The impact of climate change on Yam (Dioscorea alata) yield in the savanna zone of West Africa

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A B S T R A C T

This study elucidates the effects of the projected climate variables and CO2 on yam yield in relation to three major soils in the Upper Ouémé basin (Benin Republic) on yam (Dioscorea alata) yield. The impact of the SRES climate scenarios A1B and B1 based on the output of the GCM ECHAM5 downscaled with the REMO model and the A1B scenario output of the GCM HADC3Q0 downscaled with the RCM, SMHIRCA and HADRM3P were analyzed. The A1B scenario, as expected with highest increase in temperature and extreme decline in rainfall, exhibited a decrease of 33% in yield until 2050 under ambient CO2 concentration (350 ppmv), while under B1 around 27% decline was registered. Whereas, decline under A1B emission scenario of SMHIRCA and HADRM3P accounted 19% and 18%, respectively. The soil type “Ferruginous soils impoverished without concretions” (S1) was most sensitive to climate change registering a decline of 48% in yam yield in the decade 2041–2050 followed by “Ferralitic soils” (S2) and “Raw mineral soils” (S3) showing a decline of 36% and 33%, respectively under A1B scenario derived from REMO model. Analysis of the growth constraints suggest that besides water stress, the indirect effect of reduced rainfall on the release of nitrogen from soil organic matter and hence nitrogen deficiency in the yam crop was the major constraint in the S1 soil type.

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1. Introduction

Climate change is likely to change the existing agricultural systems (Rosenzweig and Parry, 1994; Parry et al., 2004; Olesen et al., 2007; IPCC, 2007) and has gained significant attention over the past few decades due to its detrimental effect on food security. The anticipated increase in both climate variability and extreme events may influence crop production and agricultural profitability (Wheeler et al., 2000; Schär et al., 2004; Leckebusch et al., 2007; Siva Kumar and Hansen, 2007). According to the IPCC Fourth Assessment Report (IPCC, 2007), global mean temperature has risen approximately 0.74 °C in the last 100 years and is likely due to anthropogenic activities that have elevated greenhouse gas concentrations to unprecedented levels. In case of agriculture, changes in temperature, rainfall, atmospheric CO2 concentration, all can have significant effects on crop production, rendering it perhaps the most sensitive to climate change among all key economic sectors (Downing, 1996; Watson et al., 1996). This is of particular importance for yam crop (Dioscorea spp.) in Republic of Benin as it constitutes the major staple crop for many subsistence farmers and their source of income. Yam is the third most important tropical root crop after cassava (Manihot esculenta Crantz,) and sweet potato (Ipomoea batatas L. Lam.) in West Africa, Central America, the Caribbean, Pacific Islands and Southeast Asia. Although, there has been a decline in yam production relative to cassava and rice in Africa, yam is such a preferred staple food that, bearing in mind population increases, demand will remain and the absolute production will rather increase (Srivastava and Gaiser, 2008). Thus, the ability to meet the future demand may hinge upon proper assessment of medium- and long-term yam production vulnerability to climate change and the measures taken to adapt accordingly.

This work addresses the global climate change impacts on tuber crops in a tropical savanna region by using a simulation approach to assess the long-term regional-scale changes in yam production under A1B and B1 IPCC SRES scenarios. In addition, the vulnerability of yam to climate change in relation to the soil conditions is investigated.

2. Methods

The approach adopted in this study was to assess the climate change impact on yam (Dioscorea alata) production in the Upper Ouémé basin, a typical catchment within the sub-humid savanna zone of West Africa by combining regional climate model outputs, a
regional soil database, and regional cropland database with the EPIC (Environmental Policy Integrated Climate) crop growth simulation model. Comparison of EPIC output for baseline (1961–2000) and time horizon (2001–2050) provides an idea and insight into how yam yields may change under the IPCC SRES A1B and B1 scenarios. The SRES A1B and B1 have been chosen as the primary scenarios to investigate since they portray a good range of possibilities between a pessimistic and optimistic projection. The more pessimistic scenario A2 has not been included in the planning since: (i) it is not expected to be much different from A1B in the near-future time horizon (in this early period, A1B is actually above A2 in terms of temperature and then the median estimates cross); (ii) the uncertainty around A1B overlaps with A2; (iii) the impact on agriculture is expected to be more important by an increase in extreme events rather than in the temperature between A1B and A2 (thereby limiting the added value of including an extra SRES in this analysis). We considered not to assess the climate change impact in far-future time window on yam yield to avoid degree of uncertainty in far future as we are not accounting for the most likely adaptation (such as genetically improved varieties, technological innovations and land use change) strategies in this assessment that which takes place. However, statistically speaking, it would be better to take longer periods to characterize the climatology.

