Scientific Electronic Archives
Issue ID: Sci. Elec. Arch. Vol. 16 (3)
March 2023
DOI: http://dx.doi.org/10.36560/16320231672
Article link: https://sea.ufr.edu.br/SEA/article/view/1672

ISSN 2316-9281

Productivity and penalty in sugarcane from three meteorological databases in Jataí-GO

Corresponding author
João Carlos Rocha dos Anjos
Universidade Federal de Goiás
agrojoaocarlos@gmail.com

Derblai Casaroli
Universidade Federal de Goiás

José Alves Júnior
Universidade Federal de Goiás

Jéssica Sousa Paixão
Universidade Federal de Goiás

Gustavo Cassiano da Silva
Universidade Federal de Goiás

Jaurene Moura Fé Moraes
Universidade Federal do Piauí

José Gil dos Anjos Neto
Universidade Federal do Piauí

Lucas de Castro Medrado
Universidade Federal de Goiás

Fillipe de Paula Almeida
Universidade Federal de Goiás

Djavan Pinheiro Santos
Universidade Federal de Goiás

Abstract. The agroecological zone model proposed by FAO (ZAE/FAO) is an important tool in agricultural planning and can be used in Jataí, which has been gaining space in the production of sugarcane. The objective of this study was to compare the observed meteorological databases (BDMEP) with the estimated ones (Xavier and NASA POWER), in the estimation of potential productivity (PP) and attainable (PA) of sugarcane and its penalties for management (PMJ) and water deficit (PDF), using the ZAE/FAO model in the municipality of Jataí - GO. To this end, the BDMEP, Xavier and NASA POWER database, 33 years old (1984-2017), were used. Using BDMEP, Xavier and NASA POWER as input in the ZAE model, we observed an average PP of 259±11, 275±10 and 267±11 Mg ha^{-1} as, respectively. PA reaches 200 Mg ha^{-1} when using BDMEP in ZAE, with 50% of the crop year with PA above 180 Mg ha^{-1}. There was an average penalty of 114.01±6.9 for management and 85.67±4.08 Mg ha^{-1} in stem yield. The meteorological variables of

Xavier's database can be used in the ZAE model in the prediction of productivity penalty for water deficit and sugarcane management, with 63% and 88% adjustment to BDMEP, respectively. NASA POWER can be used in the simulation of penalty for failures in sugarcane management, with up to 87% approximation of those observed. Both sources when used in the prediction model assist in agricultural planning.
Keywords: Crop forecast, ZAE-FAO model; ZARC, Saccharum Spp.

Introduction

Brazil stands out with the largest producer of food, energy and fiber from agriculture and livestock. In this scenario sugarcane gains prominence with 10.24 million hectares cultivated and average productivity of 72.54 Mg ha^{-1} of stem, 37.87 million megagram of sugar and 27.76 billion liters of alcohol. Being Goiás the second largest national producer (10.81% of the cultivated area) (Conab, 2018). In this state, Jataí, municipalities that have gained prominence in the last five years with productivity in the area of cultivation and productivity (IBGE, 2019). However, Jataí still needs research that can predict possible penalties for water deficit and crop management, thereby planning its crop year and increasing productivity.

Despite the importance in the production of renewable energy, the sugar-energy sector still goes through penalties in the productivity of sugarcane, mainly caused by the prolonged period of water deficit and management. Because the main climatic elements that determine the productivity of agricultural crops are air temperature, solar radiation, photoperiod, real insolation, distribution, duration and frequency of precipitations and crop management. Which can predict its effect on plant growth and development, and thus make the most assertive decisions in agricultural planning (Alvares et at., 2013; Cardozo & Sentelhas, 2013; Angels et al., 2017; Caetano & Casaroli 2017; Dias & Sentelhas 2018, Cassaroli et al., 2019, Anjos et al., 2020b).

The Agroecological Zoning proposed by Doorenbos & Kassam (1994), is a mathematical model that enables predicts the productivity of any crop due to climatic conditions and its genetics. From then on, obtaining potential productivity (limited only by local weather conditions, and without water deficit), and attainable productivity (limitation of potential productivity due to water deficit), which together with real productivity (obtained at the field level that is conditioned to climatic and management limitations), allows predicts possible penalties in productivity due to water deficit and management. From then on, reduce agroclimatic risks and improve the edaficating, nutritional and sanitary conditions in the cultivation system.

