Vol. 13(37), pp. 1924-1931, 13 September, 2018
DOI: 10.5897/AJAR2018.13344
Article Number: 185C1A658473
ISSN: 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Identification and estimation of the sugarcane production potential of Mozambique

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Received 22 June, 2018; Accepted 19 July, 2018

Identifying the potential areas that can produce sugarcane is extremely important, especially for developing countries. Most of the territories in Mozambique have soils with high and medium agricultural potential but are hampered by water conditions. Therefore, irrigation is the only solution to ensure certainty in agricultural production. In addition, to set up new business a minimum of infrastructure is required, like roads. The objective of this work is to estimate sugarcane productivity and production potential of Mozambique from agrometeorological data and soil maps using the intersection buffers of 25 km of rivers and 50 km of land transport routes. The analysis allowed the identification of potential areas and it is concluded that irrigation is necessary for high yield of sugarcane in Mozambique, but there are areas where it is possible for the cultivation just by rain fed. The estimated available area was 11,943,071 ha for irrigated areas and 11.640.221 ha for rainfall areas (15% of the country area). From the yield on these areas, it was possible to estimate the potential production of 1,030 Mt year^{-1}, with full irrigation and 611 Mt year^{-1} by rainfall. The productivity values generated by the model showed satisfactory results compared to the data observed in a production unit located in Marromeu, both for rainfed and irrigated.

Key words: Area, geotechnology, modeling, yield.

INTRODUCTION

Mozambique has a large agricultural potential for the production of bioenergy, mainly due to availability of potential areas (Watson, 2011). Furthermore, the energy shortages in the country underscore the need for identifying the possibility of production of either ethanol as electric energy from the use of biomass. There is an opportunity for investment in bioenergy because the country is largely rural and imports all fossil fuels

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(Econergy International Corporation, 2008).

To identify potential areas, the characterization of the climatic conditions is important since it is the main cause of variability of agricultural production. The knowledge of these variables during the growing season associated with agrometeorological yield models allows analysis of reduced productivity. Thus, the use of simple models with essential climatic elements (temperature and precipitation) facilitates the practical application and its integration into the process of crop management.

For the application of agrometeorological yield models, there is a need for meteorological data, which are generally derived from conventional or automatic weather stations. However, these data may have errors or are difficult to access. Agro-meteorological data from global models like the European Center for Medium-Range Weather Forecast (ECMWF) are an alternative. These are available free of charge by the meteorological database Joint Research Centre (JRC), a research center of the European Commission which collects weather information from stations scattered throughout the world, radar, satellites and other sources (Person and Grazziani, 2007).

As a developing country, investments in Mozambique need to be near a minimum of infrastructure such as roads and connection to ports (Schut et al., 2010). On the other hand, in places where the irregularity of rainfall and the influence of El Niño are frequent, the irrigation of sugarcane is a mandatory aspect (Ellis and Merry, 2004).

So in this context, the aim of this study is to estimate the potential yield and total production of sugarcane for Mozambique from agro-meteorological data and soil map, using the intersection of 25 km of river buffers and 50 km of land transportation routes buffers.

MATERIALS AND METHODS

This study considered the total area of Mozambique, considering the years 2008 to 2013 (due to data availability), the annual period from July to June (12 months), and totaling five periods. The analysis was divided into two stages, the first being the estimated average degree days, water deficit and productivity and total production (Figure 1); the second, determining potential areas (Figure 2).

For the first stage, estimated data of average air temperature (°C), precipitation (mm) and reference evapotranspiration (mm) of the ECMWF global model, with spatial resolution of 0.25° and temporal resolution of ten days, available in raster format were used (JRC, 2015). It was also used data, format shape suitable for the production of sugarcane in the type of soil in Mozambique. The potential was classified according to the presentation in CGEE (2009), which was applied in Brazil, as high (81.4 t ha^{-1} $year^{-1}$), medium (73.1 t ha^{-1} $year^{-1}$) and low (64.8 t ha^{-1} $year^{-1}$); areas with unfit classification, restricted and others were considered equal to zero. This productivity was transformed into raster format with a spatial resolution of 0.25°, where each pixel was classified according to the predominance of area classification.

