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Adaptation to climate change: The impacts of optimized planting dates on attainable maize yields under rainfed conditions in Burkina Faso

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ABSTRACT

The high intra-seasonal rainfall variability and the lack of adaptive capacities are the major limiting factors for rainfed agricultural production in smallholder farming systems across Sub-Saharan Africa. Therefore, the crop planting date, a low-cost agricultural management strategy aiming to alleviate crop water stress can contribute to enhance agricultural decision-making, particularly as a climate change adaptation strategy. By considering the crop water requirements throughout the crop growing cycle using a process-based crop model in conjunction with a fuzzy rule-based planting date approach, location-specific planting rules were derived for maize cropping in Burkina Faso (BF). Then, they were applied to regional future climate projections to derive optimized planting dates (OPDs) for the 2020s (2011–2030) and the 2040s (2031–2050), respectively. Based on potential maize yield simulations driven by climate change projections and planting dates, the OPD approach was compared with a well-established planting date method for West Africa and evaluated as a potential adaptation strategy for climate change. On average, the OPD approach achieved approximately +15% higher potential maize yield regardless of the regional climate model (RCM) and the period. However, the potential yield surpluses strongly decreased from the North to the South. Regarding climate change adaptation, the combined impact of climate change and the OPD approach has shown on average, a mean maize yield deviation between −23% and 34% in comparison to the 1989–2008 baseline period. Yield deviation is found to depend strongly on the RCM and location. The RCM ensemble mean yield for the period 2011–2050 revealed a maximum decrease of 8% compared to the baseline period. On the one hand, these findings highlight the potential of the OPDs as a crop management strategy but, on the other hand, it is apparent that farmers need to combine the OPDs with others suited farming practices to adequately respond to climate change.

1. Introduction

The literature abounds with evidences that global climate change is expected to have negative impacts on socio-economical sectors, particularly in agriculture (e.g. Darwin et al., 1995; Rosenzweig and Hillel, 1998; Thomas et al., 2004; Risbey, 2008; Müller et al., 2011; Aaheim et al., 2012; Gosling, 2013). The impact of climate change on agricultural productivity is not expected to be geographically uniform. In the tropical regions, rising temperatures and changes in rainfall patterns, including increased seasonal and interannual rainfall variability, can directly cause yield reduction for most of the food crops and, therefore, reduce food production (Nelson et al., 2009; IPCC, 2014). Sub-Saharan Africa (SSA) is one of the most vulnerable regions to climate change since agriculture is heavily dominated by rainfed agriculture. Moreover, rainfed agriculture in SSA is dominated by a smallholder farming system with limited options for investment (i.e. fertilizers, pesticides, machines) and irrigation, thereby the most vulnerable agricultural system (Roudier et al., 2011; Calzadilla et al., 2013). Nonetheless, with low yield, rainfed agriculture is the main occupation and source of income for the majority of SSA population and, therefore, has a great influence on regional food security (Ringler et al., 2010; Webber et al., 2014). Amongst others, crop production changes are mainly driven by both precipitation and temperature changes (Wallach et al., 2006). Consequently, climate change will pose huge challenges to food security.

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Climate change without adaptation is projected to strongly impact on crop productivity. Indeed, temperature increases of 2 °C or more above late-20th century levels is expected to negatively affect the major crops (i.e. wheat, rice, and maize) in temperate and tropical regions, although for individual locations the signal is of medium confidence (IPCC, 2014). For temperature, Lobell et al. (2011) found that each degree-day above 30 °C reduces crop yield by 1% under optimal rainfed conditions and by 1.7% under drought conditions in Africa. On average, climate change is expected to decrease crop yields by 18% and 22% by mid-21st century in Southern Africa and across SSA, respectively (IPCC, 2014). Simulations based on a warmer climate change scenario have shown that maize yield is expected to be decreased by more than 5% for 2050 in East Africa, particularly in the northernmost regions (Thornton et al., 2010). In addition, a meta-analysis of 16 studies over West Africa by Roudier et al. (2011) has highlighted that overall climate scenarios and models, countries and crops, projected impacts are in general slightly negative (−10%). Likewise, from a systematic review and meta-analysis of 52 publications, Knox et al. (2012) found that projected mean change in yield of −5% (maize), −15% (sorghum) and −10% (millet) are expected by 2050 across Africa. Faced with the underlying threats and challenges, management decisions regarding cultural practices and inputs will play a crucial role in the enhancement of crop production in SSA (Lobell et al., 2008; Tingem et al., 2009)

