot N - 0.94S \cdot N^2$$

$$(\text{Adj } R^2 = 0.9278,\ \ F = 851.7,\ \ P < 0.001)$$

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Validation of the Wheat Model

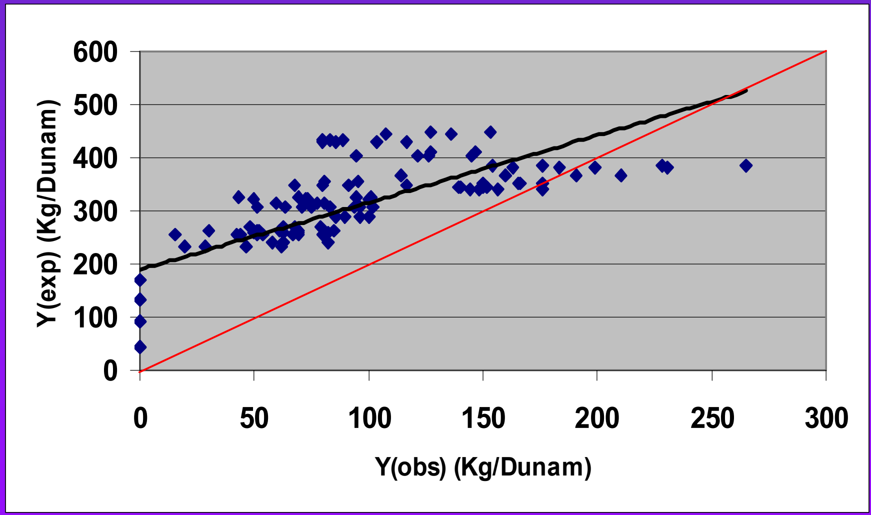
II: Verification of the production function:

Data: An experiment carried out 1996-2003 at the Gilat Experimental Center in the south of Israel

Four applications of nitrogen fertilization were tested: 0, 5, 10, 15 (Kg/Dunam)

Y(obs) = -48.5+0.45Y(exp)

(R^2=0.57, F=157.6, P<0.001)



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Estimating a Response Function for Cotton w.r.t. Water, Salinity and Temperature

- *Stage I:* Using cotton2K simulation to produce evapotranspiration and lint yield data
- *Stage II:* Fitting a response function to the data by a regression

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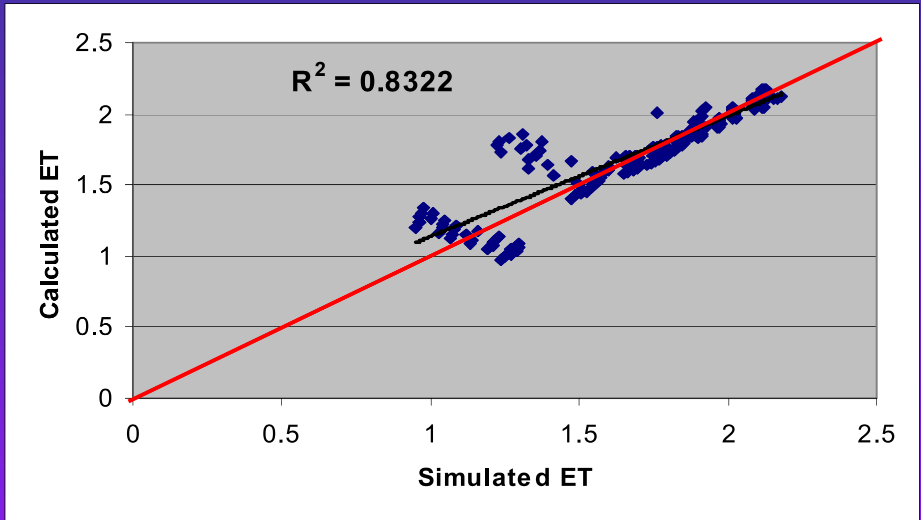
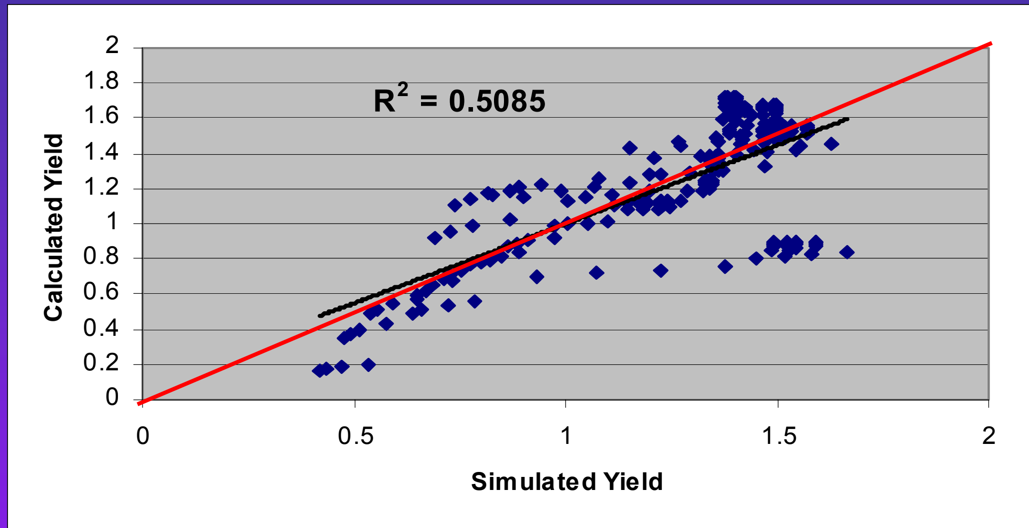
Cotton: Assessing the Functions' Fitness





$$Y = (3.7876 - 0.1309T) \cdot \left[\frac{0.067T + 0.2842}{1 + 9.91 \cdot 10^{-9} \cdot (C + 104.3W^{-1.2})^{3.75}} \right]^{(0.4052T - 8.4042)}$$

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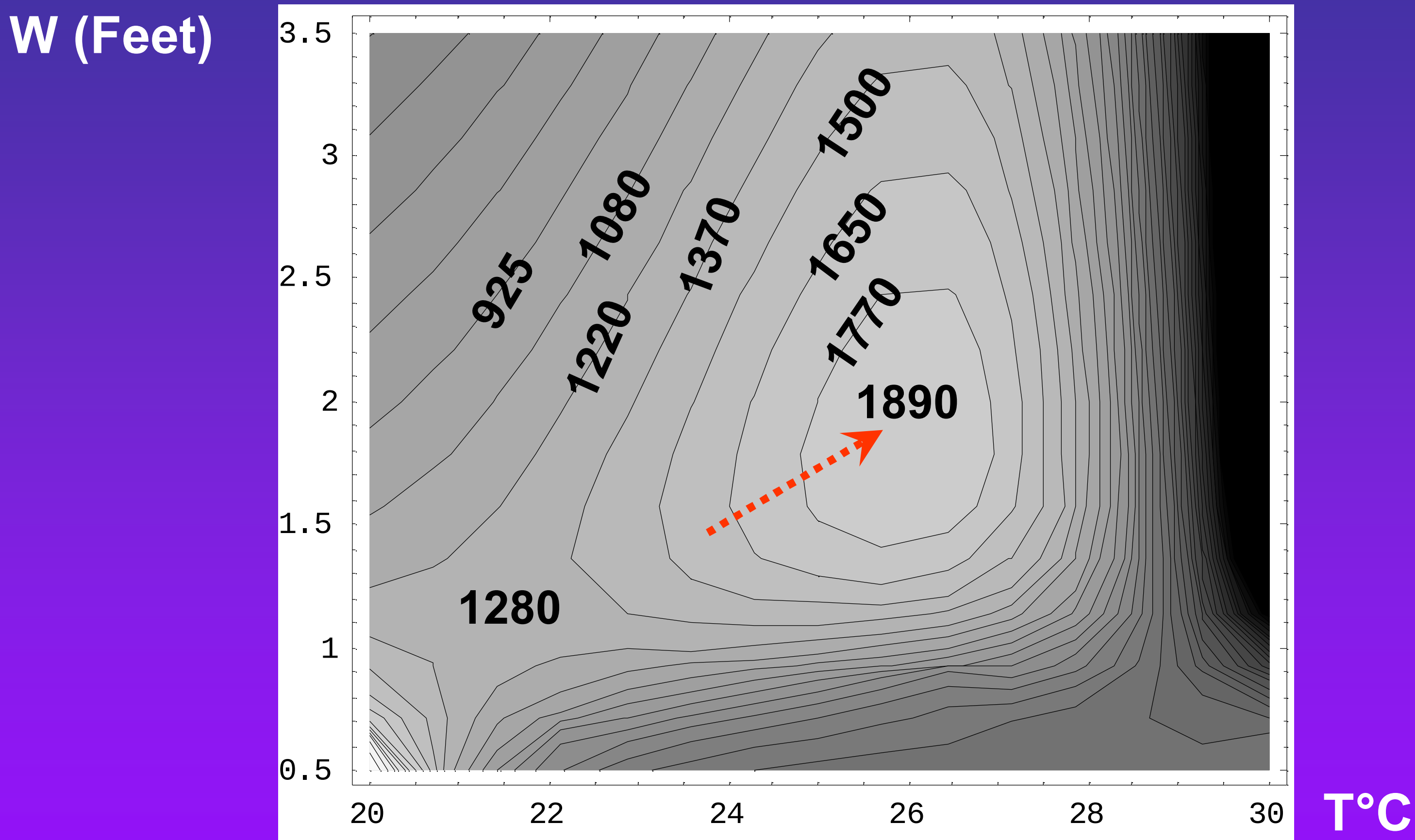
GLOWA Jordan River

Net Revenue Contours ($/acre)



$$\underset{W,C}{NR} = Py \cdot Y(W, C; T) - Pw \cdot W$$

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The Cotton Agronomic Model

Cotton 2K crop simulation Model:

A process-level model, adapted for irrigated cotton production in arid regions, simulating the processes occurring in the soil, the plant, the microenvironment, the interactions among these processes, and production factor inputs (water nitrogen)

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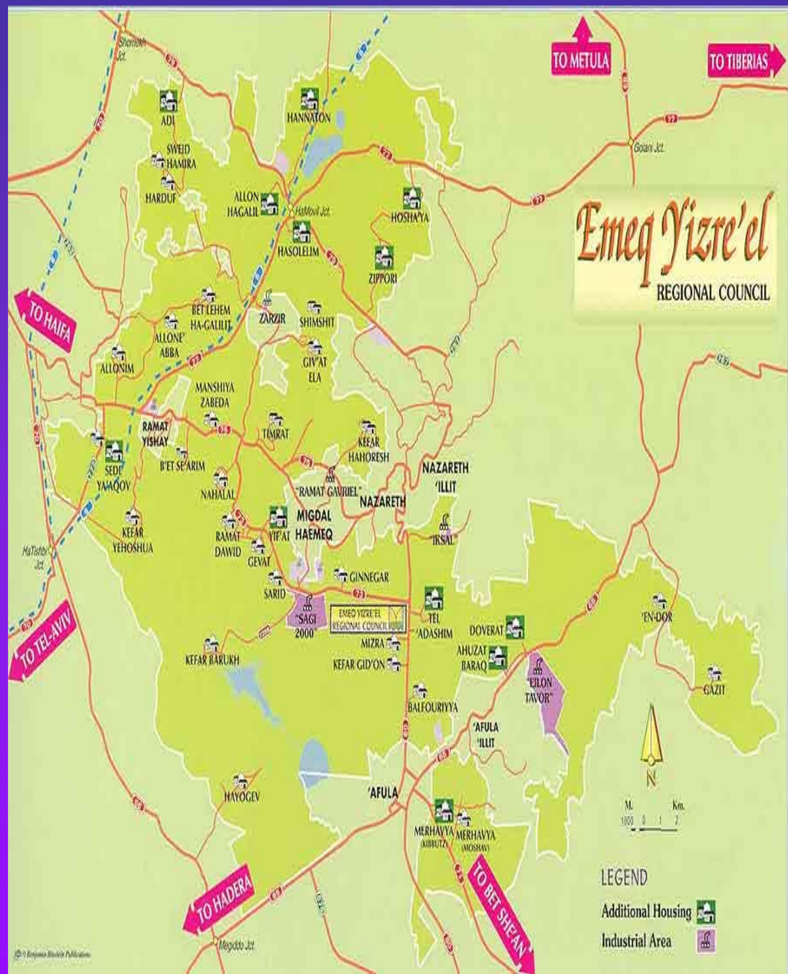
Validation of the Cotton Model

- Kibbutz Mizra: 3 consecutive years 2001-2003, Acala variety
- Kibbutz Hazorea: 2003, 4 plots of Acala variety

t - test for paired samples revealed no difference between the observed and expected yield (R^2 =0.57)



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Adjusting the Response Function for Wheat in order to Use it in the Regional Scale Model

- *Stage I:* Using the water-balance model in order to produce evapotranspiration and yield data set for different amounts of water supplied to the field

- *Stage II:* Estimating the parameters of the response function of evapotranspiration to water and salinity (Letey & Dinar, 1985) by using the data set created in stage *I*

- Stage *III*: Fitting a yield response function (Korentajer et al., 1989) to the data by a regression

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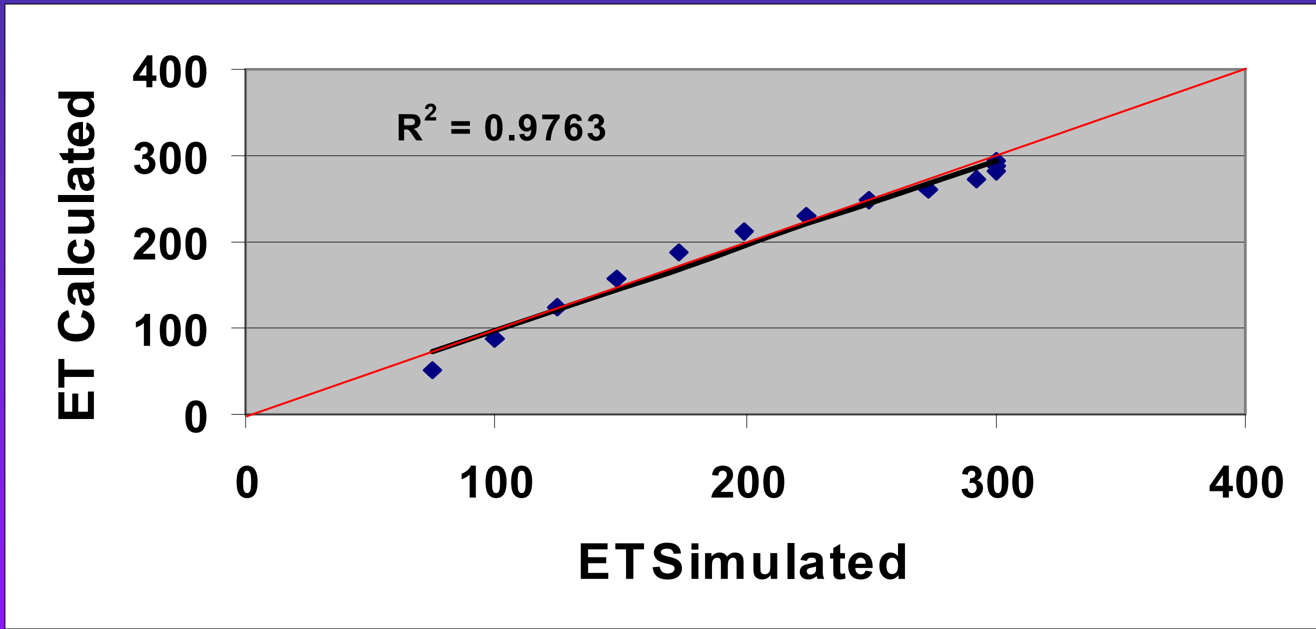
Wheat : Assessing the Functions' Fitness



$$Y = 328.79 - 7.23N + \frac{1}{1 + 4.55 \cdot 10^{-6} \cdot (C + 1052.41 \cdot W^{-0.65})^{3.56}} \cdot (35.02 + 7.98 \cdot N - 0.17 \cdot N^2)$$