The degree days (DD) were calculated according to the number of hours favorable for growth in basal temperature (Tb) of 18°C (Equation 1).

$$DD = \frac{(Tmax + Tmin)}{2} - Tb \quad (1)$$

The hydric deficit (HD) was calculated as the difference between precipitation (P) and the reference evapotranspiration (ETo) provided by the ECMWF global model (Equation 2).

$$HD = P - ETo \quad (2)$$

The base model for the estimation of productivity (Y) is given by Equation 3, where the factor considered is productivity given by the presented potential CGEE (2009) and the DD and HD values were obtained based on the average of 5 times. B and c factors were considered with the values, 0.01 and 0.1 respectively. These factors were obtained from multiple regression data with historical series of 5 years for rain fed sugarcane areas in Piracicaba, São Paulo, Brazil. In this manner, they are standard values. Due to the absence of historical sugarcane productivity data in Mozambique, it is not possible to calculate calibrated factors for the country.

Therefore, the model is based on simplicity, expressing the importance of the water supply from the water deficit and the efficiency of interception of solar radiation from the degree days during the harvest period. In practice, with lower HD, DD will be lower due to the few hours of sunshine (clouds). Two outputs were considered for the model and productivity considering the water deficit and others, excluding it in the case of irrigation.

$$Y = a + b\,DD - c\,HD \quad (3)$$

In step 2 (Figure 2), potential areas were identified as well as the main features of water availability, that is, the presence of water courses with constant flow and transport infrastructure by land routes, such as main and secondary roads or railway line. Thus, from these data, a 25 km buffer for water availability (perennial rivers) was first made; this distance is related to canals built in Marromeu. A buffer of 50 km of land routes was also made for the displacement of production. According to CGEE (2009), usually sugarcane growing areas are located at an average distance of 25 km of the plants (on average) due to cost of shipping. Potential areas were determined from the intersection of the buffer areas, thus having the two major characteristics considered.

In order to exclude restricted areas of the previous result after processing, the restricted were excluded as follows: bad soil, slope greater than 13%, high carbon, cropland and mixed, high DUAT (right to use and benefit from the land known as Direito do Uso e Aproveitamento da Terra) and reserves. Thus, the productivity from the map obtained in step 1 was determined in the final area of the intersections for the total production, considering only the performance without water deficit, in case of use of irrigation. All phases of the study were performed using spreadsheets in Microsoft Excel and the ESRI ArcGIS 10.2.2 for Desktop to process and generate the maps.

RESULTS AND DISCUSSION

Figure 3 shows the potential yield by soil type and average periods of precipitation, hidric deficit and total degree days.

It appears that there is great potential in the northern region of the country, both in soil characterized as having high potential, required amount of degree days and minimal rainfall, but requiring supplemental irrigation. The total degree days showed results consistent with the

