Assessment of Impact of Climate Change on Wheat in Armenia, Azerbaijan and Georgia

March 2012

Project:
Regional Analytical and Advisory Activities Program on Developing Adaptation and Mitigation Strategies in the Agricultural Sector for Armenia, Azerbaijan and Georgia

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World Bank Eastern Europe and Central Asia Group

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1 Introduction

Agriculture[1] continues to be critical for rural poverty reduction, employment, economic growth and food security in Europe and Central Asia (ECA). Despite a perception that ECA is an urbanized region, roughly one third to one half of people still live in rural areas, with the figure approaching two thirds in Central Asia. Agricultural production, processing, and related services remain an important source of income in many ECA countries (approaching 30% of GDP in Central Asia). However, the agricultural sector is highly climate sensitive and potential adverse changes in temperature, precipitation and the frequency of extreme events (for example, droughts, heat waves, floods, forest fires) as a result of climate change are likely to increase the vulnerability of poor rural communities. This will place a strain on institutions, food supply and rural growth. This risk is further exacerbated by the relatively low productivity associated with a lack of capacity to adapt to the present climate in many ECA countries, resulting in an adaptation deficit. In addition, even for farmers in countries that have the potential to benefit from climate change in the future, many are poorly positioned to take full advantage of such opportunities, unless investments and policy changes are implemented. The World Bank's ECA Region is working with client countries to meet these challenges through an innovative regional, multi-year program of analytical and advisory activities (AAA) on Reducing Vulnerability to Climate Change in ECA Agricultural Systems.

The World Bank has embarked on a project to complete agriculture sector climate change impact assessment and adaptation and mitigation strategy identification and evaluation for the three countries of the Southern Caucasus region: Armenia, Azerbaijan, and Georgia. The project also includes components for capacity building among in-country staff, and support of the World Bank team's awareness raising, communication, and dissemination goals for climate change.

As part of this project a National Awareness Raising Workshops in Armenia, Azerbaijan, and Georgia, will be organized. To support these Workshops initial impact of climate change on wheat has been assessed using the AquaCrop model. After these workshop additional analysis, focusing on more crops and potential adaptation options will be assessed.

[1] Summarized from: http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/0,,contentMDK:22626153~pagePK:146736~piPK:146830~theSitePK:258599,00.html

2 Methods and Data

2.1 Caucasus

The Caucasus, is a geopolitical region at the border of Europe and Asia, and situated between the Black and the Caspian Sea. It is home to the Caucasus Mountains, including Europe's highest mountain (Mount Elbrus). Politically, the Caucasus region is separated between Northern and Southern parts. The northern part contains the larger majority of the Greater Caucasus Mountain range, also known as the Major Caucasus Mountains. It includes Southwestern Russia and northern parts of Georgia and Azerbaijan.

Figure 1. Overview of the three Caucasus countries included in the study (source: MapQuest and Google Maps).

Southern Caucasus is bordered on the north by Russia, on the west by the Black Sea and Turkey, on the east by the Caspian Sea, and on the south by Iran. It includes the Caucasus

Mountains and surrounding lowlands. All of Armenia, Azerbaijan (excluding the northern parts) and Georgia (excluding the northern parts) are in South Caucasus.

The nation states that comprise the Caucasus today are Georgia, Armenia, and Azerbaijan. Other Russian divisions, some autonomous republics and three self-declared territories belong to the Caucasus as well. The natural landscape of the Caucasus is one of mixed forest, with substantial areas of rocky ground above the treeline.

2.2 Model selection

Potential impacts of climate change on world food supply have been estimated in several studies (e.g. 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; Hunink and Droogers, 2011a; 2011b). 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 analyzing the impact of fertilizer use, the ability to simulate different crop varieties, farmer practices, etc. However, for this particular 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 2). Based on previous experiences it was selected to use AquaCrop as it has:

- relatively 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.

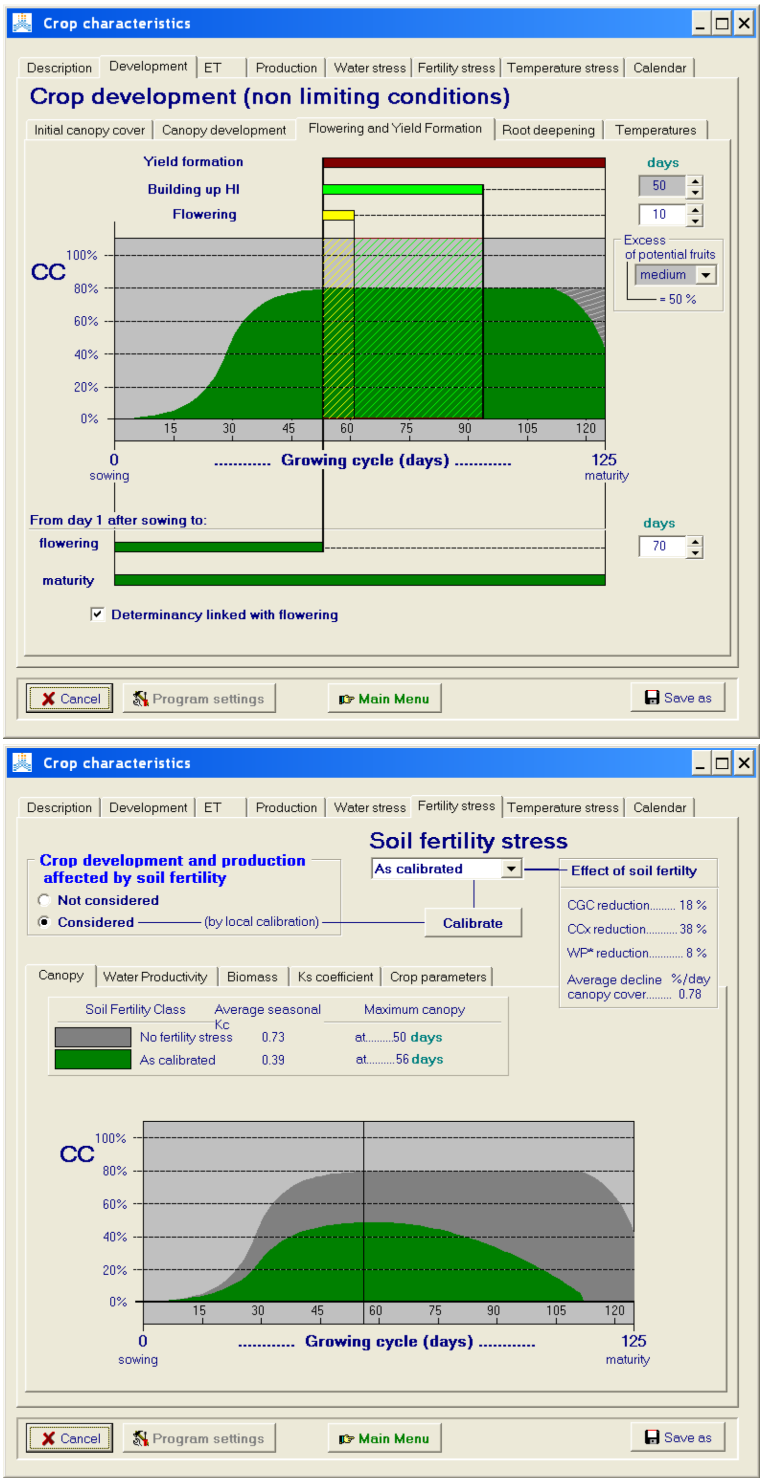

Figure 2. Typical examples of input screen of AquaCrop: crop development (top) and soil fertility stress (bottom).

2.3 AquaCrop model features

AquaCrop is the FAO crop-model to simulate yield response to water (Steduto et al., 2009; Raes et al., 2009). 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 3.

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.

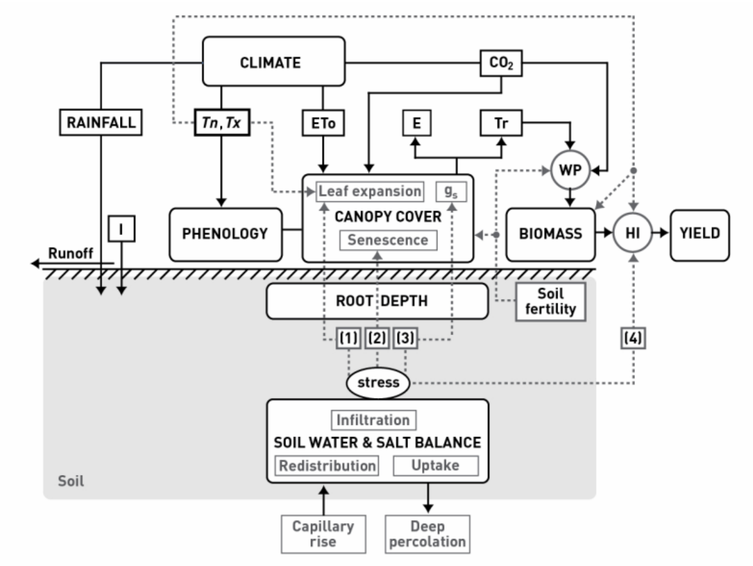

Figure 3. Main processes included in AquaCrop.

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 Y_a are the maximum and actual yield, ET_x and ET_a 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 to Eq. 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 to AquaCrop is in the time scale used for each one. In the case of Eq. 1, the relationship is used seasonally or for long periods (of the order of months), while in the case of Eq. 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 4:

- 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).

Figure 4. 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; 2006). 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

2.4 Climate data

Climate data required to run AquaCrop originates from the so-called GSOD data set (Global Summary of the Day). GSOD data for 18 surface meteorological elements are derived from the synoptic/hourly observations contained in USAF DATSAV3 Surface data and Federal Climate Complex Integrated Surface Data (ISD). Historical data are generally available for 1929 to the present, with data from 1973 to the present being the most complete.

For some periods, one or more countries' data may not be available due to data restrictions or communications problems. In deriving the summary of day data, a minimum of 4 observations for the day must be present (allows for stations which report 4 synoptic observations/day). Since the data are converted to constant units (e.g, knots), slight rounding error from the originally reported values may occur (e.g, 9.9 instead of 10.0).

The mean daily values are based on the hours of operation for the station. For some stations/countries, the visibility will sometimes ‘cluster’ around a value (such as 10 miles) due to the practice of not reporting visibilities greater than certain distances. The daily extremes and totals–maximum wind gust, precipitation amount, and snow depth–will only appear if the station reports the data sufficiently to provide a valid value. Therefore, these three elements will appear less frequently than other values. Also, these elements are derived from the stations’ reports during the day, and may comprise a 24-hour period which includes a portion of the previous day. The data are reported and summarized based on Greenwich Mean Time (GMT, 0000Z – 2359Z) since the original synoptic/hourly data are reported and based on GMT.

As for quality control (QC), the input data undergo extensive automated QC to correctly ‘decode’ as much of the synoptic data as possible, and to eliminate many of the random errors found in the original data. Then, these data are QC’ed further as the summary of day data are derived. However, we expect that a very small % of the errors will remain in the summary of day data.

Further details regarding data, data processing and climate projections can be found in Boehlert (2012).