In agricultural planning, producers and extensionists use information on possible productivity and penalties in agricultural productivity. Being the Agroecological Zone model (ZAE) (Doorenbos & Kassam, 1994), used in these predictions. This technological tool requires climatological variables as input. However, this information observed through the meteorological stations installed on the surface of the earth does not cover the entire municipality of Jataí according to the recommendations of the World Meteorological Organization (WMO), besides having a high cost and time for its acquisition. Therefore, it is necessary to use an estimated database to fill these failures.

Some studies have already used estimated databases, obtaining positive results, especially the database known as Xavier and NASA POWER (NASA Prediction of Worldwide Energy Resources) (Dender & Sentelhas, 2018, Casaroli et al., 2019, Anjos et al., 2020a).Xav

ier's database is limited to The Brazilian territory and was estimated from 3,625 rainfall stations and 735 weather stations installed on the surface of the territory, with the averages corresponding to high resolution grides ($0.5^{o} \times 0.5^{o}$). Nasa POWER data, on the other hand, is based on solar radiation derived from satellite observations and meteorological data from the Goddard Earth Observing System assimilation model, with 1st × 1st grides, available from 1983 to the present day, for any region of the planet Earth.

Estimated data has become a viable alternative, this, because the cost of acquiring and maintaining weather stations is high. However, it is worth mentioning that there is a need for studies that prove its applicability and reliability for certain uses. In this sense, the objective was to compare observed meteorological databases (BDMEP) with the estimated ones (Xavier and NASA POWER), in the estimation of potential and attainable productivity of sugarcane and its penalties for management and water deficit, using the ZAE/FAO model in the municipality of Jataí - GO.

Materials and Methods

Crop model simulation

The productivity simulations were made following the methodology described by FAO (Food and Agriculture Organization of the United Nations), in the Agroecological Zone model (Doorenbos & Kassam, 1994). Thus, potential productivity (PP, Mg ha 1), without water restriction, and attainable productivity (PA, Mg ha 1) were estimated, with restriction, for sugarcane crop, in cycles of 12 months, with planting/cutting date 01/04.

Weather and soil data

In obtaining the input parameters of the ZAE model, different agrometeorological databases were used: meteorological database for teaching and research - BDMEP (INMET, 2018), corresponding to the MMO station 83464; those estimated by Xavier (2018); and NASA POWER (2018), obtained for the geographic coordinates of the municipality of Jataí, Goiás, Brazil (17° 54' 36" S; 51° 42' 36" W; altitude of 662.86 m).

The historical series of meteorological variables comprised the period from 1984 to 2017 (33 years). The existing failures in the BDMEP were filled with the daily climatological normals of each meteorological variable.

Water balance

The reference evapotranspiration (ETo, mm day^{-1}) was obtained by the Penman-Monteith method (Allen et al., 1998), which was used to estimate crop potential evapotranspiration (ETc=ETo·Kc), using crop coefficient (Kc) values, the water deficit response factor (ky) and the leaf area index (LAI) described in the FAO Bulletin (Allen et al., 1998) (Table 1).

The actual evapotranspiration (ETR, mm day^{-1}) was obtained by the daily sequential water balance (Thornthwaite & Mather, 1955), using initial available water capacity value (CADi=18.6mm) and final (CADf=99.2mm), being obtained from moisture values in field capacity and permanent wilting point estimated by pedotransfer functions (Assad et al., 2001), which has as its input variable the total sand (AT=36%), derived from the RADAMBRASIL project (Brazil, 1981,1982 and 1983), having as predominant soil in the region the dystrophic Red-yellow Latosols, being the effective depth of the initial root system (Ze=0.15m) and final (Ze=0.80 m) (Sousa et al., 2013).

Potential yield (PP)

The PP expressed in the amount of dry mass per area (kg DM ha-1) maximum was estimated by the Agroecological Zone model, described in fao-bulletin nº33 (ZAE-FAO) (Doorenbos & Kassam, 1994), according to the following sequence of equations:

$$\mathrm{PP} = \sum_{1=1}^{m}(YpBpi \cdot Ciaf \cdot Cresp \cdot Ccolh \cdot Cum)$$

where m represents the number of days of the cycle; YpBp the standard crude potential productivity of dry matter for a hypothetical crop with AFA = 5 (kg DM ha^{-1} day^{-1}), calculated by the sum of gross potential productivity on clear sky days (YpBc, kg DM ha^{-1}·day^{-1}) and cloudy (YpBn, kg MS ha^{-1} day^{-1}), estimated by the Eqs. [2] and [3]:

$$YpBc = (107.2 + 8.604 \cdot Qo) \cdot \frac{n}{N} \cdot cTc \qquad [2]$$

$$YpBn = (31.7 + 5.234 \cdot Qo) \cdot \left(1 - \frac{n}{N}\right) \cdot cTn \qquad [3]$$

onden is heat stroke (day^{-1}hours); No photoperiod (day^{-1}hours); Ro extraterrestrial solar irradiation (MJ m^{-2} day^{-1}); cTc and cTn are the correction factors for the average air temperature (Ta, °C) and metabolic cycle of the species (C4) on clear skies and cloudy skies, respectively, being:

Towards T ≥ 16.5 °C:

$$cTn = -1.064 + 0.173T - 0.0029T^2 \qquad [4]$$

Towards T< 16.5 °C:

$$cTn = -4.16 + 0.4325T - 0.00725T^2 \qquad [6]$$

$$cTc = -9.32 + 0.865T - 0.0145T^2 \qquad [7]$$

O *Ciaf* é o coeficiente para correção do índice de área foliar (Eq.[8]).

$$Ciaf = 0.0093 + 0.185 \cdot IAFmax_i - 0,0175 \cdot IAFmax_i^{\ 2} \qquad [8]$$

IAFmaxi being the maximum value of AFA on day i, case of IAFmax≥5 the Ciaf=0.5. IAF values were considered for a 12-month crop (Table 1); Cresp is the coefficient for correction of crop maintenance breathing, being a function of T (°C). Case T ≥ 20 °C, Cresp = 0.5; but, if t<20°C, Cresp = 0.6; Ccolh is the coefficient relative to the harvested part (stems), which for sugarcane represent 80% of the total mass of the plant (Doorenbos & Kassam, 1994); and is the coefficient of correction of stem moisture (Eq.[9]).

$$Cum = [1 - 0.01 \cdot U]^{-1} \qquad [9]$$

Where U represents the percentage value of the stem moisture (%).

Attainable yield (PA)

The relative drop in productivity $\left(1 - \frac{\mathrm{PA}}{\mathrm{PP}}\right)$ has a direct relationship with the relative water deficit $\left(1 - \frac{ETa}{ETc}\right)$. In addition, sugarcane Ya is also a function of the crop response coeff[1]ient to water deficit (ky), which varies with phenological phases (Table 1). Thus, PA (in kg ha-1) was estimated by Eq. [10].

$$\mathrm{PA} = \mathrm{PP} \cdot \prod_{i=1}^{7}\left[1 - ky_i \cdot \left(1 - \frac{ETa_i}{ETc_i}\right)\right] \qquad [10]$$

in which kyi is the index of sensitivity to water deficit, dimensional; ETai (mm) is the actual evapotranspiration determined by the sequential water balance of the crop (Thornthwaite & Mather, 1955); ETci is the maximum evapotranspiration of the harvest; i is the phenological phase considered (Table 1).

Yield gap water deficit and yield gap crop management

The penalties for water deficit (PDH, Mg ha-1) and management (PMJ, Mg ha 1) were estimated by the Eqs. [11] and [12]:

$$\text{PDH} = \text{PP} - \text{PA} \quad [11]$$

$$\text{PMJ} = \text{PA} - \text{PR} \quad [12]$$

where PP is potential productivity (Mg ha-1); PA is attainable productivity (Mg ha^{-1}); and PR is the corrected real productivity (Mg ha^{-1}) obtained from the IBGE database (2019).

Table 1. Phenological phases, duration time (Days) of each phenological phase, leaf area index (INA), water deficit response coefficients (ky) and crop coefficient (Kc) of sugarcane cultivated in Goiás.

Phenological phase	DAYS	IAF	*KY*	KC
25% cultived	30	2.0	0.75	0.50
25 - 50%	30	2.5	0.75	0.80
50 - 75%	15	3.0	0.50	1.00
75 - 100%	50	3.5	0.50	1.10
Maximum growth	180	4.5	0.50	1.20
Senescence	30	4.0	0.50	0.95
Ripening	30	3.5	0.10	0.65
Number of days	365	-	-	-

Source: Adapted from the Bulletin of the FAO, n° 33 (1994).

Statistical analysis

The data were analyzed by descriptive statistics (means, medians, deviations) and linear regression tests and the means compared to each other by Tukey.