Little is known about the effect of the planting date on the underlying mechanisms controlling yam growth and yield. A field study from the French Antilles showed that in the absence of water and nutrient stresses, the planting date had only a slight effect on the total above-ground biomass and yields of water yam (Clairon and Zinsou, 1980). Onwueme and Haverkort (1991) reported that for the yam belt of West Africa tuber initiation usually occurs about two months after emergence regardless the planting date, which is due to the very small variation of daylength in equatorial regions (Marcos et al., 2011). In view of this we maintained the planting date for yam constant in the simulations to avoid the effects of photoperiod when comparing the baseline and future scenarios. Changes in temperature and precipitation are the variables analyzed in this study to assess the effects of future changes on yam production taking also into account the response of soil types to these changes. All other factors influencing crop yield are assumed to be unchanged over time.

2.1. Study region and simulation units

The Upper Ouémé basin covers an area of 14,500 km² within the Republic of Bénin. The climate is tropical sub-humid with a mean annual temperature of 26.8 °C and mean annual precipitation of 1150 mm (Mulindabigwi et al., 2008).

The catchment has been subdivided into 121 sub-basins. Each sub-basin is composed of up to 15 hydrological and more than 30 agronomic response units of variable size which constitute the spatial simulation units (LUSAC = Land Use-Soil Association-Climate units). A total of 7200 simulation units were identified. The LUSAC units have variable surface and represent an area with similar climate conditions, soil characteristics and a representative crop and soil management. All data were gathered in the database of the spatial decision support system PEDRO (Protection du sol Et Durableté des Ressources agricoles dans le bassin versant de l’Ouémé) (Enders et al., 2010; Gaiser et al., 2010), which combines the agro-ecosystem model EPIC with the hydrological model SWAT (Soil Water Assessment Tool) (Arnold et al., 1998). PEDRO provided representative soil profile data for the dominant soil type of each of the 38 mapping units of the soil association map. Topographical information for each sub-basin including average slope inclination and length were extracted from the DEM (Digital Elevation Model) provided by the global (Satellite Radar Topographic Mission) SRTM (Satellite Radar Topographic Mission).

![Fig. 1. Workflow and aggregation procedure for the up-scaling of EPIC simulation results to the sub-basin and district level.](Image)

Tuber yield of yam was calculated within each LUSAC for the period of 40 years (1961–2000) and 50 years (2001–2050). Then, tuber yields were aggregated from the LUSAC level to the basin level according to the procedure described by Gaiser et al. (2009) (Fig. 1) taking into account the area share of the LUSACs within the basin in order to obtain the average grain yield $Y_i$ as

$$Y_i = \sum_{i}^{N} Y_i \times \text{Area}_i$$

with

$Y_i$ is the average tuber yield over the basin in t ha$^{-1}$ a$^{-1}$

$Y_i$ is the tuber yield in LUSAC unit $i$ in t ha$^{-1}$ a$^{-1}$

Area$_i$ is the decimal area percentage of LUSAC unit $i$ in the basin.

