Climate Change Impact Assessment on Crop Production in Albania

World Bank Study on Reducing Vulnerability to Climate Change in Europe and Central Asia (ECA) Agricultural Systems

November 2010

Client
World Bank

Authors
J.E. Hunink
P. Droogers

Report FutureWater: 105

FutureWater
Costerweg 1G
6702 AA Wageningen
The Netherlands

+31 (0)317 460050

info@futurewater.nl

www.futurewater.nl

Table of contents

Tables

Figures

1 Introduction

The World Bank has embarked on a study on climate change impact assessment and adaptation strategy identification and evaluation for each of four countries in the Eastern Europe/Central Asia (ECA) region. The overall objective is to enhance the ability of these four countries to mainstream climate change adaptation into agricultural policies, programs, and investments. This objective will be achieved by raising awareness of the threat, analyzing potential impacts and adaptation responses, and building capacity among national and local stakeholders with respect to assessing the impacts of climate change and developing adaptation measures in the agricultural sector.

The four countries selected to be included in the study are Albania, Macedonia, Moldova and Uzbekistan. The study is undertaken by Industrial Economics (Cambridge, MA, USA) with as subcontractor FutureWater (Wageningen, The Netherlands).

A major component of the study is the analytical assessment of the impact of climate change on crop production in the four countries and the evaluation of a set of adaptation measures. Results of these analysis will be used to support capacity building, awareness rising and linkage with the water resources analysis.

This report describes the impact assessment for Albania using the state-of-the-art AquaCrop model.

2 Methods and Data

2.1 Overview

Several crops were recommended by the Albanian counterparts as the most important to evaluate within the study. To study the climate impact on these rainfed and/or irrigated crops, the following two approaches were used, to assess:

a) The impact on yields, assuming same future irrigation amounts
b) The impact on crop irrigation water requirements, assuming same future yields

These two approaches guarantee an integral overview of the possible consequences on the agricultural production and water demands under different climate scenarios for each agro-ecological zone and for each crop in Albania.

To assess (a) and (b), simulations have been carried out over a large number of dimensions, as is summarized in Table 1. The results of these simulations are evaluated over decadal periods from 2010 until 2050. These results were compared with the reference situation which was taken as 2000-2010.

Table 1. Dimensions for modeling assessment

Type	**A** **Crop types**	**B** **Agro-Ecological Zones**	**C** **Climate scenarios**	**D** **CO2 fertilization**
Classes	1. Alfalfa irrigated 2. Alfalfa non irrigated 3. Grapes 4. Grassland 5. Maize 6. Olives 7. Tomatoes 8. Watermelons 9. Wheat	1. Coastal Lowlands 2. Intermediate 3. Southern Highlands 4. Northern Mountains	1. Dry 2. Median 3. Wet	1. Yes 2. No
Number	**9**	**4**	**3**	**2**
	Total dimensions (A*B*C*D) = **216**			

2.2 Model selection

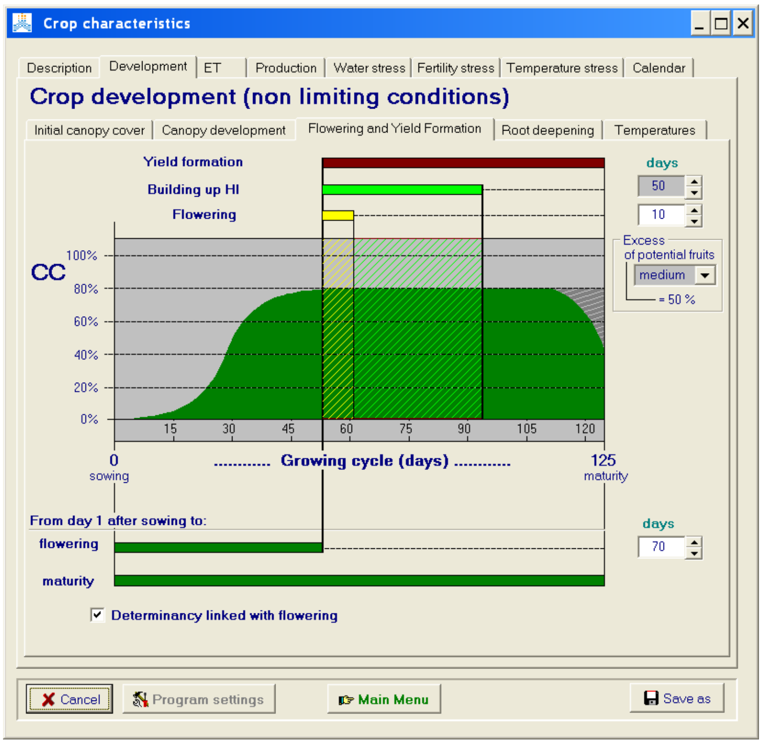
Potential impacts of climate change on world food supply have been estimated in several studies (Parry et al., 2004). Results show that some regions may improve production, while others suffer yield losses. This could lead to shifts of agricultural production zones around the world. Furthermore, different crops will be affected differently, leading to the need for adaptation of supporting industries and markets. Climate change may alter the competitive position of countries with respect, for example, to exports of agricultural products. This may result from yields increasing as a result of altered climate in one country, whilst being reduced in another. The altered competitive position may not only affect exports, but also regional and farm-level income, and rural employment.

In order to evaluate the effect of climate change on crop production and to assess the impact of potential adaptation strategies models are used frequently (Aerts and Droogers, 2004). The use of these models can be summarized as: (i) better understanding of water-food-climate change interactions, and (ii) exploring options to improve agricultural production now and under future climates. Some of the frequently applied agricultural models are:

- CropWat
- AquaCrop
- CropSyst
- SWAP/WOFOST
- CERES
- DSSAT
- EPIC

Each of these models is able to simulate crop growth for a range of crops. The main differences between these models are the representation of physical processes and the main focus of the model. Some of the models mentioned are strong in analysing the impact of fertilizer use, the ability to simulate different crop varieties, farmer practices, etc. However, for the project it is required to use models with a strong emphasis on crop-water-climate interactions. The three models that are specifically strong on the relationship between water availability, crop growth and climate change are CropWat, AquaCrop and SWAP/WOFOST. Moreover, these three models are in the public domain, have been applied world-wide frequently, and have a user-friendly interface (Figure 1). Based on previous experiences it was selected to use AquaCrop as it has:

- limited data requirements,
- a user-friendly interface enabling non-specialist to develop scenarios,
- focus on climate change, CO_2, water and crop yields,
- developed and supported by FAO,
- fast growing group of users world-wide,
- flexibility in expanding level of detail.



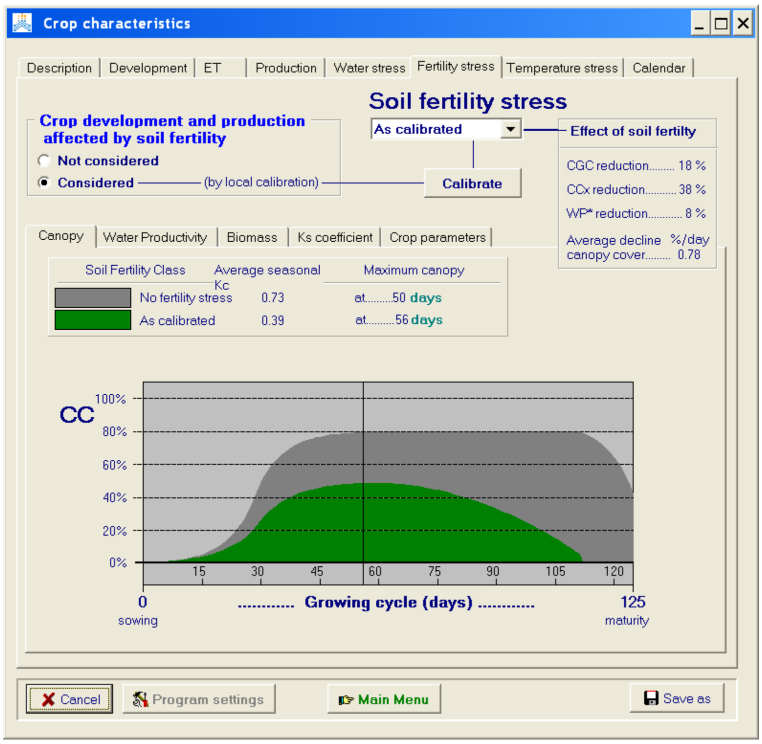
Crop development (non limiting conditions)

days: 50, 10

Excess of potential fruits: medium = 50 %

days: 70

☑ Determinancy linked with flowering



Crop development and production affected by soil fertility

○ Not considered

● Considered (by local calibration)

As calibrated

Effect of soil fertilty

CGC reduction......... 18 %

CCx reduction.......... 38 %

WP* reduction........... 8 %

Average decline canopy cover......... %/day 0.78

	Soil Fertility Class	Average seasonal Kc	Maximum canopy
▨	No fertility stress	0.73	at.........50 days
🟩	As calibrated	0.39	at.........56 days

Figure 1. Typical examples of input screen of AquaCrop: crop development (top) and soil fertility stress (bottom).

2.3 Model specifications

AquaCrop is the FAO crop-model to simulate yield response to water. It is designed to balance simplicity, accuracy and robustness, and is particularly suited to address conditions where water is a key limiting factor in crop production. AquaCrop is a companion tool for a wide range of users and applications including yield prediction under climate change scenarios. AquaCrop is a completely revised version of the successful CropWat model. The main difference between CropWat and AquaCrop is that the latter includes more advanced crop growth routines.

AquaCrop includes the following sub-model components: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and CO2 concentration; and the management, with its major agronomic practice such as irrigation and fertilization. AquaCrop flowchart is shown in Figure 2.

The particular features that distinguishes AquaCrop from other crop models is its focus on water, the use of ground canopy cover instead of leaf area index, and the use of water productivity values normalized for atmospheric evaporative demand and of carbon dioxide concentration. This enables the model with the extrapolation capacity to diverse locations and seasons, including future climate scenarios. Moreover, although the model is simple, it gives particular attention to the fundamental processes involved in crop productivity and in the responses to water, from a physiological and agronomic background perspective.

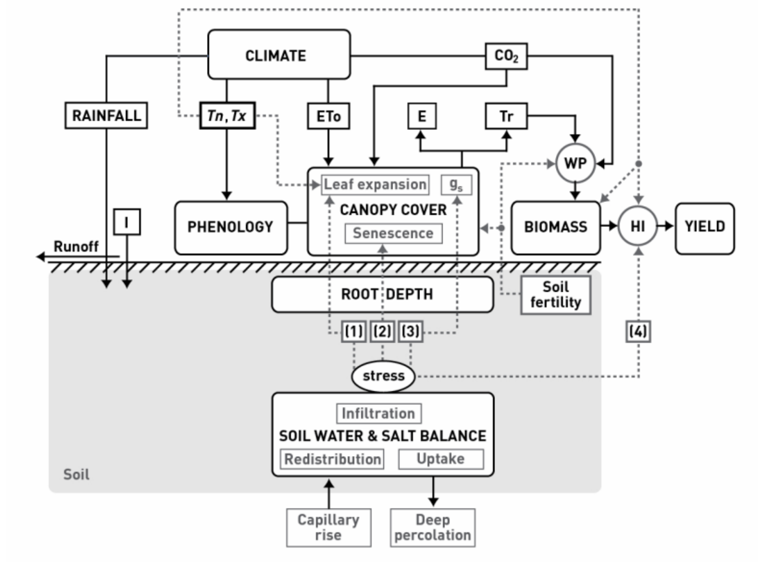


Figure 2. Main processes included in AquaCrop.

2.3.1 Theoretical assumptions

The complexity of crop responses to water deficits led to the use of empirical production functions as the most practical option to assess crop yield response to water. Among the empirical function approaches, FAO Irrigation & Drainage Paper nr 33 (Doorenbos and Kassam, 1979) represented an important source to determine the yield response to water of field, vegetable and tree crops, through the following equation:

$$\left(\frac{Y_x - Y_a}{Y_x}\right) = k_y \left(\frac{ET_x - ET_a}{ET_x}\right) \qquad \text{Eq. 1}$$

where Y_x and Ya are the maximum and actual yield, ET_x and ETa are the maximum and actual evapotranspiration, and k_y is the proportionality factor between relative yield loss and relative reduction in evapotranspiration.

AquaCrop evolves from the previous Doorenbos and Kassam (1979) approach by separating (i) the ET into soil evaporation (E) and crop transpiration (Tr) and (ii) the final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into E and Tr avoids the confounding effect of the non-productive consumptive use of water (E). This is important especially during incomplete ground cover. The separation of Y into B and HI allows the distinction of the basic functional relations between environment and B from those between environment and HI. These relations are in fact fundamentally different and their use avoids the confounding effects of water stress on B and on HI. The changes described led to the following equation at the core of the AquaCrop growth engine:

$$B = WP \cdot \Sigma Tr \qquad \text{Eq. 2}$$

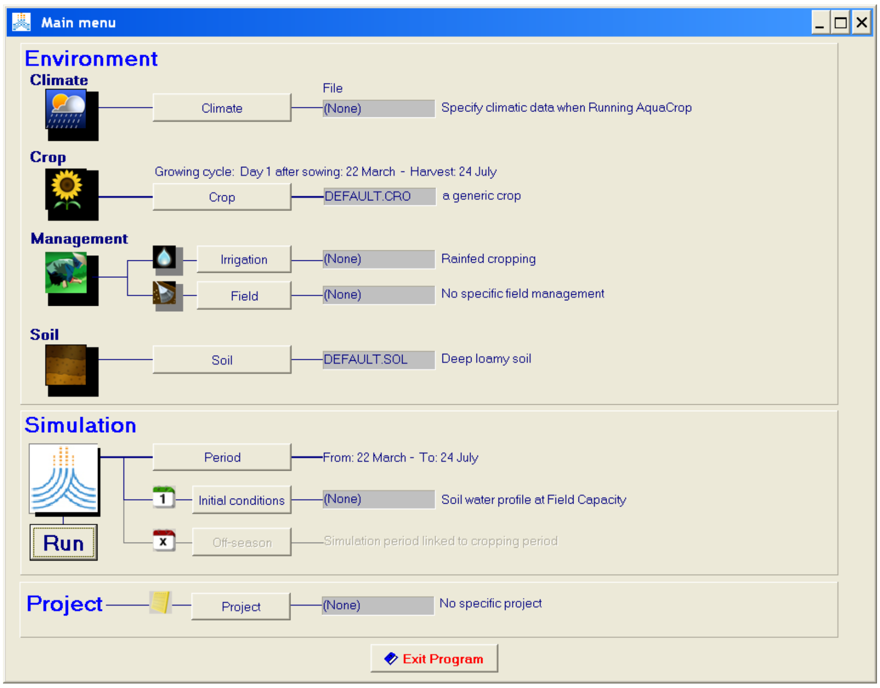
where Tr is the crop transpiration (in mm) and WP is the water productivity parameter (kg of biomass per m^2 and per mm of cumulated water transpired over the time period in which the biomass is produced). This step from Eq. 1.1 to Eq. 1.2 has a fundamental implication for the robustness of the model due to the conservative behavior of WP (Steduto et al., 2007). It is worth noticing, though, that both equations are different expressions of a *water-driven growth-*

engine in terms of crop modeling design (Steduto, 2003). The other main change from Eq. 1.1 to AquaCrop is in the time scale used for each one. In the case of Eq. 1.1, the relationship is used seasonally or for long periods (of the order of months), while in the case of Eq. 1.2 the relationship is used for daily time steps, a period that is closer to the time scale of crop responses to water deficits.

The main components included in AquaCrop to calculate crop growth are Figure 3:

- Atmosphere
- Crop
- Soil
- Field management
- Irrigation management

These five components will be discussed here shortly in the following sections. More details can be found in the AquaCrop documentation (Raes et al., 2009)



File
(None) Specify climatic data when Running AquaCrop
Growing cycle: Day 1 after sowing: 22 March - Harvest: 24 July
DEFAULT.CRO a generic crop
(None) Rainfed cropping
(None) No specific field management
DEFAULT.SOL Deep loamy soil
From: 22 March - To: 24 July
(None) Soil water profile at Field Capacity
Simulation period linked to cropping period
(None) No specific project

Figure 3. Overview of AuqaCrop showing the most relevant components.

2.3.2 *Atmosphere*

The minimum weather data requirements of AquaCrop include the following five parameters:

- daily minimum air temperatures
- daily maximum air temperatures
- daily rainfall
- daily evaporative demand of the atmosphere expressed as reference evapotranspiration (ETo)
- mean annual carbon dioxide concentration in the bulk atmosphere

The reference evapotranspiration (ETo) is, in contrast to CropWat, not calculated by AquaCrop itself, but is a required input parameter. This enables the user to apply whatever ETo method based on common practice in a certain region and/or availability of data. From the various options to calculate ETo reference is made to the Penman-Monteith method as described by FAO (Allen *et al.*, 1998). The same publication makes also reference to the Hargreaves method in case of data shortage.

A companion software program (ETo calculator) based on the FAO56 publication might be used if preference is given to the Penman-Monteith method. A few additional parameters were used for a more reliable estimate of the reference evapotranspiration. Besides the minimum and maximum temperature, measured dewpoint temperature and windspeed were used for the calculation.

AquaCrop calculations are performed always at a daily time-step. However, input is not required at a daily time-step, but can also be provided at 10-daily or monthly intervals. The model itself interpolates these data to daily time steps. The only exception is the CO_2 levels which should be provided at annual time-step and are considered to be constant during the year.

2.3.3 Crop

AquaCrop considers five major components and associated dynamic responses which are used to simulate crop growth and yield development:

- phenology
- aerial canopy
- rooting depth
- biomass production
- harvestable yield

As mentioned earlier, AquaCrop strengths are on the crop responses to water stress. If water is limiting this will have an impact on the following three crop growth processes:

- reduction of the canopy expansion rate (typically during initial growth)
- acceleration of senescence (typically during completed and late growth)
- closure of stomata (typically during completed growth)

Finally, the model has two options for crop growth and development processes:

- calendar based: the user has to specify planting/sowing data
- thermal based on Growing Degree Days (GDD): the model determines when planting-sowing starts.

2.3.4 Soil

AquaCrop is flexible in terms of description of the soil system. Special features:

- Up to five horizons
- Hydraulic characteristics:
    - hydraulic conductivity at saturation
    - volumetric water content at saturation
    - field capacity
    - wilting point
- Soil fertility can be defined as additional stress on crop growth influenced by:
    - water productivity parameter
    - the canopy growth development
    - maximum canopy cover

  - rate of decline in green canopy during senescence.

AquaCrop separates soil evaporation (E) from crop transpiration (Tr). The simulation of Tr is based on:

- Reference evapotranspiration
- Soil moisture content
- Rooting depth

Simulation of soil evaporation depends on:

- Reference evapotranspiration
- Soil moisture content
- Mulching
- Canopy cover
- Partial wetting by localized irrigation
- Shading of the ground by the canopy

2.3.5 Field management

Characteristics of general field management can be specified and are reflecting two groups of field management aspects: soil fertility levels and practices that affect the soil water balance. In terms of fertility levels one can select from pre-defined levels (non limiting, near optimal, moderate and poor) or specify parameters obtained from calibration. Field management options influencing the soil water balance that can be specified in AquaCrop are mulching, runoff reduction and soil bunds.

2.3.6 Irrigation management

Simulation of irrigation management is one of the strengths of AquaCrop with the following options:

- rainfed-agriculture (no irrigation)
- sprinkler irrigation
- drip irrigation
- surface irrigation by basin
- surface irrigation by border
- surface irrigation by furrow

Scheduling of irrigation can be simulated as

- Fixed timing
- Depletion of soil water

Irrigation application amount can be defined as:

- Fixed depth
- Back to field capacity

2.3.7 Climate change

The impact of climate change can be included in AquaCrop by three factors: (i) adjusting the precipitation data file, (ii) adjusting the temperature data file, (iii) impact of enhanced CO_2 levels.

The first two options are quite straightforward and require the standard procedure of creating climate input files in AquaCrop. Impact of enhanced CO_2 levels are calculated by AquaCrop itself. AquaCrop uses for this the so-called normalized water productivity (WP*) for the simulation of aboveground biomass. The WP is normalized for the atmospheric CO_2 concentration and for the climate, taking into consideration the type of crop (e.g. C3 or C4). The C4 crops assimilate carbon at twice the rate of C3 crops.

2.4 Agro-ecological zones

2.4.1 Soils

The Harmonized World Soil Database is a 30 arc-second raster database that integrates existing regional and national soil databases worldwide. The database was assembled by FAO and partners especially for studies on the scale of agro-ecological zones, in 2008. This digitized and online accessible soil information system allows policy makers, planners and experts to overcome some of the shortfalls of data availability to address today's pressing challenges of food production and food security and plan for new challenges of climate change.

For the four agro-ecological zones defined in Albania, the dominant soil types used for agriculture were selected using GIS-techniques. These will be used for each AEZ as representative for the agricultural soils in that region.

Table 2. Dominant soil types for each AEZ

AEZ	***FAO-90 classification***	***USDA Texture Class***
Intermediate	Eutric Regosol	loam
Lowlands	Calcaric Cambisol	loam
Northern & Central Mtns	Eutric Cambisol	silty clay loam
Southern Highlands	Eutric Regosol	loam

2.4.2 Meteorological data

Meteorological data from weather stations all over the world can be found at the public domain Global Summary of the Day (GSOD) database archived by the National Climatic Data Center (NCDC). This database offers a substantial number of stations with long-term daily time series. The GSOD database submits all series (regardless of origin) to extensive automated quality control. Therefore, it can be considered a uniform and validated database where errors have been eliminated.

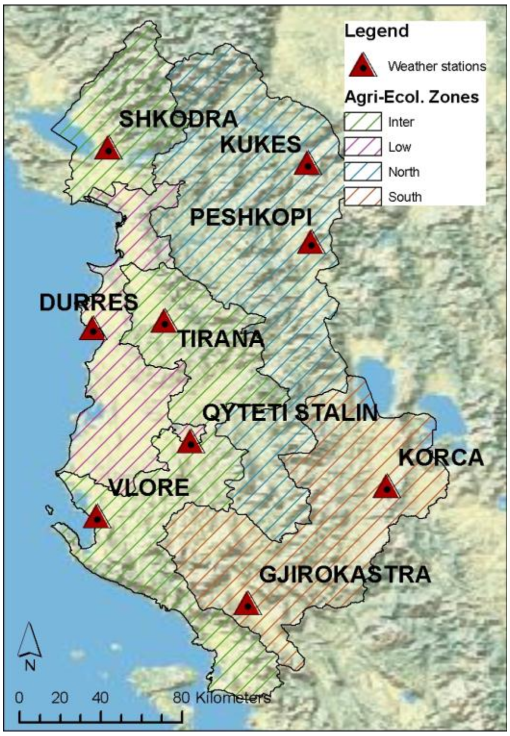


Figure 4. Weather stations in each AEZ

Data from before 1990 in Albania can be found in the GSOD database for various stations, as shown in Figure 4. For each of the AEZs a representative station was selected based on the availability of data for the period of interest and the position relative to the main agricultural areas. Table 3 shows the selected stations.

Table 3. Weather stations selected for each AEZ

AEZ	*Station*	*Reason*
Intermediate	Tirana	Largest timeseries available
Lowlands	Durres	Only station available in this AEZ
Northern & Central Mtns	Kukes	Close to region with high agricultural productivity
Southern Highlands	Korce	Close to region with high agricultural productivity

For each of these stations the climate scenarios were established as discussed elsewhere. The minimum and maximum temperature and rainfall projections were used as input for the AquaCrop model and to estimate the future reference evapotranspiration using the FAO tool EToCalculator.

2.5 Crop parameterization

The standard AquaCrop package has some pre-defined crop files that can be used and adjusted to local conditions. Not all crops required for this particular study are included in the AquaCrop package and have been developed using expert knowledge, documentation and local expertise obtained during the capacity building workshop in Tirana on October 2010.

The following crops are standard included in the AquaCrop package:

- Vegetables
- Cotton

- Maize
- PaddyRice
- Potato
- Quinoa
- Soybean
- SugarBeet
- Sunflower
- Tomato
- Wheat

2.5.1 Alfalfa

Alfalfa is not included as one of the standard crop files within AquaCrop. Therefore, a new crop file has been created representing average conditions in Albania. The latest version of AquaCrop (3.1) does not support yet the so-called forage crop type. However, using the leafy vegetable producing crops, one can mimic alfalfa, with the exception of multiple harvesting. It was therefore assumed that the total yield of alfalfa, often harvested in between 4 to 5 times for the rainfed and 6-7 times for irrigated, will be represented by one harvesting at the end of the season (15-Oct).

Crop development

The crop is grown in climates where average daily temperature during the growing period is above 5°C. The optimum temperature for growth is about 25°C and growth decreases sharply when temperatures are above 30°C and below 0°C.

Following seeding, the crop takes about 3 months to establish. Number of cuts varies with climate and ranges between 2 and 12 per growing season. Also, yield per cut for a given location varies over the year due to climatic differences. In Albania, about 4-5 cuts are normal under rainfed conditions. Under irrigation, 6-7 cuts can be reached.

Table 4. Crop characteristics of different stages of development of alfalfa

Crop characteristic	*Initial*	*Crop Development*	*Mid-season*	*Late*	*Total*	*Plant date*
Stage length, days - Alfalfa 1st cutting cycle	10	20	20	10	60	Jan
Stage length, days - Alfalfa other cutting cycles	5	10	10	5	30	Mar
	5	20	10	10	45	June
Depletion Coefficient, p:					0.55	
Root Depth, m	-	-	-	-	-	
Crop Coefficient, Kc: Afalfa Hay	0.4		0.951	0.9		
Yield Response Factor, Ky	-	-	-	-	1.1	

Fresh yield vs. dry matter yield

Biomass production and yields are calculated by AquaCrop, like almost all other crop growth models, as dry matter. In farm management practice and crop statistics however, yields are always expressed as fresh yields. On average alfalfa haS a low dry matter content of only 20%, so about 80% moisture is included in the fresh yield. In order to convert AquaCrops results into fresh yields, one has to divide by 0.20. E.g.

- 1000 kg dry matter
- 1000 / 0.20 = 5,000 kg fresh
- 5,000 * 80% = 4.000 kg moisture

Alfalfa is not included in FAOstat in terms of yields. Only imports and exports are provided. Based on local expertise one can conclude that average alfalfa yields are about 25 ton / ha for non-irrigated conditions and 45 ton / ha for irrigated fields (fresh yield). About 70% of the alfalfa is irrigated. Converting these values into dry matter yield:

- 25,000 kg fresh * 0.2 = 5,000 kg dry matter yield
- 45,000 kg fresh * 0.2 = 9,000 kg dry matter yield

Reported alfalfa yields

In general good commercial yields under irrigation range from 20 ton/ha up to 30 ton/ha under good management practices and natural conditions. In case irrigation is applied yields range between 30 and 60 ton/ha (fresh).

Local expertise on yields and management practices were obtained during the capacity workshop in Tirana on October 2010 (Table 9).

In summary it might be concluded that fresh alfalfa yields are around 25,000 kg/ha under non-irrigated and 45,000 kg under irrigated conditions in Albania. This translates into dry matter yields of 5,000 and 9,000 kg/ha respectively.

Table 5. Alfalfa yields (fresh) reported by local statistics and local experts.

	local statistics (ton/ha)	local experts (ton/ha)
Lowlands	30	60
Intermediate	21	50
North/Central Mnts	19	30
Southern Highlands	20	40

Crop growth parameters

The AquaCrop data file for watermelons has been created by adjusting parameters to the local conditions in the country. Some basic assumptions are:

- 70% of alfalfa is irrigated in Albania. A total application of about 500-600 mm per year (100 mm per cut) is normal practice.

Most important crop parameters within AquaCrop relevant to grapes are:

- Planting density is about 75,000 plants per ha and the size of the canopy cover per plant at 90% emergence is 6.5 cm^2
- Growing season is from 15 February to 15 October.
- Soils are having medium fertilizer status for alfalfa in the country.
- CCx: Maximum canopy cover in fraction soil cover: it was assumed that 65% of canopy covers the soil during mid-season.
- HIo: Reference Harvest Index: set to 40% (for non-irrigated crops at 50%).

2.5.2 Grapes

Grapes are not yet included as one of the standardized crop files within AquaCrop. Based on various references and local expertise a specific grape file for Albania has been created. Some particular technical notes on the creation of this crop file with respect to AquaCrop, will be discussed here.

Fresh yield vs. dry matter yield

Biomass production and yields are calculated by AquaCrop, like almost all other crop growth models, as dry matter. In farm management practice and crop statistics however, yields are always expressed as fresh yields. On average grapes have a dry matter content of 20%, so about 80% moisture is included in the fresh yield. In order to convert AquaCrops results into fresh yields, one has to divide by 0.20. E.g.

- 1000 kg dry matter
- 1000 / 0.20 = 5000 kg fresh
- 5000 * 80% = 4000 kg moist

Average grapes yields in Albania according to FAOstat are 19 ton / ha (fresh yield). Converting into dry matter yield:

- 19,000 kg fresh * 0.20 = 3,800 kg dry matter yield

Reported grape yields

Good commercial yields in the subtropics are in the range of 15 to 20 kg grapes per vine or 15 to 30 (or more) tons/ha (80 to 85 percent moisture). According to FAOstat yields in Albania are very high compared to other countries and regions.

Local expertise on yields was obtained during the capacity workshop in Tirana on October 2010 (Table 9). Overall fresh yields ranges from about 8 up to 13 ton/ha according to these local experts. This is substantial lower compared to the official FAOstat statistics. It should be however taking into account that yields in FAOstat are often based on total production in a country divided by the reported area. Especially for grapes, total official area might be an underestimation given the many small farms growing some grapes and these small areas are not always registered.

In summary it might be concluded that fresh grape yields in Albania are between 8,000 and 13,000 kg/ha. This translates into dry matter yields between 1,600 and 2,600 kg/ha.

Table 6. Grapes yields reported by local experts.

AEZ	Yield (kg/ha)
Lowlands	13,000
Intermediate	10,000
North/Central Mnts	10,000
Southern Highlands	8,000

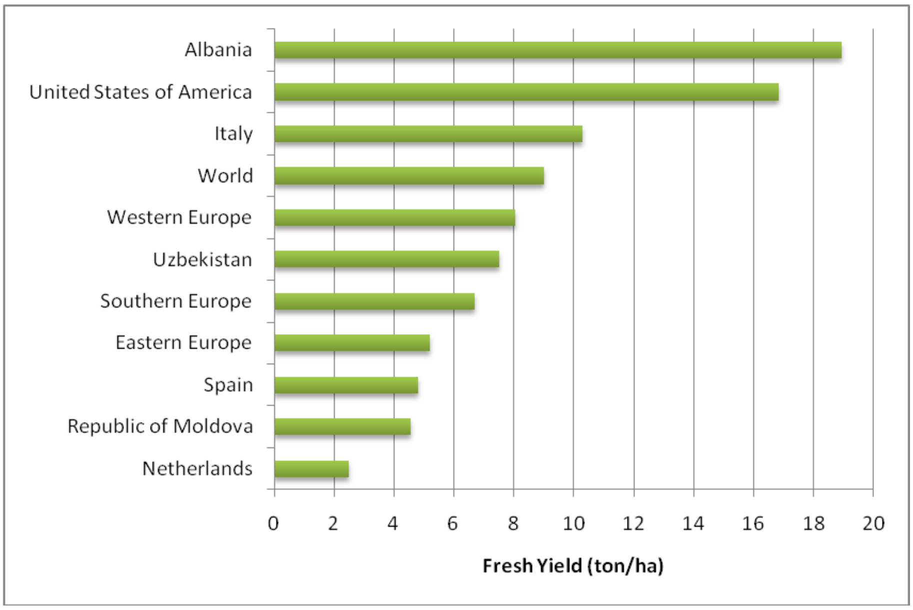


Figure 5. Grape fresh yields in some selected relevant countries (according to FAOstat)

Crop growth parameters

The AquaCrop data file for grapes has been created by adjusting parameters to the local conditions in the country. Some basic assumptions are:

- Grapes are never irrigated in Albania.
- Grapes are sensitive to water stress, especially during the beginning of the growing season. However, grapes can develop deep roots which enable the crop to make use of water stored in deeper soil layers.
- Grapes are medium sensitive to fertilizer stress. A medium amount of organic fertilizer is provided to grapes in Albania.

Most important crop parameters within AquaCrop relevant to grapes are:

- Planting density is about 2.0 x 4.0 meters. So number of plants per hectare is 10,000 / (2.0 * 4.0) = 1250
- Assuming that grapes about 10% of the area initially (at spring, just after initial leave development) the size of the canopy cover per tree = 10% / 1250 * (10,000*10,000) = 8,000 [cm^2]
- Growing season is from 15-March to 15 September.
- Grapes are considered to have moderate stress for fertilizer shortage.
- Soils are having near optimal fertilizer status for grapes in the country.
- CCx: Maximum canopy cover in fraction soil cover:
- It was assumed that on average 70% of canopy covers the soil
- HIo: Reference Harvest Index. Low for grapes as only part of biomass is converted to harvested yield. For grapes in Albania on universal value for all AEZ is assumed and set at 15%.
- CGC: Canopy growth coefficient (CGC): Increase in canopy cover (fraction soil cover per day). For grapes, like other tree crops, this parameter is high and set at 0.2
- CDC: Canopy decline coefficient is decrease in canopy cover (in fraction per day). Is relatively low and set at 0.08

2.5.3 Grasslands

Grasslands are grown under quite diverse conditions and management practices in Albania. For this study a generic grassland was considered with average crop and soil conditions. It was assumed that the growing season for grasslands were from 1-March to 1-November. Soils are in general not well fertilized.
No clear reported grassland yield numbers are available, but it was assumed that by various cuttings and livestock grazing a total of amount of fresh product of about 10 ton/ha will be produced.

Biomass production and yields are calculated by AquaCrop as dry matter. In farm management practice and crop statistics however, yields are always expressed as fresh yields. On average grasslands have a low dry matter content of only 20%, so about 80% moisture is included in the fresh yield. In order to convert AquaCrops results into fresh yields, one has to divide by 0.20. E.g.

- 1000 kg dry matter
- 1000 / 0.20 = 5,000 kg fresh
- 5,000 * 80% = 4.000 kg moisture

Based on expert knowledge it was assumed that grasslands produce about 10 ton/ha. Converting this value into dry matter gives:

- 10,000 kg fresh * 0.2 = 2,000 kg dry matter yield

2.5.4 Maize

The Maize crop file is calibrated for a highly productive cultivar for optimal conditions in the United States. It was adapted using the information obtained from public domain sources as well as local data obtained during the workshop in Albania October 2010.

Crop development

The crop is grown during the period of the year when mean daily temperatures are above 15°C and frost-free. The adaptability of varieties in different climates varies widely. In Albania maize is planted normally the start of April and harvested half of September.

For optimum light interception, for grain production, the density index (number of plants per ha/row spacing) varies but on average it is about 150 for the large late varieties and about 500 for the small early varieties. Plant population varies from 20000 to 30000 plants per ha for the large late varieties to 50000 to 80000 for small early varieties. Spacing between rows varies between 0.6 and 1 m. Sowing depth is 5 to 7 cm with one or more seeds per sowing point. When grown for forage, plant population is 50 percent higher.

Table 7. Crop characteristics of different stages of development of maize

Crop characteristic	*Initial*	*Crop Development*	*Mid-season*	*Late*	*Total*
Stage length, days	30	40	50	30	150
Depletion Coefficient, p	0.5	0.5	0.5	0.8	-
Root Depth, m	0.3			1	-
Crop Coefficient, Kc	0.3		1.2	0.5	-
Yield Response Factor, Ky	0.4	1.0.40	1.3	0.5	1.25

Water Needs

Maize is an efficient user of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water depending on climate.

When evaporative conditions correspond to ETm of 5 to 6 mm/day, soil water depletion up to about 55 percent of available soil water (Sa) has a small effect on yield ($p = 0.55$). To enhance rapid and deep root growth a somewhat greater depletion during early growth periods can be advantageous. Depletion of 80 percent or more may be allowed during the ripening period.

Although in deep soils the roots may reach a depth of 2 m, the highly branched system is located in the upper 0.8 to 1 m and about 80 percent of the soil water uptake occurs from this depth. Normally 100 percent of the water is taken up from the first 1 to 1.7 m soil depth ($D = 1$ to 1.7 m). Depth and rate of root growth is, however, greatly affected by rainfall pattern and irrigation practices adopted.

In Albania, maize tends to be irrigated, using furrows. Irrigation is normally applied 4 times during the growth season, between 40 – 60 mm each.

Yields

Under irrigation a good commercial grain yield is 6 to 9 ton/ha (10 to 13 percent moisture). In this study a dry matter content of 87% was assumed. In the lowlands of Albania, these values are reached, however, in the highlands, yields of 4-5 are normal.

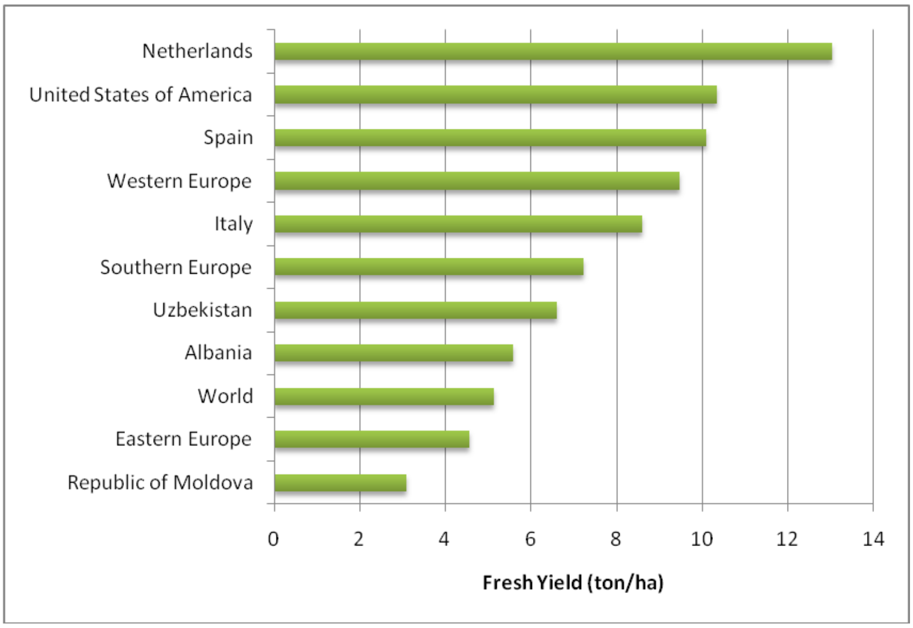


Figure 6. Maize fresh yield in some selected relevant countries

Fertility stress

The fertility demands for grain maize are relatively high and amount, for high-producing varieties, up to about 200 kg/ha N, 50 to 80 kg/ha P and 60 to 100 kg/ha K. In general the crop can be grown continuously as long as soil fertility is maintained. In Albania, especially in the lowlands, the level of fertilizer use is high, while in the mountaineous areas considerable less amounts of fertilizers are used (NEA, 1998). The sensitivity to stress of the crop was assumed to be moderate, leading to the following parameter values:

- Shape factor for the response of canopy expansion for limited soil fertility: 3.92
- Shape factor for the response of maximum canopy cover for limited soil fertility: 1.77
- Shape factor for the response of crop Water Productivity for limited soil fertility: 6.26
- Shape factor for the response of decline of canopy cover for limited soil fertility: -1.57

2.5.5 Olives

Olives are not included as one of the pre-calibrated crop files within AquaCrop. Therefore the olive crop file has been created, based on various references and local expertise. Some particular technical notes on the creation of the olive crop file with respect to AquaCrop, will be discussed here.

Crop development

The crop is indigenous to the Mediterranean region with a mild, rainy winter and a hot, dry summer. A dormancy period of about two months with average temperatures lower than 10° C is conducive to flower bud differentiation.

Raised for two years in the nursery, the tree is transplanted early in the season with 15 to 20 trees/ha under poor rainfed conditions and up to 300 trees/ha under irrigated conditions. Tree density is also dependent on the method of pruning.

Green canopy growth starts in Albania in March. Harvest is normally in November.

Table 8. Crop characteristics of different stages of development of olives

Crop characteristic	*Initial*	*Crop Development*	*Mid-season*	*Late*	*Total*
Stage length, days	30	90	60	90	270
Depletion Coefficient, p	-	-	-	-	0.65
Root Depth, m	-	-	-	-	1.7
Crop Coefficient, Kc	0.65		0.7	0.7	-
Yield Response Factor, Ky	0.2				

Water Needs

Olive trees are commonly grown without irrigation in areas with an annual rainfall of 400 to 600 mm but are even found in areas with about 200 mm rainfall. For high yields, 600 to 800 mm are required. The crop coefficient (kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is between 0.4 and 0.6.

Only a small percent of the olives orchards of Albania are under irrigation (10%).

Fresh yield vs. dry matter yield

Biomass production and yields are calculated by AquaCrop, like almost all other crop growth models, as dry matter. In farm management practice and crop statistics however, yields are always expressed as fresh yields. On average olives have about 30% moisture include in the fresh yield. So in order to convert AquaCrops results into fresh yields, one has to divide by the dry matter content of 0.7. E.g.

- 1000 kg dry matter

- 1000 / 0.7 = 1429 kg fresh
- 1429 * 30% = 429 kg moist

So for example average olives yields in Albania according to FAOstat are 1200 kg / ha (fresh yield). Converting to dry matter yield:

- 1200 kg fresh * 0.7 = 840 kg dry matter yield

Reported olive yields

Various sources are available reporting olive yields. In general yields can vary substantially, depending on natural growing conditions and farm management practices. A more complicated factor with olives is that yields are often reported per tree rather than per hectare. Some references are provided here.

In general olive yields (fresh) can vary substantial from region. According to the FAO crop description the following yields have been observed:

- 50-65 kg / tree (good commercial yields, under irrigation)
- 100 kg / tree (possible maximum)
- 15-20 trees / ha (rainfed)
- 300 trees / ha (irrigated)
- Taking these numbers variations can be enormous:
    - Minimum: 50 kg/tree * 15 trees/ha = 750 kg/ha
    - Maximum: 100 kg/tree * 300 = 30,000 kg/ha

Somewhat more consolidated statistics can be obtained from FAOstat (Figure 7). According to these statistics average country yields can be in the range from 1 ton/ha up to 3 ton/ha. For Albania average yields are about 1.2 ton/ha.

Local expertise on yields was obtained during the capacity workshop in Tirana on October 2010 (Table 9). The reported tree per hectare were however somewhat difficult to assess as huge variation exists in the country. Overall fresh yields range from about 800 up to 1600 kg/ha according to these local experts.

Table 9. Olives yields reported by local experts.

	kg/tree	trees/ha	kg/ha
Lowlands	16	100	1600
Intermediate	10	100	1000
North/Central Mnts	8	100	800
Southern Highlands	14	100	1400

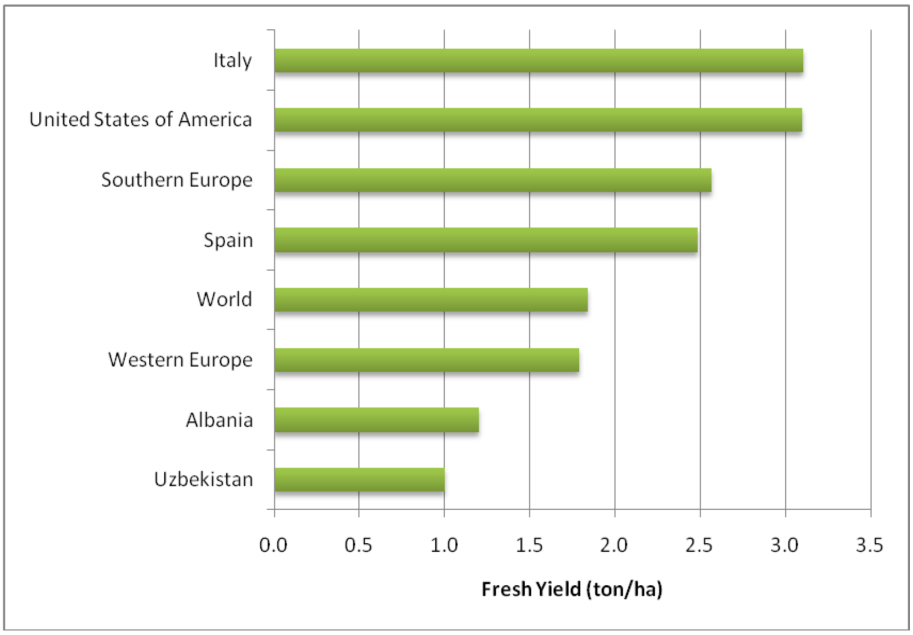


Figure 7. Olive fresh yield in some selected relevant countries (according to FAOstat)

Green Canopy Cover

The Green Canopy Cover (GCC) dynamics is one of the main basics of the AquaCrop model. Initial GCC is the product of plant density and the size of the canopy cover per seedling:
*GCC_0 [fraction] = plant density [ha^{-1}] * size of the canopy cover per seedling [cm^2] / (10,000*10,000)*

So the size of canopy cover per seedling (or per tree) can be calculated by using:
*Size of the canopy cover per seedling [cm^2] = GCC_0 [fraction] / plant density [ha^{-1}] * (10,000*10,000)*

Olives are planted in density on average of 300 trees per ha in Albania. Assuming that these trees cover about 10% of the area initially (at spring, just after initial leave development) the size of the canopy cover per tree = 0.1 / 300 * (10,000*10,000) = 33,000 [cm^2]

Note that within the current AquaCrop interface both parameters ”Cover per seedling” and “Plant density” can only be set within certain limits that are not appropriate to trees. Therefore changes have to be made to the ASCII crop file using a text editor.

Crop growth parameters

The olive crop data file has been created by adjusting parameters to the local conditions in the country. Some basic assumptions are:

- Olives are hardly irrigated in Albania.
- Olives are not very sensitive to fertilizer stress.
- Olives are tolerant to water shortage.
- Limited fertilizer is provided to olives in Albania.

Most important crop parameters within AquaCrop relevant to olives are:

- Shape factors for fertilizer stress (four): lower values → less impact on yield
- HIo: Reference Harvest Index (HIo) (%)
  - Small impact on Biomass

    - High impact on Yield
- CGC: Canopy growth coefficient (CGC): Increase in canopy cover (fraction soil cover per day)
    - High impact on Biomass for values < 0.3
    - Low impact on Yield
- CCx: Maximum canopy cover in fraction soil cover:
    - It was assumed that on average 60% of canopy covers the soil
- CDC: Canopy decline coefficient is decrease in canopy cover (in fraction per day):
    - Low for olives and set to 1%
- HIo: Reference Harvest Index (HIo)
    - Very low for olives as only part of biomass is converted to harvested yield. For olives in Albania this is 8%

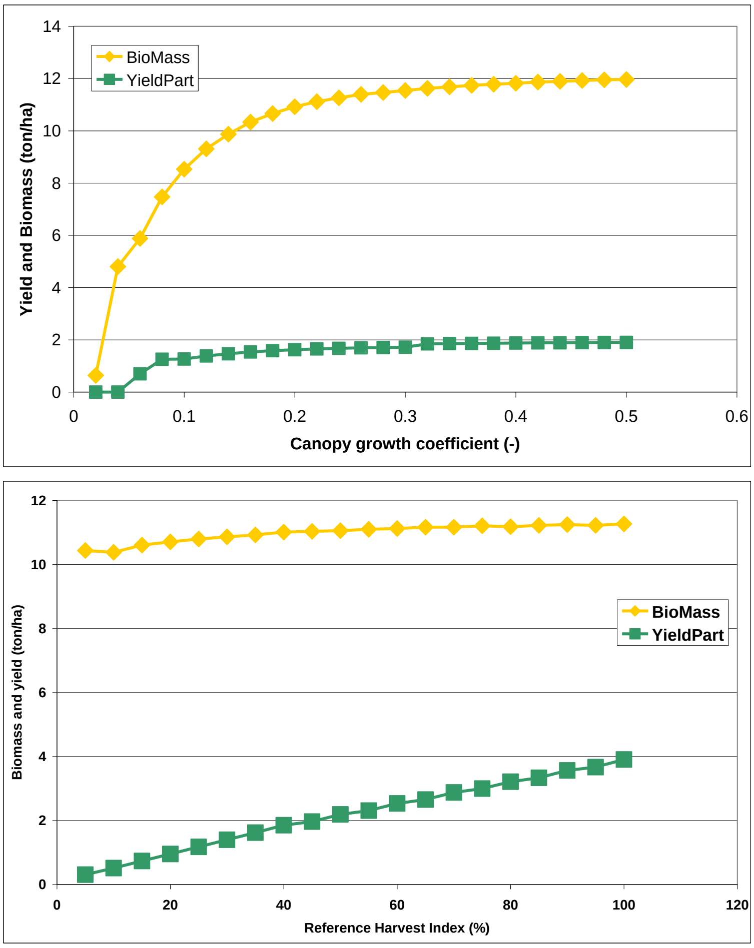


Figure 8. Example of sensitivity analysis for olives for two important crop growth parameters using AquaCrop.

