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EVALUATION OF MODIS LST V6/WEATHER STATION-BASED TEMPERATURE DATASETS IN PREDICTING MAIZE CROP YIELD RESPONSE USING AQUACROP: CASE OF BENIN

Running title: Comparison of MODIS/weather temperature dataset using Aquacrop.

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ABSTRACT

Daily meteorological temperature datasets in Benin, West Africa is provided by only six known weather stations which do not cover the temperature variation information of the whole country while these local details are required for field simulations. This paper introduces a summarized evaluation of the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) temperature dataset as opposed to weather station measured temperature using Aquacrop model outputs calibrated with maize crop file specifics, as maize is the most consumed cereal crop in the country. The method used relies on a statistical comparison of two distinct dataset inputs in Aquacrop model which was calibrated based on a previous field experiment performed in a recent study. The results indicated MODIS corrected temperature might not be suitable to estimate crop yield. Also, there is a strong correlation between soil salinity and the output crop yield response, as the least R^2 was 0.70 (Bohicon station), and the highest yield recorded for each station was obtained at the lowest soil salinity value. However, the model output crop yield response also shows that there is a significant difference between the simulated crop yield based on the two datasets.

Keywords: Aquacrop, maize crop yield, temperature, MODIS, Weather station.

1. INTRODUCTION

In Africa, maize represents the main staple food, consumed by more than 300 million people, occupying 24% of farmlands [1]. In sub-saharan Africa, maize cereal crop plays a major part in ensuring the food security in the region [2]. In Benin (West Africa), among all the produced cereals, the harvesting area of maize can take up to 30%, representing 11.2% of the overall

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agricultural production in terms of volume. Even though maize trend is prospected maize yield is 1.9 million tons, which is similar to the average of the previous five years, it decreased by 7.8 percent compared to 2018 [3], which suggest that the crop production faces some limiting factors that decreases its productivity. Such factors range from the inaccessibility to inputs and capital, to the inappropriate environment in which farmers operate [4]. Maize crop output variation can be explained by the impacts of climate change in association with land degradation and the non-availability of adequate fertilizers [5]. The vulnerability of the country to climate variability can be indicated by the even distribution of rainfall across the country, drought pockets which occur during the rainy season in the central and northern part, and temperature rise [6]. In addition to that, with the introduction of new maize varieties in Benin, community farmers have been facing soil depletion issues [7]. In North western Benin for instance, under a scenario of high temperature and low precipitation, maize yield will significantly decrease, as indicated by the APSIM model [8]. The climatic effects may have contributed to the extension of the cropping season in northern Benin. Therefore, the risk to operate during cropping season becomes higher in the sense that climatic conditions reduce the efficiency of the farming system. This requires the need of climate related information to facilitate farmers' shift from cropping calendars to scientifically based reality [9]. In southern Benin, the consequences of climate variability have engendered socio-economic disorders during these recent 15 years. These impacts stem from the succession of inundation, of pronounced drought, high wind frequency, and high temperature. Small farmers are the most vulnerable [10]. to the output variations in maize crop cultivation. This paper evaluates two different sources (MODIS and weather-based stations) of temperature datasets to understand the annual crop yield variation over six different sites in order to capture the discrepancies to serve for better decision making.

2. MATERIAL AND METHODS

2.1 Study area

Benin is a western African country which occupies 114,76 square kilometers of area. It is located between 6°10' and 12°25' of latitude north and between 0°45' and 3°55' of longitude east. Of the total area, 63% is estimated to be the amount that can be exploited for agriculture [11]. Six weather stations are available to record daily temperature.