Results and discussion

In the evaluated period (1984 to 2017) potential productivity (PP) was observed, with 75% of the crop years ranging from 273 to 290 Mg ha^{-1} of stem when using Xavier meteorological database in the ZAE model, and these values were higher than those observed (BDMEP) and estimated (NASA POWER) (Figures 1A and 1B). However, it is observed in Figuraura 1C and 1D, better fit of the model of prediction of potential productivity of sugarcane when using NASA POWER data. These results can be justified, because temperature and irradiation are input variables in the ZAE model, and among them the one that most influences the production of photoassimilates, besides presenting good fit with those observed (Dender & Sentelhas, 2018).

Attainable productivity (PA) is observed, between 144 and 200 Mg ha^{-1} when BDMEP was used in zae, with 50% of the crop years with PA above 180 Mg ha^{-1} (Figures 2A and 2B). However, differently from what occurred with PP, when using xavier and nasa power data in the productivity prediction model, PA was underestimated when compared to the observed data. Despite the estimated PA used Xavier data better to adjust (R2 = 0.63) to the observed (Figures 2C and 2D), NASA POWER presented the lowest productivity variation over the harvest years. The best fit between Xavier and BMMEP in predicting PA is due to NASA POWER's low efficiency in estimating precipitation (Dender & Sentelhas, 2018), which is responsible for penalizing potential productivity.

The fact that the study presented a higher relationship between PA using BDMEP and Xavier data than with NASA POWER may be related to the way the data were obtained. NASA POWER's meteorological variables are composed of satellite data, radioprobes, surface observations and numerical modeling of data assimilation with horizontal resolution (1° × 1°) (Dender & Sentelhas, 2018). Xavier's data were estimated from 3.625 rainfall stations and 735 meteorological stations installed on the surface of the Brazilian territory, with the averages corresponding to high resolution ($0.5^o \times 0.5^o$) (Xavier et at., 2016), making it closer to the actual data (BDMEP).

In the period evaluated (1984 to 2017), it was observed that water stress throughout the year of cultivation penalized the stem PP in 85.9±4.1 Mg ha^{-1} when the BDMEP was used in the ZAE model (Figure 3A and 3B). Xavier and NASA POWER overestimated the penalty for water deficit reaching an average value of up to 79.7±3 Mg ha^{-1} higher than BDMEP

