MERIT RESEARCH JOURNALS
www.meritresearchjournals.org

Merit Research Journal of Agricultural Science and Soil Sciences (ISSN: 2350-2274) Vol. 7(3) pp. 037-042, March, 2019
Available online http://meritresearchjournals.org/asss/index.htm

DOI: 10.5281/zenodo.2617355

Original Research Article

Contribution of simulation tools to study climate change effects on agriculture in an African country

Haj-Amor Z

Water, Energy, and Environment Laboratory, National Engineering School of Sfax, 3038 Sfax, Tunisia

E-mail: ziedhadj@yahoo.com
Tel.: +216 25 919 074
Fax: +216 75 276 605

Abstract

African agriculture is highly vulnerable to climate change. The continuance of agricultural production in regions of the African continent with chronic water shortages depends upon understanding how major crops (such as wheat and maize) are impacted by climate change (i.e. higher temperatures and fluctuating rainfall). In the present study, a four-year field study (2015-2018) was conducted in an African country (Tunisia) to determine how the wheat yield and nitrate leaching were affected by climate change in 2050. DSSAT model was used as a simulation tool. The results of this study show that the wheat yield will decrease significantly by 2050 (decreasing percentage = 28%) due to climate change condition. Also, the simulation results showed that the used model (DSSAT model) is powerful tool for evaluating the effects of climate change on wheat yield and nitrate leaching. Furthermore, it is recommended to apply the adequate fertilizer amounts to enhance wheat yield resistance to future climate change. The findings of this study could be an effective guide to improve wheat management in Tunisia with respect to climate change. Overall, the study can be used to implement the most appropriate strategy of soil and crop management to minimize effects of climate changes on wheat yield.

Keywords: African agriculture; African continent; Climate change; DSSAT; Wheat yield

INTRODUCTION

Agriculture is an extremely important sector on the African continent (Schlenker and Lobell, 2010). Totally, this sector accounts for 70% of the labor force and over 25% of GDP and make an important contribution to the international agricultural production due to the favorable biophysical and climatic conditions of the continent (UNECA, 2009). Currently, climate change is a the sustainability of this sector tends to be very critical due to the negative effects of climate change (i.e. higher temperatures and fluctuating rainfall) on agricultural systems (Keane et al., 2009). Warming trends have already become evident across the continent, and it is likely that the continent’s 2000 mean annual temperature change will exceed +2°C by 2100 (IPCC, 2013). As revealed by several studies (Jarvis et al. 2008; Karmakar et al., 2016; Karimi et al., 2018), it is well understood that this sector is very vulnerable to climate change due to the low capacity to respond or adapt to the effects of climate change (CDKN 2014). Climate change will affect agriculture in different ways, for examples: future projections foresee that climate change could reduce plant water availability and increase agricultural area under drought, affecting crop production (Collins et al., 2013). A rise in temperatures, for instance, could lead to soil moisture deficits and a growing risk of vegetation desiccation due to increased evapotranspiration and decreased soil moisture (Riediger et al., 2014). Also, negative economic effects of climate change on agricultural productivity are expected to increase depending on the spatial patterns of land cover, crop type, land use practices, and regional climate variability (Iglesias et al., 2012).

The effects that climate change presents to the African agriculture require an unprecedented ability to predict the responses of soils and crops to environment and management. The interactions between soil, crop, and

