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Utilização do FAO 56 no Brasil e na América do Sul

Utilização do Boletim FAO 56 no Brasil

Da Teoria à Aplicação

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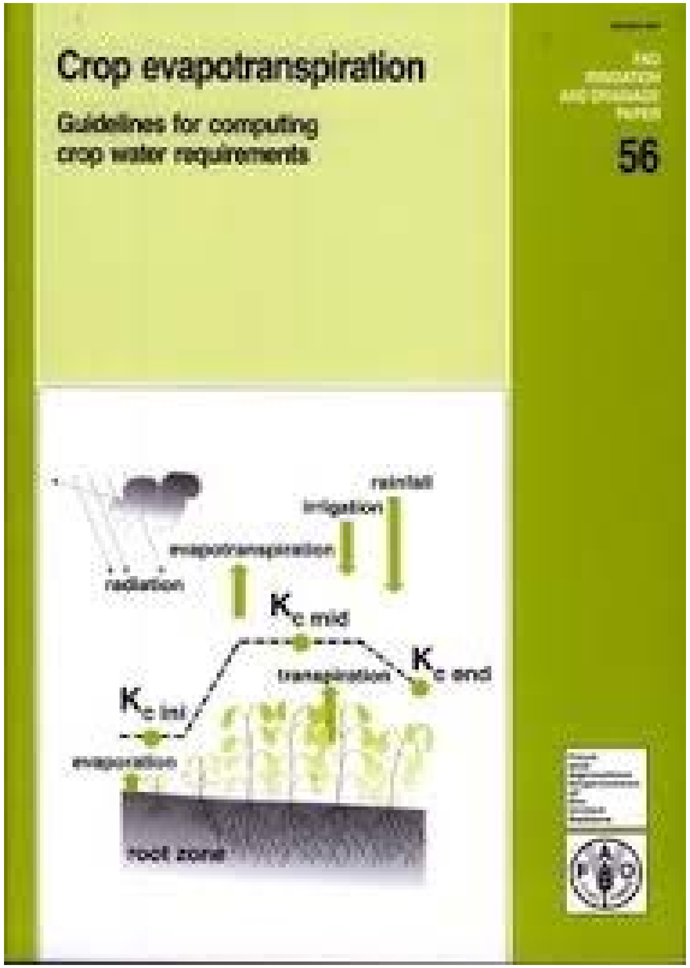
AGRO METEORO LOGIA USP · ESALQ

Utilização do Boletim FAO 56 no Brasil
Da Teoria à Aplicação

- ✓ Primórdios da utilização do Boletim FAO 56 no Brasil
- ✓ Avaliação da ETo FAO56 e de métodos alternativos de ETo
- ✓ Caracterização da disponibilidade hídrica no Brasil
- ✓ Aplicações na determinação de lâminas de irrigação para outorga
- ✓ Aplicações na simulação da produtividade e do "yield gap" de culturas agrícolas
- ✓ Outras aplicações

Primórdios da utilização do Boletim FAO 56 no Brasil



BOLETIM FAO 56 – Crop Evapotranspiration – Guidelines for computing crop water requeriments

A partir de sua publicação em 1998, o Boletim FAO 56 passou a fazer parte da literatura recomendada nos programas de gradução de Engenharia Agronômica/ Agronomia e de Engenharia Agrícola, assim como dos Programas de Pós-Graduação em diversas áreas, mas principalmente de Irrigação e Drenagem e Agrometeorologia, no Brasil.