3. EPIC model

EPIC (Environmental Policy Integrated Climate) is a biophysical model that can simulate crop biomass production, soil evolution, and their mutual interactions given detailed farm management practices and climate data (Williams, 1995). EPIC calculates daily potential biomass as a function of solar radiation, leaf area index (LAI), and a crop parameter for converting energy to biomass. The potential plant growth is driven by photosynthetically active radiation. The amount of solar radiation captured by the crop is a function of LAI and the amount of solar radiation converted into plant biomass is a function of the crop-specific radiation use efficiency. The daily potential biomass is decreased by stresses caused by water shortage, temperature extremes, nutrient insufficiency and soil aeration inadequacy. The daily potential biomass is decreased in proportion to the severity of the most severe stress of the day. Crop yield of cereals is estimated by multiplying above-ground biomass at maturity by a water stress adjusted harvest index. The detailed description of the EPIC model can be found in Williams et al. (1989). The EPIC model simulates the effects of temperature on crop yield mainly in two ways. First, the daily potential biomass is reduced by temperature stress, as mentioned earlier. Second, EPIC uses heat unit accumulation to determine phenological development and the duration of the crop cycle. Heat units are calculated daily as the difference between mean air temperature and a crop specific base temperature, and accumulated over time from planting to maturity. In addition, temperature is a determinant of soil evaporation and crop transpiration; hence, it affects the availability of soil moisture that sustains crop growth. The EPIC model
simulates the effects of precipitation on crop yield using a concept of water stress. When crop water demand exceeds soil moisture supply, a water stress day occurs and potential crop yield is reduced by a certain amount. In this study, a calibrated EPIC model (version 3060) for yam (*Dioscorea alata*) for the study region (Srivastava and Gaiser, 2010) has been used for simulating the effect of climate change on its production. The harvest index value used for yam in this study was measured in field experiments conducted in the studied region (Srivastava and Gaiser, 2008). EPIC (version 3060) has the capacity to simulate the CO₂ – fertilization effect on RUE and evapotranspiration (ET) to account for increased photosynthesis and reduced ET in plants due to reduced stomatal conductance under conditions of elevated CO₂ concentrations (Stöckle et al., 1992a,b), thereby improving water use efficiency (Chavas et al., 2009). EPIC also dynamically accounts for soil C interactions in response to land use change, soil management, and climate change, and long-term field experiments have verified reasonable precision in representing these interactions in many regions of the world (Tan and Shibasaki, 2003; Izaurralde et al., 2006).

In order to test the sensitivity of the model to different cardinal temperatures, daily stress index to changes in daily mean temperature and to crop optimum temperature has been calculated between reference run (1961–2000) and climate scenario (2001–2050) which is approximately 2 °C does not affect the temperature stress index for biomass production of yam (Fig. 2). This could be attributed to the following reasons:

(i) The daily temperatures of reference runs (i.e., time horizon 1961–2000 and 2001–2050) are close to the optimum temperature of yam (Fig. 3).

(ii) On most of the days during the growing period of yam there are the other daily stress factors (water stress) which are higher than the temperature stress (data not shown).

The reason of choice of EPIC model for the present study at a glance:

(i) EPIC is the only model which is calibrated for *D. alata* in this agroecological zone, and considers at the same time the simultaneous effect of temperature, CO₂ and drought stress (Srivastava and Gaiser, 2010).

(ii) The model has been applied and used extensively to simulate crop growth and yield for a range of crops such as maize, rice in diverse environments including local environments found within the Benin Republic showing the robustness and accuracy. The model has been applied for yam (Srivastava and Gaiser, 2010), cassava, millets, sorghum (Adejuwon, 2004) and maize with reasonable accuracy except for sites with highly acid soils (Gaiser et al., 2010). In the present study, EPIC version 3060 has been used at the regional scale within the same catchment where the calibration was done.

### 3.1. Validation and simulations performed in the study

The EPIC model has been validated at the global scale for wheat with satisfactory results (Priya and Shibasaki, 2001; Tan and Shibasaki, 2003). EPIC has also been validated extensively in many regions of the world under varying climates, soils, and management practices, including US (Cavero et al., 1998; Chung et al., 1999; Izaurralde et al., 2003; Legler et al., 1999), Canada (Puurveen et al., 1997; Roloff and de Jong, 1998), Italy (Rinaldi, 2001), Argentina (Bernardos et al., 2001), Great Britain (Boardman and Favis-Mortlock, 1993), India (Priya and Shibasaki, 2001) and subhumid West Africa (Gaiser et al., 2009). A total of four climate scenarios based on A1B and B1 emission scenarios with different RCM output has been simulated in this study: The baseline period (1961–2000) with simulated historical data and the time horizon (2001–2050) under IPCC SRES A1B and B1 scenario conditions. For the baseline simulations, the CO₂ concentration was set at 350 ppmv. Crop management was defined in the simulations according to the prevailing, traditional field activities for long cycle varieties of yam which are dominant in the study region. The start and end of the growing season were set to February and December, respectively. Plant density was set at 0.88 plants m⁻². Potential heat units (PHU) were estimated as 1945 °C-day using the average of two years growing degree days (GDD) accumulation during the growing season (i.e., planting to maturity) for yam (Srivastava and Gaiser, 2010). *Sesbania* spp. was used as a fallow crop for the baseline and scenarios simulations with the climate data derived from REMO regional climate model whereas Switch grass (*Panicum virgatum*) was used as the fallow crop in the simulations for the SMHIRCA and HADRM3P regional climate models. The start and end period of the growing season of fallow crops were set to March and February, respectively. Replanting was done every year to mimic the process of re-growth after the dry season. Plant density was 10.0 plants m⁻² with PHU of 5000 °C-day. No mineral fertilizer was applied in the simulations.