2.5.6 Tomatoes

The tomato crop file was calibrated for conditions in a semi-arid area of Spain (Córdoba) with a similar temperature regime as in most parts of Albania, although a little drier. Small changes have been made to the less conservative parameters in order to tailor the crop parameters to the Albanian situation.

Crop development

Tomato is a rapidly growing crop with a growing period of 90 to 150 days. In Albania, the crop is planted the start of April and harvested in the beginning of July. It is a daylength neutral plant. Optimum mean daily temperature for growth is 18 to 25ºC with night temperatures between 10 and 20ºC. Larger differences between day and night temperatures, however, adversely affect yield. The crop is very sensitive to frost.

The seed is generally sown in nursery plots and emergence is within 10 days. Seedlings are transplanted in the field after 25 to 35 days. In the nursery the row distance is about 10 cm. In the field spacing ranges from 0.3/0.6 x 0.6/1 m with a population of about 40,000 plants per ha. The crop should be grown in a rotation with crops such as maize, cabbage, cowpea, to reduce pests and disease infestations.

Table 10. Crop characteristics of different stages of development of tomatoes

Crop characteristic	***Initial***	***Crop Development***	***Mid-season***	***Late***	***Total***
Stage length, days	30	40	45	30	145
Depletion Coefficient, p	0.3		0.4	0.5	0.3
Root Depth, m	0.25			1	-
Crop Coefficient, Kc	0.6		1.15	0.7-0.9	-
Yield Response Factor, Ky	0.4	1.1	0.8	0.4	1.05

Water Needs

Total water requirements (ETm) after transplanting, of a tomato crop grown in the field for 90 to 120 days, are 400 to 600 mm, depending on the climate. In Albania, tomatoes are normally irrigated using drip irrigation. Amounts of 1l/s/ha are normal, resulting in about 300 mm for the entire growth season.

The crop has a fairly deep root system and in deep soils roots penetrate up to some 1. 5 m. The maximum rooting depth is reached about 60 days after transplanting. Over 80 percent of the total water uptake occurs in the first 0.5 to 0.7 m and 100 per-cent of the water uptake of a full grown crop occurs from the first 0.7 to 1.5 m (D = 0.7 - 1.5 m). Under conditions when maximum evapotranspiration (ETm) is 5 to 6 mm/ day water uptake to meet full crop water requirements is affected when more than 40 percent of the total available soil water has been depleted (p = 0.4).

Reported Yields

A good commercial yield under irrigation is 45 to 65 tons/ha fresh fruit, of which around 90 - 95 percent is moisture. For this study it was assumed that dry matter content is 10%. A part of the total production in Albania comes from greenhouses. However, cultivation in the open field is dominant (about 75%), taking as a measure the total area harvested. In the lowlands, yields of about 30 – 60 ton/ha are normally reached. In the highlands, these values are around 20 ton/ha.

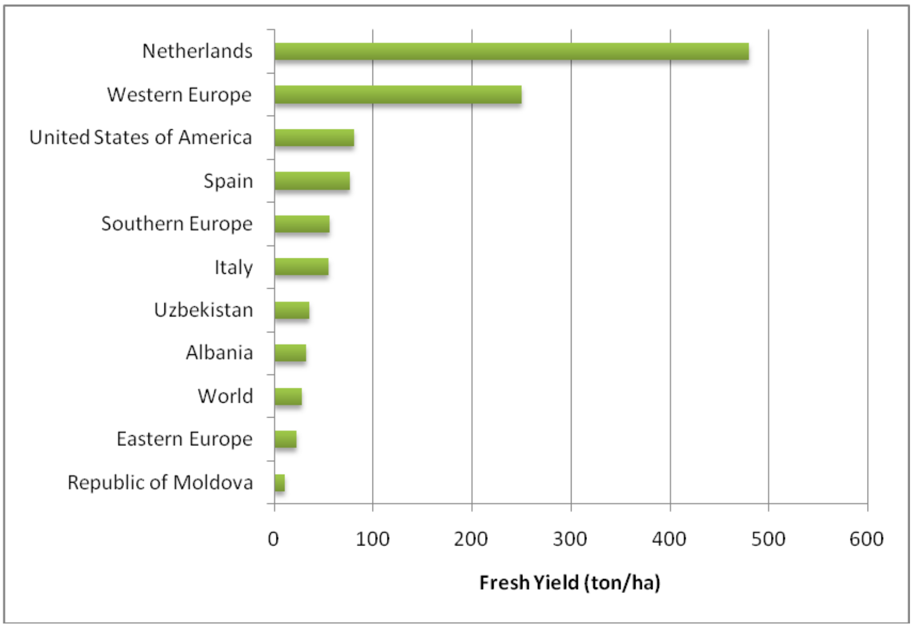


Figure 9. Tomato fresh yield in some selected relevant countries.

Fertility stress

The fertilizer requirements amount, for high producing varieties, to 100 to 150 kg/ha N, 65 to 110 kg/ha P and 160 to 240 kg/ha K. Optimal fertilizing amounts are only applied in greenhouses, in Albania. In the open field, minimum to medium amounts are applied. A moderate sensitivity to fertility stress of the crop was assumed, taking the following parameter values:

- Shape factor for the response of canopy expansion for limited soil fertility: 3.92
- Shape factor for the response of maximum canopy cover for limited soil fertility: 1.77
- Shape factor for the response of crop Water Productivity for limited soil fertility: 6.26
- Shape factor for the response of decline of canopy cover for limited soil fertility: -1.57

2.5.7 Watermelons

Watermelons are not one of the standard crop files within AquaCrop that can be used to adjust to local conditions. Therefore, a new watermelons crop file has been created, specifically tailord towards the local conditions in Albania. The new crop file is based on crop files for similar crops, from a modelling point of view, and various references and local expertise. Some particular technical notes on the creation of the watermelon crop file with respect to AquaCrop, will be discussed here.

Crop development

The crop prefers a hot, dry climate with mean daily temperatures of 22 to 30°C. Maximum and minimum temperatures for growth are about 35 and 18°C respectively. The optimum soil temperature for root growth is in the range of 20 to 35°C. Fruits grown under hot, dry conditions have a high sugar content of 11 percent in comparison to 8 percent under cool, humid conditions. The crop is very sensitive to frost. The length of the total growing period ranges from 80 to 110 days, depending on climate. In Albania, the crop is normally planted in the start of April and harvested half of July.

Watermelon is normally seeded directly in the fields. Thinning is practised 15 to 25 days after sowing. Spacing between plants and rows varies from 0.6 x 0.9 to 1.8 x 2.4 m. Seeds are sometimes placed on hills spaced 1.8 x 2.4m. In areas prone to frost, sowing time is dictated often by the occurrence of frost; sometimes black plastic mulch is used for frost protection.

Table 11. Crop characteristics of different stages of development of watermelons

Crop characteristic	*Initial*	*Crop Development*	*Mid-season*	*Late*	*Total*
Stage length, days	20	30	30	30	110
Depletion Coefficient, p	-	-	-	-	0.4
Root Depth, m	-	-	-	-	0.8
Crop Coefficient, Kc	0.4		1	0.75	-
Yield Response Factor, Ky	0.45	0.8	0.8	0.3	1.1

Fresh yield vs. dry matter yield

Biomass production and yields are calculated by AquaCrop, like almost all other crop growth models, as dry matter. In farm management practice and crop statistics however, yields are always expressed as fresh yields. On average watermelons have a low dry matter content of only 7%, so about 93% moisture is included in the fresh yield. In order to convert AquaCrops results into fresh yields, one has to divide by 0.07. E.g.

- 1000 kg dry matter
- 1000 / 0.07 = 14,000 kg fresh
- 14,000 * 93% = 13.000 kg moisture

Average grapes yields in Albania according to FAOstat are 31 ton / ha (fresh yield). Converting into dry matter yield:

- 31,000 kg fresh * 0.07 = 2,170 kg dry matter yield

Reported watermelon yields

In general good commercial yields under irrigation range from 12 ton/ha up to 20 ton/ha under good management practices and natural conditions. Most favorable conditions might result in yields from 25 to 35 ton/ha. According to FAOstat average yields in Albania are 31 ton/ha.

Local expertise on yields and management practices were obtained during the capacity workshop in Tirana on October 2010 (Table 9). Watermelon are only grown in the lowlands AEZ. Fresh yields are reported to be 29 ton/ha, close to the reported values in FAOstat.

In summary it might be concluded that fresh watermelon yields are around 30,000 kg/ha in Albania. This translates into dry matter yields of 2,100 kg/ha.

Table 12. Watermelons yields (fresh) reported by local experts.

	ton/ha
Lowlands	29
Intermediate	N/A
North/Central Mnts	N/A
Southern Highlands	N/A

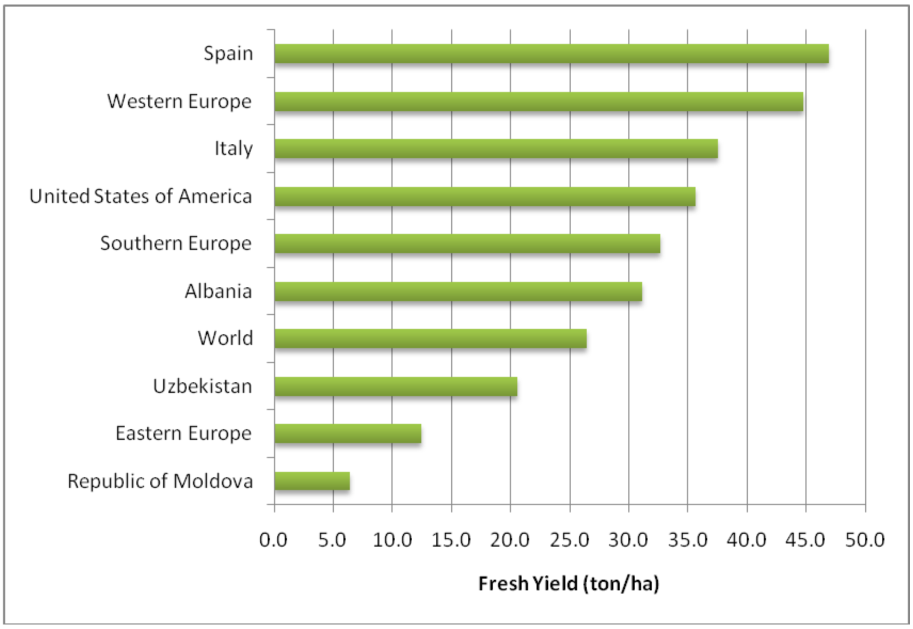


Figure 10. Watermelon fresh yield in some selected relevant countries (source: FaoStat)

Crop growth parameters

The AquaCrop data file for watermelons has been created by adjusting parameters to the local conditions in the country. Some basic assumptions are:

- Watermelons are only grown in the lowlands AEZ
- Watermelons are always irrigated in Albania. Irrigation application is by drip and a total application of about 200 mm per year is normal practice.
- Water shortage has a negative impact on total yields. Moreover, sugar content, shape and weight of watermelons are sensitive to water stress.
- Watermelons are sensitive to fertilizer stress. The fertilizer level soils where watermelons are grown in Albania is very good.

Most important crop parameters within AquaCrop relevant to grapes are:

- Planting density is about 10,000 plants per ha
- Assuming that watermelons cover about 10% of the area initially (at spring, just after initial leave development) the size of the canopy cover per tree = 10% / 10,000 * (10,000*10,000) = 1,000 [cm^2]
- Growing season is from 1 April to 15 July.
- Soils are having optimal fertilizer status for grapes in the country.
- CCx: Maximum canopy cover in fraction soil cover: it was assumed that 75% of canopy covers the soil during mid-season.
- HIo: Reference Harvest Index. Low for watermelons as only part of biomass is converted to harvested yield and is set to 16%.
- CGC: Canopy growth coefficient (CGC): Increase in canopy cover (fraction soil cover per day). For watermelons this parameter is set at 0.11
- CDC: Canopy decline coefficient is decrease in canopy cover (in fraction per day). Is relatively low and set at 0.07

2.5.8 Wheat

The wheat crop file is calibrated for a location in Italy with similar climate conditions as Albania, meaning that only slight changes have been done, using the following information.

Crop development

The different existing wheat varieties can be grouped as winter or spring type. Winter wheat requires a cold period or chilling during early growth for normal heading under long days. This is the main wheat variety cultivated in Albania.

The minimum daily temperature for growth is about 5°C for both winter and spring wheat. Mean daily temperature for optimum growth is between 15 and 20°C. Mean daily temperatures of less than 10 to 12°C during the growing season make wheat a hazardous crop.

The length of the total growing period of winter wheat is about 180 to 250 days to mature.

Table 13. Crop characteristics of different stages of development of wheat

Crop characteristic	*Initial*	*Crop Development*	*Mid-season*	*Late*	*Total*
Stage length, days	30	140	40	30	240
Depletion Coefficient, p	0.6		0.6	0.9	0.55
Root Depth, m	0.3			1.4	
Crop Coefficient, Kc	0.2	0.65	0.55		1.05
Yield Response Factor, Ky	0.2	0.6	0.5		1.15

Under favorable water supply including irrigation and adequate fertilization row spacing is 0.12 to 0.15 m (450 to 700000 plants/ha) but increases to 0.25 m or more under poor rainfall conditions (less than 200000 plants/ha).

Water Needs

Wheat is grown as a rainfed crop in the temperate climates, as well as in Albania. For high yields water requirements (ETm) are 450 to 650 mm depending on climate and length of growing period. The crop coefficient (kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is: during the initial stage 0.3-0.4 (15 to 20 days), the development stage 0.7-0.8 (25 to 30 days), the mid-season stage 1.05-1.2 (50 to 65 days), the late-season stage 0.65-0.7 (30 to 40 days) and at harvest 0.2-0.25.

Water uptake and extraction patterns are related to root density. In general 50 to 60 percent of the total water uptake occurs from the first 0.3 m, 20 to 25 percent from the second 0.3 m, 10 to 15 percent from the third 0.3 m and less than 10 percent from the fourth 0.3 m soil depth. Normally 100 percent of the water uptake occurs over the first 1.0 to 1.5m (D = 1.0-1.5m). Under conditions when maximum evapotranspiration is about 5 to 6 mm/day water uptake of the crop is little affected at soil water depletion of less than 50 percent of the total available soil water (p = 0.5). Moderate water stress to the crop occurs at depletion levels of 70 to 80 percent and severe stress occurs at levels exceeding 80 percent.

Yields

Under irrigation a good commercial grain yield is 6 to 9 ton/ha (10 to 13 percent moisture). In this study a dry matter content of 87% was assumed. In Albania about 4 ton/ha is reached, more or less the same in each AEZ.

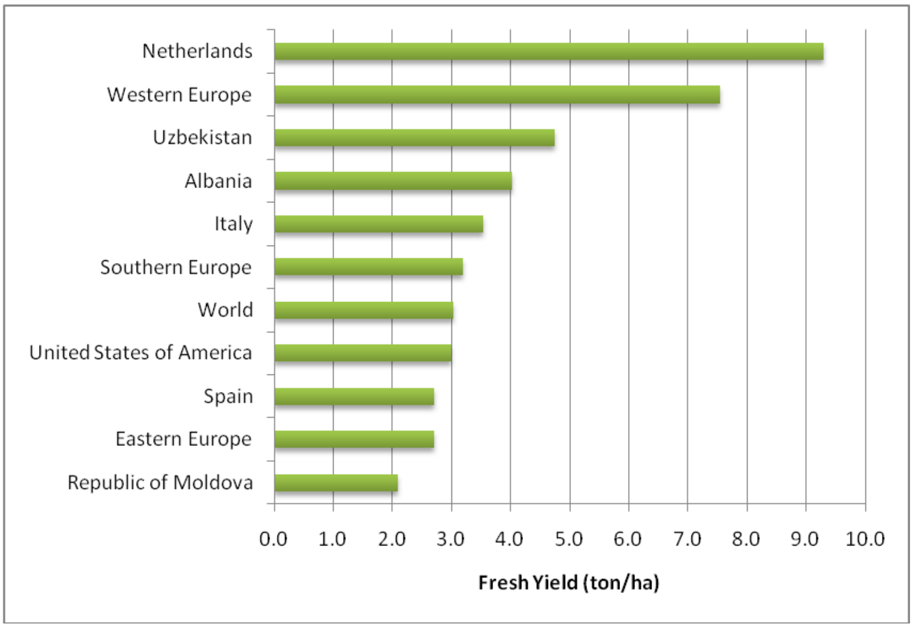


Figure 11. Wheat fresh yield in some selected relevant countries,

Fertility stress

For good yields the fertilizer requirements are up to 150 kg/ha N, 35 to 45 kg/ha P and 25 to 50 kg/ha K. In Albania, optimal amounts of Nitrogen fertilizers are applied, while for phosphorus minimum to medium amounts are used, according to information from local experts.

The sensitivity of the crop to fertility stress was defined as moderate, as defined by the following parameter values:

- Shape factor for the response of canopy expansion for limited soil fertility: 3.92
- Shape factor for the response of maximum canopy cover for limited soil fertility: 1.77
- Shape factor for the response of crop Water Productivity for limited soil fertility: 6.26
- Shape factor for the response of decline of canopy cover for limited soil fertility: -1.57

2.6 CO2 fertilization

Potential production of a crop is based on the fixation of solar energy in biomass, referred to as photosynthesis, according to the well-known process:

$$H_2O + CO_2 \xrightarrow{light} CH_2O + O_2$$

In this process CO_2 from the atmosphere is transformed into glucose (CH_2O), resulting in the so-called gross assimilation of the crop. The required energy for this originates from (sun) light, or, more precisely from the Photosynthetically Active Radiation (PAR). The amount of PAR in the total radiation reaching the earth's surface is about 50%. However, some part of the produced glucose is directly used by the plant through the process of respiration. The difference between gross assimilation and respiration is the so-called biomass production or crop production.

It is important in this process is to make a distinction between C3 and C4 plants. The difference between C3 and C4 plants is that they have different carbon fixation properties. C4 plants are more efficient in carbon fixation and the loss of carbon during the photorespiration process is also negligible for C4 plants. C3 plants may lose up to 50% of their recently-fixed carbon through photorespiration. This difference has suggested that C4 plants will not respond positively to rising levels of atmospheric CO_2. However, it has been shown that atmospheric CO_2 enrichment can, and does, elicit substantial photosynthetic enhancements in C4 species (Wand et al., 1999).

Examples of C3 plants that can be found in Albania are potato, sugarbeet, wheat and barley, and most trees as olives. C4 plants are mainly found in the tropical regions but maize of a C4 crop and a major crop produced in Albania. A third category are the so-called CAM plants (Crassulacean Acid Metabolism) which have an optional C3 or C4 pathway of photosynthesis, depending on conditions: examples are cassava, pineapple, and, onions.

As a result the maximum gross assimilation rate (A_{max}) is about 40 (20-50) kg CO_2 ha^{-1} h^{-1} for C3 plants and 70 (50-80) kg CO_2 ha^{-1} h^{-1} for C3 plants. This maximum is only reached if no water, nutrient or light (PAR) limitations occur. Examples of C3 plants are potato, sugarbeet, wheat, barley, rice, and most trees except Mangrove. C4 plants include millet, maize, and sugarcane. It is interesting to note that only about 1% of the plant species are in C4 category and these are mainly found in the warmer regions. The main reason is that optimal temperatures for maximum assimilation rates are about 20^oC for C3 plants and 35^oC for C4 plants.

Modeling studies based on detailed descriptions of crop growth processes also indicate that biomass production and yields will increase under elevated CO_2 levels. For example Rötter and Van Diepen (1994) showed that potential crop yields for several C3 plants in the Rhine basin will increase by 15 to 30% in the next 50 years as a result of increased CO_2 levels. According to their model the expected increase in yield for maize, a C4 plant, will be only 3%, indicating that their model was indeed based on the assumption that C4 species don’t benefit from higher CO_2 levels.

In addition to these theoretical approaches, experimental data has been collected to assess the impact of CO_2 enriched air on crop growth. A vast amount of experiments have been carried out over the last decades, where the impact of increased CO_2 levels on crop growth has been quantified. The Center for the Study of Carbon Dioxide and Global Change in Tempe, Arizona, has collected and combined results from these kind of experiments (CSCDGH, 2003).

Impact of enhanced CO_2 levels is calculated by AquaCrop itself. AquaCrop uses for this the so-called normalized water productivity (WP*) for the simulation of aboveground biomass. The WP is normalized for the atmospheric CO_2 concentration and for the climate, taking into consideration the type of crop (e.g. C3 or C4). AquaCrop considers 369.47 parts per million by volume as the reference. It is the average atmospheric CO_2 concentration for the year 2000 measured at Mauna Loa Observatory in Hawaii. This is the concentration used for the analysis without CO_2 fertilization. Other CO_2 concentrations will alter canopy expansion and crop water productivity.

The effect of CO_2 increase on crop growth is still under debate. Many experiments have been done, most under laboratory conditions. However, crops in field conditions usually are grown in dense populations where they compete for space and light. Under more realistic field conditions, crop plants are likely to respond as a community rather than individual plants, wherein light (solar radiation) becomes a limiting factor for growth. Under these conditions, elevated CO_2 cannot promote horizontal expansion and greater light capture (Bazzaz and

Sombroek, 1996). In general, there is still a lack of knowledge on the CO_2 responses for many crops. There is quite some experimental data on the effects of elevated CO_2 on crops under both optimal and limiting conditions. However, scaling this knowledge to farmers' fields and even further to regional scales, including predicting the CO_2 levels beyond which saturation may occur, remain a challenge (Tubiello et al, 2007).

3 Results Impact Assessment

3.1 Overview

Detailed results for each combination of (i) crop (ii) AEZ (iii) climate and (iv) CO_2 are given in the two appendices. Appendix A shows the impact of climate change on crop yields assuming that the irrigation application remains the same as under current conditions. In Appendix B the changes of irrigation requirements under climate change are given for those crops that are irrigated in Albania.

In this Chapter these results are summarized and discussed. The Chapter will start with a summary table of impact of climate change on crop yields and irrigation water requirements for each climate change scenario (dry, medium and wet). The Chapter continues with some specific results for the crops considered and ends with some general conclusions.

Table 14 to Table 16 list the yield changes relative to the reference situation, expressed in %/ 10 year. The red color indicates a decrease in yield, compared to the current situation, while the green color indicates an increase in yield. This was calculated by taking the average percentual change for each of the four periods (2010s, 2020s, 2030s and 2040s) relative to the current situation. It has to be noted that these percentual changes in many cases cannot be summed to reach to a total percentage over f.e. 40 years, because for some crops, AEZs and scenarios, the changes do not show a linear trend. This can also be clearly observed in the tables and figures of Appendix A.

Table 14. Yield changes relative to the current situation (%/10yr) under the DRY climate scenario, for each crop and AEZ (assuming no CO2 fertilization)

Crop	Interme-diate	Coastal Lowlands	Northern Mountains	Southern Highlands
Alfalfa irrigated	1%	0%	2%	8%
Alfalfa non irrigated	-9%	-9%	-5%	0%
Grapes	-14%	-14%	-11%	-12%
Grassland	-10%	-9%	-9%	1%
Maize	-2%	-7%	-8%	10%
Olives	-4%	-12%	-11%	-6%
Tomatoes	-1%	-3%	-6%	-1%
Watermelons		-2%		
Wheat	3%	2%	6%	9%

Table 15. Yield changes relative to the current situation (%/10yr) under MEDIAN climate scenario, for each crop and AEZ (assuming no CO2 fertilization)

Crop	Interme-diate	Coastal Lowlands	Northern Mountains	Southern Highlands
Alfalfa irrigated	2%	2%	4%	8%
Alfalfa non irrigated	-1%	-1%	4%	0%
Grapes	-8%	-10%	-6%	-10%
Grassland	-2%	1%	3%	1%

Maize	-1%	-2%	-4%	7%
Olives	-1%	-8%	-5%	-5%
Tomatoes	0%	-2%	-3%	-1%
Watermelons		-1%		
Wheat	4%	3%	11%	8%

As can be seen in the previous two tables, most crops are affected negatively by the climate change scenarios, except for alfalfa and winterwheat. The dry climate scenario has the strongest impact, with less rainfall and higher evapotranspiration demand due to the higher temperature regime. For the median climate scenario the impact is a little less severe as this scenario is less pessimistic in terms of rainfall projections.

Table 16. Yield changes relative to the current situation (%/10yr) under WET climate scenario, for each crop and AEZ (assuming no CO2 fertilization)

Crop	Interme-diate	Coastal Lowlands	Northern Mountains	Southern Highlands
Alfalfa irrigated	1%	2%	2%	6%
Alfalfa non irrigated	7%	11%	9%	4%
Grapes	3%	5%	4%	-5%
Grassland	7%	13%	10%	7%
Maize	-1%	4%	0%	5%
Olives	0%	3%	2%	-2%
Tomatoes	0%	-1%	-1%	-1%
Watermelons		0%		
Wheat	2%	1%	3%	3%

The wet scenario shows for most crops a net positive impact, as the increased rainfall amounts cause more water available to the plants. The higher temperatures cause also a higher evaporative demand, but only a part is lost through non-productive soil evaporation. Most of the crops are affected positively by the increased water availability. Especially the production of the rainfed crops is enhanced by the increased rainfall amounts, as in the current situation they experience a certain amount of water-stress and growth is water-limited.

The following three tables show the same information, but for the simulations done where the debated yield-enhancing effect of CO2 fertilization was assumed.

Table 17. Yield changes relative to the current situation (%/10yr) under DRY climate scenario, for each crop and AEZ (assuming CO2 fertilization)

Crop	Intermediate	Coastal Lowlands	Northern Mountains	Southern Highlands
Alfalfa irrigated	8%	8%	9%	16%
Alfalfa non irrigated	-3%	-2%	1%	7%
Grapes	-9%	-9%	-6%	-6%
Grassland	-5%	-3%	-3%	9%
Maize	5%	-1%	-3%	19%
Olives	3%	-6%	-5%	0%
Tomatoes	7%	5%	1%	7%
Watermelons		5%		
Wheat	10%	9%	14%	17%

For the dry scenario, some of the crops experience an increase in production due to the assumed CO2 fertilization effect. This effect compensates part of the negative impact of the increased water stress caused by the higher temperatures and evaporative demand. This can be seen clearly when comparing Table 17 with Table 14, under the same climate conditions but no CO2 fertilization. For other crops (grapes, grassland) the impact under this scenario maintains negative and the impact on crop yields are considerable.

Table 18. Yield changes relative to the current situation (%/10yr) under MEDIAN climate scenario, for each crop and AEZ (assuming CO2 fertilization)

Crop	Intermediate	Coastal Lowlands	Northern Mountains	Southern Highlands
Alfalfa irrigated	9%	9%	11%	15%
Alfalfa non irrigated	6%	6%	11%	7%
Grapes	-2%	-4%	0%	-4%
Grassland	5%	8%	10%	8%
Maize	6%	5%	2%	14%
Olives	6%	-2%	1%	1%
Tomatoes	8%	5%	5%	7%
Watermelons		6%		
Wheat	12%	10%	20%	17%

Table 19. Yield changes relative to the current situation (%/10yr) under WET climate scenario, for each crop and AEZ (assuming CO2 fertilization)

Crop	Intermediate	Coastal Lowlands	Northern Mountains	Southern Highlands
Alfalfa irrigated	6%	8%	8%	12%
Alfalfa non irrigated	13%	18%	15%	10%
Grapes	9%	11%	9%	0%
Grassland	13%	20%	16%	13%
Maize	4%	10%	6%	11%
Olives	6%	9%	8%	3%
Tomatoes	5%	5%	5%	6%
Watermelons		5%		
Wheat	7%	7%	9%	9%

For the median and wet climate scenario, assuming CO2 fertilization, part of the increased water demands through higher evapotranspirative demand is compensated. For the wet scenario this results in all non-negative relative changes. In other words, under this climate scenario, crop yields are likely to increase. This is under the same irrigation amounts for the irrigated crops and no additional irrigation for the rainfed crops. Again, similar to the non-CO2 fertilization scenario, positive impacts are highest for the rainfed crops, under the wet scenario.

Of the irrigated crops, the climate impact on irrigation amounts was assessed, assuming same future yields. The following tables summarize for each of the crops the results. In the appendix the full results can be found for each crop and AEZ. The orange color indicates an increase in crop irrigation water requirements, while green indicates a decrease.

Again, the following tables were calculated by taking the average percentual change for each of the four periods (2010s, 2020s, 2030s and 2040s) relative to the current situation. As in many cases, the changes do not show a linear trend, these percentual changes can mostly not be summed to obtain a total percentage over f.e. 40 years, because for some crops, AEZs and scenarios. This can be clearly observed in the tables and figures of Appendix B, where the changes for each decade are shown.

Table 20. Irrigation water requirements changes relative to current situation (%/10yr) under the 3 climate scenarios, for each crop and AEZ (assuming no CO2 fertilization)

Scenario	Crop	Interme-diate	Coastal Lowlands	Northern Mountains	Southern Highlands
DRY	Alfalfa irrigated	5%	4%	0%	-6%
	Maize	25%	11%	11%	6%
	Tomatoes	44%	18%	8%	29%
	Watermelons		15%		
MEDIAN	Alfalfa irrigated	-3%	-2%	-6%	-6%
	Maize	11%	7%	6%	9%
	Tomatoes	25%	14%	4%	24%
	Watermelons		9%		
WET	Alfalfa irrigated	-11%	-5%	-5%	-8%
	Maize	-1%	-4%	-2%	0%
	Tomatoes	2%	1%	-10%	17%
	Watermelons		-4%		

For the dry and median scenario, the overall trend is that more water is required to maintain the current yields. Especially tomatoes and maize will need substantial increased amounts of water (see also Appendix B for absolute numbers for each decade). The wet scenario predicts more rainfall, also during the cropping period, which results in a slight decrease in water demands.

The same overview as in Table 20 on relative changes in irrigation water requirements is given in the following Table 21, but assuming now assuming the yield enhancing effect of CO2.

Table 21. Irrigation water requirements changes relative to the current situation (%/10yr) under the 3 climate scenarios, for each crop and AEZ (assuming CO2 fertilization)

Scenario	Crop	Interme-diate	Coastal Lowlands	Northern Mountains	Southern Highlands
DRY	Alfalfa irrigated	-6%	-11%	-16%	-15%
	Maize	16%	5%	5%	-1%
	Tomatoes	-35%	-4%	4%	-21%
	Watermelons		0%		
MEDIAN	Alfalfa irrigated	-17%	-17%	-22%	-15%
	Maize	3%	0%	0%	2%
	Tomatoes	-52%	-14%	-2%	-21%
	Watermelons		-9%		
WET	Alfalfa irrigated	-29%	-12%	-14%	-17%
	Maize	-9%	-8%	-6%	-5%
	Tomatoes	-52%	-37%	-21%	-36%
	Watermelons		-23%		

Generally, less water will be available to maintain the current yields in the future, under climate change, and assuming CO2 fertilization. For maize this effect is less clear. The other crops will need require less water for irrigation under these scenarios and assuming that fertility levels and other boundary conditions are unaffected.

In the following paragraphs, some more detailed observations are done on each crop.

3.2 Alfalfa

About 70% of the alfalfa is irrigated in Albania. Simulated yields are around 50% higher when the crop is irrigated. This is similar to what is observed in the field. Rainfed alfalfa is much more affected by the climate change scenarios as irrigated alfalfa. Especially for the dry scenario, the difference between both is obvious. Rainfed alfalfa experiences currently a certain amount of water stress so less rainfall will limit growth even further. The wet scenario on the other hand, affects growth of rainfed alfalfa positively, with a higher relative increase compared to irrigated alfalfa.

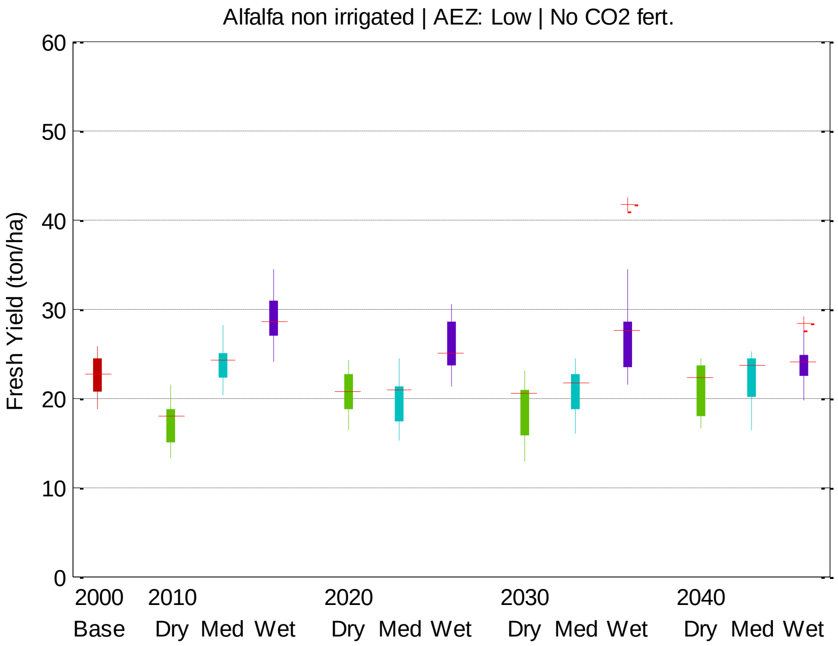


Figure 12. Fresh weight yields for non-irrigated alfalfa for Coastal Lowlands (no CO2 fertilization)

Future irrigation water requirements were analyzed for irrigated alfalfa keeping yields and all the other boundary conditions constant. For most scenarios, irrigation water requirements will decrease for irrigated alfalfa. Only for the dry scenario, water requirements are slightly higher compared to the current situation (see Figure 13 and the Appendix B). For the other scenarios, crop yields are enhanced by the higher temperatures while current irrigation amounts are sufficient or even less water is required to obtain the same yield. This effect is even stronger when CO2 fertilization is assumed.

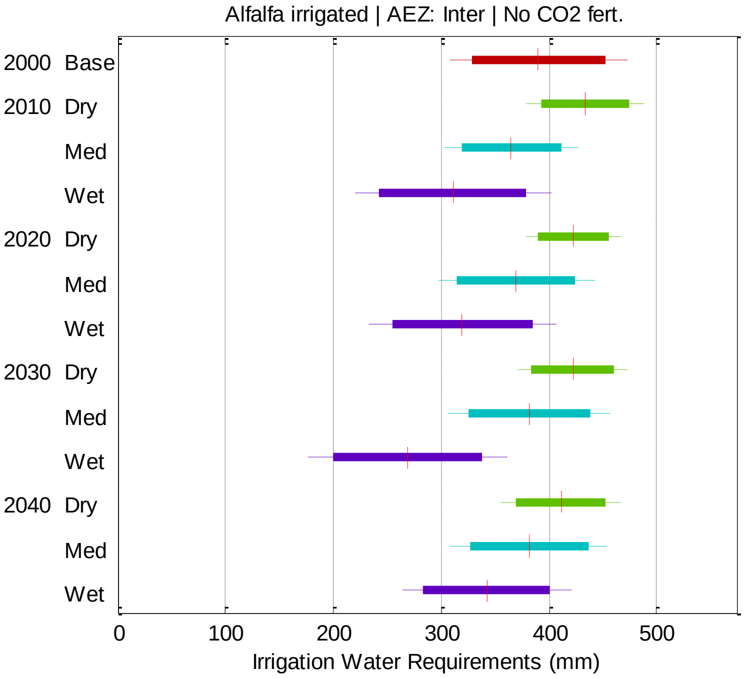


Figure 13. **Irrigation Water Requirements for Alfalfa, Intermediate AEZ (No CO2 fertilization)**

3.3 Grapes

Grapes are generally not irrigated in Albania. For this reason, the crop production tends to be water-limited to a certain extent, depending on the climate conditions in each location. The climate scenario simulations confirm this growth-limiting effect. The dry scenario predicts the lowest yields in each AEZ while the wet scenario shows the highest yields. The difference between both is about 15%. The median scenario, with CO2 fertilization shows hardly any impact on crop yields, while the scenario without CO2 fertilization shows that yields will decline considerably.

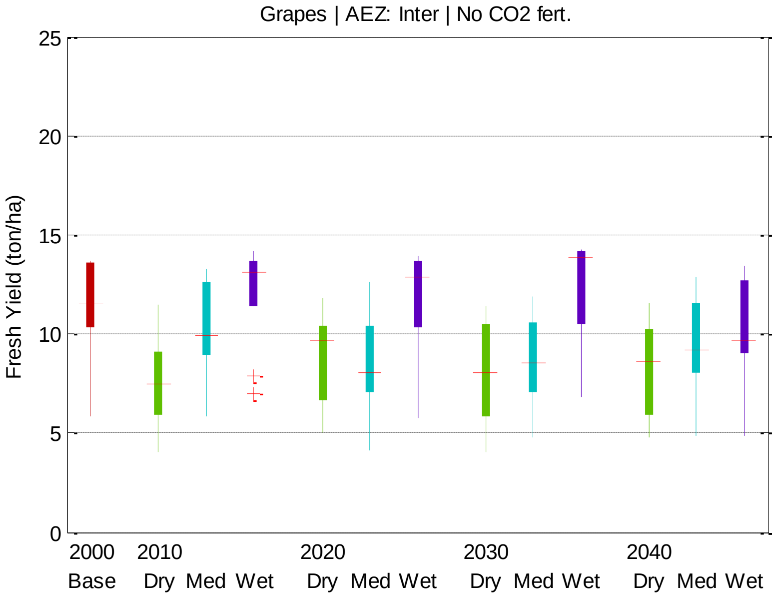


Figure 14. Fresh weight yields for Grapes, AEZ: Intermediate, no CO2 fertilization

3.4 Grasslands

A clear benefiting effect can be seen for the wet scenario for grasslands, which shows the water-limiting effect on current growth. Even for the simulations without CO2 fertilization, yields are predicted to increase considerably in all AEZs. The dry and median scenarios, however, show a decrease in yield when no CO2 fertilization is assumed. Under CO2 fertilization, a general slight increase in yields can be observed for the median scenario, while for the dry scenario, the production is lower over the whole period.

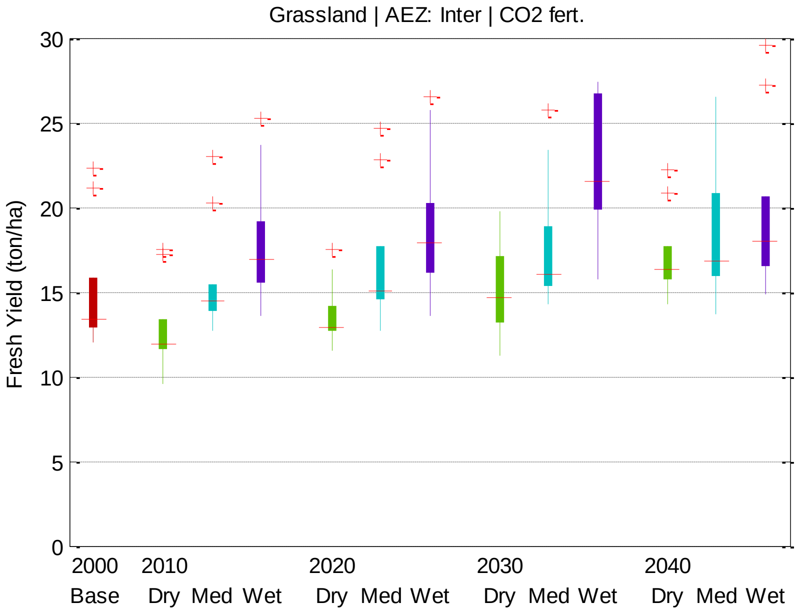


Figure 15. Yields for Grassland, AEZ: Inter | CO2 fert.

3.5 Maize

These simulations without CO2 fertilization show a decrease in yields for the dry and median climate projections. For the wet climate scenario the yields remain more or less the same over the whole period. The yield enhancing effect of CO2 fertilization for maize is thought to be limited being a C4 crop.

The variability in predicted yields is relatively high for the dry scenario. This scenario shows an increase in standard deviation of about two times the baseline scenario (Figure 16 and Appendix A). The drier years of this scenario affect the yields considerably, causing a large difference between minimum and maximum yields.

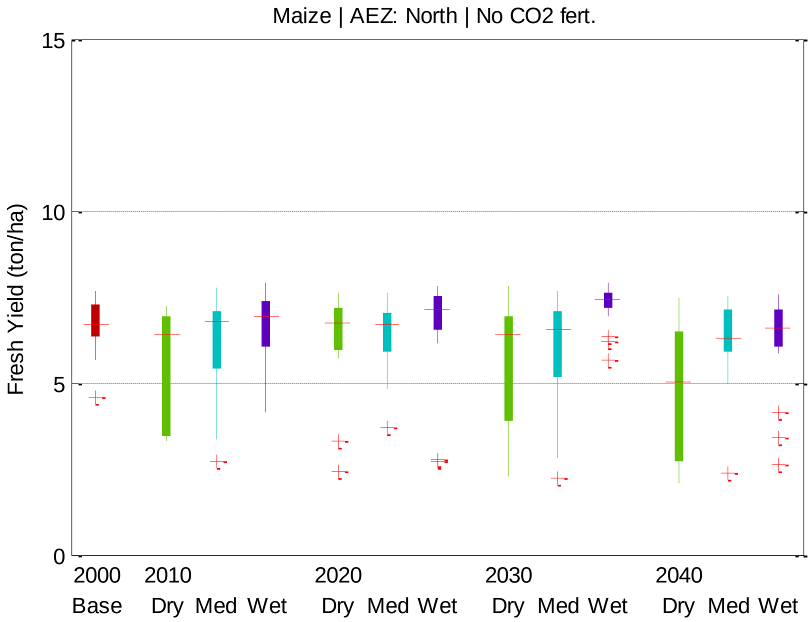


Figure 16. Yields for Maize, AEZ: North | No CO2 fert.

Future irrigation water requirements were analyzed for irrigated maize keeping yields and all the other boundary conditions constant. For all the AEZs, the dry scenario shows a considerable increase in water demands, as expected, for both CO2 scenarios. Also the median scenario shows a noteworthy increase in water requirements. For the wet scenario the crop irrigation water demands remain more or less the same over the whole period.

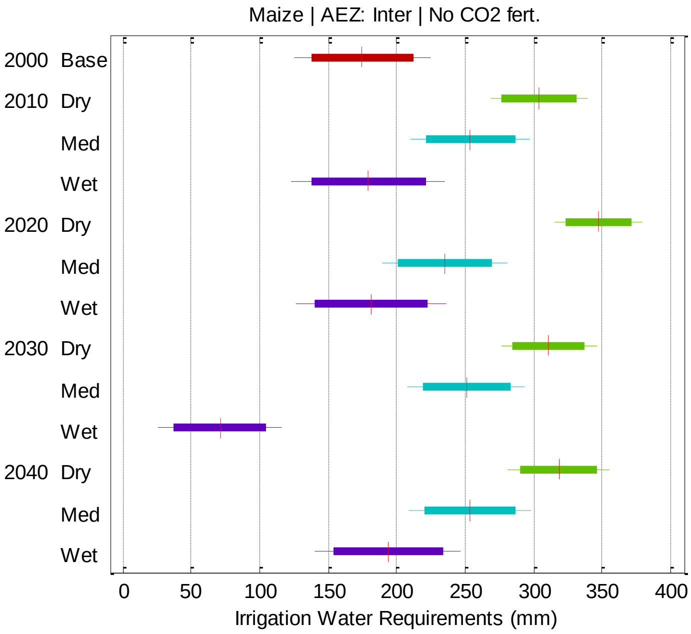


Figure 17. Irrigation Water Requirements for Maize, AEZ: Intermediate (No CO2 fertilization)

3.6 Olives

Olives are mostly not irrigated in Albania. The water availability through rainfall therefore determines to a great extend the obtained yields. The dry scenario shows a considerable decrease in yields, even when CO2 fertilization is assumed. The median scenario shows also a general decrease in yields, as well as the wet scenario without CO2 fertilization. Only for the wet scenario and with CO2 fertilization, yields are unaffected or increasing. In general the results show that for most scenarios the climate impact on olive yields is considerable.

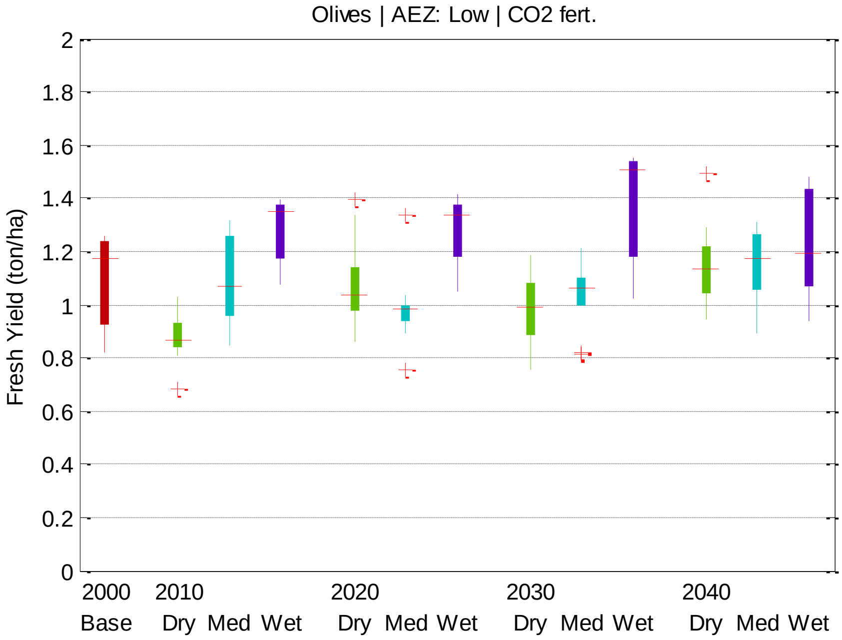


Figure 18. Yields for Olives, AEZ: Low | CO2 fert.

3.7 Tomatoes

The climate impact on tomato yield in Albania is best expressed in terms of variability. Especially for the dry climate scenario, variability in yields is expected to increase considerably compared to the baseline scenario, with the standard deviation about 4 times higher compared to the current situation (see f.e. Figure 19 and Appendix A).

