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Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios

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ABSTRACT

Climate change projections for the Mediterranean region are predicting a significant rainfall decrease and an increase of temperatures. The consequences of these changes on food security and natural resources in this region might be very dramatic. Anticipating climate change impacts by improving agricultural systems efficiency is a critical need.

Therefore, this study was conducted to assess the vulnerability of water resources and performance of two major rainfed crops (Winter wheat & Sunflower) to climate change impact in R'dom watershed. The study aimed also, to evaluate some adaptation strategies to improve crops water productivities while preserving hydrologic resources. The study site is a typical Mediterranean agro-silvo-pastoral watershed in North-western Morocco, where water resources are facing an increasing demand.

Both hydrologic and plants growth modules of Soil and Water Assessment Tool Model (SWAT) have been calibrated and validated over the period 2004 to 2009. SWAT model and downscaled Global Circulation Model CNRM CM5 were used to simulate water yield and crops water productivities in 2031–2050 period under two Representative Concentration Pathways (RCP 4.5 and RCP 8.5). The RCM data revealed that the study area will experience important precipitation drop and mean temperature increase in the period 2031 to 2050. About 26.4% (± 2.89) decrease of basin water yield and up to 44.7% (± 9.03) drop down of crops water productivities were consequently predicted. After simulation of 5 combinations of no tillage and two early sowing dates' strategies, TOPSIS technique was used to prioritize strategies according to different management policies. Both no tillage and the 10 days early sowing strategies have stood out as two best adaptation strategies among the management policies evaluated as compared to business as usual.

1. Introduction

According to the revised 2017 report of United Nations regarding world population forecasts "The World Population Prospects" (UN, 2017), and with an increase rate of 83 million people per year, the world population will reach 9.8 billion people by 2050. Satisfying demand to feed this growing population is one of the major challenges of agriculture in the future (FAO, 2013).

Moreover, agricultural systems should face climate change impacts while reducing emission intensities and preserving the natural resources (FAO, 2013; Grafton et al., 2015; Steduto et al., 2012). Climate change is, certainly, already showing impacts on agriculture and food security especially in many world vulnerable areas such as the Mediterranean region (Abouabdillah et al., 2010; Bucak et al., 2017; De Gerolamo et al., 2015; Ons et al., 2015; Pascual et al., 2017; Senatore et al., 2010). Increasing incidence of extreme climatic events and unpredictable weather patterns was always the driving issue of low performing farming seasons in Morocco (extreme droughts in seasons: 1986–1987, 1991–1992, 1994–1995, 1998–2000 and floods in 2014, 2011, 2009…etc) (Balaghi and Dahan, 2015; Bouignane, 2010).

Climate-smart agriculture, as defined by FAO in 2010 Hague Conference on "Agriculture, Food Security and Climate Change", is offering an integrated framework that includes management policy and technical practices to achieve higher agricultural efficiency for food

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security under climate change (FAO, 2013). One of the advantages of this concept is its location-specificity that is based on the technical limitations of the concerned area.

Because of the pessimistic future climate projections for Morocco (1.3 °C increase of yearly mean temperature and 11% drop of yearly average rainfall within 2050) the country will definitely be facing economical and food security related challenges (Balaghi and Dahan, 2015). The drought events of the seasons 1994/1995 and 1998/1999, where cereals production has dropped down by 60% and agriculture GDP decreased by 30%, illustrate how Morocco is threatened by climate change (Bouignane, 2010).

Agriculture is a key sector in the Moroccan economy, as it represents around 15% of the GDP (HCP, 2011) and employs about 43% of the workforce. The Moroccan government launched its strategic 2008–2020 vision for agriculture (Green Morocco Plan); to face major internal and external challenges and to increase farmers' incomes sustainably (MAPM, 2013). One of the strategies of this plan is to decrease cereal cropped surfaces by 22% and to increase the cereals production by 44% by 2020, which means more efficiency is needed from the production systems (Mrabet et al., 2012).

Rainfed crops water productivity in Morocco is generally low, due to technological constraints, to low rainfall in some areas and to improper management of rainy periods when they occur (Balaghi, 2014). In this study, winter wheat (*Triticum aestivum*) and sunflower (*Helianthus annuus*) crops have been considered due to their roles in the world food security programs and because cereals and oilseed grains are the major imported food by Morocco despite their local production (around 50% of the total imported agricultural product in terms of value in 2012 (MAPM, 2013)).

In this paper, SWAT, a semi-distributed model has been used to predict both hydrological processes and water productivity of two major crops under climate change projections within an agro-silvo-pastoral watershed in Morocco. The main objectives of this work are: (i) to model hydrology and plants growth in the study watershed, (ii) to investigate the potential climate change impact on hydrologic resources and crops water productivity, and (iii) to investigate sustainable adaptation strategies under different management policies scenarios.