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Global Circulation Models (Mediterranean Region)

According to the third IPCC* report (2001), as a result of CO2 accumulation in the atmosphere, climate change predictions for the period of 2070-2100, in relation to 1990, in the Mediterranean region are:

- Increase of 3-5°C in the mean temperature
- Decrease of 3-35% in annual precipitation
- Increase in frequency of extreme climatic events

Intergovernmental Panel for Climate Change

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Incorporating CC Scenarios into the Crop Level Analysis

- We used daily projections from Hadley Center's General Circulation Model (GCM) - *HadCM3* - using two families scenarios: **A2** & **B2** for the years 2070-99, and a control run for the period 1960-90
- Compare with A2, the B2 scenario emphasizes environmental sustainability

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Difficulties in Using The HadCM3 Model

We found significant differences in averages of climatic parameters (rain & temperature) between observations and control run in both research locations

Reason – The global model resolution is too coarse

Therefore, we cannot use the global model projections in a direct way in the study

The solution – We used a weather generator to Downscale HadCM3 results to research locations

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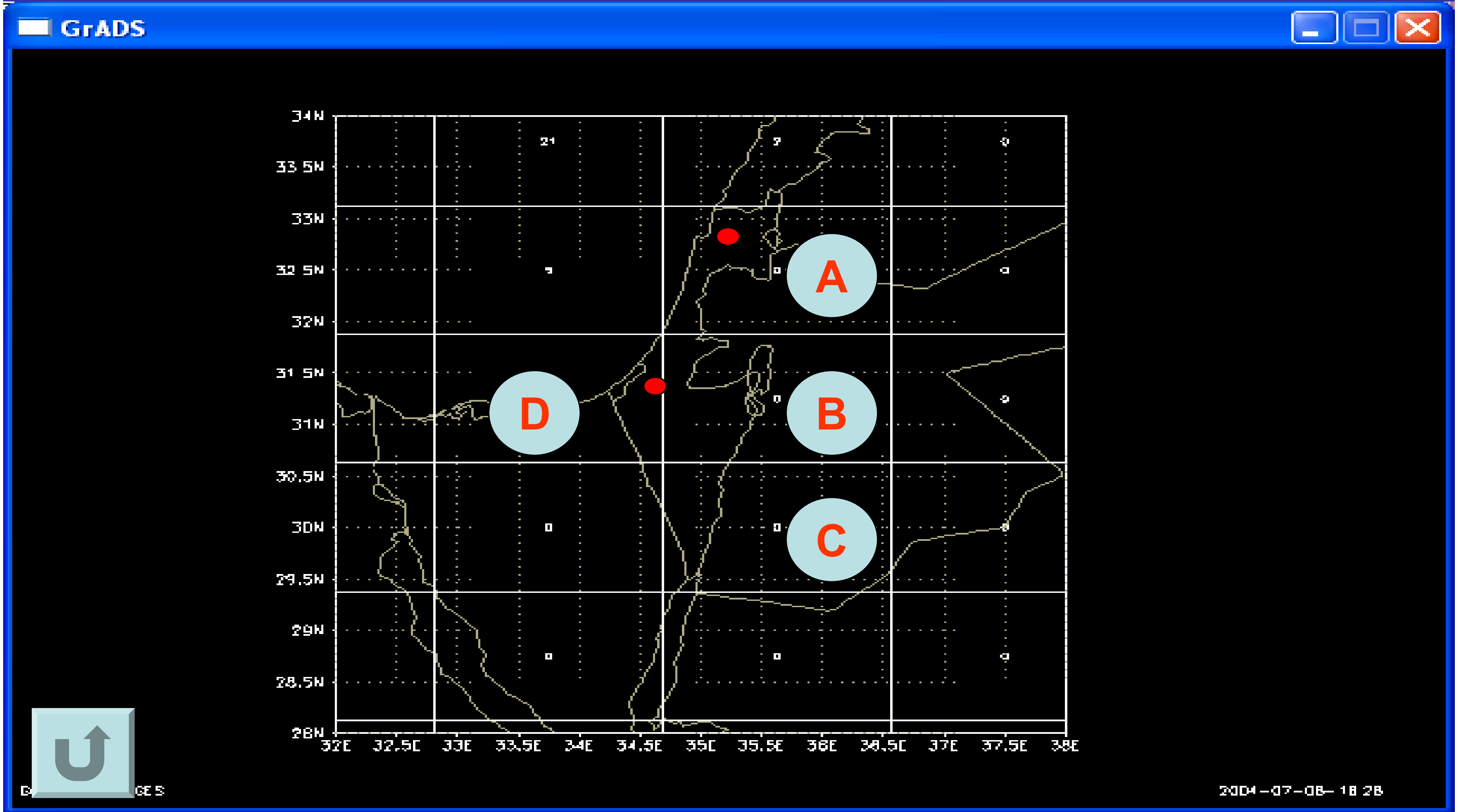
GrADS
34N
33.5N
33N
32.5N
32N
31.5N
31N
30.5N
30N
29.5N
29N
28.5N
28N
32E
32.5E
33E
33.5E
34E
34.5E
35E
35.5E
36E
36.5E
37E
37.5E
38E
A
B
C
D
2004-07-08-18 28

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Using a Weather Generator for Incorporating CC Predictions

We used LARS-WG (Long Ashton Research Station Weather Generator) developed by Mikhail A. Semenov (1990) to translated the results from the coarse resolution of HadCM3 to site-specific values

The WG generate synthetic daily weather data for specific sites using:

1. Statistic parameters calculated from the climatic data in HadCM3 scenarios
2. Statistic characteristics of climatic parameters from the sites (more than 20 years observation is recommended)