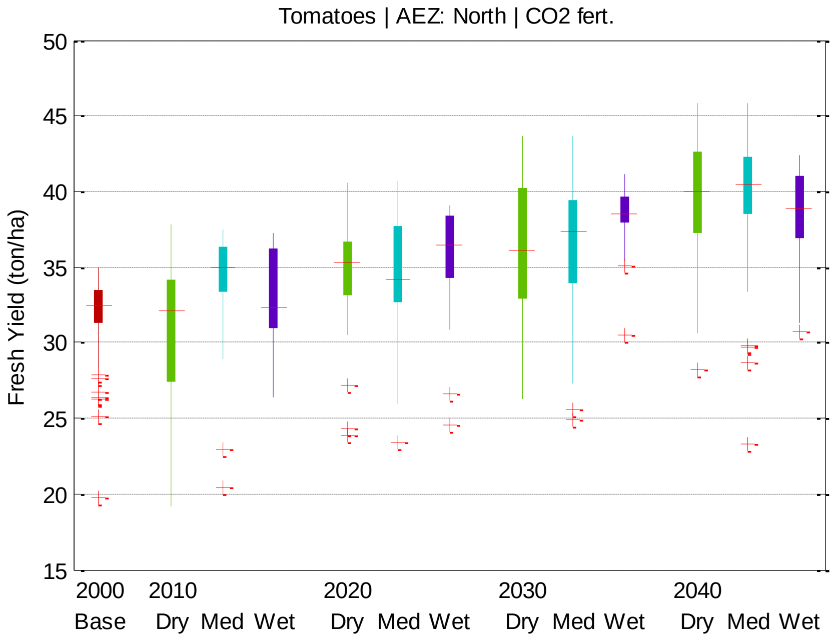


Figure 19. Yields for Tomatoes, AEZ: North | CO2 fert.

The climate impact on the tomato yields depend very much on whether CO2 fertilization is assumed or not. Without CO2 fertilization, yields are generally decreasing, even for the wet scenario. With CO2 fertilization, yields will increase for most scenarios and in most AEZs, assuming that soil fertility levels will not change.

Future irrigation water requirements were analyzed for tomatoes keeping yields and all the other boundary conditions constant. Assuming no significant effect of CO2 fertilization, for the dry and median scenario, irrigation water requirements will increase, compared to the current applied amount. For the wet scenario, no clear trend can be observed (see Figure 20 and Appendix B).

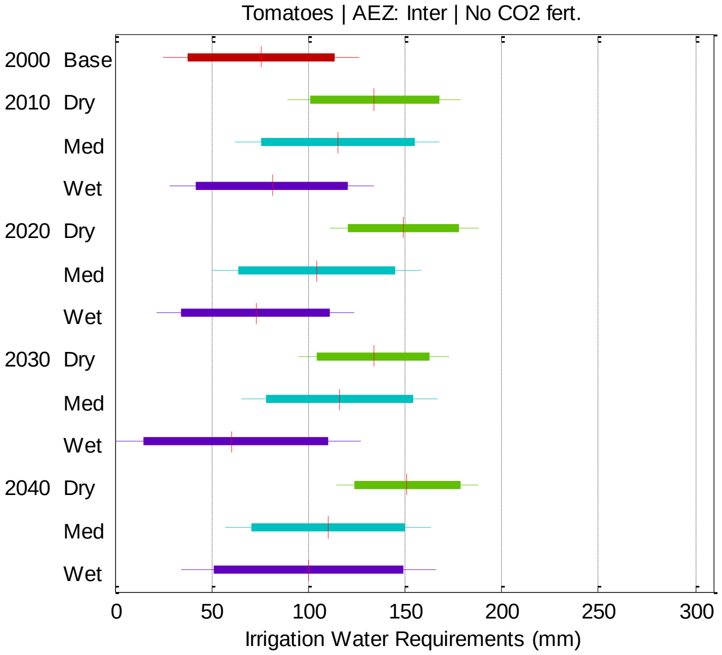


Figure 20. Irrigation Water Requirements for Tomatoes, AEZ: North | No CO2 fert.

3.8 Watermelons

Watermelons are only cultivated in the coastal lowlands. In this region, yields of watermelons are almost unaffected for all the scenarios assuming no CO2 fertilization. Yields are slightly enhanced when CO2 fertilization is taken into account. Apparently, the relative high irrigation amounts assure that the production is not or hardly water-limited.

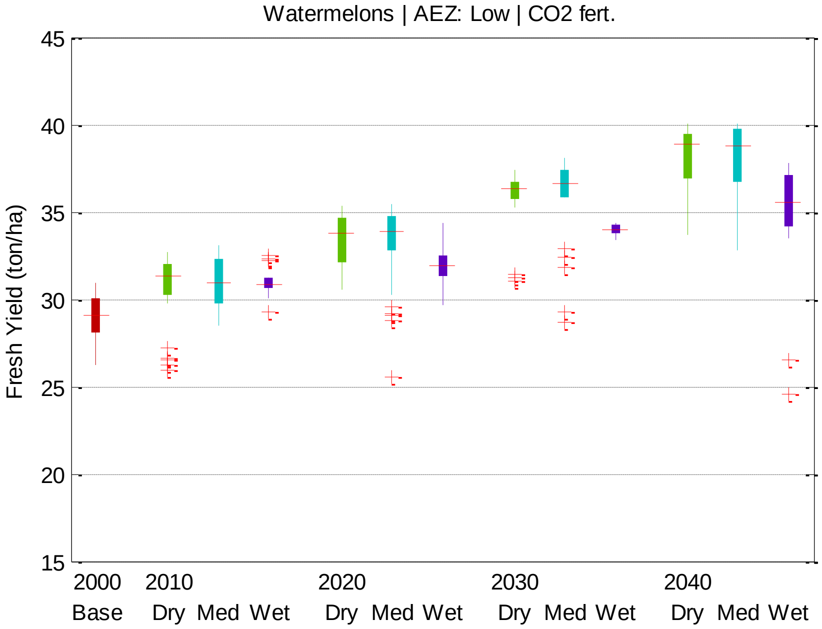


Figure 21. Yields for Watermelons, AEZ: Low | CO2 fert.

Future irrigation water requirements were analyzed for watermelons keeping yields and all the other boundary conditions constant. For the dry and median climate scenario, irrigation water demands show a considerable increase while for the wet scenario demands remain more or less the same. If CO2 fertilization is assumed, irrigation water requirements are lower compared to the current situation (Figure 22).

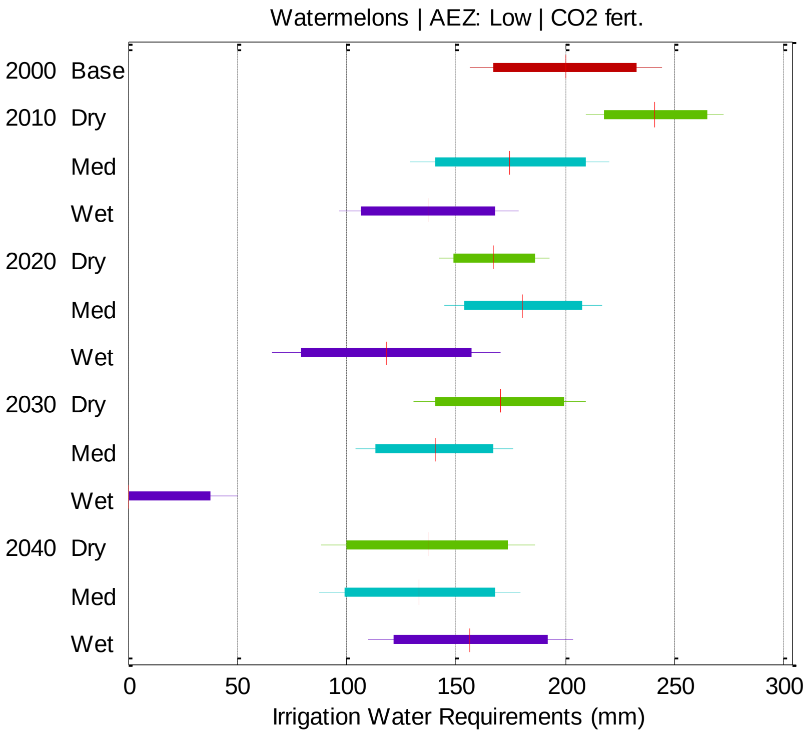


Figure 22. Irrigation Water Requirements for Watermelons, AEZ: Low | CO2 fertilization

3.9 Wheat

The main wheat variety cultivated in Albania is winter wheat. Results show a general increase in yield of the variety, due to the increasing temperatures. Especially spring temperatures affect the crop development, and frost during spring can even lead to head sterility. Increasing temperatures therefore may an enhancing effect on yields. This effect is observed in all three climate scenarios, but less in the wet scenario which is most conservative in terms of temperature increase. Without CO2 fertilization there is a little enhancing effect of increased temperatures but yield increase is more noteworthy when CO2 fertilization is assumed.

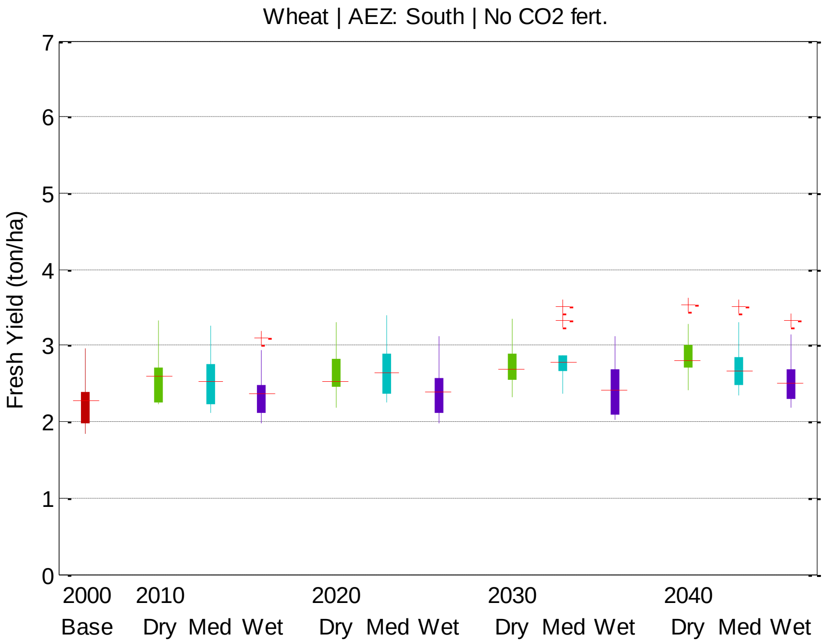


Figure 23. Yields for Wheat, AEZ: South | No CO2 fert.

3.10 Conclusion

For most of the crops and AEZs, the dry and median climate scenarios predict a reduction in fresh weight yields, while the wet climate scenario generally shows a slight increase. This is especially the case for the rainfed crops. For the irrigated crops, the predicted temperature rise may also affect positively the crop production, which is the case for alfalfa and winterwheat. Not all regions are affected to the same extent by the climate change scenarios. In some cases, yields were negatively affected in one region while positively affected in another.

If the debated effect of CO_2 fertilization is taken into account, yields show generally an overall increase, except for the dry climate scenario, where for some crops water stress still limits crop production. Also for the median climate scenario, the enhancing effect is not always as pronounced, as for example for olives and grapes.

Irrigation water requirements for the four irrigated crops are likely to increase, when no CO2 fertilization is assumed. Especially for tomatoes and maize, additional requirements are considerable. CO2 fertilization would lead for most crops and scenarios to a decrease in water demands maintaining current yields.

In summary, two of three scenarios studied (dry and median) give an overall negative impact on crop yields and irrigation water requirements. The wet climate scenario promotes crop production, especially for the rainfed crops, as for these crops growth is currently water-limited.

4 Results Adaptation Assessment

Several adaptation strategies were selected for Albania that may increase the national crop production. The potential for yield increase of these adaptation strategies was evaluated by assessing them with the crop process model AquaCrop. The following five adaptation options are addressed:

1) Increasing fertilizer application.
Several crops in Albania are currently cultivated while applying non-optimal amounts of fertilizers. This leaves a margin for yield increase in the future. The influence of more fertilizer use was assessed with the crop model and compared with the current situation. It was assumed that fertility stress can be reduced by 20% for crops that are currently cultivated using less than sub-optimal amounts of fertilizers. For crops which are currently grown under sub-optimal fertilizer conditions, it was assumed that there is a potential to reduce fertility stress by 10%.The sensitivity to these lower stress levels depend on the crop which is something that is accounted for in the model.

2) Enhanced varieties.
It is likely that future crop enhancements will lead to more water-efficient varieties. This will allow higher crop yields in the future. The crop model is used to assess the potential yield increases and the results were compared with the current situation. It was assumed that the crop water productivity can be enhanced in the future by 15%. The use of these varieties together with the different future climatic conditions would lead to changes in planting and harvest dates. It was assumed that these new enhanced varieties can be planted 7 days earlier and harvested 14 days earlier compared to the current situation. This leads to a total growing period which is 7 days shorter than the variety used in the impact assessment.

3) Increasing irrigation water application.
The current irrigation amounts applied to the crops are not equal to the full crop irrigation water requirements. Applying more water to the irrigated crops can enhance crop growth. The crop model was used to estimate the yields when applying 100 mm of additional water to the crops and the results were compared with the current situation.

4) Changing from rainfed to irrigated agriculture.
Changing from rainfed to irrigated agriculture requires much investment for new infrastructure but can be a very effective adaptation option if irrigation water is sufficiently available. This option is demonstrated through an example with alfalfa in Albania (see Box 1) and is based on the outcomes of the climate impact assessment. Information is used that was obtained from the local experts, on the current ratio between irrigated and non irrigated areas.

5) Improve drainage.
Poorly drained soils can limit crop growth and can lead to flooding problems, as highlighted by the very recent flooding episodes in the Shkoder region. Artificial drainage can remove the excess water and enhance growth. The influence of improving drainage conditions on yields is quantified with the crop model and demonstrated by comparing the yields of poorly drained soils with well drained soils for one particular crop in Albania (see Box 2)

The following table shows the results the first 3 adaptation measures for each of the AEZs and for each crop. These are (1) increasing fertilizer use, (2) use of enhanced varieties and (3) increasing irrigation water. The relevant changes were implemented in the model, based on the boundary conditions as discussed before. The increased irrigation strategy was only applied to the crops currently irrigated (alfalfa, maize, tomatoes and watermelons).

The table shows the modeled yields for the current situation, the yields for the future situation and the impact of the yields when applying one of the adaptation strategies. The percentual changes indicate the relative change in crop yield compared to the current situation. The analysis was done for the median climate scenario, assuming no effect of CO2 fertilization and for the 2040’s period (2040-2049).

Table 22. Impact on crop yields (ton/ha) of different adaptation options for the 4 AEZs in Albania

Scenario		**Intermediate**		**Coastal Lowlands**		**Northern Mountains**		**Southern Highlands**	
Alfalfa irrigated									
Current		**47.1**		**46.2**		**39.3**		**30.1**	
2040's	Impact	49.2	(+5%)	48.3	(+5%)	42.2	(+7%)	35.7	(+19%)
	Increased Fertilizer Use	50.3	(+7%)	48.1	(+4%)	42.0	(+7%)	36.4	(+21%)
	Enhanced Varieties	55.6	(+18%)	53.1	(+15%)	46.8	(+19%)	40.4	(+34%)
	Increased Irrigation	57.6	(+22%)	50.9	(+10%)	43.6	(+11%)	38.1	(+27%)
Alfalfa non irrigated									
Current		**33.4**		**22.5**		**17.3**		**15.0**	
2040's	Impact	31.4	(-6%)	21.9	(-3%)	16.9	(-2%)	16.0	(+7%)
	Increased Fertilizer Use	31.7	(-5%)	22.1	(-2%)	17.0	(-2%)	16.1	(+7%)
	Enhanced Varieties	35.7	(+7%)	24.9	(+10%)	19.5	(+12%)	18.0	(+20%)
Grapes									
Current		**11.0**		**5.7**		**4.6**		**7.5**	
2040's	Impact	9.2	(-17%)	4.5	(-20%)	3.6	(-21%)	6.1	(-18%)
	Increased Fertilizer Use	9.2	(-17%)	4.6	(-20%)	3.6	(-21%)	6.1	(-18%)
	Enhanced Varieties	11.6	(+6%)	5.7	(+1%)	5.0	(+10%)	7.8	(+4%)
Grassland									
Current		**14.9**		**9.6**		**8.3**		**5.6**	
2040's	Impact	14.1	(-5%)	9.3	(-3%)	7.7	(-7%)	6.2	(+10%)
	Increased Fertilizer Use	17.0	(+14%)	10.7	(+11%)	8.5	(+3%)	6.7	(+18%)
	Enhanced Varieties	16.2	(+9%)	10.5	(+9%)	8.8	(+6%)	7.0	(+24%)
Maize									
Current		**7.7**		**8.8**		**6.7**		**5.2**	
2040's	Impact	7.7	(+1%)	8.6	(-2%)	6.2	(-8%)	6.0	(+15%)
	Increased Fertilizer Use	9.7	(+27%)	8.9	(+2%)	6.9	(+2%)	8.2	(+57%)
	Enhanced Varieties	9.3	(+21%)	9.4	(+6%)	7.5	(+12%)	7.3	(+40%)
	Increased Irrigation	11.0	(+44%)	11.0	(+25%)	8.9	(+33%)	8.6	(+65%)
Olives									
Current		**1.3**		**1.1**		**1.0**		**1.2**	
2040's	Impact	1.2	(-3%)	0.9	(-21%)	0.8	(-19%)	1.1	(-9%)
	Increased Fertilizer Use	1.6	(+28%)	1.1	(+5%)	1.1	(+9%)	1.3	(+12%)
	Enhanced Varieties	1.4	(+13%)	1.1	(-1%)	1.0	(+0%)	1.3	(+10%)
Tomatoes									
Current		**33.8**		**33.2**		**30.9**		**33.7**	
2040's	Impact	33.6	(-0%)	29.1	(-12%)	29.1	(-6%)	33.7	(-0%)
	Increased Fertilizer Use	55.4	(+64%)	51.2	(+54%)	42.7	(+38%)	54.5	(+62%)
	Enhanced Varieties	38.9	(+15%)	37.2	(+12%)	35.0	(+13%)	38.8	(+15%)
	Increased Irrigation	35.0	(+4%)	36.4	(+10%)	42.2	(+37%)	34.4	(+2%)
Watermelons									
Current				**28.5**					
2040's	Impact			28.4	(-0%)				
	Increased Fertilizer Use			29.1	(+2%)				
	Enhanced Varieties			32.7	(+15%)				
	Increased Irrigation			30.5	(+7%)				
Wheat									
Current		**4.2**		**4.6**		**2.8**		**2.3**	
2040's	Impact	4.6	(+10%)	5.0	(+7%)	3.5	(+24%)	2.8	(+20%)
	Increased Fertilizer Use	6.8	(+63%)	7.3	(+57%)	5.3	(+87%)	4.3	(+86%)
	Enhanced Varieties	5.2	(+24%)	5.6	(+22%)	3.8	(+34%)	2.9	(+27%)

Box 1

Adaptation option 4. Converting rainfed to irrigated agriculture

About 70% of the currently cultivated alfalfa is irrigated in Albania. Converting part of the currently rainfed acreage to irrigated can lead to considerable gains in agricultural production. The following table shows how nationally averaged alfalfa yields in Albania can be increased when part of the currently rainfed areas are converted to irrigated alfalfa. It is assumed that the current irrigation practices remain unaltered. The total area where alfalfa is currently cultivated is 130.000 ha. The example was worked out with results of the dry climate scenario (with no CO2 fertilization).

Table 23. Impact on average crop yield of converting from rainfed to irrigated agriculture

Period	Irrigated (% ha)	Converted (ha)	Yield (ton/ha)	
Current	70%		33.4	
2040's	70%		33.1	(-1%)
	75%	6500	34.2	(+2%)
	80%	13000	35.2	(+6%)
	85%	19500	36.3	(+9%)

Box 2

Adaptation option 5. Improving drainage

In several parts of Albania, soils are relatively poorly drained. This means that excess water in the soil may limit crop growth. Implementing artificial drainage can be a way to enhance agricultural production and serve as a climate adaptation measure. The following table demonstrates the influence of drainage on crop yield of alfalfa for the intermediate AEZ in Albania (the northern coastal part of this AEZ experiences drainage and flooding problems).

For this example, the current situation is a poorly drained soil, with drainage conditions comparable to a clayey soil. It has to be noted that the model only accounts for the influence of water logging on the aeration of the plant. It does not account for crop damage by flooding and the possible delaying of planting date because of saturated soils and the resulting shortening of the growth season.

Table 24. Impact of drainage conditions on non-irrigated alfalfa yield

Period	Drainage	Yield (ton/ha)	
Current	poorly	31.8	
2040's	poorly	30.2	(-5%)
	sub-optimal	31.5	(-1%)
	optimal	31.5	(-1%)

5 References

Aerts, J. and P. Droogers (Eds). 2004. Climate change in contrasting river basins: Adaptation strategies for water, food, and environment. CABI Books, Londen. 288 p.

Bazzaz FA, Sombroek WG (1996) Global Climate Change and Agricultural Production: Direct and Indirect Effects of Changing Hydrological, Pedological, and Plant Physiological Processes. Food and Agriculture Organization of the United Nations/Wiley, Chichester, UK/New York

NEA, 1998. State of the Environment Report 1997 – 1998. Republic Of Albania, National Environmental Agency

Parry M.L,. Rosenzweig C, Iglesias A, Livermore M, Fischer G, 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environ. Change. 14, 53–67.

Rötter, R.P., and C.A. van Diepen. 1994. Rhine basin study: Land use projections based on biophysical and socio-economic analyses. Volume 2. Climate change impact on crop yield potentials and water use. Wageningen, DLO Winand Staring Centre, Report 85.2, 152 p.

Tubiello FN, Soussana JF, Howden SM, 2007. Crop and pasture response to climate change. Proceedings of the National Academy of Sciences, USA 2007b;104:19686-19690.

Wand, S.J.E., Midgley, G.F., Jones, M.H. and Curtis, P.S. 1999. Responses of wild C4 and C3 grass (Poaceae) species to elevated atmospheric CO2 concentration: a meta-analytic test of current theories and perceptions. Global Change Biology 5: 723-741.

You, L., Z. Guo, J. Koo, W. Ojo, K. Sebastian, M.T. Tenorio, S. Wood, U. Wood-Sichra. Spatial Produciton Allocation Model (SPAM) 2000 Version 3 Release 1. http://MapSPAM.info. (Your accessing date – e.g. Nov. 20, 2009)

Climate Impact Assessment on Crop Production in Albania

Appendices

World Bank Study on Reducing Vulnerability to Climate Change in Europe and Central Asia (ECA) Agricultural Systems

February 2011

Client

World Bank

Author

J.E. Hunink

P. Droogers

FutureWater
Costerweg 1G
6702 AA Wageningen
The Netherlands

+31 (0)317 460050

info@futurewater.nl

www.futurewater.nl

Table of contents

A. Appendix - Impact on Crop Yields

A.1 Alfalfa irrigated

Table A-1. Yield Statistics for Alfalfa irrigated, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	47.1	45.2	49.7	1.3
2010	Dry	46.9	43.1	51.0	1.8
2010	Med	48.5	45.3	51.6	1.5
2010	Wet	47.7	45.8	50.9	1.5
2020	Dry	47.7	43.1	51.6	1.8
2020	Med	48.8	45.4	52.4	1.7
2020	Wet	48.1	46.3	50.7	1.2
2030	Dry	48.4	45.0	52.7	1.8
2030	Med	49.4	45.2	53.0	1.7
2030	Wet	48.0	47.2	48.4	0.5
2040	Dry	49.1	45.0	52.8	1.7
2040	Med	49.2	45.1	52.7	1.7
2040	Wet	48.9	45.0	51.9	1.5

Figure A-1. Yields for Alfalfa irrigated, AEZ: Inter | No CO2 fert.

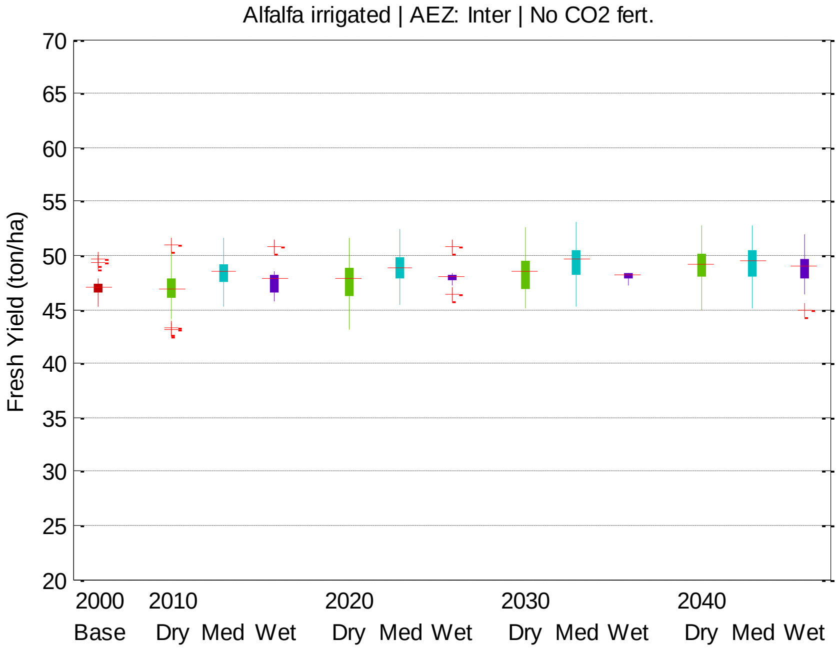


Table A-2. Yield Statistics for Alfalfa irrigated, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	48.4	46.2	51.0	1.5
2010	Dry	51.0	45.7	55.5	2.1
2010	Med	52.7	49.6	56.3	2.0
2010	Wet	51.3	49.5	54.7	1.6
2020	Dry	55.6	50.7	60.2	2.2
2020	Med	56.8	51.6	61.1	2.4
2020	Wet	54.6	52.9	57.6	1.6
2030	Dry	60.5	56.0	65.9	2.5
2030	Med	61.7	56.2	66.4	2.5
2030	Wet	56.8	56.2	57.7	0.6
2040	Dry	65.6	60.3	71.1	2.5
2040	Med	65.8	60.3	71.0	2.5
2040	Wet	61.4	56.4	65.5	2.2

Figure A-2. Yields for Alfalfa irrigated, AEZ: Inter | CO2 fert.

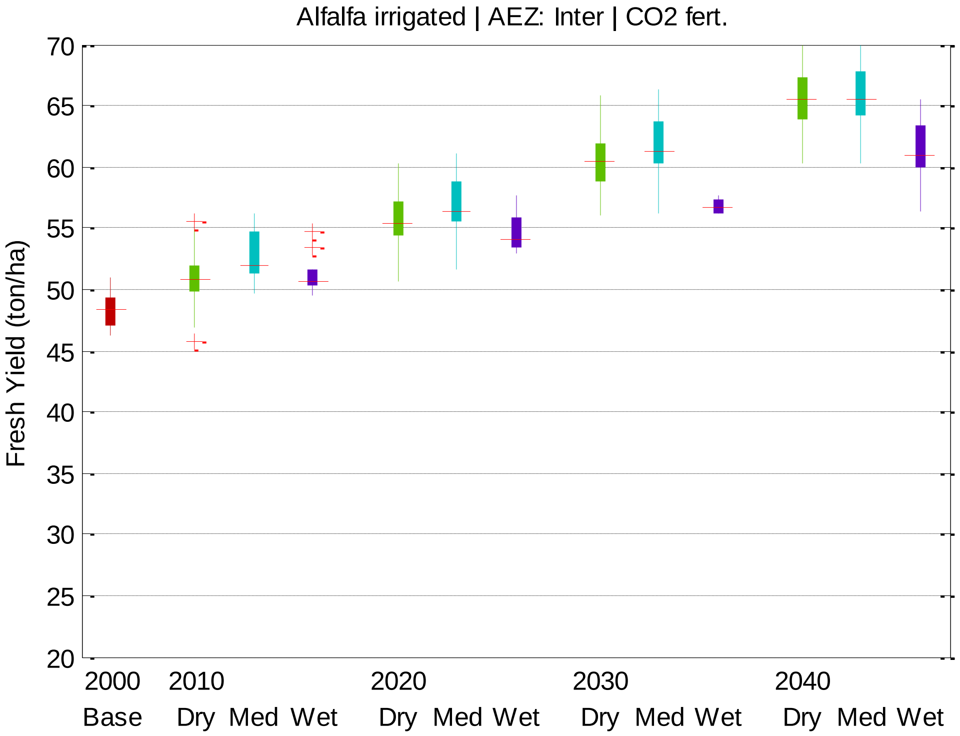


Table A-3. Yield Statistics for Alfalfa irrigated, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	46.2	42.4	50.5	1.9
2010	Dry	45.7	43.6	48.7	1.8
2010	Med	47.9	44.9	51.3	1.7
2010	Wet	48.3	44.2	51.6	1.6
2020	Dry	46.6	44.3	49.8	1.5
2020	Med	47.2	44.3	50.8	1.8
2020	Wet	47.4	43.8	51.4	1.7
2030	Dry	47.4	45.0	49.4	1.6
2030	Med	47.9	46.0	50.8	1.4
2030	Wet	47.8	44.3	51.6	1.8
2040	Dry	48.2	45.7	50.7	1.7
2040	Med	48.3	45.9	50.8	1.5
2040	Wet	48.6	45.1	52.8	2.0

Figure A-3. Yields for Alfalfa irrigated, AEZ: Low | No CO2 fert.

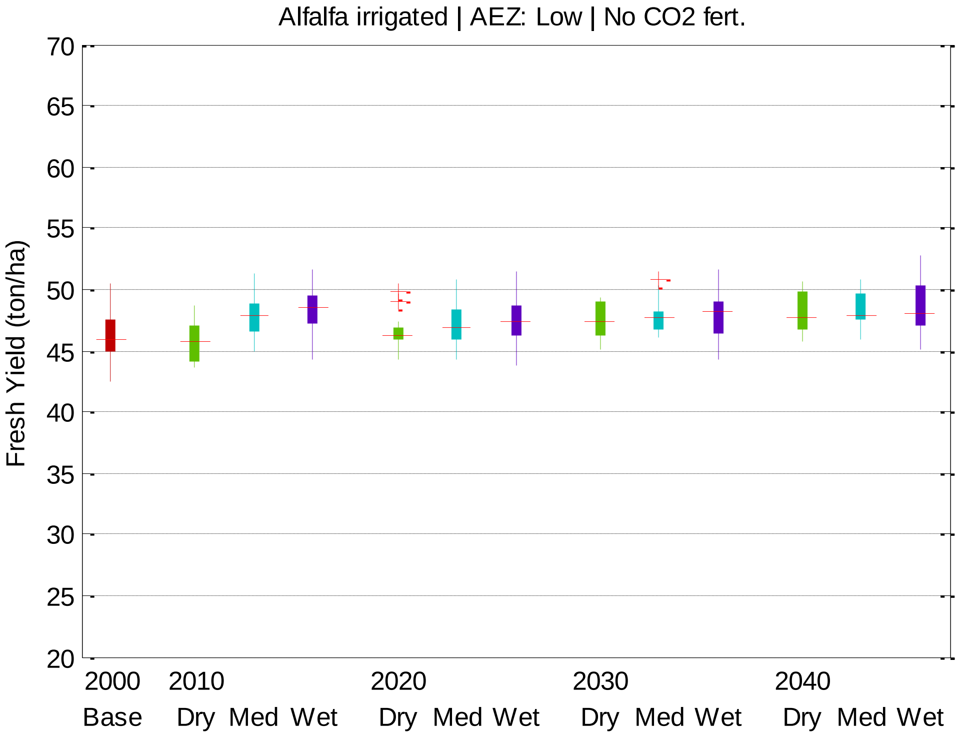


Table A-4. Yield Statistics for Alfalfa irrigated, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	47.2	43.1	51.9	1.9
2010	Dry	50.0	46.6	52.6	1.8
2010	Med	52.2	48.4	55.8	2.0
2010	Wet	51.8	47.5	55.5	1.7
2020	Dry	54.7	51.8	59.4	2.2
2020	Med	55.3	51.2	59.1	2.2
2020	Wet	53.7	49.0	58.4	2.0
2030	Dry	59.6	57.5	62.1	1.8
2030	Med	60.3	56.9	64.4	2.0
2030	Wet	57.1	52.9	61.8	2.2
2040	Dry	64.9	62.0	68.7	2.1
2040	Med	64.8	60.5	68.5	2.2
2040	Wet	61.1	56.5	66.6	2.6

Figure A-4. Yields for Alfalfa irrigated, AEZ: Low | CO2 fert.

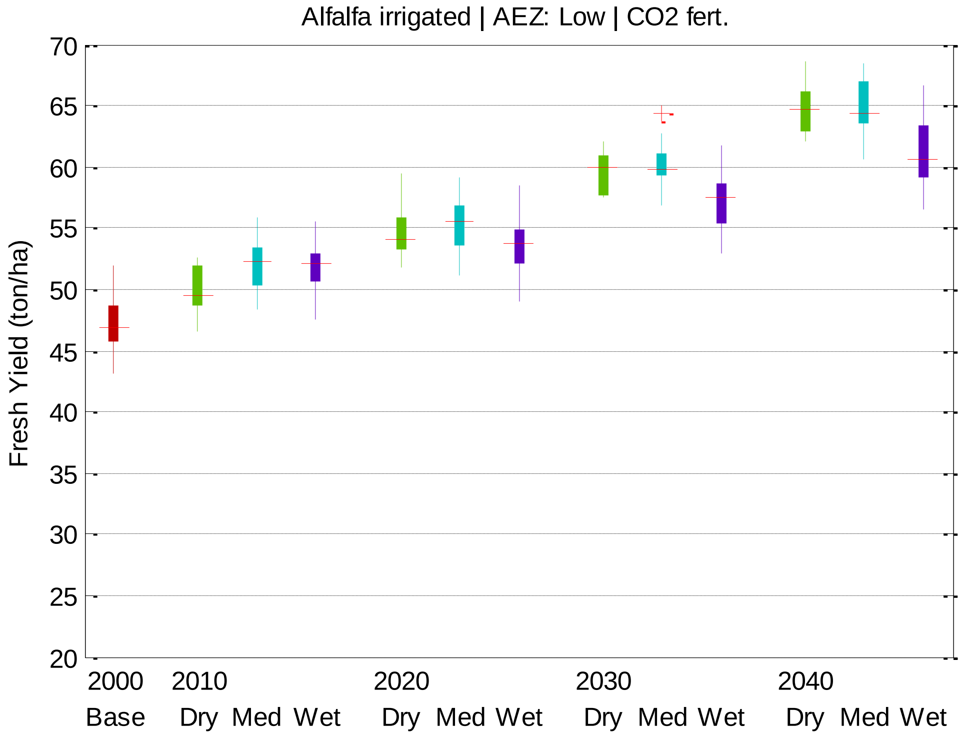


Table A-5. Yield Statistics for Alfalfa irrigated, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	39.3	36.7	41.6	1.4
2010	Dry	40.6	39.5	42.2	0.8
2010	Med	42.3	39.6	43.9	1.1
2010	Wet	40.9	38.2	42.9	1.3
2020	Dry	40.8	39.1	42.5	1.0
2020	Med	42.1	39.8	44.2	1.2
2020	Wet	40.9	37.7	42.7	1.2
2030	Dry	41.0	40.8	41.1	0.2
2030	Med	42.0	41.2	42.7	0.7
2030	Wet	41.5	38.3	43.1	1.3
2040	Dry	42.4	41.9	42.8	0.4
2040	Med	42.2	41.4	42.9	0.5
2040	Wet	42.2	39.6	43.9	1.3

Figure A-5. Yields for Alfalfa irrigated, AEZ: North | No CO2 fert.

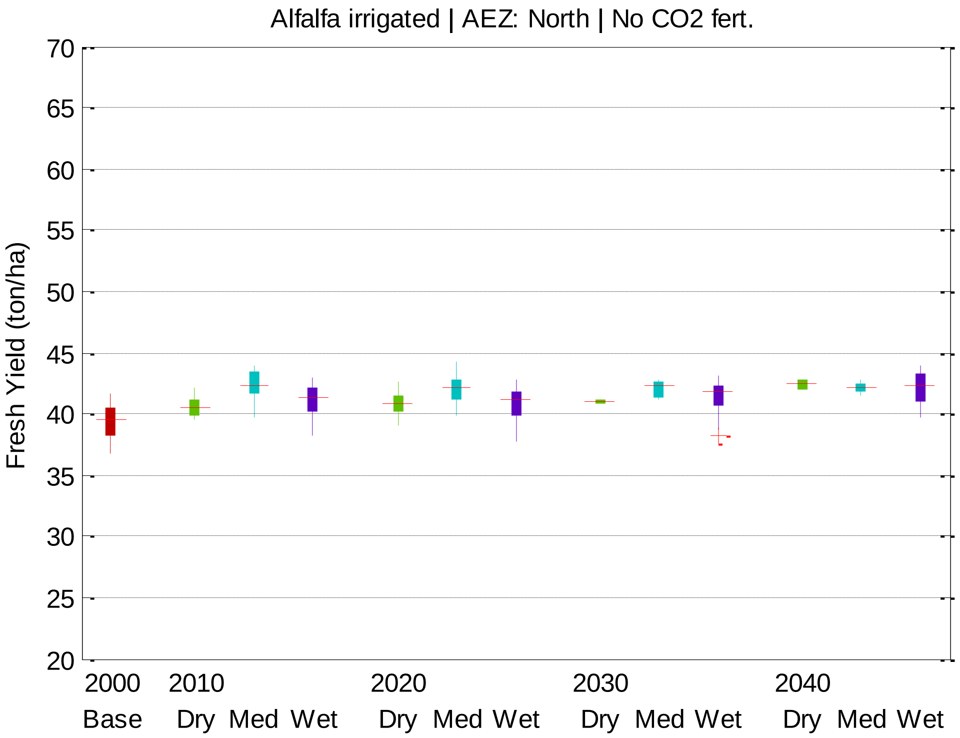


Table A-6. Yield Statistics for Alfalfa irrigated, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	40.2	37.1	42.5	1.5
2010	Dry	43.5	42.0	44.7	0.8
2010	Med	45.9	42.3	48.5	1.5
2010	Wet	44.0	40.7	46.7	1.6
2020	Dry	47.0	45.3	48.7	1.1
2020	Med	48.9	46.0	50.9	1.4
2020	Wet	46.4	42.1	49.5	1.6
2030	Dry	50.9	50.8	51.1	0.2
2030	Med	51.9	49.8	52.8	1.0
2030	Wet	49.8	45.1	52.5	1.6
2040	Dry	56.5	56.0	56.9	0.4
2040	Med	55.9	54.3	57.0	1.1
2040	Wet	52.8	49.2	55.3	1.6

Figure A-6. Yields for Alfalfa irrigated, AEZ: North | CO2 fert.

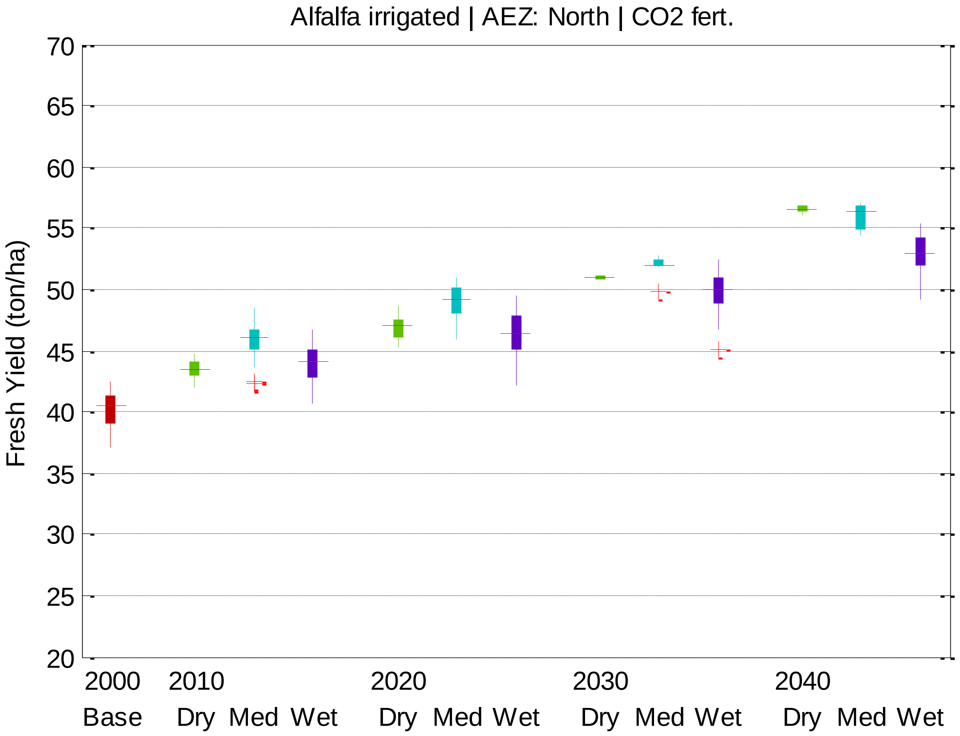


Table A-7. Yield Statistics for Alfalfa irrigated, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	30.1	25.9	32.6	2.0
2010	Dry	33.9	28.8	37.0	2.1
2010	Med	33.7	29.0	36.6	2.0
2010	Wet	33.1	29.5	35.7	1.8
2020	Dry	34.7	30.1	37.4	1.9
2020	Med	34.4	29.7	37.4	2.1
2020	Wet	32.8	29.4	35.1	1.7
2030	Dry	36.9	32.7	39.9	2.1
2030	Med	35.8	31.5	38.8	2.0
2030	Wet	33.2	30.3	35.4	1.6
2040	Dry	37.0	33.0	39.7	1.9
2040	Med	35.7	31.2	38.6	2.0
2040	Wet	35.9	32.0	38.8	1.9

Figure A-7. Yields for Alfalfa irrigated, AEZ: South | No CO2 fert.

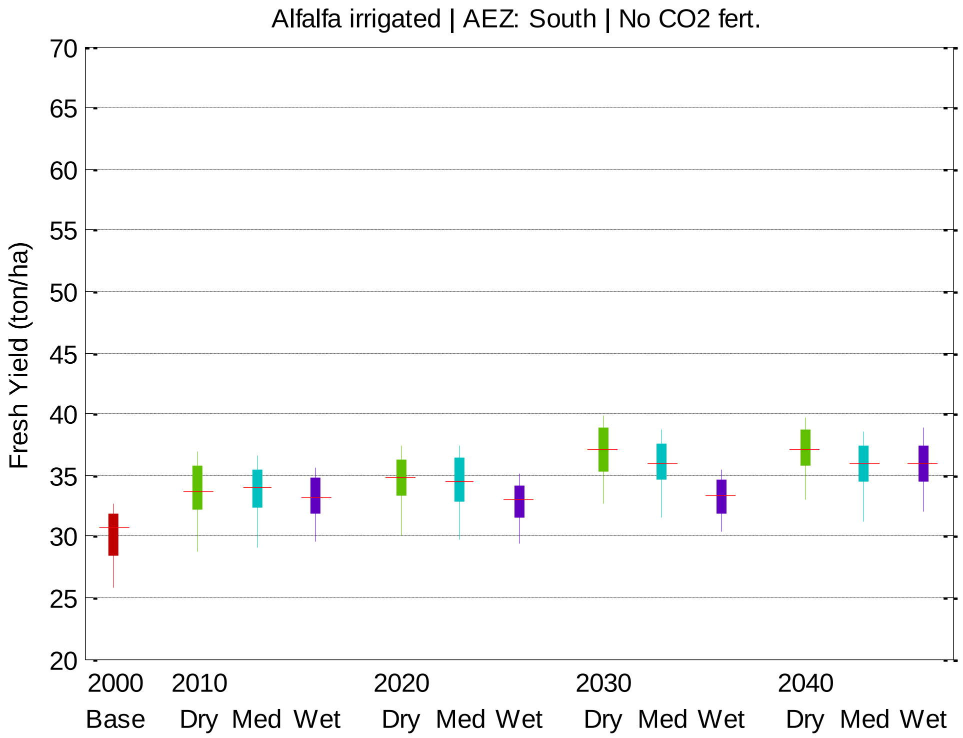
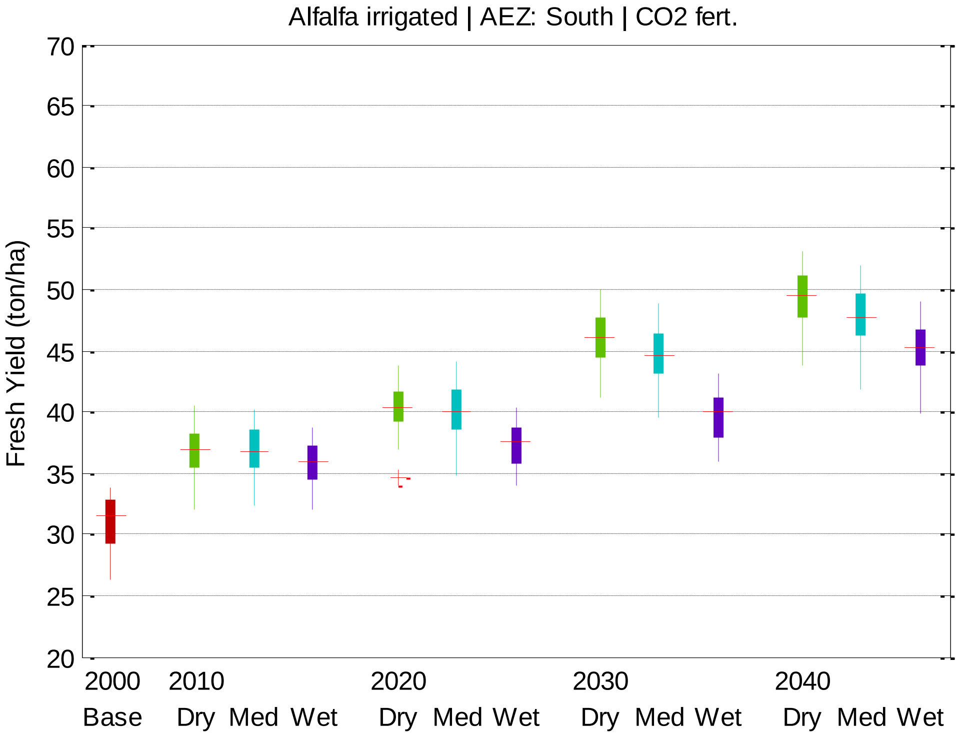


Table A-8. Yield Statistics for Alfalfa irrigated, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	31.0	26.3	33.8	2.1
2010	Dry	36.8	32.0	40.6	2.1
2010	Med	36.8	32.3	40.2	2.0
2010	Wet	35.7	31.9	38.7	2.0
2020	Dry	40.3	34.7	43.8	2.0
2020	Med	40.0	34.7	44.0	2.3
2020	Wet	37.3	34.0	40.4	1.8
2030	Dry	46.0	41.1	50.0	2.3
2030	Med	44.7	39.5	48.8	2.4
2030	Wet	39.8	36.0	43.1	1.9
2040	Dry	49.3	43.8	53.1	2.2
2040	Med	47.7	41.8	52.0	2.5
2040	Wet	45.1	39.9	48.9	2.2

Figure A-8. Yields for Alfalfa irrigated, AEZ: South | CO2 fert.



A.2 Alfalfa non-irrigated

Table A-9. Yield Statistics for Alfalfa non-irrigated, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	33.4	27.9	44.6	5.4
2010	Dry	26.7	20.0	38.3	5.0
2010	Med	34.0	29.1	44.6	5.0
2010	Wet	38.5	32.9	50.0	6.3
2020	Dry	27.9	23.6	38.0	4.1
2020	Med	32.0	23.9	44.8	5.9
2020	Wet	37.0	28.0	49.5	6.7
2030	Dry	27.5	21.1	38.6	4.9
2030	Med	31.6	25.4	44.4	5.6
2030	Wet	40.3	31.6	53.3	8.3
2040	Dry	30.2	24.7	41.4	4.8
2040	Med	31.4	25.5	43.5	5.5
2040	Wet	35.3	29.0	47.3	6.0

Figure A-9. Yields for Alfalfa non-irrigated, AEZ: Inter | No CO2 fert.

