Delimitation of Guava Water Productivity in the Brazilian Northeast

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Abstract

The intensification of agricultural crops in the Brazilian northeast results in a change of natural vegetation, making the quantification and evaluation of the additional water use important. Applications of a Geographic Information System (GIS) are presented in this paper to estimate the guava water productivity (GWP) on a large scale. Long-term weather data were used together with regression models involving crop coefficient (K_c), reference evapotranspiration (ET_0) and accumulated degree days (DD_{ac}) to quantify the guava water requirements (GWR) in the Brazilian Northeast producer states, considering an average growing season of six months and the cultivar 'Paluma' as a reference. By coupling GWR data with total precipitation for a growing season, it was possible to quantify the guava water deficit (GWD) giving an estimate about irrigation needs. Considering the whole region, the variation of the averaged GWD values ranged from 50 mm for pruning dates in January to 520 mm, with pruning done in May. Associating the average GWR values with yield data for 2010 from the Brazilian Geographical and Statistical Institute (IBGE), the average biophysical and economic values of GWP were estimated for each guava producer state. The biophysical values were between 0.86 and 4.95 kg m^{-3} for pruning dates in July and January in Rio Grande do Norte and Pernambuco states, respectively, while the economic ones ranged from 0.40 to 3.18 R\$ m^{-3} for the same pruning periods, however, with the lowest averaged value being for Paraíba state. The states of Pernambuco, Bahia and Piauí presented the largest biophysical and economic GWP values. The spatially presented analyses can subsidize programs for the expansion of rainfed guava crop as well as water allocation criteria under irrigation conditions, aiming at improvements for water resource use.

INTRODUCTION

In the Brazilian northeast, guava (*Psidium guava* L.) is one of the most important fruit crops under both, irrigated and rainfed conditions, where the beginning of the harvest is possible two years after the planting date, allowing two growing seasons along the year, with 'Paluma' being the most important cultivar. However, for the rational use of natural resources in the production process, it is important to quantify how productive the use of water is in this process.

The climate of the Brazilian northeast is very favourable to guava crop, although in semi-arid conditions, the orchards are exposed to low rates of precipitation and high atmospheric demands, with irrigation being necessary, which has to be carried out efficiently and has to be based on the water requirements (Singh et al., 2007).

Distinctions are made between reference evapotranspiration (ET_0), potential evapotranspiration (ET_p) and ET_a. ET_0 is the water flux from a reference surface, not short of water. ET_p may be referred to as the water flux from crops that are grown under optimum conditions, while ET_a involves all situations of the crop. Due to sub-optimal crop management and environmental constraints that affect crop growth and limit water consumption, ET_a from guava crop is generally smaller than ET_p (Allen et al., 1998).

Guava production and guava water requirements (GWR) are two closely linked processes. The guava water productivity (GWP) can be considered as the ratio of yield to

GWR. The economic water productivity is the value derived per unit of water used and the economic indicators may be the standard gross value of production over GWR (GWP$) (Teixeira and Bassoi, 2009).

Micro-meteorological measurements can be used to quantify GWR (Teixeira et al., 2003), however, field methods provide values for specific sites and are not suitable to estimate these requirements on a regional scale. The approach of modelling ET_a throughout the crop coefficient, suggested by the FAO, is a viable alternative for use together with a Geographic Information System (GIS) where the spatial variations in soil, hydrology and weather conditions make parameterisation of hydrological models a difficult task (Teixeira, 2009).

According to Teixeira and Bassoi (2009), economic water productivity in fruit crops is much higher than for irrigated annual crops, however, the water management requires full attention as under intensive land use change, the environment can be affected by the flow of polluted water to the rivers, which makes it necessary to promote more efficient water use, water-resources management, and planning for the expansion of irrigated areas.

The objectives of this paper were the modelling of water requirements, water deficiencies and water productivity of guava crop in the Brazilian northeast, aiming to subsidize the expansion of irrigated and rainfed guava orchards considering the environmental implications.

MATERIAL AND METHODS

Figure 1 shows details of the Brazilian geographic regions, the northeast states and the location of the rain gauges and conventional agro-meteorological stations used. The monthly total precipitation data were available from SUDENE (Superintendence of Development of the Northeast) and referred to 1455 locations of rain gauges, while the monthly mean air temperature data were from INMET (National Meteorological Institute), which were recorded in 75 conventional stations. Both meteorological parameters were long-term values for the period from 1961 to 1990. In the stations where only precipitation data were available, the monthly mean air temperature values were estimated from the geographic coordinates. The Thornthwaite method (TH), which needs only air temperature as a meteorological input parameter, was first applied to retrieve the monthly reference evapotranspiration by using the available or estimated data from the conventional stations (Thornthwaite, 1948).