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```
// This is an example of scenario file for the baseline climate
//
// m. rain - relative change in monthly mean rainfall
// wet/dry - relative change in duration of wet and dry spell
// tem and sd - relative changes in daily temperature and absolute changes in its sd
// rad - absolute changes in radiation, Mj/m2*day"
[NAME]
emek9604B2
[DATA]
Jan   1.83   1.3    0.86   1.97   0.91   -1.2
Feb   1.6    0.87   1.04   1.65   0.96   -1.3
Mar   1.54   1.21   1.83   1.34   1      -1.2
Apr   0.98   0.84   0.94   2.31   1.12   -0.2
May   0.75   1.33   0.83   3.31   1.14   -0.3
Jun   0      0.88   1.03   3.51   1.06   -0.2
Jul   0      0.94   1.04   4.26   1.16   -0.2
Aug   0      1.15   1.03   4.53   1.19   -0.3
Sep   0.78   0.99   1.27   3.83   1.17   -0.5
Oct   1.38   1.06   1.1    3.74   1.19   -0.5
Nov   1.09   1.18   1.37   2.95   1.02   -0.4
Dec   1.47   1.33   1.09   1.84   0.94   -1.1
[END]
```

Predicted changes in climatic values according to B2 scenario to south Israel

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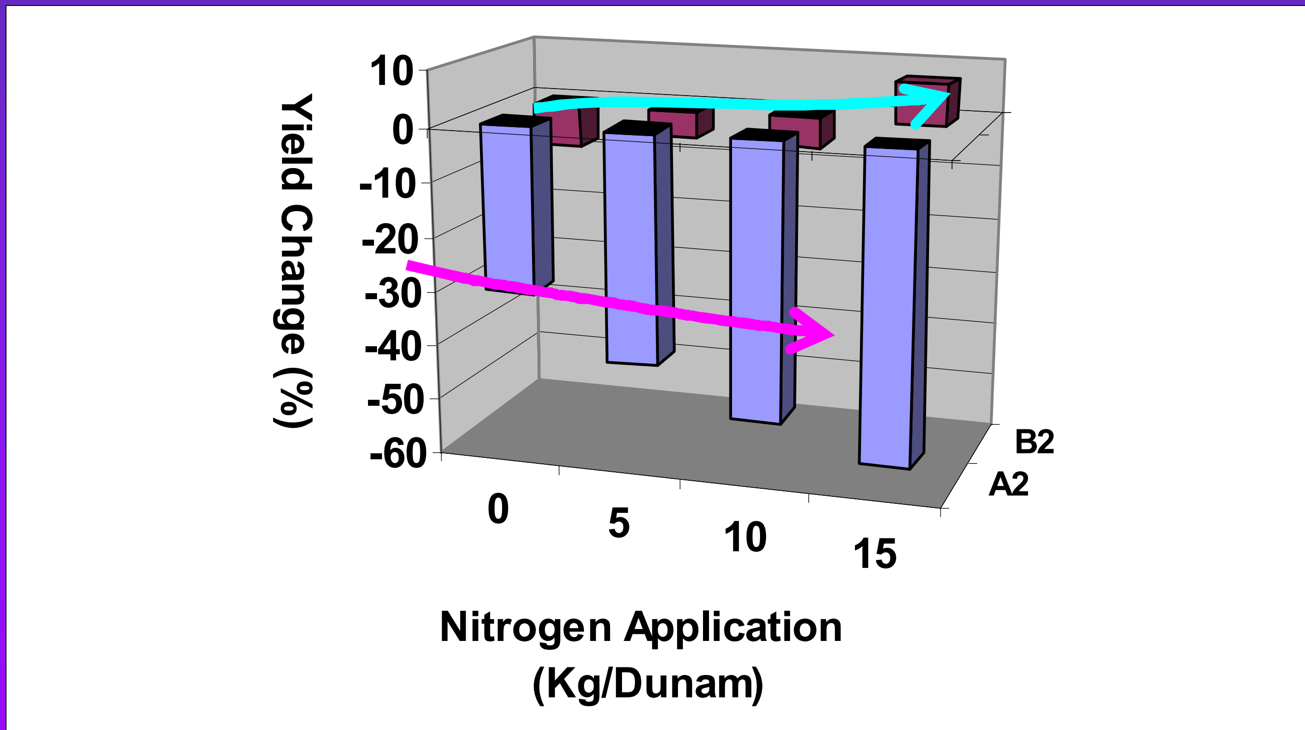
Wheat: Yield

Average annual precipitation amount at Gilat Experimental Center (control run) is 225 mm.

Change under B2: 193 mm (-14%) **Change under A2: 120 mm (-46%)**



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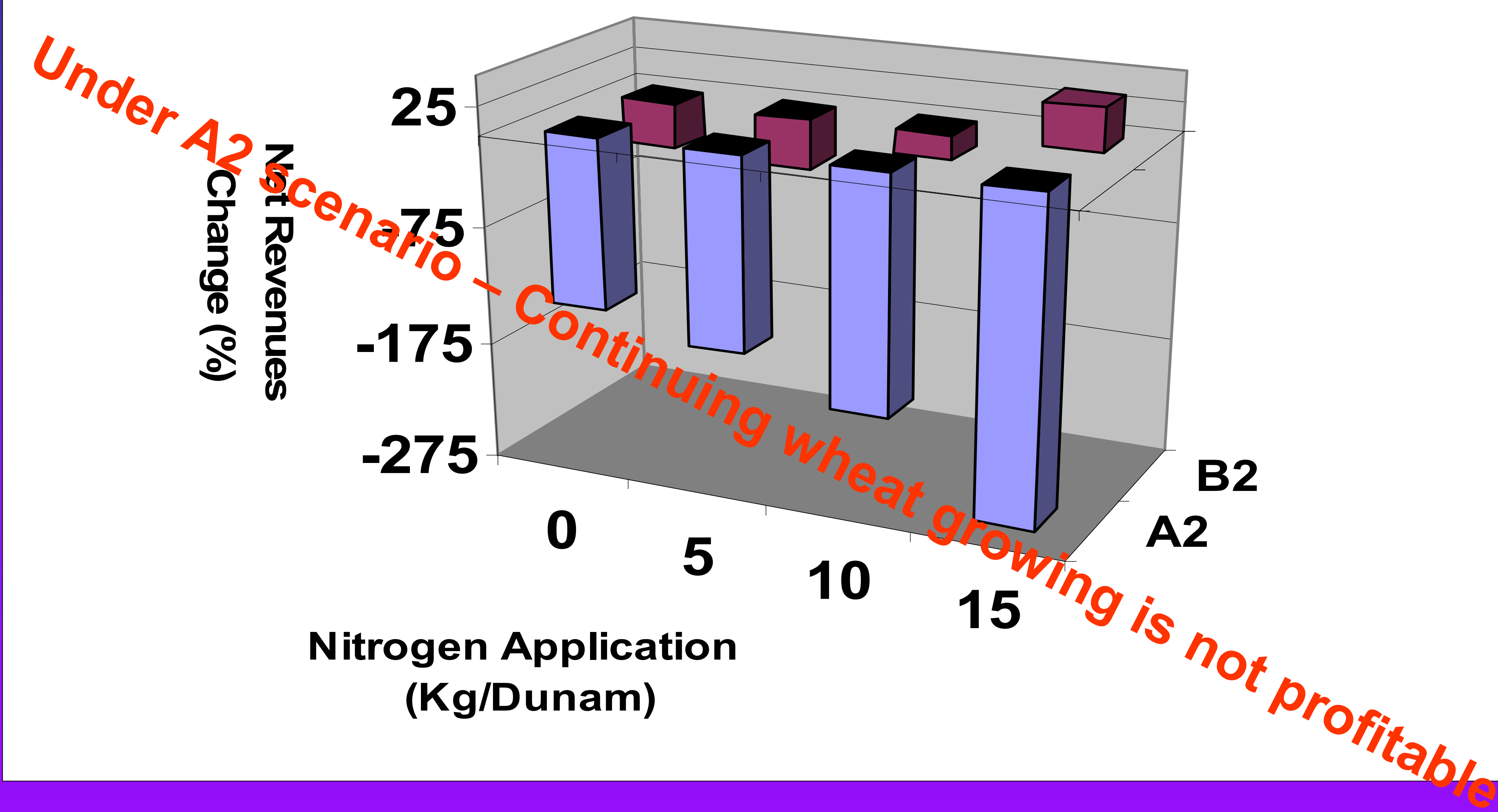
Wheat – Net Revenues



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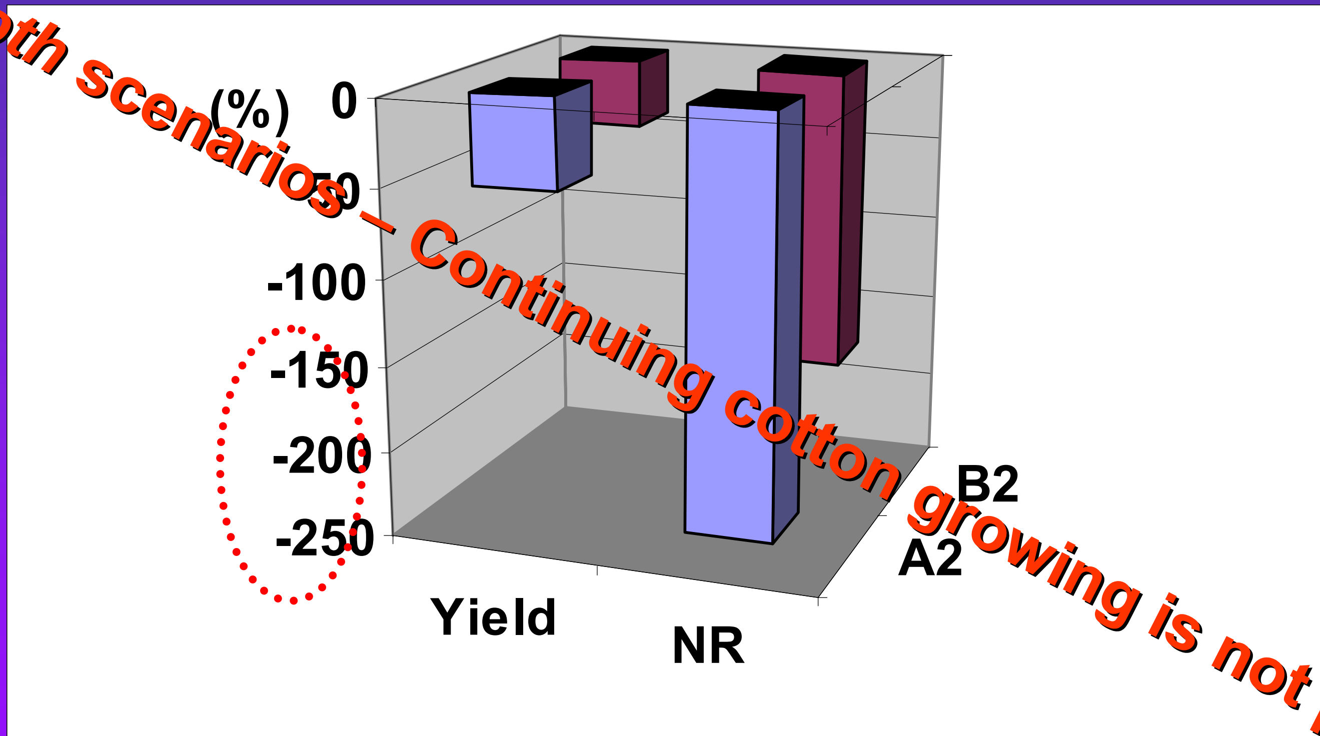
Cotton

Monthly average temperature during growing season (APR-OCT) in Yizre'el Valley (Control Run) – 24.3˚C

Change under A2: + 5.3˚C **Change under B2: + 3.6˚C**



Under both scenarios – Continuing cotton growing is not profitable

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Preliminary Analyses of Adaptation Responses to Regional CC: *Crop & Farm Level*

Modifying:

- timing of operations
- crop variety
- Land topography
- Irrigation and fertilizers amounts

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Adaptation:
Timing of Sowing: *Wheat*

Rain distribution changes between the control run and the two climatic scenario for different periods in the growing season had been examined

There is a significant decrease in rain amounts at the beginning of the winter in the future scenarios compare to the control run

Early sowing of wheat is not
An effective adaptation strategy in that region

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Adaptation Responses: Timing of Sowing: *Cotton*

Rerun Cotton-2K to examine a two-week earlier seeding

A smaller decrease in yields but net farm revenues Remain negative in both scenarios

Early sowing of cotton (as the only measure) is not an effective adaptation strategy in that region

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Adaptation Responses:
Irrigation of *Wheat*

Nitrogen application	Yield changes (%) under A2		Yield changes (%) under B2
	60 mm	120 mm	60 mm
0	-17.2	0	8
5	-23.5	0	11
10	-29	0	13.7
15	-31.3	0	16.5

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Jordan River GLOWA

Adaptation Responses:
Irrigation of *Wheat*

Nitrogen application	NR changes (%) under A2		NR changes (%) under B2
	60 mm	120 mm	60 mm
0	-146	-137	-27.3