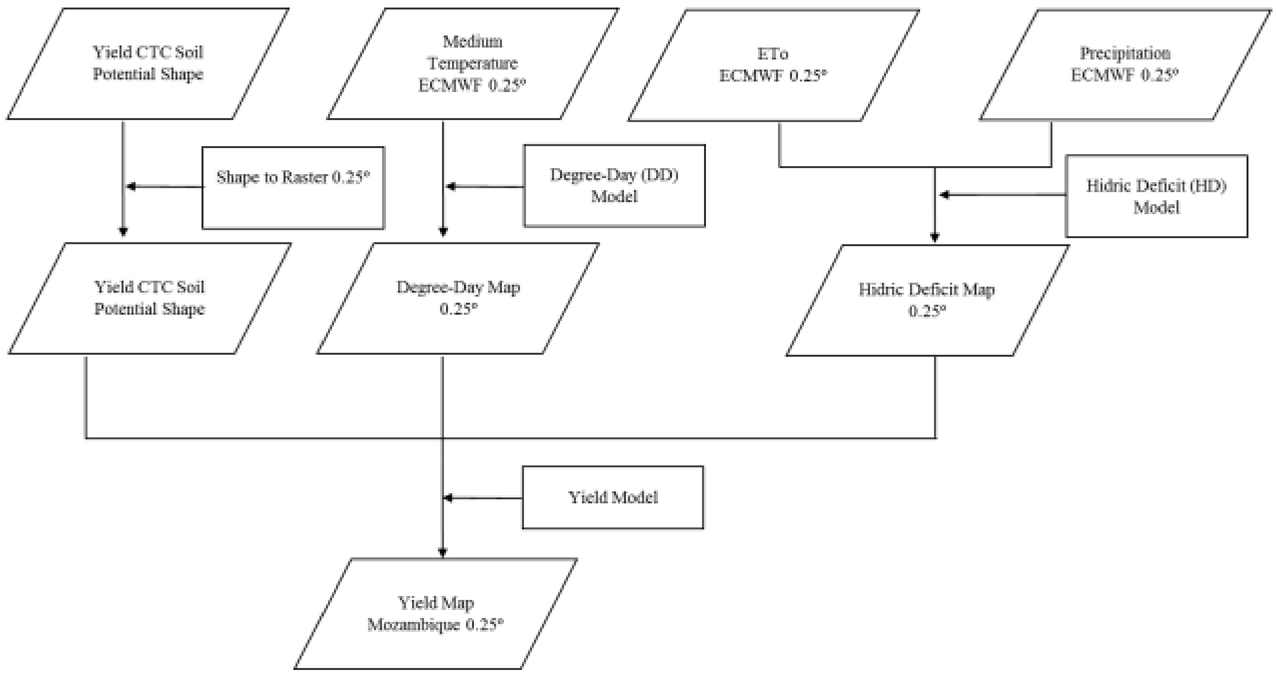

Figure 1. Flow chart of the steps for obtaining the sugarcane productivity in Mozambique.

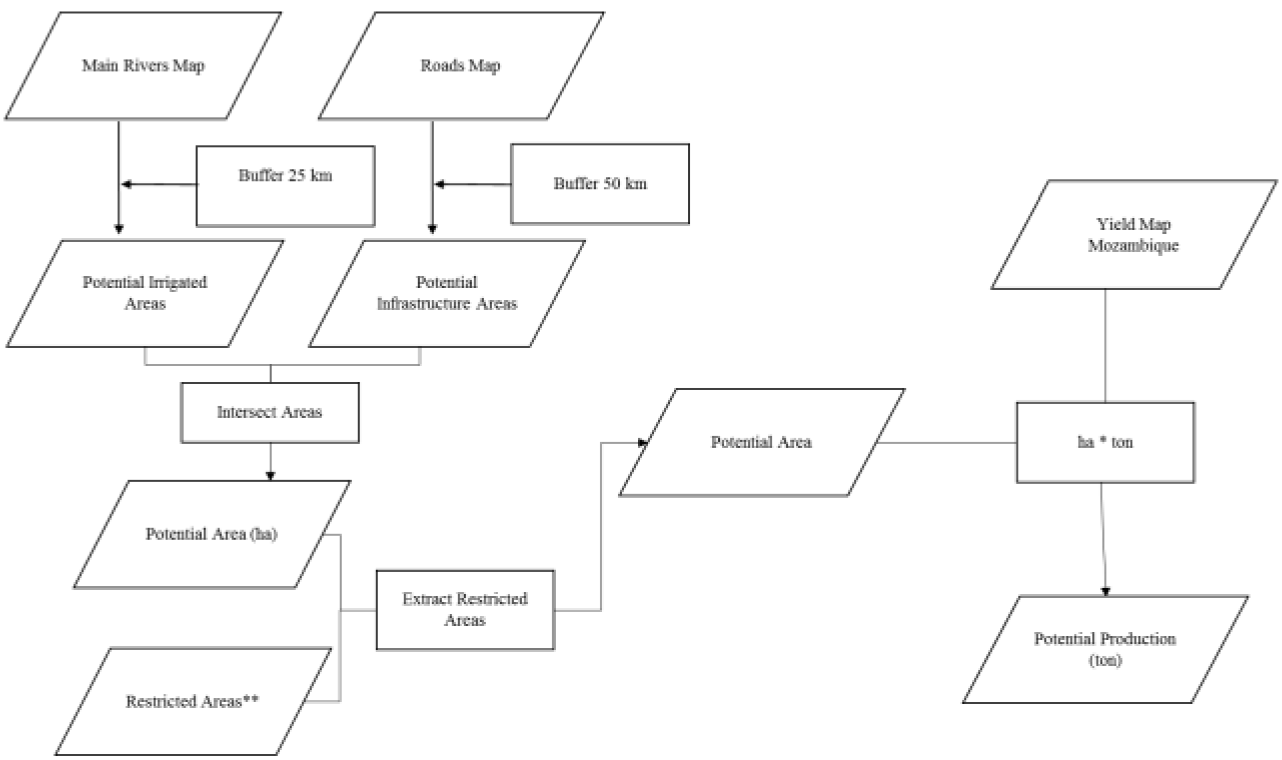

Figure 2. Flowchart of stages for obtaining potential and production areas.