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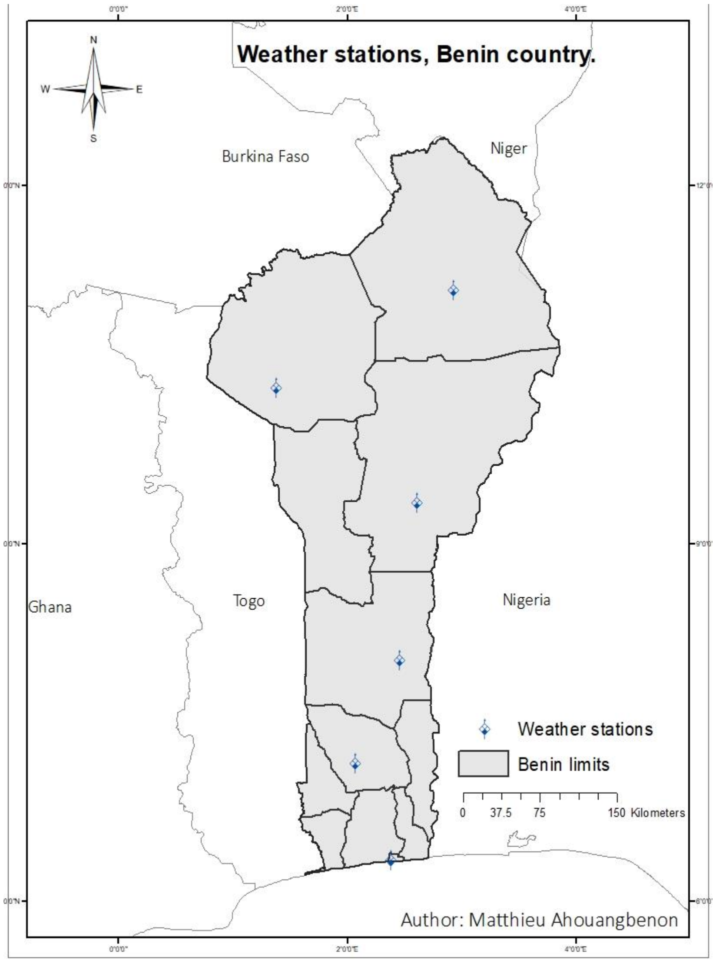

Figure 1: Study area (Benin country, West Africa)

3. METHODS

3.1. Data pre-processing

MODIS (Moderate Resolution Imaging Spectroradiometer) Land Surface Temperature (LST) was acquired for the year 2016 for the entire study area using MODIStsp, a pre-processing tool which allows the download and the automation of MODIS derived temperature for further processing.

3.1.1. MODIStsp

MODIStsp was used to create a time series of rasters that will then be combined into a mosaic. MODIStsp is a user-friendly tool that only requires Geospatial data abstraction Library with an

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HDF4 raster format [12]. The pre-processed data is saved as a GeoTiff and virtual multitemporal files was generated. NoData values are assigned a common output value.

3.2 Pre-processing of MODIS LST

MODIS temperature/emissivity product (MOD11A1) has been used for this study. MOD11A1 Version 6 at 1km resolution was acquired using MODIStsp, a tool that allows the pre-processing of MODIS data products. This tool helped to customize the study area, to re-project the raster datasets and to apply the off-scale value in order to output the temperature values needed for the analysis. MODIS/TERRA Land Surface Temperature daily (MOD11A1) 1km Global was accessed through the Earth Observing System Data and Information System (EOSDIS). The data product was automatically re-projected into the appropriate coordinate system (WGS 1984_UTM_Zone_31N) with the scale factor, applied. The output from the MODIStsp processing was a daily series of Geotiff raster stacks that were inserted in ArcGIS 10.7 for further analysis.

3.3 Temperature data extraction using ArcGIS 10.7

In ArcGIS 10.7, a shapefile of the meteorological stations was created using their respective locations (latitude/longitude). This shapefile was used in conjunction with the output rasters in ArcGIS to produce the daily temperature values (in °C) at each meteorological station. To generate these values, a batch resampling of the MODIS temperature data product was performed, and the output cell size was set to 10 x 10 km^2 for the temperature variable extraction at the same location as the meteorological stations. This resampling was necessary to the noise that can impact the sensor records and the fact that for a site very close to the ocean (Cotonou), the dataset had no record for the entire year.