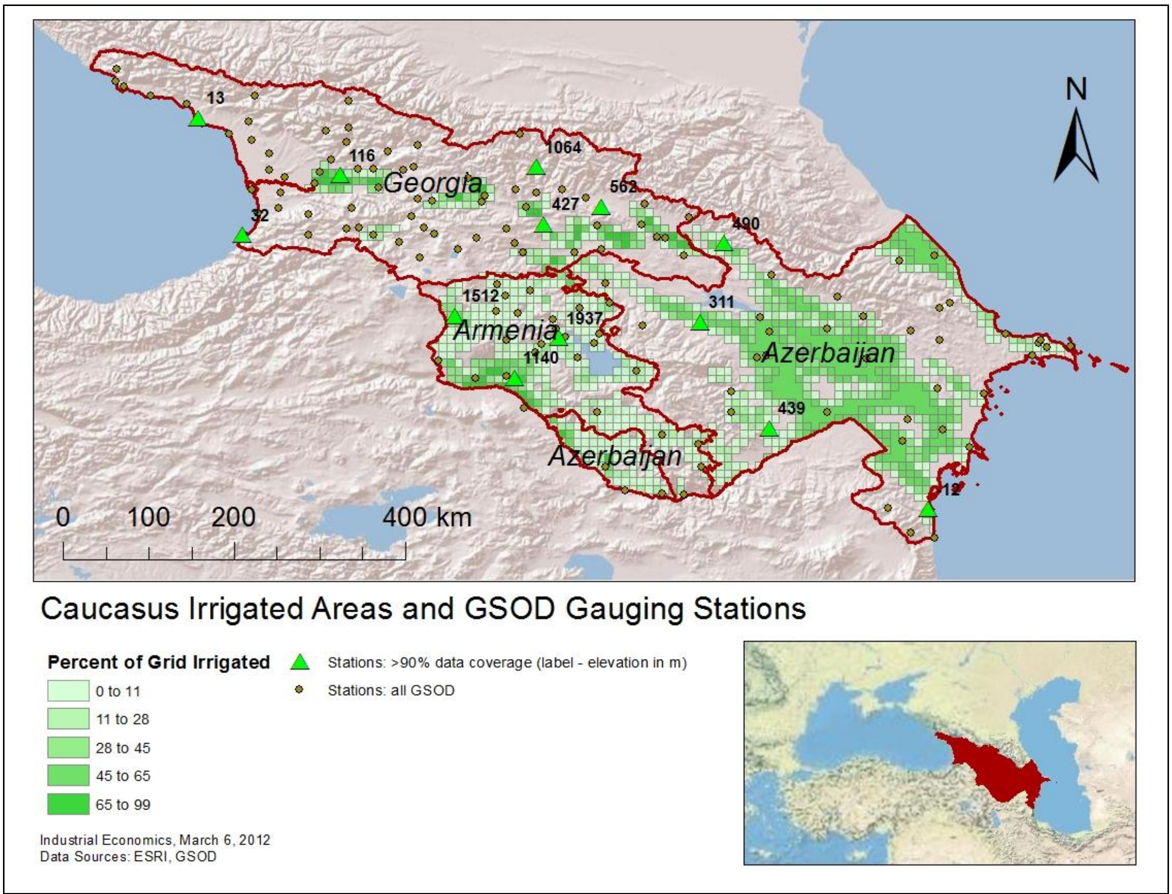

Figure 5. Irrigated areas and GSOD Climate Stations (Source: Boehlert, 2012).

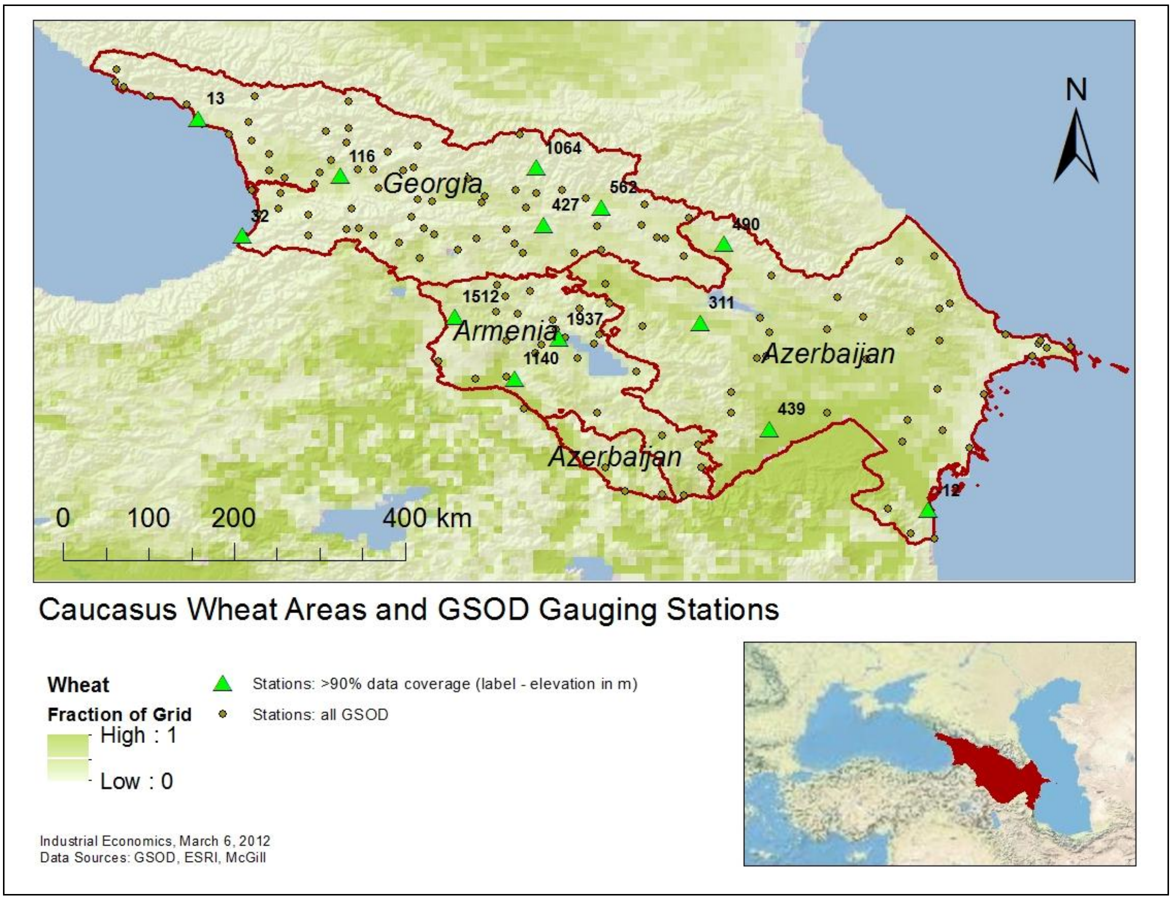

Figure 6. Wheat areas and GSOD Climate Stations (Source: Boehlert, 2012).

2.5 Impact of Climate Change

The impact of climate change on crop production has many components. Some of these components can be assessed with the AquaCrop model, while other components require other approaches. The impact of climate change on crop production that are assessed using the AquaCrop model are in summary:

- Changes in precipitation
- Changes in crop water demand due to changes in reference evapotranspiration
- Changes in crop base temperature
- Changes in crop upper temperature
- Changes in irrigation applications

Other impact of climate change that require a more expert view approach are:

- Impact on pest and diseases
- Impact on weeds

3 Armenia

3.1 Overview[2]

Armenia is a mountainous, landlocked country in the Caucasus. Only about 16 percent of the country is arable land, while 44 percent is pasture land. Sixteen percent of the country's imports are agricultural, and agriculture accounts for 19 percent of its Gross Domestic Product. Although the country has made progress in reducing both the number and proportion of undernourished people in the country, 22 percent of Armenians still remain undernourished. Due to global recession, rising food prices along with an increase in poverty from 28 percent to 34 percent (2008-2009) could continue to reflect negatively on these figures in years to come.

Land use
Land area (1000 ha): 2 848
Arable land (1000 ha): 449
Permanent crops (1000 ha): 54
Pastures (1000 ha): 1 244
Forest area (1000 ha): 262

Water
Irrigated land (1000 ha): 274
Total renewable water resources: 11 km^3

People
Total population (millions): 3.1
Life expectancy at birth: 74
Urban population: 64%
Agricultural population (1000s): 291,000

Economic
Agriculture as % of GDP: 18.9
Agricultural exports (US$ millions): 199
Agricultural exports (% of total exports): 18.8
Agricultural imports (US$ millions): 741
Agricultural imports (% of total imports): 16.7

Production
Cereals (1000 tonnes): 378
Meat (1000 tonnes): 71
Fish (1000 tonnes): 6

3.2 Agriculture[3]

3.2.1 Crops

Agriculture is carried out mainly in the valleys and mountainsides of Armenia's uneven terrain, with the highest mountain pastures used for livestock grazing. Fertile volcanic soil allows cultivation of wheat and barley as well as pasturage for sheep, goats, and horses. With the help of irrigation, figs, pomegranates, apricots, and olives also are grown in the limited subtropical

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[2] Based on FAO country profiles (http://www.fao.org/countryprofiles/)
[3] Based on http://en.wikipedia.org/wiki/Agriculture_in_Armenia

Aras River valley and in the valleys north of Yerevan, where the richest farmland is found. Armenia also produces peaches, walnuts, and quince, and cognac.

Irrigation is required by most crops, and the building of canals and a system of irrigation was among the first major state projects of the Soviet republic in the 1920s. By the 1960s, arable land had been extended by 20 percent, compared with pre-Soviet times. Most farms had electricity by the early 1960s, and machinery was commonplace. In the Soviet era, women made up most of the agricultural work force; a large percentage of the younger men had responded to the Soviet industrialization campaign by migrating to urban centers. In 1989 farms were operating about 13,400 tractors and 1,900 combines. Unlike other CIS countries, Armenia did not suffer a catastrophic decline in its farm machinery inventory during the privatization, and in 2006 there were 14,600 tractors and 1,700 combines in Armenian farms.

Agricultural production is heavily biased toward crops, which in 2006 accounted for 64% of gross agricultural output. The principal agricultural products are grains (mostly wheat and barley), potatoes, vegetables, grapes (both table and wine), and fruits.

Table 1. Dominant crops in Armenia (source FAOstat, 2010).

Crop	Area Harvested (ha)
Wheat	86,600
Barley	60,954
Potatoes	28,326
Grapes	14,613
Apples	9,400
Vegetables fresh nes[4]	7,397
Tomatoes	6,517
Peaches and nectarines	6,000
Apricots	5,600
Cereals, nes	4,800

[4] “nes” stands for “not elsewhere specified”

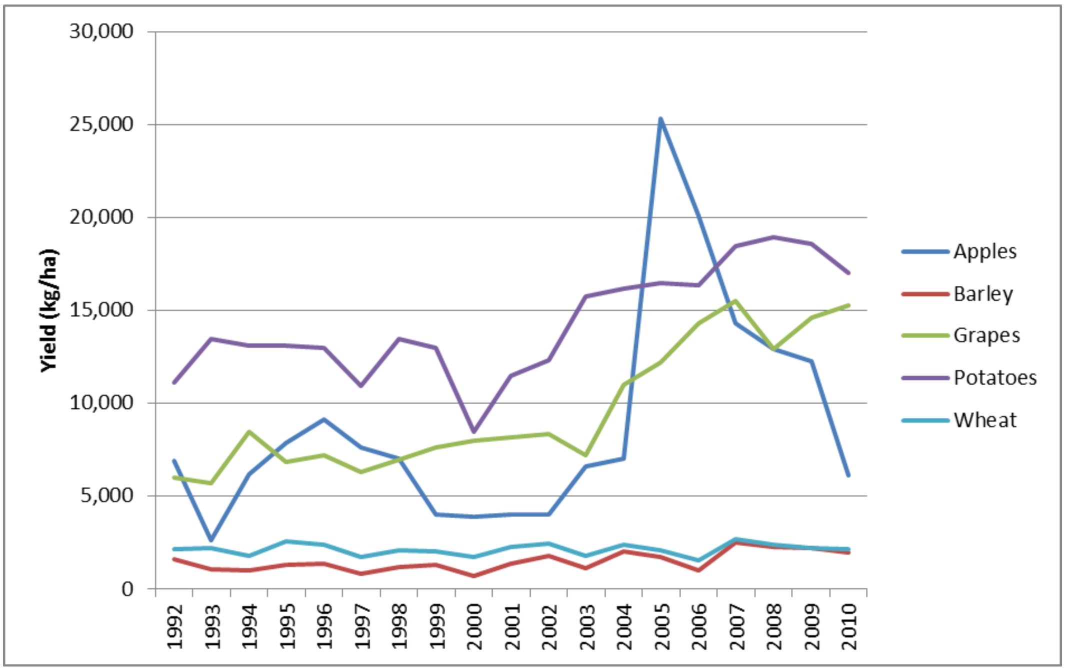

Figure 7. Yield development for the dominant crops in Armenia.

