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Climate impacts on palm oil yields in the Nigerian Niger Delta

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ABSTRACT

Palm oil production has increased in recent decades and is estimated to increase further globally. The optimal role of palm oil production, however, is controversial because of conflicts with other important land uses and ecosystem services. Local conditions and climate change affect resource competition and the desirability of palm oil production in the Niger Delta, Nigeria.

The objectives of this study are to (1) establish a better understanding of the existing yield potentials of oil palm areas that could be used for integrated assessment models, (2) quantify for the first time uncertainties in yield potentials arising from the use of climate output data from different Global Circulation Models (GCM's) with varied West African Monsoon (WAM) system representations forced to the same Regional Climate Models (RCM's). We use the biophysical simulation model APSIM (Agricultural Production Systems Simulator) to simulate spatially variable impacts of climate change on oil palm yield over the Nigerian Niger Delta. Our results show that the impact of climate change on oil palm yield is considerable across our study region. The yield differences between the IPCC RCPs were small. The net impact of climate change on oil palm is positive and is dynamically inconsistent. There is no significant change in the simulated yield arising from the differences in the forcing's data. We found the most effective strategy for oil palm yield optimization under climate change to be shifting of sowing dates and introduction of irrigation.

1. Introduction

Earth's ecosystems have been changing due to the emission of anthropogenic greenhouse gases (GHG's) which has resulted in an increase of global mean temperature, a change in precipitation regimes and an increasing frequency of extreme weather events (IPCC, 2015; Padgham, 2009). The oil palm belt of the Niger Delta, Nigeria, has been an area prone to climate change. Temporal air temperature trend has remained on the increase for the past 105 years (since 1901); temperatures have increased by 1.2 °C in the coastal cities of the Niger Delta during this period (Odjugo, 2010).

Climate change is predicted to have a great impact on agriculture and thus on global food security in the coming decades (FAO, 2016). The impact of climate change on the main crops in West Africa are controversial (Mereu et al., 2015), and the region had been identified to be a hotspot of climate change (IPCC, 2015). Estimates include both positive or negative impacts depending on the employed GCM, the climate scenario, and the chosen crop model (Mereu et al., 2015; Roudier et al., 2011). Previous studies to understand crop yield potentials under climate change regime in the Niger Delta region have focused on statistical approaches and were mostly based on single climate scenarios, not considering differences in GCM's forcing data and rarely considering the range of various IPCC (Intergovernmental Panel on Climate Change) Representative Concentration Pathways (RCPs).

While there is general agreement among GCM's about regional temperature changes, large uncertainties remain regarding the projections of the monsoon system which triggers precipitation in the region (Niang et al., 2014). Many of the studied crops were found to be more sensitive to water limitation than to temperature change. So far, analyses of climate change impacts at regional level in the Niger Delta have been done using statistical models (Idumah et al., 2016), which are not able to capture the entire sub-seasonal weather variability and are limited in their ability to project changes into the future. Such statistical models often assume stationarity of the relation between crop and weather and are not applicable outside the range of the historical weather conditions within which they were developed (Challinor et al., 2009). Furthermore, statistical models have limited explanatory power, and are not applicable to the development of climate

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change adaptation measures (Challinor et al., 2009; Müller et al., 2011; Rosenzweig et al., 2013). Improved understanding of climate change impacts can, however, be derived from outputs of biophysical modelling approaches (Araya et al., 2015). These biophysical modelling approaches can facilitate the development of potential adaptation and mitigation options that will benefit agriculture and enhance energy production when energy crops are grown for bioenergy (Holzworth et al., 2014). Biophysical modelling at various scales (e.g. Challinor et al., 2009; Holzworth et al., 2014; Hoogenboom et al., 2004) have been deployed on various occasions to assess the impacts of climate change on crop production and/or to develop agro-management strategies for adaptation to future climate change events (e.g., Challinor, 2009; Holzworth et al., 2014; Kim et al., 2013; Lehmann et al., 2013; Masutomi et al., 2009). Biophysical models have been widely used to evaluate climate change impacts on crop production globally, but rarely applied to the oil palm belt of the Niger Delta region. In response to this research need, this study employs the biophysical simulation model APSIM (Agricultural Production Systems Simulator) to (1) investigate and present a better understanding of the regional variability of yield potentials of oil palm under different climate change scenarios across the Nigerian Niger Delta based on existing oil palm areas (Okoro et al., 2016) that could be used for integrated assessment models, and (2) to examine the effect of output of different GCM forcing data with varied West African Monsoon (WAM) representations in regional impact models (e.g. APSIM). APSIM had been widely used in farming systems which includes agroforestry to simulate yield, crop/tree growth and development based on environmental variables (e.g. Amarasingha et al., 2015; Anwar et al., 2015; Bayala, 2016; Holzworth et al., 2014; Huth et al., 2002; Lv et al., 2015; Matere et al., 2015). Finally, several adaptation strategies (e.g., full irrigation, adjustment of planting date, planting depth and density, fertilization) are evaluated with the aim to reduce the negative impact of climate change on palm oil production.