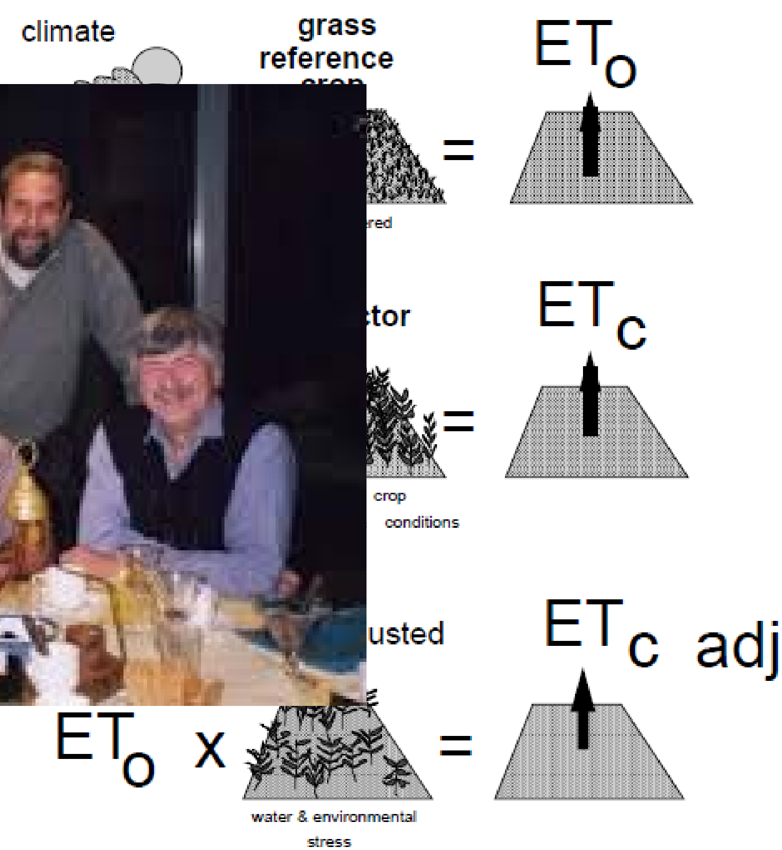
Destaque – abordagem ampla, completa e didática do tema EVAPOTRANSPIRAÇÃO.

Essa obra, assim como tantas outras da FAO, foi um marco importante para a melhoria do conhecimento do tema EVAPOTRANSPIRAÇÃO e para padronizar as estimativas da ETo, ETc e ETc adj

Crop Evapotranspiration

(guidelines for computing

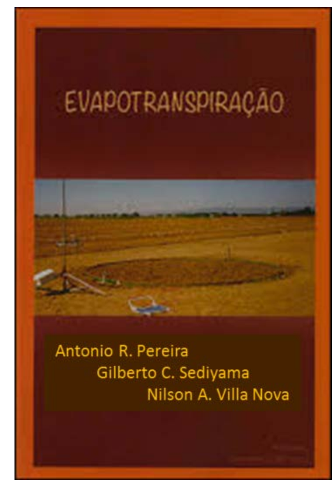
Martin SMITH
FAO, Water Resources, Development and Management Service
Rome, Italy



No Brasil, a utilização do Boletim FAO 56 se deu de forma mais expressiva a partir do final da década de 90, principalmente em duas universidades:

UFV

Prof. Gilberto C. Sediyama



ESALQ/USP

Prof. Antonio R. Pereira
Prof. Nilson A. Villa Nova
Prof. Marcos V. Folegatti
Prof. Luiz R. Angelocci

Avaliação da ETo FAO56 e de métodos alternativos de ETo

Os primeiros estudos envolvendo o método de estimativa da ETo de Penman-Monteith de acordo com a parametrização proposta pelo Boletim FAO 56, focaram em:

a) Avaliar o desempenho desse método de estimativa da ETo com base em medidas de lisímetros e considerando-se diferentes fontes de dados (EMC x EMA) e

b) Avaliar o desempenho de métodos alternativos frente à recomendação do Boletim FAO 56 para condições de dados faltantes.

Google Acadêmico

Mundo: **366.000** artigos com o termo ET, **126.000** com ET evaluation e **27.000** com ET PM

Brasil : **23.400** artigos com o termo ET, **18.000** com avaliação ET e **3.200** com ET PM

Avaliação de métodos de estimativa da ETo – Pré FAO 56

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AVALIAÇÃO DO DESEMPENHO DE DIFERENTES MÉTODOS DE ESTIMATIVA DA EVAPOTRANSPIRAÇÃO POTENCIAL NO ESTADO DE SÃO PAULO, BRASIL

PERFORMANCE EVALUATION OF DIFFERENT POTENTIAL EVAPOTRANSPIRATION ESTIMATING METHODS IN THE STATE OF SÃO PAULO, BRAZIL

Ângelo Paes de Camargo[1] e Paulo Cesar Sentelhas[2]