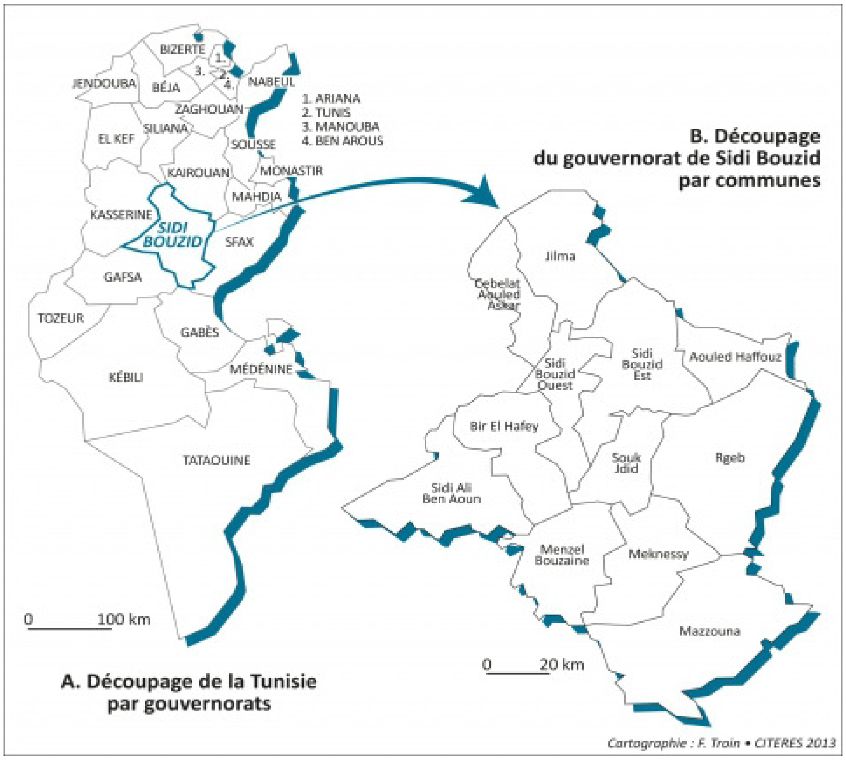

Figure 1. Map of Tunisia country and localization of Sidi Bouzid region

climate conditions are complex and affected by many factors. Evaluating the interaction of these factors through field research is difficult and expensive because numerous uncontrolled factors may affect crop performance in addition to the controlled variables. In addition, the effects of climate change on soil and crop in a single growth season is often small and may not be readily detectable by the routine soil sampling in the field. Modelling in this regard provides an effective alternative, as it can help to understand temporal as well as spatial aspects of soil water and solute fluxes in relation to irrigation practices (Haj-Amor et al. 2016). Crop and soil simulation models are powerful and highly complementary tool that are increasingly used for such predictive analyses (Masutomi et al. 2009). The flexibility of simulation tool analysis systems to handle differing scenarios in a rapid and efficient manner is another important factor. Crop models integrate the effects of soils, weather, management, genetics, and pests on daily growth, and can be used to gain insight into spatial yield variability. Among the numerous crop growth models, the most widely used are the Decision Support for Agrotechnology Transfer (DSSAT) models, which were designed to stimulate growth, development, and yield of a crop growing on a uniform area of land, as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time (Jones et al. 2003). DSSAT has been in use for the past 15 years by researchers all over the world, for a variety of purposes, including crop management (Fetcher et al., 1991), climate change impact studies, sustainability, and precision agriculture, and is well validated for a number of regions and crops. Included in the DSSAT family are modules which simulate the growth of 16 different crops, including maize, soybeans, wheat, rice, and others. DSSAT uses common modules for soil dynamics and soil–plant–atmosphere interactions regardless of the plant growth module selected. Data requirements include weather inputs (daily maximum and minimum temperature, rainfall and solar radiation), soils classification, and crop management practices (variety, row spacing, plant population, fertilizer and irrigation application dates and amounts) (Paz et al., 2003). In this context, the main objective of this study is to evaluate the effects of climate change on crop yield and nitrate leaching in an African country (Tunisia) using DSSAT model.

MATERIALS AND METHODS

Study area

For four years (2015-2018), the present work was carried out at a wheat field situated at Sidi Bouzid city (Tunisia) (Figure 1). This city is one of the largest cropping areas of wheat in Tunisia. During the four years of the study (2015-2018), various parameters needed to study the