3.2.2 Irrigation[5]

Irrigation in Armenia started about 3 000 years ago. Clay pipes were used to transport water to orchards and fields and some are still intact. In the fourth century, the total irrigated area was estimated at about 100 000 ha, in 1920 it had dropped to 60 000 ha, and in 1990 it was 320 000 ha (UNDP, 2006). The actually irrigated area declined from more than 300 000 ha in 1985 to 176 000 ha at present. Major factors that have contributed to this decline are the widespread deterioration of the irrigation conveyance systems, high pumping costs, the disintegration of the former collective farms into many small private farms (with a size of 1 to 2 ha), and drainage problems, particularly in the Ararat Valley, where groundwater tables are shallow.

At present, the area equipped for full or partial control irrigation is estimated at almost 274,000 ha. The reason for the decrease in recent years has been, on the one hand, the earthquake of 1988 that destroyed part of the area, and on the other, the difficult economic situation due to the transition period, that has made it difficult to keep or maintain the irrigation infrastructure. The major irrigation schemes are located on the left bank of the Araks River.

The irrigation systems of Armenia were mainly established during the Soviet period. The irrigation infrastructure includes 80 reservoirs (77 of which are used only for irrigation and 3 used for both irrigation and drinking water), together with more than 3 000 km of main and secondary canals, about 15 000 km of tertiary canals, over 400 small and large pumps, 1 276 tubewells, and 945 artesian wells. Eight major conveyance systems distribute irrigation water to some 150 000 ha, and minor systems cover the rest of the areas. The conveyance systems are served by main, branch and secondary canals/pipes. Three-quarters of the canals are lined with concrete or are pipes. The main water structures, together with the main and secondary canals, are under state ownership whereas the tertiary level irrigation system (the intra-community

[5] Based on: http://www.fao.org/nr/water/aquastat/countries_regions/armenia/index.stm

irrigation network) was transferred to community ownership with the establishment of the Local Self-Governments in 1997. Around 80 percent of the total irrigated land is irrigated through the main network operated by the “Vorogum-Jrar” Closed Joint Stock Company (CJSC), while the remaining 20 percent is irrigated through the community-owned networks (WB-IBRD, 2004).

Surface irrigation is practiced on over 90 percent of the area equipped for irrigation and can be divided into four categories of irrigation: furrow, borderstrip, flooding or basin, and that using hydrants and flexible hose systems. Flooding is used where soil depth does not permit the grading of either furrows or borderstrips. The water is let out over the land by cutting an irrigation head canal at intervals. In the case of irrigation using hydrants, the hydrants are generally spaced in a 50 x 50 m grid and discharge water directly onto the ground, from where it is distributed by any of the surface irrigation methods. Conveyance of water to the hydrant is by buried steel pipes, but may be by open canals further upstream. Sprinkler irrigation and localized irrigation are practised on the remaining area equipped for full or partial control irrigation.

Groundwater is used for irrigation on 19 percent of the equipped area. The remaining part is irrigated from surface water through reservoirs, river diversion or pumping in rivers.

The irrigation potential has been estimated at about 660,000 ha and 41 percent of this had been equipped for irrigation in 2006. Almost 71 percent of the irrigated area was occupied by annual crops. Cereals, mainly wheat, covered 20 percent, fodder 15 percent, potatoes 14 percent and vegetables 13 percent. More than 80 percent of total crop production is produced under irrigation. The difference in productivity between irrigated and rainfed agriculture is estimated at about US$ 900 per hectare.

An analysis based on standardized farm models indicates that even without taking into account changing cropping patterns in response to the increased reliability of irrigation, a 30 percent increase in irrigated land for an average farm will generate sufficient incremental net income to lift a family out of poverty, providing that other sources of income remained unchanged. However, an analysis based on information collected from 54 Water Users’ Associations (WUAs) revealed that although irrigation in 2005 clearly improved in terms of reliability of supply, only 125 000 ha was actually irrigated out of the 228 000 ha equipped for the service. Three main problems explain this situation. First, the high cost of water supply in areas with predominantly pumping irrigation makes irrigation economically non-viable due to very inefficient pumping schemes. Second, water losses in secondary and tertiary canals are reported to be in the order of 40–50 percent, which effectively reduces the total irrigated area, since additional water supplies are unavailable in most cases for technical or/and economic reasons. Third, most of the pumping stations have very high levels of electricity consumption compared with their design parameters and high maintenance costs due to frequent service disruptions beyond what was designed.

Annual irrigation water demand begins to increase in late April, peaks in early July, and drops off in October. Nearly 40 percent of the irrigation area depends on high-lift pumping, with pumping lifts of more than 100 m. For the larger irrigation systems, losses may amount to 50 percent of the water intake.

There are pronounced differences between the communities with respect to share of irrigated land. In 2003, 24 percent of rural communities did not have access to irrigation, 5 percent had less than 20 percent of their total arable land under irrigation, 24 percent had between 20 and 80 percent under irrigation, while 47 percent had over 80 percent of their total arable land under irrigation (WB-IBRD, 2004). In 2006, small schemes (< 200 ha) covered 20 percent of total equipped area for irrigation, while large schemes (> 200 ha) covered 80 percent.

3.3 Climate and Climate Change

Climate data for the reference period are presented in Figure 8 and Table 2. Based on various General Circulation Models (GCMs) projections for the future has been made. Given uncertainty in these projections, a low, medium and high impact scenario has been used for further analysis for two ten-years period 2020-2029 and 2040-2049. Further details can be found elsewhere.

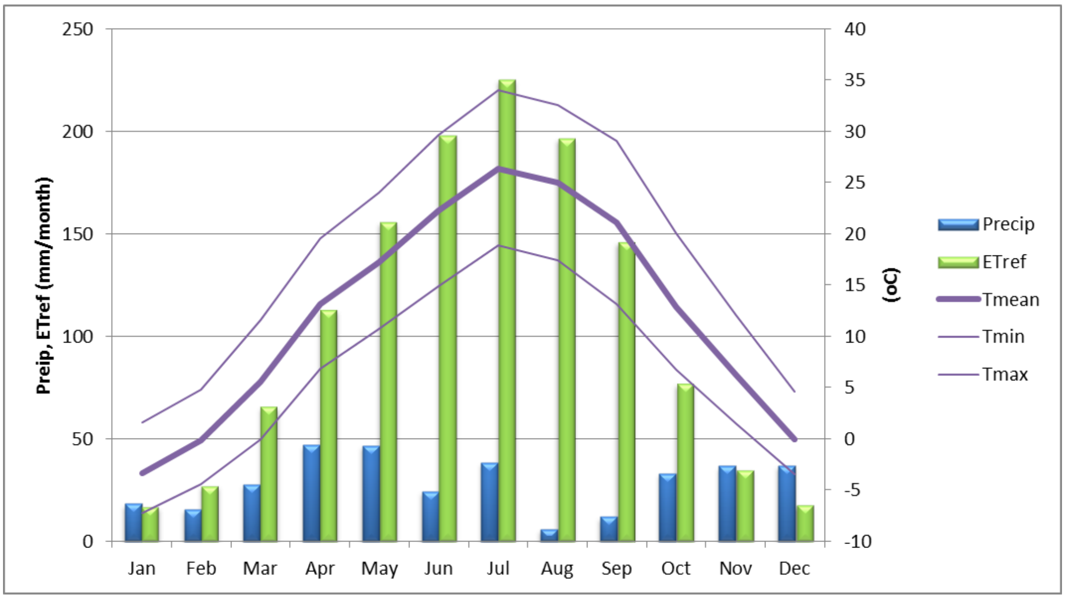

Figure 8. Monthly climate data for Armenia (1981-1990) based on station data from Yerevan (Lat: 40.133, Long: 44.467, Elev: 1140 m).

Table 2. Impact of climate change on precipitation and ETref (Armenia, Yerevan).

Period	Precipitation mm/y	ETref mm/y	Precipitation % from current	ETref % from current
1981-1990	344	1276		
2020-2029_Med	321	1339	-6.6	5.0
2020-2029_Low	371	1297	7.9	1.6
2020-2029_High	298	1340	-13.3	5.0
2040-2049_Med	322	1381	-6.4	8.2
2040-2049_Low	371	1323	7.8	3.7
2040-2049_High	278	1394	-19.0	9.2

3.4 Climate Change Impact on Wheat

3.4.1 Background

Wheat is one of the most important crops in the Armenia. About 70% of the wheat is spring-wheat, while the remainder is winter-wheat. Most of the wheat is gown under irrigation (Morgounov et al., 2001).

The AquaCrop model has been setup to simulated actual yields as well as yields under climate change. A total of 70 years have been simulated:

- One reference situation
- Two time periods of ten years: 2020-2029 and 2040-2049
- Three climate projections: Low, Medium, High

The pre-calibrated wheat crop file in AquaCrop required small changes to adapt it to the conditions in the country.

Under very good conditions and applying an intensive farming system grain yield can go up to 9 ton/ha (10 to 13 percent moisture). In this study a dry matter content of 87% was assumed. In the three countries average fresh yields in 2010 were 2.1 ton/ha (Armenia), 1.9 ton/ha (Azerbaijan) and 1.0 ton/ha (Georgia) according to FAOstat (Figure 9).

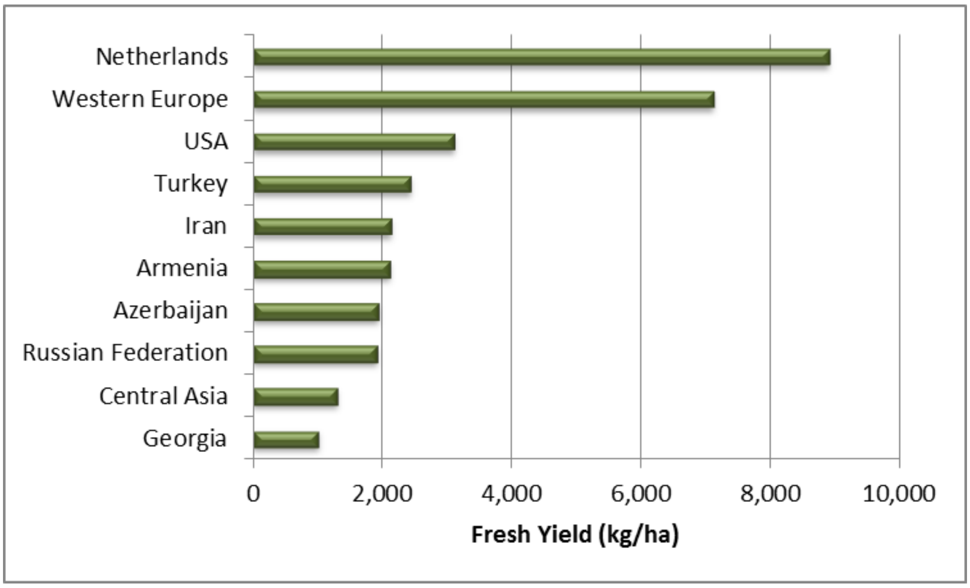

Figure 9. Wheat fresh yield in some selected relevant countries (Source: FAOstat, 2010)

The AquaCrop data file for wheat has been created by adjusting parameters in order to represent average local conditions in the country. The most important assumptions and crop information used to parameterize the crop files in AquaCrop are:

- Planting date: 1-Apr (DOY 91)
- Harvest date: 1-Aug (DOY 213)
- Length of growing season: 123
- Dry matter content harvested product: 87%
- Irrigation method: furrow
- Irrigation application: 200 mm

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 wheat has a dry matter content of 87%, so about 13% moisture is included in the fresh yield. In order to convert AquaCrops results into fresh yields, one has to divide by 0.87. E.g.