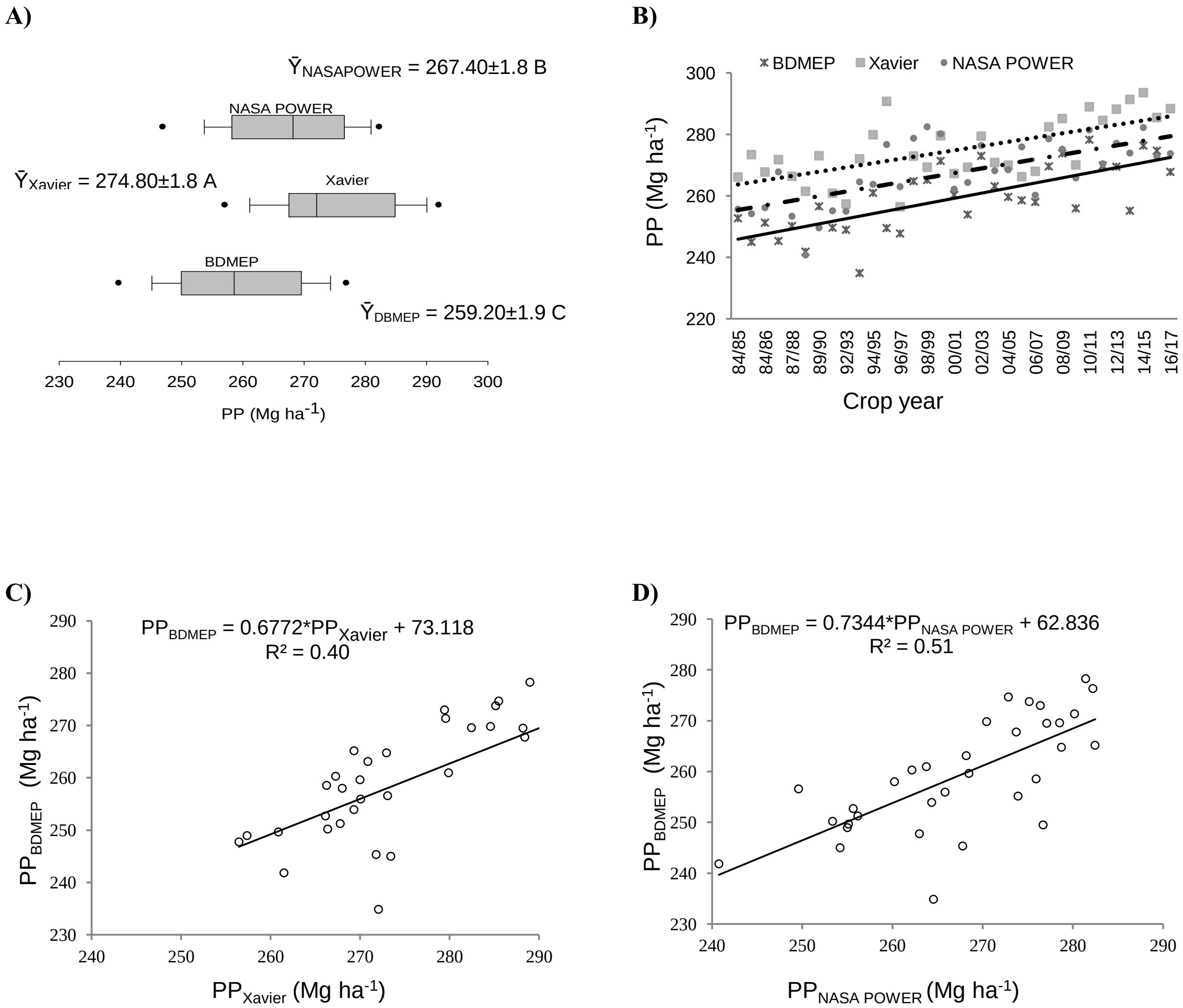

Figure 1. Trend measurements (Figure A) of potential productivity (PP) at the end of the sugarcane harvest years - 1984 to 2017 (Figure B), and the relationship between PP using meteorological data observed (BDMEP) and estimated by Xavier (Figure C) and NASA POWER (Figure D) in Jataí, Goiás, Brazil. Ȳ is average and its standard error and mean comparison test, where means with the same letter do not differ statistically from each other by the Tukey test at 5% probability of error.