### 4. Results and discussion

#### 4.1. Climate change projections

The input parameters for the climate scenarios were provided by Paeth et al. (2008) using the regional climate model REMO driven by the IPCC SRES scenarios A1B and B1. For the purpose of model inter-comparison, additional outputs of two other RCMs (HADRM3P and SMHIRCA) were used (ENSEMBLES, 2010; Hewitt and Griggs, 2004). REMO is a regional climate model that is nested in the global circulation model ECHAM5/MPI-OM. The other two
regional climate models, HADRM3P and SMHIRCA, were driven by the GCM HADCM3Q0. The advantages of the new set of REMO simulations are: (1) a comparatively high resolution of 0.5°; (2) the consideration of spatial patterns of future land use change and (3) a transient forcing from 1960 to 2000 and three ensemble runs for two scenarios from 2001 to 2050, reflecting the uncertainties due to unknown initial conditions. The output of the HADRM3P and SMHIRCA simulations has approximately the same resolution with transient forcing from 1960 to 2050, but land use changes were not taken into account. For these two RCMs only output from the A1B SRES scenario was available, which was considered to be sufficient for model inter-comparison as differences between models (e.g., for precipitation) were considerably higher than differences between SRES scenarios.

In the initial REMO runs, the model systematically underestimated the amount and variability of rainfall over West Africa including a shift in rainfall distribution toward weaker events and fewer extremes. To address this issue, model output statistics (MOS) were applied in order to adjust the rainfall data using other near-surface parameters such as temperature and sea level pressure wind components (Paeth et al., 2008) (Fig. 4). A cross-validated multiple regression analysis was used in order to adjust monthly data to the CRU observational dataset (CRU dataset).

The MOS correction leads to regional-mean precipitation on the basis of 0.5° by 0.5° model grid boxes. However, at the daily scale, this regional-mean presentation differs strongly from the real spatial distribution of rain events. In order to transform the MOS-corrected regional-mean precipitation from REMO to a local pattern of rain events, a weather generator (WEGE) was applied and produced virtual station data, matching the BD MET stations in Benin (Le Barbé et al., 2002) which was finally adjusted to the statistical characteristics of observed daily precipitation at the BD MET stations by probability matching (Helmer and Ruefenacht, 2005; Paeth and Diederich, 2010). It is used to transfer the simulated rainfall data with distribution function to a new sample of virtual data which fit the observed distribution function. For this purpose, the dataset has been sub-divided into a part below and above the 80% quantile. For the weaker rain events we have fitted functions to daily precipitation (Dunn, 2004), whereas extreme precipitation is assessed by the Generalized Pareto distribution (GPD) (Paeth and Hense, 2005).

Under the A1B scenario some parts of tropical Africa may warm by more than 3°C until 2050, whereas under B1 scenario the warming pattern is very similar but the amplitudes are generally 1°C lower. The absolute annual mean temperature is slightly lower in the HADRM3P and SMHIRCA simulations, but the temperature increase until 2050 is similar to the REMO output (Fig. 5).

For the full domain, the Regional climate model (REMO) for the time horizon (2014–2050) simulates an average annual precipitation decrease of 37% and 31% under IPCC SRES A1B and B1, respectively relative to the baseline period (1961–2000) (Fig. 6). In contrast, the mean annual precipitation in the period 2041–2050 decreases in the SMHIRCA model simulations only by 7% and in the HADRM3P simulations it increases by 6% in A1B scenario. As per Fig. 6, REMO and the SMHIRCA simulates a gradual decrease of precipitation toward 2050. In the REMO model, some
acceleration toward the middle of the century, consistent with the temporal evolution of climate change signals in longer term global climate model projections from the latest IPCC report (IPCC, 2007).