RESUMO

Avaliou-se o desempenho de vinte métodos de estimativa da evapotranspiração potencial (ETp), em três localidades do Estado de São Paulo, através de dados obtidos em lisímetros conduzidos entre 1954 e 1960. Os dados medidos foram correlacionados com os estimados através de regressão linear. A avaliação do desempenho dos métodos foi baseada nos coeficientes de correlação "r", de concordância "d" de Willmott e de um novo índice proposto, de confiança ou desempenho "c", produto dos índices anteriores. As melhores estimativas de ETp, para as condições do clima sub-tropical úmido do interior do Estado de São Paulo, foram obtidas pelos métodos de Camargo, Thornthwaite, Thornthwaite com índice de calor "T" e Priestley & Taylor, todos com índice "c" entre 0,78 e 0,81, indicadores de desempenho muito bom. Os métodos de Penman-Monteith, Penman, Hargreaves modificado, Makking e Blaney & Criddle modificado, tiveram bom desempenho, com índice "c" entre 0,70 e 0,73. Os demais métodos mostraram desempenho bem inferior, com índice "c" entre 0,25 e 0,62.

Palavras-chave: evapotranspiração potencial, evapotranspirômetro, desempenho das equações, índice de concordância "d", índice de confiança "c".

SUMMARY

The performance of twenty potential evapotranspiration (ETp) estimating methods were evaluated in three places of the State of São Paulo, Brazil, through the lisimeters data obtained from 1954 to 1960. The measured data were correlated with the estimated from the methods by the linear regression. The performance evaluation of the methods were based on correlation coeficient "r", Willmott's agreement coeficient "d" and a new index of performance "c", product of previous coeficients. The best ETp estimatives for the sub-tropical climate condictions of the interior of the State of São Paulo, Brazil, were obtained by the Camargo, Thornthwaite, Thornthwaite using the heat index "T" and Priestley & Taylor methods, all with very good performance with "c" between 0.78 and 0.81. The methods of Penman-Monteith, Penman, Hargreaves modified, Makking and Blaney & Criddle modified had their performance good, with "c" between 0.70 and 0.73. Others methods showed median to very bad performance, with "c" index between 0.25 and 0.62.

Key words: potential evapotranspiration, evapotranspirometer, equations performance, agreement index "d", confidence index "c".

INTRODUÇÃO

Vários são os métodos de estimativa da evapotranspiração potencial (ETp) e a literatura sobre o assunto é bastante vasta, entre eles THORNTHWAITE (1946, 1948), PENMAN (1948), DOORENBOS & PRUITT (1977), CAMARGO & CAMARGO (1983), ROSENBERG et al. (1983), VILLA NOVA & REICHARDT (1989), PEREIRA et al. (1996), entre outros.

Dentre os vários métodos de estimativa da ETp muitos tem grande aceitação enquanto outros são bastante criticados e até desprezados (PEREIRA et al., 1996). Os critérios de rejeição, muitas vezes, não são claros ou acham-se associados à má interpretação do conceito de evapotranspiração potencial

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MATERIAL E MÉTODOS

Evapotranspirômetros, tipo Ibadan (MATHER, 1954) foram instalados em baterias de três tanques, nas estações experimentais do Instituto Agronômico do Estado de São Paulo: Campinas, localizada no Planalto Sul (Lat.: 22°54'S; Long.: 47°04'W; Alt.: 670 m); Pindamonhangaba, localizada no Vale do Paraíba (Lat.: 22°58'S; Long.: 45°25'W; Alt.: 570 m); e Ribeirão Preto, situada na região nordeste (Lat.: 21°11'S; Long.: 47°48'W; Alt.: 620 m).

Tabela 1. Classificação, área superficial (largura x comprimento ou diâmetro (D)) e profundidade dos evapotranspirômetros e material utilizado na sua fabricação.

Classificação	Área (m^2)	Dimensão (m)	Profundidade (m)	Material
Pequeno	0,25	D = 0,56	0,60	Tambor de 200 l
Médio	0,54	0,73 x 0,73	0,60	Cimento-amianto
Grande	1,28	0,85 x 1,50	0,60	Cimento-amianto

Avaliação de métodos de estimativa da ETo – Pré FAO 56

Tabela 3. Desempenho dos métodos de estimativa da ETp mensal, segundo índice de desempenho "c", em correlação com dados de evapotranspirômetros conduzidos em condições de clima subtropical úmido, do Estado de São Paulo. Os valores de "c" apresentados são médias para as três localidades utilizadas.