5	-141	-114	-6.5
10	-164	-120	5.6
15	-216	-152	17

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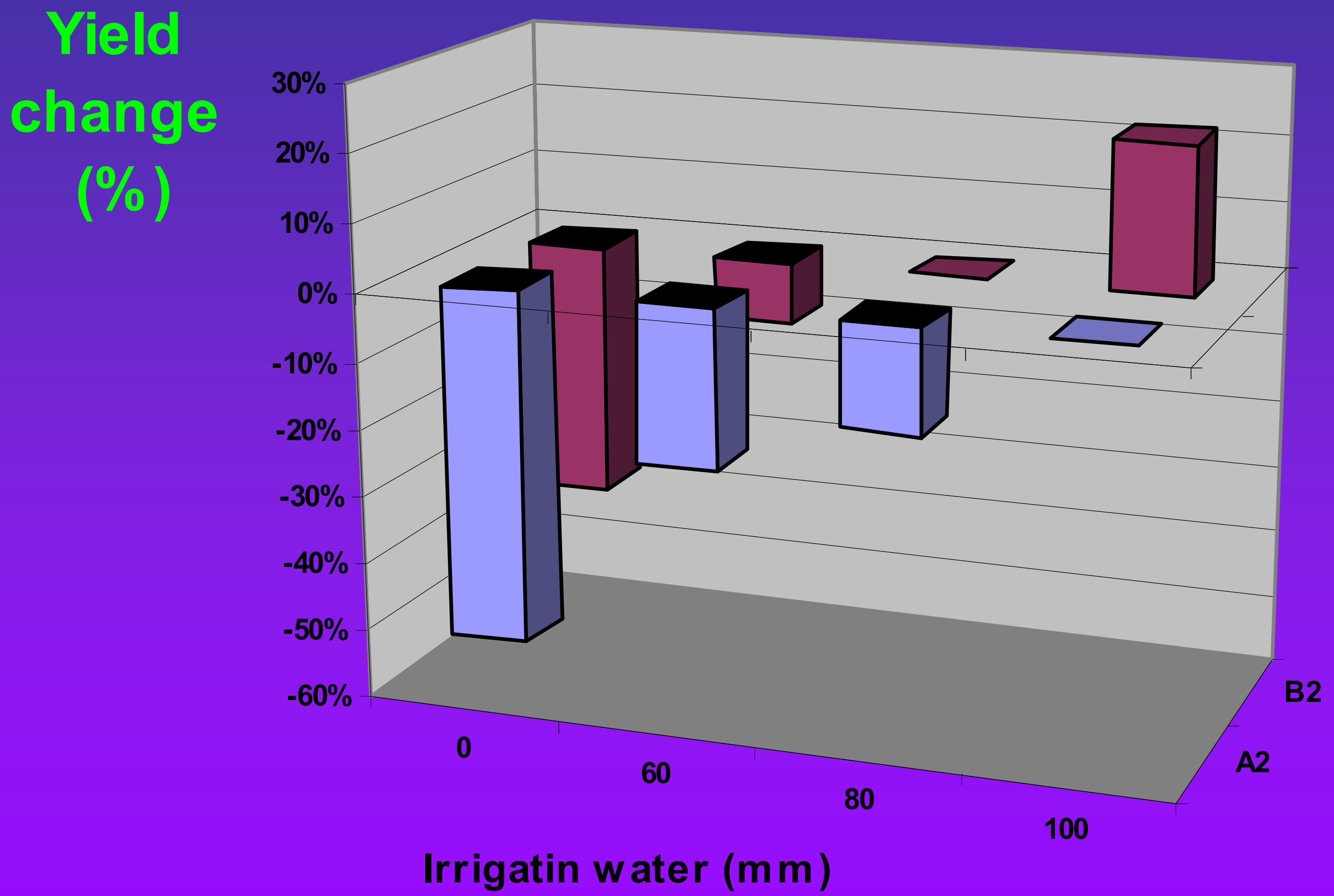
Adaptation Responses: Irrigation of *Cotton*



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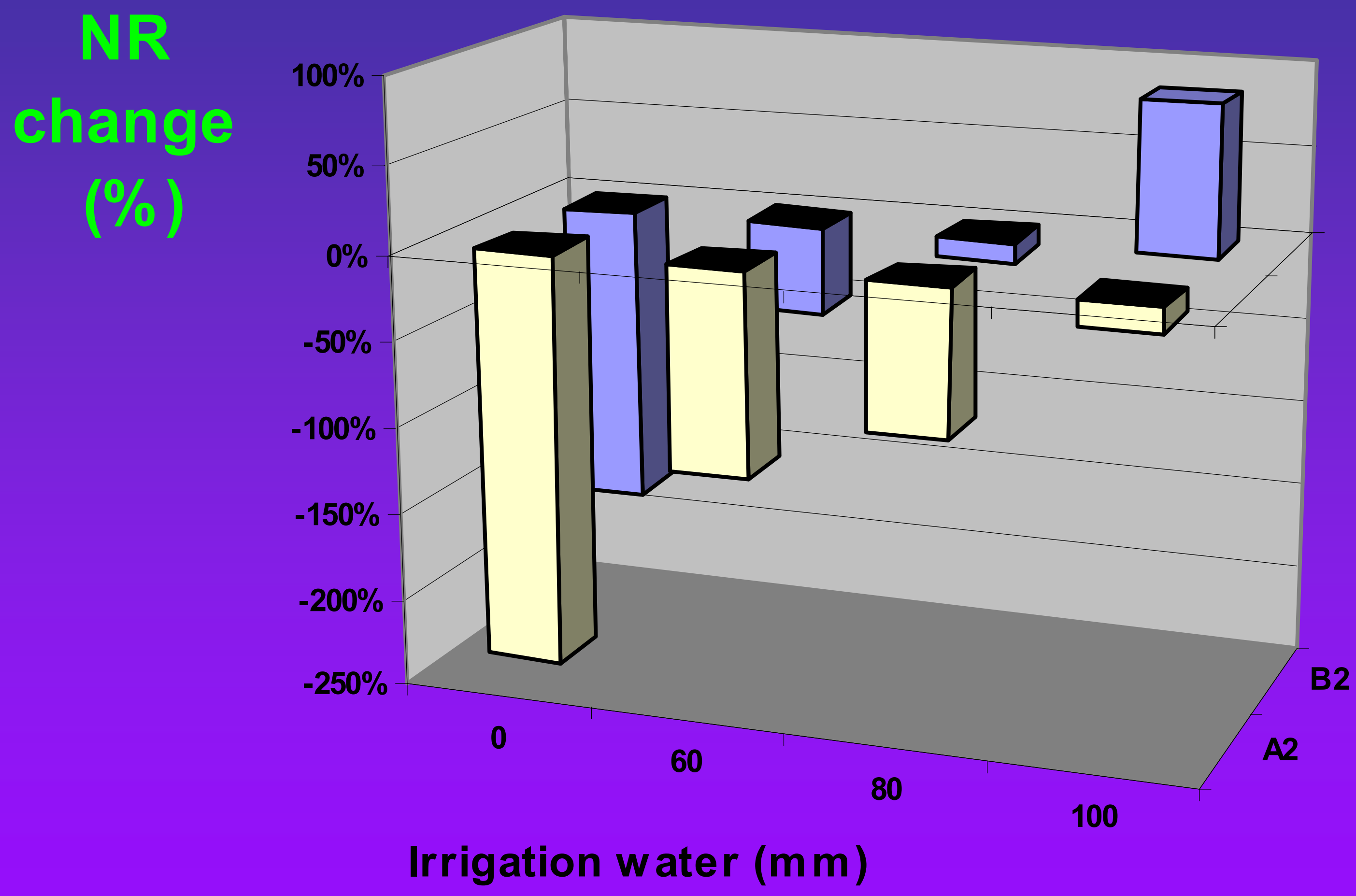
Adaptation Responses: Irrigation of *Cotton*



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Sensitivity Analysis: Output Prices

What would be the required change in P_Y (%) in order that farm reaches current net revenues under CC?

Wheat:

A2: +50% (N=0)

B2: -10% (N=15)

B2: +5% (N=10)

Cotton:

A2: +114%

B2: +71.5%

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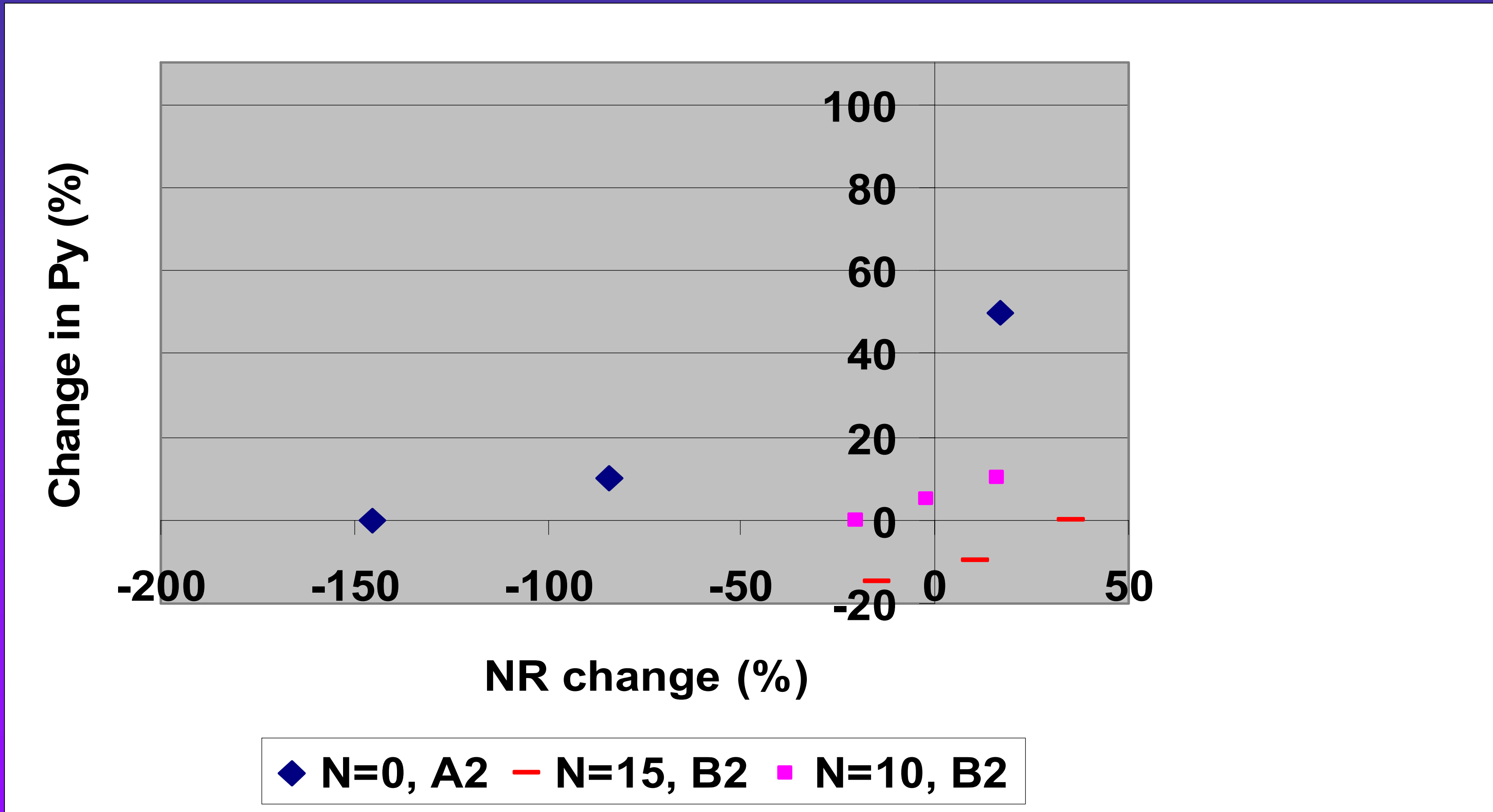
Price Sensitivity Analysis: *Wheat*



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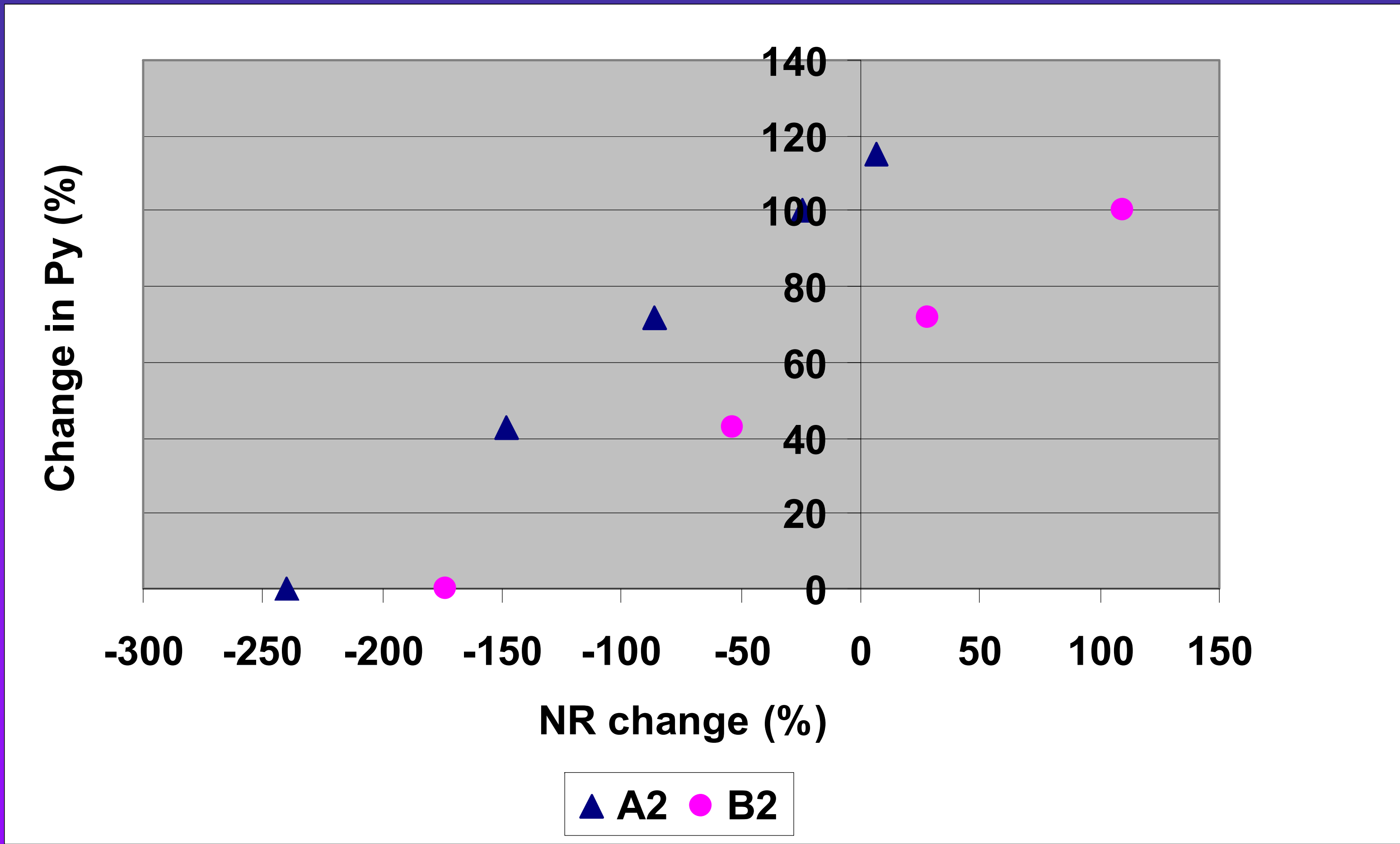
Price Sensitivity Analysis: *Cotton*



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Preliminary Conclusions

- Farm incomes regarding **wheat** production range from a slight increase to a considerable decrease, depending on climatic scenario and nitrogen application. Wheat *cannot* be grown in the Negev region under the more severe climatic scenario
- Water loses can be somewhat compensated by additional nitrogen *fertilization*
- A considerable increase is predicted in water consumption of cotton (25%)
- Changes in *timing* of farm operations, as a single adaptation measure, cannot improve economic outcomes

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From Farm Level to National Policy

- Both crop tested comprise 35% of field crops grown in Israel (Ministry of Agriculture and Rural Development, 1999)
- The Negev comprises 70% of the wheat grown in Israel
- The Yizrae'el Valley comprises 25% of the cotton grown in Israel

Additional water for field crops under B2: +217 m.c.m
(20% of total agricultural water use)

Wheat

A2 - Not worthwhile
B2 - 42 Million cu.m. (excluding the highest N application level)

Cotton

A2 – 5 Million cu.m.
B2 – 4 Million cu.m.

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6. Farm and Regional Level Analyses

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- In this stage we simulated optimal allocation of land and water resources among farm land uses, under predicted regional CC, and assess their economic implications
- We employed a two-stage mathematical programming model:

  I. A MP calibration procedure for each region

  II. Determining the optimal allocation of agricultural land and surface water among various crops

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Essentials of the Economic Analysis

INPUT
Production functions, economic data* (prices, costs), climate conditions (rainfall, temperature) and agricultural land-use** patterns;

OBJECTIVE
Selection of regional agricultural land and water allocation among crops, so as to maximize regional well-being (including external benefits such as aesthetic landscapes);

SUBJECT TO
Land, water and other constrained resources;

OUTPUT
Optimal regional land use and water allocations, measures of welfare variations as a response to climate changes, etc.

**Economic reports, 2003 ; **Central Bureau of Statistics, Israel, 2002*

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The Regional Mathematical Programming Model