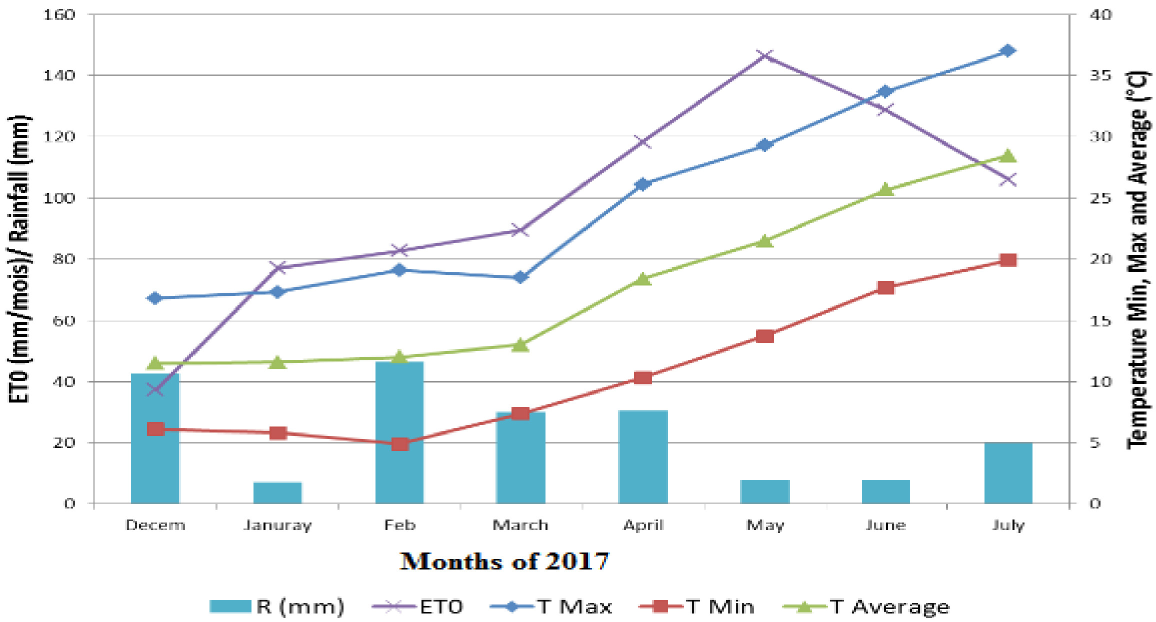

Figure 2. Variation in rainfall, temperature and potential evapotranspiration (ET0) during the culture period of wheat in Sidi Bouzid region

effects of climate change on wheat crop were collected and measured in a one plot, representative of the monitored wheat field. The climate is semi arid.

Sidi Bouzid city is mainly characterized by climatic variation expressed by rainfall, temperature and evapotranspiration (ET_0) (details in Figure 2).

We interested in wheat (major crop practiced in Tunisia) as a crop for simulation (i.e. climate change effects on this crop). In Tunisia, wheat (*Triticum aestivum*) accounts for the largest cropping area in country and a high percentage of the total wheat is grown in the semiarid regions of country. The wheat plays an important role in national food supply and any changes in wheat production due to climate change effects will pose important food supply insecurity. Furthermore, wheat production is one of the segments worst affected by the economic realities faced by the industry. Crucial plans have therefore been put into practice to elevate wheat's status as a competitive crop, not only to solidify its position as a staple food but also to strengthen food security in the country.

DSSAT model

DSSAT model presentation

The Decision Support System for Agrotechnology Transfer (DSSAT) is a set of computer programs for simulating agricultural crop growth. It has been used in over 100 countries by agronomists for evaluating farming methods. One application has been assessing the possible impacts on agriculture of climate change and testing adaptation methods. DSSAT is built with a modular approach, with different options available to represent such processes as evapotranspiration and soil organic matter accumulation, which facilitates testing different representations of processes important in crop growth. The functionality of DSSAT has also been extended through interfaces with other software such as GIS. DSSAT typically requires input parameters related to soil condition, weather, any management practices such as fertilizer use and irrigation, and characteristics of the crop variety being grown. Many common crops have their characteristics already implemented as DSSAT modules. DSSAT grew out of the International Benchmark Sites Network for Agrotechnological Transfer (IBSNAT) in the 1980s, with the first official release in 1989. Version 4, released in 2003, introduced a more modular structure and added tools for agricultural economic analysis and risk assessment. Development has continued in affiliation with the International Consortium for Agricultural Systems Applications (Jones et al., 2003).

DSSAT model inputs and calibration

The DSSAT required input information included field management practices, daily weather inputs, soil profile data, cultivar characteristics, initial soil water content and inorganic N (NO3-N, NH4-N). Management practices included planting dates and density, fertilizer application rates and times, tillage types, irrigation and the amount