- 1000 kg dry matter
- 1000 / 87% = 1149 kg fresh
- 1149 * 13% = 149 kg moist

Average wheat yields in Armenia according to FAOstat are 2.1 ton/ha (fresh yield). Converting into dry matter yield as calculated by AquaCrop:

- 2,100 kg fresh * 87% = 1,827 kg dry matter yield

In this report all yields are presented as fresh yields to ensure proper dissemination amongst stakeholders and policy makers.

3.4.2 Results

The overall results of the 70 years simulations using FAO's AquaCrop are presented in Table 3. Observed yield according to FAOstat are 2100 kg/ha and simulated yields are similar, proving that the model is able to simulate crop yields accurately. Under climate change yields can go down on average by 15% under the high climate change projection in 2040-2049. Given the variation in yields within the ten years periods, it is also interesting to look at the changes in minimum yields. These minimum yields can go down by 17%.

Variation in year-to-year yields are expected to increase in the future as can be seen in Figure 10.

Overall, the impact of climate change on wheat production can be summarized as a reduction in yield up to 15% and a substantial increase in year-to-year variation.

Table 3. Impact of climate change on wheat production in Armenia.

	Low	Medium	High
		Yield (ton/ha)	
Base		2.096	
2020-2029	2.073	2.006	1.922
2040-2049	2.074	1.929	1.780
		Changes in Yield (%)	
2020-2029	-1	-4	-8
2040-2049	-1	-8	-15
		Changes in Minimum Yield (%)	
2020-2029	-1	-5	-8
2040-2049	-3	-7	-17

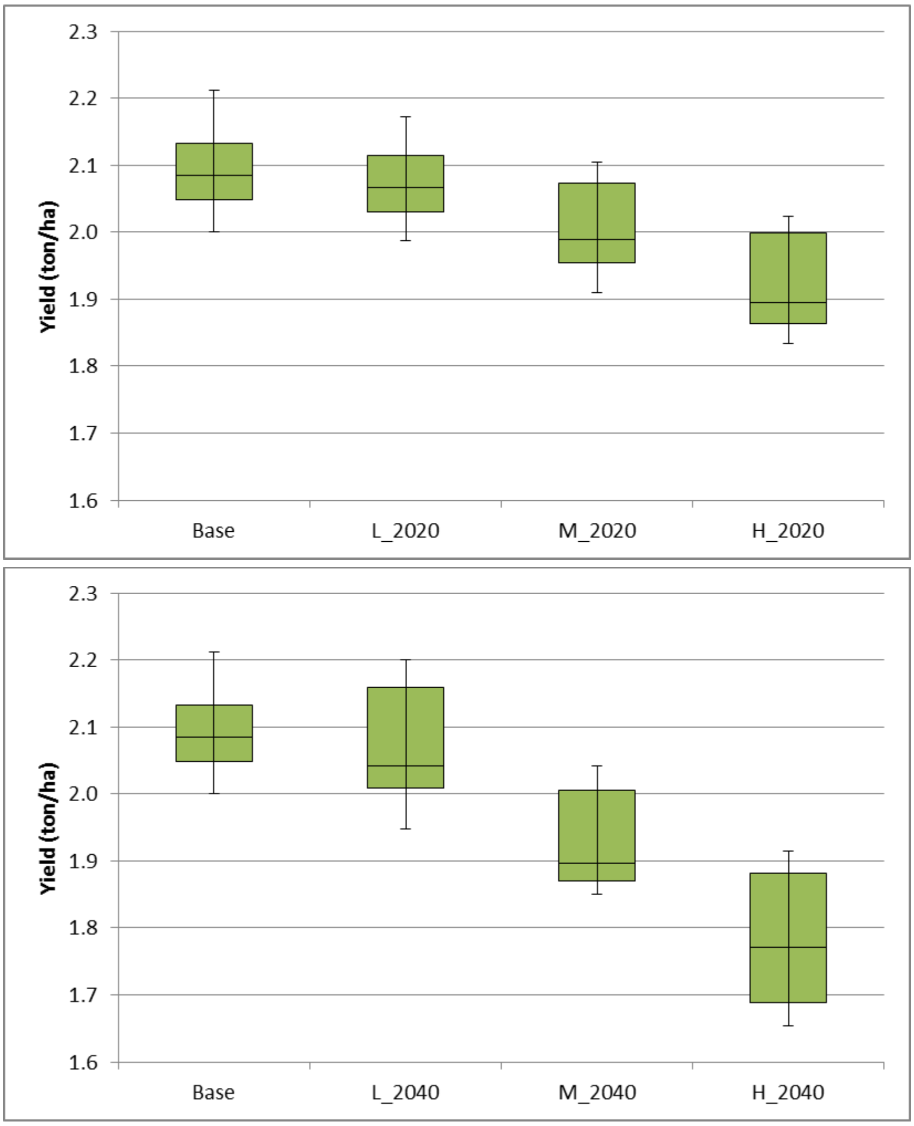

Figure 10. Impact of climate change on wheat yield in Armenia based on AquaCrop.
Base = current situation; L, M, H are Low, Medium and High climate change scenarios; 2020 = period 2020-2029; 2040 = period 2040-2049

4 Azerbaijan

4.1 Overview[6]

Azerbaijan is the largest country in the Caucasus region of Eurasia. The exclave of Nakhchivan is bounded by Armenia to the north and east. Azerbaijan's life expectancy rate rose from 67 in 2000 to 70 in 2008, and the nation's child mortality rate has improved and registers a decrease from 69 per thousand live births to 34 in the same span of nine years. Individuals consume an average of 2 996 calories per day, of which 11 percent are derived from proteins. Not only has the average Azeri's nutrition and health outlook improved, but the country's agriculture exports have jumped by almost US$500 million in the last ten years, now totaling to almost half its Gross Domestic Product. Due to temporary bans on sturgeon caviar and reduced fish quotas, Azerbaijan's fishery production has fallen significantly over the last five years.

Land
Land area (1000 ha): 8 263
Arable land (1000 ha): 1 860
Permanent crops (1000 ha): 228
Pastures (1000 ha): 2 669
Forest area (1000 ha): 936

Water
Irrigated land (1000 ha): 1 430
Total renewable water resources: 63 km^3

People
Total population (millions): 8.9
Life expectancy at birth: 70
Urban population: 52%
Agricultural population (1000s): 2 036

Economic
Agriculture as % of GDP: 7
Agricultural exports (US$ millions): 544
Agricultural exports (% of total exports): 12.2
Agricultural imports (US$ millions): 1 122
Agricultural imports (% of total imports): 15.6

Agricultural Production
Cereals (1000 tonnes): 2903
Meat (1000 tonnes): 146
Fish (1000 tonnes): 1

4.2 Agriculture[7]

4.2.1 Crops

The major crops in Azerbaijan are wheat and barley, while grapes, cotton, tobacco, citrus fruits, and vegetables are important cash crops. Grapes, cotton and tobacco account for over half of

[6] Based on FAO country profiles (http://www.fao.org/countryprofiles/)
[7] http://en.wikipedia.org/wiki/Agriculture_in_Azerbaijan

all production, and the last two together accounts for an additional 30 percent. Livestock, dairy products, and wine and spirits are also important farm products.

In the early 1990s, Azerbaijan's agricultural sector required substantial restructuring if it was to realize its vast potential. Prices for agricultural products did not rise as fast as the cost of inputs; the Soviet-era collective farm system discouraged private initiative; equipment in general and the irrigation system in particular were outdated; modern technology had not been introduced widely; and administration of agricultural programs was ineffective.

Most of Azerbaijan's cultivated lands, which total over 1 million hectares, are irrigated by more than 40,000 kilometers of canals and pipelines. The varied climate allows cultivation of a wide variety of crops, ranging from peaches to almonds and from rice to cotton. In the early 1990s, agricultural production contributed about 30 to 40 percent of Azerbaijan's net material product, while directly employing about one third of the labor force and providing a livelihood to about half the country's population. In the early postwar decades, Azerbaijan's major cash crops were cotton and tobacco, but in the 1970s grapes became the most productive crop. In 1991 grapes accounted for over 20 percent of agricultural production, followed closely by cotton.

Production of virtually all crops declined in the early 1990s. In 1990 work stoppages and anti-Soviet demonstrations contributed to declines in agricultural production. The conflict in Nagorno-Karabakh, the site of about one-third of Azerbaijan's croplands, substantially reduced agricultural production beginning in 1989.

An estimated 1,200 state and cooperative farms are in operation in Azerbaijan, with little actual difference between the rights and privileges of state and cooperative holdings. Small private garden plots, constituting only a fraction of total cultivated land, contribute as much as 20 percent of agricultural production and more than half of livestock production. Private landholders do not have equal access, however, to the inputs, services, and financing that would maximize their output.

The Ministry of Agriculture of Azerbaijan runs procurement centers dispersed throughout the country for government purchase of most of the tobacco, cotton, tea, silk, and grapes that are produced. The Ministry of Grain and Bread Products runs similar operations that buy a major portion of grain production. Remaining crops are sold in the private sector.

Table 4. Dominant crops in Azerbaijan (source FAOstat, 2010).

Crop	Harvested Area (ha)
Wheat	656,480
Barley	264,624
Potatoes	65,798
Fruit Fresh Nes	46,226
Seed cotton	30,175
Maize	29,870
Tomatoes	25,552
Apples	23,934
Hazelnuts, with shell	22,691
Watermelons	22,529

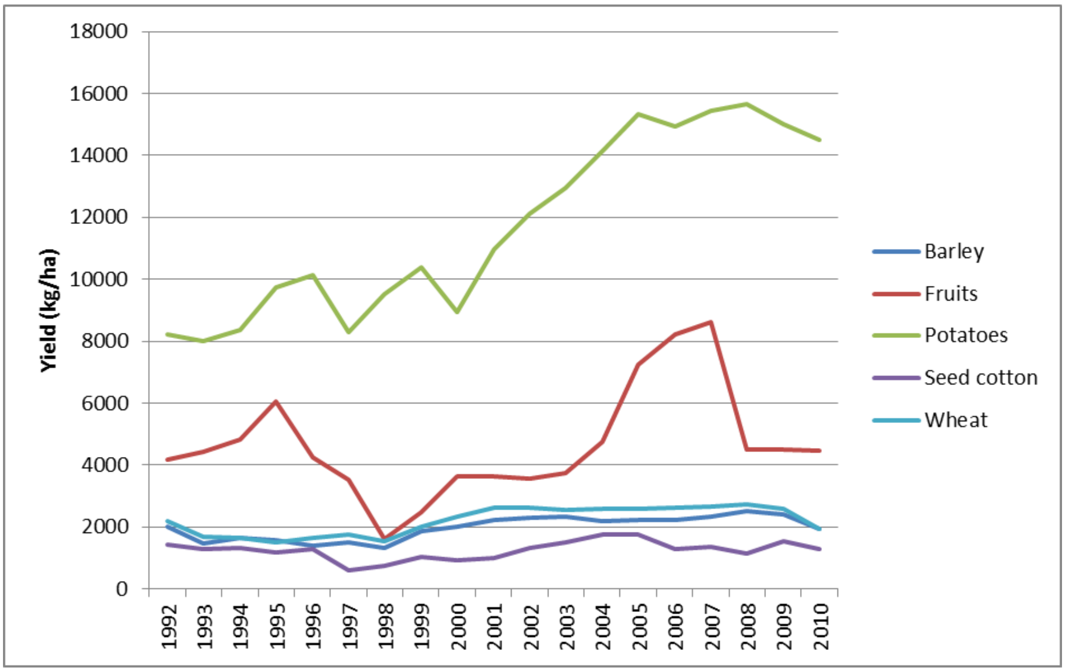

Figure 11. Yield development for the dominant crops in Azerbaijan.