Optimization model - maximizes net revenues under the assumption that farmers maximize the water and land allocation

$$\max_{x_1,\ldots,x_I,s_1,\ldots s_I} \Pi = \sum_{i=1}^{I} x_i \left[p_i y_i (s_i \mid r) - p^s s_i - c_i \right]$$

$s.t.$

$$\sum_{i=1}^{I} x_i \leq X;$$

$$\sum_{i=1}^{I} s_i x_i \leq S$$

s_i is the farmer's decision variable

$\Pi - revenues$
$i - crop$
$x - land$
$p - price$
$y - yield$
$s - SurfaceWater$
$r - rain$
$c - costs$
$S - TotalWaterConstraint$
$X - TotalLandConstraint$

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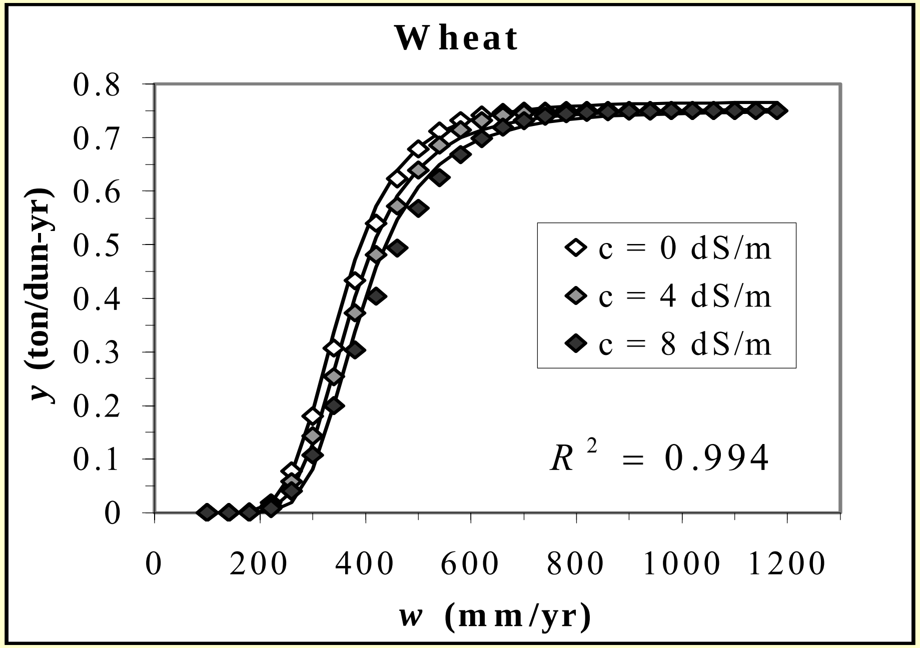
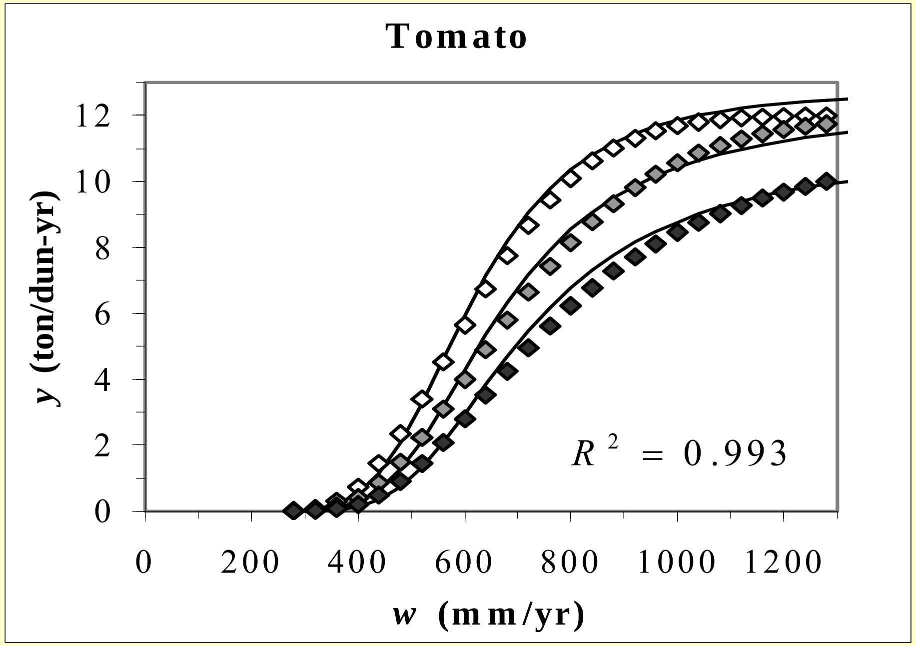
A preliminary Step in the Regional Modeling: Evaluating Yield Response Functions

Evaluating four production functions of representative crops: wheat (field crops), cotton, vetch (forage) and tomato (vegetables)





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Cont.: Employing Meta-Analyses to Incorporate Yield Response in the Regional MP Model

1. Creating yield crops data by using a model that formulates crop-water production functions combining evapotranspiration, water salinity and water quantity supplied to the field (Knapp 1992, Letey and Dinar 1985)
   - The yield is a function of evapotranspiration, while the evapotranspiration is a function of water and salinity
   - Additional crops: alfalfa, cauliflower, celery, corn, lettuce, etc.

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2. Using the yield data for evaluating production functions by regression (Kan et al, 2002)
   - Use of different levels of water and salinity
   - Calibrate the land and the water allocation in order to reconstruct the reality
   - Assume a spatial distribution function for water in the field

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Calibrating the Regional MP Model

The problem

Models' outputs may not fit observed farming activities

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- WHEN is calibration needed?

  When the model's outputs (optimal resource allocation) do not fit actual observed farming activities.

- WHY is it required?

  Because policy recommendations based on a model that is not capable of reconstructing reality, are likely to be taken skeptically

- HOW does the model fail in reconstructing real-world data?

  The impact of hidden factors like knowledge and administration limitations, are not taken into account

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Approaches to the Calibration Procedures

1. Imposing upper and lower bounds to production levels as constraints

   Shadow values of these constraints reflect the marginal costs related to the influence of the hidden factors

2. Adding a new nonlinear term to the objective function

   This nonlinear term represents the influence of the hidden factors; it is calibrated in a way that the model reproduces the optimal base year results

We use the second approach, according to a three-stage procedure developed by Howitt (1995)

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Stages in the Calibration Procedure

First stage

Specify a linear programming model and calculate shadow values for the total-land constraint and the crop-land calibration constraints