Simultaneous measurements of ET_p in guava crop, 'Paluma', and reference evapotranspiration by the Penman-Monteith (PM) method (Allen et al., 1998) allowed the acquirement of the crop coefficient (K_c) (Teixeira et al., 2003) as a function of the accumulated degree days (DD_{ac}):

$$K_c = aDD_{ac}^{\ 2} + bDD_{ac} + c \qquad (1)$$

where $a=-3\times10^{-8}$, $b=2\times10^{-4}$ and $c=0.63$ are regression coefficients found from previous experimental data.

The ET_p for an average six months growing season was considered as the GWR. After calibrating ET_0 by Thorntwaite into Penman-Monteith method by using regression equations obtained from seven automatic agrometeorological stations located in the Brazilian semi-arid region, seven modelled values of K_c from DD_{ac}, considering a base air temperature of 10°C, were averaged and the mean value multiplied by ET_0 (Allen et al., 1998):

$$GWR = K_c ET_0 \qquad (2)$$

GWR maps coupled with those of precipitation (P), allowed the quantification of guava water deficiencies (GWD), meaning the irrigation requirements.

$$GWD = P - GWR \tag{3}$$

With data of actual production (Y_a) from the IBGE for the year of 2010, the GWP was obtained:

$$GWP = \frac{Y_a}{GWR} \tag{4}$$

RESULTS AND DISCUSSION

Figure 2 depicts the GWR values for 'Paloma', at different pruning dates in the Brazilian northeast producer states, based on the long-term data from 1961 to 1990. As Maranhão is not a guava producer, it was cut from Figure 1. Analyzing the producer region as a whole, the pruning dates with maximum GWR are in July when the average value is 754 mm. The minimum is found when the pruning is done in January, with GWR around 556 mm. Highlights were for Piauí (PI), Ceará (CE) and Rio Grande do Norte (RN) as the states with the highest GWR values, while the lowest ones were found in Bahia (BA), Alagoas (AL) and Pernambuco (PE).

Table 1 presents the variation of GWR among the Brazilian northeast producer states considering the averaged values and different pruning dates. In general, GWR above 700 mm happened when the pruning dates were between June and September. The lowest ones occurred when the pruning was done between January and March, being verified average values even lower than 600 mm. The extremes represent a GWR daily range from 2.9 to 4.5 mm day^{-1}.

The water use in a micro sprinkler irrigated guava crop from a field experiment in Petrolina, Brazil, showed an average of 4.5±0.7 mm day^{-1} (Teixeira et al., 2003), which was inside the range of the daily GWR in the Brazilian northeast producer states, however, higher than that reported by Singh et al. (2007) of 2.7 mm day^{-1} in West Bengal, India with the crop under drip irrigation and plastic mulch.

Large GWR values mean a higher guava yield, due to a direct relation between the water vapour fluxes and the CO_2, as that gas enters into the leaves stomata for the photosynthetic process, however, it is important to verify if the yield reduction is significant under conditions of lower water requirements and situations of big competition for water by other sectors besides agriculture (Teixeira and Bassoi, 2009).

For analyses of the real availability of natural water for guava crop, the input and the output over the vegetated surface has to be quantified. The first is represented by the precipitation (P) while the second, can be considered as GWR. Figure 3 depicts the GWD regional values for 'Paluma', at different pruning dates in the Brazilian northeast producer states, based on the long-term data from 1961 to 1990. A general characteristic was the occurrence of deficiencies in all pruning periods. However, for those from November to March, there were large areas where the rains can satisfy the guava crop with reduced or even absence of irrigation water.

The pruning dates with maximum and minimum GWD values were also in July and January, with 523 and 52 mm being the highest and lowest averages, respectively. Highlights, in relation to the largest values, were for the same states as for GWR, however, the highest one for Piauí occurred differently in May due to its particular precipitation regime. The lowest GWD values, below 20 mm, were for Sergipe (BA), in February and Paraíba and Ceará, in January.

Table 2 presents the variation of GWD among the Brazilian northeastern producer states considering the averaged values and different pruning dates. GWD values above 400 mm happened when the pruning dates were between May and August, making the irrigation essential for the commercial guava crop. The lowest deficiency rates happened when the pruning was done between December and February, with averaged values lower than 100 mm, presenting a good opportunity for rain fed guava crop.