3.4 Aquacrop model

3.4.1. Description

Aquacrop model simulates crop yield for herbaceous plants, by considering the plant-soil relationship. It helps to evaluate the impact of crop environment on dry yield and biomass production. It is used in management decisions and for both irrigated and rainfed agriculture. The model inputs are subdivided into four components: Weather, crop management, soil profile, and ground water [13]. The model estimates the overall biomass using the actual crop transpiration and a normalized water productivity parameter [14]. Under various crop management scenarios, Aquacrop can simulate the canopy cover with a model efficiency ranging from 0.42 to 0.94 [15], outputting the corresponding yield and biomass.

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Table 1: Aquacrop parameters calibration for simulations, from Sandhu and Irmak (2019).

Parameters	*Default*	*Calibrated*
Base Temperature (°C)	8	8
Cut off temperature (°C)	30	30
Canopy cover per seedling (Cm²/plant)	6.5	6.5
Initial Canopy cover (%)	0.49	0.47
Maximum canopy cover (%)	96	94
Maximum Rooting depth (m)	2.3	1.5
Canopy Growth Coefficient (%/day)	16.3	13.7
Canopy Decline Coefficient (%/GDD)	1.06	1.31
Crop coefficient for transpiration (K_{ch})	1.05	1.05
Reference Harvest Index (%)	48	52
Normalized crop water productivity (g/m^2)	33.7	31.7
Expansion stress coefficient (P_{upper})	0.14	0.14
Expansion stress coefficient (P_{lower})	0.72	0.72
Stomatal conductance threshold (P_{upper})	0.69	0.40
Shape factor	6	6
Senescence stress coefficient (% vol saturation)	5	5
Aeration stress coefficient (% vol saturation)	5	5

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3.4.2. Calibration

Yield simulation can be overestimated, especially when the model is calibrated in water limiting and rainfed conditions [16]. In a wet year of during low precipitation, Aquacrop model may not accurately simulate biomass and soil content. Actually, the model is sensitive to water stress/excess water environment and can adequately estimate dry yield [17]. The following table indicates the default and the calibrated parameters of Aquacrop used for an appropriate simulation [18].

In addition to this information that served for the crop file conception, each parameter has been set at a constant value except "soil salinity", so that the impact of one variable while tuning the system can be easily measured. The irrigation scheme selected was "rainfed". The following table shows the input parameters defined to be at a constant level throughout the simulation runs. The following table shows the parameters that have been set as constant through the runs.

Table 2: Conservative input parameters set at constant value for model calibration, from Matthieu (2019).

Parameter	*Calibration option selected*
Irrigation scheme	rainfed
Soil mulches cover	50 (about half)
Weed management	50 (about half)
Soil water content	25

The model basically computes the evapotranspiration required for the crop yield simulations. The simulated yield was recorded for each soil salinity value to generate a crop yield response trend.

3.5 Analysis

Compared to developmental stages, salt stress has a stronger impact on maize germination stage. It affects grain weight and the number of grains, causing low grain yield [19]. Plant growth can be affected by water and salinity. According to Läuchli [20], the latter can potentially inhibit root and shoot growth. While conservative parameters in this model are kept at an average value the initial soil salinity content was modified at a 0.5 dS/m increment from 0.00 to 50 dS/m. For each increment, the model was run to simulate the crop yield response for the specific value of soil salinity. To better visualize the results, the output yield which generated no values were

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excluded. Based on the above-mentioned system calibration explanation, the correlation between the soil salinity and crop yield was summarized for each location to capture the variability in maize crop yield and the error between the output results provided in using both datasets. To indicate the error between the simulated output crop yield responses, the Root Mean Square Error was used (RMSE) as metric. The equation of the RMSE is :

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (Predicted_i - Actual_i)^2}{N}}$$

Where the actual values represent the simulated maize crop yield response using weather-based temperature values, and the predicted estimates indicated by the crop yield simulations using the MODIS corrected temperature data.