4.2.2 Irrigation[8]

The irrigation potential is estimated at 3.2 million ha. In the last century, irrigation was concentrated alongside the rivers and it was only at the beginning of this century that the construction of large irrigation canals started. In 1913, 582,000 ha were irrigated. The most intensive development took place after the Second World War and in 1975 the area equipped for irrigation was 1.17 million ha. By 1995 this had become 1.45 million ha, which is 45 percent of the irrigation potential.

In 1995, the total length of all irrigation canals was 65,900 km, of which only 2,400 km, or 3.6 percent, were concrete canals. National irrigation efficiency was estimated at 55 percent. The largest canals are the Upper Garabakh, the Upper Shirvan and the Samur-Apsheron, all earthen. The Upper Gabarakh canal runs southeast from the Mingacevir reservoir to the Araks River. It is about 174 km long and has a capacity of 113.5 m3/s. About 85 000 ha were irrigated by this canal in 1995. The Upper Shirvan canal also starts from the Mingacevir reservoir and runs east to the Akhsu River. It is about 126 km in length and has a capacity of 78 m3/s and in 1995 irrigated about 91 100 ha.

In 1995, almost 90 percent of the irrigation was surface irrigation, mainly furrow and border strip irrigation. Sprinkler irrigation and localized irrigation were used mainly on perennial plantations and vineyards. Surface water was used on 93 percent of the area, mainly from reservoirs and through direct pumping in rivers and canals. About 96 700 ha were irrigated by groundwater through more than 5 000 wells. Private farmers exploit this source intensively as the major irrigation installations are seriously degraded.

[8] http://www.fao.org/nr/water/aquastat/countries_regions/azerbaijan/index.stm

In 1995, small schemes (<10 000 ha) covered 5.3 percent of the total area equipped for irrigation, medium size schemes (10 000–20 000 ha) 13.3 percent and large schemes (>20 000 ha) 81.5 percent (Figure 5). Most schemes were state-owned. Farmer-owned irrigation started to appear in 1992 and in 1996 represented 1 percent of the area.

In 2003, the total area equipped for irrigation was about 1 426 000 ha and the power-irrigated area was estimated at 479 249 ha.

4.3 Climate and Climate Change

Climate data for the reference period are presented in Figure 8 and Table 5Table 2. Based on various General Circulation Models (GCMs) projections for the future has been made. Given uncertainty in these projections, a low, medium and high impact scenario has been used for further analysis for two ten-years period 2020-2029 and 2040-2049. Further details can be found elsewhere.

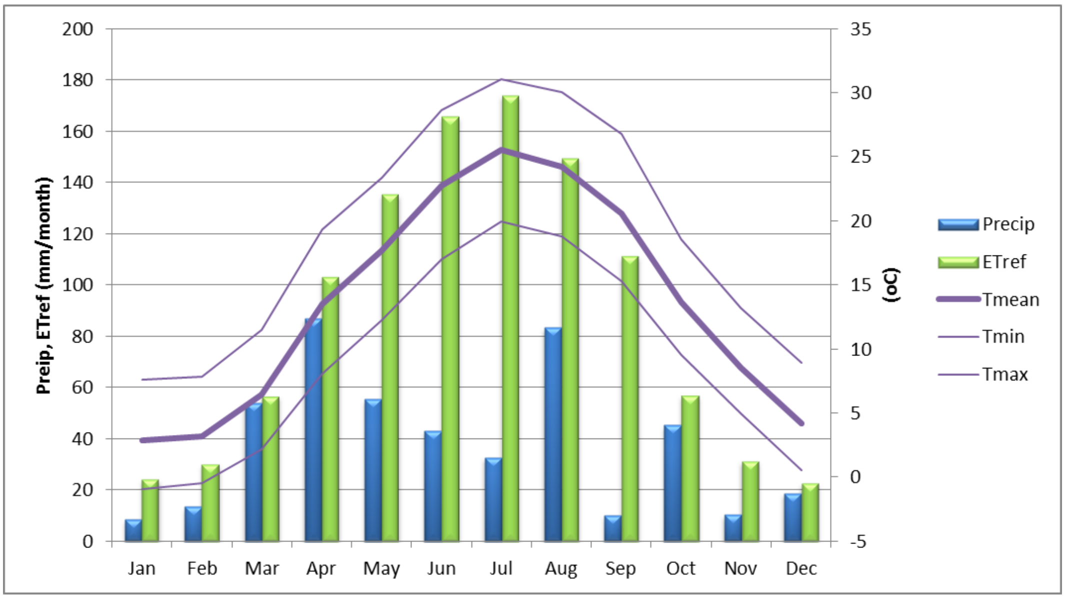

Figure 12. Monthly climate data for Azerbaijan (1981-1990) based on station data from Gandja (Lat: 40.717, Long: 46.417, Elev: 311 m).

Table 5. Impact of climate change on precipitation and ETref (Gandja, Azebaijan).

Period	Precipitation mm/y	ETref mm/y	Precipitation % from current	ETref % from current
1981-1990	463	1062		
2020-2029_Med	433	1105	-6.4	4.0
2020-2029_Low	556	1079	20.0	1.5
2020-2029_High	339	1109	-26.8	4.4
2040-2049_Med	415	1148	-10.4	8.1
2040-2049_Low	484	1104	4.5	3.9
2040-2049_High	343	1146	-26.0	7.9

4.4 Climate Change Impact on Wheat

4.4.1 Background

Wheat is gown on about 650 thousand hectare in the country according to FAOstat. About 70% of the wheat is spring-wheat, while the remainder is winter-wheat. Most of the wheat is gown under irrigation (Morgounov et al., 2001).

The AquaCrop model has been setup to simulated actual yields as well as yields under climate change. A total of 70 years have been simulated:

- One reference situation
- Two time periods of ten years: 2020-2029 and 2040-2049
- Three climate projections: Low, Medium, High

The pre-calibrated wheat crop file in AquaCrop required small changes to adapt it to the conditions in the country.

Under very good conditions and applying an intensive farming system grain yield can go up to 9 ton/ha (10 to 13 percent moisture). In this study a dry matter content of 87% was assumed. In the three countries average fresh yields in 2010 were 2.1 ton/ha (Armenia), 1.9 ton/ha (Azerbaijan) and 1.0 ton/ha (Georgia) according to FAOstat (Figure 9).

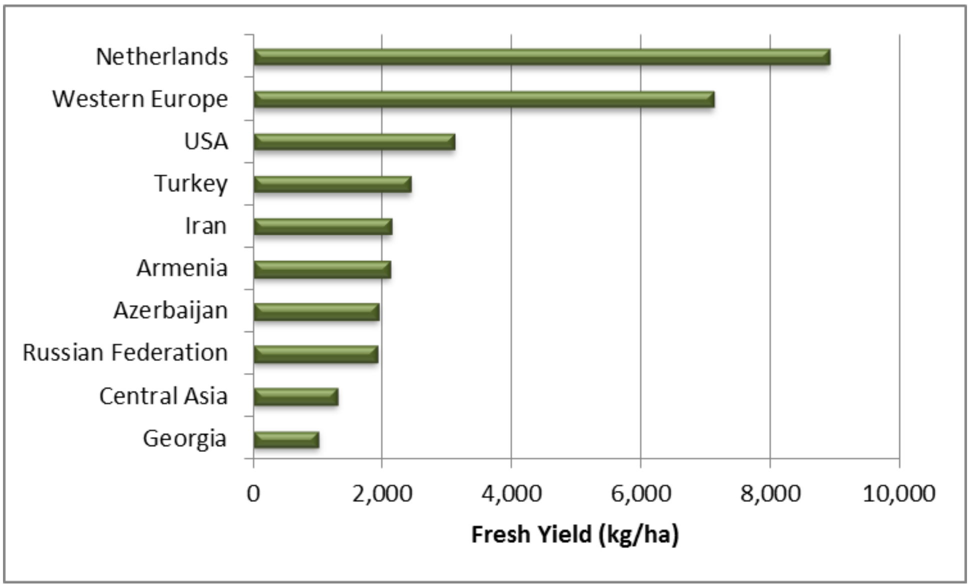

Figure 13. Wheat fresh yield in some selected relevant countries (Source: FAOstat, 2010)

The AquaCrop data file for wheat has been created by adjusting parameters in order to represent average local conditions in the country. The most important assumptions and crop information used to parameterize the crop files in AquaCrop are:

- Planting date: 1-Apr (DOY 91)
- Harvest date: 1-Aug (DOY 213)
- Length of growing season: 123
- Dry matter content harvested product: 87%

- Irrigation method: furrow
- Irrigation application: 200 mm

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 wheat has a dry matter content of 87%, so about 13% moisture is included in the fresh yield. In order to convert AquaCrops results into fresh yields, one has to divide by 0.87. E.g.

- 1000 kg dry matter
- 1000 / 87% = 1149 kg fresh
- 1149 * 13% = 149 kg moist

Average wheat yields in Azebaijan according to FAOstat are 1.9 ton/ha (fresh yield). Converting into dry matter yield as calculated by AquaCrop:

- 1,900 kg fresh * 87% = 1,653 kg dry matter yield

In this report all yields are presented as fresh yields to ensure proper dissemination amongst stakeholders and policy makers.

4.4.2 Results

The overall results of the 70 years simulations using FAO's AquaCrop are presented in Table 6. Observed yield according to FAOstat are 1900 kg/ha and simulated yields are similar, proving that the model is able to simulate crop yields accurately. Under climate change yields can go down on average by 8% under the high climate change projection in 2040-2049. Given the variation in yields within the ten years periods, it is also interesting to look at the changes in minimum yields. These minimum yields can go down by 12%.

Variation in year-to-year yields are expected to increase in the future as can be seen in Figure 14.

Overall, the impact of climate change on wheat production can be summarized as a reduction in yield up to 8% based on 10-years averages. Reduction in minimum yields in a period of years can be even 12%.

Table 6. Impact of climate change on wheat production in Azerbaijan.

