Science of the Total Environment 543 (2016) 1019–1027

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Modelling climate change impacts on and adaptation strategies for agriculture in Sardinia and Tunisia using AquaCrop and value-at-risk

David Neil Bird [a,*], Sihem Benabdallah [b], Nadine Gouda [c], Franz Hummel [d], Judith Koeberl [a], Isabelle La Jeunesse [e], Swen Meyer [f], Franz Prettenthaler [a], Antonino Soddu [g], Susanne Woess-Gallasch [a]

[a] *Joanneum Research Forschungsgesellschaft mbH, Leonhardstraße 59, A-8010 Graz, Austria*
[b] *Centre de Recherche et des Technologies des Eaux (CERTE), BP 273, 8020 Soliman, Tunisia*
[c] *Thalkirchnerstraße 22, 80337 Munich, Germany*
[d] *Deutsches Zentrum fuer Luft- und Raumfahrt e.V. (DLR) Muenchener Str 20, 82234 Wessling, Germany*
[e] *Université François-Rabelais de Tours, UMR CNRS Citeres, 33, allée Ferdinand de Lesseps, 37045 Tours Cedex 1, France*
[f] *Ludwig-Maximilians-Universitaet Muenchen, Department of Geography, Luisenstraße 37, 80333 München, Germany*
[g] *AGRIS SARDEGNA — Agenzia per la Ricerca in Agricoltura, Dipartimento per le Produzioni Vegetali, Viale Trieste 111, Cagliari, Italy*

HIGHLIGHTS

- Rainfed wheat yields in Sardinia in 2040-2070 will be 64% less on clay loams soils.
- With today's irrigation, tomato yields in Cap Bon in the future will be 17% less.
- With 10% less irrigation, tomatoes sown in Mar. in Cap Bon will not be viable in the future.
- Changing sowing dates, matching crops to soils and mulching may limit yield losses.

ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form 3 July 2015
Accepted 6 July 2015
Available online 15 July 2015

Keywords:
Crop yield modelling
Adaptation strategies
Irrigation
Mulching
Tomato
Wheat

ABSTRACT

In Europe, there is concern that climate change will cause significant impacts around the Mediterranean. The goals of this study are to quantify the economic risk to crop production, to demonstrate the variability of yield by soil texture and climate model and to investigate possible adaptation strategies. In the Rio Mannu di San Sperate watershed, located in Sardinia (Italy) we investigate production of wheat, a rainfed crop. In the Chiba watershed located in Cap Bon (Tunisia), we analyze irrigated tomato production.

We find, using the FAO model AquaCrop that crop production will decrease significantly in a future climate (2040–2070) as compared to the present without adaptation measures. Using "value-at-risk", we show that production should be viewed in a statistical manner. Wheat yields in Sardinia are modelled to decrease by 64% on clay loams, and to increase by 8% and 26% respectively on sandy loams and sandy clay loams. Assuming constant irrigation, tomatoes sown in August in Cap Bon are modelled to have a 45% chance of crop failure on loamy sands; a 39% decrease in yields on sandy clay loams; and a 12% increase in yields on sandy loams. For tomatoes sown in March; sandy clay loams will fail 81% of the time; on loamy sands the crop yields will be 63% less while on sandy loams, the yield will increase by 12%. However, if one assume 10% less water available for irrigation then tomatoes sown in March are not viable.

Some adaptation strategies will be able to counteract the modelled crop losses. Increasing the amount of irrigation one strategy however this may not be sustainable. Changes in agricultural management such as changing the planting date of wheat to coincide with changing rainfall patterns in Sardinia or mulching of tomatoes in Tunisia can be effective at reducing crop losses.

1. Introduction

The main climatic changes in the Mediterranean region as summarised by the European Environment Agency (EEA, 2012) are: a decrease in the total amount of precipitation but with an increase of the number and intensity of extreme events such as floods and droughts; and a change in the seasonal distribution of precipitation. In addition,

* Corresponding author.
E-mail addresses: neil.bird@joanneum.at (D.N. Bird), sihem.benabdallah@certe.rnrt.tn (S. Benabdallah), nadine_gouda@yahoo.com (N. Gouda), Franz.Hummel@dlr.de (F. Hummel), judith.koeberl@joanneum.at (J. Koeberl), isabelle.lajeunesse@univ-tours.fr (I. La Jeunesse), s.meyer@iggf.geo.uni-muenchen.de (S. Meyer), franz.prettenthaler@joanneum.at (F. Prettenthaler), asoddu@agrisricerca.it (A. Soddu), Susanne.woess@joanneum.at (S. Woess-Gallasch).