The GWP was considered in terms of water consumption in potential conditions of the guava crop, 'Paluma', in the Brazilian northeast producer states (Fig. 4). The pruning dates with maximum and minimum values for the whole region were in January and July, respectively around 2.48 and 1.82 kg m^{-3} as a consequence of the lowest and highest rates of GWR. Considering the different states, highlights were for Pernambuco (PE), Bahia (BA) and Piauí (PI) as those with the highest GWP values. On the other hand, the states of Rio Grande do Norte (RN) and Paraíba (PB) presented the lowest ones, below 1.00 kg m^{-3}. The range of the bio-physical GWP values were between 0.86 and 4.95 kg m^{-3} for Rio Grande do Norte (RN) and Pernambuco (PE) states, while the monetary values ranged from 0.40 to 3.18 R$ m^{-3}, however, with the lowest averaged value being for Paraíba (PB) state.

Table 3 presents the variation of GWP among the Brazilian northeast producer states. In general, GWP values above 2.30 kg m^{-3} happened when the pruning dates were between December and March. The lowest ones occurred when the pruning was done between July and September, with averaged values lower than 2.00 kg m^{-3}. In the semiarid region of Brazil, in Petrolina-PE, Teixeira et al. (2003) found GWP values of 2.66 kg m^{-3}, similar to the value of 2.74 kg m^{-3} reported by Singh et al. (2007) in India, evidencing ample room for water productivity improvements in GWP values in some states of the Brazilian Northeast.

ACKNOWLEDGEMENTS

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Tables

Table 1. Average values of the guava water requirements (GWR), 'Paluma', for different pruning dates, considering an average growing season of six months, in the Brazilian northeast producer states of Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE) and Bahia (BA).

Prune	GWR_{PI} (mm)	GWR_{CE} (mm)	GWR_{RN} (mm)	GWR_{PB} (mm)	GWR_{PE} (mm)	GWR_{AL} (mm)	GWR_{SE} (mm)	GWR_{BA} (mm)
Jan.	554.5	597.8	598.7	551.3	541.5	534.1	562.6	521.4
Feb.	572.4	610.5	605.1	558.4	546.4	538.0	564.0	534.7
Mar.	617.6	651.9	633.1	586.2	572.2	555.7	577.2	558.9
Apr.	665.1	687.5	656.7	611.0	598.1	572.9	591.3	584.7
May	715.4	733.6	695.8	651.8	641.7	609.2	624.9	620.9
Jun.	756.3	774.2	735.1	693.7	685.5	650.0	665.2	661.1
Jul.	808.1	821.9	784.6	745.5	740.3	702.6	718.0	712.0
Aug.	793.3	808.2	777.3	737.9	735.6	697.9	715.2	700.7
Sep.	753.2	769.5	753.4	715.3	716.3	688.0	710.0	680.4
Oct.	703.3	733.3	729.2	689.9	689.5	670.7	696.2	652.5
Nov.	647.4	686.1	688.4	646.4	641.9	630.7	659.4	610.6
Dec.	604.2	645.5	648.4	603.4	596.3	587.5	616.0	569.2

Table 2. Average values of the guava water deficiencies (GWD), 'Paluma', for different pruning dates, considering an average growing season of six months, in the Brazilian northeast producer states of Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE) and Bahia (BA).

Prune	GWD_{PI} (mm)	GWD_{CE} (mm)	GWD_{RN} (mm)	GWD_{PB} (mm)	GWD_{PE} (mm)	GWD_{AL} (mm)	GWD_{SE} (mm)	GWD_{BA} (mm)
Jan.	-70.9	-13.4	-43.0	-18.6	-92.2	-28.2	-13.8	-133.0
Feb.	-183.0	-60.6	-78.6	-56.7	-143.0	-31.3	-12.1	-234.5
Mar.	-373.5	-280.2	-246.6	-198.4	-262.2	-58.5	-20.5	-337.2
Apr.	-528.6	-503.7	-423.1	-343.3	-364.1	-104.9	-47.0	-378.6
May	-543.8	-644.0	-551.1	-455.8	-435.6	-216.2	-134.8	-332.5
Jun.	-484.7	-695.1	-631.3	-537.0	-490.3	-340.4	-272.6	-282.6
Jul.	-430.4	-733.2	-707.5	-618.5	-555.4	-474.2	-418.2	-242.3
Aug.	-279.5	-641.7	-667.8	-577.5	-509.7	-490.1	-460.7	-159.1
Sep.	-108.2	-394.9	-491.9	-415.5	-375.7	-427.6	-429.3	-109.5
Oct.	-40.9	-174.2	-312.0	-252.2	-250.1	-319.1	-321.5	-80.1
Nov.	-35.3	-62.8	-182.3	-133.5	-159.8	-176.5	-159.9	-73.4
Dec.	-48.4	-31.4	-103.2	-62.1	-119.5	-73.1	-55.0	-89.4

Table 3. Average values of the guava water productivities (GWP), 'Paluma', for different pruning dates, considering an average growing season of six months, in the Brazilian Northeast producer states of Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE) and Bahia (BA).

