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Multi-genes programing and local scale regression for analyzing rice yield response to climate factors using observed and downscaled data in Sahel

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ABSTRACT

This study investigated the yield response to climate variables towards the causal interdependency analysis between upland rice yield and major climatic variables in three provinces located in Sahelian region, Burkina Faso. Sahel is amongst the most vulnerable regions to weather stressors largely attributed to its typical climatic condition and low capacity to adapt. When promoting climate adaptation measures, data limitation makes very hard to analyze crop yield responses complexity to local weather variables. Therefore, this study attempts to assess the upland rice yield response to rains and temperature factors by using multi-gene-expression programing (GEP) and a conventional local scale time series regression approaches supported by ground station data. Statistically, the results suggested that there is a substantial climate variables combination factors affecting rice yield. It was found that 31%, 37% and 52% of the variance in year-to-year rainfed rice yield changes were explained by the changes observed in temperatures and precipitation variables in the study area. It was observed that a 1 °C increase of temperature combined with 200 mm decrease of rains caused yields reduction from 7% to 21%. The results attested that GEP model is a powerful tool in downscaling (CC = 0.88 – 97, RRSE = 0.474 – 0.261), and in expressing yields responses function (CC = 0.88, RRSE = 0.472 and RAE = 0.070) to climate variables, deployed for the first time in yield coding in Sahel. Rain is the most important variable in the yield model counting for 70%, while maximum temperature counts for 29.3%. The findings suggested that a robust climate adaptation measure should be axed on rainwater management.

1. Introduction

Managing crop yield response with climate stress factors is a crucial step in developing the most appropriated adaptation measure to climate change in Sahel. Climate change has emerged as a key concern for agricultural sector (Sarker et al., 2012), and Traore and Owiyo (2013) have reported severe impacts on livelihood in Sahel region. Temperatures are expected to rise, and the precipitation patterns and quantities will likely change (IPCC, 2007), and the frequency of drought extremes events will also increase (Roudier et al., 2011), consequently agriculture sector will take closely hits. Impacts will be severe where livelihoods are highly dependent on rainfed production, and people have very low adaptive capacity. Crop yields will substantially be impacted by climate adverse.

Therefore, agriculture sector response to climate change requires the development of a right adaptation strategy which implies a good knowledge of the interaction existing between climate parameters and crop yields pattern. Doorenbos and Kassam (1979) defined the yield by the ratio of actual over potential evapotranspiration, subjected to weather conditions. As reported by Jalota et al. (2013), it is the integrated effect of several climate parameters such as temperature, CO_2, rainfall, solar radiation, relative humidity, etc. that determine the crop yield.

Rice crop specially, one of the most important major staple foods in Africa needs suited rainwater management practices. Rainwater management based on a good understanding of the causal interdependency relationship between crops and climate variables is very relevant for adopting effective adaptation measures. In the past, investigations focused mostly on crop yield and field water balance (Asseng et al., 1997), or yield responses to water management strategies (Mo et al., 2005), yield response with irrigation amount (Chen et al., 2010; Garg and Dadhich, 2014), and crop yield function

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to drought response factor (Ferreira and Gonçalves, 2007). However, there are still huge knowledge gap on causal interdependency between crop yield and climate variables under a typical Sahel arid environment consideration. Rice production is subjected to both rainfall amount and distribution, exacerbated by climate variability, consequently affecting yields. With the predicted increase of temperature (IPCC, 2007) and the erratic pattern of rainfall which induces drought, rice yields are seriously affected year by year, and will drastically decrease. In the past 10 years, the growth of rice yield has dropped below 1% per year worldwide, while 1.2% increase is required to meet the growing demand for food (Normile, 2008).

There are substantial published researches that informed on the climate adverse impacts on crops at global scale (Schlenker and Lobell, 2010); although they are subjected to uncertainties. Contrary to global scale, local scale analyses are poorly referenced in literature. However, local scale time series approach is very useful for a comprehensive view of climate variability in specific agro-climatic zone. A conventional (empirical) statistical regression model is often used to evaluate locally a causal relationship between yield time series and climate. According to Lobell (2010), these models are particularly useful in situations where there is insufficient data to calibrate more process-based models, and where detailed spatial datasets are not available, both of which are accurate descriptions of the situation in many developing countries. The approach has less data requirements, and can be readily implemented for large geographic areas especially in an area as Burkina Faso. Time series approach relies on predicting future responses based on past relationships. The model's main requirement is the availability of sufficiently long time series (at least 20 years) of both weather and crop harvests (Chen et al., 2004). The approach analyzes the impact of year to year effects of climate change on crop yield for a specific site. It examines the short-run impact of climate change on yields assuming that the climate change was not fully anticipated (Hertel and Rosch, 2010).