4.2. Impact of climate change on crop production

In order to analyze the effect of climatic variables (temperature and rainfall) solely on the yam yield, baseline and future scenario simulations were performed only with ambient CO2 concentration (350 ppmv). The effect of the climate scenarios until 2050 is shown in Fig. 7.

As per the output of the climate models, yam yield show a declining trend in the study region within the time slice 2021–2050 (Fig. 7). The decrease is more pronounced with the output of the REMO model compared to SMHIRCA and HADRM3P model output.

According to Fig. 7, in the climate scenarios derived from the REMO model, the yield of yam would be further reduced significantly in the Upper Ouémé basin (Benin Republic) in the decade 2041–2050 compared to the baseline period (1961–2000) which accounts for about 33% and 27% yield loss under IPCC SERES A1B and B1, respectively. However, the yam yield for baseline and scenarios derived under REMO model is more compared to yield under SMHIRCA and HADRM3P due to the fact that for REMO model, we used Sesbania spp. as a fallow crop which is a leguminous crop which in turn leads to more yam yield. For SMHIRCA and HADRM3P under A1B scenario it accounts for 19% and 18% decline, respectively. The simulated results from this study agree well with some earlier simulation studies that indicate a decrease in crop production in Africa (Parry et al., 2004; Reilly and Schimmmelpennig, 1999; Jones and Thornton, 2003). However, Liu et al. (2008) and Lobell et al. (2008) reported that yield of cassava (Manihot esculenta) will generally not be highly affected by climate change in Sub-Saharan Africa by 2030 which is also quite in agreement with our findings with yam. Recently Gaiser et al. (2011) reported decline in the maize yield by 18% (based on REMO A1B scenario) in the Upper Ouémé basin (Benin Republic).

The optimal temperature for growth of yam is between 25 and 30 °C, depending on the species of yam. The annual average temperature across Ouémé basin is 26.8 °C which is within the range of the optimal temperature required for yam growth and development during the crop growing period. Due to global warming, temperatures will further increase until 2040s by about 8% under A1B and 6.5% under B1 IPCC SERES scenarios (Fig. 5). Therefore, reduction in yam yield is not explainable by the change in temperature but must be due to a decline in precipitation (Fig. 6) eventually translating into frequent dry spells, although other climatic factors may play roles.

Similar assessment in 8 agricultural regions of Cameroon was carried out which estimated decrease of maize and sorghum yields in the range of 14.6 and 39.9%, respectively due to high temperatures and decreased precipitation worked in unison varying according to the climate scenario and the agricultural region (Tingem et al., 2008).

4.3. Climate change impact on yam yield in relation to soil type in the Upper Ouémé basin

In order to study the interaction between climate change and soil conditions three major soil types were taken into consideration (Table 1). In the study area the simulated maximum decline in yam yield in the period 2041–2050 was observed on S1 (Ferruginous soils impoverished without concretions) which registered a decline of 48% followed by S2 (Ferralitic soils) and S3 (Raw mineral soils) which registered a decline of about 36% and 33% in yam yield, respectively compared to the yield in the baseline period (1961–2000) under A1B scenario derived from REMO model, whereas, there is no significant “response difference” foreseen within soil types under A1B scenario derived from SMHIRCA and HADRM3P climate models. The decline in yam yield ranges from 14% to maximum of 19% (Fig. 8).

As shown in Fig. 6, in both scenarios (REMO A1B and B1 scenario) a decrease in rainfall is observed in particular in the period 2041–2050 (mean annual precipitation of about 700 mm compared to 1100 mm in the baseline period) which (1) will increase drought stress and (2) could hamper the mineralization of soil organic matter inducing nitrogen limitations to the plants. The EPIC model calculates stress indices for different crop growth limitations (temperature, water, nitrogen, phosphorus, potassium, oxygen deficiency in the root zone) on daily basis. The analysis of the model results show that in the last decade of the simulation

<table>
<thead>
<tr>
<th>Soil type</th>
<th>pH</th>
<th>Organic carbon (g kg⁻¹ soil)</th>
<th>Characteristics drainage</th>
<th>Texture</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Topsoil</td>
<td>Subsoil</td>
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<tr>
<td>S1</td>
<td>5.9</td>
<td>2.1</td>
<td>Well drained</td>
<td>S</td>
</tr>
<tr>
<td>S2</td>
<td>5.2</td>
<td>4.8</td>
<td>Well drained</td>
<td>LS–SL</td>
</tr>
<tr>
<td>S3</td>
<td>4.9</td>
<td>10.2</td>
<td>Moderate</td>
<td>LS</td>
</tr>
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</table>