Prune	GWP_{PI} (mm)	GWP_{CE} (mm)	GWP_{RN} (mm)	GWP_{PB} (mm)	GWP_{PE} (mm)	GWP_{AL} (mm)	GWP_{SE} (mm)	GWP_{BA} (mm)
Jan.	2.68	1.89	1.13	1.31	4.95	2.23	2.30	3.31
Feb.	2.60	1.85	1.12	1.29	4.90	2.21	2.29	3.22
Mar.	2.41	1.74	1.06	1.23	4.68	2.14	2.24	3.08
Apr.	2.25	1.65	1.03	1.18	4.48	2.07	2.19	2.95
May	2.09	1.54	0.96	1.11	4.18	1.95	2.08	2.78
Jun.	1.98	1.47	0.93	1.04	3.91	1.83	1.94	2.60
Jul.	1.85	1.38	0.86	0.96	3.62	1.69	1.80	2.42
Aug.	1.89	1.39	0.86	0.97	3.65	1.71	1.80	2.46
Sep.	1.98	1.47	0.89	1.01	3.74	1.73	1.81	2.53
Oct.	2.12	1.55	0.94	1.05	3.89	1.77	1.87	2.64
Nov.	2.30	1.65	0.97	1.11	4.17	1.89	1.96	2.82
Dec.	2.46	1.75	1.05	1.19	4.49	2.02	2.10	3.03

Figures

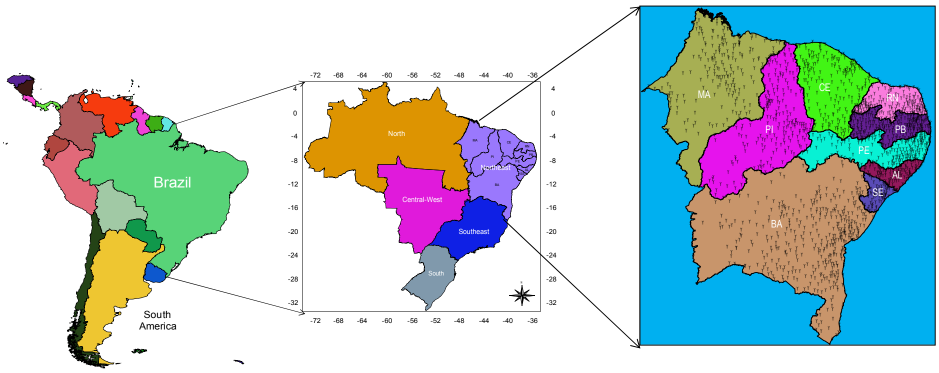

Fig. 1. Brazilian regions and the northeast states of Maranhão (MA); Piauí (PI); Ceará (CE); Rio Grande do Norte (RN); Paraíba (PB); Pernambuco (PE); Alagoas (AL); Sergipe (SE); and Bahia (BA), together with the location of the rain gauges and conventional agro-meteorological stations.