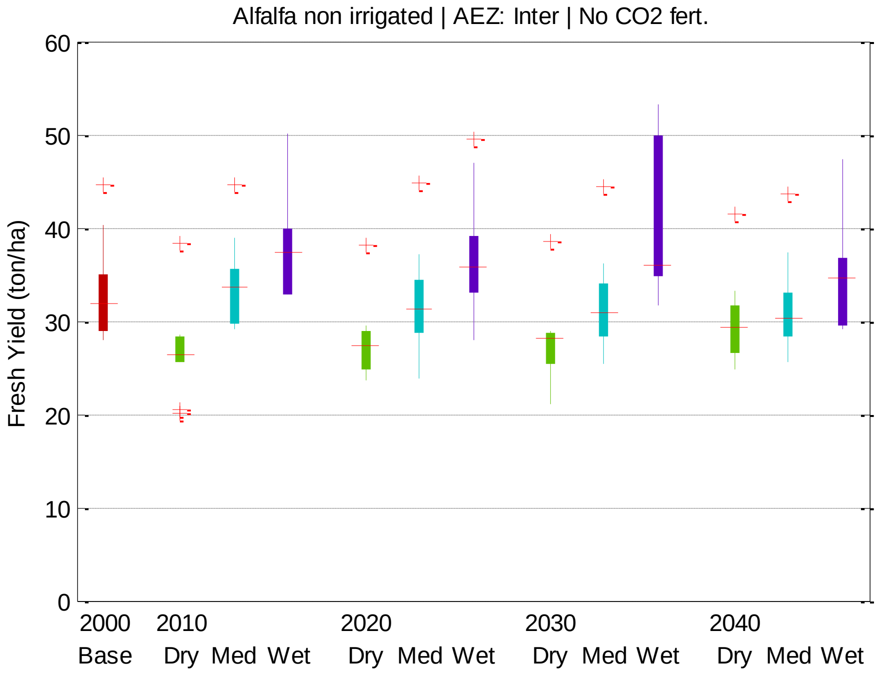


Table A-10. Yield Statistics for Alfalfa non-irrigated, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	34.1	29.1	45.0	5.4
2010	Dry	29.0	21.2	40.9	5.3
2010	Med	36.9	31.3	47.6	5.3
2010	Wet	41.4	34.7	54.7	6.9
2020	Dry	32.5	27.8	43.5	4.5
2020	Med	37.2	27.1	51.2	6.8
2020	Wet	41.9	31.1	55.3	7.6
2030	Dry	34.3	26.0	47.3	5.8
2030	Med	39.4	30.9	54.4	6.9
2030	Wet	48.2	36.9	62.8	10.1
2040	Dry	40.3	32.3	54.6	6.2
2040	Med	42.0	33.4	57.4	7.3
2040	Wet	44.3	36.6	58.7	7.5

Figure A-10. Yields for Alfalfa non-irrigated, AEZ: Inter | CO2 fert.

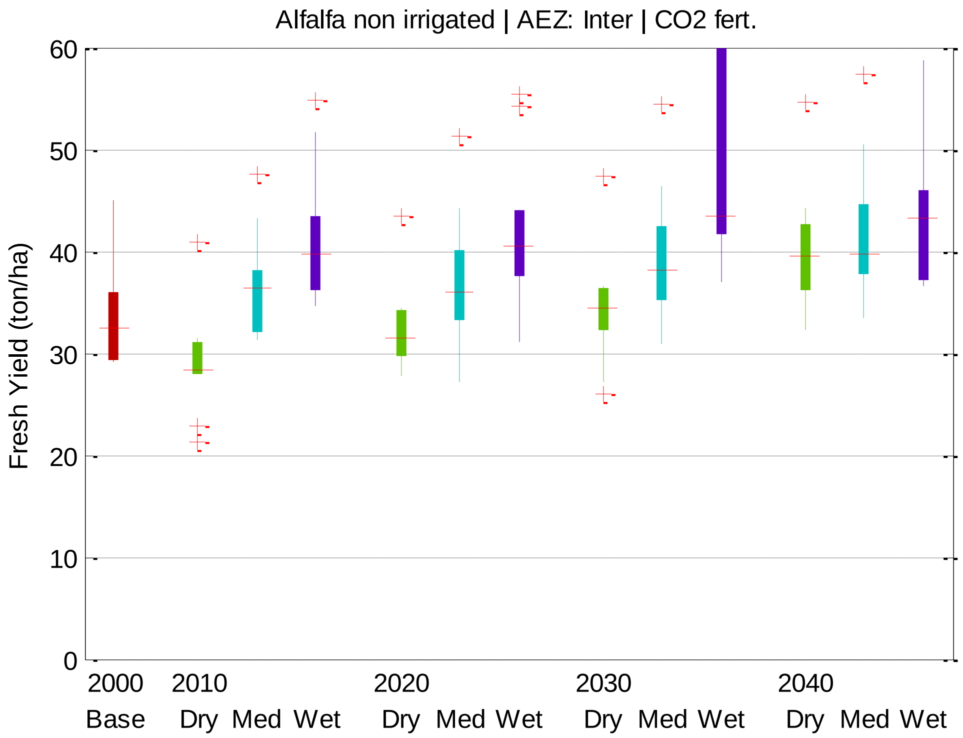


Table A-11. Yield Statistics for Alfalfa non-irrigated, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	22.5	18.7	25.8	2.5
2010	Dry	17.4	13.2	21.4	2.6
2010	Med	23.8	20.3	28.1	2.3
2010	Wet	29.0	24.1	34.4	3.3
2020	Dry	20.6	16.4	24.2	2.6
2020	Med	20.2	15.2	24.4	3.0
2020	Wet	25.6	21.2	30.5	3.3
2030	Dry	18.7	12.9	22.9	3.4
2030	Med	20.8	15.9	24.4	2.9
2030	Wet	28.1	21.4	41.7	6.1
2040	Dry	21.3	16.6	24.3	2.9
2040	Med	21.9	16.4	25.2	3.2
2040	Wet	24.0	19.7	28.4	2.6

Figure A-11. Yields for Alfalfa non-irrigated, AEZ: Low | No CO2 fert.

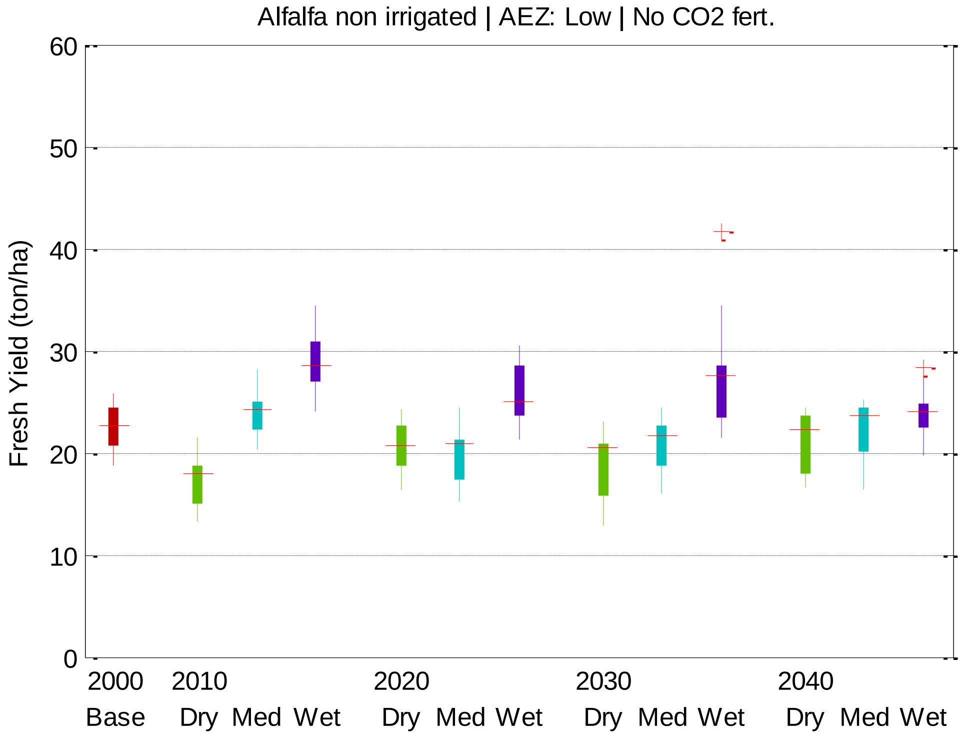


Table A-12. Yield Statistics for Alfalfa non-irrigated, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	23.1	18.9	26.8	2.7
2010	Dry	18.9	14.1	23.1	3.0
2010	Med	25.9	21.7	31.2	2.9
2010	Wet	31.1	25.6	37.6	3.6
2020	Dry	24.0	18.5	28.0	3.3
2020	Med	23.5	17.4	29.1	3.8
2020	Wet	29.0	23.6	35.2	3.7
2030	Dry	23.4	15.6	28.3	4.4
2030	Med	26.0	19.6	30.3	4.0
2030	Wet	33.7	25.1	49.9	7.6
2040	Dry	28.4	21.5	32.9	4.2
2040	Med	29.3	21.4	34.1	4.5
2040	Wet	30.1	24.4	36.1	3.5

Figure A-12. Yields for Alfalfa non-irrigated, AEZ: Low | CO2 fert.

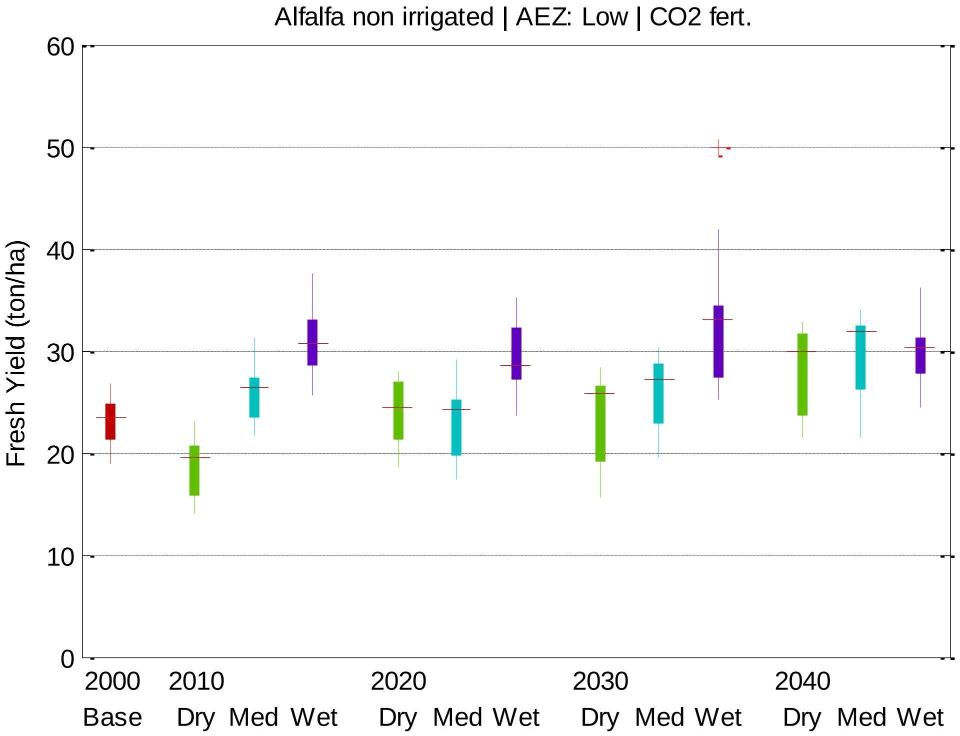


Table A-13. Yield Statistics for Alfalfa non-irrigated, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	17.3	12.9	20.8	2.7
2010	Dry	15.2	11.6	17.6	2.0
2010	Med	19.9	14.9	23.5	3.0
2010	Wet	19.7	13.9	24.2	3.3
2020	Dry	16.1	12.5	18.5	2.2
2020	Med	17.9	13.2	21.9	2.7
2020	Wet	20.3	14.4	24.2	3.4
2030	Dry	15.4	12.1	19.4	2.2
2030	Med	16.5	12.9	19.5	2.3
2030	Wet	23.4	16.1	29.1	4.1
2040	Dry	17.2	13.3	20.6	2.4
2040	Med	16.9	13.0	20.0	2.4
2040	Wet	18.0	13.1	21.4	2.8

Figure A-13. Yields for Alfalfa non-irrigated, AEZ: North | No CO2 fert.

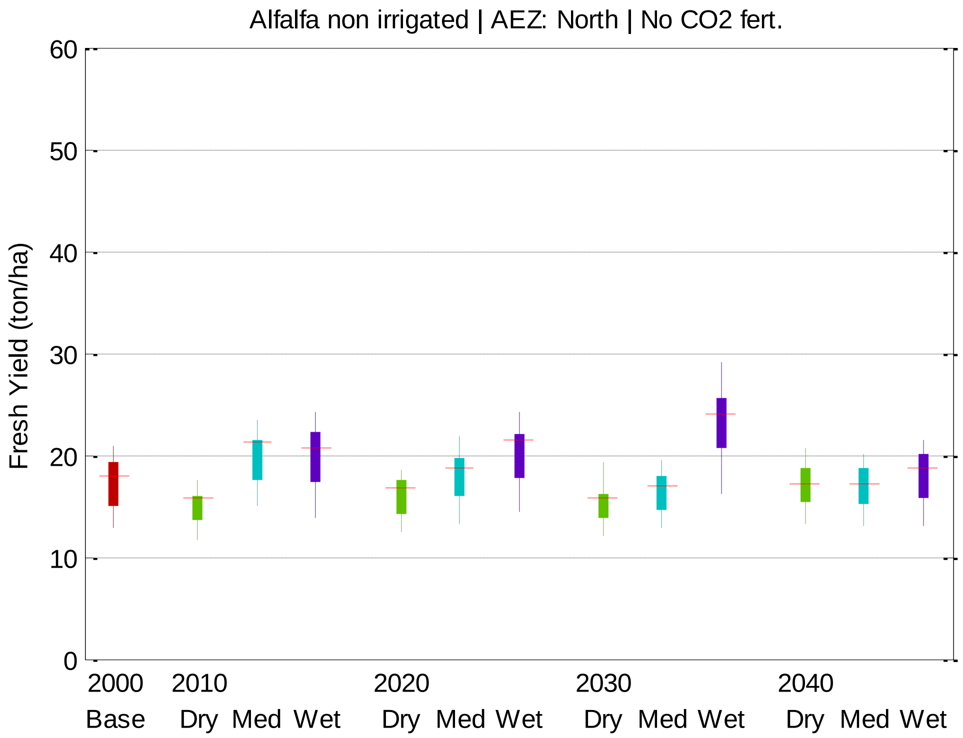


Table A-14. Yield Statistics for Alfalfa non-irrigated, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	17.7	13.0	21.2	2.8
2010	Dry	16.5	12.7	18.7	2.2
2010	Med	21.6	15.9	25.3	3.2
2010	Wet	21.2	15.0	25.8	3.6
2020	Dry	18.8	14.3	21.0	2.5
2020	Med	20.9	15.6	25.2	3.2
2020	Wet	23.0	16.2	27.3	3.8
2030	Dry	19.2	14.8	23.9	2.8
2030	Med	20.7	15.9	24.0	2.9
2030	Wet	27.9	19.0	34.0	4.9
2040	Dry	22.9	17.5	27.0	3.2
2040	Med	22.6	17.2	26.6	3.1
2040	Wet	22.6	16.2	26.7	3.5

Figure A-14. Yields for Alfalfa non-irrigated, AEZ: North | CO2 fert.

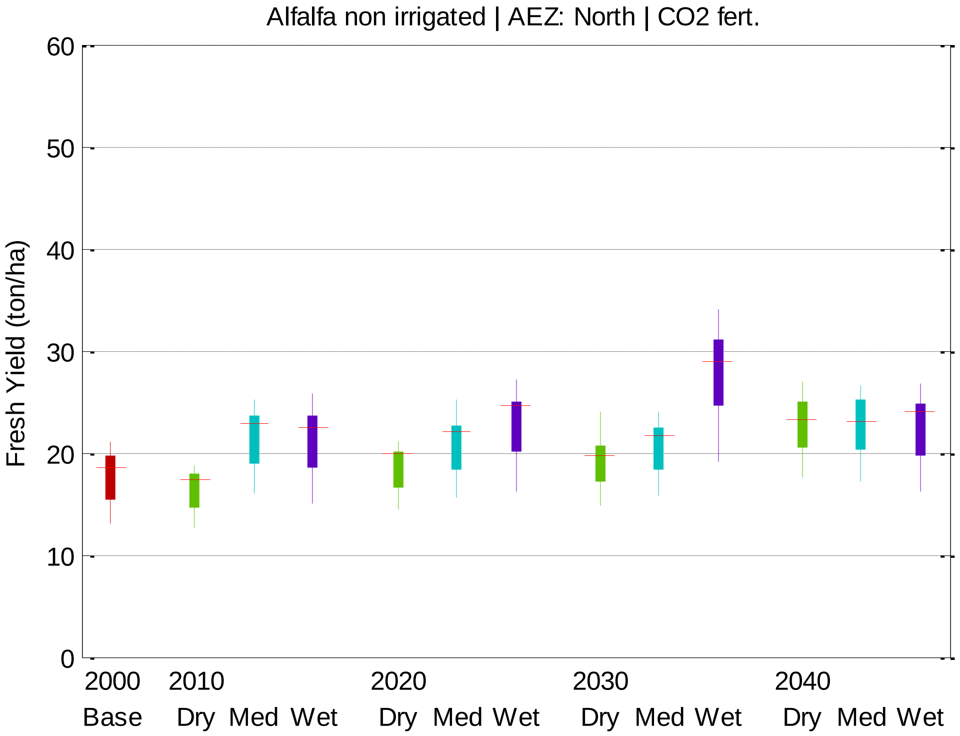


Table A-15. Yield Statistics for Alfalfa non-irrigated, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	15.0	10.6	21.1	4.0
2010	Dry	14.4	9.6	20.9	4.1
2010	Med	15.0	9.8	20.9	3.9
2010	Wet	16.0	10.9	22.4	4.3
2020	Dry	15.3	10.2	21.2	3.8
2020	Med	14.5	9.9	20.3	4.3
2020	Wet	15.6	10.5	23.1	4.2
2030	Dry	15.8	11.3	20.6	3.7
2030	Med	15.5	10.9	20.7	3.9
2030	Wet	16.6	11.2	24.4	4.3
2040	Dry	16.1	11.0	21.3	3.9
2040	Med	16.0	11.4	21.9	4.0
2040	Wet	16.5	12.5	22.7	3.6

Figure A-15. Yields for Alfalfa non-irrigated, AEZ: South | No CO2 fert.

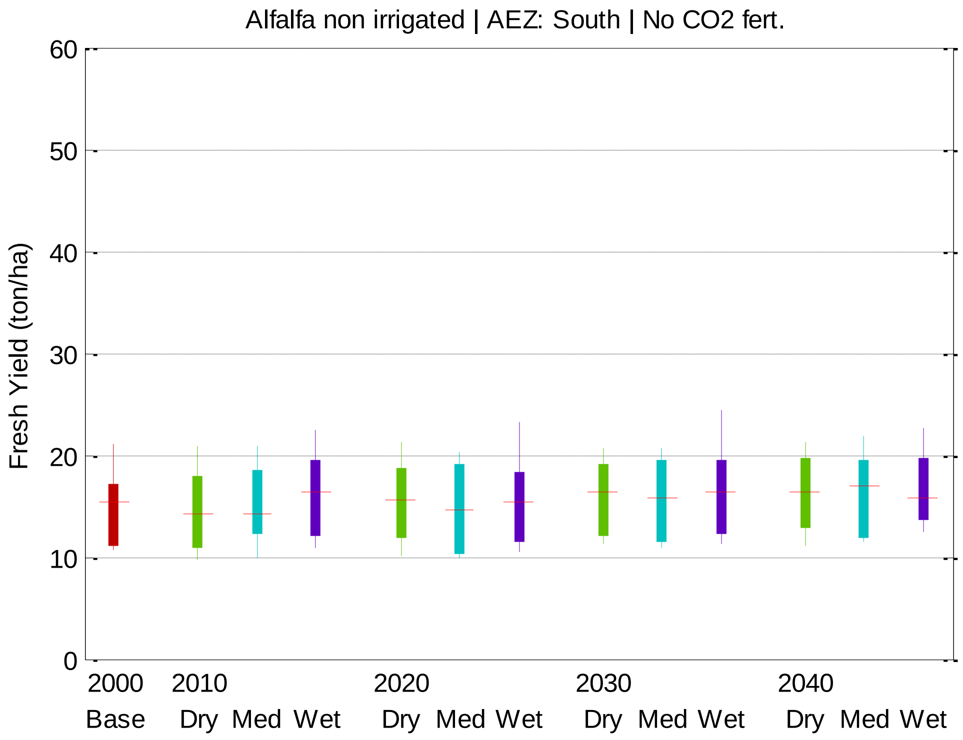
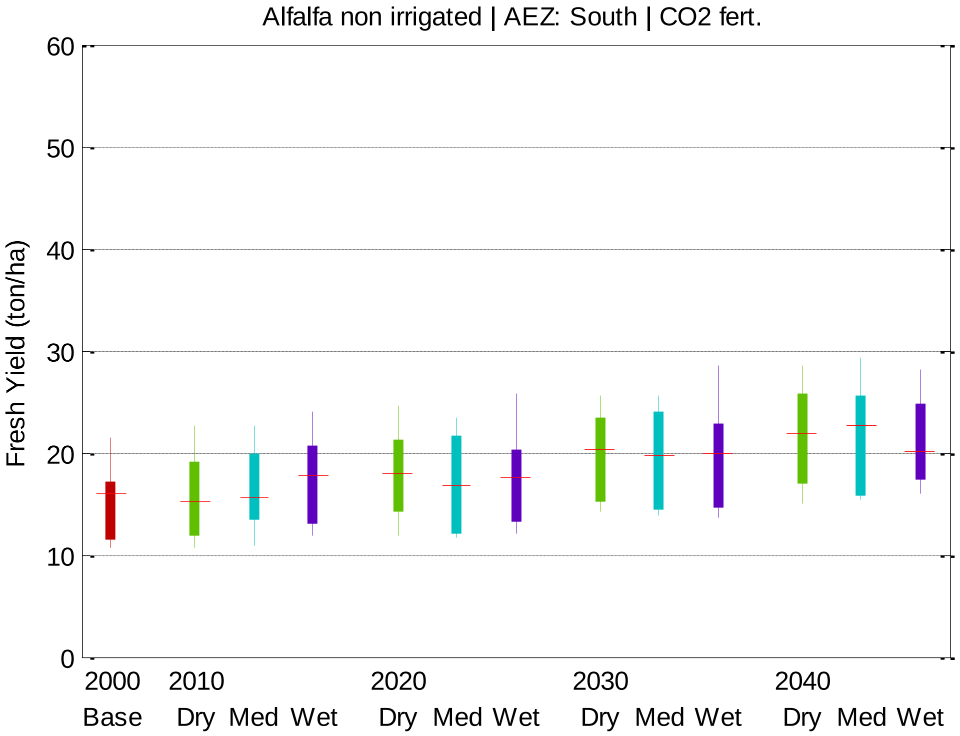


Table A-16. Yield Statistics for Alfalfa non-irrigated, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	15.3	10.8	21.5	3.9
2010	Dry	15.6	10.7	22.6	4.3
2010	Med	16.3	10.9	22.6	4.0
2010	Wet	17.2	11.9	24.0	4.4
2020	Dry	17.8	12.0	24.6	4.2
2020	Med	16.9	11.7	23.4	4.8
2020	Wet	17.6	12.1	25.7	4.6
2030	Dry	19.6	14.2	25.7	4.4
2030	Med	19.3	13.8	25.6	4.7
2030	Wet	19.7	13.5	28.6	4.9
2040	Dry	21.4	15.0	28.5	5.0
2040	Med	21.4	15.4	29.3	5.2
2040	Wet	20.7	15.9	28.0	4.3

Figure A-16. Yields for Alfalfa non-irrigated, AEZ: South | CO2 fert.



A.3 Grapes

Table A-17. Yield Statistics for Grapes, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	11.0	5.8	13.7	3.0
2010	Dry	7.5	4.0	11.5	2.4
2010	Med	10.0	5.8	13.3	2.7
2010	Wet	12.0	7.0	14.1	2.4
2020	Dry	9.0	5.0	11.8	2.4
2020	Med	8.5	4.1	12.6	2.8
2020	Wet	11.4	5.8	14.0	3.0
2030	Dry	7.7	4.0	11.4	2.6
2030	Med	8.6	4.7	11.9	2.5
2030	Wet	12.4	6.8	14.2	2.7
2040	Dry	8.2	4.8	11.6	2.4
2040	Med	9.2	4.8	12.8	2.8
2040	Wet	9.9	4.9	13.4	3.0

Figure A-17. Yields for Grapes, AEZ: Inter | No CO2 fert.

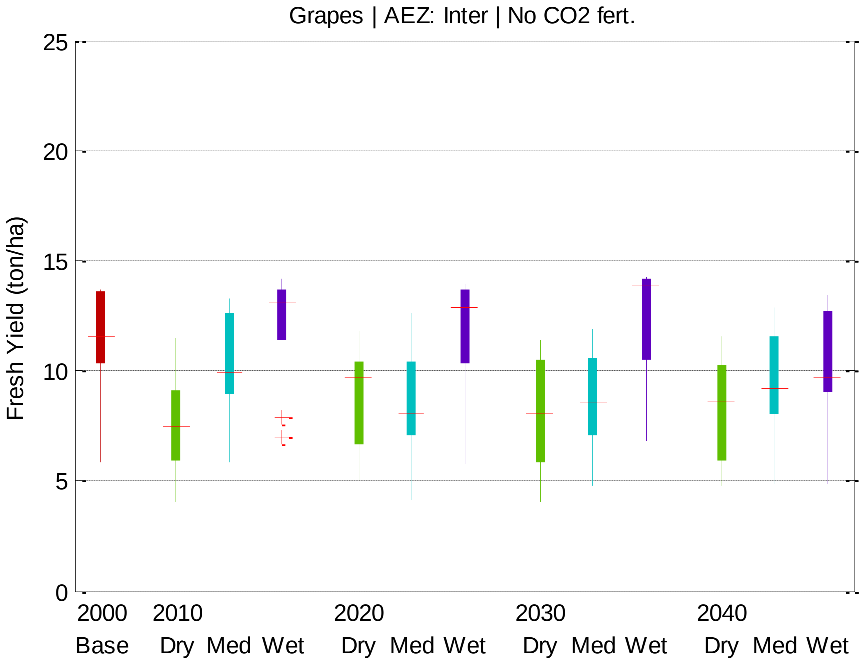


Table A-18. Yield Statistics for Grapes, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	11.2	5.9	14.1	3.1
2010	Dry	8.1	4.3	12.3	2.6
2010	Med	10.9	6.2	14.5	2.9
2010	Wet	12.9	7.4	15.0	2.6
2020	Dry	10.4	6.0	13.8	2.7
2020	Med	9.9	4.6	14.5	3.2
2020	Wet	12.9	6.4	15.6	3.4
2030	Dry	9.6	4.9	14.1	3.2
2030	Med	10.7	5.8	14.8	3.1
2030	Wet	14.9	8.0	17.3	3.2
2040	Dry	11.0	6.3	15.6	3.2
2040	Med	12.2	6.3	17.3	3.7
2040	Wet	12.5	6.0	16.9	3.7

Figure A-18. Yields for Grapes, AEZ: Inter | CO2 fert.

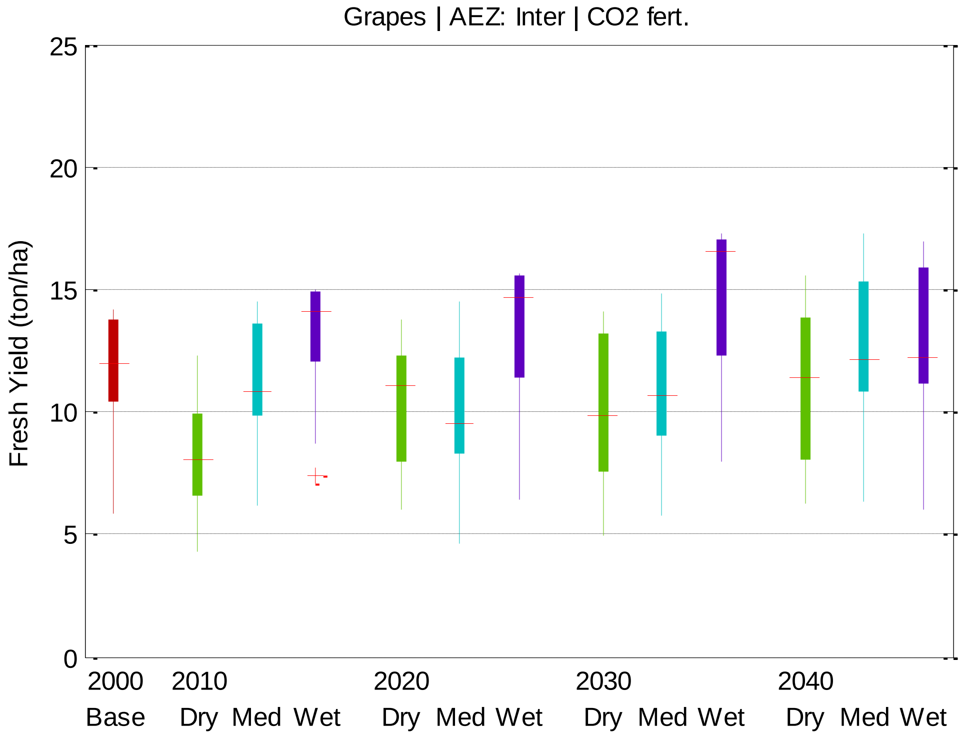


Table A-19. Yield Statistics for Grapes, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	5.7	3.2	9.0	1.7
2010	Dry	3.7	2.5	5.8	1.0
2010	Med	5.1	3.1	8.0	1.5
2010	Wet	6.7	3.9	10.2	2.0
2020	Dry	4.9	2.6	7.8	1.5
2020	Med	4.1	2.5	6.0	1.2
2020	Wet	5.6	3.2	9.1	1.7
2030	Dry	3.9	2.4	6.0	1.1
2030	Med	4.1	2.5	6.0	1.1
2030	Wet	7.2	3.2	13.4	3.1
2040	Dry	4.4	2.5	7.0	1.3
2040	Med	4.5	2.5	6.8	1.2
2040	Wet	4.7	2.5	7.8	1.6

Figure A-19. Yields for Grapes, AEZ: Low | No CO2 fert.

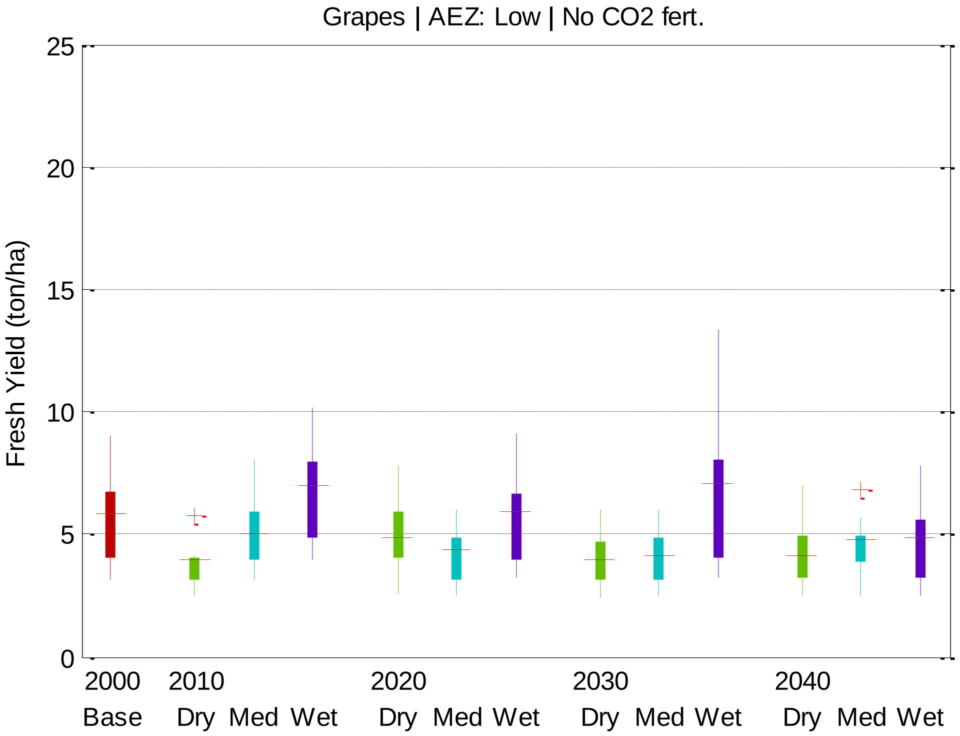


Table A-20. Yield Statistics for Grapes, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	5.8	3.2	9.2	1.8
2010	Dry	4.1	2.6	6.2	1.1
2010	Med	5.6	3.3	8.6	1.6
2010	Wet	7.2	4.1	10.9	2.2
2020	Dry	5.7	2.9	9.0	1.7
2020	Med	4.7	2.9	6.9	1.4
2020	Wet	6.4	3.6	10.2	2.0
2030	Dry	4.9	2.9	7.4	1.4
2030	Med	5.1	3.0	7.4	1.4
2030	Wet	8.6	3.8	16.0	3.7
2040	Dry	5.8	3.3	9.3	1.8
2040	Med	6.1	3.3	9.0	1.7
2040	Wet	5.9	3.1	9.8	2.0

Figure A-20. Yields for Grapes, AEZ: Low | CO2 fert.

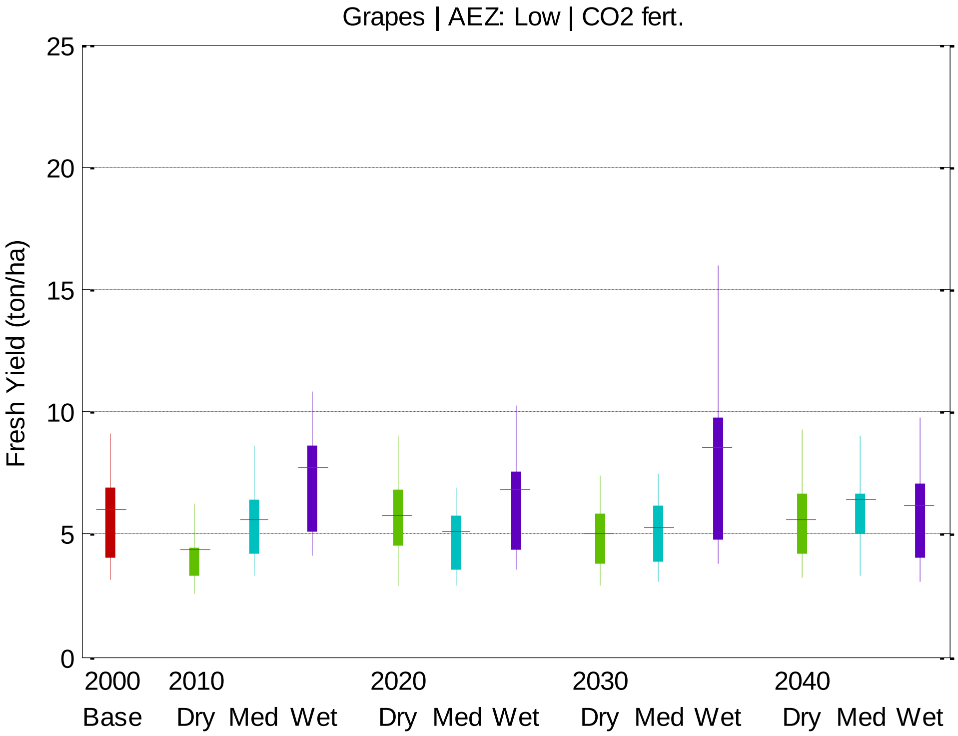


Table A-21. Yield Statistics for Grapes, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	4.6	3.1	6.7	1.0
2010	Dry	3.6	2.5	4.8	0.7
2010	Med	4.3	3.1	5.9	0.9
2010	Wet	5.0	3.2	6.9	1.2
2020	Dry	3.7	2.5	4.9	0.6
2020	Med	3.9	2.6	5.9	0.9
2020	Wet	4.7	3.2	6.9	1.0
2030	Dry	3.4	2.5	4.9	0.7
2030	Med	3.6	2.5	4.9	0.7
2030	Wet	5.6	3.3	8.0	1.4
2040	Dry	3.3	2.5	4.9	0.7
2040	Med	3.6	2.5	4.9	0.7
2040	Wet	3.8	2.5	5.7	0.9

Figure A-21. Yields for Grapes, AEZ: North | No CO2 fert.

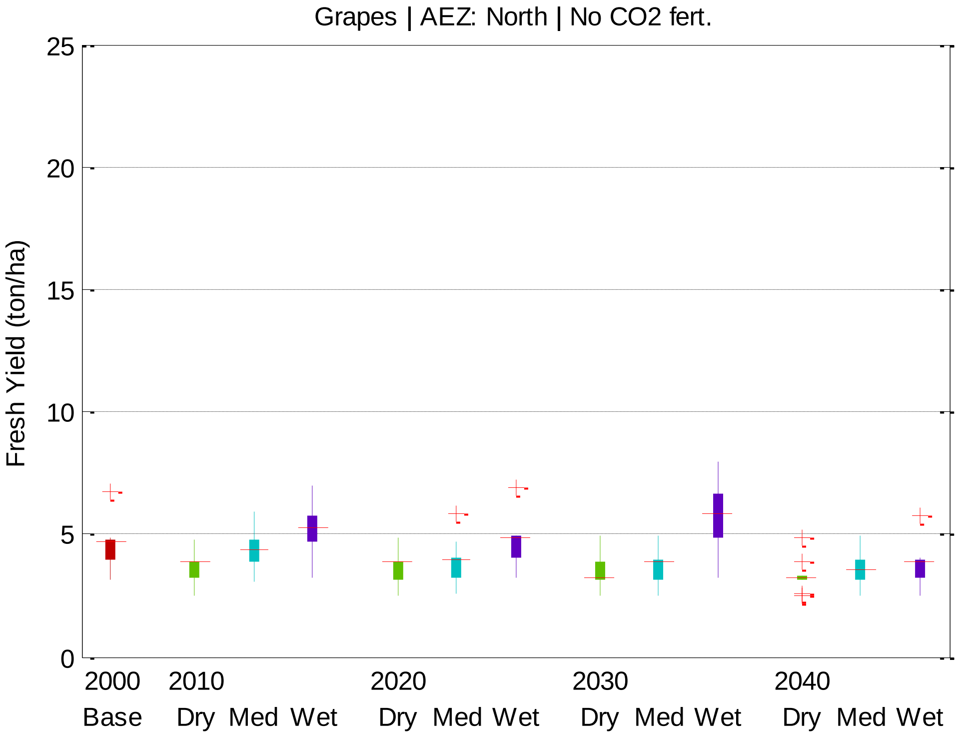


Table A-22. Yield Statistics for Grapes, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	4.7	3.2	6.8	1.0
2010	Dry	3.9	2.7	5.2	0.8
2010	Med	4.7	3.3	6.4	1.0
2010	Wet	5.4	3.5	7.4	1.3
2020	Dry	4.3	2.9	5.6	0.7
2020	Med	4.6	3.0	6.7	1.0
2020	Wet	5.3	3.6	7.8	1.2
2030	Dry	4.2	3.0	6.1	0.9
2030	Med	4.5	3.1	6.1	0.9
2030	Wet	6.7	3.8	9.5	1.7
2040	Dry	4.4	3.3	6.5	0.9
2040	Med	4.8	3.3	6.6	0.9
2040	Wet	4.7	3.1	7.2	1.1

Figure A-22. Yields for Grapes, AEZ: North | CO2 fert.

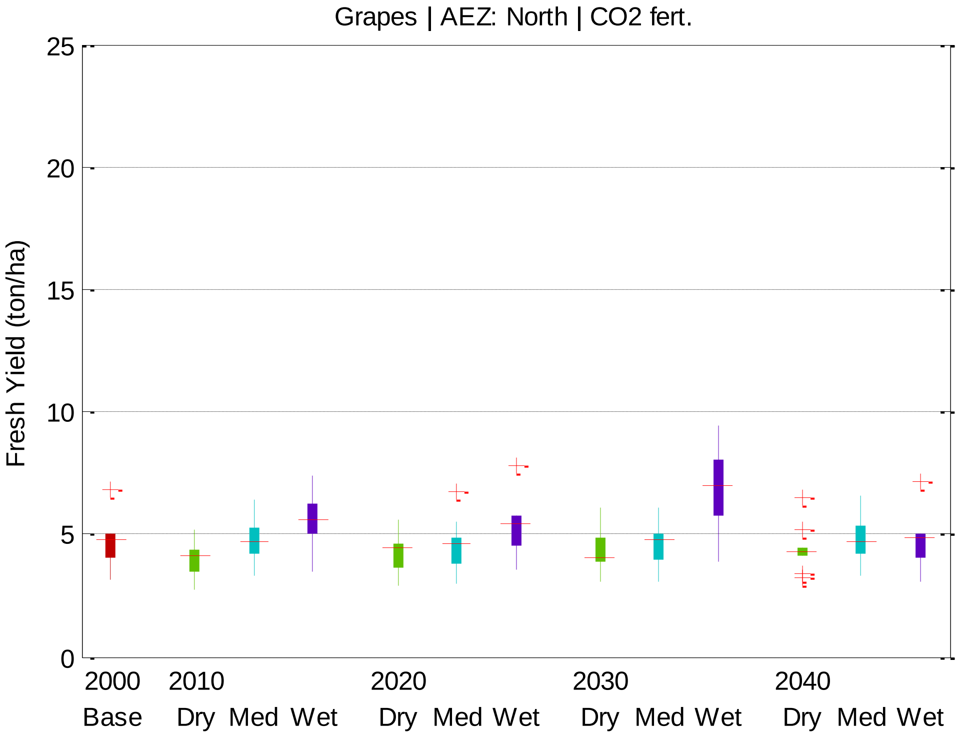


Table A-23. Yield Statistics for Grapes, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	7.5	4.6	10.3	1.9
2010	Dry	5.7	3.2	8.0	1.6
2010	Med	6.4	3.2	9.0	1.8
2010	Wet	6.8	3.3	10.2	2.2
2020	Dry	5.9	3.9	8.1	1.4
2020	Med	5.7	3.2	8.0	1.6
2020	Wet	6.7	3.9	10.0	2.0
2030	Dry	6.0	3.3	7.9	1.6
2030	Med	5.7	3.2	8.0	1.5
2030	Wet	7.4	4.0	11.3	2.2
2040	Dry	5.7	3.2	7.0	1.2
2040	Med	6.1	3.9	8.1	1.4
2040	Wet	5.8	3.2	7.9	1.5

Figure A-23. Yields for Grapes, AEZ: South | No CO2 fert.

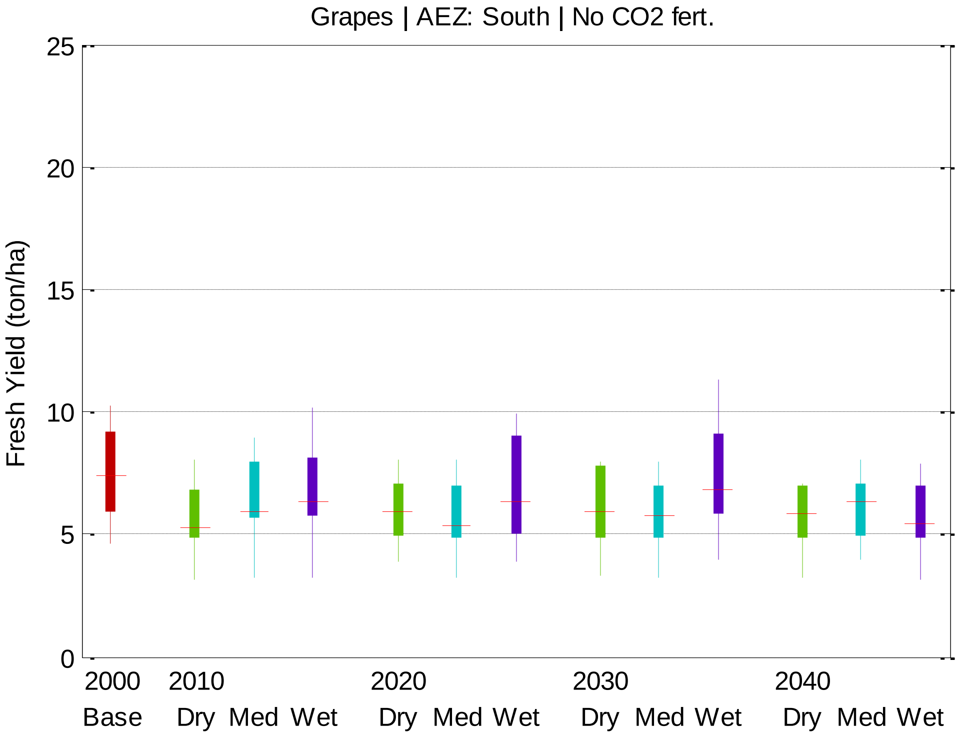
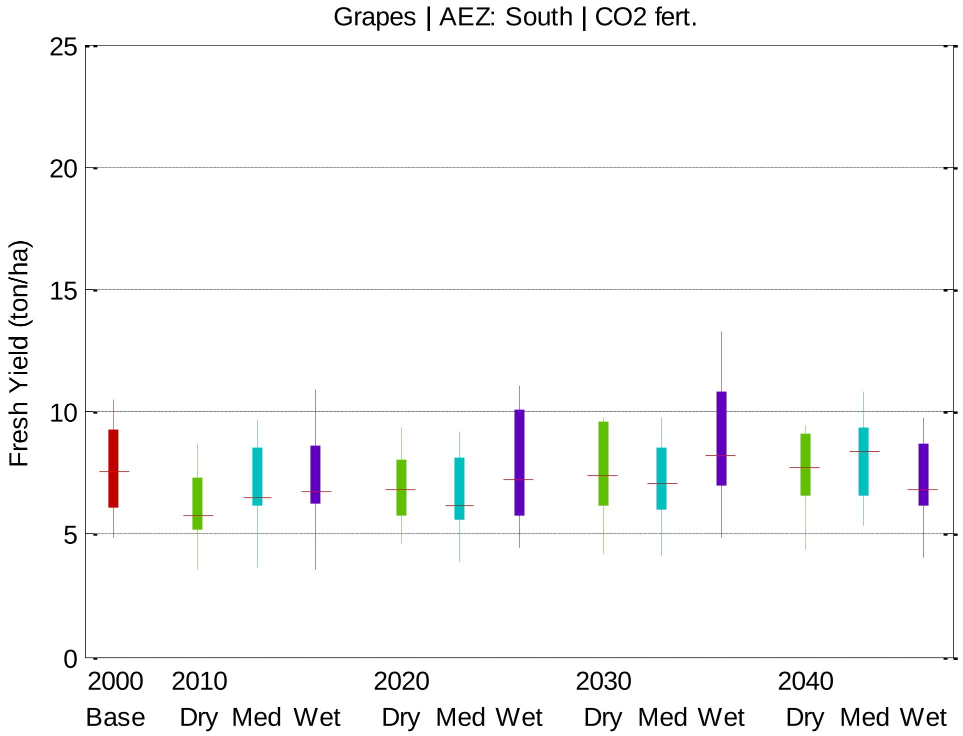


Table A-24. Yield Statistics for Grapes, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	7.6	4.8	10.5	1.9
2010	Dry	6.1	3.5	8.7	1.7
2010	Med	6.9	3.6	9.7	1.9
2010	Wet	7.3	3.6	10.9	2.3
2020	Dry	6.9	4.6	9.3	1.5
2020	Med	6.7	3.9	9.2	1.9
2020	Wet	7.6	4.5	11.1	2.2
2030	Dry	7.5	4.2	9.7	1.9
2030	Med	7.1	4.1	9.8	1.9
2030	Wet	8.8	4.8	13.2	2.6
2040	Dry	7.5	4.4	9.4	1.6
2040	Med	8.1	5.3	10.8	1.8
2040	Wet	7.3	4.0	9.7	1.8

Figure A-24. Yields for Grapes, AEZ: South | CO2 fert.