	Low	Medium	High
		Yield (ton/ha)	
Base		1.887	
2020-2029	1.888	1.846	1.728
2040-2049	1.872	1.771	1.735
		Changes in Yield (%)	
2020-2029	0	-2	-8
2040-2049	-1	-6	-8
		Changes in Minimum Yield (%)	
2020-2029	0	-3	-12
2040-2049	-1	-7	-12

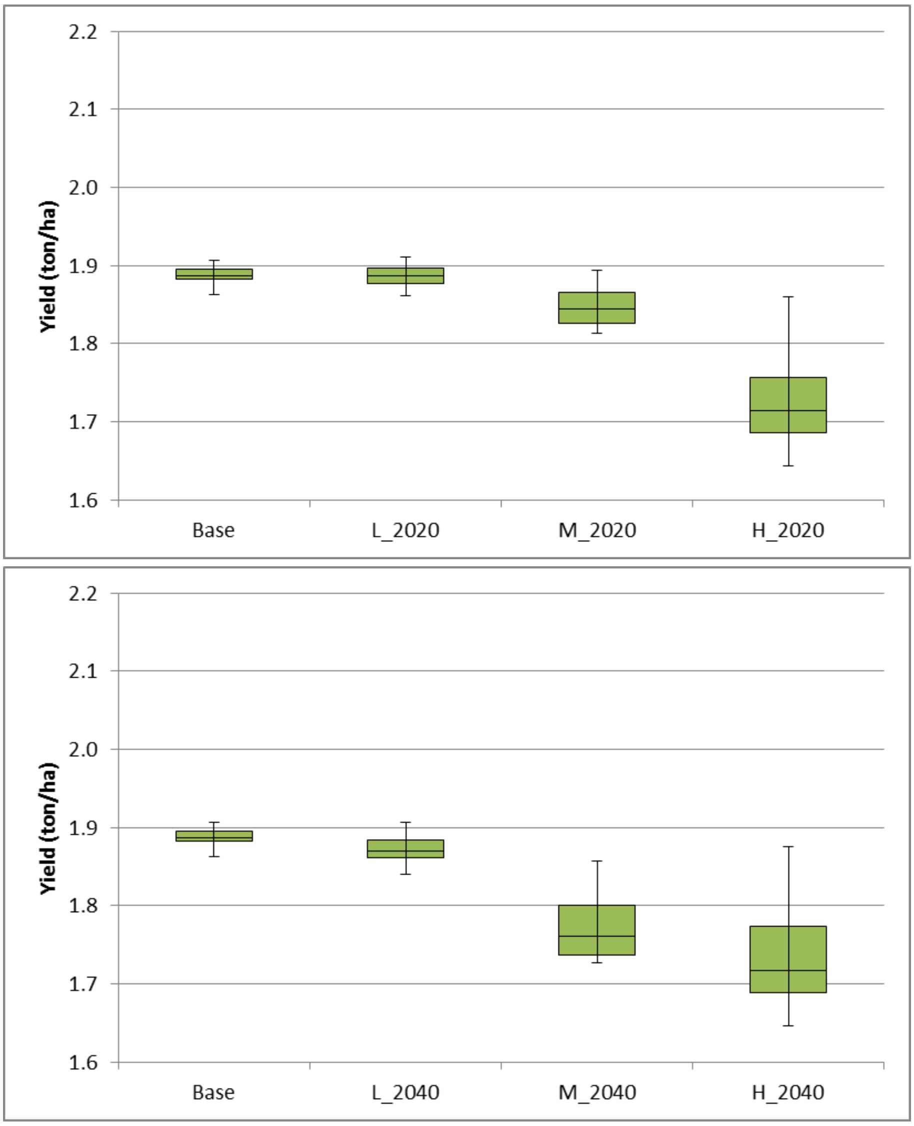

Figure 14. Impact of climate change on wheat yield in Azerbaijan based on AquaCrop.
Base = current situation; L, M, H are Low, Medium and High climate change impact scenarios; 2020 = period 2020-2029; 2040 = period 2040-2049

5 Georgia

5.1 Overview

Georgia is a very mountainous country and has a quite varied landscape. Western Georgia's landscape ranges from low-land marsh-forests, swamps, and temperate rainforests to snows and glaciers, while the eastern part of the country even contains a small segment of semi-arid plains. Forests cover around 40% of Georgia's territory while the alpine/subalpine zone accounts for roughly around 10% of the land.

More than half of Georgia’s 4.2 million population are urban dwellers, while the livelihood of 3 out of ten Georgians depends on agriculture. However, work in agriculture has been affected by the ongoing regional conflicts and displacement of the labor force. Undernourishment is a very minor problem in the country, but a lowering in Georgia’s child mortality rate (which has dropped significantly since 1990) and in stunting from child malnutrition would be a clear sign of increased food security.

Land Land area (1000 ha): 6 949 Arable land (1000 ha): 468 Permanent crops (1000 ha): 115 Pastures (1000 ha): 1 940 Forest area (1000 ha): 2 742 **Water** Irrigated land (1000 ha): 433 Total renewable water resources: 63 km^3 **People** Total population (millions): 4.2 Life expectancy at birth: 72 Urban population: 63% Agricultural population (1000s): 636	**Economic** Agriculture as % of GDP: 14.7% Agricultural exports (US$ millions): 246 Agricultural exports (% of total exports): 16.5% Agricultural imports (US$ millions): 1 156 Agricultural imports (% of total imports): 18.3% **Agricultural Production** Cereals (1000 tonnes): 372 Meat (1000 tonnes): 45 Fish (1000 tonnes): 25

The country has two quite distinct climate zones. On the West coast region along the Black Sea, the climate is humid and subtropical, where the average temperature is 14°C to 15° C and extremes range from -15°C to 45°C and annual precipitation between 1,500 mm and 2,500 mm. The influence of the Black Sea leads to mild winters, hot summers, and large amounts of precipitation. In the mountainous and high mountainous parts of the region, annual average air temperature ranges from 2 to 10°C with a minimum of -30°C to -35°C, and annual precipitation from 1,200 mm to 2,000 mm. The climate in the East is also complex. The plains in eastern Georgia make up lowlands with a dry subtropical climate and a mountainous area that has an alpine climate. The average annual temperature is 11 to 13°C in the plains, and 2 to 7°C in the mountains, with a minimum of -25°C and -36°C, respectively. Temperature in the high mountains ranges from -42°C to 42°C. Annual precipitation is 400 to 600 mm in the plains, and 800 to 1,200 mm in the mountains.

Because of this quite diverse climate it was decided to do all the analysis for one representative location in the eastern part of the country (using climate data from Kutaisi) and for one representative location in the western part (Tiblisi).

5.2 Agriculture[9]

5.2.1 Crops

In 1993 about 85 percent of cultivated land, excluding orchards, vineyards, and tea plantations, was dedicated to grains. Within that category, corn grew on 40 percent of the land, and wheat on 37 percent. The second most important agricultural product is wine. Other important crops are tea, citrus fruits, and non-citrus fruits, which account for 18 percent, 8 percent, and 8 percent of Georgia's agricultural output, respectively. Cultivation of tea and citrus fruit is confined to the western coastal area. Animal husbandry, mainly the keeping of cattle, pigs, and sheep, accounts for about 25 percent of Georgia's agricultural output, although high density and low mechanization have hindered efficiency.

Until 1991 other Soviet republics bought 95 percent of Georgia's processed tea, 62 percent of its wine, and 70 percent of its canned goods. In turn, Georgia depended on Russia for 75 percent of its grain. One-third of Georgia's meat and 60 percent of its dairy products were supplied from outside the republic. Failure to adjust these relationships contributed to Georgia's food crises in the early 1990s.

During the Soviet era, agriculture was characterized by absolute state ownership of all agricultural land and concentration of production in large-scale collective farms, which averaged 428 hectares in size. When Georgia became independent after the dissolution of the Soviet Union at the end of 1991, the entire country was in total disarray facing a bitter civil war. Georgian agriculture collapsed, and the land held by large collective farms was quickly distributed to rural households in an attempt to avoid famine. This desperate goal was achieved as Georgian agriculture quickly recovered in 1993-95. The recovery raised the volume of agricultural production in recent years by 25%-30% above its lowest level in 1993, yet the initial collapse was so dramatic that agricultural output today is still 40% below what it was in 1990.

Georgia completely individualized its agriculture as early as 1992-93. The individual sector in Georgia currently produces almost 100% of agricultural output, up from 40% before 1990. The shift of production to the individual sector is a reflection of the dramatic increase in the land holdings of rural households. Prior to 1990, only 7% of agricultural land was individual use. A

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[9] http://en.wikipedia.org/wiki/Agriculture_in_Georgia_(country)

decade later, in 2000, 37% of agricultural land (or more than 70% of arable land) is used by individual farmers. The universality of land distribution to rural families produced relatively small holdings. Thus, the average size of an individual farm in Georgia is 0.96 hectares and only 5% of farms are larger than 2 hectares.

Table 7. Dominant crops in Georgia (source: FAOstat, 2010).

item	Area Harvested (ha)
Maize	99,800
Wheat	47,500
Grapes	45,400
Potatoes	20,700
Barley	20,600
Hazelnuts, with shell	15,000
Tangerines, mandarins, clem.	12,000
Sunflower seed	9,300
Beans, dry	6,700
Tomatoes	6,700

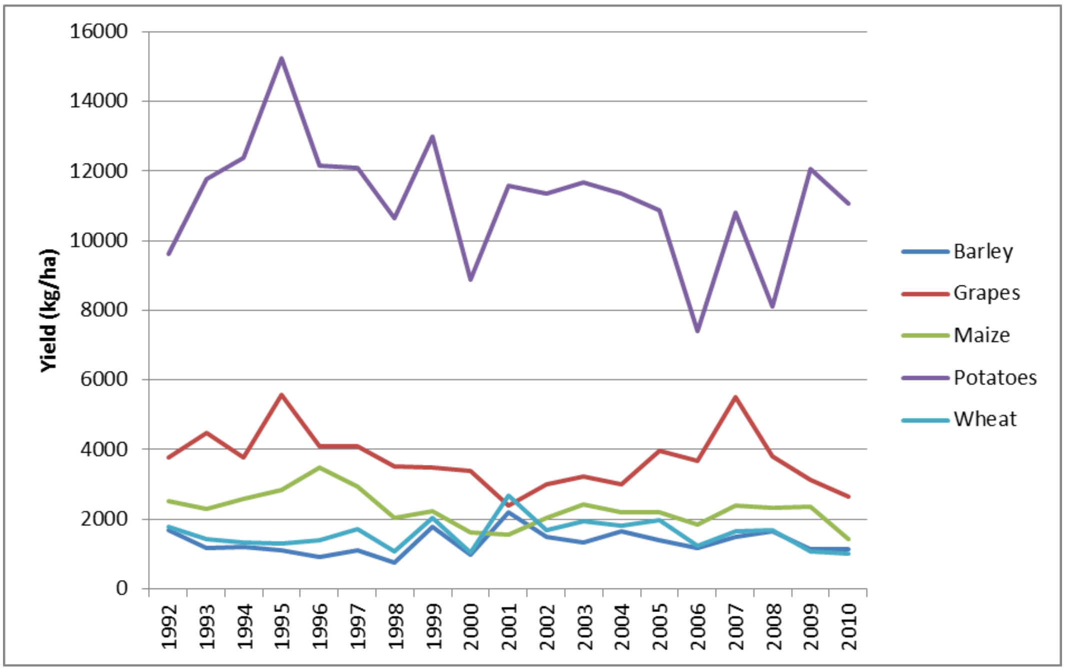


Figure 15. Yield development for the dominant crops in Georgia (source: FAOstat).

5.2.2 Irrigation[10]

The irrigation potential in Georgia is estimated at 725,000 ha. The country has a tradition of land improvement through irrigation and drainage. At the beginning of the twentieth century, the total

[10] Based on: http://www.fao.org/nr/water/aquastat/countries_regions/armenia/index.stm

irrigated area in Georgia was about 112,000 ha. Major investments were made in the irrigation sector during the Soviet period, resulting in a total area of about 500,000 ha equipped for irrigation at the beginning of the 1980s, mainly located in the more arid eastern part of the country.