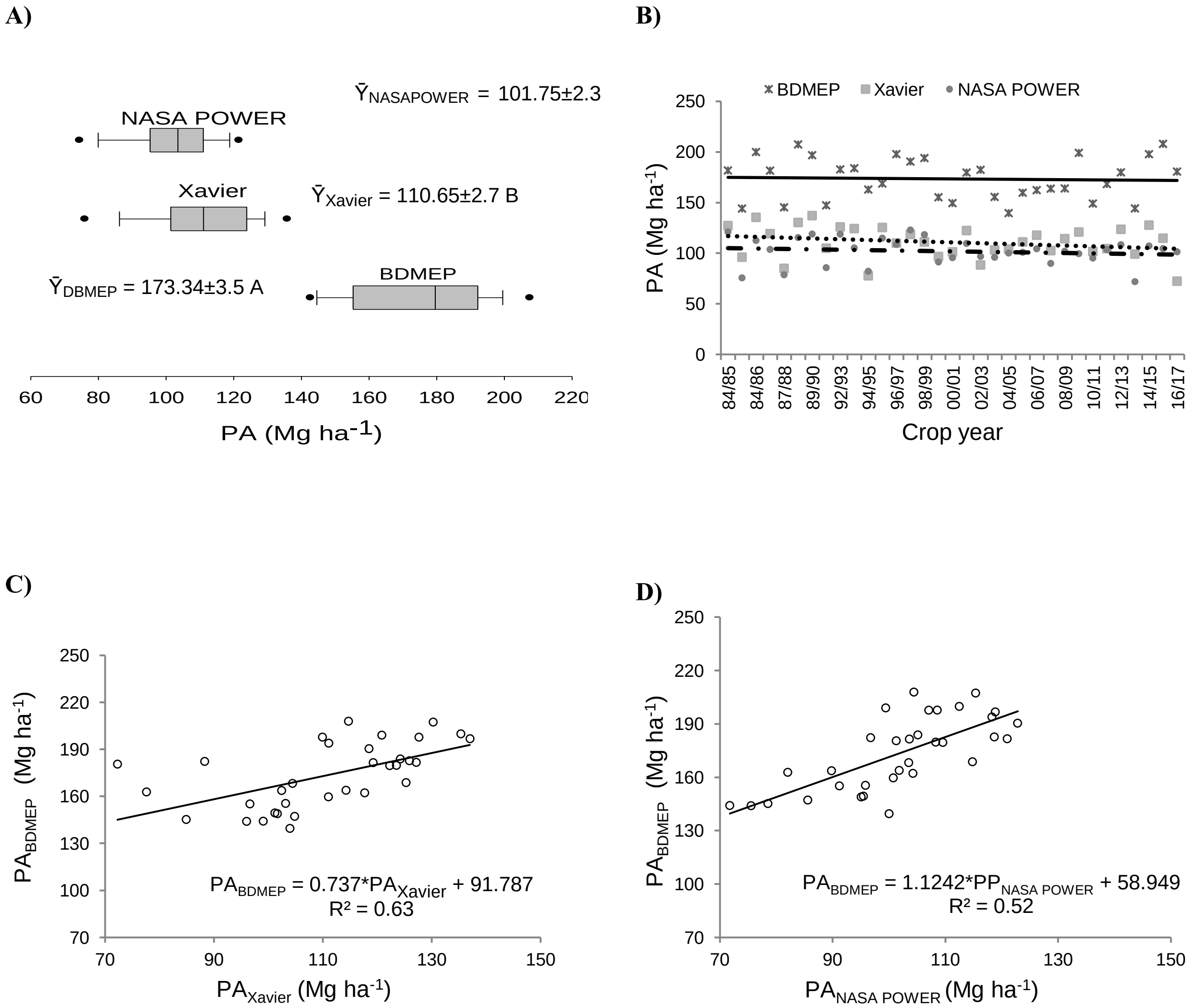

Figure 2. Trend measurements (Figure A) of attainable productivity (PA) at the end of the sugarcane harvest years - 1984 to 2017 (Figure B), and the relationship between PA using observed meteorological data (BDMEP) and estimated by Xavier (Figure C) and NASA POWER (Figure D), in Jataí, Goiás, Brazil. Ȳ is average and its standard error and mean comparison test, where means with the same letter do not differ statistically from each other by the Tukey test at 5% probability of error.

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The results corroborate studies by Dender & Sentelhas (2018), which observed a low coefficient of determination (R2=0.2) when comnoting the precipitation observed with that estimated by NASA POWER. These authors justify the result to the high local spatial variability associated with topography and terrestrial coverage that makes it difficult to obtain the meteorological variable when using satellite data, radioprobes, surface observations and numerical modeling with horizontal resolution (1° × 1°). In addition, figures 3C and 3D found that the estimated PDHs presented adjustment of only 63% (R2=0.63), and 55% (R2=0.55) of the data observed when used in the Xavier and NASA POWER model, respectively. Xavier, unlike NASA POWER, estimates rain from 3.625 rainfall stations and 735 weather stations installed on the surface of The Brazilian territory, corresponding to high resolution (0.5^{o} × 0.5^{o}) (Xavier et at., 2016).