Second stage

Using the shadow values to calculate the parameters of a nonlinear element added to the objective function, with respect to "non-marginal crops"

Third stage

Using yield-variation data to recalculate the nonlinear-element's parameters for all crops, including the "marginal crop"

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First Stage: Specify the LP Model

Without the calibration, the land will be allocated to one most profitable crop

$$\max_{x_1,\dots,x_i,\dots,x_I} \Pi = \sum_{i=1}^{I} x_i\left(p_i y_i\left(\tilde{s}_i \mid \tilde{r}\right) - p^s \tilde{s}_i - c_i\right)$$

$$s.t.$$

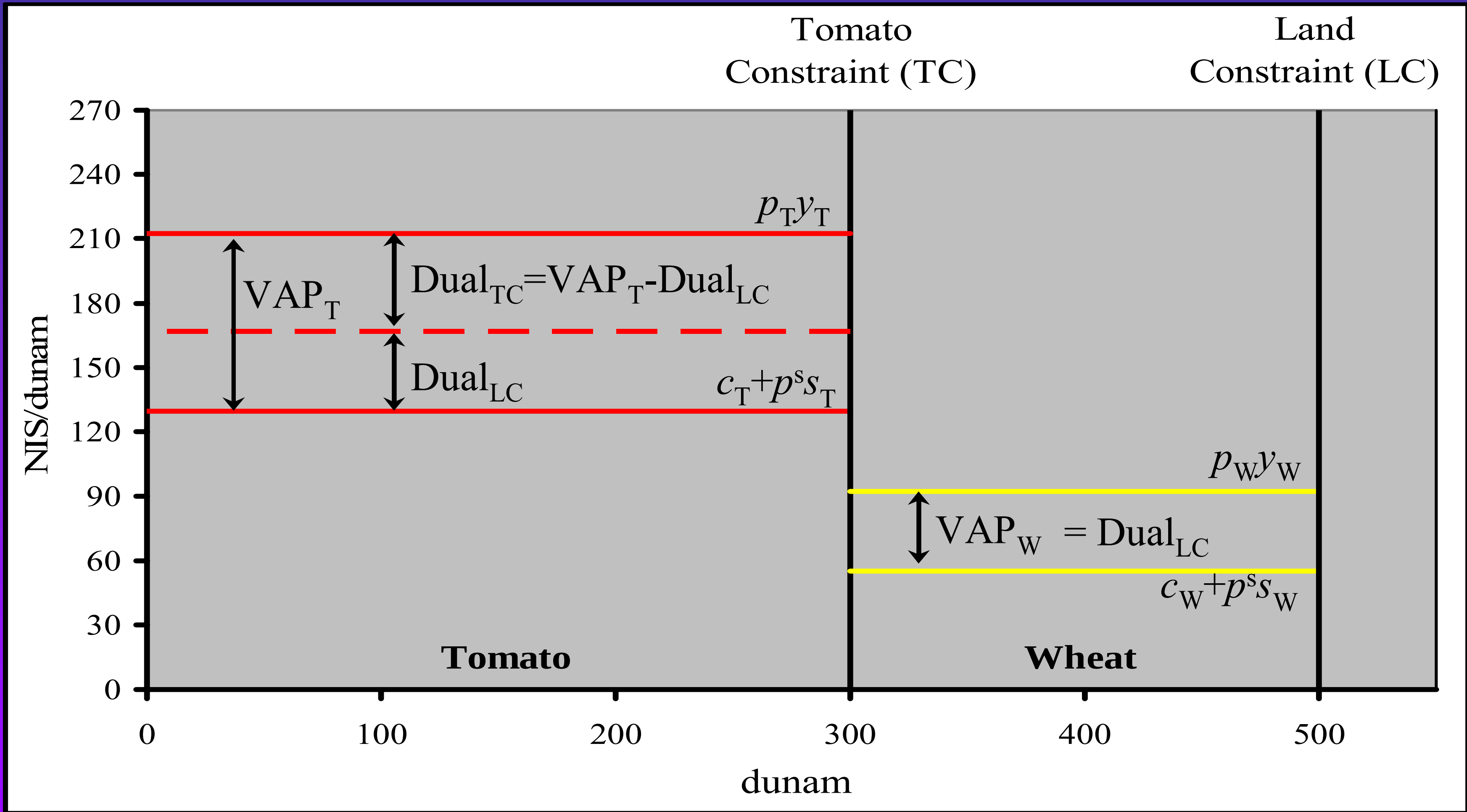
$$x_i \le \tilde{x},\ \ i = 1,2,3,\dots,I$$

$$\sum_{i=1}^{I} x_i \le X$$

$\tilde{s}_i$ is the observed amount of surface water at the base year

$\sim$ – BaseYear
Π – profit
i – crop
x – land
p – price
y – yield
s – SurfaceWater
r – rain
c – costs
$\tilde{x}_i$ – CropLandConstraint
X – TotalLandConstraint

Calculating Shadow Prices for the Constraints (Dual Values)



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Stages in the Calibration Procedure

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Second Stage: Deriving an "Adjustment" Factor: δ, γ

A highly probable source of nonlinearity is the heterogeneous land quality, and declining marginal yields as the proportion of a crop in a specific area is increased

Assume a yield function that decreases the marginal crop yield per acre as a linear function of the acreage planted

$$y_i = \gamma_i - \delta_i x_i$$

Where δ_i *and* γ_i *are, respectively, the intercept and slope of the marginal yield function for crop i*

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We now have a modified, *nonlinear* programming model

$$\max_{x_1,\ldots,x_I} \Pi = \sum_{i=1}^{I} x_i \left(p_i(\gamma_i - \delta_i x_i) \frac{y_i(\tilde{s}_i | r)}{\tilde{y}_i} - p^s \tilde{s}_i - c_i \right)$$

$s.t.$

$$x_i \leq \tilde{x}_i \,, i = 1,2,3,\ldots,I$$

$$\sum_{i=1}^{I} x_i \leq X$$

Unite the response to land and water into the model.

In the base year:

$$\frac{y_i(\tilde{s}_i | r)}{\tilde{y}_i} = 1$$

$\sim$ − *BaseYear*

Π − *profit*

i − *crop*

x − *land*

p − *price*

γ, δ − *YieldParameters*

s − *SurfaceWater*

c − *costs*

$\tilde{x}_i$ − *CropLandConstraint*

X − *TotalLandConstraint*

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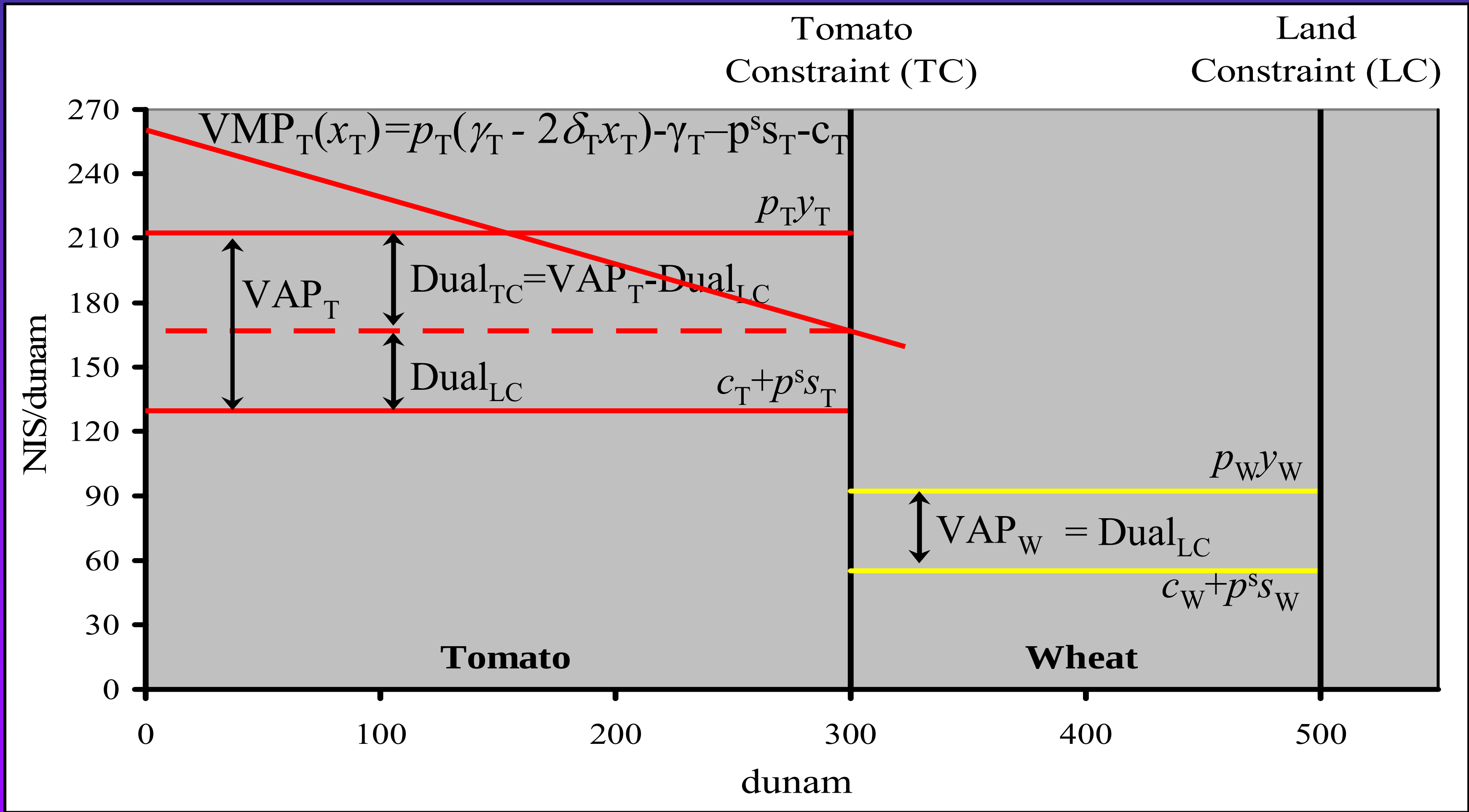
Readjusting Farm-Level and Regional-Level Cropland Allocations



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Estimating δi and γi

For the non-marginal crops, i.e., $VAP_i(\tilde{x}_i) > DualLC$:

$$\text{Dual}_i = \text{VAP}_i(\tilde{x}_i) - \text{Dual}_{\text{LC}} = \text{VAP}_i(\tilde{x}_i) - \text{VMP}_i(\tilde{x}_i)$$

$$\text{VAP}_i(\tilde{x}_i) = [\tilde{x}_i(p_i y_i - \gamma_i - p^s \tilde{s}_i - c_i)] / \tilde{x}_i$$
$$= \tilde{x}_i[p_i(\gamma_i - \delta_i \tilde{x}_i) - \gamma_i - p^s \tilde{s}_i - c_i] / \tilde{x}_i$$
$$= p_i \gamma_i - p_i \delta_i \tilde{x}_i - \gamma_i - p^s \tilde{s}_i - c_i$$

$$\text{VMP}_i(\tilde{x}_i) = [\tilde{x}_i(p_i y_i - \gamma_i - p^s \tilde{s}_i - c_i)]'$$
$$= [\tilde{x}_i(p_i(\gamma_i - \delta_i \tilde{x}_i) - \gamma_i - p^s \tilde{s}_i - c_i)]'$$