During the 1990s, civil strife, war, vandalism and theft, as well as problems associated with land reform, the transition to a market economy, and the loss of markets with traditional trading partners, contributed to a significant reduction of the irrigated area. It has been reported that during the severe drought of 2000 only about 160 000 ha were irrigated. Almost all pumping schemes (about 143 000 ha) were out of order. As a consequence, Georgia's State Department of Melioration and Water Resources started a rehabilitation programme to renew the infrastructure of existing irrigation and drainage schemes and to establish Amelioration Service Cooperatives. About 255 000 ha are covered by these programmes.

In 2007, irrigation covered 432 790 ha, of which 31 500 ha equipped wetland and inland valley bottoms and 401 290 ha full or partial control irrigation. River diversion is the main source of water for irrigation and groundwater is not used for irrigation in Georgia. The main irrigation technology is surface irrigation (372 980 ha). Localized irrigation is practiced on 28 300 ha (Table 3 and Figure 3).

Most of the schemes are large-scale. The largest one are: the upper Alazani (41 100 ha), the lower Alazani (29 200 ha), the upper Samgori (28 100 ha), and the lower Samgori (29 200 ha). There is no private irrigation in Georgia. All irrigation schemes are managed by the State through its Department of Melioration and Water Resources. Though irrigation remains the responsibility of the State, the land irrigated can be owned either by private farmers or by the State but leased to farmers, cooperatives or agro-firms.

The unfavourable location of plots, low soil fertility, the failure of old irrigation and drainage systems, desertification, secondary bogging, salinization and erosion processes contribute to the non-lease and non-transfer of land to private owners. In addition, the slow pace of registering land ownership is due to the fact that the existing system deals with owner registration only, which is an insufficient basis for the full exercise of land ownership rights and the conclusion of subsequent transactions. Moreover, land registration and the process of proving land ownership are time consuming as old Soviet data have to be checked thoroughly (Government of Georgia, 2002).

At the beginning of 1997, irrigation water charges were introduced in Georgia, at a rate of US$3 per 1 000 m3. This figure was the same for all schemes in Georgia. The water charges covered about 12 percent of total O&M costs, the government budget covered 15 percent of the total, while the remaining 73 percent was not covered, resulting in the degradation of irrigation systems. In 1996, over 300 000 ha were estimated to be in need of rehabilitation. The current policy is for the government to pay for the O&M of the dams and headworks which have been constructed, while the O&M costs of the distribution and on-farm network are to be paid by irrigation users through a higher water charge.

No recent data for irrigation costs are available. In 1996 the average cost of irrigation development varied between US$3 500 and US$4 500/ha for surface irrigation, and between US$6 500 and 7 200/ha for sprinkler irrigation. Average O&M costs vary between US$55 and US$70/ha per year respectively.

In 2006, the total irrigated crop area was estimated at 126 060 ha, but no details for the different crops are available. In 1986, the major crops cultivated under full or partial control irrigation were fruit trees and grapes, pasture and fodder crops, vegetables, potatoes, wheat, maize and sunflower. Irrigated crop yields compared relatively favourably with rainfed crop yields, although the average difference is very small due to the good climatic conditions in the areas where rainfed agriculture is practiced. In 1986, in the full or partial control irrigation schemes, the average irrigated crop yields were 3.0 tonnes/ha for winter wheat, 2.9 tonnes/ha for maize, 4.8 tonnes/ha for grapes, 5.0 tonnes/ha for fruits and 12 tonnes/ha for potatoes.

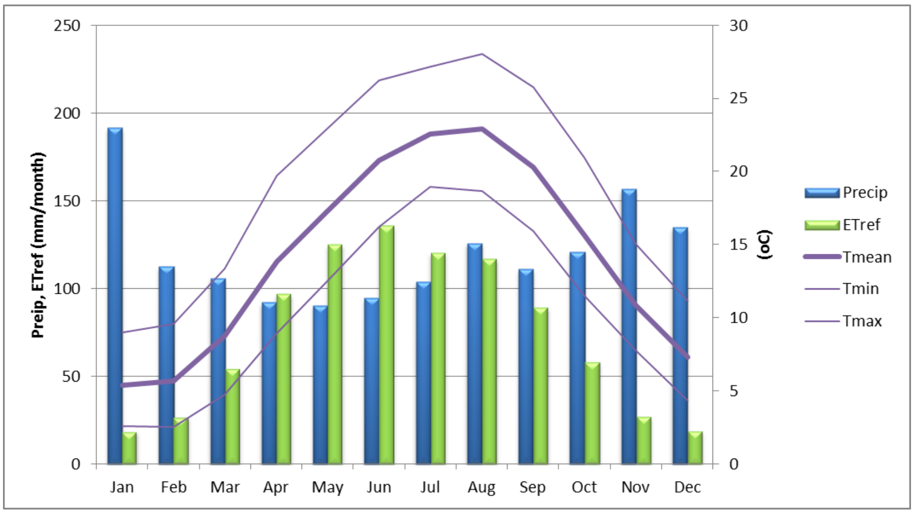


Figure 16. Monthly climate data for Western Georgia (1981-1990) based on station data from Kutaisi (Lat: 42.267, Long: 42.633, Elev: 116 m).

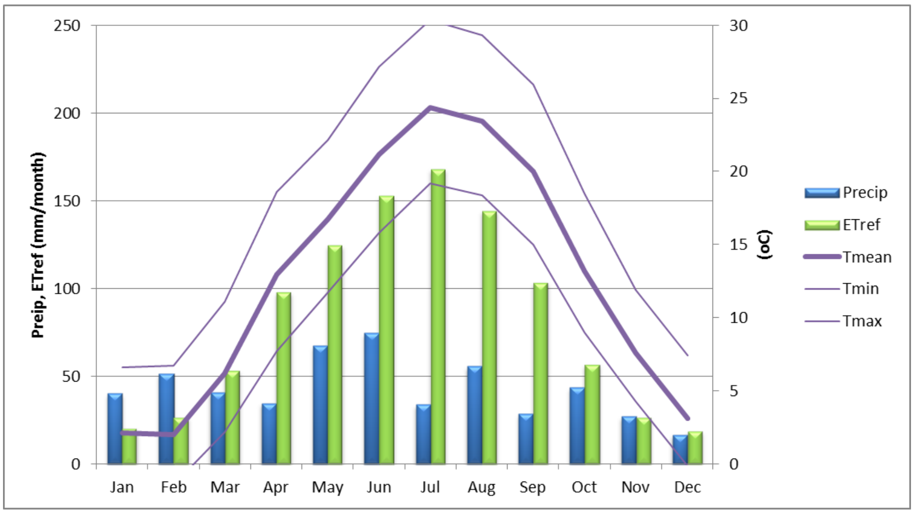


Figure 17. Monthly climate data for Eastern Georgia (1981-1990) based on station data from Tiblisi/Lochini (Lat: 41.750, Long: 44.767, Elev: 427 m).

Table 8. Impact of climate change on precipitation and ETref (Kutaisi, Western Georgia).

Period	Precipitation mm/y	ETref mm/y	Precipitation % from current	ETref
1981-1990	1441	889		
2020-2029_Med	1318	932	-8.5	4.8
2020-2029_Low	1622	898	12.5	1.0
2020-2029_High	1191	945	-17.3	6.2
2040-2049_Med	1479	949	2.7	6.7
2040-2049_Low	1554	921	7.8	3.5
2040-2049_High	1134	987	-21.3	10.9

Table 9. Impact of climate change on precipitation and ETref (Tiblisi, Eastern Georgia).

Period	Precipitation mm/y	ETref mm/y	Precipitation % from current	ETref
1981-1990	515	995		
2020-2029_Med	469	1040	-8.9	4.5
2020-2029_Low	582	1011	13.0	1.6
2020-2029_High	420	1049	-18.5	5.4
2040-2049_Med	517	1063	0.5	6.8
2040-2049_Low	556	1031	7.9	3.6
2040-2049_High	387	1093	-24.8	9.9

5.3 Climate Change Impact on Wheat

5.3.1 Background

Wheat is gown on about 48 thousand hectare in the country according to FAOstat. About 70% of the wheat is spring-wheat, while the remainder is winter-wheat. Most of the wheat is gown under irrigation (Morgounov et al., 2001).

The AquaCrop model has been setup to simulated actual yields as well as yields under climate change. A total of 70 years have been simulated:

- One reference situation
- Two time periods of ten years: 2020-2029 and 2040-2049
- Three climate projections: Low, Medium, High

The pre-calibrated wheat crop file in AquaCrop required small changes to adapt it to the conditions in the country.

Under very good conditions and applying an intensive farming system grain yield can go up to 9 ton/ha (10 to 13 percent moisture). In this study a dry matter content of 87% was assumed. In Georgia average yields are 1019 kg/ha in 2010 according to FAOstat (Figure 9).

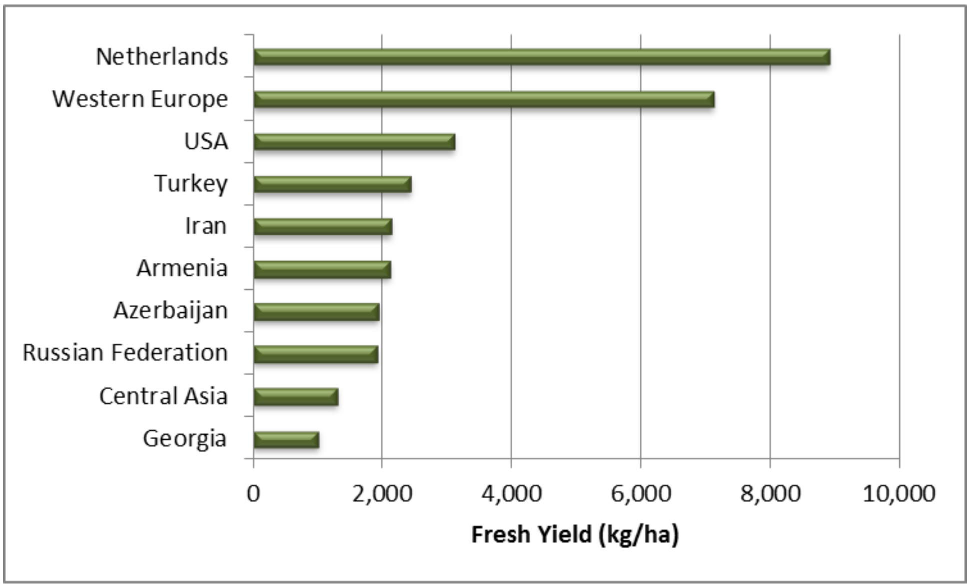


Figure 18. Wheat fresh yield in some selected relevant countries (Source: FAOstat, 2010)

The AquaCrop data file for wheat has been created by adjusting parameters in order to represent average local conditions in the country. The most important assumptions and crop information used to parameterize the crop files in AquaCrop are:

- Planting date: 1-Apr (DOY 91)
- Harvest date: 1-Aug (DOY 213)
- Length of growing season: 123
- Dry matter content harvested product: 87%
- No irrigation for Eastern location
- 200 mm irrigation for Western location

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 wheat has a dry matter content of 87%, so about 13% moisture is included in the fresh yield. In order to convert AquaCrops results into fresh yields, one has to divide by 0.87. E.g.

- 1000 kg dry matter
- 1000 / 87% = 1149 kg fresh
- 1149 * 13% = 149 kg moist

Average wheat yields in Georgia according to FAOstat are 1019 kg/ha (fresh yield). Converting into dry matter yield as calculated by AquaCrop:

- 1000 kg fresh * 87% = 870 kg dry matter yield

In this report all yields are presented as fresh yields to ensure proper dissemination amongst stakeholders and policy makers.