Technologies or approaches that have the potential to support farmers in the fields of soil conservation and water management are likely to make a difference for food security and agricultural development in SSA. However, since farmers' options for coping and adaptation are particularly limited in that region (Antwi-Agyei et al., 2013), it is necessary to carefully select crop management strategies that account for capacity constraints and therefore, can efficiently help farmers adapting to climate change. Many studies have stressed farmers' coping and adaptation strategies in SSA (e.g. Roncoli et al., 2001; Kaboré and Reij, 2004; Barbier et al., 2009; Zampaligré et al., 2014; Webber et al., 2014). Among the broad range of crop management strategies, strategies fitting in the pool of low-cost strategies have been adopted by farmers. Thus, low-cost strategies such as stone bunds, micro-water harvesting (*Zaï*) and water harvesting (*Demi-Lune*) have been largely adopted by farmers (Kaboré and Reij, 2004; Sawadogo, 2011). In fact, the high level of poverty in SSA leads farmers to abandon some crop management technologies and approaches, even though they are proven to be efficient. Thereby, only those strategies which require little resources in terms of labor and money have a chance to engage a large number of farmers. Given farmers' capacity constraints and the high variability of the onset of the rainy season in SSA, approaches to better estimate the onset of growing season for planting crops might be valuable options as crop management strategies.

Adapted crop planting date estimation is crucial for rainfed agriculture and a challenging task for scientists in SSA. Efforts have been made to estimate the suitable time for planting crops. Approaches which use crop-generic assumptions in combination with the onset of the rainy season are the most often used in SSA (e.g. Stern et al., 1981, 1982; Sivakumar, 1988; Dodd and Jolliffe, 2001; Diallo, 2001). They have the potential to alleviate crop failure caused by water stress during the juvenile stage of crop development. Although these approaches have proven to be useful in SSA (Sivakumar, 1992), they do not account for the risk of prolonged dry spells during the following crop development stages. For this reason, Laux et al. (2010) highlighted that crop planting date have to aim to minimize water stress during the entire growing period to significantly increase the crop production. Likewise, Waongo et al. (2014) stressed that optimized planting dates (OPDs) have the potential to improve crop production in SSA. The latter study demonstrated that the OPDs achieved higher potential yield for maize cropping in Burkina Faso. Besides, the OPDs have the potential to narrow inter-annual variability of maize yield. Moreover, this study highlighted that such management strategy which required no implementation costs from farmers might have the consent of farmers for uptake. However, present climate data are concerned in the aforementioned study and the performance of the OPDs in the context of climate change is still an open question. Apart from that, the simulation of the impacts of regional climate change using potential adaptation strategies can help support stakeholders for evaluating climate change adaptation options at finer spatial scale rather than global scale. Finer scale climate impact studies would, however, require regional climate data, which are commonly derived from RCMs and statistical methods.

Nested modeling (i.e. dynamic downscaling modeling) and empirical-statistical downscaling approaches are the most commonly used (Moriondo and Bindi, 2006; Jung and Kunstmann, 2007) to derive climate data at finer scale. The first approach used global circulation models (GCMs) outputs to provide boundary conditions for RCMs with higher spatial resolution (Giorgi and Mearns, 1999). The second approach combines assumptions and statistical techniques to downscale local and regional climate variables from GCM outputs (e.g. Bárdossy, 1997). Because of the crucial role of climate models in the process of decision-making, these two approaches are intensively used to derived regional climate change data which are subsequently used for regional climate change impact studies. For instance, the ongoing Coordinated Regional Climate Downscaling Experiment (CORDEX) is using the nested modeling approach in combination with the latest developed GHG emission scenarios, the Representative Concentration Pathways (RCPs) (Moss et al., 2008, 2010) to produce projected future climate data at regional scale for different regions worldwide. Thus, in light of the regional climate change simulations over Africa domain – CORDEX-Africa (e.g. Nikulin et al., 2012), further impact studies are necessary to explore combined effects of climate change and potential adaptation strategies in Africa.

By using regional climate change projections from CORDEX-Africa, the aim of this study is (1) to evaluate the comparative benefits of the OPD approach against a rainfall-based planting date approach in the context of climate change and (2) to assess the potential impact of regional climate change in combination with the OPDs on maize productivity. For this purpose, regional climate change data from eight RCMs and two RCPs are used to drive a crop model. First, RCM control runs (CTRL) are analyzed to have a comprehensive overview of the performance of RCMs for the study area. Second, potential maize yield is simulated using the General Large Area Model for annual crops, GLAM (Challinor et al., 2004) and RCM outputs for the GHG emission scenarios RCP4.5 and RCP8.5 (Detlef et al., 2009). Planting date computation approaches of Diallo (2001) and Waongo et al. (2014) are used as crop management strategies in the process of crop yield simulation. Then, based on the two planting date strategies, a comparative analysis of the simulated crop yield is performed and the OPD approach is evaluated as climate change adaptation strategy.

2. Study area

Burkina Faso (BF) is a West African country located in the mid-west SSA region. It covers an area of about 274,200 km^2 and lies between 9 and 15.5° N and between 6° W and 3° E. The country is mainly flat, with a mean altitude of about 300 m a.s.l. (Azoumah et al., 2010). Its climate is characterized by two distinct seasons: a rainy season and a dry season. Rainfall distribution across the country follows predominantly a southward gradient: mean annual precipitation decreases from more than 1100 mm in the South to