$$= [\tilde{x}_i p_i \gamma_i - \tilde{x}_i p_i \delta_i x_i - \tilde{x}_i \gamma_i - \tilde{x}_i p^s \tilde{s}_i - c_i]'$$
$$= p_i \gamma_i - 2 p_i \delta_i \tilde{x}_i - \gamma_i - p^s \tilde{s}_i - c_i$$

$$\text{Dual}_i = p_i \delta_i \tilde{x}_i$$

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Now it is possible to calculate δ_i and γ_i

$$\Rightarrow \text{Dual}_i = p_i \delta_i \widetilde{x}_i$$

$$\delta_i = \frac{\text{Dual}_i}{p_i \widetilde{x}_i}, \quad \gamma_i = y_i + \delta_i \widetilde{x}_i$$

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Stages in the Calibration Procedure

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Third Stage: Identifying the "Marginal" Crop in Cropland Allocations

We need some more information for calculating the parameters for the marginal crop. Therefore, we'll use information regarding the yield variance

Given that Δy_1 = $\pm$ certain percentage of the average field:

$$\text{Dual}_{LC} = \text{VAP}_1\left(y_1 - \Delta y_1\right)$$

$$\text{Dual}_1 = \text{VAP}_1\left(y_1\right) - \text{Dual}_{LC}$$

δ_i and γ_i parameters are calculated for all crops, including the marginal crop, according to the updated value of the DualLC

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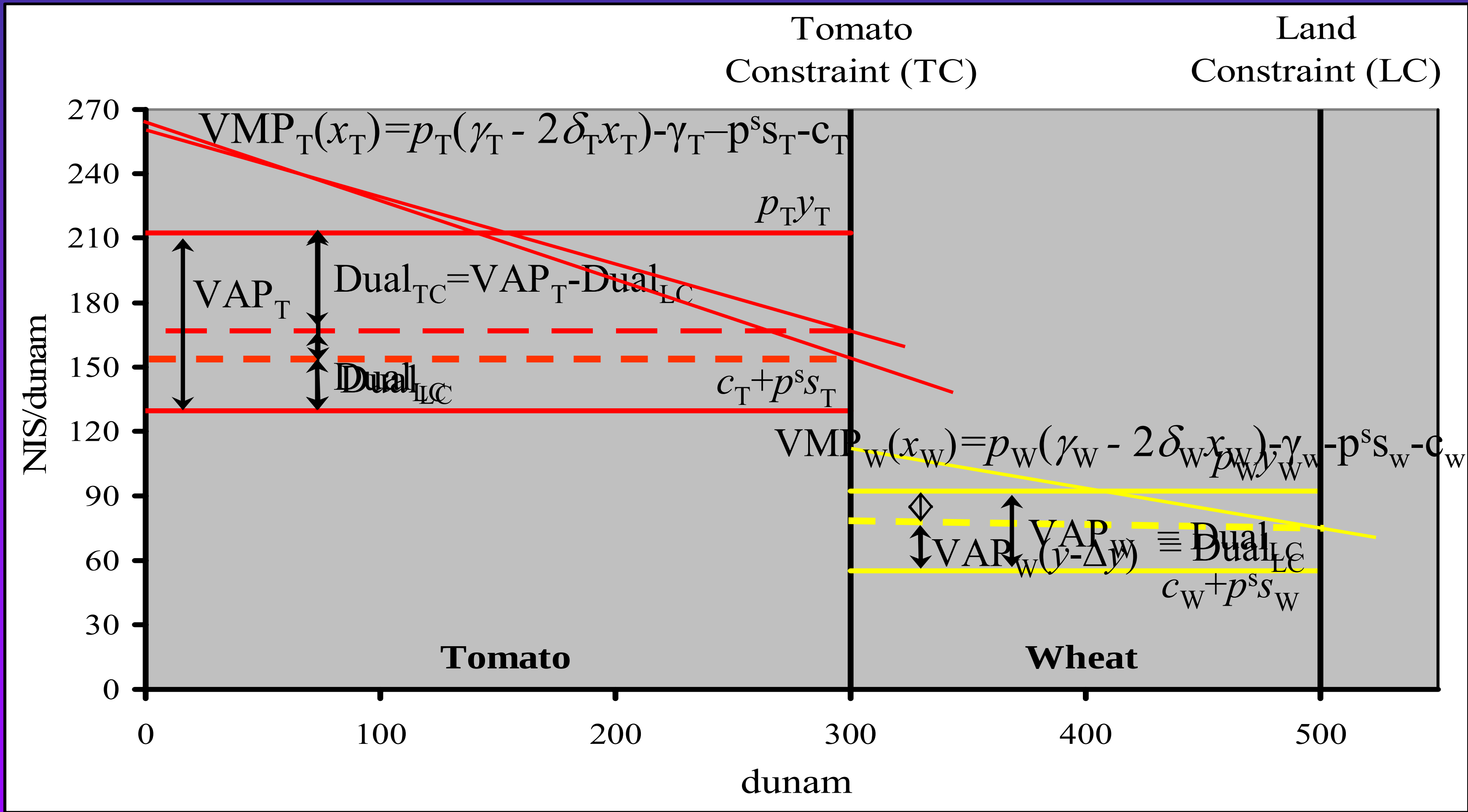
Third Stage: The Marginal Crop



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Final Outcome: A *Calibrated,* NL Programming Model for Cropland Allocations

$$\max_{x_1,\ldots,x_I,s_1,\ldots s_I} \Pi = \sum_{i=1}^{I} x_i \left[p_i(\gamma_i - \delta_i x_i) \frac{y_i(s_i \mid r)}{\tilde{y}_i} - p^s s_i - c_i \right]$$

$s.t.$

$$\sum_{i=1}^{I} x_i \le X$$

$$\sum_{i=1}^{I} s_i x_i \le S$$

Unite the response to land and water into the model.

In the base year: $\frac{y_i(\tilde{s}_i \mid r)}{\tilde{y}_i} = 1$

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Downscaling CC Projections (For Israel's Coastal Region)

(Dayan & Koch, 1999)

Year	Annual Mean Temperature	Annual Precipitation
2020	0.3 - 0.4°C	(-2) - (-1)%
2050	0.7 - 0.8°C	(-4) - (-2)%
2100	1.6 -1.8°C	(-8) - (-4)%

Evaluating Annual Level and Distribution of Precipitation

The Gamma distribution fits probability distributions density to rainfall totals (Ben Gai et al., 1999)

$$f\left(r \mid \alpha_j, \beta_j\right) = \left(\beta_j\right)^{\alpha_j} \left(r\right)^{\alpha_j - 1} e^{-\beta_j r} \left[\Gamma\left(\alpha_j\right)\right]^{-1}$$

- ***j*** - region
- ***r*** – annual rainfall (a random variable distributed according to Gamma-distribution function)
- α - the shape parameter of the distribution expressing the extent of the symmetry around the mode
- β - the reciprocal of the scale parameter of the distribution, scaling the rainfall amounts at respective frequencies

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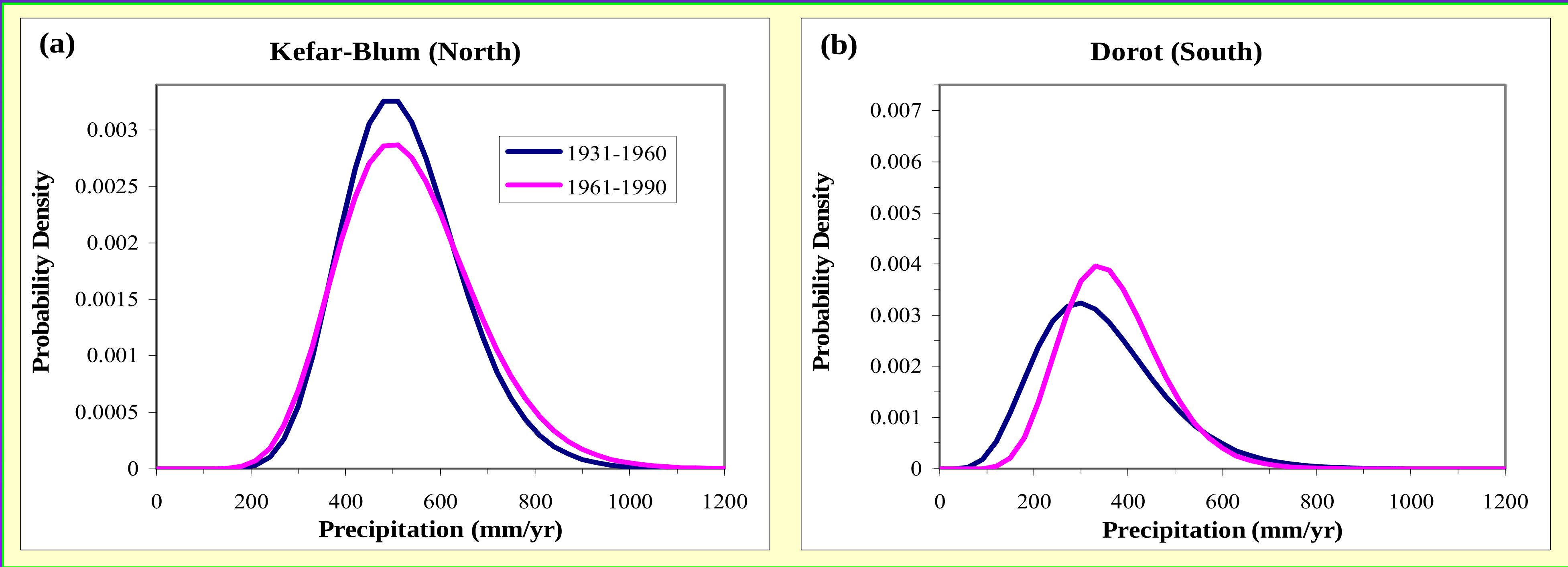
Density Functions for Annual Regional Precipitation Levels

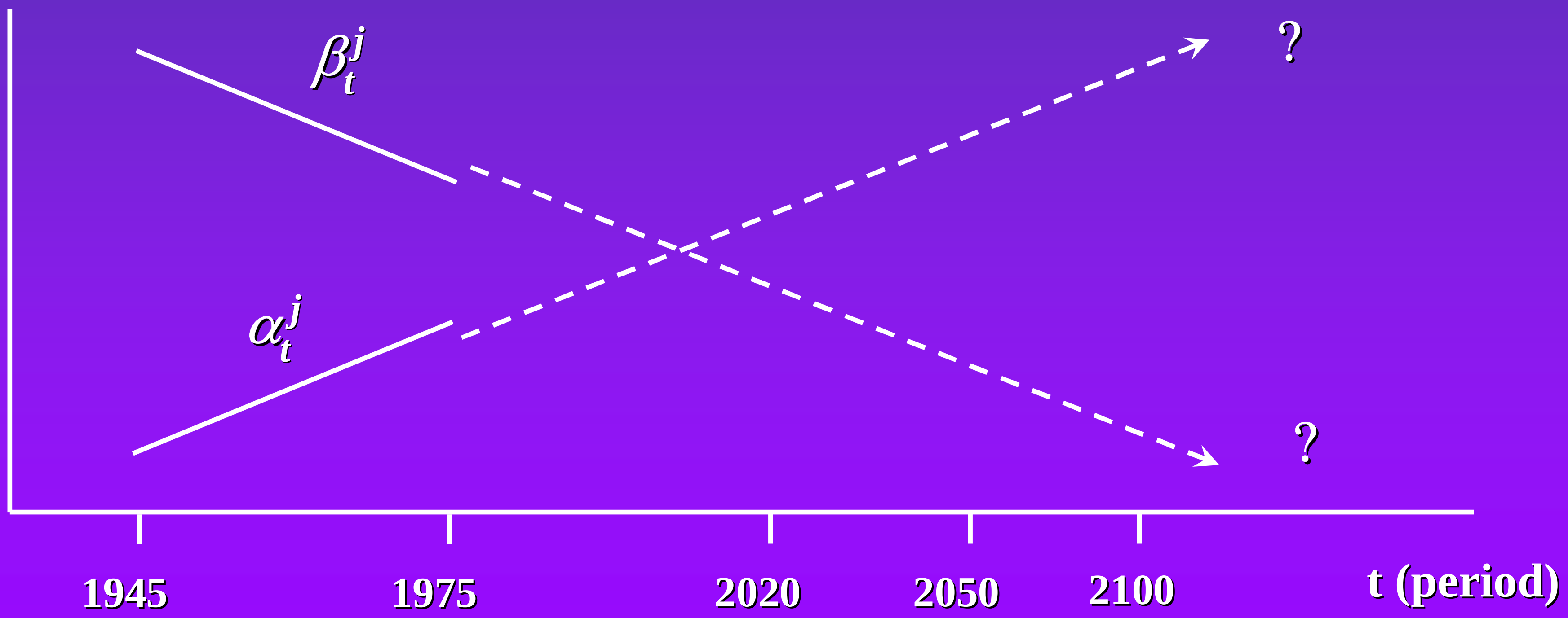
Evaluating Gamma distribution functions for two periods based on 60 stations distributed over Israel:

First period: 1931-1960 ; Second period: 1961-1990



Estimating *Future* Density Functions Parameters

- 1945 - median year of the first period 1931-1960