A.4 Grassland

Table A-25. Yield Statistics for Grassland, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	14.9	11.9	21.4	3.5
2010	Dry	11.8	9.1	16.2	2.3
2010	Med	14.5	12.0	20.7	2.9
2010	Wet	16.7	12.8	23.1	3.5
2020	Dry	11.6	9.8	14.6	1.6
2020	Med	14.5	11.2	20.7	3.3
2020	Wet	16.8	12.2	23.0	3.7
2030	Dry	12.2	9.2	16.1	2.2
2030	Med	14.3	11.7	20.1	3.0
2030	Wet	18.7	13.5	22.9	3.5
2040	Dry	12.9	10.9	16.4	1.8
2040	Med	14.1	10.4	19.6	3.2
2040	Wet	15.7	12.0	23.2	3.8

Figure A-25. Yields for Grassland, AEZ: Inter | No CO2 fert.

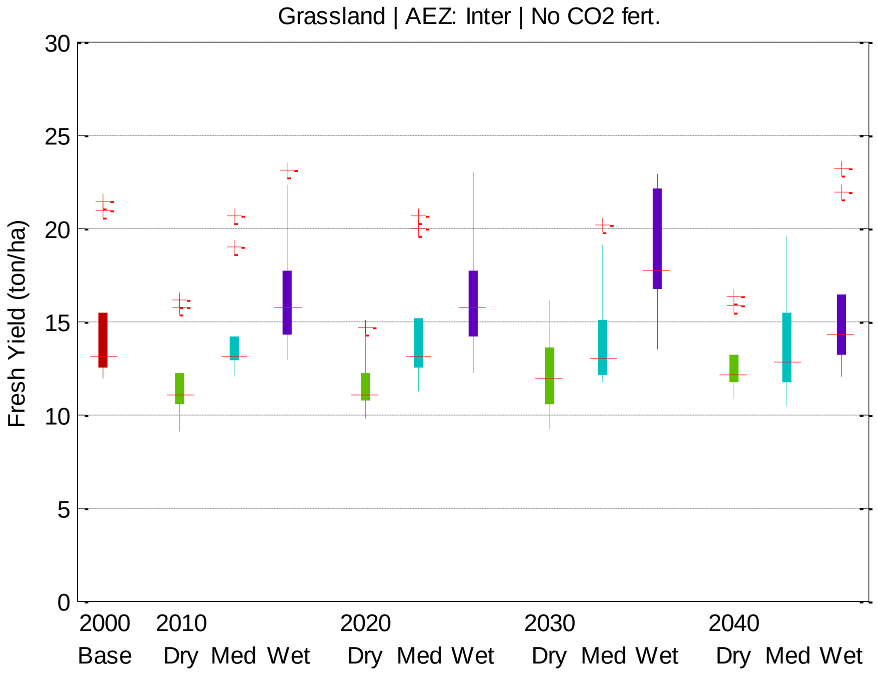


Table A-26. Yield Statistics for Grassland, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	15.3	12.0	22.3	3.7
2010	Dry	12.8	9.6	17.5	2.6
2010	Med	15.7	12.7	23.0	3.3
2010	Wet	18.0	13.6	25.3	3.9
2020	Dry	13.5	11.5	17.5	2.0
2020	Med	16.9	12.7	24.6	3.9
2020	Wet	19.0	13.6	26.5	4.2
2030	Dry	15.2	11.2	19.7	2.8
2030	Med	17.9	14.3	25.8	3.9
2030	Wet	22.3	15.7	27.4	4.4
2040	Dry	17.2	14.2	22.2	2.5
2040	Med	18.9	13.6	26.5	4.4
2040	Wet	19.7	14.9	29.6	4.9

Figure A-26. Yields for Grassland, AEZ: Inter | CO2 fert.

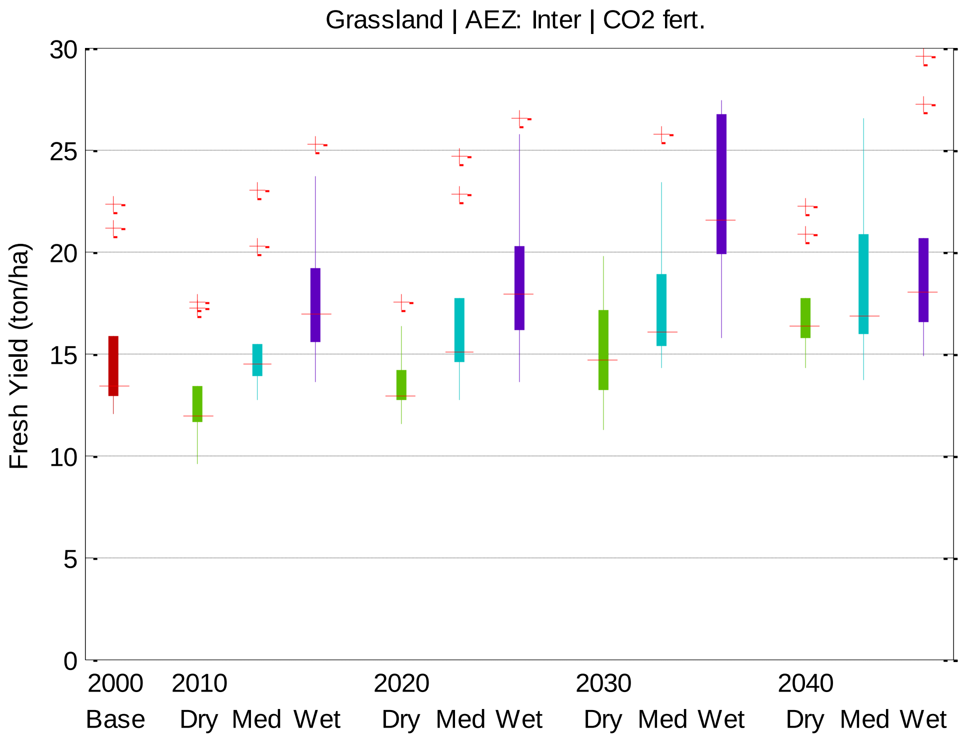


Table A-27. Yield Statistics for Grassland, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	9.6	7.7	14.1	2.0
2010	Dry	7.6	5.7	9.7	1.2
2010	Med	10.3	8.4	15.3	2.0
2010	Wet	12.4	9.3	16.6	2.1
2020	Dry	8.5	6.8	12.8	1.7
2020	Med	9.2	7.3	11.9	1.3
2020	Wet	11.2	8.4	16.3	2.2
2030	Dry	7.5	5.1	8.7	1.1
2030	Med	9.1	7.7	12.1	1.4
2030	Wet	13.0	9.3	19.1	3.4
2040	Dry	9.0	7.7	12.8	1.5
2040	Med	9.3	8.0	13.5	1.6
2040	Wet	10.4	8.4	14.8	2.0

Figure A-27. Yields for Grassland, AEZ: Low | No CO2 fert.

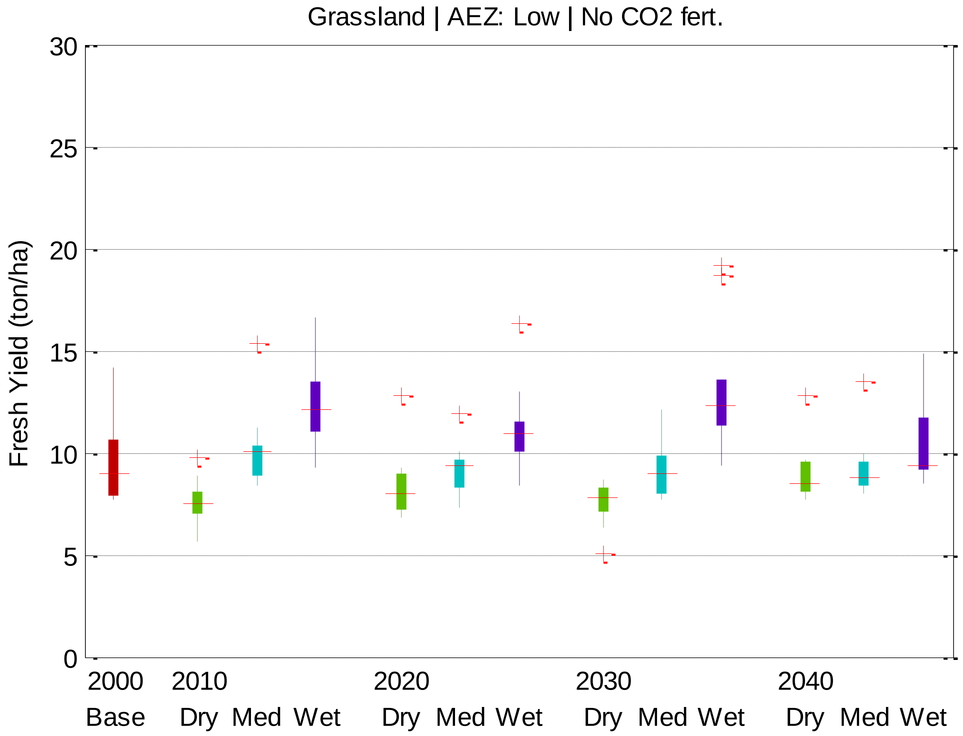


Table A-28. Yield Statistics for Grassland, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	9.8	7.9	14.7	2.0
2010	Dry	8.2	6.1	10.2	1.3
2010	Med	11.2	9.2	17.1	2.2
2010	Wet	13.4	10.2	18.1	2.3
2020	Dry	9.9	8.0	15.3	2.1
2020	Med	10.7	8.3	14.2	1.6
2020	Wet	12.7	9.8	18.8	2.5
2030	Dry	9.4	6.1	11.1	1.5
2030	Med	11.4	9.4	15.5	1.8
2030	Wet	15.6	11.1	22.9	4.1
2040	Dry	12.0	10.4	17.3	2.1
2040	Med	12.5	10.8	18.3	2.2
2040	Wet	13.1	10.5	18.9	2.5

Figure A-28. Yields for Grassland, AEZ: Low | CO2 fert.

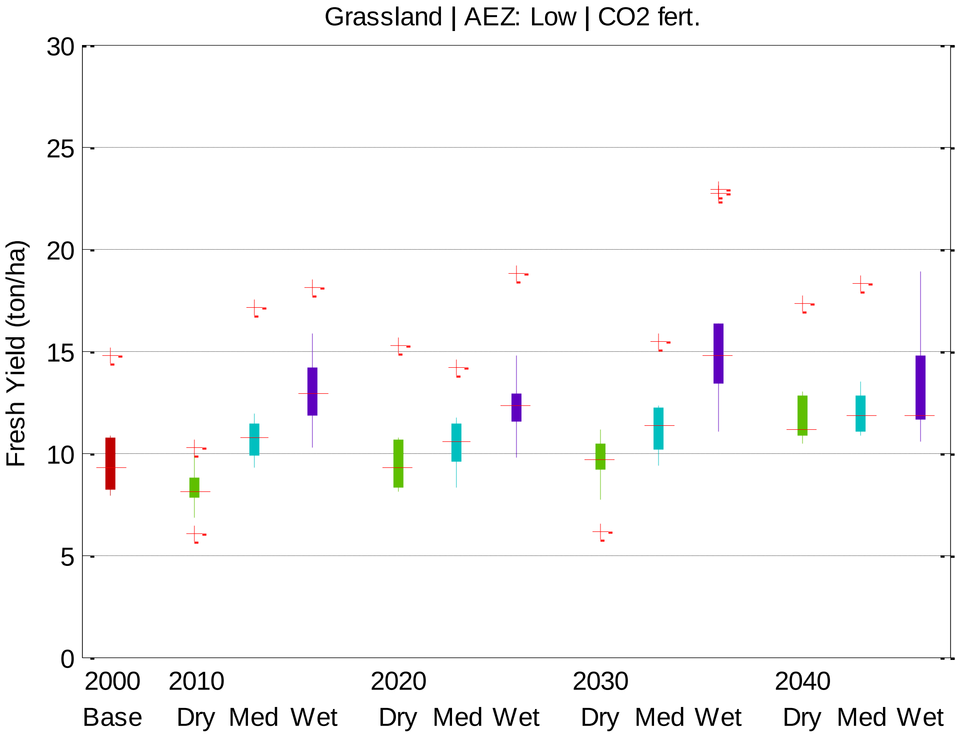


Table A-29. Yield Statistics for Grassland, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	8.3	4.8	10.7	1.9
2010	Dry	6.6	4.2	8.2	1.5
2010	Med	9.7	5.9	12.5	1.9
2010	Wet	9.5	5.7	13.5	2.4
2020	Dry	7.2	4.2	9.2	1.6
2020	Med	8.3	4.9	10.6	2.0
2020	Wet	9.9	5.6	12.9	2.1
2030	Dry	6.3	3.4	8.2	1.6
2030	Med	7.5	4.4	9.4	1.7
2030	Wet	11.8	6.4	16.5	2.9
2040	Dry	8.1	5.4	9.9	1.4
2040	Med	7.7	4.2	10.0	2.0
2040	Wet	8.7	5.0	11.6	1.9

Figure A-29. Yields for Grassland, AEZ: North | No CO2 fert.

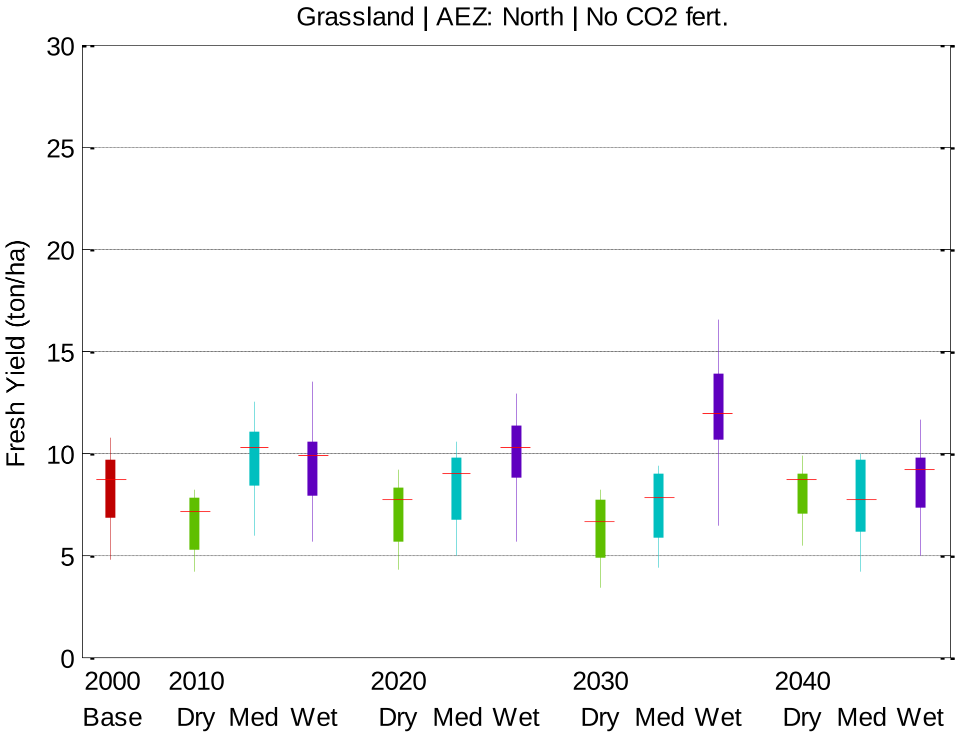


Table A-30. Yield Statistics for Grassland, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	8.5	4.8	10.7	1.9
2010	Dry	7.2	4.5	8.7	1.6
2010	Med	10.5	6.3	13.2	2.1
2010	Wet	10.2	6.0	14.2	2.6
2020	Dry	8.4	4.8	10.4	1.8
2020	Med	9.7	5.6	12.3	2.3
2020	Wet	11.3	6.3	14.3	2.4
2030	Dry	7.9	4.1	10.2	2.0
2030	Med	9.3	5.4	11.4	2.1
2030	Wet	14.1	7.6	19.3	3.4
2040	Dry	10.9	7.1	13.3	1.9
2040	Med	10.3	5.5	13.1	2.6
2040	Wet	10.9	6.2	14.3	2.4

Figure A-30. Yields for Grassland, AEZ: North | CO2 fert.

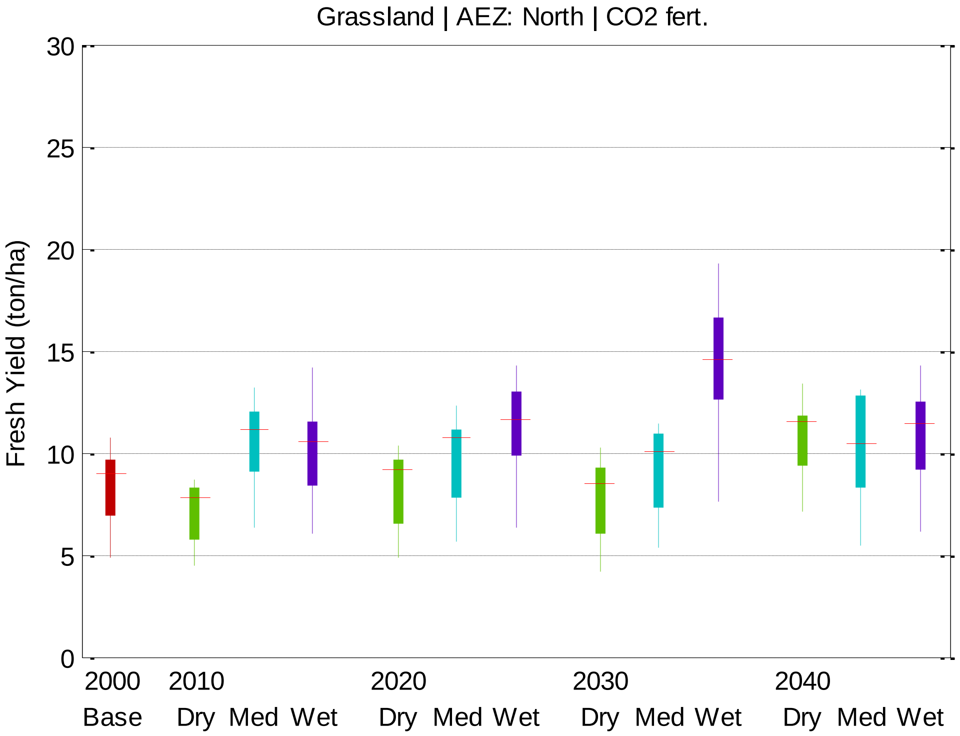


Table A-31. Yield Statistics for Grassland, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	5.6	2.7	8.6	2.3
2010	Dry	5.6	3.3	9.2	2.2
2010	Med	5.4	3.3	8.8	2.1
2010	Wet	6.1	3.6	9.1	2.2
2020	Dry	5.7	3.1	9.4	2.1
2020	Med	5.9	3.0	9.6	2.3
2020	Wet	6.3	3.7	11.1	2.4
2030	Dry	6.0	2.6	10.2	2.4
2030	Med	6.2	3.1	9.7	2.3
2030	Wet	7.0	3.6	11.4	2.7
2040	Dry	6.2	3.2	10.0	2.3
2040	Med	6.2	3.1	10.0	2.4
2040	Wet	6.4	3.7	9.5	2.0

Figure A-31. Yields for Grassland, AEZ: South | No CO2 fert.

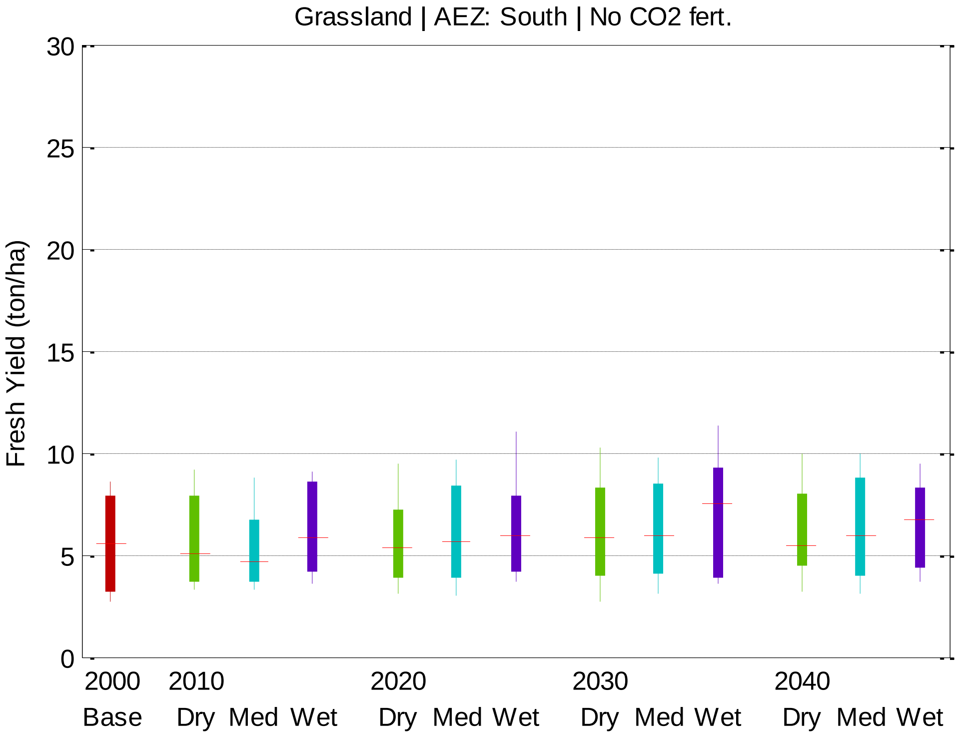
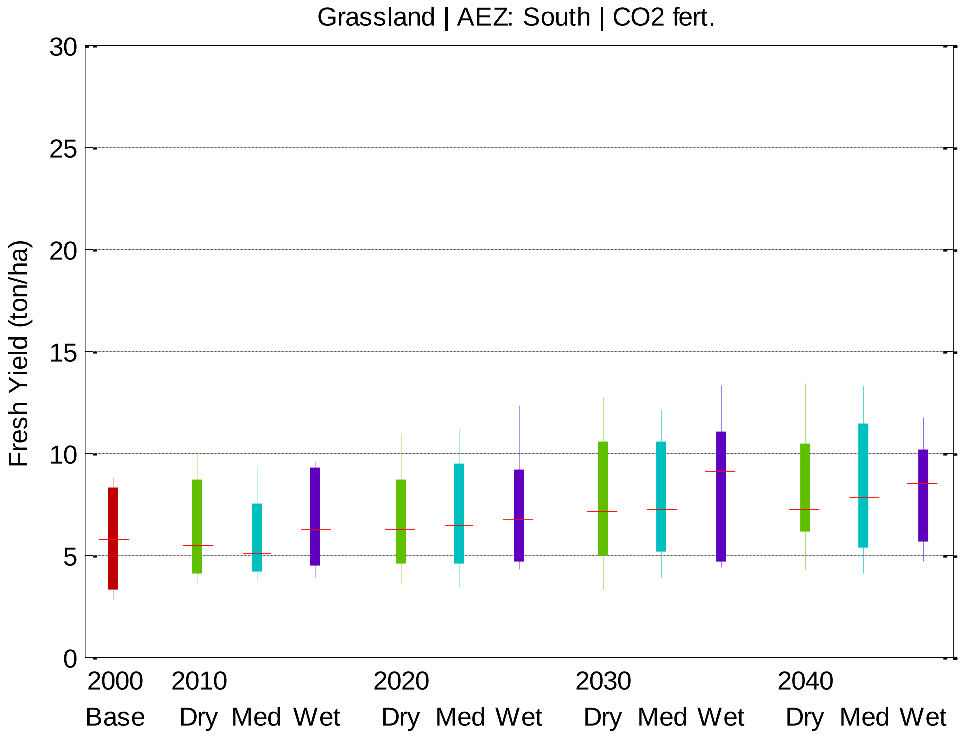


Table A-32. Yield Statistics for Grassland, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	5.8	2.8	8.8	2.3
2010	Dry	6.1	3.6	10.0	2.3
2010	Med	5.9	3.6	9.3	2.2
2010	Wet	6.6	3.9	9.6	2.3
2020	Dry	6.6	3.5	10.9	2.4
2020	Med	6.9	3.4	11.2	2.7
2020	Wet	7.2	4.2	12.3	2.7
2030	Dry	7.5	3.3	12.7	3.0
2030	Med	7.7	3.8	12.1	2.8
2030	Wet	8.4	4.4	13.3	3.2
2040	Dry	8.2	4.2	13.3	3.1
2040	Med	8.3	4.1	13.3	3.2
2040	Wet	8.1	4.7	11.7	2.5

Figure A-32. Yields for Grassland, AEZ: South | CO2 fert.



A.5 Maize

Table A-33. Yield Statistics for Maize, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	7.7	7.2	8.0	0.3
2010	Dry	7.2	6.2	7.9	0.4
2010	Med	7.3	6.3	8.1	0.5
2010	Wet	7.4	6.4	8.2	0.5
2020	Dry	7.3	6.6	7.9	0.4
2020	Med	7.6	6.6	8.5	0.5
2020	Wet	7.7	7.2	8.1	0.3
2030	Dry	7.5	6.5	8.0	0.5
2030	Med	7.6	7.2	8.2	0.3
2030	Wet	7.8	7.8	7.9	0.0
2040	Dry	7.4	6.6	8.0	0.5
2040	Med	7.7	7.3	8.4	0.3
2040	Wet	7.3	5.9	7.9	0.6

Figure A-33. Yields for Maize, AEZ: Inter | No CO2 fert.

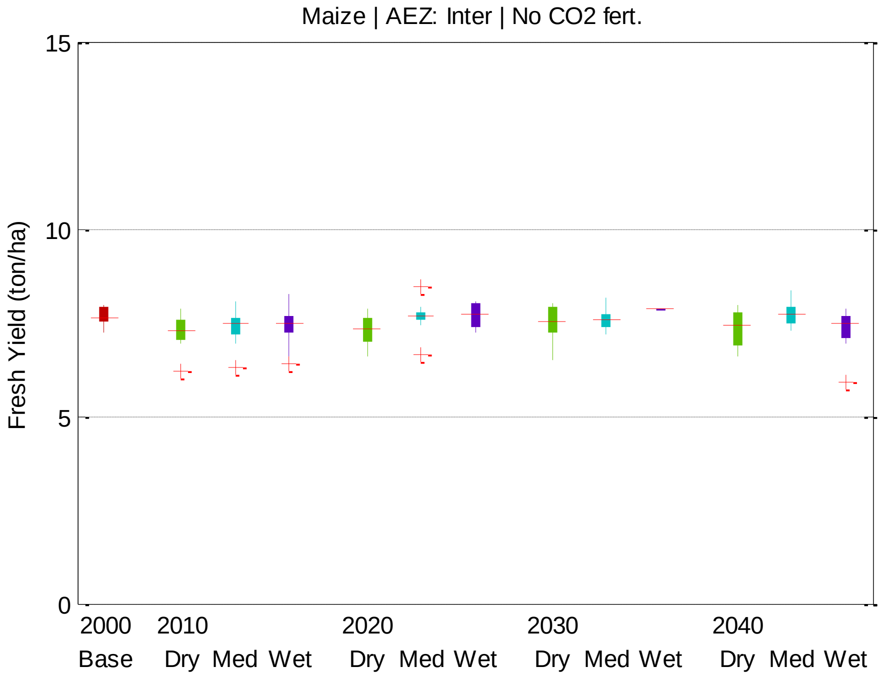


Table A-34. Yield Statistics for Maize, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	7.8	7.4	8.3	0.4
2010	Dry	7.8	6.7	8.8	0.6
2010	Med	7.9	6.7	8.8	0.6
2010	Wet	7.9	6.7	9.0	0.7
2020	Dry	8.5	7.7	9.4	0.6
2020	Med	8.8	7.6	9.9	0.6
2020	Wet	8.7	8.2	9.4	0.4
2030	Dry	9.3	8.4	10.3	0.6
2030	Med	9.4	8.9	10.2	0.4
2030	Wet	9.2	9.1	9.2	0.0
2040	Dry	9.8	8.6	10.7	0.7
2040	Med	10.2	9.7	11.3	0.5
2040	Wet	9.1	7.3	10.1	0.8

Figure A-34. Yields for Maize, AEZ: Inter | CO2 fert.

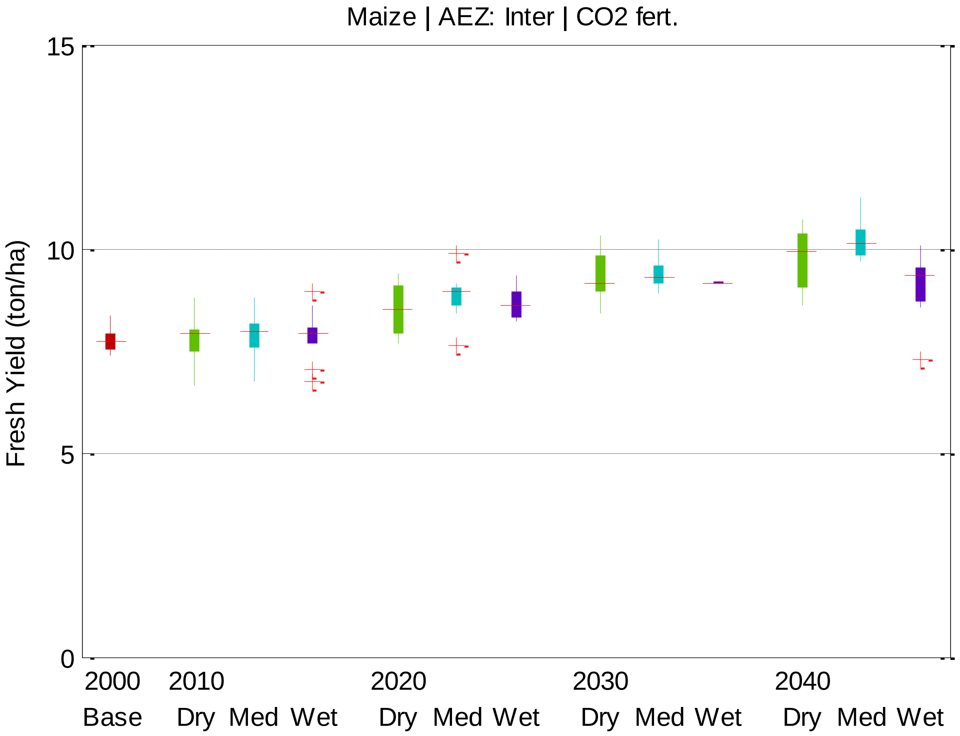


Table A-35. Yield Statistics for Maize, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	8.8	3.1	11.4	1.8
2010	Dry	7.8	4.9	9.8	1.4
2010	Med	8.6	2.8	11.3	2.0
2010	Wet	9.5	6.1	11.3	1.4
2020	Dry	7.5	2.7	9.6	1.9
2020	Med	8.0	3.5	10.8	2.0
2020	Wet	9.6	3.3	11.8	1.9
2030	Dry	7.3	3.2	9.5	1.6
2030	Med	8.3	3.1	11.4	2.0
2030	Wet	10.2	5.6	11.9	1.5
2040	Dry	6.9	3.7	8.7	1.7
2040	Med	8.6	5.8	11.1	1.5
2040	Wet	8.7	5.4	12.1	1.6

Figure A-35. Yields for Maize, AEZ: Low | No CO2 fert.

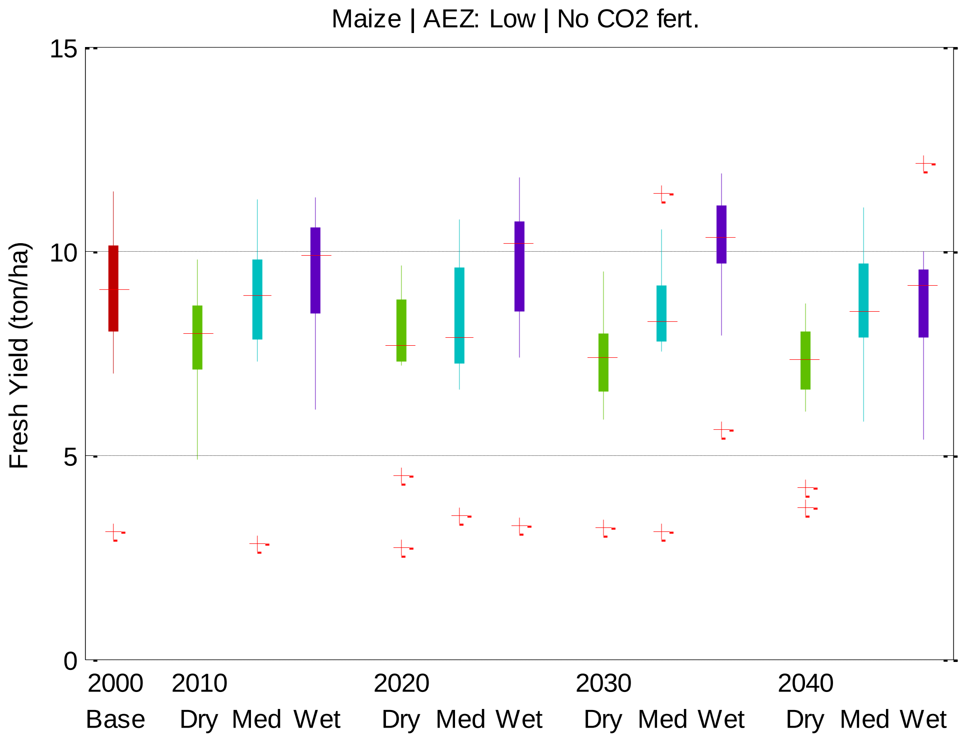


Table A-36. Yield Statistics for Maize, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	9.0	3.1	11.7	1.9
2010	Dry	8.5	5.2	10.6	1.5
2010	Med	9.4	3.0	12.3	2.2
2010	Wet	10.2	6.4	12.4	1.6
2020	Dry	8.8	3.1	11.2	2.2
2020	Med	9.3	4.0	12.5	2.4
2020	Wet	10.9	3.6	13.4	2.2
2030	Dry	9.1	3.9	11.9	2.0
2030	Med	10.3	3.8	14.3	2.5
2030	Wet	12.2	6.6	14.5	1.9
2040	Dry	9.3	4.8	11.7	2.2
2040	Med	11.5	7.7	14.9	2.0
2040	Wet	10.9	6.7	15.3	2.0

Figure A-36. Yields for Maize, AEZ: Low | CO2 fert.

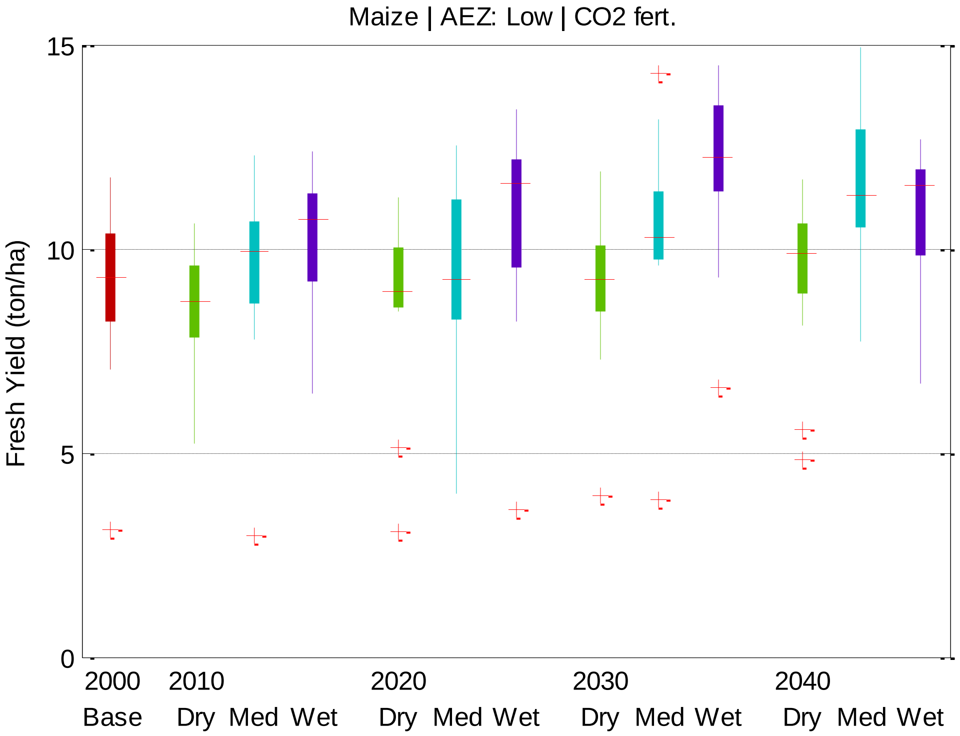


Table A-37. Yield Statistics for Maize, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	6.7	4.6	7.6	0.7
2010	Dry	5.7	3.3	7.3	1.6
2010	Med	6.2	2.7	7.8	1.6
2010	Wet	6.7	4.1	7.9	0.9
2020	Dry	6.2	2.4	7.6	1.5
2020	Med	6.4	3.7	7.6	1.0
2020	Wet	6.8	2.7	7.8	1.3
2030	Dry	5.6	2.3	7.8	1.9
2030	Med	5.8	2.2	7.6	1.7
2030	Wet	7.3	5.7	7.9	0.6
2040	Dry	4.6	2.1	7.5	2.0
2040	Med	6.2	2.4	7.5	1.3
2040	Wet	6.3	2.6	7.6	1.3

Figure A-37. Yields for Maize, AEZ: North | No CO2 fert.

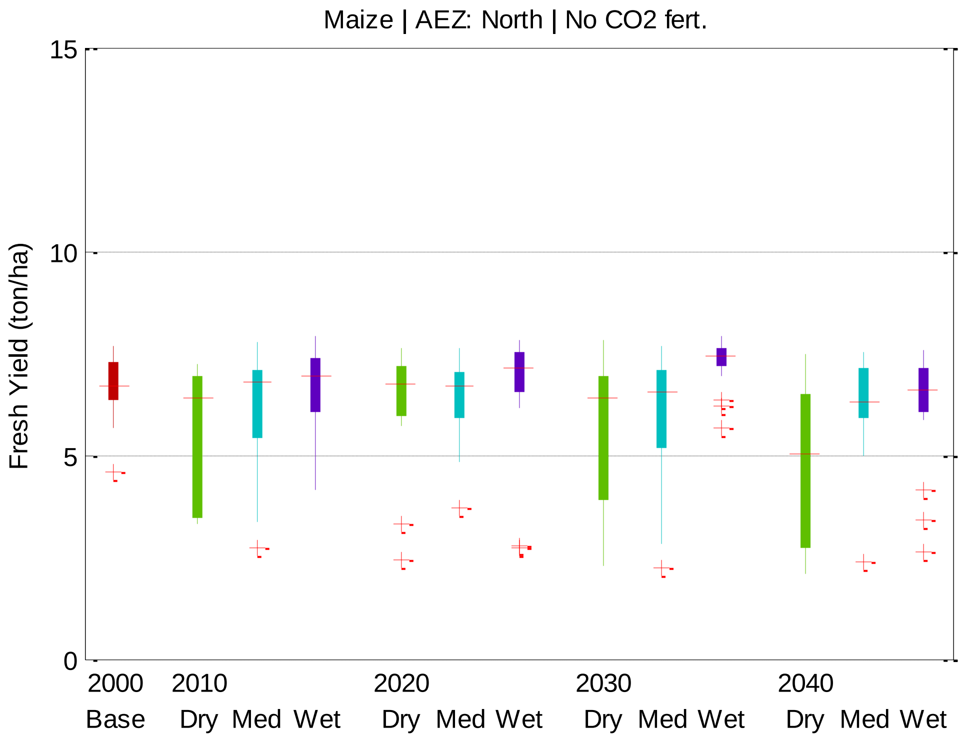


Table A-38. Yield Statistics for Maize, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	6.9	4.8	7.9	0.8
2010	Dry	6.1	3.6	7.8	1.7
2010	Med	6.7	3.0	8.5	1.7
2010	Wet	7.2	4.5	8.5	1.0
2020	Dry	7.2	2.8	8.8	1.7
2020	Med	7.5	4.4	8.8	1.1
2020	Wet	7.7	3.1	8.9	1.5
2030	Dry	7.0	2.9	9.6	2.3
2030	Med	7.3	2.8	9.4	2.0
2030	Wet	8.7	6.7	9.4	0.7
2040	Dry	6.2	2.8	9.9	2.7
2040	Med	8.2	3.2	9.8	1.7
2040	Wet	7.9	3.3	9.4	1.6

Figure A-38. Yields for Maize, AEZ: North | CO2 fert.

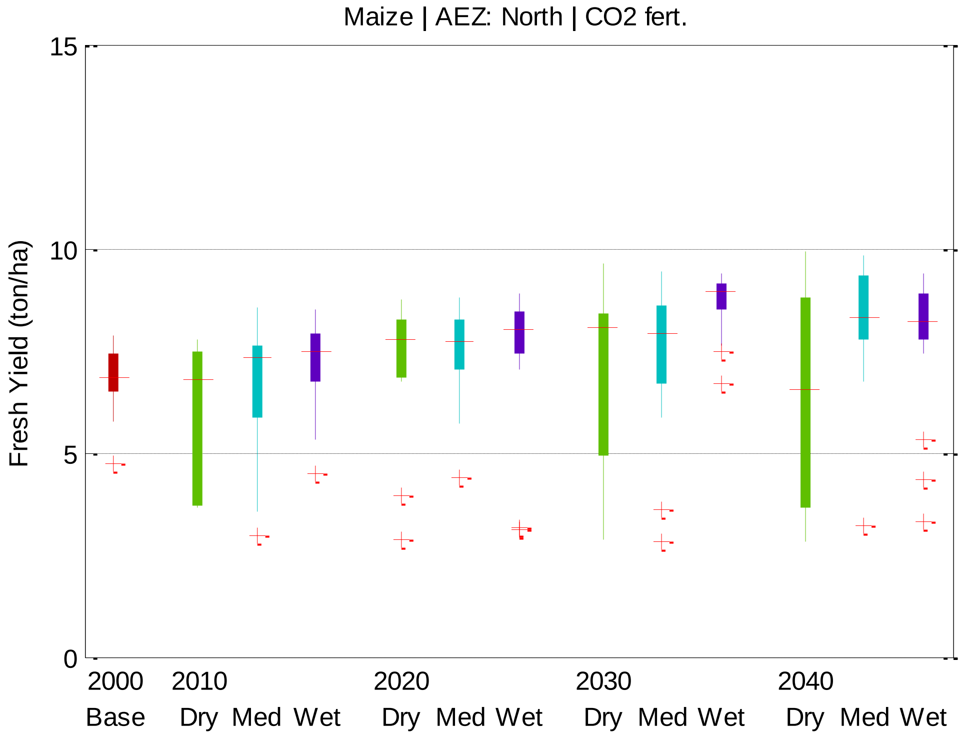


Table A-39. Yield Statistics for Maize, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	5.2	4.8	5.5	0.4
2010	Dry	6.4	5.3	6.9	0.5
2010	Med	5.9	4.8	6.5	0.5
2010	Wet	5.9	5.0	6.5	0.6
2020	Dry	6.1	4.3	6.9	0.8
2020	Med	5.6	3.3	6.9	1.1
2020	Wet	5.7	4.9	6.5	0.6
2030	Dry	6.1	5.2	7.1	0.7
2030	Med	6.3	5.3	7.1	0.7
2030	Wet	5.3	4.8	5.7	0.4
2040	Dry	6.5	4.8	7.5	0.8
2040	Med	6.0	5.2	7.1	0.6
2040	Wet	5.9	4.3	6.6	0.7

Figure A-39. Yields for Maize, AEZ: South | No CO2 fert.

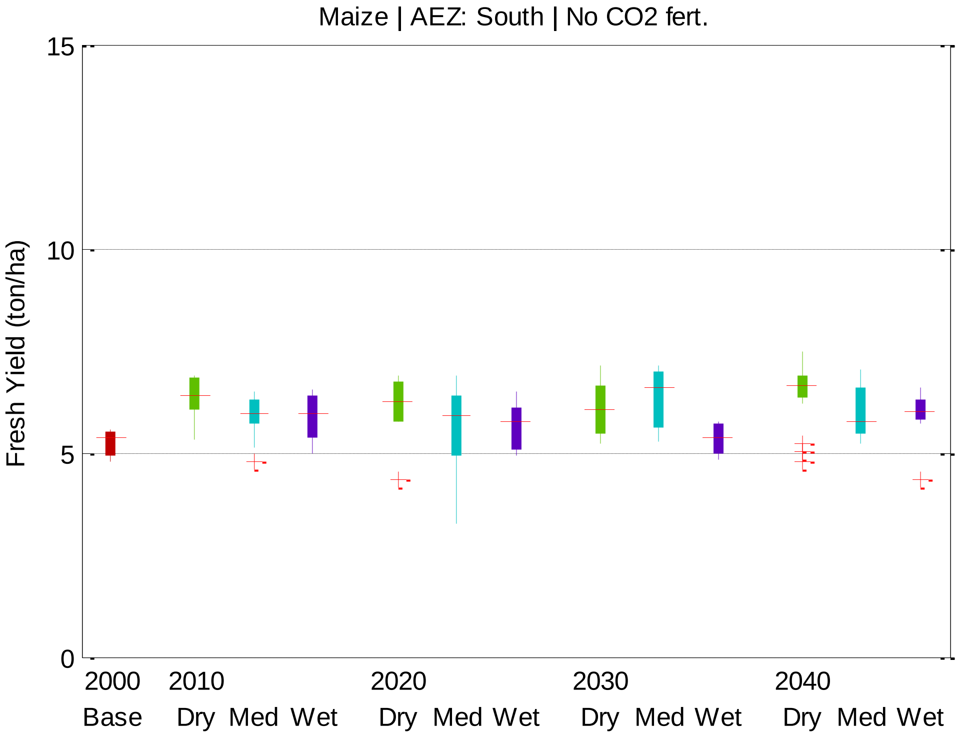
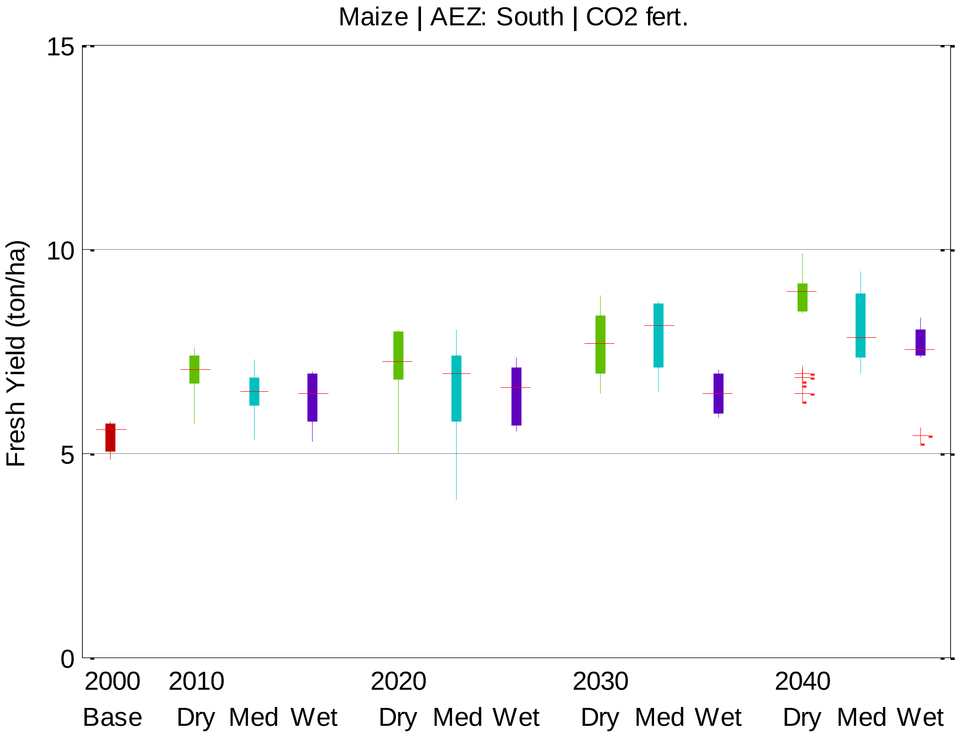


Table A-40. Yield Statistics for Maize, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	5.4	4.9	5.7	0.5
2010	Dry	6.9	5.7	7.6	0.5
2010	Med	6.4	5.3	7.3	0.6
2010	Wet	6.3	5.3	7.0	0.7
2020	Dry	7.1	5.0	8.0	1.0
2020	Med	6.5	3.9	8.0	1.3
2020	Wet	6.5	5.5	7.3	0.7
2030	Dry	7.7	6.5	8.9	0.8
2030	Med	7.9	6.5	8.7	0.9
2030	Wet	6.4	5.8	7.0	0.6
2040	Dry	8.6	6.5	9.9	1.0
2040	Med	8.1	6.9	9.4	0.9
2040	Wet	7.4	5.4	8.3	0.9

Figure A-40. Yields for Maize, AEZ: South | CO2 fert.