Fig. 6. Comparison of the output of mean annual rainfall for the period 1961–2050 from three regional climate models (REMO driven by ECHAM5, SMHIRCA and HADRM3P driven by HadCM3QO) with observed data (1961–2000) in the Upper Ouémé basin.
period water and nitrogen stress where the most serious growth constraints for yam. In the period 2041–2050 the mean annual number of days with water stress (number of days where water stress is the most serious constraint to biomass increase) were 29, 26.5 and 26 days in the soil types S1, S2 and S3, respectively and the mean number of days with nitrogen stress (number of days where nitrogen stress is the most serious constraint to biomass increase) was in the tune of 33 days for the soil type S1, 29 days in S2 and 14 days in S3 (Table 2). It should be noted that it is possible that there was simultaneously nitrogen stress on the days when water stress occurred, but it was not accounted for because it was lower than the water stress. Compared to the baseline period, water stress increased whereas nitrogen stress decreased (Table 2). Thus, in the low input systems which are typical for Sub-Saharan Africa, nitrogen is currently the most severe constraint to yam production, but a decline in rainfall in the future will affect water supply to the crop more seriously especially in well drained soils with low fertility level like S1 (Ferruginous soils impoverished without concretion) soil type (Tables 2 and 3).

4.4. Uncertainties in scenario simulations

The yield change estimates include different sources of uncertainty. The REMO climate scenarios are based on a 55 km grid

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Nitrogen stress (days)</th>
<th>Water stress (days)</th>
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<tr>
<td></td>
<td>Baseline</td>
<td>A1B</td>
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<td>S1</td>
<td>45</td>
<td>33</td>
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<td>S2</td>
<td>39</td>
<td>29</td>
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<tr>
<td>S3</td>
<td>27</td>
<td>14</td>
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Fig. 7. Comparison of Yam yield (Mg dry matter ha⁻¹ a⁻¹) in the whole Upper Ouémé basin under IPCC SERES scenarios from three regional climate models (REMO driven by ECHAM5, SMHIRCA and HADRM3P driven by HadCM3Q0) under ambient CO₂ concentration (350 ppmv) in the atmosphere.

Fig. 8. Comparison of changes in Yam yield (%) on three soil types under IPCC SERES scenario A1B derived from regional climate models REMO, SMHIRCA and HADRM3P. The soil types are S1 (Ferruginous soil impoverished without concretion), S2 (Ferrallitic soil) and S3 (Raw mineral soil).

Table 2
Comparison of simulated mean annual number of days with nitrogen and water stress in the period 2041–2050 under climate scenario (REMO A1B) and Baseline scenario in the period 1961–2000 in three different soil types S1 (Ferruginous soil impoverished without concretion), S2 (Ferrallitic soil) and S3 (Raw mineral soil) in the Upper Ouémé basin.

<table>
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<th>Nitrogen stress (days)</th>
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<td>S3</td>
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Table 3
Yam yield under baseline and A1B scenario derived from three regional climate models (REMO, SMHIRCA and HADRM3P) along with the values of absolute and relative difference in three different soil types S1 (Ferruginous soil impoverished without concretion), S2 (Ferrallitic soil) and S3 (Raw mineral soil) in the Upper Ouémé basin.
5. Conclusion

This study concludes that the impact of climate change under A1B IPCC SRES scenario on yam production in the Ouémé basin is significant and prominent particularly in 2040s. During the period 2041–2050 it would decline significantly ranging from 18 to 33% based on the outcome of all three regional climate models considered. The soil type S1 (Ferruginous soils impoverished without concretions) seems to be the most sensitive to climate change followed by S2 (Ferrallitic soils) and S3 (Raw mineral soils) which accounted for a decline in yield of about 48%, 36% and 33%, respectively. Depending on the soil type, drought stress and indirect effects of reduced rainfall on nutrient availability can be a determining growth constraint. However, the conclusions presented here must not be seen as accurate predictions of future yam yields, but more as indicators of the possible impacts of climate change. Therefore, we strongly recommend the necessity of including the management factor into the assessment of climate impacts on crop yields. Future research needs to combine climate scenarios from several climate models with crop models in order to reduce the uncertainties in the crop model simulations.

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