- 1975 - median year of the second period 1961-1990



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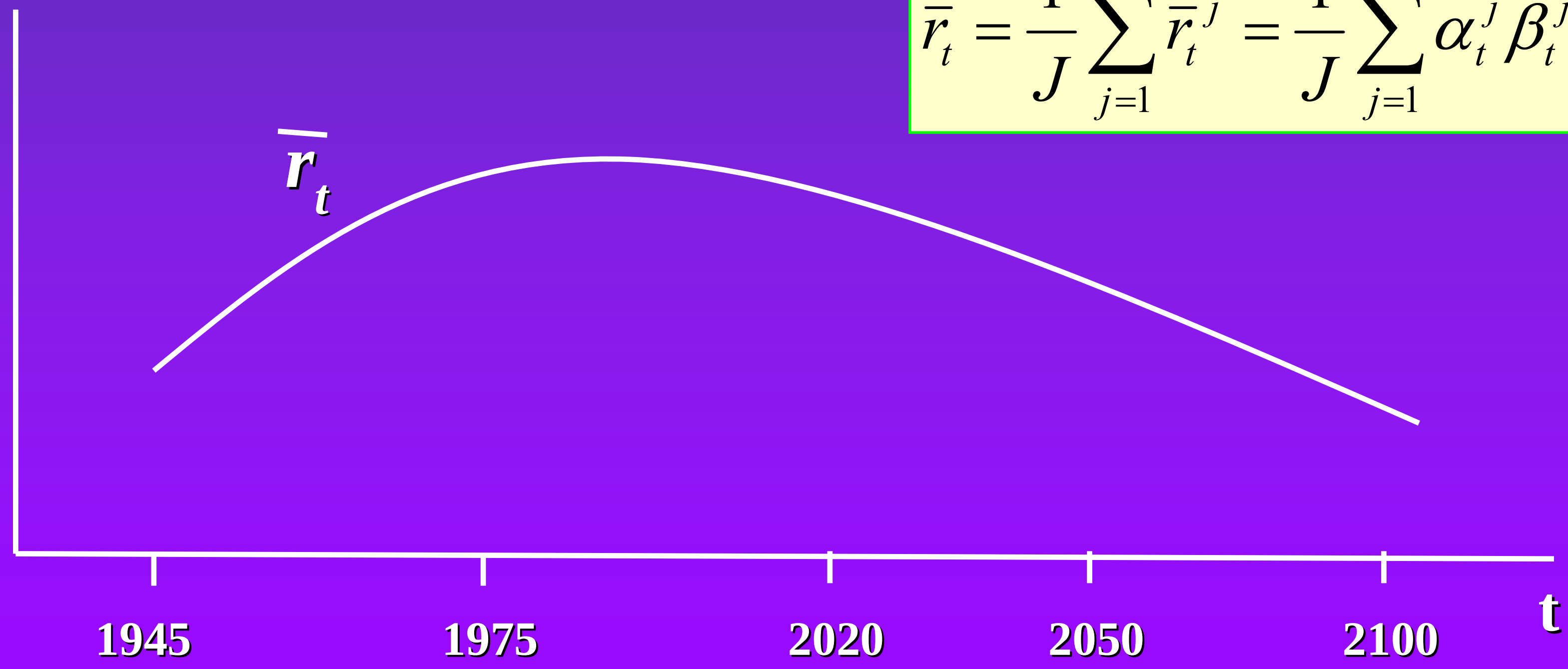
Result: Future Trends in Expected Precipitation

α and β give the expected annual precipitation for each region in Israel for the years: 2020, 2050 & 2100 in a way that the average annual rainfall expectations will match these predictions:

$$\bar{r}_t = \frac{1}{J}\sum_{j=1}^{J} \bar{r}_t^{\,j} = \frac{1}{J}\sum_{j=1}^{J} \alpha_t^j \beta_t^j$$



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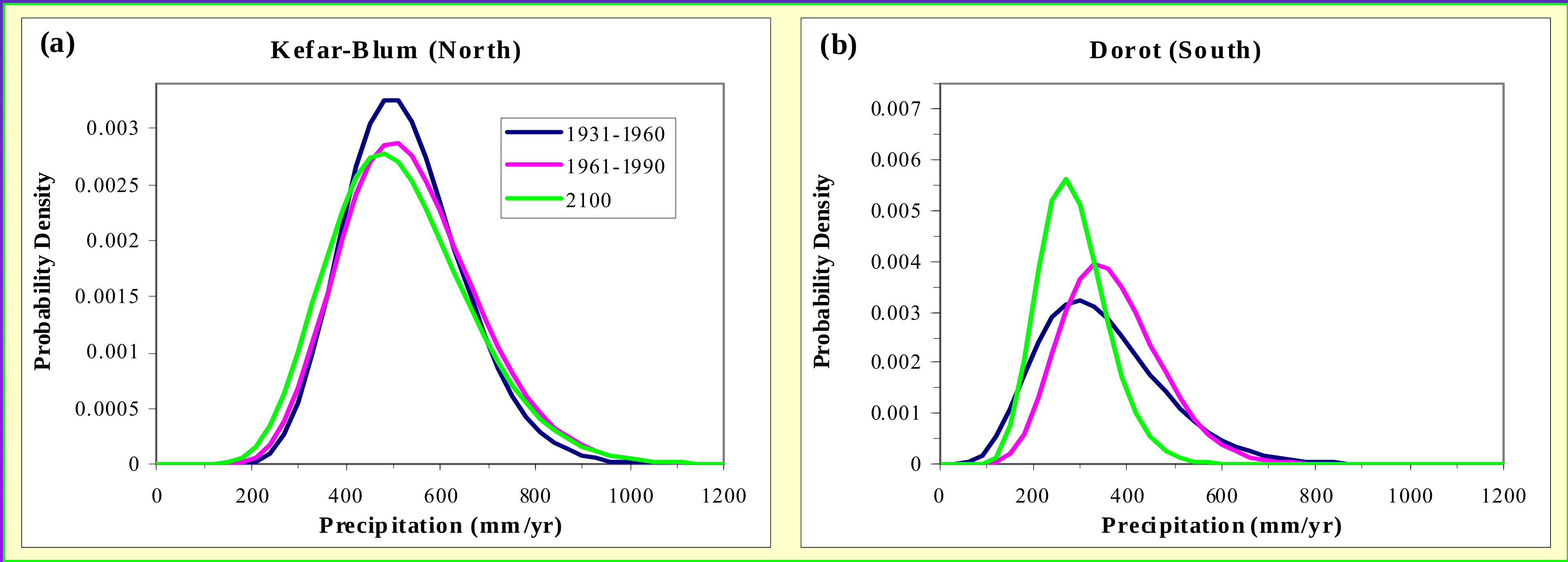
Example: Applying Future Precipitation to a Regional CC Scenario



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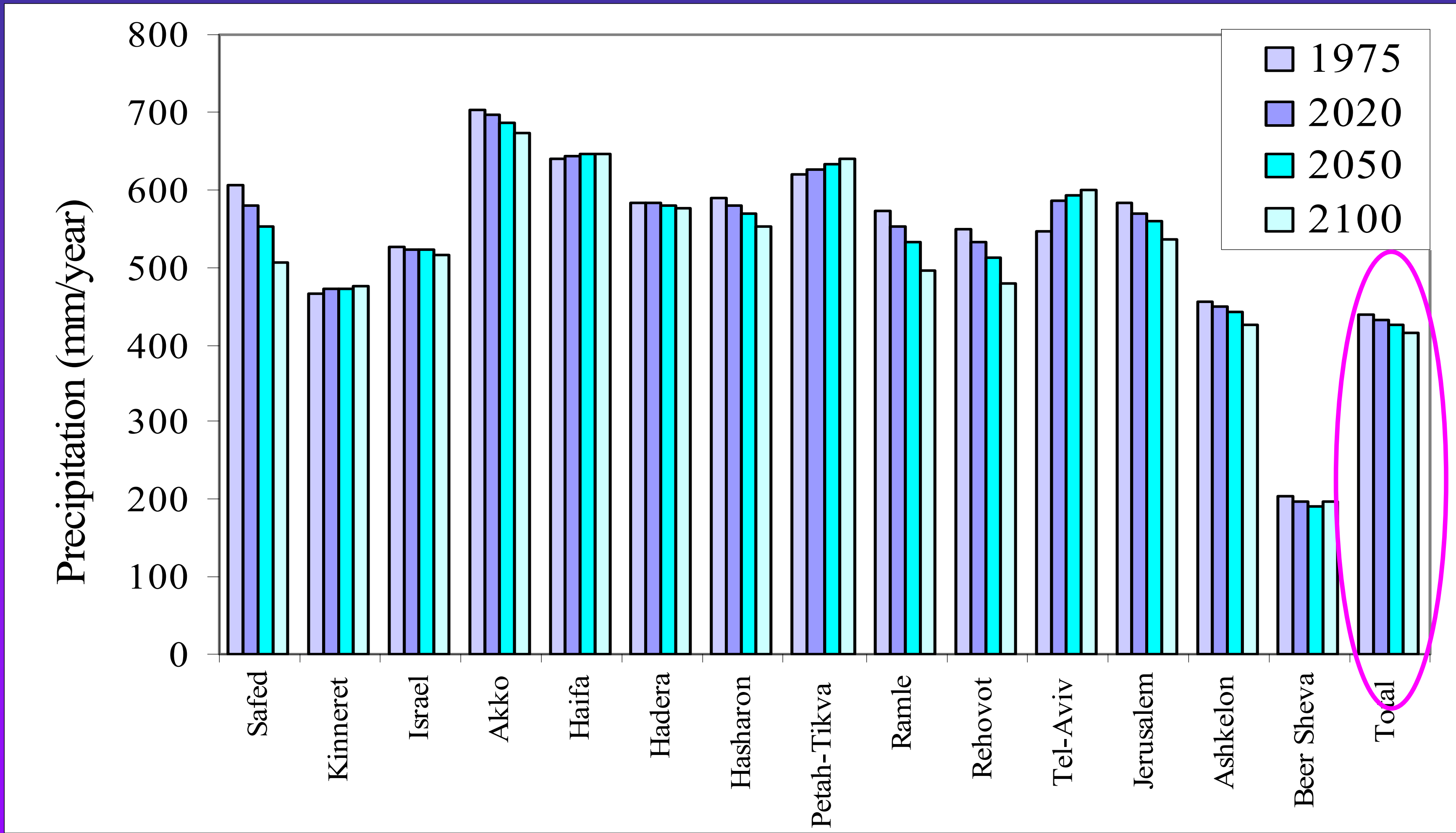
Regional Trends in Expected Precipitation



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Recap

Applying the calibrated MP model to estimate optimal cropland and water allocation adjustments under predicted regional CC (w.r.t. precipitation)

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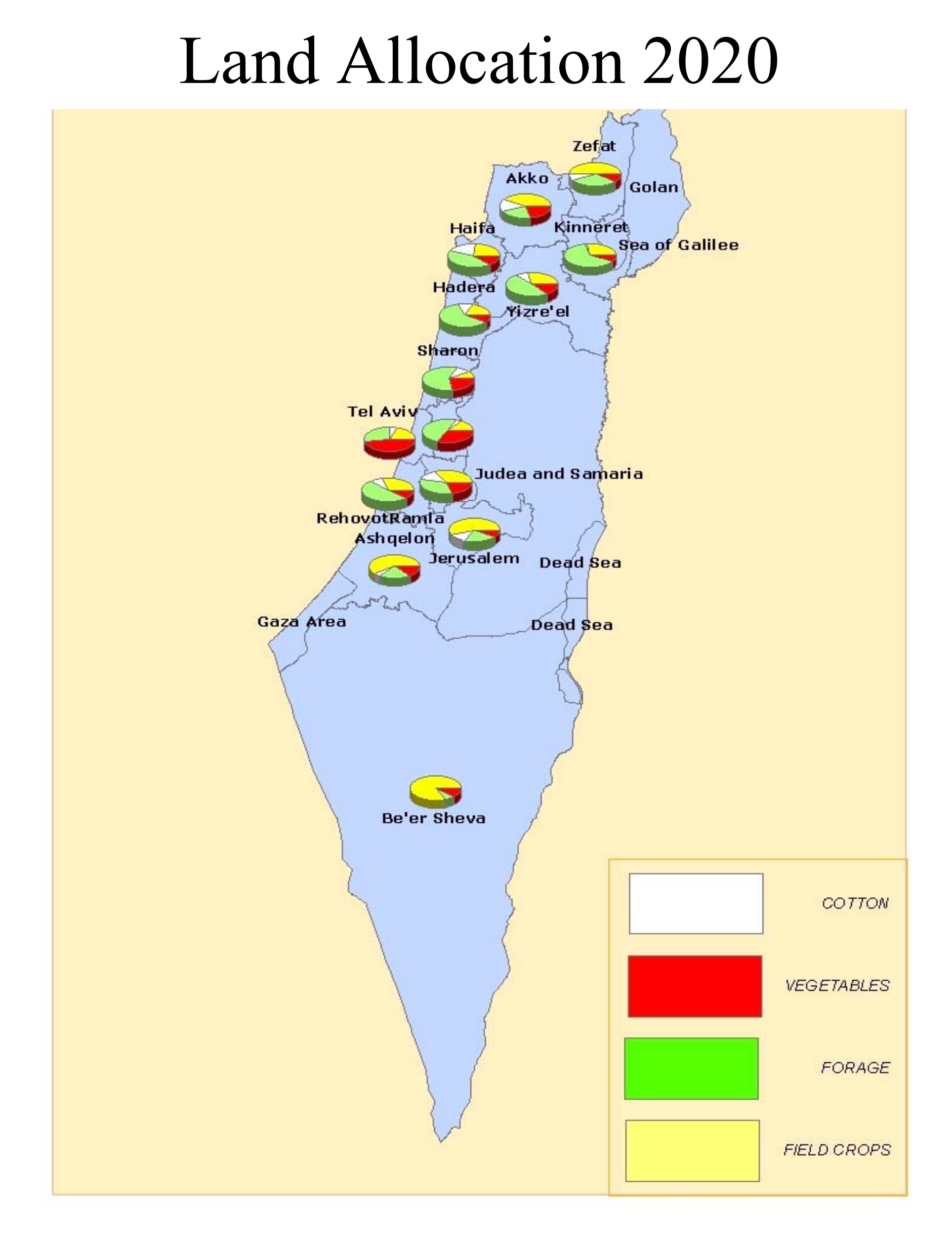

Initial Results

The model was run based on 2003 agricultural and economic data, under rainfall conditions in 1975, as well as under projected precipitations in 2020, 2050 and 2100

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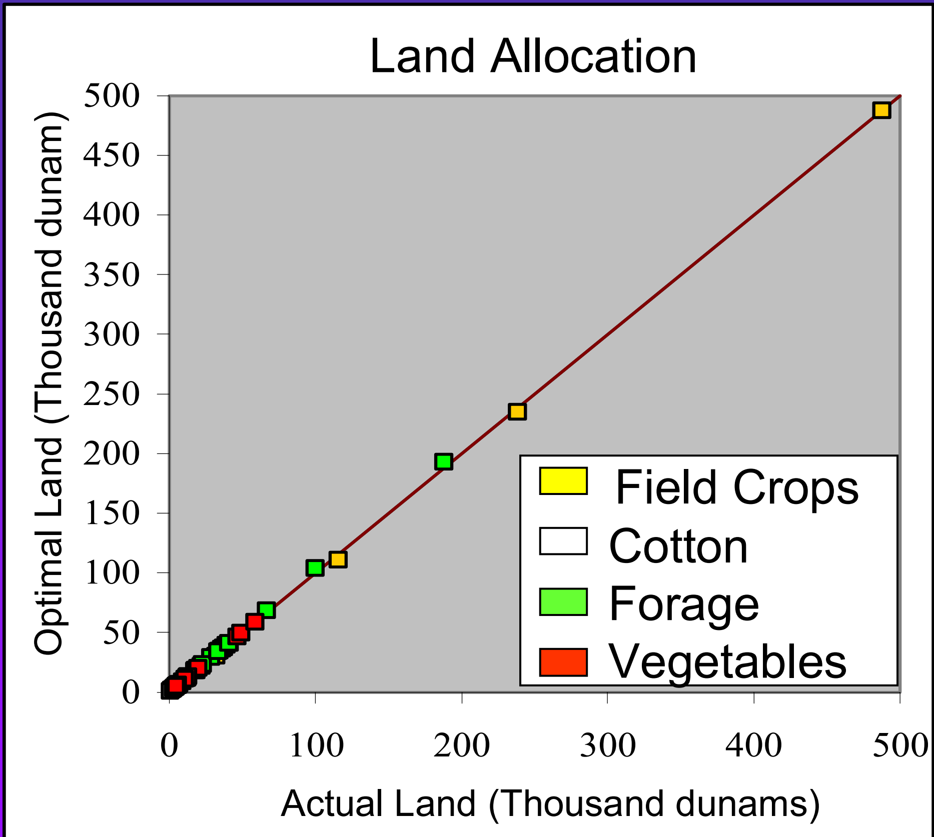
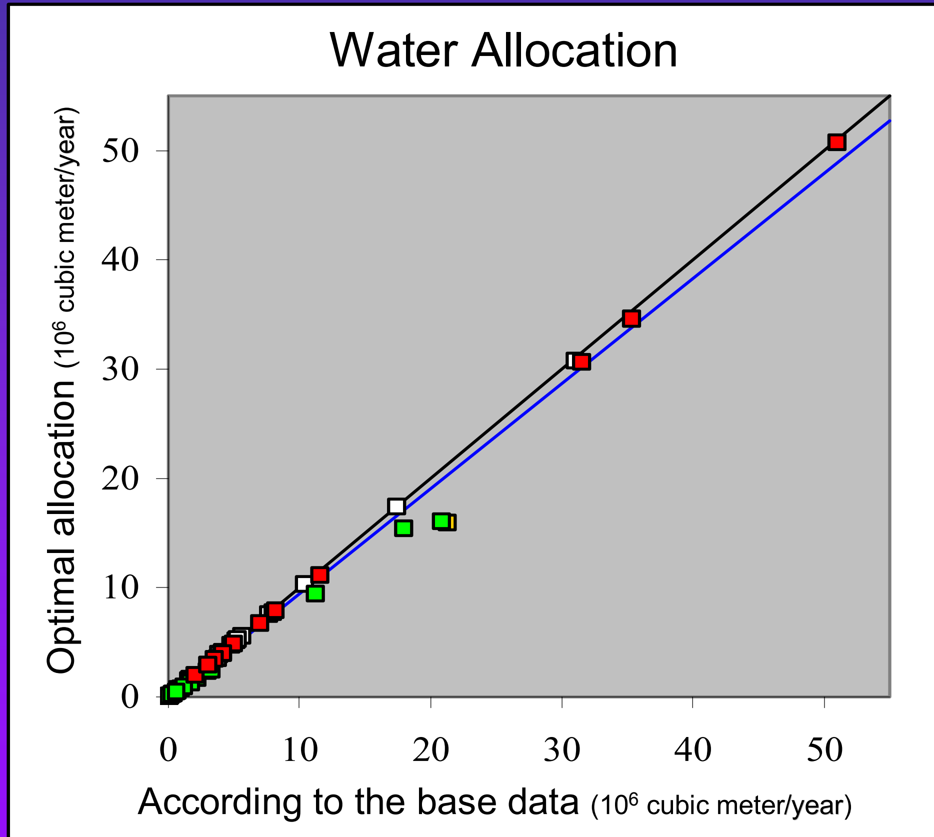
Sideline: Assessing the Efficacy of the Calibration Procedure





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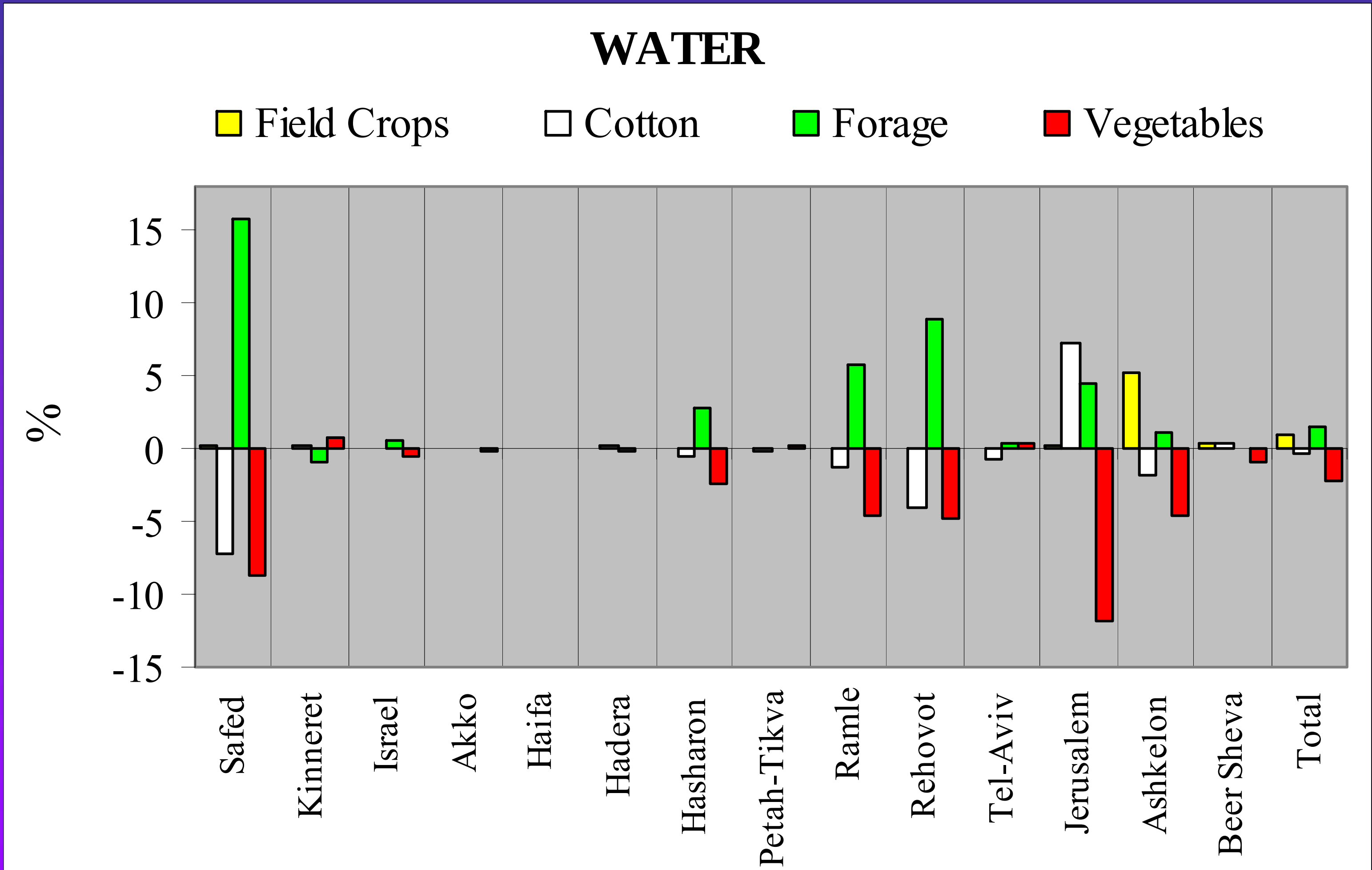
“Bottom Line”: Changes in *Water Allocation*: 1975 to 2100



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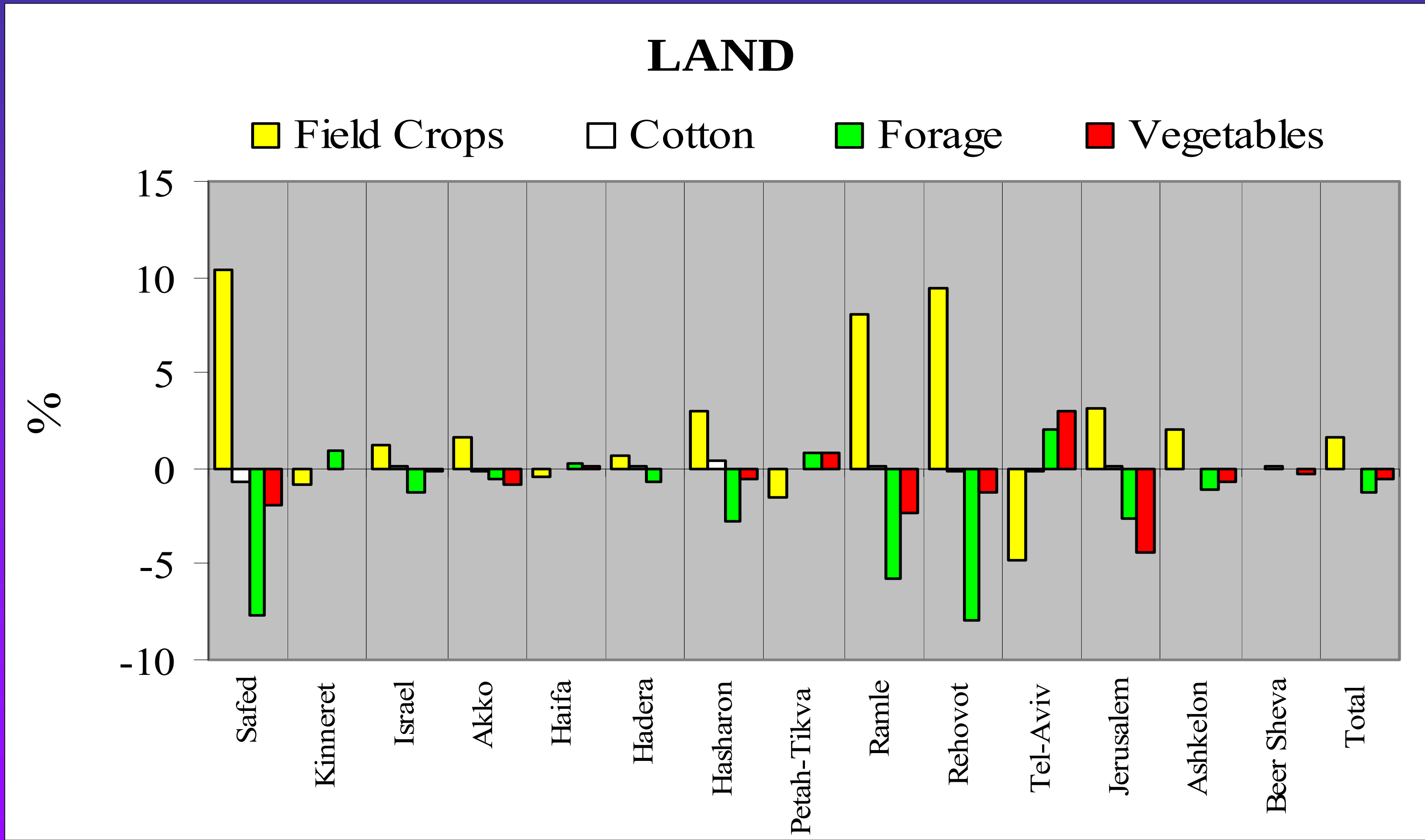
“Bottom Line”: Changes in *Land Allocation*, 1975 to 2100



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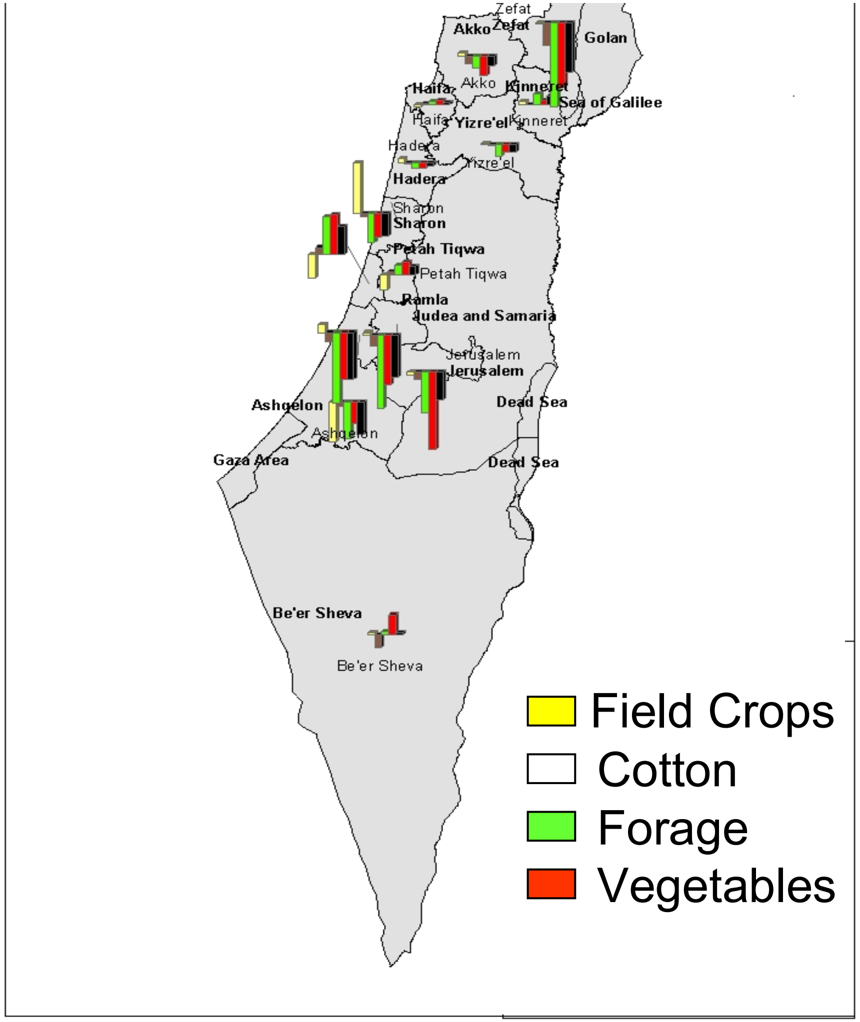
“Bottom Line”: Regional Trends in Net Revenues, 1975 to 2100



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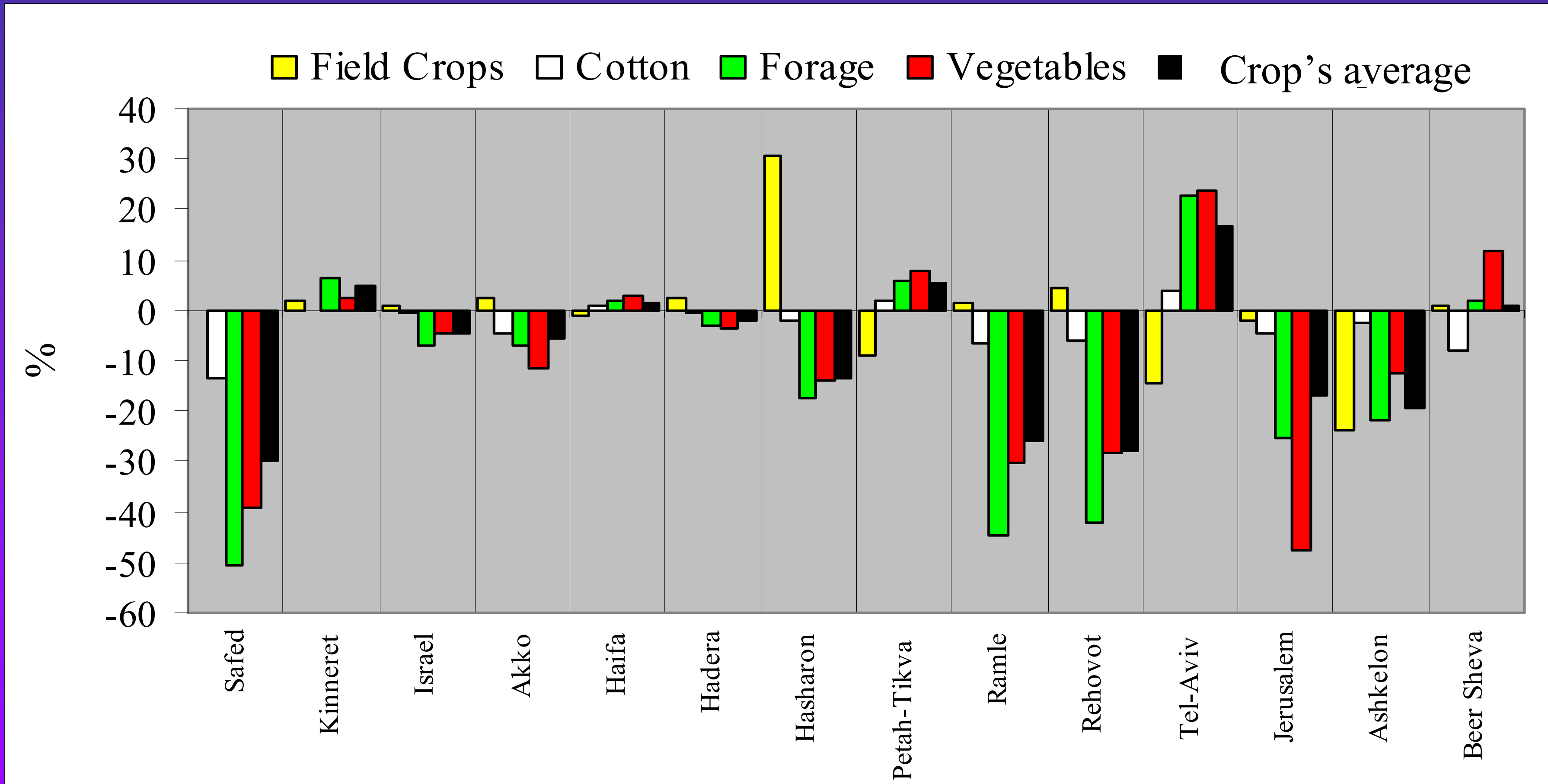
"Bottom Line": Changes in *Net Revenues by region*, 1975 to 2100



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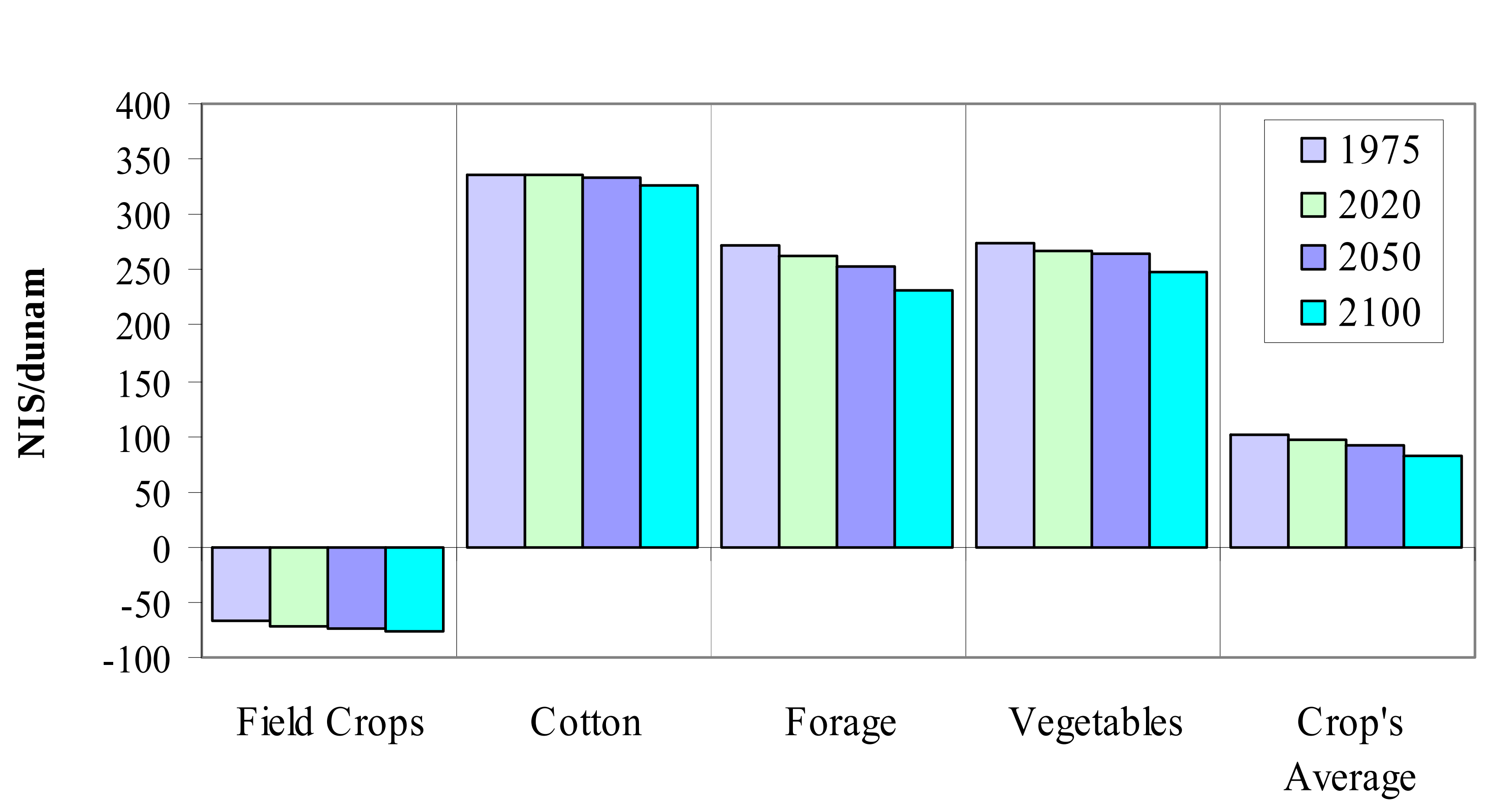
Bottom-Line: Net Income per dunham, national averages, 1975-2100



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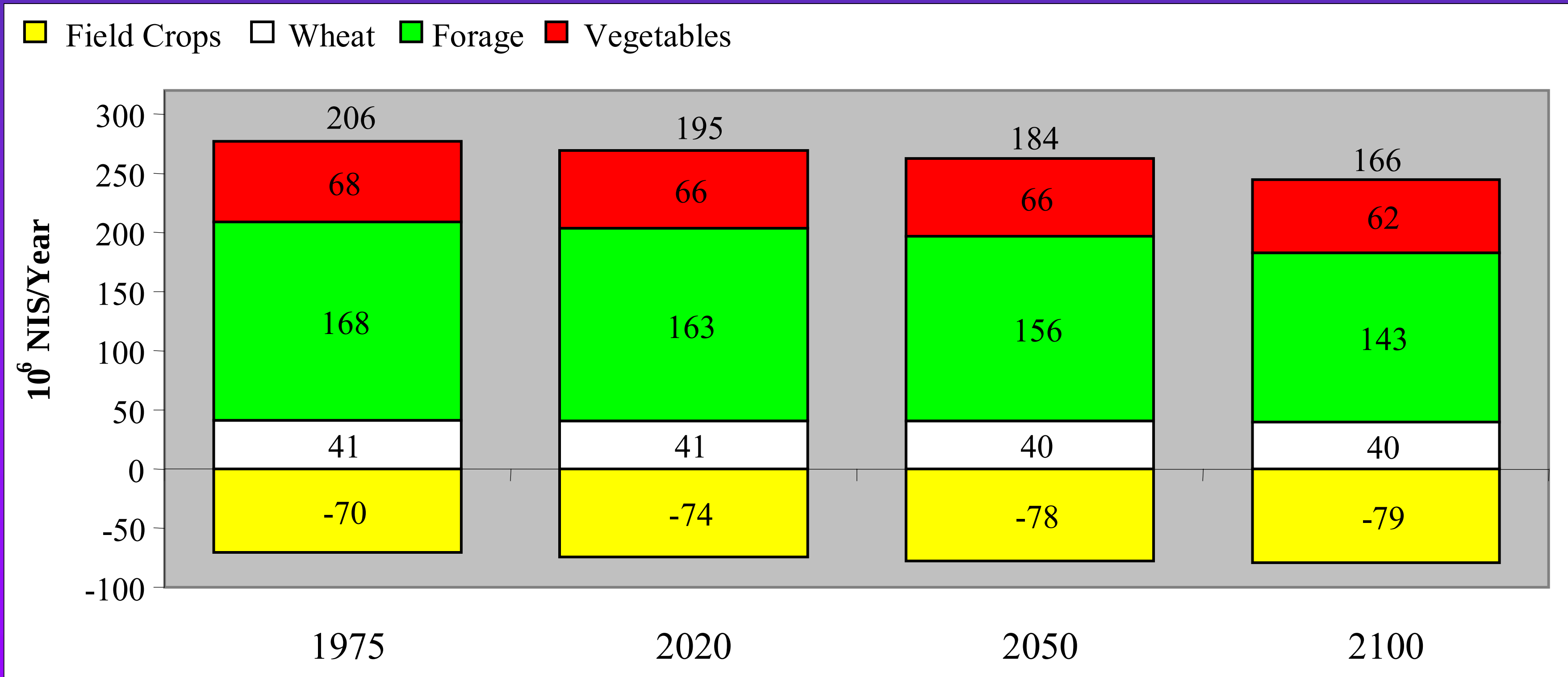
Trends in Expected Net Revenue, National, 1975 to 2100

Profitability decrease in relation to 1975 (%):

1975	2020	2050	2100
0%	5%	11%	20%



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8. Planned GLOWA-JR *II* Extensions

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- Incorporating and assessing the impact of CC on natural vegetation and internalizing the scenery externalities of open space lands
- Estimate yield response functions for additional crop groups
- Assess changes in water demand function due to water allocation adjustments under CC
- Assess additional CC scenarios w.r.t. fresh water availability, use of recycled waste water, food price changes, water price changes
- Explicit incorporation of future regional temperature changes

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Thank you for your patience and attention!

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