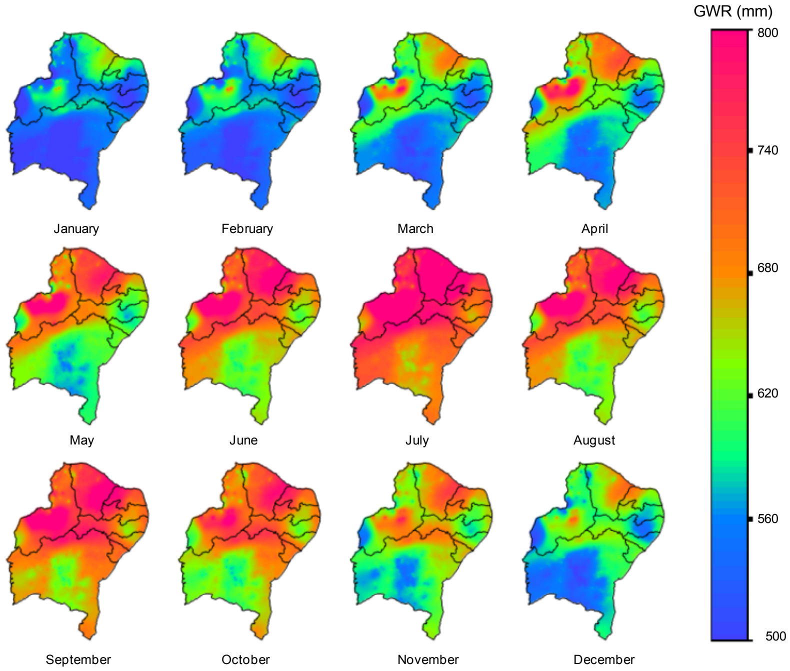

Fig. 2. Maps of the guava water requirements (GWR), ‘Paloma’, for different pruning dates, and an average growing season of six months, in the Brazilian northeast producer states.

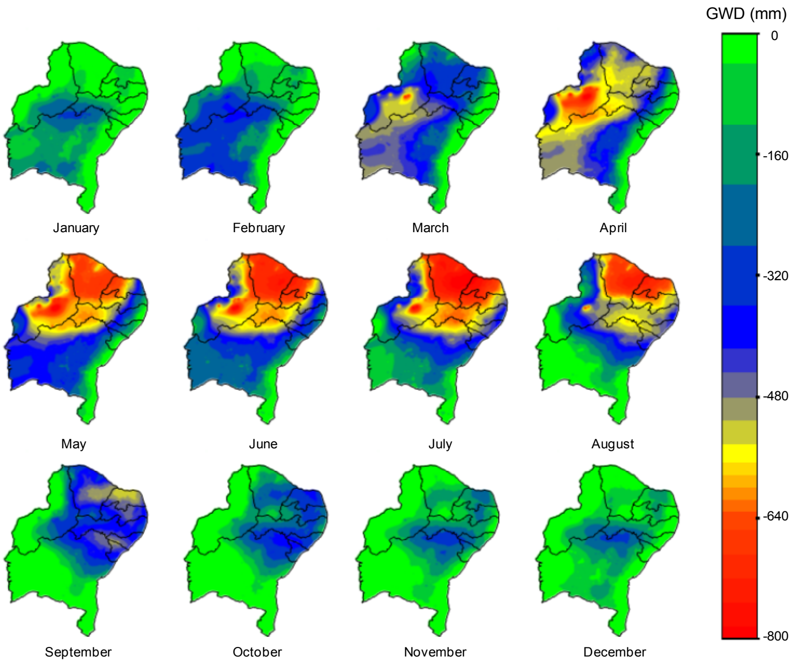

Fig. 3. Maps of the guava water deficiencies (GWD), ‘Paloma’, for different pruning dates, and an average growing season of six months, in the Brazilian northeast producer states.

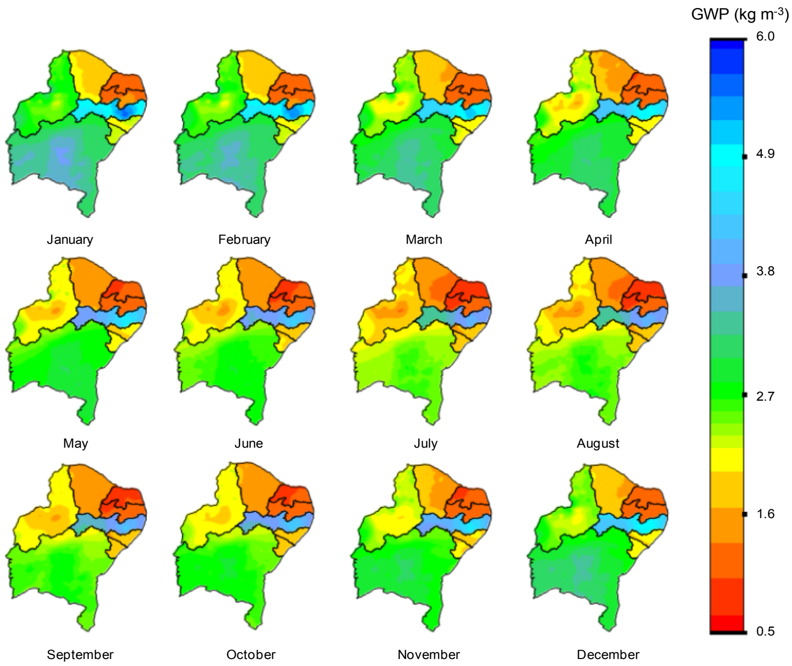

Fig. 4. Maps of the guava water productivity (GWP), 'Paloma', for different pruning dates, and an average growing season of six months, in the Brazilian northeast producer states.