A.6 Olives

Table A-41. Yield Statistics for Olives, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.3	1.2	1.3	0.0
2010	Dry	1.2	0.8	1.3	0.2
2010	Med	1.3	1.2	1.3	0.0
2010	Wet	1.3	1.3	1.3	0.0
2020	Dry	1.2	1.1	1.3	0.1
2020	Med	1.2	0.9	1.3	0.1
2020	Wet	1.3	1.2	1.3	0.0
2030	Dry	1.2	0.8	1.3	0.2
2030	Med	1.2	1.0	1.3	0.1
2030	Wet	1.3	1.3	1.3	0.0
2040	Dry	1.2	1.1	1.3	0.1
2040	Med	1.2	1.1	1.3	0.1
2040	Wet	1.3	1.1	1.3	0.1

Figure A-41. Yields for Olives, AEZ: Inter | No CO2 fert.

Table A-42. Yield Statistics for Olives, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.3	1.2	1.3	0.0
2010	Dry	1.3	0.9	1.4	0.2
2010	Med	1.4	1.3	1.4	0.1
2010	Wet	1.4	1.3	1.4	0.0
2020	Dry	1.4	1.3	1.5	0.1
2020	Med	1.4	1.0	1.5	0.2
2020	Wet	1.5	1.4	1.5	0.0
2030	Dry	1.4	1.0	1.6	0.2
2030	Med	1.5	1.4	1.6	0.1
2030	Wet	1.5	1.5	1.6	0.0
2040	Dry	1.6	1.4	1.7	0.1
2040	Med	1.6	1.4	1.7	0.1
2040	Wet	1.6	1.4	1.7	0.1

Figure A-42. Yields for Olives, AEZ: Inter | CO2 fert.

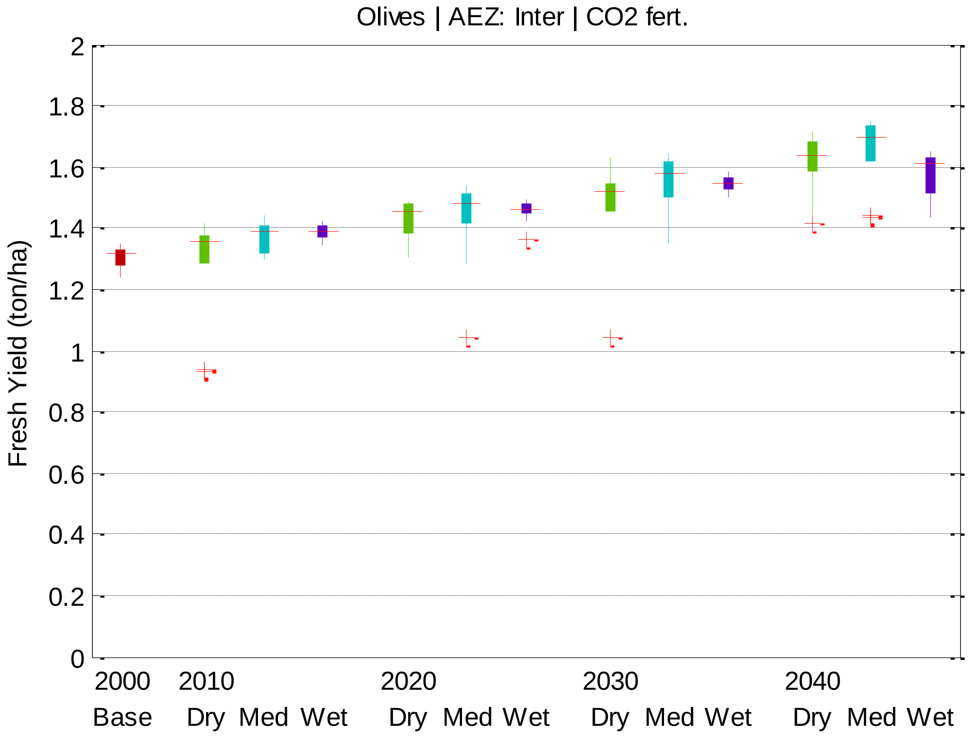


Table A-43. Yield Statistics for Olives, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.1	0.8	1.2	0.2
2010	Dry	0.8	0.6	1.0	0.1
2010	Med	1.0	0.8	1.2	0.1
2010	Wet	1.2	1.0	1.3	0.1
2020	Dry	0.9	0.8	1.2	0.1
2020	Med	0.8	0.7	1.2	0.1
2020	Wet	1.1	1.0	1.3	0.1
2030	Dry	0.8	0.6	1.0	0.1
2030	Med	0.8	0.7	1.0	0.1
2030	Wet	1.2	0.9	1.3	0.2
2040	Dry	0.9	0.7	1.1	0.1
2040	Med	0.9	0.7	1.0	0.1
2040	Wet	1.0	0.8	1.2	0.1

Figure A-43. Yields for Olives, AEZ: Low | No CO2 fert.

Table A-44. Yield Statistics for Olives, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.1	0.8	1.3	0.2
2010	Dry	0.9	0.7	1.0	0.1
2010	Med	1.1	0.8	1.3	0.2
2010	Wet	1.3	1.1	1.4	0.1
2020	Dry	1.1	0.9	1.4	0.2
2020	Med	1.0	0.8	1.3	0.1
2020	Wet	1.3	1.1	1.4	0.1
2030	Dry	1.0	0.8	1.2	0.1
2030	Med	1.0	0.8	1.2	0.1
2030	Wet	1.4	1.0	1.6	0.2
2040	Dry	1.2	0.9	1.5	0.2
2040	Med	1.1	0.9	1.3	0.1
2040	Wet	1.2	0.9	1.5	0.2

Figure A-44. Yields for Olives, AEZ: Low | CO2 fert.

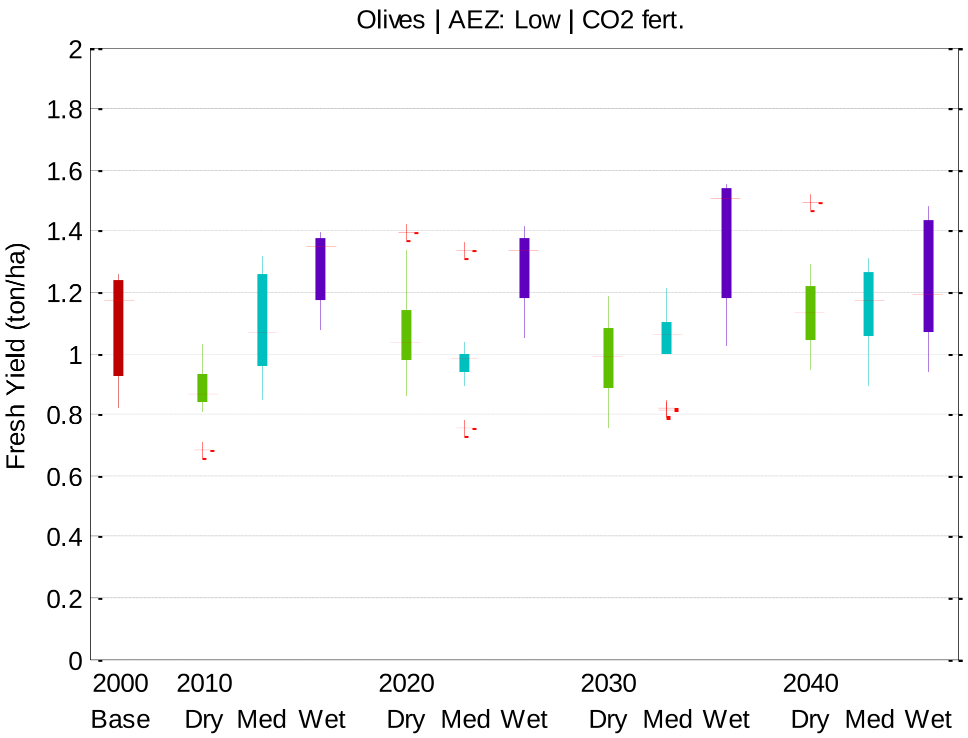


Table A-45. Yield Statistics for Olives, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.0	0.7	1.2	0.2
2010	Dry	0.8	0.6	1.0	0.1
2010	Med	1.0	0.7	1.2	0.2
2010	Wet	1.0	0.8	1.2	0.2
2020	Dry	0.8	0.6	1.0	0.1
2020	Med	0.8	0.7	1.0	0.1
2020	Wet	1.0	0.7	1.2	0.2
2030	Dry	0.8	0.6	0.9	0.1
2030	Med	0.8	0.6	1.0	0.1
2030	Wet	1.1	0.8	1.3	0.1
2040	Dry	0.8	0.6	0.9	0.1
2040	Med	0.8	0.6	1.0	0.1
2040	Wet	0.9	0.7	1.1	0.2

Figure A-45. Yields for Olives, AEZ: North | No CO2 fert.

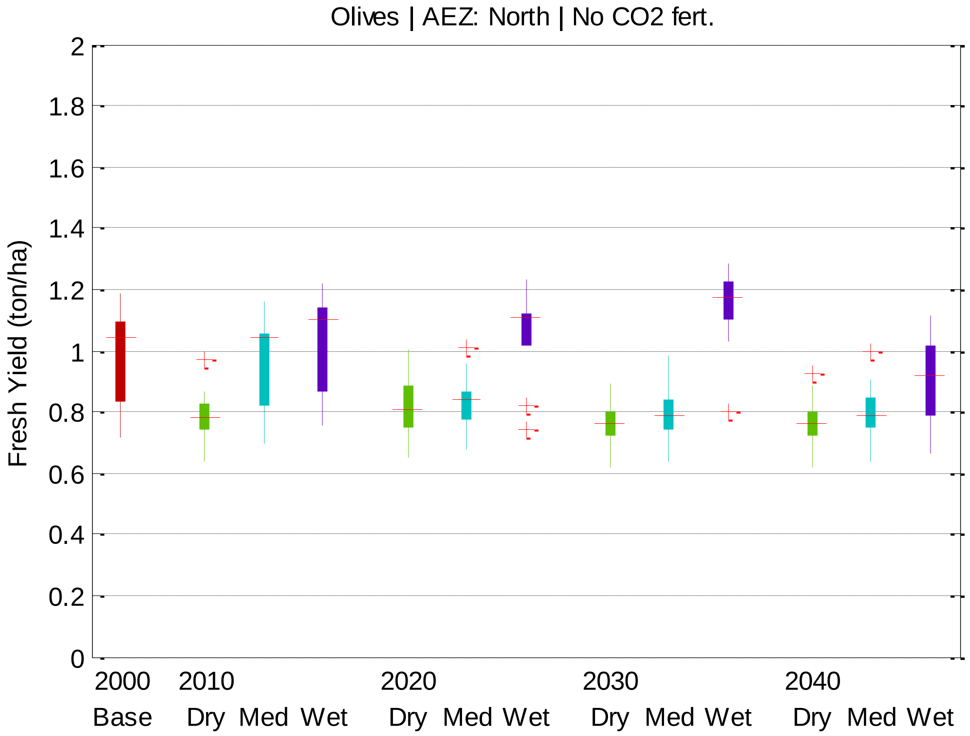


Table A-46. Yield Statistics for Olives, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.0	0.7	1.2	0.2
2010	Dry	0.9	0.7	1.0	0.1
2010	Med	1.1	0.7	1.2	0.2
2010	Wet	1.1	0.8	1.3	0.2
2020	Dry	1.0	0.7	1.1	0.1
2020	Med	1.0	0.8	1.1	0.1
2020	Wet	1.2	0.8	1.4	0.2
2030	Dry	0.9	0.8	1.1	0.1
2030	Med	1.0	0.8	1.2	0.1
2030	Wet	1.4	0.9	1.5	0.2
2040	Dry	1.0	0.8	1.2	0.1
2040	Med	1.1	0.8	1.3	0.1
2040	Wet	1.1	0.8	1.4	0.2

Figure A-46. Yields for Olives, AEZ: North | CO2 fert.

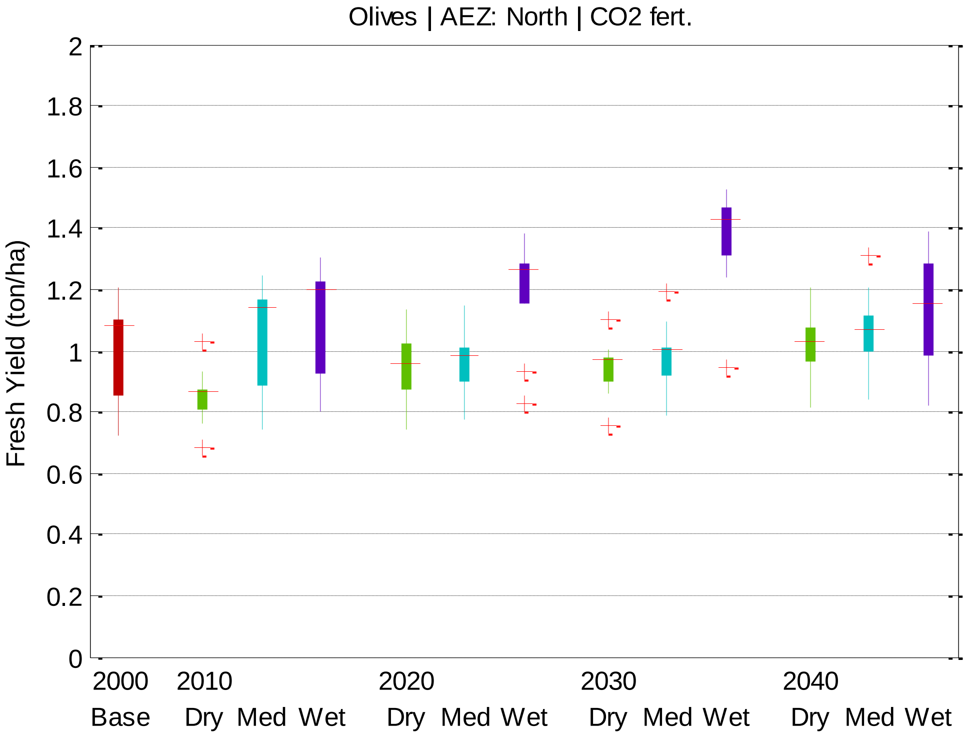


Table A-47. Yield Statistics for Olives, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.2	0.9	1.3	0.1
2010	Dry	1.0	0.8	1.3	0.2
2010	Med	1.1	0.8	1.3	0.2
2010	Wet	1.1	0.8	1.3	0.2
2020	Dry	1.1	0.8	1.3	0.2
2020	Med	1.0	0.8	1.3	0.2
2020	Wet	1.1	0.9	1.3	0.2
2030	Dry	1.1	0.8	1.3	0.2
2030	Med	1.0	0.8	1.3	0.2
2030	Wet	1.2	0.9	1.3	0.1
2040	Dry	1.0	0.7	1.2	0.2
2040	Med	1.1	0.8	1.3	0.2
2040	Wet	1.1	0.9	1.3	0.2

Figure A-47. Yields for Olives, AEZ: South | No CO2 fert.

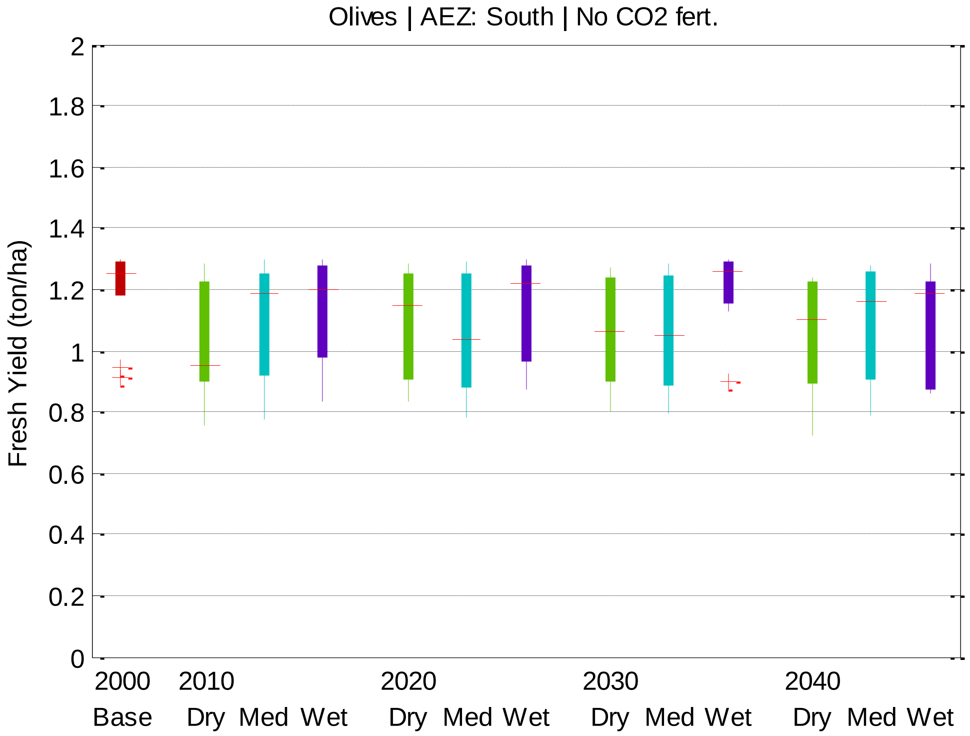
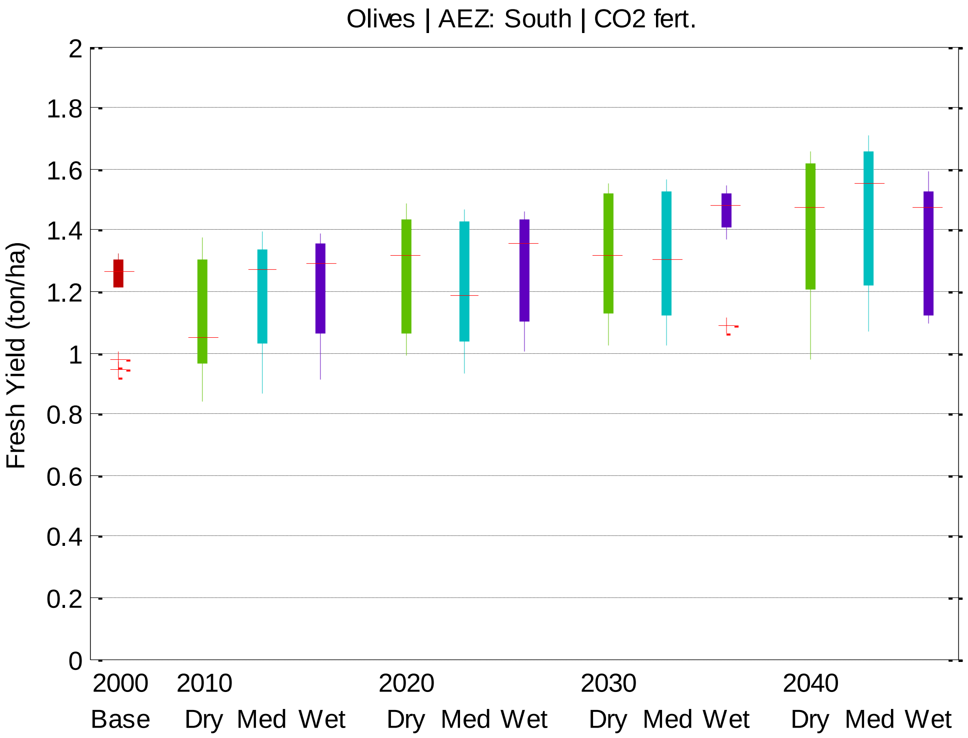


Table A-48. Yield Statistics for Olives, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	1.2	0.9	1.3	0.1
2010	Dry	1.1	0.8	1.4	0.2
2010	Med	1.2	0.9	1.4	0.2
2010	Wet	1.2	0.9	1.4	0.2
2020	Dry	1.3	1.0	1.5	0.2
2020	Med	1.2	0.9	1.5	0.2
2020	Wet	1.3	1.0	1.5	0.2
2030	Dry	1.3	1.0	1.6	0.2
2030	Med	1.3	1.0	1.6	0.2
2030	Wet	1.4	1.1	1.5	0.1
2040	Dry	1.4	1.0	1.7	0.2
2040	Med	1.4	1.1	1.7	0.2
2040	Wet	1.4	1.1	1.6	0.2

Figure A-48. Yields for Olives, AEZ: South | CO2 fert.



A.7 Tomatoes

Table A-49. Yield Statistics for Tomatoes, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	33.8	33.6	33.9	0.2
2010	Dry	33.4	32.1	34.0	0.6
2010	Med	33.7	33.3	34.0	0.2
2010	Wet	33.9	33.6	34.1	0.2
2020	Dry	33.6	32.4	34.0	0.4
2020	Med	33.7	33.1	34.0	0.3
2020	Wet	33.8	33.6	33.9	0.2
2030	Dry	33.2	31.7	33.9	0.7
2030	Med	33.7	33.0	34.0	0.3
2030	Wet	33.6	32.1	34.1	0.5
2040	Dry	33.5	32.2	34.0	0.5
2040	Med	33.6	32.6	34.0	0.4
2040	Wet	33.7	33.2	34.0	0.3

Figure A-49. Yields for Tomatoes, AEZ: Inter | No CO2 fert.

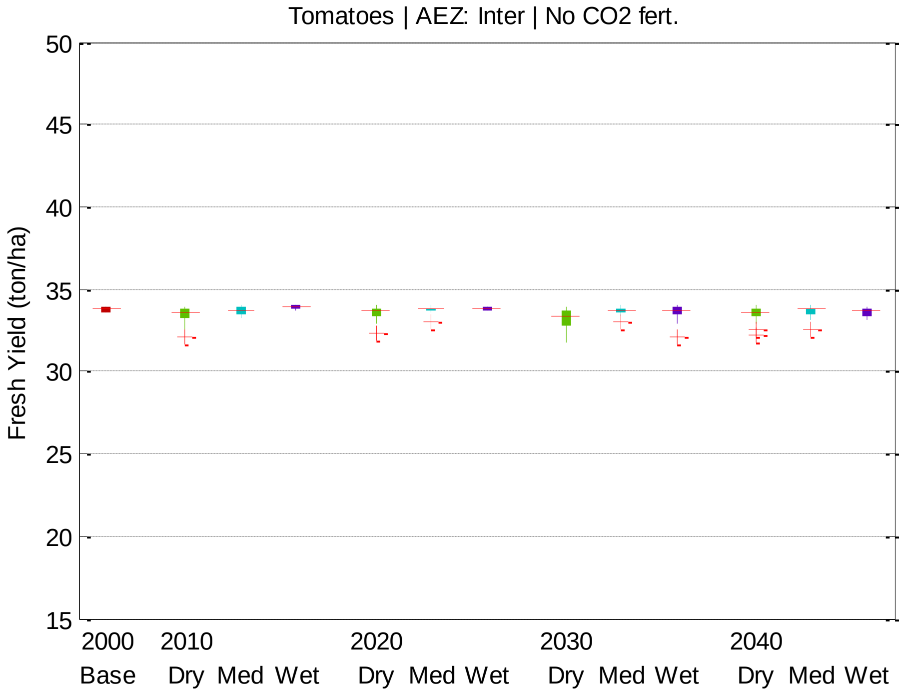


Table A-50. Yield Statistics for Tomatoes, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	33.9	33.7	34.1	0.2
2010	Dry	36.2	34.6	37.5	0.8
2010	Med	36.4	35.3	37.7	0.8
2010	Wet	35.7	35.5	35.9	0.1
2020	Dry	39.0	36.7	40.5	0.9
2020	Med	39.0	37.5	40.5	1.0
2020	Wet	37.6	37.4	37.8	0.2
2030	Dry	41.6	38.7	42.9	1.2
2030	Med	42.0	40.2	43.5	1.1
2030	Wet	39.3	37.7	40.3	0.6
2040	Dry	44.7	42.1	46.0	0.9
2040	Med	44.6	42.6	46.0	1.0
2040	Wet	41.9	41.0	43.3	0.7

Figure A-50. Yields for Tomatoes, AEZ: Inter | CO2 fert.

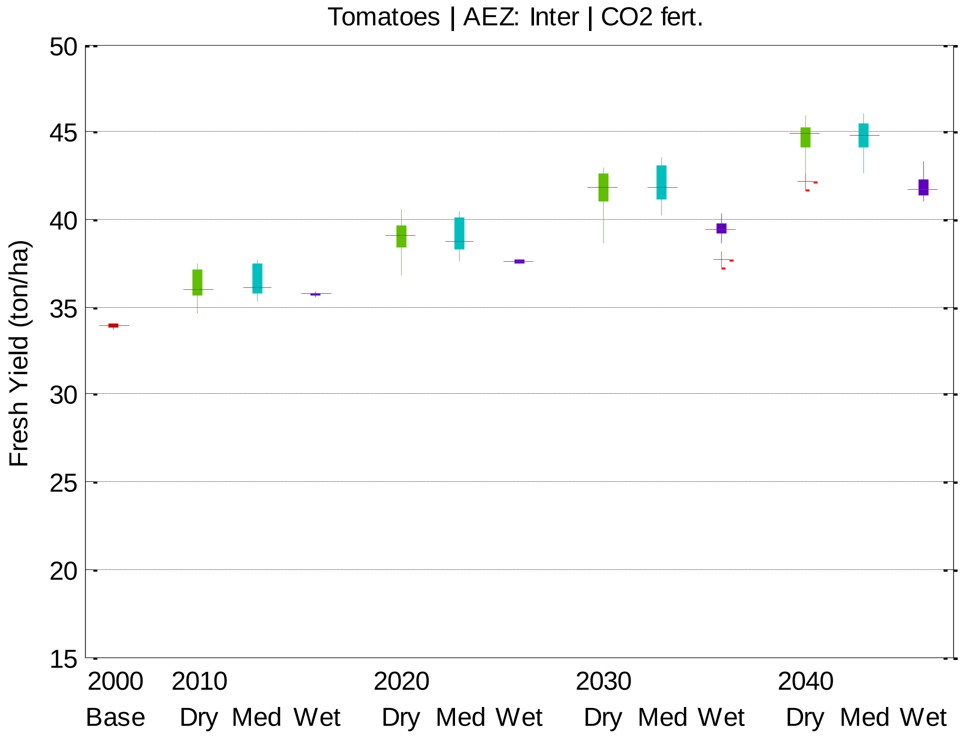


Table A-51. Yield Statistics for Tomatoes, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	33.2	31.5	34.0	0.7
2010	Dry	31.7	20.0	33.9	3.2
2010	Med	33.2	31.0	34.0	0.7
2010	Wet	33.5	31.5	34.1	0.6
2020	Dry	33.1	31.1	33.9	0.6
2020	Med	31.7	22.9	34.0	2.9
2020	Wet	33.2	31.3	34.1	0.7
2030	Dry	32.0	24.1	33.9	2.5
2030	Med	32.2	24.6	34.0	2.3
2030	Wet	33.0	32.0	33.9	0.6
2040	Dry	29.9	0.0	34.0	9.6
2040	Med	29.1	0.0	34.0	10.6
2040	Wet	29.6	0.0	34.0	10.2

Figure A-51. Yields for Tomatoes, AEZ: Low | No CO2 fert.

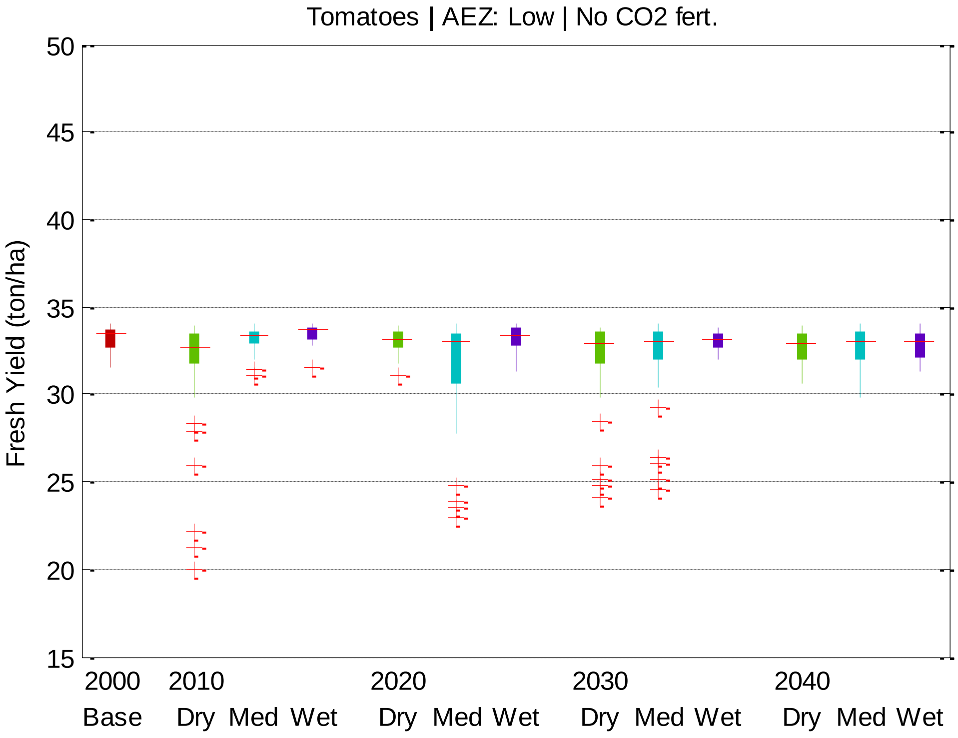


Table A-52. Yield Statistics for Tomatoes, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	33.8	31.8	35.4	1.0
2010	Dry	34.5	21.3	37.8	3.8
2010	Med	35.9	32.7	37.9	1.2
2010	Wet	35.8	34.4	37.3	0.8
2020	Dry	38.5	35.6	40.5	1.2
2020	Med	37.0	26.2	40.6	3.8
2020	Wet	37.5	34.9	39.3	1.2
2030	Dry	40.1	29.6	43.5	3.6
2030	Med	40.2	30.1	43.6	3.4
2030	Wet	38.8	37.5	40.8	0.9
2040	Dry	40.0	0.0	46.0	12.8
2040	Med	38.9	0.0	46.1	14.2
2040	Wet	37.2	0.0	43.4	12.8

Figure A-52. Yields for Tomatoes, AEZ: Low | CO2 fert.

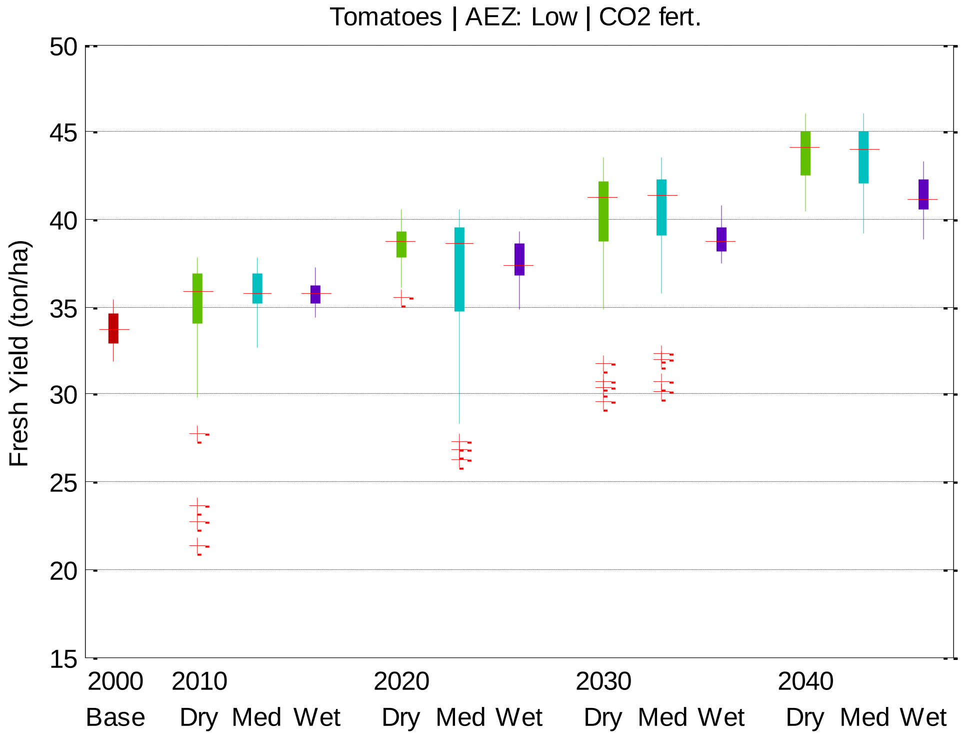


Table A-53. Yield Statistics for Tomatoes, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	30.9	19.5	34.0	2.8
2010	Dry	27.4	0.0	33.8	7.7
2010	Med	31.4	19.1	33.9	2.8
2010	Wet	30.6	24.8	34.0	2.5
2020	Dry	28.4	0.0	33.8	7.3
2020	Med	28.2	0.0	34.1	6.7
2020	Wet	31.5	21.9	34.0	2.6
2030	Dry	28.3	0.0	33.9	5.1
2030	Med	27.9	0.0	33.9	7.5
2030	Wet	31.7	25.9	33.8	2.3
2040	Dry	29.1	0.0	34.0	5.1
2040	Med	29.1	0.0	33.9	5.2
2040	Wet	29.7	0.0	33.9	6.2

Figure A-53. Yields for Tomatoes, AEZ: North | No CO2 fert.

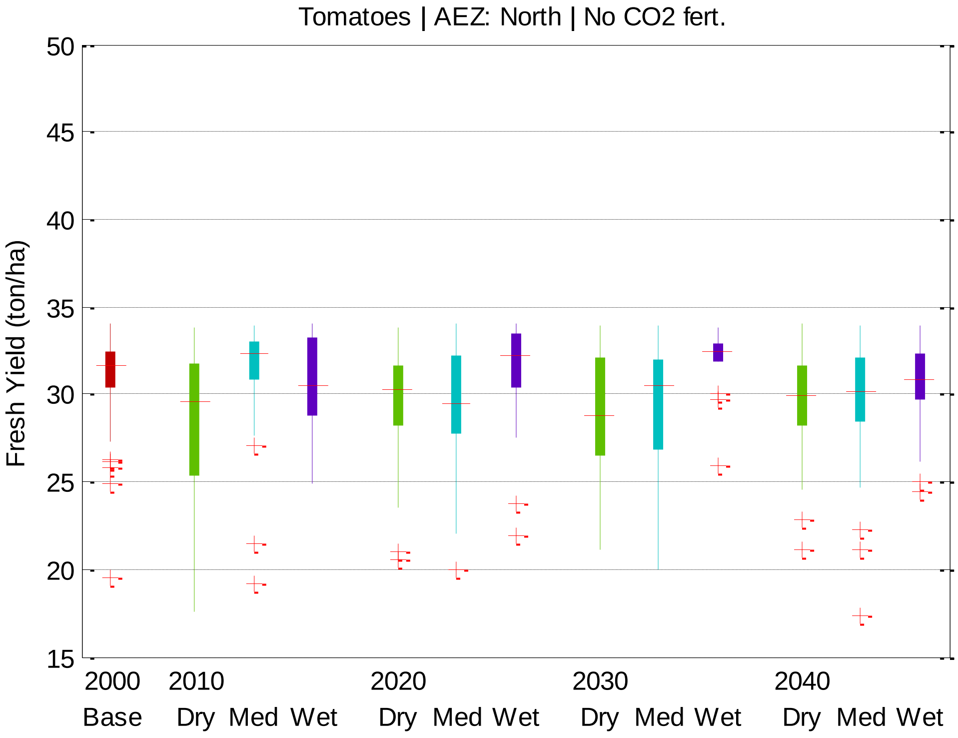


Table A-54. Yield Statistics for Tomatoes, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	31.7	19.7	35.0	3.0
2010	Dry	29.8	0.0	37.9	8.4
2010	Med	34.1	20.4	37.5	3.2
2010	Wet	32.9	26.3	37.3	3.0
2020	Dry	33.0	0.0	40.6	8.5
2020	Med	33.0	0.0	40.7	7.9
2020	Wet	35.7	24.5	39.1	3.2
2030	Dry	35.4	0.0	43.6	6.4
2030	Med	34.9	0.0	43.7	9.4
2030	Wet	37.8	30.5	41.2	3.0
2040	Dry	38.9	0.0	45.9	6.8
2040	Med	38.9	0.0	45.8	6.9
2040	Wet	37.4	0.0	42.4	7.8

Figure A-54. Yields for Tomatoes, AEZ: North | CO2 fert.

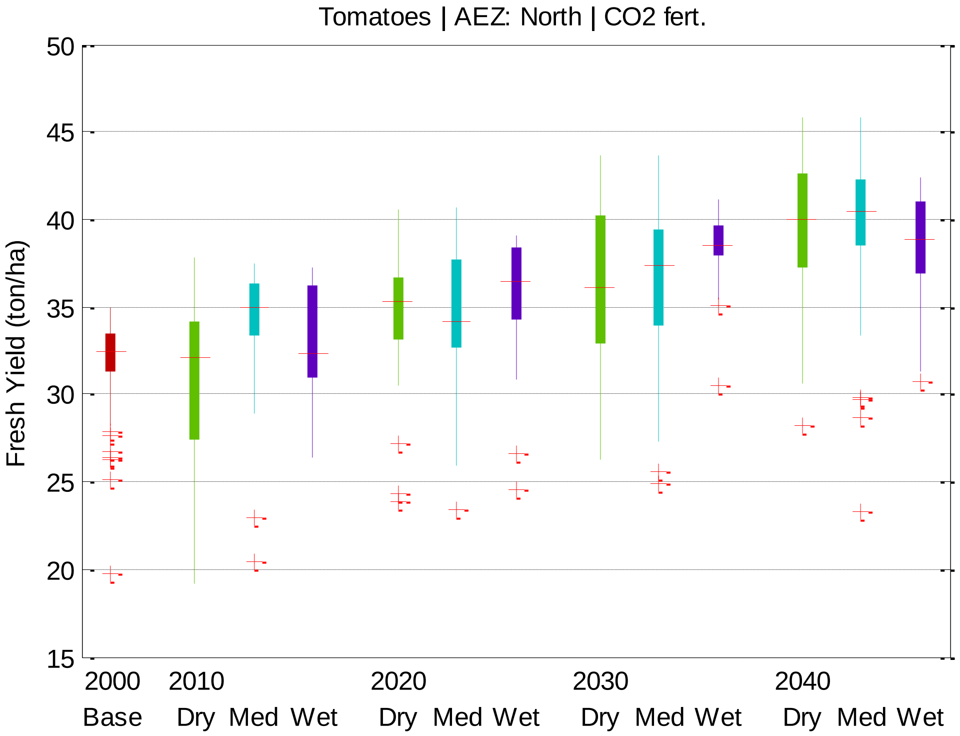


Table A-55. Yield Statistics for Tomatoes, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	33.7	33.5	33.9	0.2
2010	Dry	33.4	32.0	34.0	0.6
2010	Med	33.7	33.2	34.0	0.2
2010	Wet	33.8	33.6	34.0	0.1
2020	Dry	33.7	33.1	34.0	0.3
2020	Med	33.0	30.9	33.9	0.9
2020	Wet	33.8	33.5	34.0	0.2
2030	Dry	33.5	32.4	34.1	0.4
2030	Med	33.5	32.6	34.1	0.4
2030	Wet	33.8	33.5	34.0	0.2
2040	Dry	33.3	30.8	34.1	0.9
2040	Med	33.7	32.5	34.1	0.4
2040	Wet	33.5	30.4	34.1	0.8

Figure A-55. Yields for Tomatoes, AEZ: South | No CO2 fert.

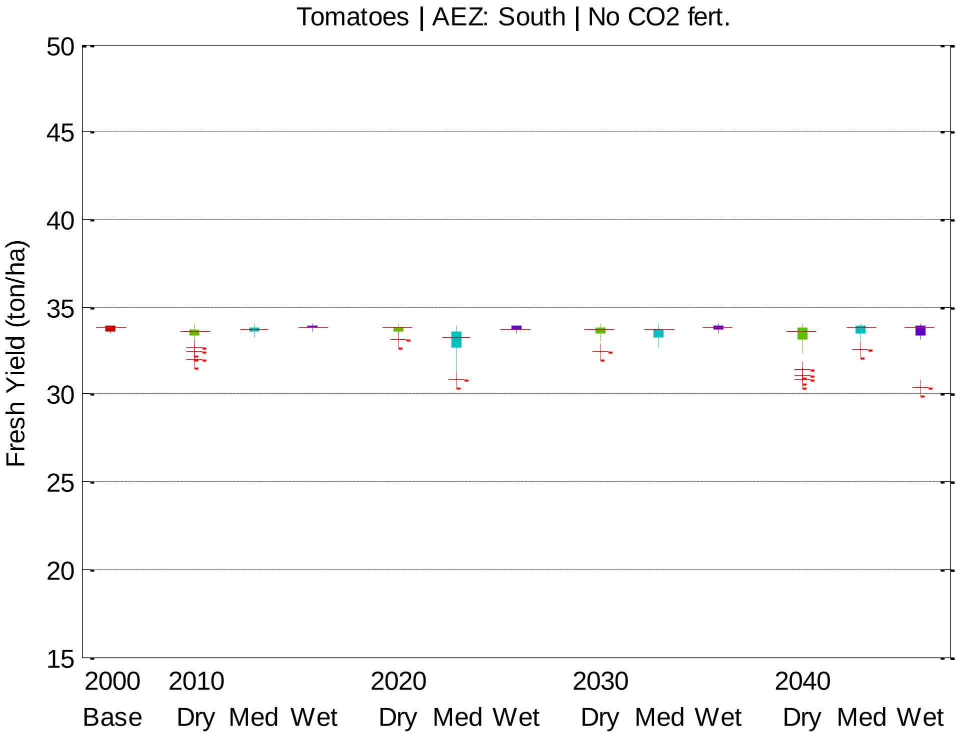
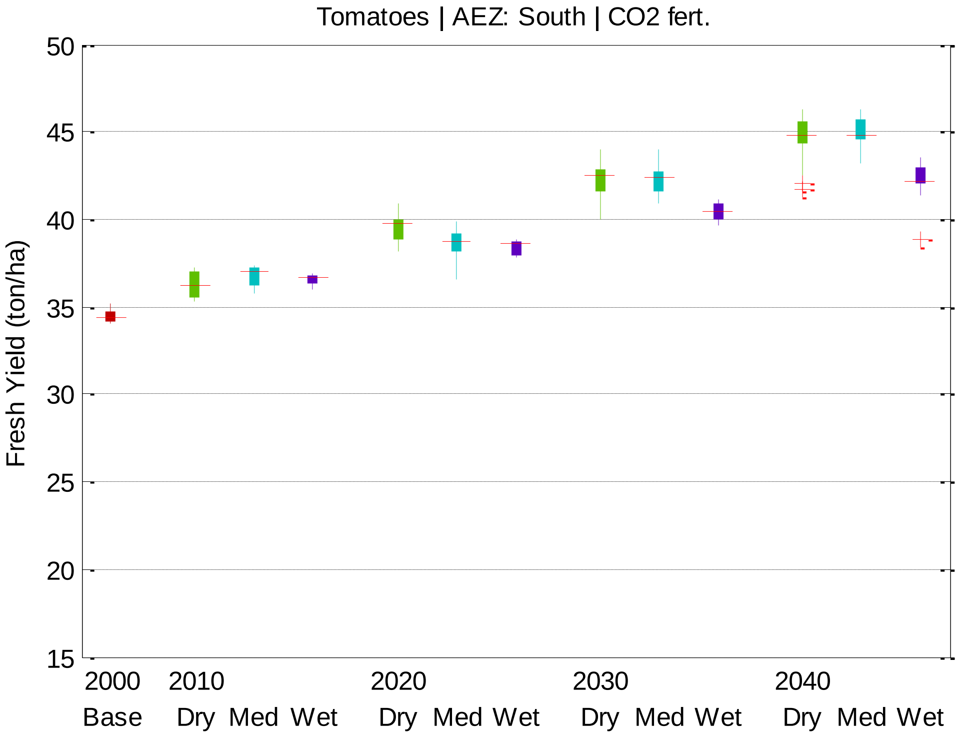


Table A-56. Yield Statistics for Tomatoes, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	34.5	34.0	35.1	0.5
2010	Dry	36.3	35.3	37.3	0.7
2010	Med	36.8	35.7	37.4	0.6
2010	Wet	36.5	36.0	36.9	0.3
2020	Dry	39.5	38.1	40.9	0.8
2020	Med	38.5	36.6	39.8	0.9
2020	Wet	38.4	37.8	38.9	0.5
2030	Dry	42.1	40.0	43.9	1.0
2030	Med	42.2	40.9	43.9	0.8
2030	Wet	40.4	39.7	41.1	0.6
2040	Dry	44.6	41.7	46.3	1.3
2040	Med	45.0	43.2	46.3	0.8
2040	Wet	42.3	38.8	43.6	1.0

Figure A-56. Yields for Tomatoes, AEZ: South | CO2 fert.



A.8 Watermelons

Table A-57. Yield Statistics for Watermelons, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	28.5	26.2	29.5	0.9
2010	Dry	28.0	24.2	29.4	1.5
2010	Med	28.6	27.1	29.6	0.8
2010	Wet	29.1	27.9	29.6	0.4
2020	Dry	28.6	26.8	29.6	0.8
2020	Med	28.1	22.3	29.6	1.8
2020	Wet	28.5	26.8	29.6	0.8
2030	Dry	28.4	25.5	29.4	1.2
2030	Med	28.4	23.4	29.5	1.7
2030	Wet	29.0	28.4	29.3	0.3
2040	Dry	28.5	25.5	29.5	1.0
2040	Med	28.4	24.9	29.6	1.3
2040	Wet	27.8	20.0	29.6	2.6

Figure A-57. Yields for Watermelons, AEZ: Low | No CO2 fert.