reality of growth. According to Moraes et al. (2014) who quantified the degree days in the cycle of sugarcane in São Paulo, Brazil, the main areas had values between 1500 and 2500 DD, with a maximum of 3398.

The average precipitation available for the period does not exceed 1500 mm in some points, being that most parts of the country have less than 1000 mm. In the case of hydric deficit, there are few areas without problems,

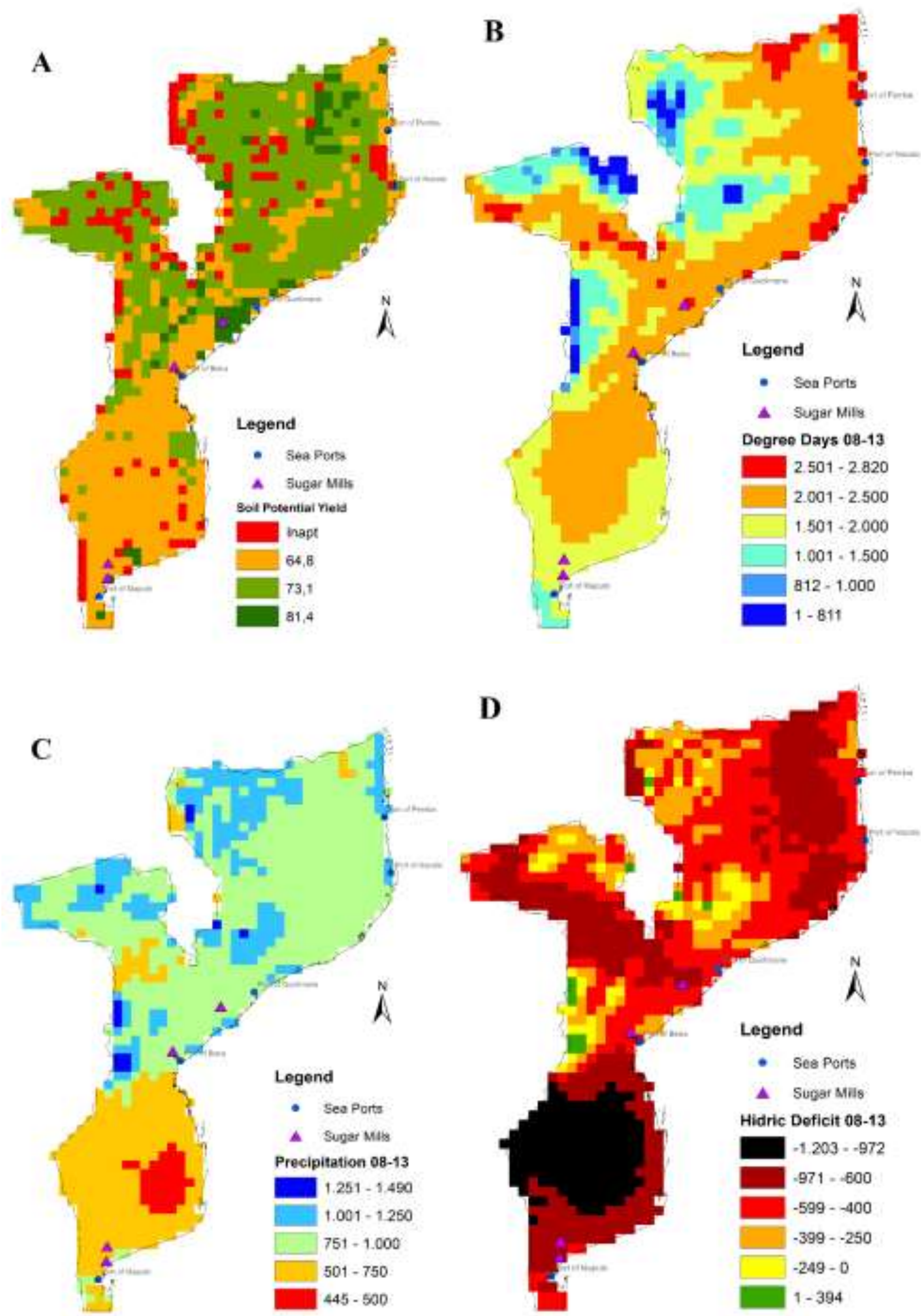

Figure 3. Yield potential for soil type (A); total degree days (B); average rainfall (C); and water deficit (D) in the period.