2. Materials and methods

2.1. Study site

This study was conducted on a watershed (R'dom) located in North western Morocco, laying partly in the South on the Sais plateau and partly in the North on the Pre-Rif ridges, with an area of about 1990 km^2. This watershed is considered among the main sub-watersheds of the Sebou river basin (one of the largest basins in the country). Both Meknes and Sidi Kacem cities are located within the watershed. Souk Elhad gauge (34° 17′ 37″ N; 5° 46′ 2″ W) represents the watershed outlet (Fig. 1).

The R'dom climate is Semi-arid, Average annual precipitation is about 467 mm, and the rainiest seasons are winter (44%) and spring (25%). Average annual temperature is 16.2 °C, with January being the coldest month and August the warmest one (Zian, 2011). The R'dom river is intermittent, with mean annual discharge of 2.1 m^3/s measured at the unique flow-gauge station of Souk Elhad (Brouziyne et al., 2017b).

The watershed topography is variable; altitudes are ranging from 32 m to 1800 m (Fig. 1). Variability is reported also on soil types across the watershed; soils in the Northern part of the watershed are sandy and well drained, and are more clay-loamy with high swelling activity in the South (Brouziyne et al., 2017b).

The main socio-economic activities in the area rely on agriculture, with mixed forest-pasture system. Cereals, legumes and oil seeds are the main cultivated crops in the area (around 40% of the total cropped lands).

Despite the increasing water demand (mainly due to agricultural activities), the water resources in this watershed are characterized by a massive spatial and temporal variability and uneven distribution within the landscape (Brouziyne et al., 2017a).

3. SWAT model

3.1. Model presentation

The Soil and Water Assessment Tool (SWAT) developed by the US Department of Agriculture (Agricultural Research Services) (Arnold et al., 2011) was adopted for the present study. The main components of the model are climate, hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing.

The watershed is partitioned, according to topography, into a number of sub-basins connected by a stream network. Each sub-basin is further divided into several homogonous Hydrological Response Units (HRU) based on soil characteristics, cropping pattern and management practices. HRUs are used by SWAT model as units where water budget and crops yields are predicted (Arnold et al., 2012).

SWAT uses a simplified version of Erosion Productivity Impact Calculator model (EPIC) (Neitsch et al., 2002) to simulate crop growth process and yield. In EPIC model, plant development is simulated based on actual evapotranspiration, leaf area development, light interception and its conversion to biomass and yield. Plant growth can be limited by temperature, water, Nitrogen or Phosphorous stress. For the study of carbon dioxide climate change effects, carbon fertilization is accounted through different fundamental processes such as the radiation use efficiency and the canopy resistance (Neitsch et al., 2002).

3.2. Model parameterization

Watershed delineation tool of ArcSWAT has been used to delineate sub-basins based on Digital Elevation Model (DEM) data. 27 connected sub-watersheds were identified and stream network of R'dom basin was defined. Watershed outlet was manually defined to match the geographic location of the Souk El Had gauge station (Fig. 1) where flow out processes were monitored to compare measured and predicted flows.

A SWAT soil map has been developed based on available survey reports and ministry of agriculture maps covering the basin at a 1:50,000 scale. Data included soil texture, soil hydrological group, number of soil layers, organic carbon, clay, sand and silt contents, erodibility factor, pH and electrical conductivity, …etc). SWAT land use map was created based on image scenes from LANDSAT8 (captured April 2015) that were classified using several ground truths sites.

Farming practices patterns were added to the model according to the agricultural practices applied in the study watershed, especially the ones with high potential effect on water cycle and crop performance such as: sowing and harvest dates, tillage operation features, fertilization operation. In this study optimal nutrient quantities were supplied to crops and were not considered as limitating factors to plant growth; only heat and water stress (due to potential climate change impact) were taken into account. Winter wheat and sunflower were chosen as target crops for this study. The conventional practices used are given in Table 1 (Ait Houssa et al., 2014; Bamouh, 1993; Si Bennasseur, 2014).

In order to reflect, as much as possible, the real crops behaviours against the watershed conditions some cultivar characteristics of the selected crops were amended based on previous studies (Aboudrar et al., 2004; Balaghi and Mohammed, 1993; Jlibene, 2009; Zwart, 2010) (Table 2).

Observed weather parameters were imported into SWAT model, which includes daily maximal and minimal temperature from 6 weather stations and daily rainfall from 4 recording stations within and around the watershed (Fig. 1). The data series were ranging from January 2003 to December 2010.