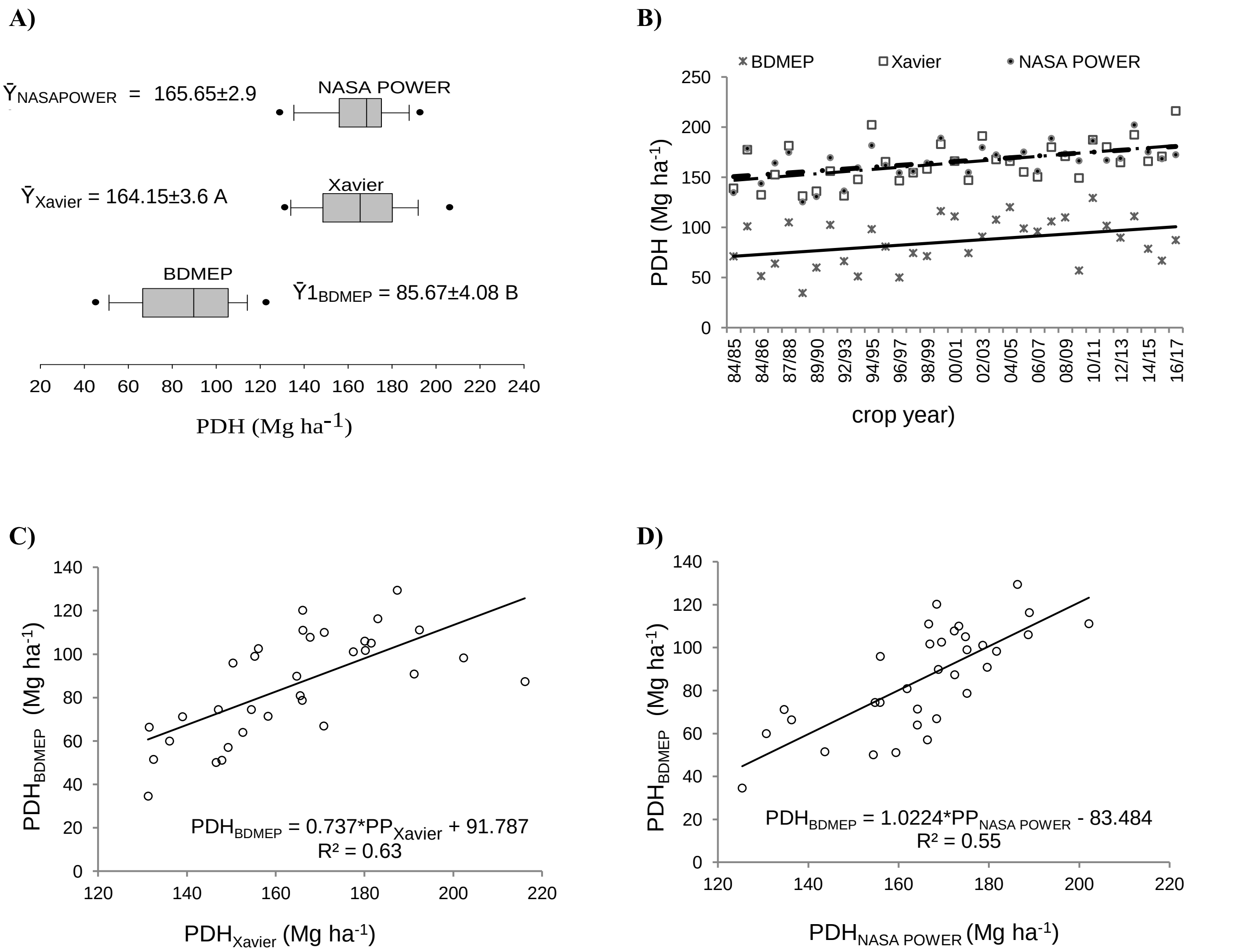

Figure 3. Trend measures (Figure A), penalty of productivity by water deficit (PDH) at the end of the sugarcane harvest years - 1984 to 2017 (Figure B), and the relationship between The PDH using meteorological data observed (BDMEP) and estimated by Xavier (Figure C) and NASA POWER (Figure D), in Jataí, Goiás, Brazil. Ȳ is average and its standard error and mean comparison test, where means with the same letter do not differ statistically from each other by the Tukey test at 5% probability of error.

It is observed that the lack of adequate management of agricultural production factors such as fertilization, weed control, pests and diseases penalized stem yield on average 42.2±6.9 Mg ha^{-1} in Jataí (Figure 4A). Differently from what occurred with PDH, Xavier and NASA POWER began to underestimate the crop management penalty (PMJ) when compared to BDMEP.

The error caused when using these databases estimated in the ZAE model is clear by the presence of negative PDH (Figure 4B). This is not possible in practice, because even if it supplied all water needs of the crop and controlled all factors related to crop management, PR would only equal PA (PR≤PA). Even presenting these failures, an adjustment of up to 88% (R2 = 0.88) was observed between the observed and estimated data, with a variation of only one 1% among the estimated ones.

It is interesting to note that Jataí, with the application of technology in sugarcane management, greatly improved the management in the crop years 2006/2007 to 2016/2017, mainly in the last five years, obtaining exponential growth and reaching stem PR at 140 Mg ha^{-1} (IBGE, 2019), higher than the State of Guace7 73.86 Mg ha^{-1} (CONAB, 2018).