with insufficient rainfall in almost all. According to Doorenbos and Kassan (1979), a minimum of 1500 mm of rainfall is required during harvest. But Brunini (2010) recommended a minimum of 1000 mm, establishing some criteria where hydric deficit values with smaller deficits than 250 mm are acceptable by sugarcane; between 250 and 400 mm supplementary water is required (CAD 125 mm); between 400 and 600 mm requires irrigation, and for larger deficits, production is impossible but possible only with full irrigation.

Besides the relatively low annual precipitation (Figure 4), there is irregularity of rainfall in Marromeu, located in

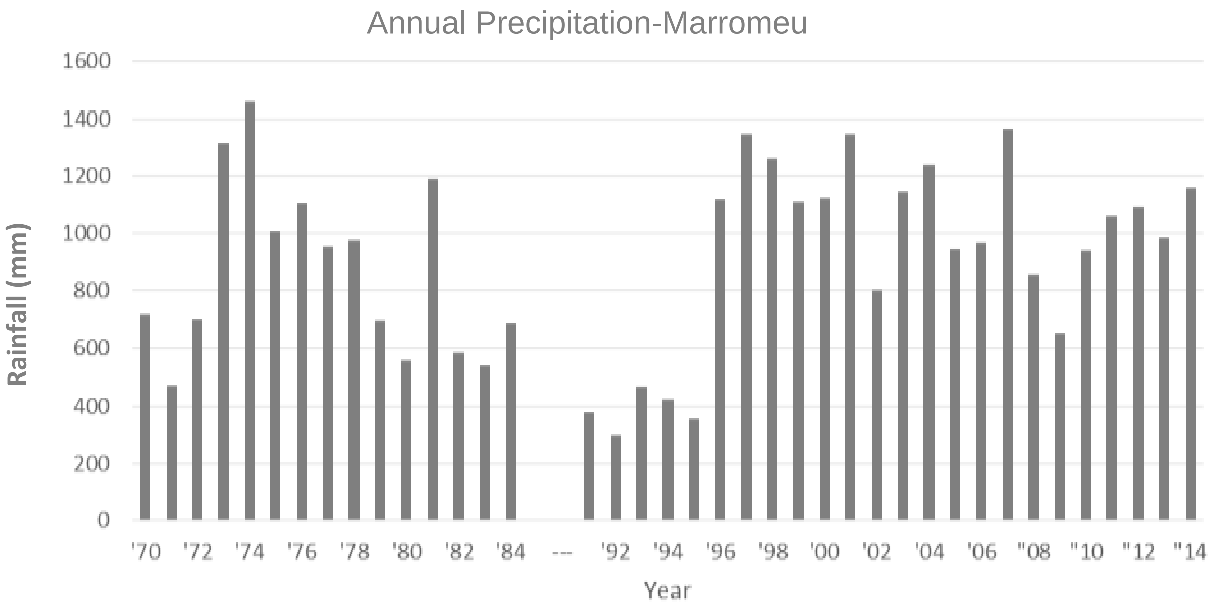

Figure 4. Annual rainfall in Marromeu/Sofala/Mozambique between 1970 and 2014 (except between 1985 and 1990).