Table 1. Summary of input data for DSSAT CSM-Wheat simulation

Data	Input data	Value
Crop management	Crop	wheat
	Cultivar	SB farmers
	Planting date (date)	10-April 2015
	Plant density (no. m^{-2})	160
	Fertilizer N rate (kg N ha^{-1})	60
	Tillage depth (m)	0.15
Soil data	Soil profile depth (m)	1.2
	Soil layers (cm)	0.0-20, 20-40,40-60,60-80, 80-100,100-120
	Bulk density (Mg m^{-3})	1.11
	Soil organic C (kg C ha^{-1})	1.62
	Field capacity ($m^3 m^{-3}$)	0.22
	Wilting point ($m^3 m^{-3}$)	0.12
	Saturated water content ($m^3 m^{-3}$)	0.44
	Silt content (%)	40
	Clay content (%)	15
	pH	5.6
Initial conditions	Soil water content ($m^3 m^{-3}$)	0.25
	Soil NH4 (kg N ha^{-1})	0.31
	Soil NO3 (kg N ha^{-1})	36
Climate data	Daily climate variables	Solar radiation, T_{max}, T_{min} and rainfall

and method of residue incorporation. The minimum weather inputs included daily maximum and minimum temperature (°C), daily solar radiation (MJ m^{-2}) and daily precipitation (mm). The soil profile data included field capacity (m^3 m^{-3}), wilting point (m^3 m^3), saturated water content (m^3 m^{-3}), soil bulk density (Mg m^{-3}), pH, organic C (kg C ha^{-1}), silt content (%) and clay content (%).

The DSSAT model was calibrated and evaluated with the experimental data based on the field experiments performed in the monitored wheat field situated at Sidi Bouzid city. Initial soil organic carbon was 1.74% and conventional tillage was used in this experiment. The CSM-CERES-Wheat model in DSSAT was calibrated and evaluated using wheat yield, N uptake, soil water content and soil NO3-N in the 0-20 cm from 2015 to 2018 at the studied area (Table 1). Initial conditions, as well as soil and crop management data pertinent to this study were summarized in Table 1.

The calibrated parameters were based upon the previous studies of for wheat conducted in many Tunisian areas. We then used them for both baseline and future climate scenarios to simulate the effects of climate change on wheat yields, soil water balance and soil N dynamics. Three statistical indictors were used to validate the simulation results: index of agreement (d), the mean error (E), and normalized root mean square error (nRMSE) (Priesack et al., 2006).

Climate scenarios and simulations

After integration of various data (e.g. initial condition, crop data, soil data, etc.) needed for the simulations, the validated DSSAT model was used to simulate the effects of climate change on crop yield, soil water balance and nitrate leaching in 2050 under 2 scenarios: baseline scenario and climate change scenario. For the baseline scenario, the daily climate data for 2050 year were estimated without any consideration of climate change (i.e. no climate change scenario), whereas for the climate change scenario by 2050, we assumed climate change to occur as estimated by the Tunisia Meteorological Department (TMD). This was done as follows: based on a long past daily climate data that were collected from many weather stations distributed over Tunisia, a weather generator was developed by the TMD and then used to project the daily climate data for 2050 year under two conditions: no climate change (baseline) and climate change condition (climate change scenario).

RESULTS AND DISCUSSION

DSSAT model evaluation

The results of model evaluation were showed in Table 2. As indicated in this table, a goodness of fit between measured and simulated data with the DSSAT model was assured as showed by the values of statistical parameters E, d, and nRMSE. Similar good results with DSSAT model were reported by several studies (e.g. Paz et al., 2003; Li et al., 2015; López-Cedrón et al., 2008).

The noted discrepancy between the measured and estimated data could be the result of some experimental measurements conditions, soil parameters data. In addition, complex soil physical processes were not considered to the coupled system, largely simplifying DSSAT model simulations.

Table 2. Values of the statistical indictors used to validate the simulations of DSSAT model

Data	Simulated	Measured	Sample N°	E	nRMSE	d
Grain yield (kg ha^{-1})	1120	1238	39	112	19.2	0.81
Grain N uptake (kg N ha^{-1})	32.5	42.5	38	7.8	26.1	0.83
Soil water content (m-3 m^{-3})	0.187	0.194	77	0.004	24.5	0.79
Soil NO3-N (kg N ha^{-1})	16.7	18.2	95	1.5	28.0	0.75