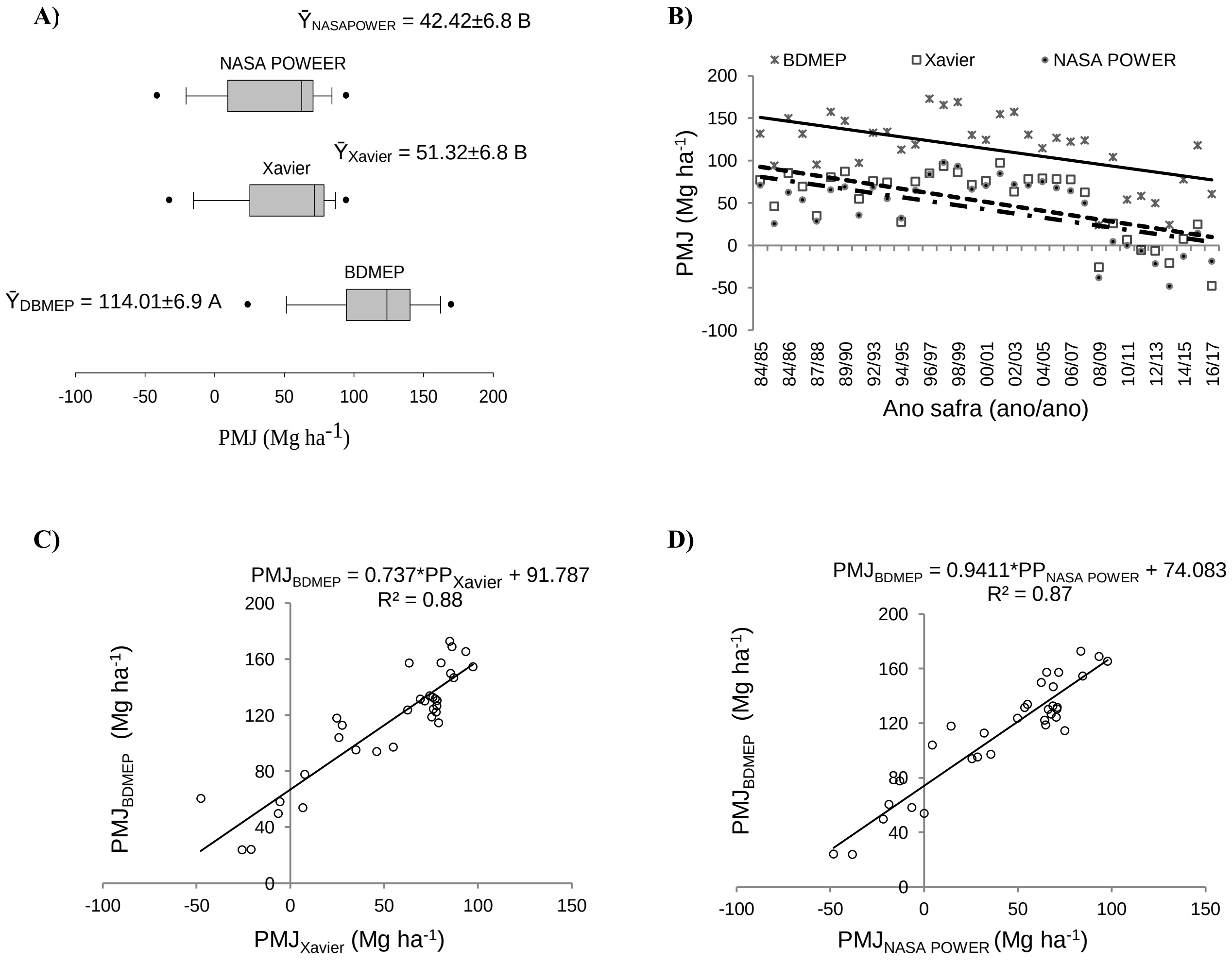

Figure 4. Trend measures (Figure A), management productivity penalty (PMJ) at the end of the sugarcane harvest years - 1984 to 2017 (Figure B), and the relationship between PMJ using observed meteorological data (BDMEP) and estimated by Xavier (Figure C) and NASA POWER (Figure D), in Jataí, Goiás, Brazil. Ȳ is average and its standard error and mean comparison test, where means with the same letter do not differ statistically from each other by the Tukey test at 5% probability of error.

Conclusion

The meteorological variables of xavier's database can be used in the ZAE model in the prediction of productivity penalty for water deficit and sugarcane management, with 63% and 88% adjustment to BDMEP, respectively. NASA POWER can be used in the simulation of penalty for failures in sugarcane management, with up to 87% approximation of those observed. Both sources when used in the prediction model assist in agricultural planning

Acknowledgment

The authors would like to thank the Brazilian National Council for Scientific and Technological Development (CNPq), for the supply of the experimental area, the Federal University of Goiás (UFG), for support and research materials granted.

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