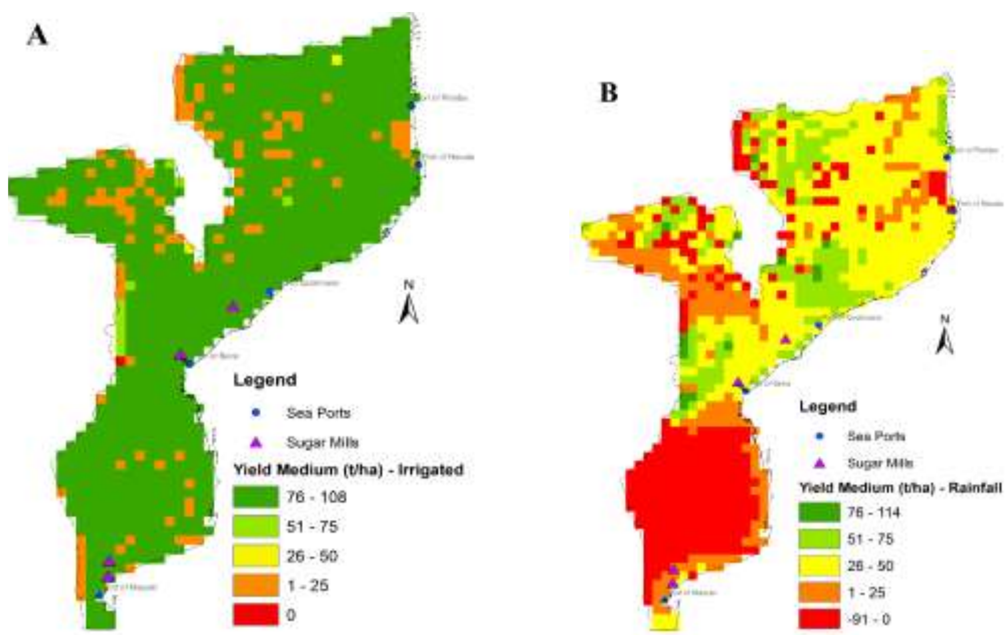

Figure 5. Average productivity estimated from the proposed model, being with no water deficit (A) and with water deficit (B).

Central Mozambique. The annual accumulated is from 1970 to 2014 (except 1985 and 1990). According to Rojas et al. (2014), the influence of El Niño events between 1991 and 1994 favored the water deficit in the region, damaging agriculture. According to Aragón et al. (1998), the drought of 1991 to 1992 strongly affected both Mozambique and the entire southern African region. Matyas et al. (2013) also show that Mozambique is vulnerable to extreme events such as cyclones, causing problems with floods and losses in agriculture.

In Figure 5, the average yield was estimated from the proposed model, being with no water deficit (Figure 5A) and with water deficit (Figure 5B). It was found that without hydric deficit, the productivity of sugarcane is

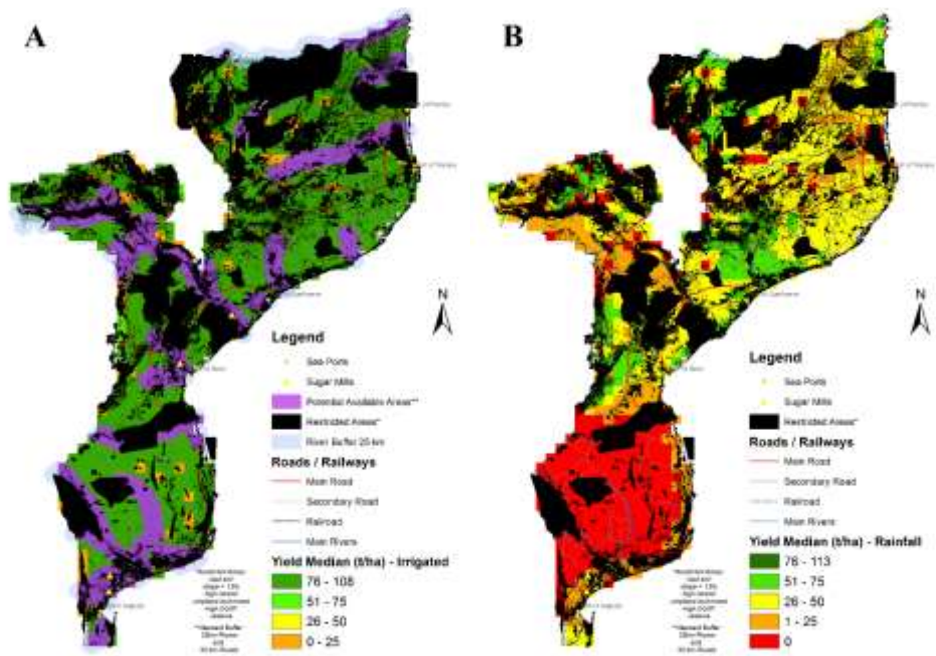

Figure 6. Maps with the potential area in the buffer junction of rivers and roads (A) and potential areas considering just rainfall (B); exclusion of the restricted areas.