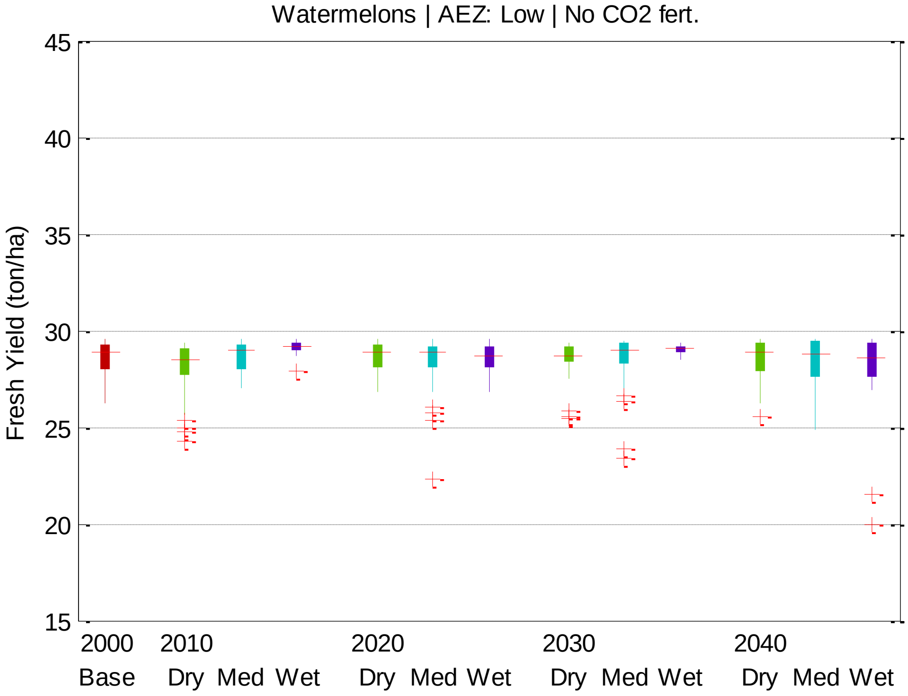
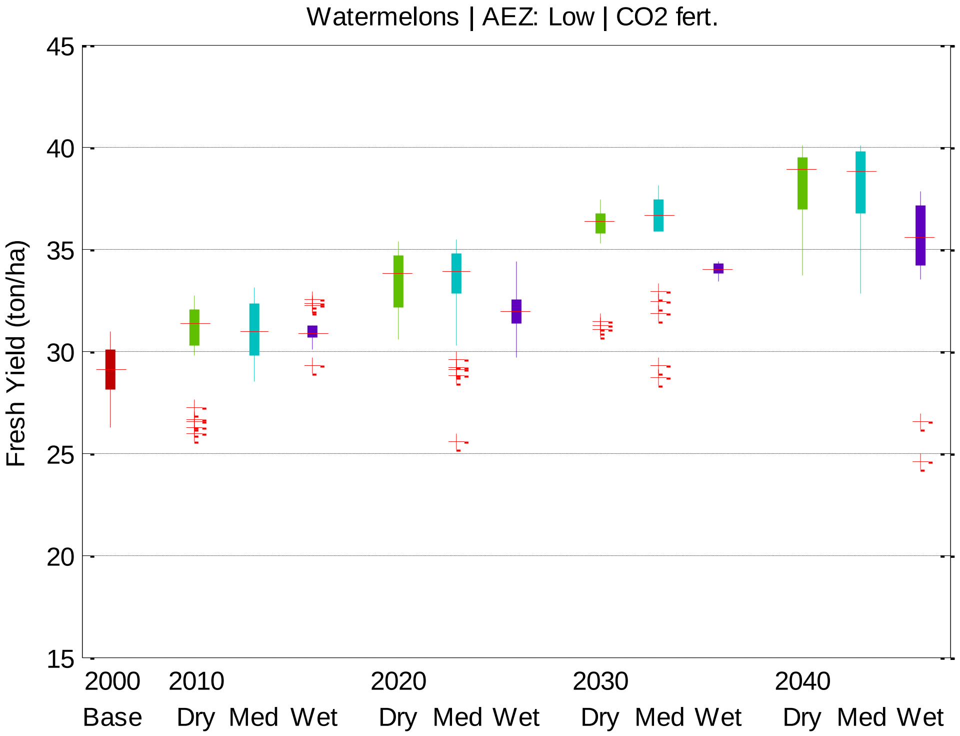


Table A-58. Yield Statistics for Watermelons, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	29.0	26.2	30.9	1.3
2010	Dry	30.7	25.9	32.7	2.0
2010	Med	31.0	28.5	33.1	1.5
2010	Wet	31.0	29.3	32.5	0.9
2020	Dry	33.4	30.6	35.4	1.6
2020	Med	33.0	25.5	35.5	2.6
2020	Wet	32.0	29.6	34.3	1.4
2030	Dry	35.8	31.0	37.4	1.8
2030	Med	35.8	28.7	38.1	2.6
2030	Wet	33.9	33.4	34.4	0.3
2040	Dry	38.3	33.7	40.0	1.7
2040	Med	38.0	32.8	40.1	2.1
2040	Wet	34.9	24.5	37.8	3.5

Figure A-58. Yields for Watermelons, AEZ: Low | CO2 fert.



A.9 Wheat

Table A-59. Yield Statistics for Wheat, AEZ: Inter | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	4.2	3.9	4.6	0.2
2010	Dry	4.4	4.1	4.7	0.2
2010	Med	4.4	4.1	4.8	0.2
2010	Wet	4.3	4.0	4.7	0.2
2020	Dry	4.4	4.1	4.7	0.2
2020	Med	4.5	4.2	4.8	0.2
2020	Wet	4.3	4.0	4.7	0.2
2030	Dry	4.5	4.1	4.8	0.2
2030	Med	4.6	4.3	4.9	0.2
2030	Wet	4.3	4.0	4.7	0.2
2040	Dry	4.5	4.2	4.8	0.2
2040	Med	4.6	4.3	4.9	0.2
2040	Wet	4.4	4.1	4.8	0.2

Figure A-59. Yields for Wheat, AEZ: Inter | No CO2 fert.

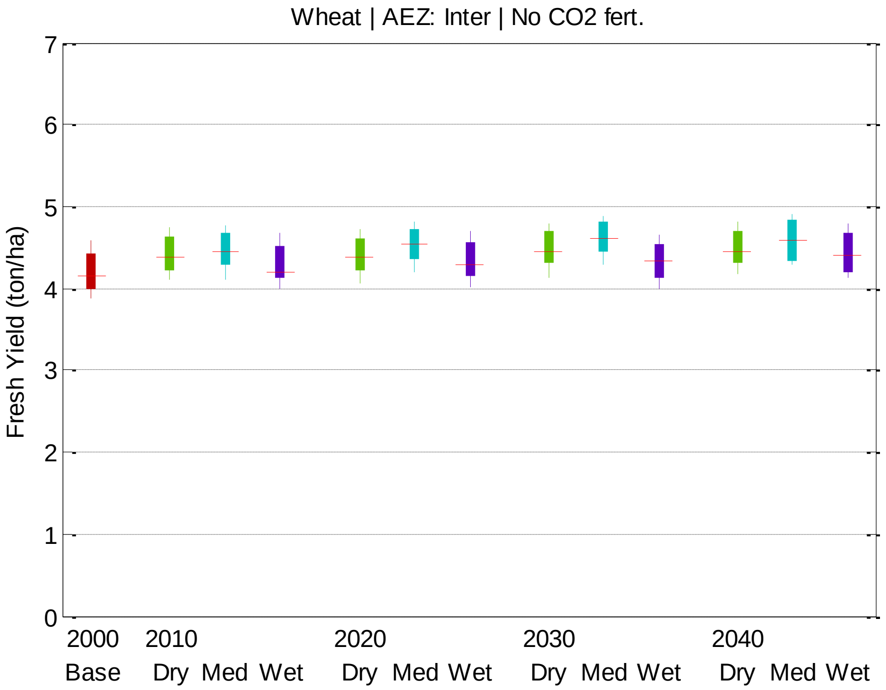


Table A-60. Yield Statistics for Wheat, AEZ: Inter | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	4.3	3.9	4.8	0.3
2010	Dry	4.8	4.4	5.3	0.3
2010	Med	4.8	4.4	5.3	0.3
2010	Wet	4.6	4.2	5.1	0.3
2020	Dry	5.1	4.6	5.7	0.3
2020	Med	5.3	4.8	5.8	0.3
2020	Wet	4.9	4.5	5.4	0.3
2030	Dry	5.6	5.1	6.2	0.4
2030	Med	5.8	5.3	6.3	0.3
2030	Wet	5.2	4.7	5.7	0.3
2040	Dry	6.0	5.5	6.5	0.4
2040	Med	6.1	5.7	6.7	0.4
2040	Wet	5.6	5.1	6.1	0.3

Figure A-60. Yields for Wheat, AEZ: Inter | CO2 fert.

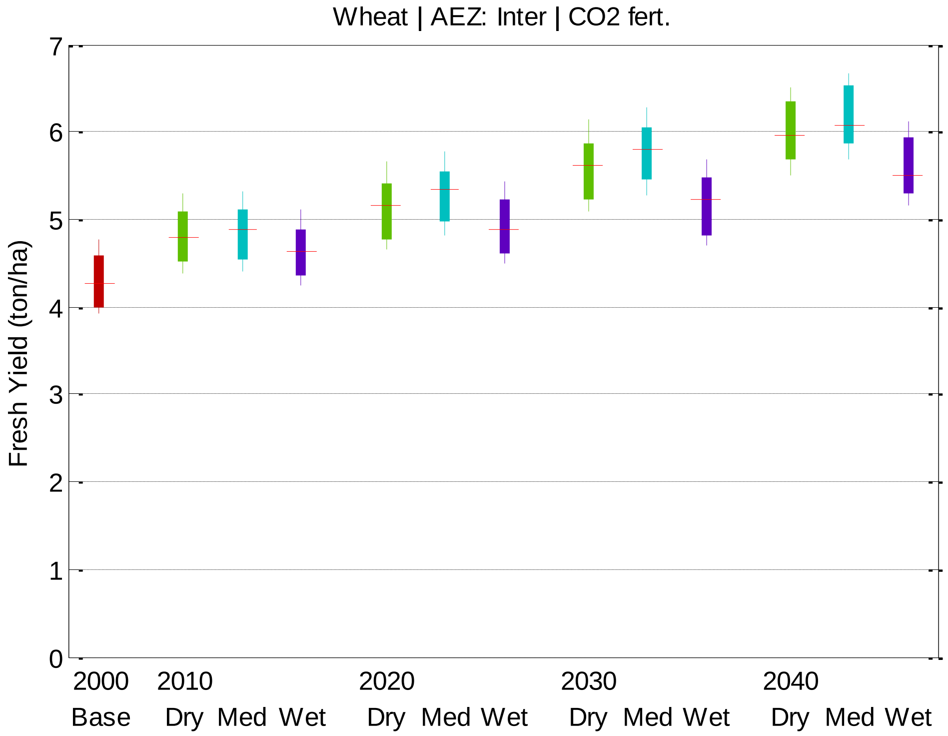


Table A-61. Yield Statistics for Wheat, AEZ: Low | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	4.6	4.1	4.9	0.2
2010	Dry	4.8	4.3	5.0	0.2
2010	Med	4.8	4.3	5.0	0.2
2010	Wet	4.7	4.2	5.0	0.2
2020	Dry	4.8	4.3	5.0	0.2
2020	Med	4.9	4.4	5.1	0.2
2020	Wet	4.7	4.3	5.0	0.2
2030	Dry	4.8	4.4	5.1	0.2
2030	Med	5.0	4.5	5.2	0.2
2030	Wet	4.7	4.3	4.9	0.2
2040	Dry	4.9	4.4	5.1	0.2
2040	Med	5.0	4.5	5.2	0.2
2040	Wet	4.8	4.4	5.0	0.2

Figure A-61. Yields for Wheat, AEZ: Low | No CO2 fert.

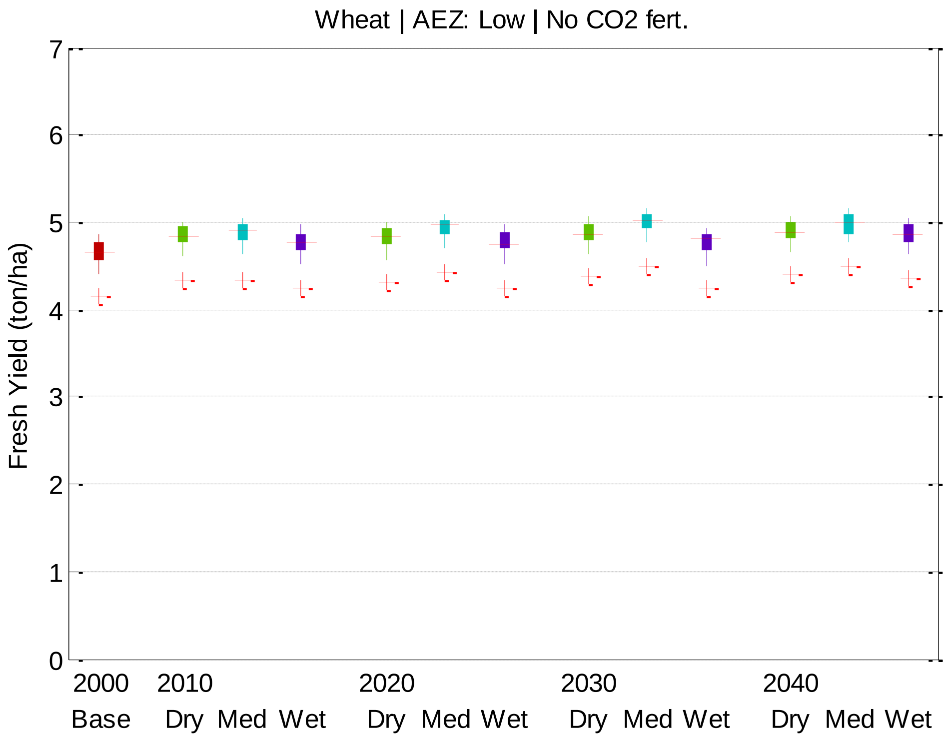


Table A-62. Yield Statistics for Wheat, AEZ: Low | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	4.7	4.3	5.1	0.3
2010	Dry	5.2	4.7	5.5	0.3
2010	Med	5.3	4.8	5.6	0.3
2010	Wet	5.1	4.6	5.4	0.3
2020	Dry	5.6	5.0	6.0	0.3
2020	Med	5.7	5.2	6.1	0.3
2020	Wet	5.4	4.8	5.8	0.3
2030	Dry	6.1	5.5	6.5	0.3
2030	Med	6.2	5.7	6.6	0.3
2030	Wet	5.7	5.1	6.0	0.3
2040	Dry	6.5	5.9	6.9	0.3
2040	Med	6.6	6.1	7.0	0.3
2040	Wet	6.1	5.5	6.4	0.3

Figure A-62. Yields for Wheat, AEZ: Low | CO2 fert.

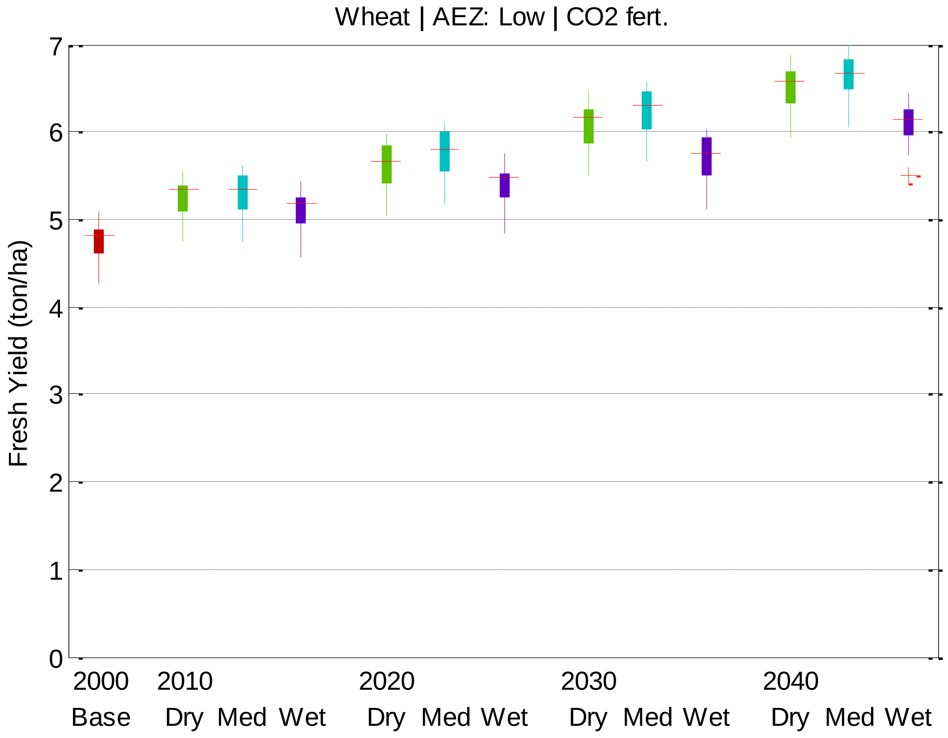


Table A-63. Yield Statistics for Wheat, AEZ: North | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	2.8	2.6	3.1	0.1
2010	Dry	3.1	2.9	3.4	0.1
2010	Med	3.3	3.1	3.5	0.1
2010	Wet	3.0	2.7	3.2	0.1
2020	Dry	3.1	2.9	3.3	0.1
2020	Med	3.5	3.3	3.7	0.1
2020	Wet	2.9	2.7	3.2	0.1
2030	Dry	3.2	3.0	3.4	0.1
2030	Med	3.5	3.4	3.7	0.1
2030	Wet	3.0	2.7	3.2	0.1
2040	Dry	3.3	3.1	3.5	0.1
2040	Med	3.5	3.3	3.7	0.1
2040	Wet	3.1	2.9	3.4	0.1

Figure A-63. Yields for Wheat, AEZ: North | No CO2 fert.

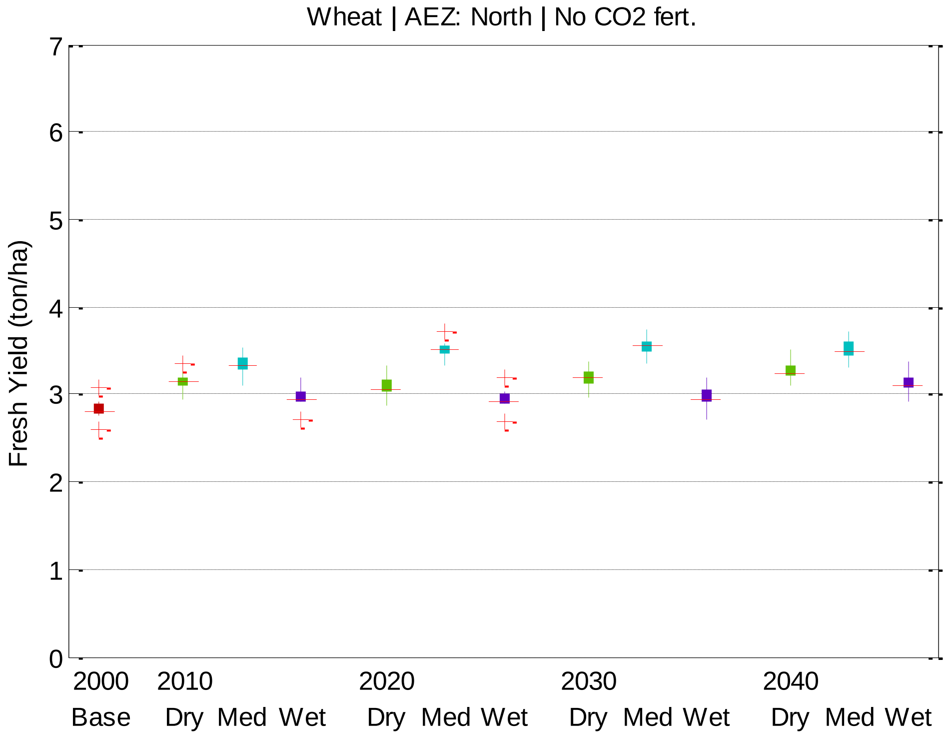


Table A-64. Yield Statistics for Wheat, AEZ: North | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	2.9	2.6	3.2	0.2
2010	Dry	3.4	3.1	3.7	0.2
2010	Med	3.7	3.3	3.9	0.2
2010	Wet	3.2	2.9	3.5	0.2
2020	Dry	3.6	3.3	4.0	0.2
2020	Med	4.1	3.8	4.5	0.2
2020	Wet	3.3	3.0	3.7	0.2
2030	Dry	4.0	3.6	4.4	0.2
2030	Med	4.4	4.1	4.8	0.2
2030	Wet	3.6	3.2	3.9	0.2
2040	Dry	4.4	4.0	4.8	0.2
2040	Med	4.7	4.3	5.1	0.2
2040	Wet	3.9	3.6	4.3	0.2

Figure A-64. Yields for Wheat, AEZ: North | CO2 fert.

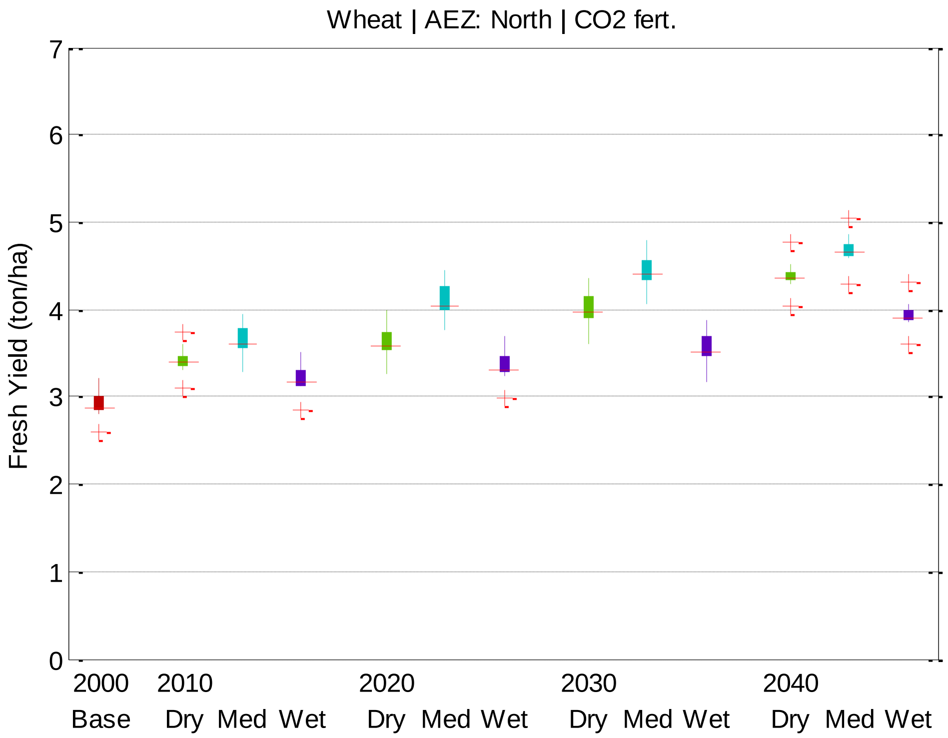


Table A-65. Yield Statistics for Wheat, AEZ: South | No CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	2.3	1.9	3.0	0.4
2010	Dry	2.6	2.2	3.3	0.4
2010	Med	2.6	2.1	3.3	0.4
2010	Wet	2.4	2.0	3.1	0.4
2020	Dry	2.6	2.2	3.3	0.4
2020	Med	2.7	2.3	3.4	0.4
2020	Wet	2.4	2.0	3.1	0.4
2030	Dry	2.7	2.3	3.4	0.3
2030	Med	2.8	2.4	3.5	0.4
2030	Wet	2.5	2.0	3.1	0.4
2040	Dry	2.9	2.4	3.5	0.3
2040	Med	2.8	2.3	3.5	0.4
2040	Wet	2.6	2.2	3.3	0.4

Figure A-65. Yields for Wheat, AEZ: South | No CO2 fert.

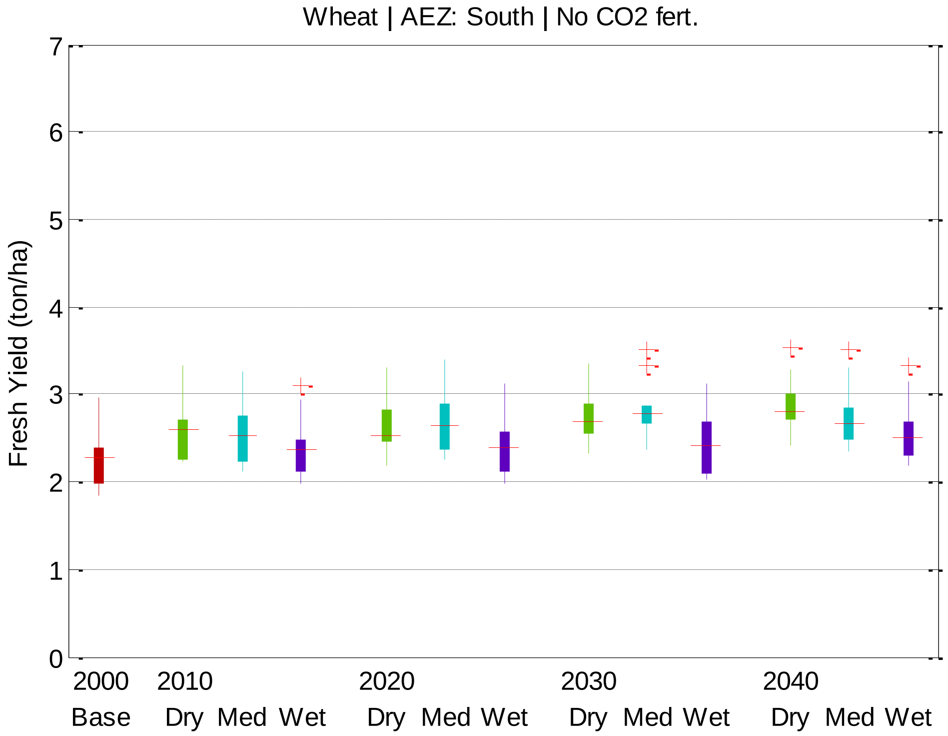
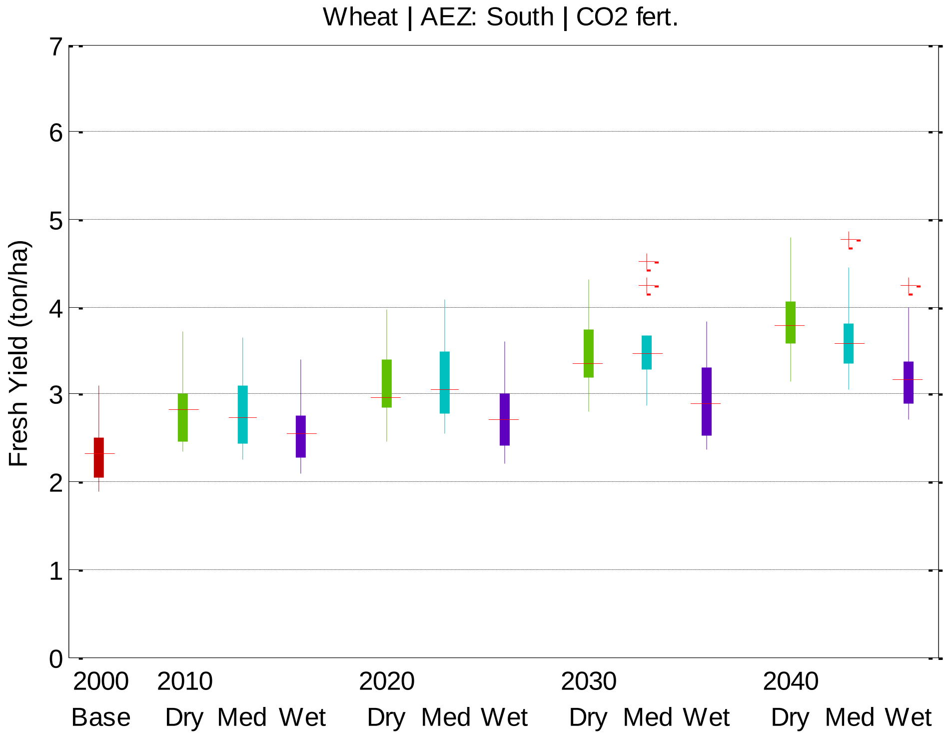


Table A-66. Yield Statistics for Wheat, AEZ: South | CO2 fert.

Period	Scenario	Mean	Min	Max	StDev
2000	Base	2.4	1.9	3.1	0.4
2010	Dry	2.9	2.3	3.7	0.5
2010	Med	2.8	2.2	3.6	0.5
2010	Wet	2.6	2.1	3.4	0.4
2020	Dry	3.1	2.5	4.0	0.5
2020	Med	3.2	2.6	4.1	0.5
2020	Wet	2.8	2.2	3.6	0.5
2030	Dry	3.4	2.8	4.3	0.5
2030	Med	3.6	2.9	4.5	0.5
2030	Wet	3.0	2.4	3.8	0.5
2040	Dry	3.8	3.1	4.8	0.5
2040	Med	3.7	3.1	4.8	0.5
2040	Wet	3.3	2.7	4.2	0.5

Figure A-66. Yields for Wheat, AEZ: South | CO2 fert.



B. Appendix - Impact on Crop Irrigation Water Requirements

B.1 Alfalfa irrigated

Table B-1. IWR Statistics for Alfalfa irrigated, AEZ: Inter | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	390	82
2010	Dry	434	55
2020	Dry	423	44
2030	Dry	422	51
2040	Dry	411	56
2010	Med	365	62
2020	Med	370	73
2030	Med	382	75
2040	Med	381	73
2010	Wet	311	91
2020	Wet	320	88
2030	Wet	269	92
2040	Wet	342	79

Figure B-1. IWR for Alfalfa irrigated, AEZ: Inter | No CO2 fert.

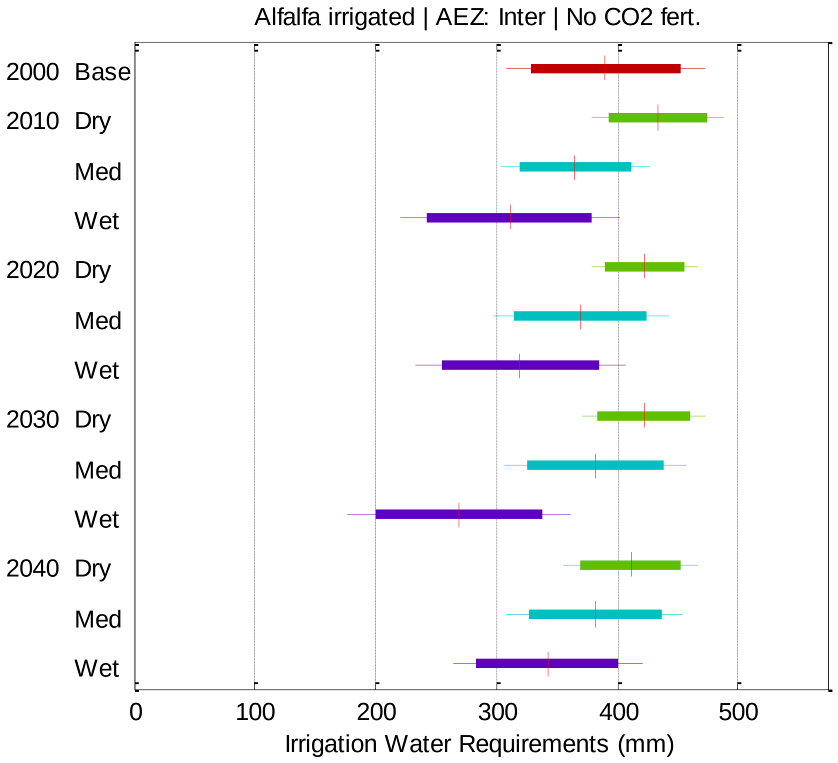


Table B-2. IWR Statistics for Alfalfa irrigated, AEZ: Inter | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	397	84
2010	Dry	391	67
2020	Dry	350	123
2030	Dry	289	32
2040	Dry	272	121
2010	Med	288	50
2020	Med	251	105
2030	Med	260	136
2040	Med	214	150
2010	Wet	238	64
2020	Wet	172	46
2030	Wet	59	25
2040	Wet	86	83

Figure B-2. IWR for Alfalfa irrigated, AEZ: Inter | CO2 fert.

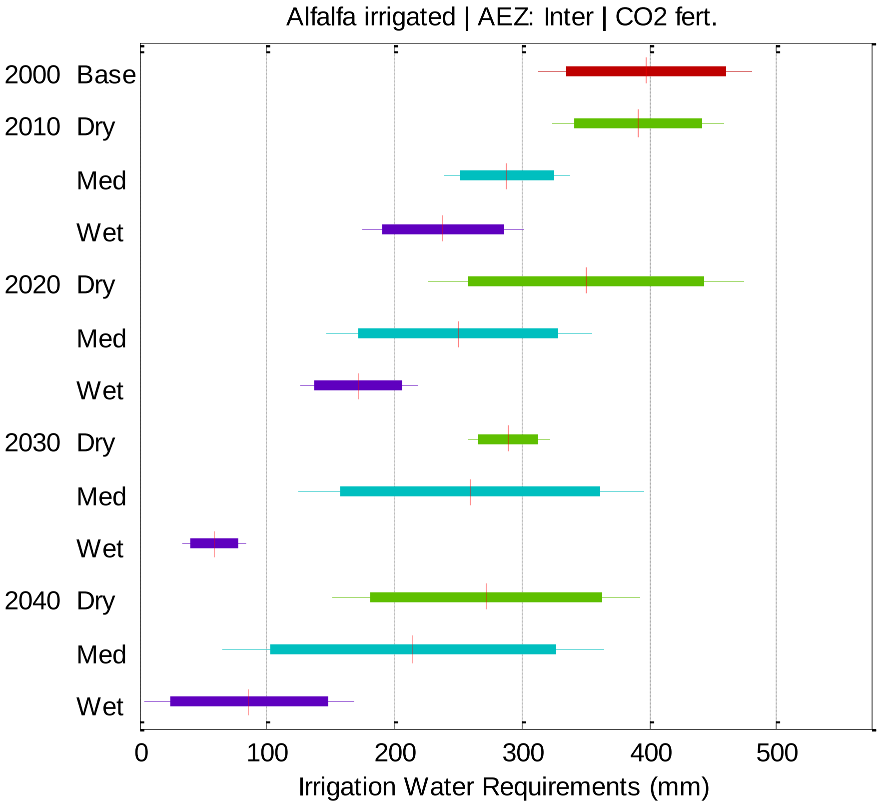


Table B-3. IWR Statistics for Alfalfa irrigated, AEZ: Low | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	469	25
2010	Dry	521	52
2020	Dry	477	41
2030	Dry	504	59
2040	Dry	467	56
2010	Med	435	25
2020	Med	475	49
2030	Med	460	53
2040	Med	446	55
2010	Wet	418	61
2020	Wet	435	34
2030	Wet	426	39
2040	Wet	435	25

Figure B-3. IWR for Alfalfa irrigated, AEZ: Low | No CO2 fert.

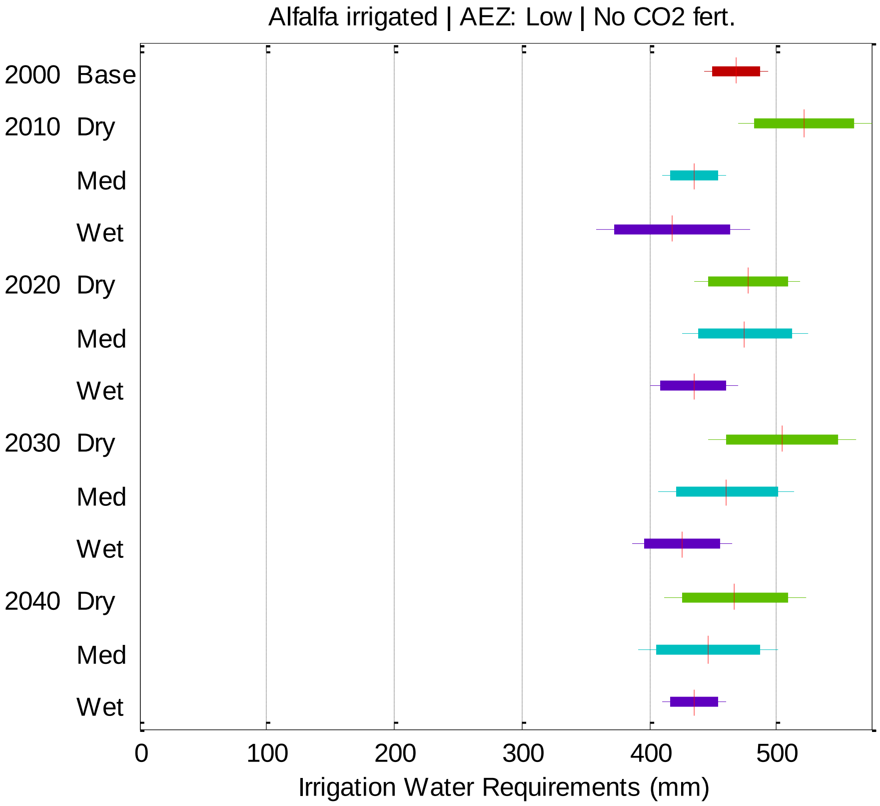


Table B-4. IWR Statistics for Alfalfa irrigated, AEZ: Low | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	469	25
2010	Dry	452	55
2020	Dry	324	37
2030	Dry	298	75
2040	Dry	192	79
2010	Med	374	25
2020	Med	338	45
2030	Med	239	66
2040	Med	155	75
2010	Wet	397	96
2020	Wet	350	25
2030	Wet	341	40
2040	Wet	266	25

Figure B-4. IWR for Alfalfa irrigated, AEZ: Low | CO2 fert.

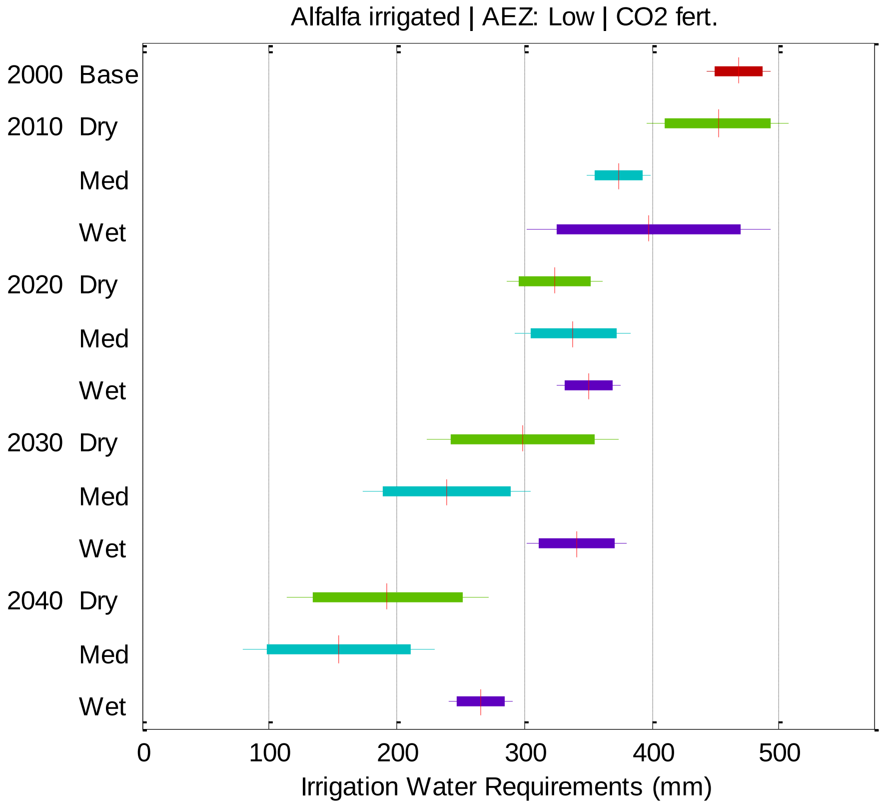


Table B-5. IWR Statistics for Alfalfa irrigated, AEZ: North | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	476	48
2010	Dry	480	68
2020	Dry	463	70
2030	Dry	495	61
2040	Dry	444	77
2010	Med	412	25
2020	Med	417	60
2030	Med	432	70
2040	Med	418	81
2010	Wet	448	35
2020	Wet	436	40
2030	Wet	391	60
2040	Wet	420	27

Figure B-5. IWR for Alfalfa irrigated, AEZ: North | No CO2 fert.

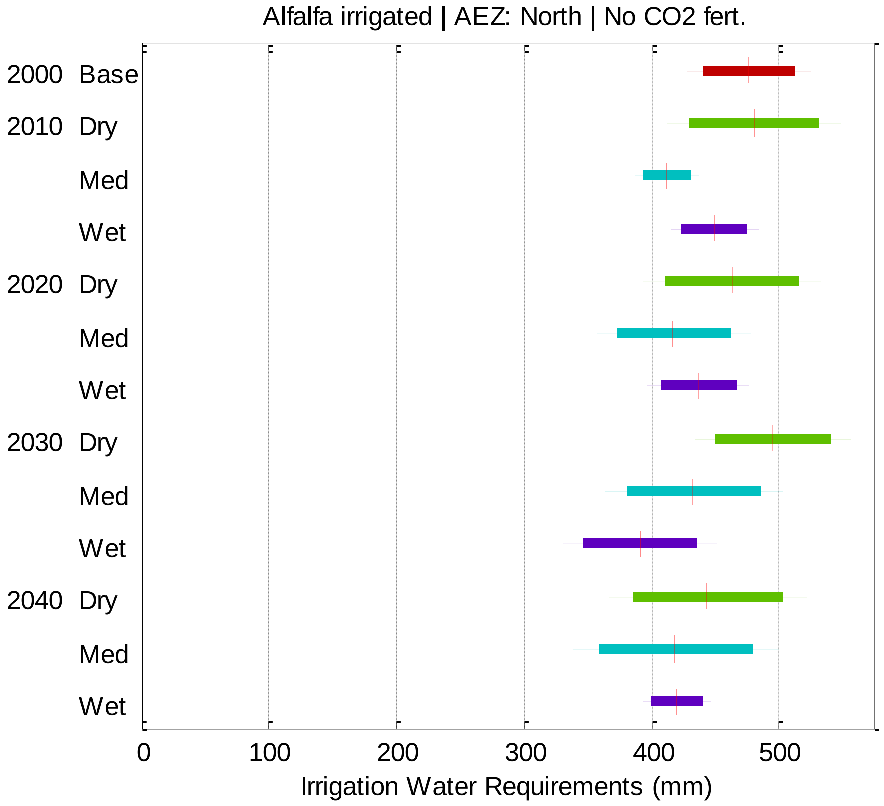


Table B-6. IWR Statistics for Alfalfa irrigated, AEZ: North | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	475	48
2010	Dry	400	81
2020	Dry	301	94
2030	Dry	296	81
2040	Dry	158	125
2010	Med	352	25
2020	Med	262	59
2030	Med	180	101
2040	Med	84	131
2010	Wet	410	25
2020	Wet	356	25
2030	Wet	234	75
2040	Wet	233	25

Figure B-6. IWR for Alfalfa irrigated, AEZ: North | CO2 fert.

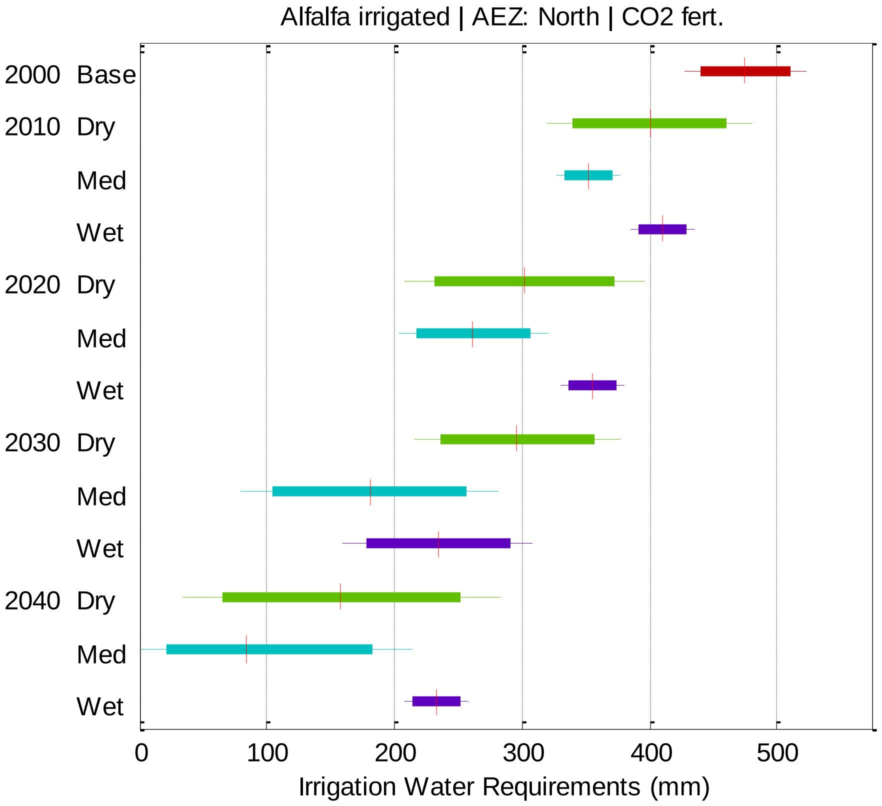


Table B-7. IWR Statistics for Alfalfa irrigated, AEZ: South | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	400	64
2010	Dry	377	56
2020	Dry	346	67
2030	Dry	351	28
2040	Dry	308	25
2010	Med	370	67
2020	Med	352	65
2030	Med	333	61
2040	Med	335	57
2010	Wet	339	68
2020	Wet	349	68
2030	Wet	332	76
2040	Wet	317	68

Figure B-7. IWR for Alfalfa irrigated, AEZ: South | No CO2 fert.

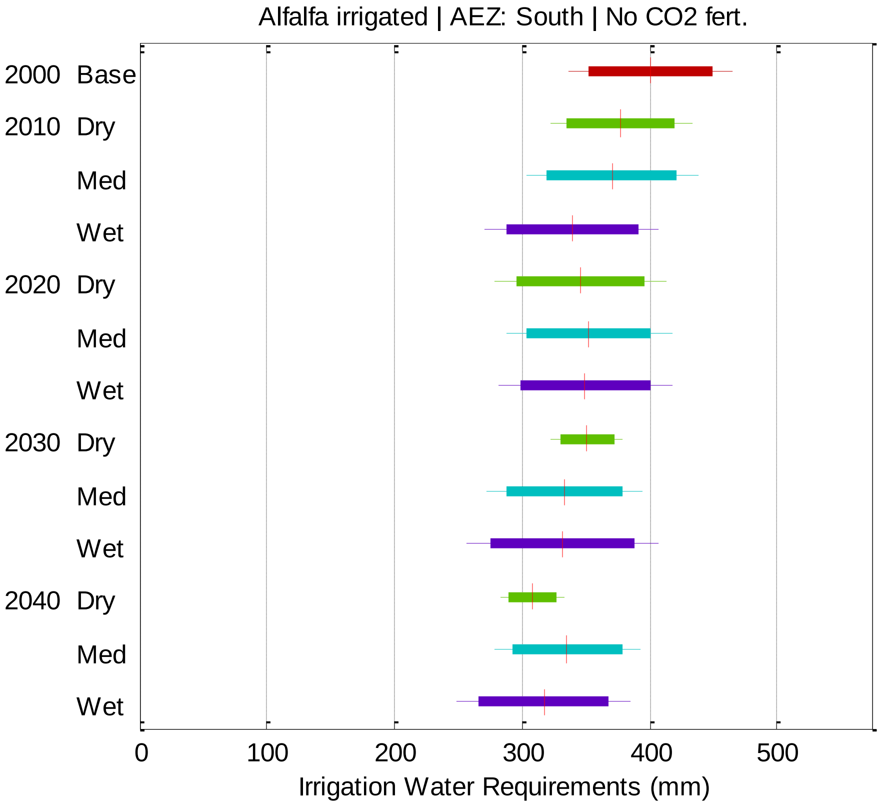
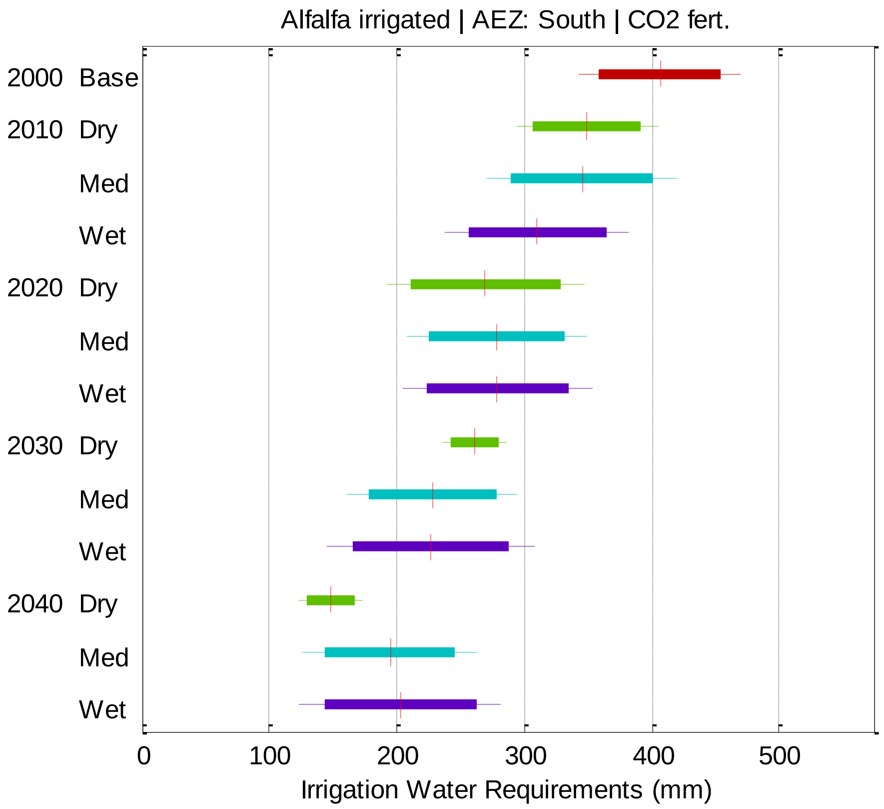


Table B-8. IWR Statistics for Alfalfa irrigated, AEZ: South | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	406	63
2010	Dry	349	56
2020	Dry	269	78
2030	Dry	261	25
2040	Dry	148	25
2010	Med	345	75
2020	Med	278	71
2030	Med	228	67
2040	Med	195	68
2010	Wet	310	72
2020	Wet	279	75
2030	Wet	227	82
2040	Wet	202	79

Figure B-8. IWR for Alfalfa irrigated, AEZ: South | CO2 fert.