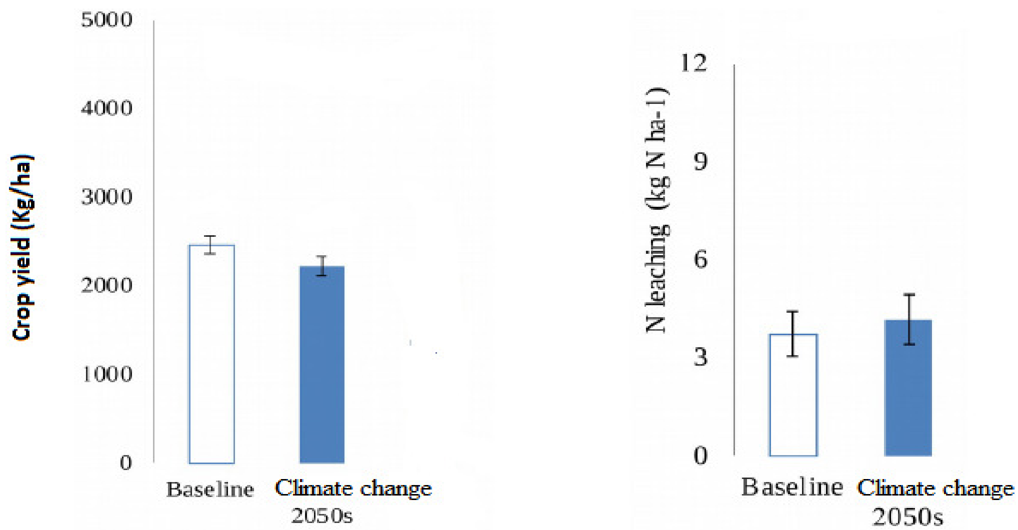

Figure 3. Effects of climate scenarios on crop yield and nitrate leaching

The DSSAT model has been used worldwide to simulate crop yield, and soil N dynamics under different management practices and various climatic conditions (Li et al 2015). The present study is a demonstration of the performance of this model under a wide range of environments and cropping practices in Sidi Bouzid area. This study was focused on the evaluation of the performance of the wheat crop to study the response of this crop to different soil management under semi-arid condition. The model evaluation is in alignment with previous international studies and could be considered acceptable comparing with other published works. Furthermore, the DSSAT model validation can be more improved with further data. Hence, future amelioration of the achieved results could be easily obtained. Indeed, a better input data adjustment to specific field conditions is important to obtain more accurate simulation results. Also, the application of calibrated model could be helpful to assess management practices for reducing N leaching in intensive irrigated areas.

Effects of climate change on crop yield and nitrate leaching

The changes in crop yield and nitrate leaching under the two simulated scenarios (baseline and climate change) were showed in Figure 3.

As shown in Figure 3, it is clear that climate changes by 2050 pose serious negative effects on wheat yield and nitrate leaching. First, compared to the no climate change scenario (i.e. (baseline scenario), wheat yield is predicted to change significantly by 2050. Second, the most critical effect was recorded for crop yield which is predicted to decrease by 28% in 2050. Third, based on these findings, it is recommended to apply the adequate fertilizer amounts to enhance soil characteristics resistance to future climate change.

The impact of climate change has also been observed on many other cultivated crops in terms of yield in many Tunisian agricultural regions. In the period of 1990-2010, several areas in Tunisia had a considerable increase in yield, because of technological improvement. But in the past 10 years, yields have leveled off in most of these regions, with even more reduction in the South domain of the country due to the harsh climate conditions. However, there was an exception for few regions like regions in the north where yield increase was observed. These observed changes in yield in North of the country can be attributed to the overall observed temperature trends and precipitation patterns. The crop growth cycles are no longer the same and are expected to change over time as long as the frequency of heatwaves continues to rise. Over the coming decades, the growing food demand driven by income growth and population must be offset by considerably increasing crops production and yields.

However, one of the threats to food security is the increasingly changing climate especially in Tunisia and also at global level. Negative impacts of climate change on crop production are expected in many parts of Tunisia. The sensitivity of the intensive farming systems is mostly low in Tunisia, this is due to the fact that, the given changes in temperature or rainfall have modest impact and because of capacity of farmers to adapt and compensate by changing management. Still, the capacity of adaption might differ significantly between cropping systems and farms based on their specialization (Li et al 2015).