Table 1. Area data, productivity and total production for areas considering the water deficit and with full irrigation.

Parameter	Area	Yield (t ha^{-1})	Total production
Irrigated	11.943.071	86	1.030.722.901
Rainfall	11.640.221*	71	611.929.424

*Considering areas where the yield was greater than 40 t/ha.

above 75 t ha^{-1} in almost all the territory of Mozambique. Already considering the water deficit, this is extremely high in some places like the southern region; while applying the model, the values become negative. It is only in the north central region that there are areas with yields above 50 t ha^{-1} for rain fed crop, but with chances of harvest loss due to these tracks of small extent.

In Figure 6A, there is a representation of potential areas considering water availability, given by large flow rivers, and infrastructure displacement given by the main roads, secondary and railway roads. This was added to the map, the position of the four currently existing plants in Mozambique, where they are present in the areas classified as potential. On the other hand, in Figure 6B, there are potential areas considering only the rainfall, including restrictions.

Table 1 shows the existence of large areas available for growing sugarcane countrywide, unrestricted and immediate implementation. The available area is equal to 11.943.071 ha for irrigated areas and 11.640.221 ha for rainfall areas (considering areas where the yield was greater than 40 t/ha), that is some 15% of the territory (considering Mozambique area equal to 799.380 km^2). From the yield in these areas, it was possible to estimate the potential production of 1.030 Mt year^{-1}, with full irrigation and 611 Mt year^{-1} by rainfall. In 2013, in Mozambique, only 46.149 ha of sugarcane with a total of 3.166.110 tons of production were collected (Mussuale, 2014), representing a small fraction of its potential.

The data obtained from the model were compared with the observed data of irrigated and rain fed income collected at the plant installed in Marromeu. Also, available data were used, the period considered in the study, the average air temperature for calculating degree days and rainfall for estimating the water deficit. Here, Thornthwaite methodology was used with CAD 100 mm. The methodology differs from the model used in the deficiency of agro-meteorological data to estimate evapotranspiration reference. Table 2 shows the results comparing the model with the observed data.

Table 2. Comparison of model results and observed (Obs) of the total degree days (DD), precipitation (P) and water deficit (HD) during the study period; and model performance with and without HD with rain fed and irrigated areas.

Parameter	Period July-June	
	2009/2010	2010/2011
Total Degree-days (Obs)	4053	4009
DD estimated (ECMWF)	2300	2270
Total Precipitation (Obs)	784	1133
P (ECMWF)	700	960
Total HD (Thornthwaite)	1062,1	723,1
HD estimated (ECMWF)	745	437
Yield Rainfall (Obs)	48 (39*)	76.9 (62.55**)
Model $Y_{rainfall}$	33	61
Yield Irrigation (Obs)	61 (93***)	64.5 (106.1***)
Modelo $Y_{irrigated}$	105	104

*Average larger area. **Average larger area except high yield. ***High yield attained.

According to Table 2, the model is coherent with the results observed in the cultivation area located in Marromeu. As previously shown, data of degree days were high, but it should be considered that the estimated ECMWF data contains average data in pixels of approximately 25 × 25 km. But the observed data are obtained in a point and open area, where the daily averages tend to be higher.

In relation to precipitation, the values were approximated, considering the coverage area of the ECMWF model. The water deficit, despite being higher at the station, showed similar variation, decreasing from 2009/2010 to 2010/2011.

The yield values generated by the model reflected relative similarity with those observed at the sugar mill. For rain-fed areas, we estimated in the first period 33 and 61 t ha^{-1} in the second. In the sugar mill, the values observed for rain fed, for the first period, were an average stands of 48 t ha^{-1}. However, considering only the largest field for the periods, the average was 39 and 62.55 t ha^{-1} respectively, similar to the values obtained by the model. It is worth considering that the value of 62.55 for 2010/2011 was derived from the average of the fields, excluding only a high yield field, which was considered spurious.