http://dx.doi.org/10.1016/j.scitotenv.2015.07.035

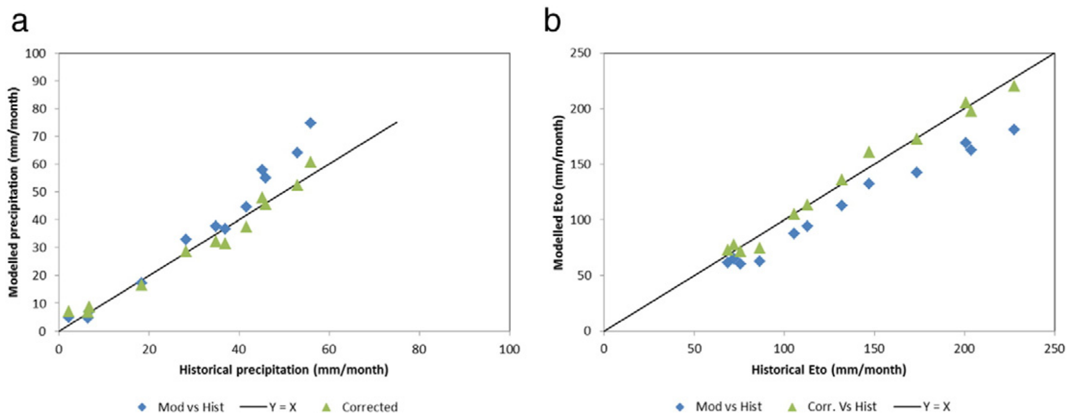

Fig. 1. A comparison of historic (Hist) and modelled (Mod) for a) precipitation and b) evapotranspiration from the ECH–RCA climate ensemble with and without correction for Chiba.

an increase of temperature and linked effects of heat stress during summer period is expected. According to EEA (2012) and Iglesias et al., 2007 these climatic changes are expected to decrease of crop yields and quality due to higher temperatures and changes in water availability; and increase the risk of agricultural pests, diseases and weeds. As a result, they forecast the following impacts: a reduction of water availability combined with an increase of water demand for irrigation; an increase in the risk of drought and water scarcity; and a decrease in water resources with negative effects on soil structure, reduced soil drainage and increased salinity.

The same studies (Iglesias et al., 2007) have recognised that there is a gamut of agricultural adaptation measures that could be adopted in the future. They can be grouped as:

1. *Management measures*: These include changes in agricultural management made autonomously by farmers based on experience or available information. For example changing crop variety, planting dates and the amount and use of fertilizers and pesticides.
2. *Technical and equipment measures*: These may include technical measures such as improved irrigation equipment, or the introduction of new crops. Since these measures have some investment, they may need financial support by public or private institutions or collaborative organizations.
3. *Policy/economic measures*: Policy initiatives may comprise crop insurance, improved water demand management by local and/or regional water authorities; financial support of farmers; and
4. *Infrastructural measures*: These could include larger infrastructural changes designed for one or more farmers, such construction of dams to store more rainwater. As these require substantial investment, they will also need public advice and public support of necessary investments.

The climate impacts and adaptation measures noted above are somewhat generic and more detail, particularly in understanding the variability of the modelled impacts based on various climatic models and soils, is required to quantify the risks to agricultural production. A portion of the project CLIMB — *Climate Induced Changes on the Hydrology of Mediterranean Basins Reducing Uncertainty and Quantifying Risk through an Integrated Monitoring and Modelling System* funded by the seventh framework programme of the European Commission had specifically the goal of assessing in detail socioeconomic vulnerability and possible adaptation strategies in two study sites in future climates (2040–2070). The two study sites are the river basin of Rio Mannu di San Sperate, located in Sardinia (Italy) and the Chiba watershed located on the peninsula Cap Bon (Tunisia).

In 2010, durum wheat production in the province of Cagliari, in which Rio Mannu is situated, was 25,552 tonnes (ISTAT, 2015). It had an estimated value of 2.384 million USD using a national value per tonne derived from FAOSTAT (2014). At Rio Mannu, wheat is traditionally sown in November or December and allowed to mature over the winter for harvest in June.

For the Chiba watershed, the production of tomatoes for El Mida, Korba and Menzel Boulzelfa delegations in 2010 was 221,050 tonnes (Commissariat Régional au Développement Agricole, personal communication). This had an estimated value of 81.69 million USD, using a national value per tonne derived from FAOSTAT (2015). Tomatoes are sown twice during the year: a crop is planted in August and a second crop is planted in March. Both crops are heavily irrigated.

The detailed variability of the modelled impacts on agricultural production from these two crops based on various climatic models and soils, and the impacts of possible adaptation strategies are presented in this paper.

2. Materials and methods

To estimate the change in agricultural productivity in a future climate, the FAO model AquaCrop (Steduto et al., 2009; FAO, 2015a) and the software EToCalc (FAO, 2015b) were used.

AquaCrop was chosen because it is a crop water productivity model that simulates yield response to water of herbaceous crops, and can be used specifically in situations where water is a key limiting factor in crop production (Steduto et al., 2009). AquaCrop has the additional advantage that it is relatively simple and robust and uses "*a relatively small number of explicit and mostly-intuitive parameters and input variables requiring simple methods for their determination*". AquaCrop was specifically designed for "*assessing water-limited, attainable crop yields at a given geographical location*" and "*carrying out future climate scenario analyses*".

2.1. Historical and future climatic data

To model crop yields using AquaCrop daily estimate of temperature, precipitation, and evapotranspiration are required.

Table 1
Final AquaCrop parameters.

Parameter	Rio Mannu, Sardinia	Chiba, Tunisia
Crop	Wheat	Tomato
Planting density	340 plants/m^2	1.5 plants/m^2
Sowing date	Variable 15 mm of rain After Sept. 1st	Fixed March 1st or August 15th depending on crop cycle
Number of days to crop maturity	194	120
Reference harvest index	20%	63% Default value
Initial soil water content	30%	10%
Soils	Clay loam, sandy loam, sandy clay loam	Loamy sand, sandy loam, sandy clay loam