B.2 Maize

Table B-9. IWR Statistics for Maize, AEZ: Inter | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	111	57
2010	Dry	160	41
2020	Dry	172	40
2030	Dry	163	37
2040	Dry	162	43
2010	Med	135	52
2020	Med	133	47
2030	Med	133	46
2040	Med	135	49
2010	Wet	119	64
2020	Wet	120	66
2030	Wet	56	56
2040	Wet	120	62

Figure B-9. IWR for Maize, AEZ: Inter | No CO2 fert.

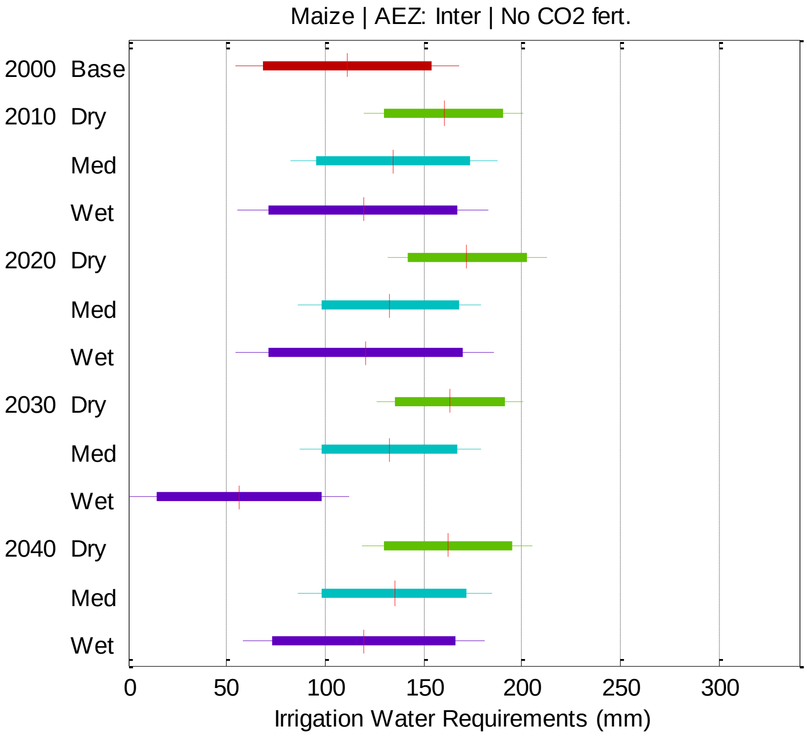


Table B-10. IWR Statistics for Maize, AEZ: Inter | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	110	57
2010	Dry	150	39
2020	Dry	152	39
2030	Dry	132	33
2040	Dry	125	38
2010	Med	125	50
2020	Med	113	43
2030	Med	107	41
2040	Med	100	43
2010	Wet	108	59
2020	Wet	100	56
2030	Wet	27	29
2040	Wet	90	50

Figure B-10. IWR for Maize, AEZ: Inter | CO2 fert.

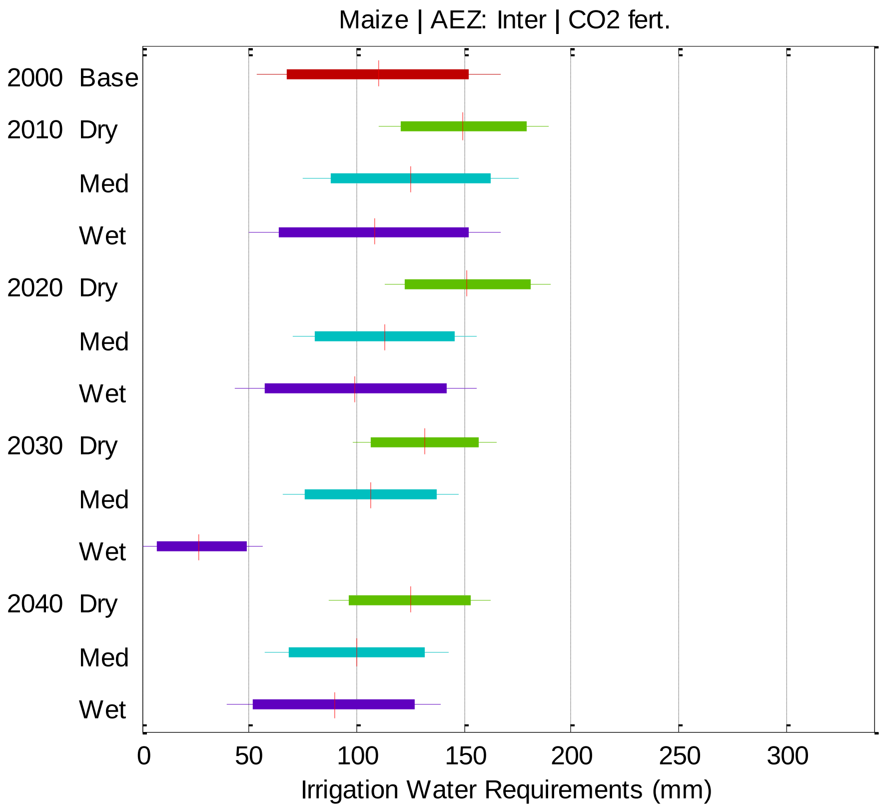


Table B-11. IWR Statistics for Maize, AEZ: Low | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	186	45
2010	Dry	228	113
2020	Dry	216	47
2030	Dry	221	101
2040	Dry	233	64
2010	Med	201	49
2020	Med	219	105
2030	Med	220	62
2040	Med	213	56
2010	Wet	176	41
2020	Wet	177	46
2030	Wet	142	63
2040	Wet	198	52

Figure B-11. IWR for Maize, AEZ: Low | No CO2 fert.

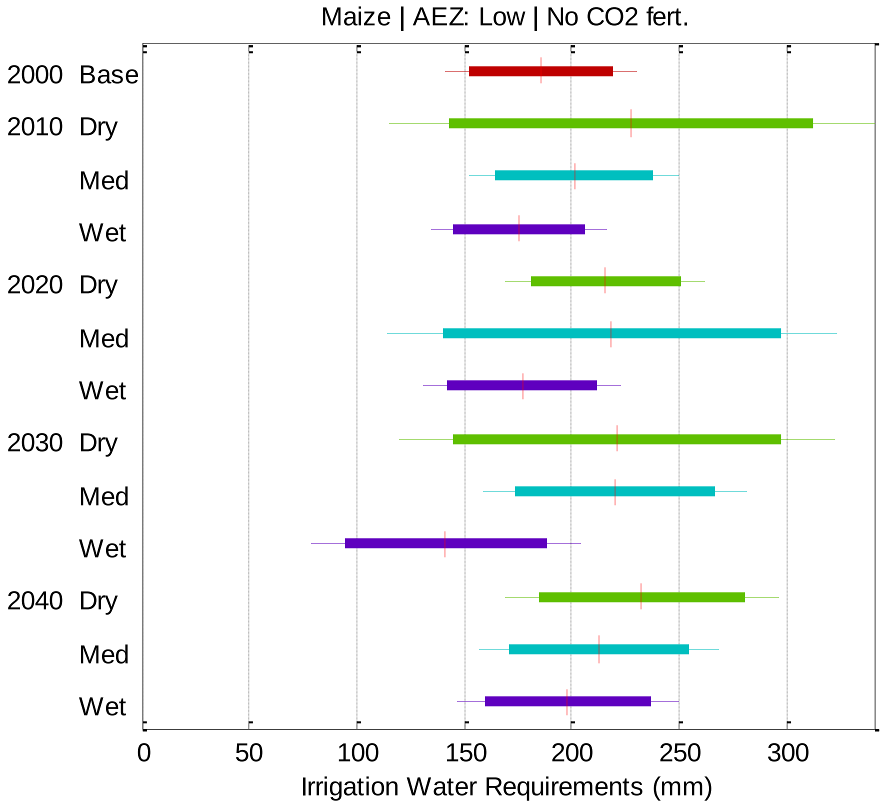


Table B-12. IWR Statistics for Maize, AEZ: Low | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	186	45
2010	Dry	216	108
2020	Dry	193	45
2030	Dry	188	90
2040	Dry	184	60
2010	Med	189	48
2020	Med	196	94
2030	Med	183	54
2040	Med	166	51
2010	Wet	168	41
2020	Wet	159	46
2030	Wet	112	58
2040	Wet	163	50

Figure B-12. IWR for Maize, AEZ: Low | CO2 fert.

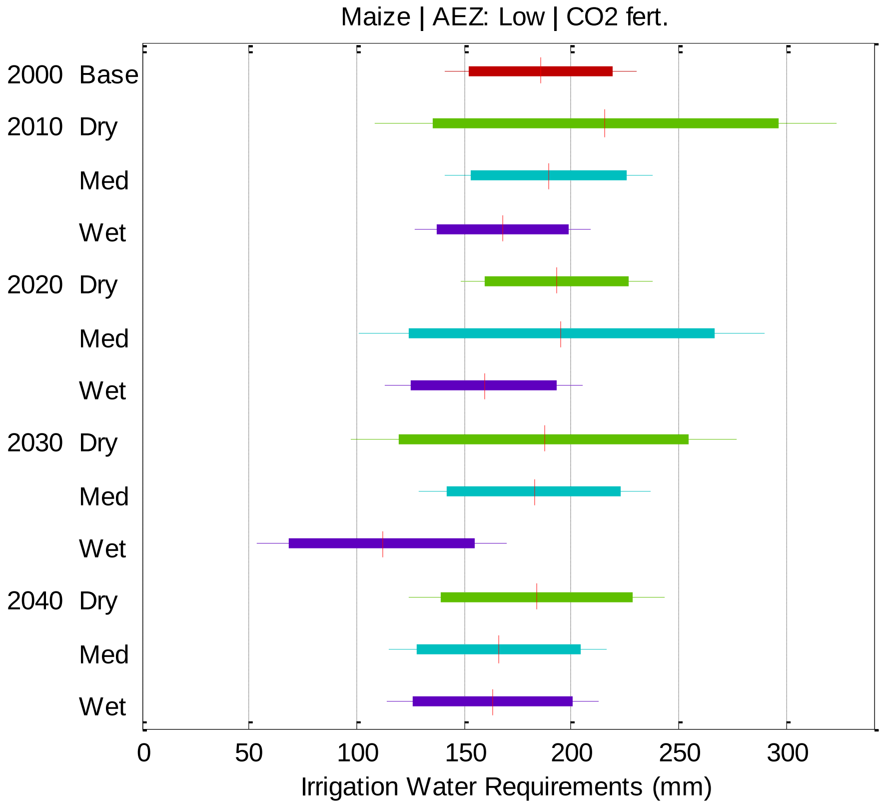


Table B-13. IWR Statistics for Maize, AEZ: North | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	177	61
2010	Dry	213	107
2020	Dry	204	84
2030	Dry	215	96
2040	Dry	241	83
2010	Med	189	62
2020	Med	191	73
2030	Med	218	92
2040	Med	218	85
2010	Wet	173	30
2020	Wet	171	53
2030	Wet	156	30
2040	Wet	186	63

Figure B-13. IWR for Maize, AEZ: North | No CO2 fert.

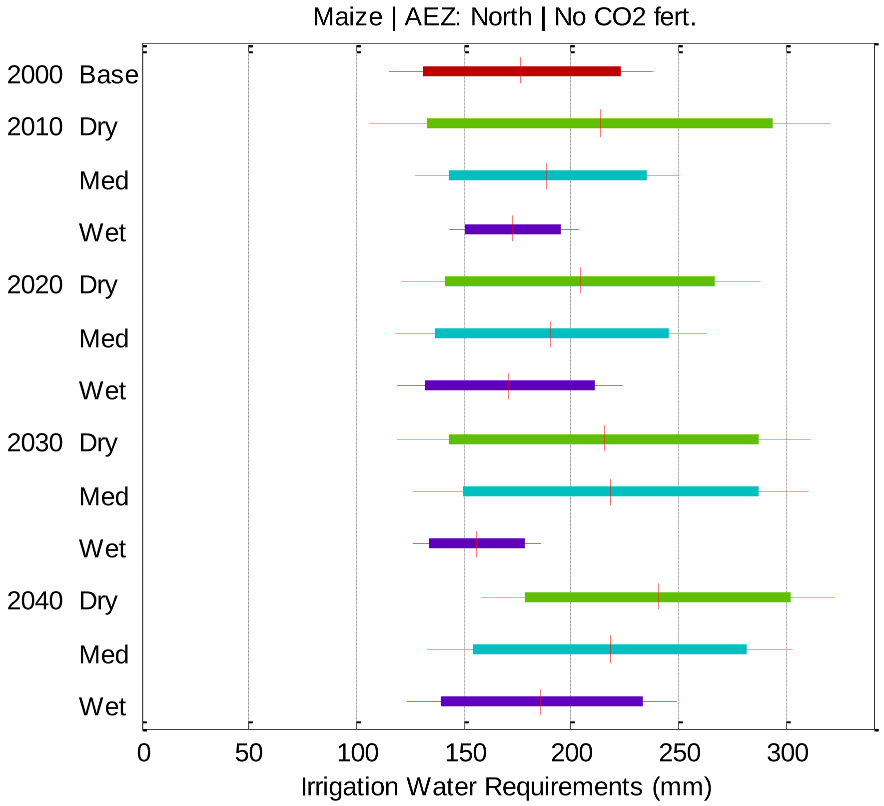


Table B-14. IWR Statistics for Maize, AEZ: North | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	176	61
2010	Dry	204	103
2020	Dry	184	76
2030	Dry	182	81
2040	Dry	195	68
2010	Med	180	60
2020	Med	172	66
2030	Med	185	79
2040	Med	174	70
2010	Wet	165	33
2020	Wet	158	50
2030	Wet	128	30
2040	Wet	158	58

Figure B-14. IWR for Maize, AEZ: North | CO2 fert.

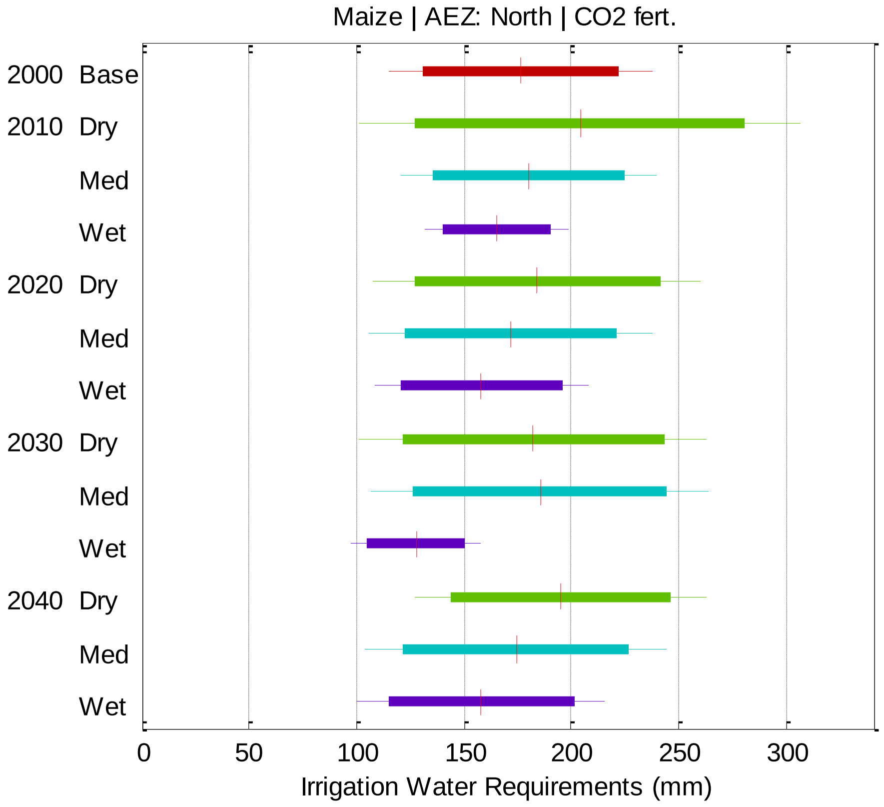


Table B-15. IWR Statistics for Maize, AEZ: South | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	112	32
2010	Dry	127	43
2020	Dry	122	38
2030	Dry	118	37
2040	Dry	130	25
2010	Med	140	37
2020	Med	126	39
2030	Med	119	36
2040	Med	119	37
2010	Wet	115	39
2020	Wet	113	37
2030	Wet	107	44
2040	Wet	115	47

Figure B-15. IWR for Maize, AEZ: South | No CO2 fert.

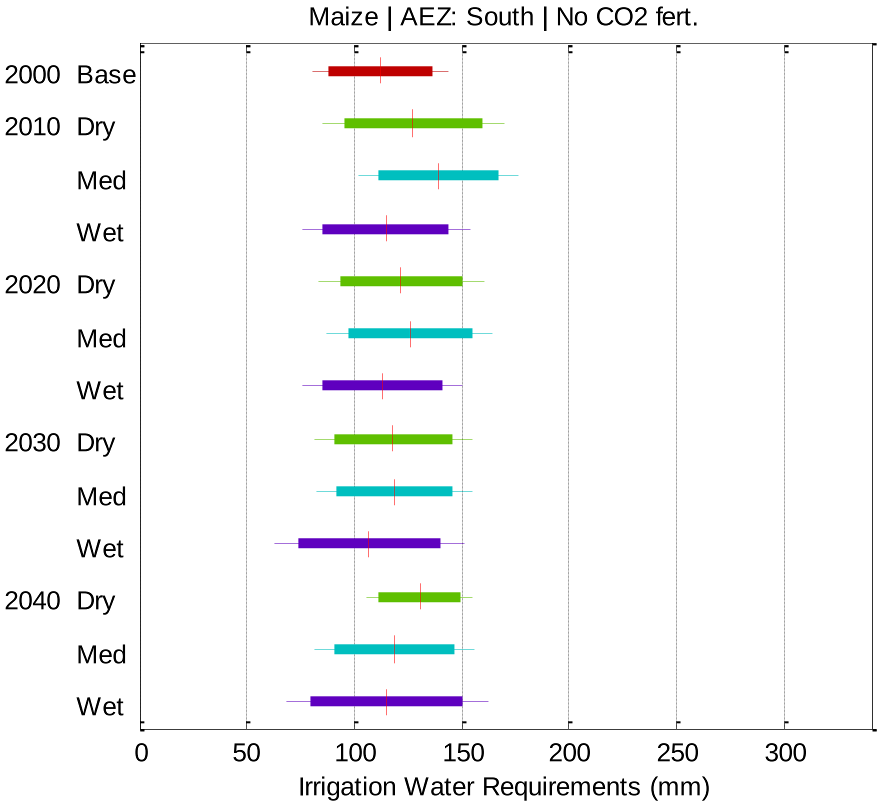
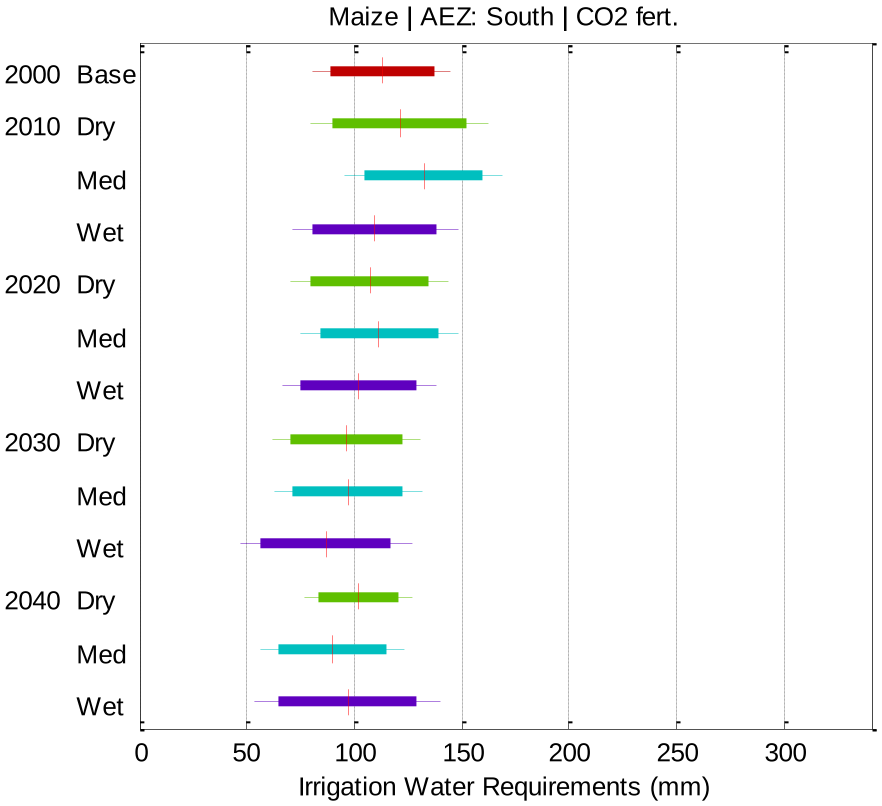


Table B-16. IWR Statistics for Maize, AEZ: South | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	113	32
2010	Dry	121	41
2020	Dry	107	36
2030	Dry	97	34
2040	Dry	102	25
2010	Med	132	37
2020	Med	112	37
2030	Med	97	34
2040	Med	90	34
2010	Wet	110	38
2020	Wet	102	36
2030	Wet	87	40
2040	Wet	97	43

Figure B-16. IWR for Maize, AEZ: South | CO2 fert.



B.3 Tomatoes

Table B-17. IWR Statistics for Tomatoes, AEZ: Inter | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	76	51
2010	Dry	134	45
2020	Dry	149	38
2030	Dry	134	39
2040	Dry	151	37
2010	Med	115	53
2020	Med	104	54
2030	Med	116	51
2040	Med	110	53
2010	Wet	81	53
2020	Wet	73	51
2030	Wet	60	67
2040	Wet	100	66

Figure B-17. IWR for Tomatoes, AEZ: Inter | No CO2 fert.

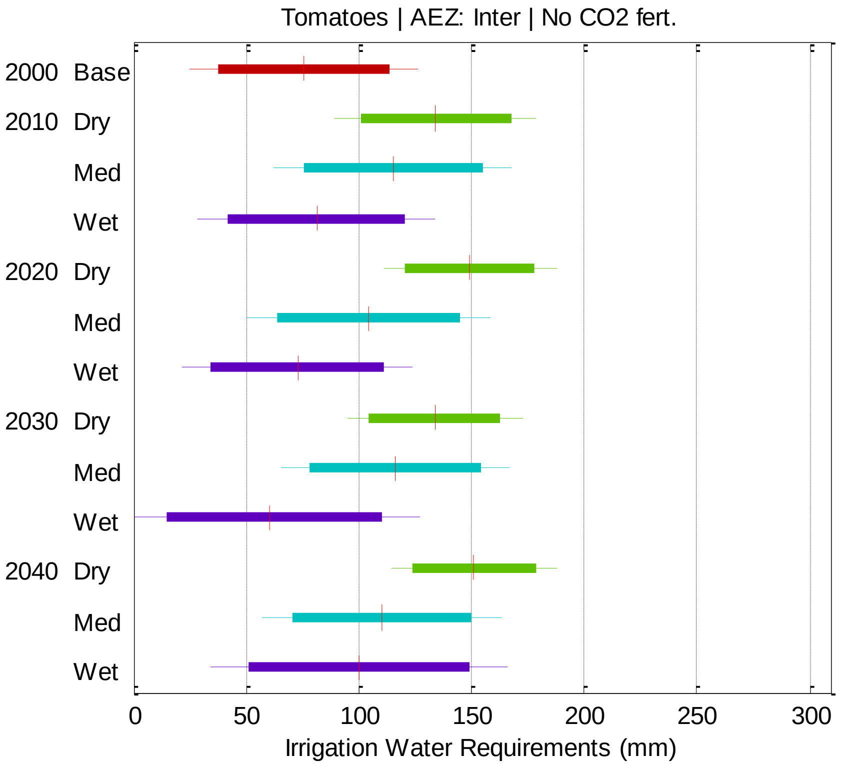


Table B-18. IWR Statistics for Tomatoes, AEZ: Inter | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	68	39
2010	Dry	46	34
2020	Dry	0	25
2030	Dry	0	61
2040	Dry	0	42
2010	Med	0	25
2020	Med	0	25
2030	Med	0	25
2040	Med	0	25
2010	Wet	0	29
2020	Wet	0	31
2030	Wet	0	50
2040	Wet	0	25

Figure B-18. IWR for Tomatoes, AEZ: Inter | CO2 fert.

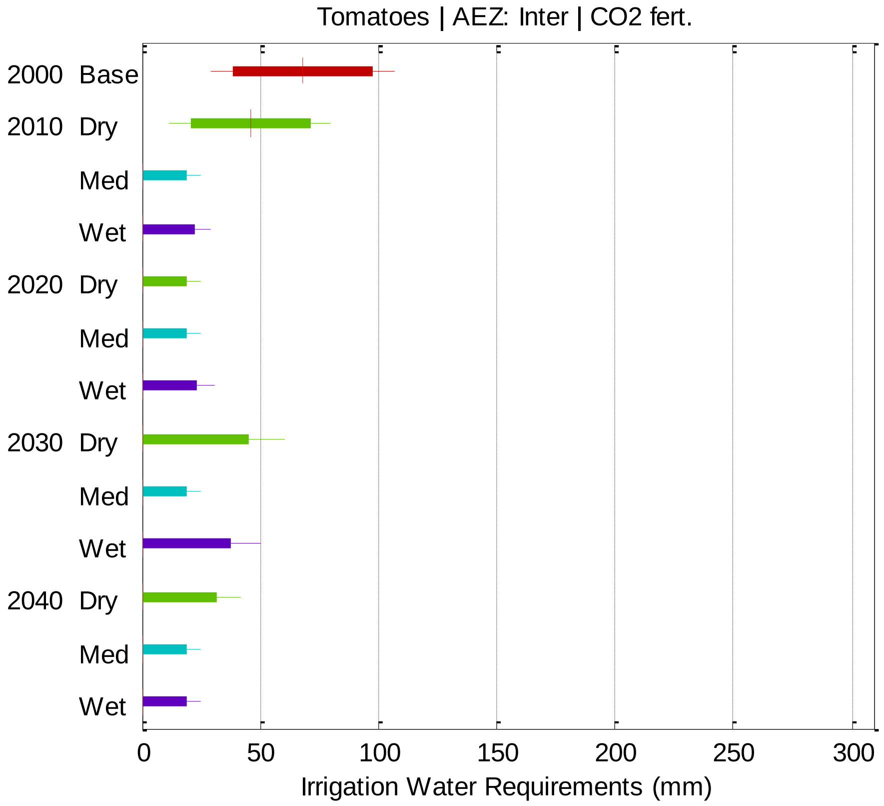


Table B-19. IWR Statistics for Tomatoes, AEZ: Low | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	140	38
2010	Dry	192	25
2020	Dry	170	25
2030	Dry	185	27
2040	Dry	226	25
2010	Med	158	33
2020	Med	175	26
2030	Med	178	27
2040	Med	257	25
2010	Wet	127	42
2020	Wet	137	41
2030	Wet	96	58
2040	Wet	284	25

Figure B-19. IWR for Tomatoes, AEZ: Low | No CO2 fert.

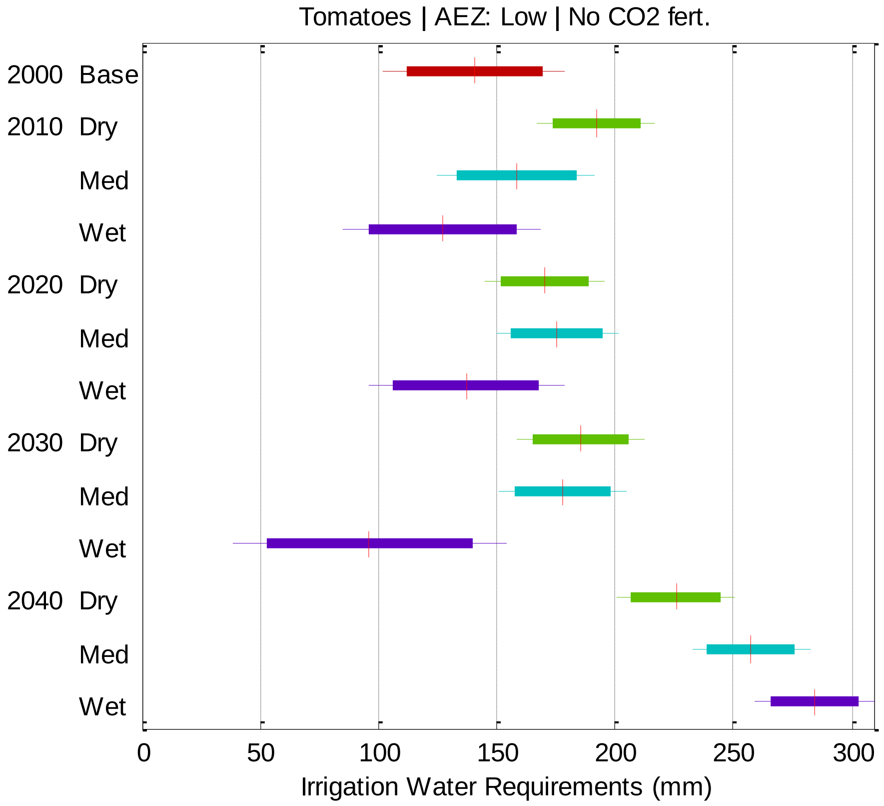


Table B-20. IWR Statistics for Tomatoes, AEZ: Low | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	138	39
2010	Dry	162	31
2020	Dry	107	58
2030	Dry	77	54
2040	Dry	102	98
2010	Med	106	45
2020	Med	136	40
2030	Med	78	68
2040	Med	38	66
2010	Wet	55	57
2020	Wet	23	78
2030	Wet	12	85
2040	Wet	47	64

Figure B-20. IWR for Tomatoes, AEZ: Low | CO2 fert.

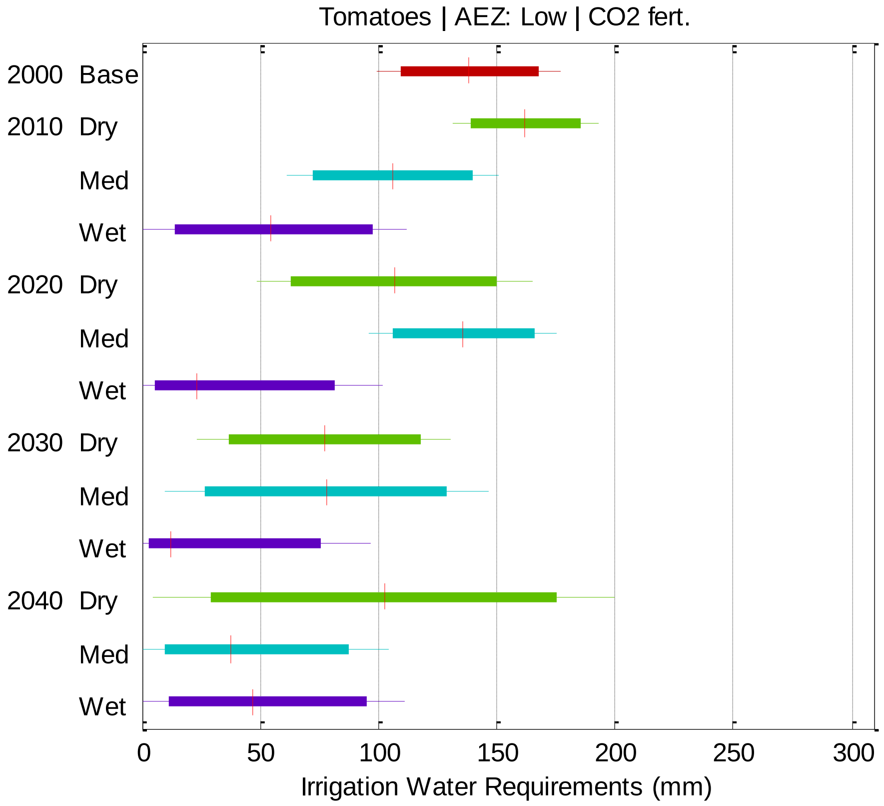


Table B-21. IWR Statistics for Tomatoes, AEZ: North | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	164	25
2010	Dry	193	25
2020	Dry	183	25
2030	Dry	185	25
2040	Dry	187	25
2010	Med	166	25
2020	Med	184	25
2030	Med	189	25
2040	Med	176	25
2010	Wet	139	39
2020	Wet	144	34
2030	Wet	72	34
2040	Wet	177	25

Figure B-21. IWR for Tomatoes, AEZ: North | No CO2 fert.

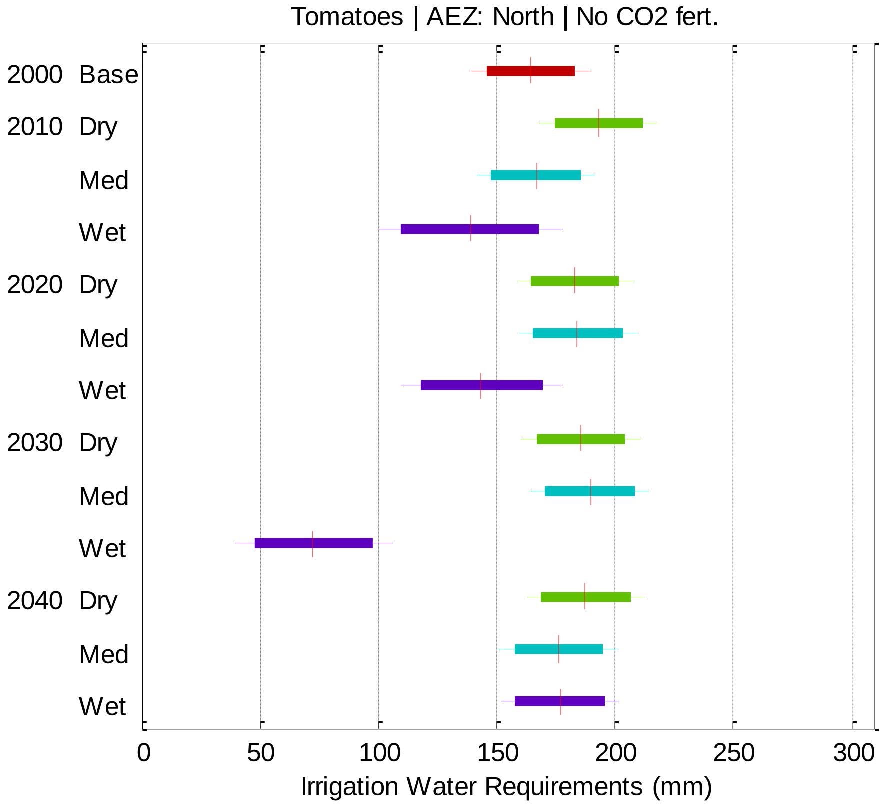


Table B-22. IWR Statistics for Tomatoes, AEZ: North | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	165	25
2010	Dry	186	25
2020	Dry	172	25
2030	Dry	167	25
2040	Dry	159	25
2010	Med	152	32
2020	Med	164	25
2030	Med	168	25
2040	Med	163	29
2010	Wet	123	42
2020	Wet	88	82
2030	Wet	0	25
2040	Wet	158	33

Figure B-22. IWR for Tomatoes, AEZ: North | CO2 fert.

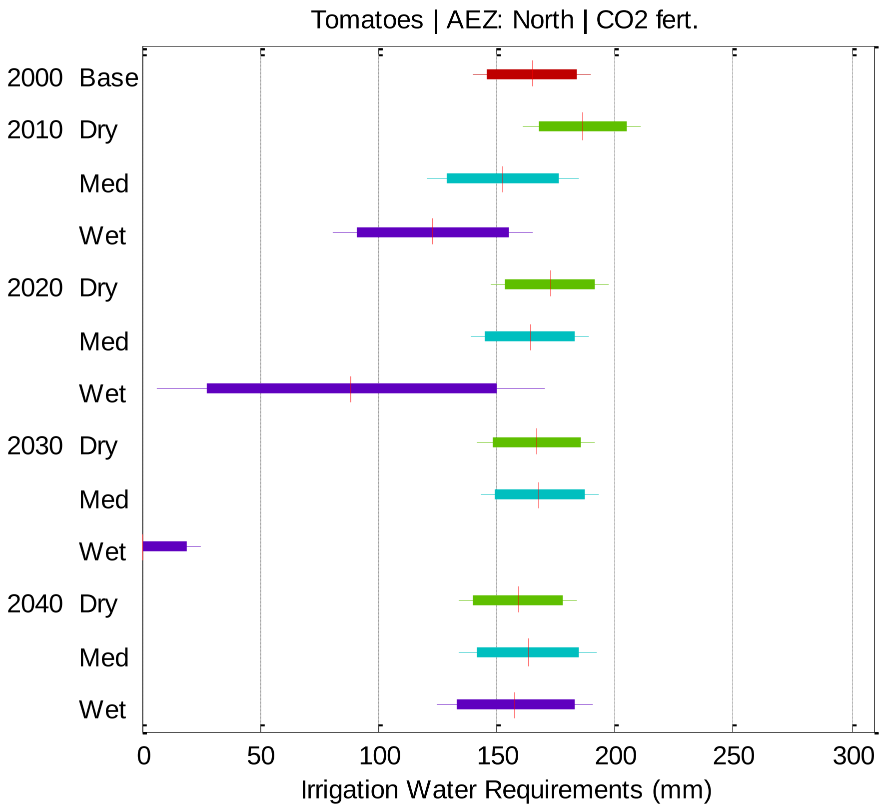


Table B-23. IWR Statistics for Tomatoes, AEZ: South | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	92	46
2010	Dry	148	42
2020	Dry	140	45
2030	Dry	130	47
2040	Dry	148	39
2010	Med	128	41
2020	Med	142	41
2030	Med	137	44
2040	Med	129	46
2010	Wet	127	44
2020	Wet	119	52
2030	Wet	94	52
2040	Wet	147	44

Figure B-23. IWR for Tomatoes, AEZ: South | No CO2 fert.

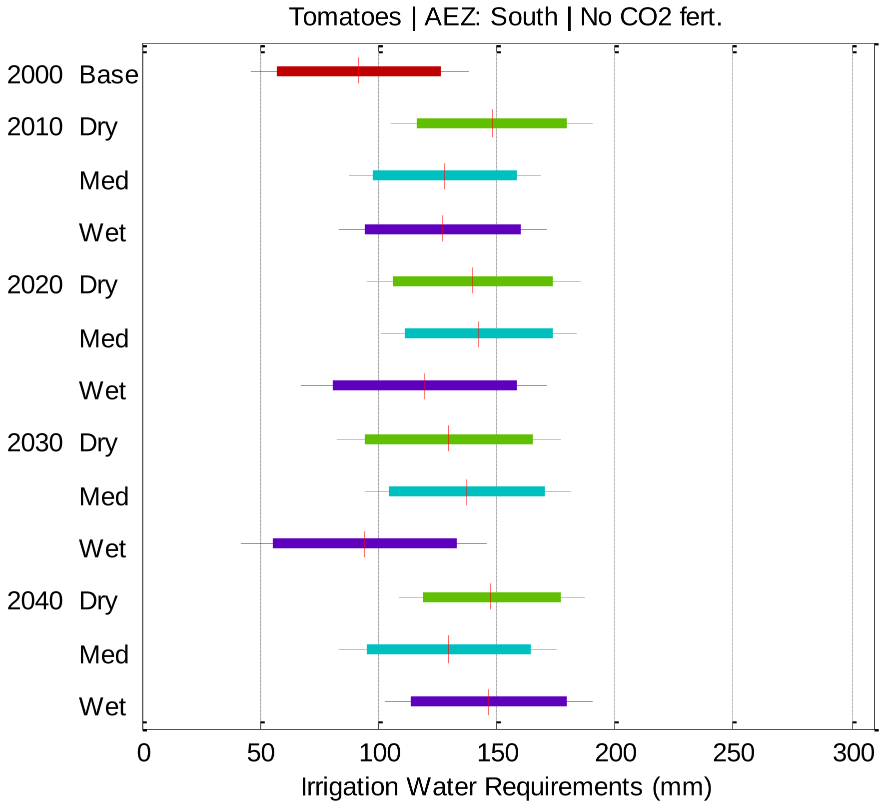
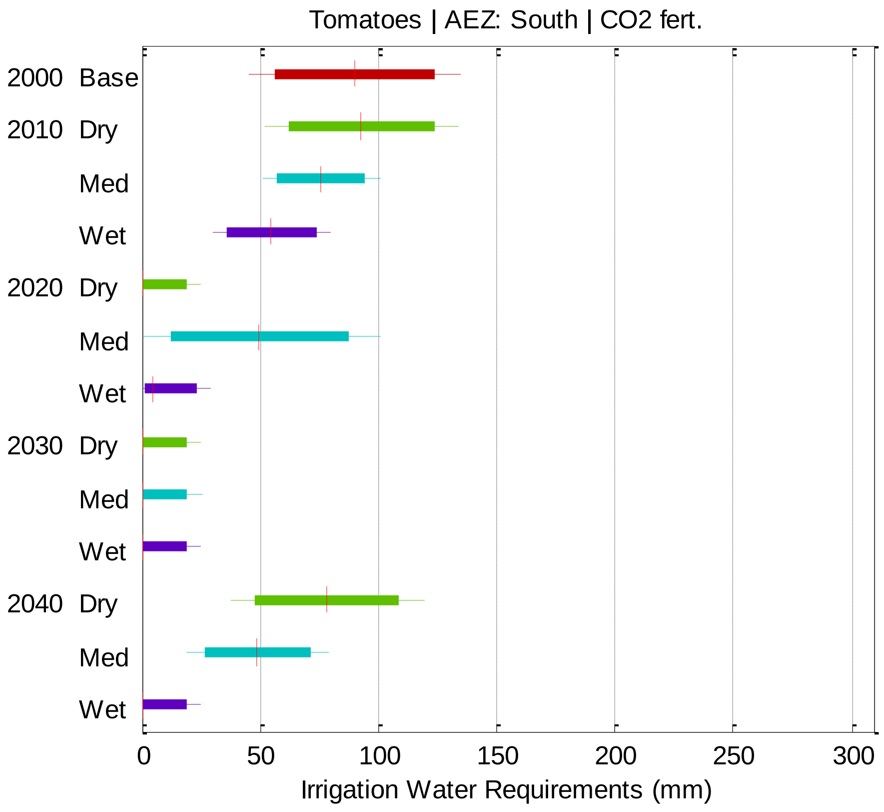


Table B-24. IWR Statistics for Tomatoes, AEZ: South | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	90	45
2010	Dry	93	41
2020	Dry	0	25
2030	Dry	0	25
2040	Dry	78	41
2010	Med	76	25
2020	Med	49	52
2030	Med	0	26
2040	Med	49	30
2010	Wet	55	25
2020	Wet	4	25
2030	Wet	0	25
2040	Wet	0	25

Figure B-24. IWR for Tomatoes, AEZ: South | CO2 fert.



B.4 Watermelons

Table B-25. IWR Statistics for Watermelons, AEZ: Low | No CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	200	44
2010	Dry	265	37
2020	Dry	233	34
2030	Dry	265	38
2040	Dry	262	34
2010	Med	218	42
2020	Med	254	35
2030	Med	250	36
2040	Med	247	33
2010	Wet	180	46
2020	Wet	193	45
2030	Wet	147	50
2040	Wet	233	35

Figure B-25. IWR for Watermelons, AEZ: Low | No CO2 fert.

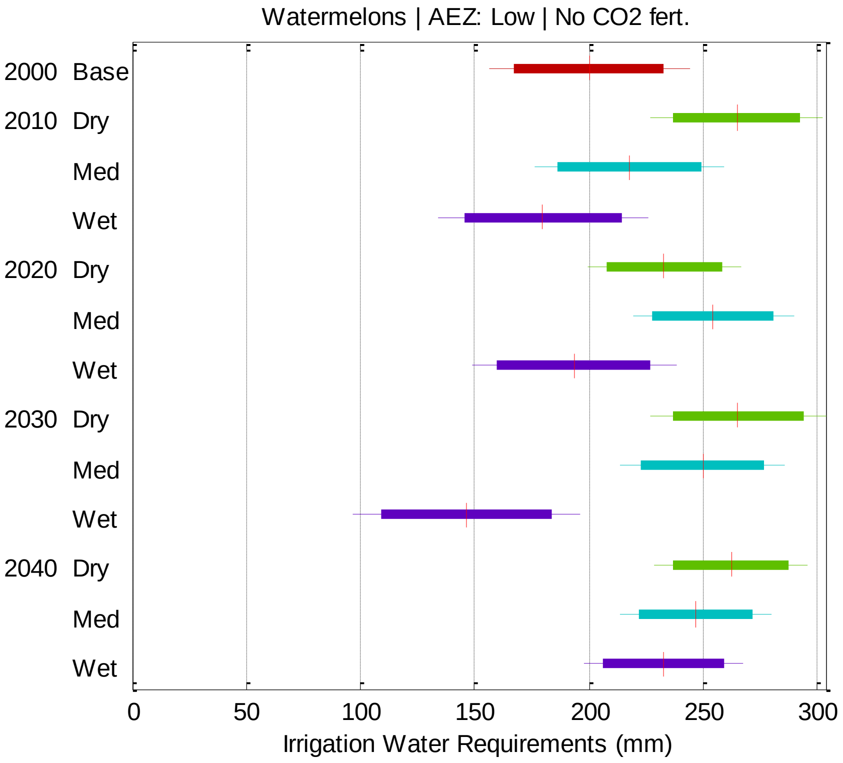


Table B-26. IWR Statistics for Watermelons, AEZ: Low | CO2 fert.

Period	Scenario	IWR (mm)	StDev (mm)
2000	Base	200	44
2010	Dry	241	31
2020	Dry	167	25
2030	Dry	170	39
2040	Dry	137	49
2010	Med	175	46
2020	Med	181	36
2030	Med	140	36
2040	Med	133	46
2010	Wet	138	41
2020	Wet	118	52
2030	Wet	0	50
2040	Wet	157	47

Figure B-26. IWR for Watermelons, AEZ: Low | CO2 fert.