For the irrigated areas, considering the average yield of the stands the values were similar in periods, 61 and 64.5 t ha^{-1}. However, considering the areas with the highest yields were 93 and 106.1 t ha^{-1} for each period, respectively, with values similar to those obtained by the model, 105 and 104 t ha^{-1}.

Figure 7 shows the daily average temperature and total precipitation from July 2010 to June 2011 in Marromeu. It can be observed that the temperatures are extremely high in summer, as well as precipitation; but in the winter and early spring, higher average temperature (above 21°C) and practically no rainfall were observed. Scarpari and Beauclair (2004) show that accumulation of sucrose is important for water deficit and accumulation of negative degree days. Thus, interruption of irrigation is necessary, but can have problems due to the absence of negative degree-days.

Conclusion

From a simple model and data free access it was possible to estimate potential production of sugarcane in Mozambique, with a value of 1,030 Mt $year^{-1}$, being significant for the country. In addition, the analysis identified potential areas and concluded that irrigation is necessary for high yield of sugarcane in Mozambique, but there are areas where the cultivation is possible just by rain fed. It is important to remember that the rain fed crop has a low yield and instability in yield crop predictability. A larger-scale analysis of the locations identified with high agricultural potential is recommended for further studies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to the São Paulo Research Foundation for the financial support to Project LACAf I (Process N°2012/00282-3) that made possible the development of the work covered partially in this article; FAPESP (Project 2014/23323-2) for funding the study in

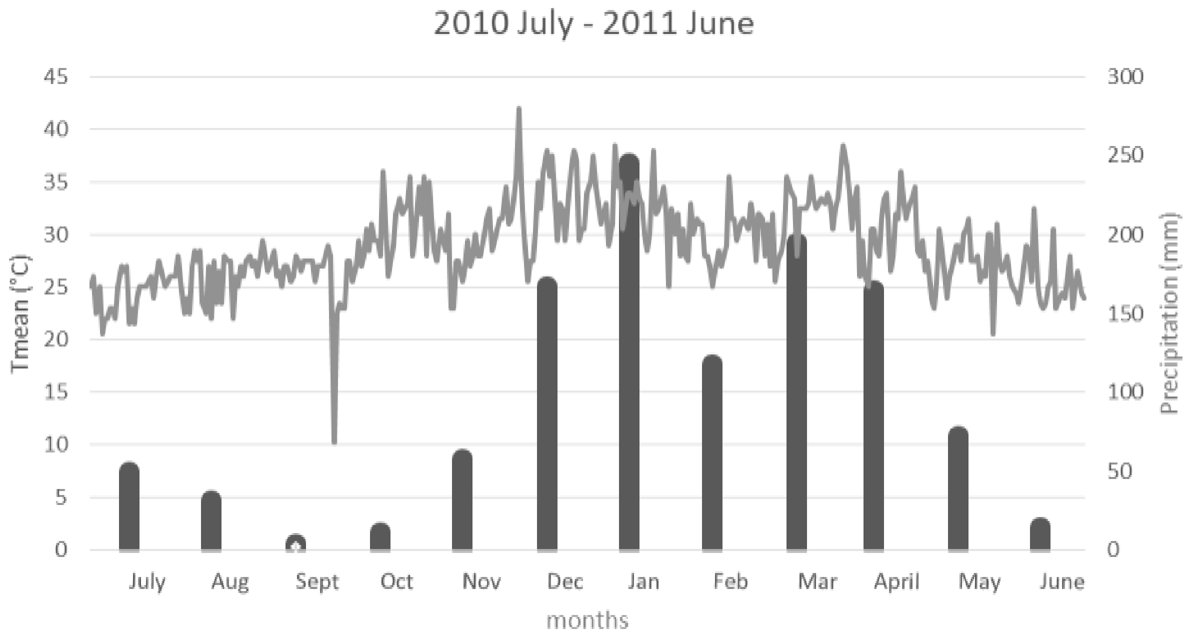

Figure 7. Daily temperature and monthly rainfall in the period considered as harvest from July to June for Marromeu.

the persons of the Juliano Braga and Jony dos Santos, for supporting in Companhia De Sena SA (Marromeu/Mozambique); and Dr. Momade Mamudo Ibrahimo (IIAM) for the support in Nampula/Mozambique.

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