Indeed, there are several other outstanding studies that have suggested the use of downscaled variables to assess climate impacts on crops. Downscaling has been proven to be useful tools in climate impacts studies for producing information from coarse-resolution to local scale (Wilby et al., 2004). Nkomozepi and Chung (2012) used it to assess impact on maize water and irrigation requirement in Zimbabwe. Harmsen et al. (2009) downscaled precipitation and temperature data using the DOE/NCAR PCM global circulation model projections and evaluated the seasonal climate change impact on crop yield in Puerto Rico. Mostly, in climate impact studies, the raw outputs from GCM are too coarse that may prevent them for being applied directly to analyze the behavior of local crop yield under climate variable change. To explore yield response function to current and future climate variables, Gene-expression programing computation model (GEP) was employed in this study, as the program has been used with success in statistical downscaling and agriculture engineering research in the recent past. It was recently reported that GEP can generate local scale climate data information from the global circulation model outputs (Tung et al., 2009). Britaldo et al. (2013) used it to calibrate land-use change models, and Traore and Guven (2011, 2012) deployed it for modeling evapotranspiration for irrigation purposes. The success of GEP is due to the model ability to solve nonlinear problems and explain the relationships mathematically. With climate changes threats in Sahel that required proper adaptation for rainfed crops, GEP model is very much desirable tool in formulating yield response expression as a function of climate variables in order to support the development of climate change adaptation strategies, locally. Using GEP, it is crucial to diagnose the potential implication of long-term climate change scenario on crop yield expression.

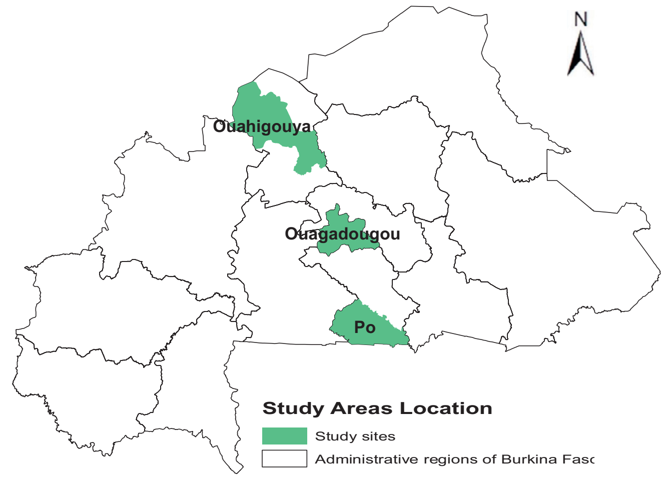

Fig. 1. Location of the study area.

This study is the first of its kinds in Sahel, and is aiming to deploy multi-gene-expression programing (GEP) and a conventional local scale time series regression approaches for analyzing the yields response to both observed and downscaled temperature and rains variables. The GEP is used in the study to develop algebraic formulations that express the interdependency between most influential climatic variables and observed crop yields at a local scale. Upland rice yields were chosen versus GCM downscaled outputs and local weather parameters to analyze the yield responses. The findings of this study will assist policymakers and stakeholders in their decision-making vis-à-vis to climate change adaptation strategies in a timely and robustly manner.

2. Materials and method

2.1. Location and data collected

2.1.1. Study area

The study area covered three provinces of Burkina Faso: Ouagadougou, Ouahigouya and Po (Fig. 1). In Burkina Faso, rainfall depends on the West African monsoon which takes place during the boreal summer as the result of differential warming of the ocean (the Gulf of Guinea) and the land surface. The West African Monsoon varies considerably on inter-annual and inter-decadal timescales: the large-scale drought of the 70s and 80s (Dai et al., 2004) stands at the greatest regional climatic signal over the second half of the last century in terms of precipitation (Trenberth et al., 2007) and affects strongly the country. Naturally, such variability has had direct consequences on crop production, highlighting the country's vulnerability to potential change of the West African Monsoon due to climate change. The main climatic features are the low rainfall that is spatially and temporally variable, the high temperatures, and high evapotranspiration, particularly during the dry season.

2.1.2. Observed and GCM data

The observed data were comprised of monthly and annual precipitation, minimum and maximum air temperatures data. The meteorological data were collected from 1980 to 2011. Meanwhile, the observed yield data were collected from 1985 to 2010. Located in the Sahelian zone, Ouahigouya registered an average annual rainfall of less than 600 mm (Table 1), and since the 1980 has experienced serious drought shocks. Ouahigouya is characterized by a wide margin in its maximum and minimum temperatures and had lower rice yields compared to Ouagadougou and Po (Fig. 2). The