5.3.2 Results

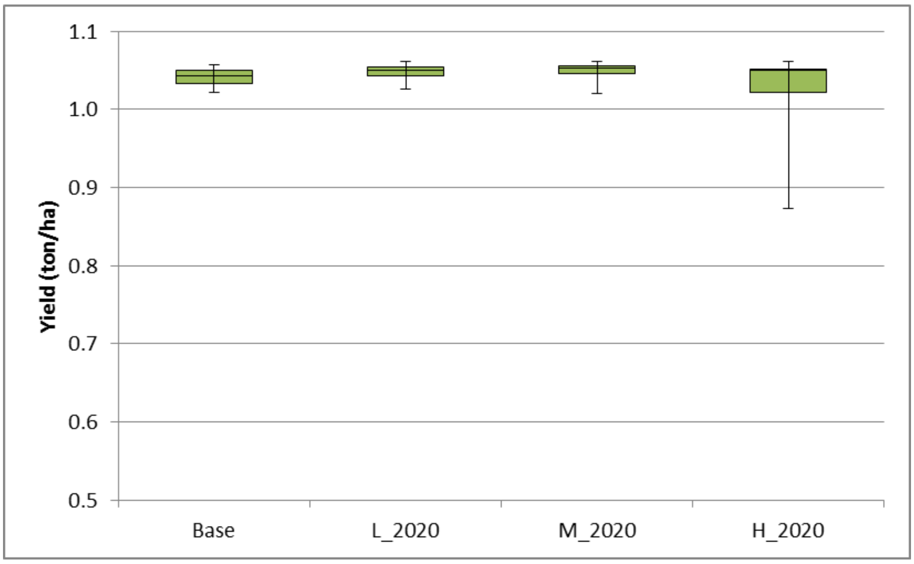
The overall results for the Western location in Georgia using FAO's AquaCrop are presented in the Tables below. Observed yield according to FAOstat are 1019 kg/ha and simulated yields are almost similar, proving that the model is able to simulate crop yields accurately. Under climate change yields can go down on average by 6% under the high climate change projection in 2040-2049. Given the variation in yields within the ten years periods, it is also interesting to look at the changes in minimum yields. These minimum yields can go down by 47%.

Variation in year-to-year yields are expected to increase in the future as can be seen in the Figure below. Striking is specifically that some years in the future might expect to produce very low yields due to heat stress as well as water shortage.

Overall, the impact of climate change on wheat production can be summarized as a reduction in yield up to 6% based on 10-years averages. Reduction in minimum yields in a period of years can be even 47%.

Table 10. Impact of climate change on wheat yields in Western Georgia.

	Low	Medium	High
		Yield (ton/ha)	
Base		1.041	
2020-2029	1.047	1.048	1.022
2040-2049	1.053	1.043	0.974
		Changes in Yield (%)	
2020-2029	1	1	-2
2040-2049	1	0	-6
		Changes in Minimum Yield (%)	
2020-2029	0	0	-15
2040-2049	1	-5	-47



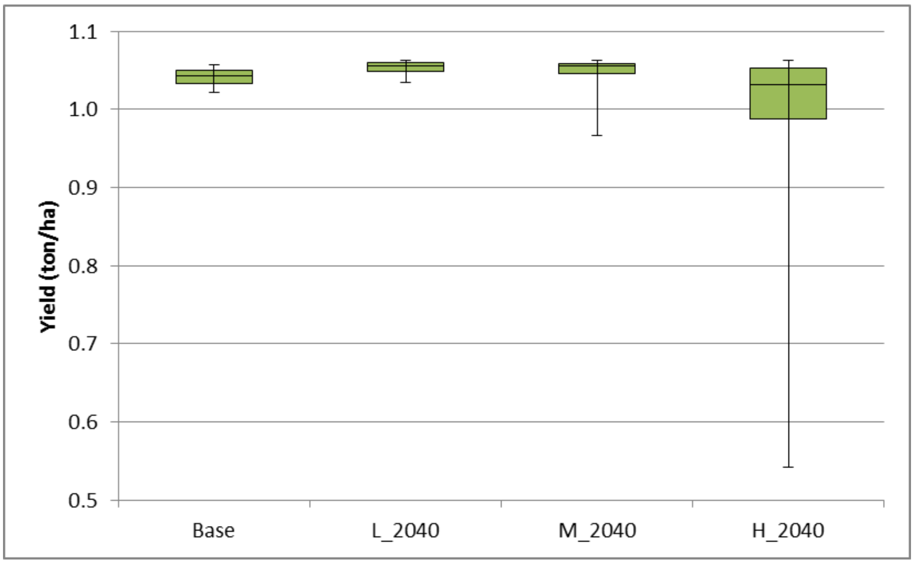


Figure 19. Impact of climate change on wheat yield in Western Georgia based on AquaCrop.

Base = current situation; L, M, H are Low, Medium and High climate change impact scenarios; 2020 = period 2020-2029; 2040 = period 2040-2049

Results of the AquaCrop analysis for the Eastern location of Georgia are presented in Table 11 and Figure 20. Overall, yields are higher compared to the Western part of the country as a results of irrigation. Under climate change yields can go down on average by 15% under the high climate change projection in 2040-2049. However, yields are still higher than under rainfed conditions as assumed for the Western part of the country. Given the variation in yields within the ten years periods, it is also interesting to look at the changes in minimum yields. These minimum yields can go down by even 61%.

Variation in year-to-year yields are expected to increase in the future as can be seen in the Figure below. Striking is specifically that some years in the future might expect to produce very low yields due to heat stress as well as water shortage.

Overall, the impact of climate change on wheat production can be summarized as a reduction in yield up to 15% based on 10-years averages. Reduction in minimum yields in a period of years can be even 61% under the dry scenario.

Table 11. Impact of climate change on wheat yields in Eastern Georgia.

	Low	Medium	High
		Yield (ton/ha)	
Base		1.687	
2020-2029	1.699	1.639	1.571
2040-2049	1.637	1.637	1.426
		Changes in Yield (%)	
2020-2029	1	-3	-7
2040-2049	-3	-3	-15
		Changes in Minimum Yield (%)	
2020-2029	1	-20	-27
2040-2049	-21	-19	-61

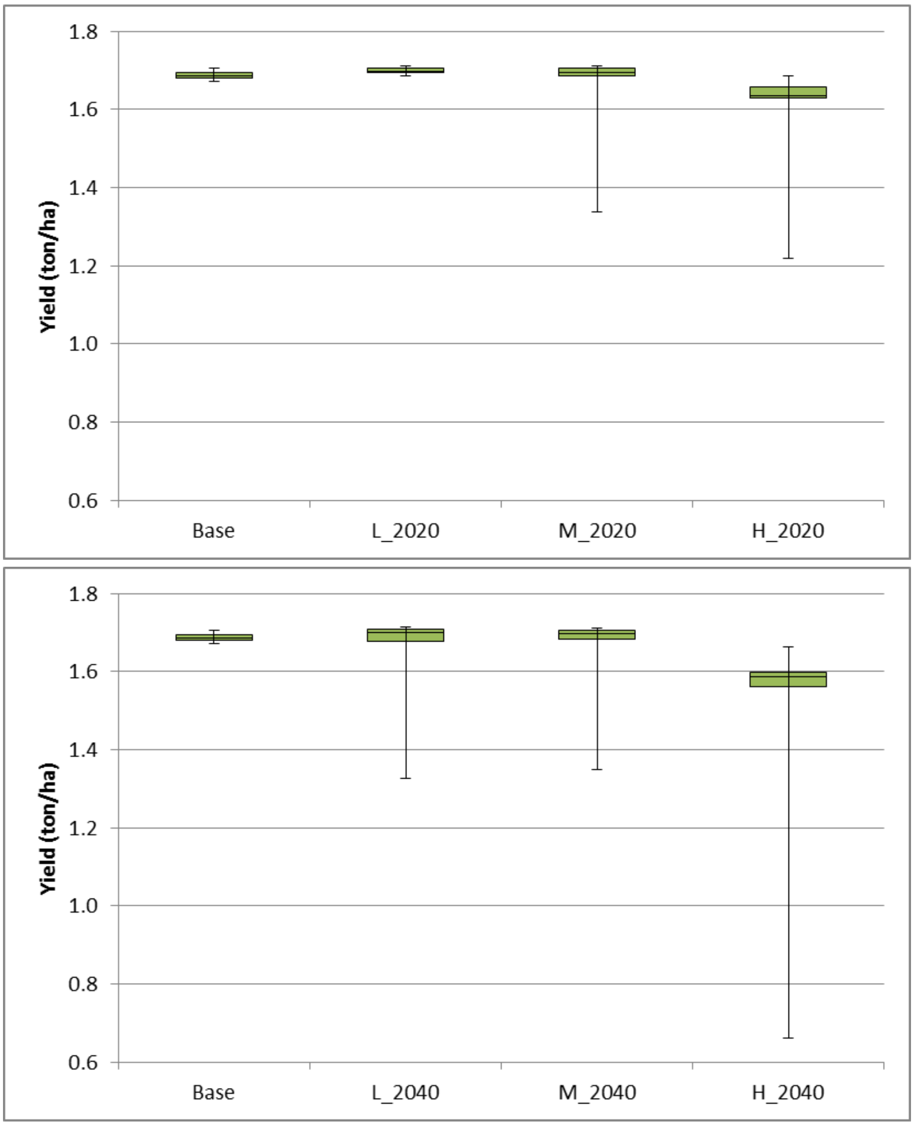


Figure 20. Impact of climate change on wheat yield in Eastern Georgia based on AquaCrop.

Base = current situation; L, M, H are Low, Medium and High climate change impact scenarios; 2020 = period 2020-2029; 2040 = period 2040-2049

6 Conclusions

For Armenia, Azerbaijan and Georgia agriculture continues to be critical for rural poverty reduction, employment, economic growth and food security. However, the agricultural sector is highly climate sensitive and potential adverse changes in temperature, precipitation and the frequency of extreme events (for example, droughts, heat waves, floods, forest fires) as a result of climate change are likely to increase the vulnerability of poor rural communities. This report describes the initial assessment of the impact of climate change on wheat production in the three countries, using FAO's AquaCrop model.

A summary of the impact of climate change on wheat yields is shown in Table 12. It is clear that average yields are expected to reduce between 0 and 8% under climate change. However, under the most extreme climate projection yields might reduce between 6 and 15%. Moreover, it is known that climate change will also influence year-to-year variation. Considering only the lowest yields in a period of 10 years, yield reductions under the medium and especially under the high climate projection are substantially.

Table 12. Summary of impact of climate change on wheat yields.

	Current Climate	Future Climate (2040-2050)		
		Medium	Low	High
		Yield (ton/ha)		
Armenia	2.1	1.9	2.1	1.8
Azerbaijan	1.9	1.8	1.9	1.7
Georgia-West	1.0	1.0	1.1	1.0
Georgia-East	1.7	1.6	1.6	1.4
		Changes in Yield (%)		
Armenia		-8	-1	-15
Azerbaijan		-6	-1	-8
Georgia-West		0	1	-6
Georgia-East		-3	-3	-15
		Changes in Minimum Yield (%)		
Armenia		-7	-3	-17
Azerbaijan		-7	-1	-12
Georgia-West		-5	1	-47
Georgia-East		-19	-21	-61

Note: all results are based on irrigated wheat, except for Georgia-West which is considered to be rainfed.

Four important remarks should be made regarding these results. First of all results presented in this report are based on state-of-the-art and well-proven methods and model. Second, however, results are presented here for "representative" areas and location-specific differences could occur for other locations. Third, results are based on globally available datasets (although obviously based on locally collected data). More detailed local data might be included during following-up activities. Fourth, results here do not include impact of changes as a results of a possible increase in pest and/or diseases.

Finally, it is clear that climate change will have an important impact on agricultural production. Adaptation is therefore required and range of options has to be considered and evaluated.

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