4. RESULTS AND DISCUSSION

4.1. Temperature trend comparison

Compared to the deterministic regression method, an efficient method to deal with missing data observation is stochastic regression imputation which can be much better [21] as this estimation can possibly minimize the existing bias impacts in the time series data set [22]. This method was used in the current work to account for missing values as the model would not compute the evapotranspiration to allow a simulation run when the number of NoData values is significant. Computing the evapotranspiration is essential in crop yield estimation using Aquacrop, as the model not only requires minimum and maximum temperature, but also necessitates the reference evapotranspiration, to compute the biomass and the dry yield (Reference manual, 2018). On this basis, the missing values in the processed MODIS temperature datasets were accounted, using above-mentioned statistical method. The output results were plotted for each site to observe the discrepancies between the actual and the corrected data. The following caption summarizes the time series between both variables which are to be used as input in the calibrated model for the output yield comparison.

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Temperature time series trends

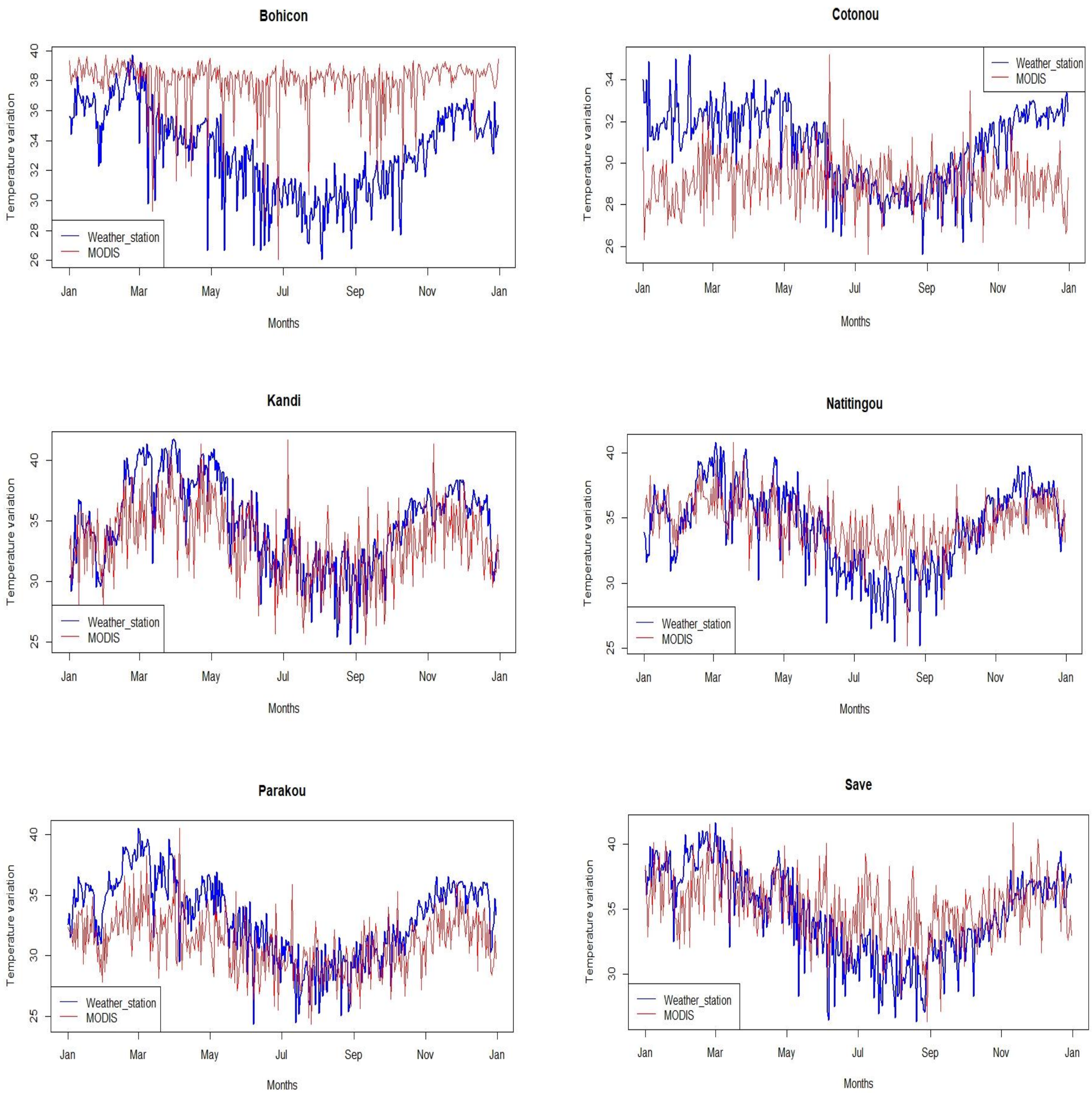

Figure 2: This caption illustrates for each station the temperature trend between the MODIS corrected dataset and the weather-based records. For the sake of simplicity, each site will be named by a capitol letter (eg: Bohicon= 'B', Cotonou= 'C', etc.)

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The simulation using both temperature data and the soil salinity as a tuning parameter was summarized for each site. The following figure shows the correlation between soil salinity and Maize crop yield response on the selected sites.