CONCLUSION

In the present study, a quantitative investigation on the effects of climate change on wheat yield and nitrate leaching in a semi arid Tunisian region (SIDI BOUZID) was performed using DSSAT model. The results of this model show that the wheat yield will decrease significantly by 2050. Also, the simulation results showed that the used simulation tool (DSSAT model) is an adequate tool for evaluating the effects of climate change on wheat yield and nitrate leaching. These findings are very useful for many Tunisian regions where the wheat is produced, that are dominated by intensive land use and a remarkably low soil organic content. Also, this study is very useful for other regions due to its viability to address soil management and climate change issues over the coming decades. Besides, it is worthwhile noting that the interactions between climate change and some soil parameters were not taken into account during the simulations. In future works, including these processes would be useful for a better soil management in wheat fields.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to the farmers of the monitored field and the Regional Office for Agriculture Development of SIDI BOUZID (Tunisia) for their help and technical support.

REFERENCES

CDKN (2014). The IPCC's Fifth Assessment Report: What is in it for Africa? London: Climate and Development Knowledge Network and Overseas Development Institute

Collins MR, Knutti R, Arblaster J, Dufresne JL, Fichefet T, Friedlingstein P, Gao X, Gutowski WJ, Johns T, Krinner G, Shongwe M, Tebaldi C, Weaver AJ, Wehner M (2013). Long-term climate change: projections, commitments and irreversibility. In: Stocker TF, Qin D, Plattner K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (Eds.), Climate Change: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Haj-Amor Z, Ibrahimi MK, Feki N, Lhomme JP, Bouri S (2016) Soil salinisation and irrigation management of date palms in a Saharan environment. Environ Monit Assess 188(8): 1-17

Iglesias A, Garrote L, Quiroga S, Moneo M (2012). A regional comparison of the effects of climate change on agricultural crops in Europe. Clim. Change 112, 29–46

IPCC (2013) Summary for Policymakers. In: Stocker T F, Qin D, Plattner G K, Tignor M, Allen S K, Boschung J, Nauels A, Xia Y, Bex V, Midgley P M, eds., Climate Change (2013). The Physical Science Basis. Contribution of Working Group to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Jarvis A, Lane A, Hijmans RJ (2008). The effect of climate change on crop wild relatives. Agriculture, Ecosystems and Environment, *126*(1–2), 13–23.

Jones JW, Hoogenboom G, Porter C, Boote KJ, Batchelor WD, Hunt LA, Wilkens P, Singh U, Gijsman A, Ritchie JT (2003). DSSAT cropping system model. Eur. J. Agron. 18 235–265.

Karimi V, Karami E, Keshavarz M (2018). Climate change and agriculture: Impacts and adaptive responses in Iran. J. Integr. Agric. 17(1), 1–15.

Karmakar R, Das I, Dutta D, Rakshit A (2016). Potential Effects of Climate Change on Soil Properties: A Review. Sci. Int. 4 (2), 51-73

Li, Z.T., J.Y. Yang., C.F. Drury et al. (2015). Evaluation of the DSSAT-CSM for simulating yield and soil organic C and N of a long-term maize and wheat rotation experiment in the Loess Plateau of Northwestern China. Agricultural Systems, 135: 90-104.

López-Cedrón XF, KJ Boote, J. Piñeiro, et al. (2008). Improving the CERES-Maize Model Ability to Simulate Water deficit Impact on Maize Production and Yield Components. Agro. J. 100: 296–307.

Masutomi Y, Takahashi K, Harasawa H, Matsuoka Y (2009). Impact assessment of climate change on rice production in Asia in comprehensive consideration of process/ parameter uncertainty in general circulation models. Agriculture, Ecosystems and Environment 131, 281–291

Paz JO, Batchelor WD, Jones JW (2003) Estimating potential economic return for variable rate soybean variety management. Trans. ASAE 46 (4), 1225–1234

Priesack E, Gayler S, Hartmann HP (2006) The impact of crop growth sub-model choice on simulated water and nitrogen balances. Nutr Cycl Agroecosyst.; 75: 1–13.

Riediger J, Breckling B, Nuske RS, Schröder W (2014). Will climate change increase irrigation requirements in agriculture of Central Europe? A simulation study for Northern Germany. Environ. Sci. Eur. 26, 18. http://dx.doi.org/10.1186/s12302- 014-0018-1. (Accessed 28 January 2019)

Schlenker W, Lobell DB (2010). Robust negative impacts of climate change on African agriculture. Environmental Research Letters, 5(1), 014010–014018

UNECA (2009). Challenges to agricultural development in Africa. In Economic Report on Africa 2009 Developing African agriculture through regional value chains (pp. 117–142). Nairobi, Kenya: United Nations Economic Commission for Africa (UNECA)