2. Study area

2.1. Description of study area

The Niger Delta region is located in the southern part of Nigeria. The broader Niger Delta region consists of nine states (Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers) and 185 local government areas (Fig. 1). It covers an area of about 70,000 km^2, i.e., about 7.5% of Nigeria's total area. Ondo state has the highest average altitude (183 m). The Niger Delta region's climate is characterised by two distinct hygric seasons: the rainy season (April to mid-October) and dry season (mid-October to end of March), whilst seasonal temperature variations are low. The region has a tropical savanna climate at higher elevations and rainforest climate at middle and lower elevations. Daily average temperature within the region is mostly above 18 °C and monthly temperatures show a low range throughout the year. The annual rainfall is in the range of 1500–3000 mm.

Oil palm grows well within the temperature range of this region and requires about 120–150 mm of water per month to meet its water needs. The planting of oil palm in this region mostly commences around late March till June, and could as well be grown during the summer period with sufficient irrigation. Harvesting takes place throughout the year with an interval of 11–14 days.

3. Data and methods

We used the APSIM model, which requires daily weather data, and detailed soil and management information. Both the model and data sources are described below.

3.1. Crop model

APSIM is a modelling framework that allows individual process-based models to be combined into a farming system simulation. The structure of APSIM includes biophysical modules, management modules, data input and output modules (Keating et al., 2003), and it is possible to add and remove modules based on the user's interest (Kirschbaum et al., 2001). Component-based design in APSIM enables models to interact via a communication protocol (Moore et al., 2007). APSIM has models for over thirty crop, pasture and tree species as well as for the main soil processes affecting agricultural systems. One of the main advantages of APSIM is its ability to integrate models derived in fragmented research efforts.

3.2. APSIM Oil Palm

APSIM Oil Palm (Huth et al., 2014) has been developed to simulate the growth of fronds, stem, roots and bunches of oil palm in response to inputs of daily weather, soil and management practices. The climate data requirements include daily minimum and maximum temperature, rainfall and solar radiation (Kirschbaum et al., 2001). The Oil Palm model calculates the growth, development, resource use and organic matter flows for the plant and communicates this information to the soil and management models within the simulation.

The existing parameterization of the APSIM Oil Palm model was based upon data from Papua New Guinea. This model parameterization was adapted to Nigerian planting material using data from the literature and local plantations. The potential frond appearance rate and maximum bunch size were adapted using yield and bunch size information for planting material used within the study region. All other palm parameters were taken from Huth et al. (2014).

Further details on the individual modules within APSIM Oil Palm are provided by Huth et al. (2014). Further information on APSIM and the community development framework can be found at www.apsim.info.

3.3. Model setup

We calculated daily weather data of rainfall, maximum temperature (Tmax) and minimum temperature (Tmin) from 1997 to 2014 from monthly averages obtained from Okomu Oil Palm Plc (5.07N–5.25N and 6.16E–6.23E). The scaling disaggregation method was employed using daily rainfall, Tmax, Tmin estimates from National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resource-POWER (Stackhouse et al., 2014) while conserving the monthly totals. The daily solar radiation data from 1997 to 2004 was obtained from NASA POWER and used uncorrected.

3.4. Soil data and soil properties

Soil textural data were obtained from the ISRIC—World Soil Information/AfSIS project (Hengl et al., 2015). The soil volumetric water content at −33 kPa and −1500 kPa as required by APSIM were calculated from these data following Minasny and Hartemink (2011) (see Table 1).

3.5. Crop data and management

Crop management data used for APSIM calibration were obtained from Okomu Oil Palm Plc (See Table 2). APSIM validation was undertaken using also data from the Okomu Oil Palm Plc for the period 2003–2013. Data included fresh fruit bunch yield (FFB, t/ha), mean bunch size (kg) and mean bunch number (/palm). Plantation records were used to derive representative data for crop