Maize crop yield curve

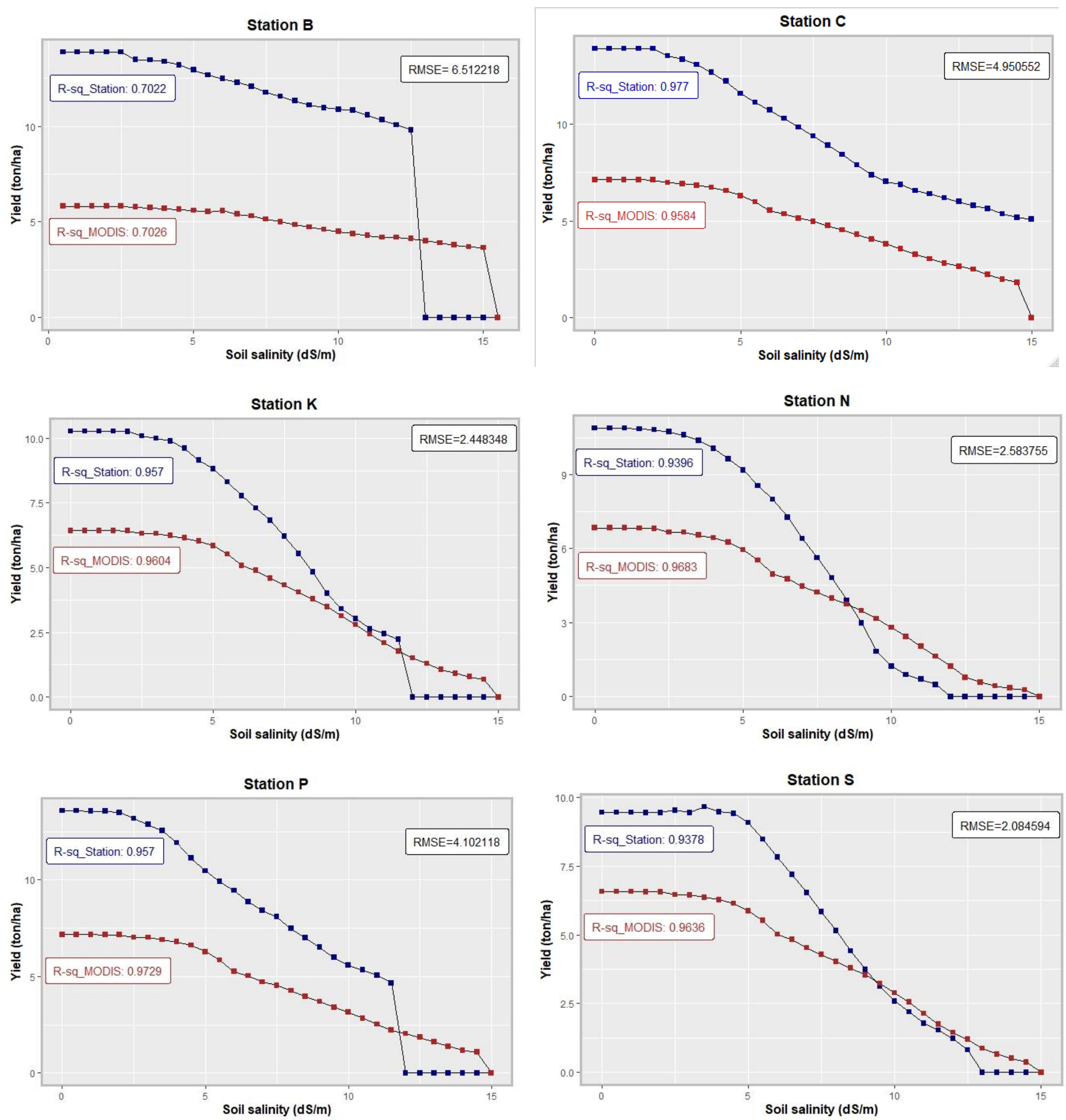

Figure 3: Illustration of maize crop yield response on each site relative to soil salinity variations.

The results revealed that there is a strong correlation between soil salinity and the crop yield response on each site. However, both simulations largely vary. However, the comparison between the actual and the predicted crop yield based on Aquacrop model calibration using the RMSE suggests that the MODIS derived temperature datasets does not fit the actual predictions of the model. For each site, the overall correlation between the soil salinity and the output crop yield is strong, indicating that maize crop yield is very sensitive to soil salinity. This is corroborated by Sugirtharan [23] which explained that the increase in soil salinity reduces dry matter content, pigments and transpiration rate in maize crop. The comparison between the simulated yield results under the different climatic conditions specified, indicated that there is a significant reduction in the output yield obtained with MODIS corrected temperature. The simulated crop yield trend using the corrected MODIS derived temperature does not capture the variation in the actual crop yield curve simulated based on the weather stations information. This might be due to the gaps in the dataset and the statistical method used for the data imputation. For a better accuracy, the daily temperature can be summarized into a monthly time step without any modification for further comparison.

In addition to the discrepancies in the results generated while using both datasets, the highest yield is obtained when soil salinity is kept at low values irrespective of the input used, suggesting that soil salinity increase has a negative influence on Maize crop yield response. Depending on the salinity level, maize crop yield can significantly vary. For instance, at low irrigation salinity does not influence crop yield, whereas at high irrigation level, salinity can possibly cause the decline in crop yield [24].

Finally, maize crop yield variations might also be due to the fertility parameter as the estimation of cumulative grain using different soil fertility scenarios levels indicated a range of agreement (R^2) ranging from 0.6 to .88, which showed that additional calibration was needed [25].

CONCLUSION

2016 weather station temperature across Benin country was used as input in Aquacrop calibrated model to be test against actual measured temperature obtained for the available meteorological stations in Benin. The simulated crop yield showed that the corrected MODIS derived daily temperature might not be the appropriate method to explain the output crop yield response when compared to the actual values. However, it could be used for a simple trend description which in this case can help to capture the overall variation in the output yield. Also, Maize cereal crop is very sensitive to soil salinity. Therefore, considering soil salinity while tuning Aquacrop model is important as it represents an important initial condition required to have a higher yield in the context of this study.

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