Métodos	Índice "c"	Desempenho
1. Camargo	0,81	Muito Bom
2. Thornthwaite	0,79	Muito Bom
3. Thornthwaite índice T, de Camargo	0,79	Muito Bom
4. Priestley & Taylor	0,78	Muito Bom
5. Penman-Monteith	0,73	Bom
6. Penman-Prère	0,71	Bom
7. Penman-VNova&Ometto	0,71	Bom
8. Hargreaves modificado	0,71	Bom
9. Penman	0,70	Bom
10. Makking	0,70	Bom
11. Blaney & Criddle modificado	0,70	Bom
12. Tanner & Pelton	0,62	Mediano
13. Turk	0,62	Mediano
14. Blaney & Criddle	0,59	Sofrível
15. Hargreaves 76	0,58	Sofrível
16. Hargreaves 74	0,58	Sofrível
17. Jensen & Haise	0,58	Sofrível
18. Radiação Solar	0,46	Mau
19. Linacre	0,46	Mau
20. Ivanov	0,25	Péssimo

Avaliação de métodos de estimativa da ETo – Pós FAO 56

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Substantiation of the daily FAO-56 reference evapotranspiration with data from automatic and conventional weather stations

Comprovação da evapotranspiração de referência diária FAO-56 com dados de estações meteorológicas automática e convencional

Antonio Roberto Pereira[1,5]; Paulo Cesar Sentelhas[1], Marcos Vinicius Folegatti[2,5], Nilson Augusto Villa Nova[1,5], Selma Regina Maggiotto[1,2] e Francisco Adriano de Carvalho Pereira[4]

Abstract - *Daily grass reference evapotranspiration (ETo) computed following the FAO-56 guidelines and parameterization of the Penman-Monteith big leaf model (P-M) were compared with lysimetric evapotranspiration (ET) measurements in an irrigated grass field. ETo was computed using two independent weather data sets. One, from an automatic weather station (AWS), located at the lysimeter site, with a complete set of data as required by the P-M model. Another, from a regional conventional weather station (CWS), about 2 km away from the lysimeter, and lacking measurements of net radiation and wind speed at 2 m above the ground, being both estimated empirically. Results with data from both weather stations substantiates the FAO-56 scheme and the proposal that the big leaf P-M model should be preferred even when some of the required weather data are missing and have to be estimated empirically. On the average, the CWS incomplete data set resulted in better estimates of ETo than the complete data from the AWS. The decoupling factor Ω was, on average, close to 0.8 indicating that grass ET was indeed strongly dependent on the net radiation as suggested elsewhere.*

Key words: *grass reference evapotranspiration, Penman-Monteith, big leaf model, decoupling factor*

Resumo - *Evapotranspiração de referência diária (ETo) computada seguindo-se as prescrições e parametrizações FAO-56 do modelo "big leaf" de Penman-Monteith (P-M) foi comparada com medidas lisimétricas de evapotranspiração (ET) de um gramado irrigado. ETo foi computado usando-se dois conjuntos independentes de dados meteorológicos. Um, fornecido por uma estação meteorológica eletrônica automática (AWS), localizada próxima ao lisímetro, continha todas as informações exigidas pelo modelo de P-M. Outro, oriundo de uma estação convencional (CWS), representativa da região e distante cerca de 2 km do lisímetro, mas sem medidas de saldo de radiação e velocidade do vento a 2 m acima da superfície, necessitando de suas estimativas. Os resultados obtidos com os dados fornecidos pelas duas estações meteorológicas comprovam a adequação do esquema FAO-56 e a proposta de que o modelo de P-M deve ser usado mesmo em situações de dados incompletos, necessitando de suas estimativas. Em média, os resultados oriundos do conjunto incompleto de dados da CWS foram melhores do que aqueles dados pelo conjunto completo da AWS. O fator de desacoplamento Ω foi, em média, próximo de 0,8 confirmando que a ET do gramado foi, de fato, fortemente dependente do saldo de radiação, como sugerido na literatura.*

Palavras-chave: *evapotranspiração de referência, Penman-Monteith, modelo "big leaf", fator de desacoplamento*

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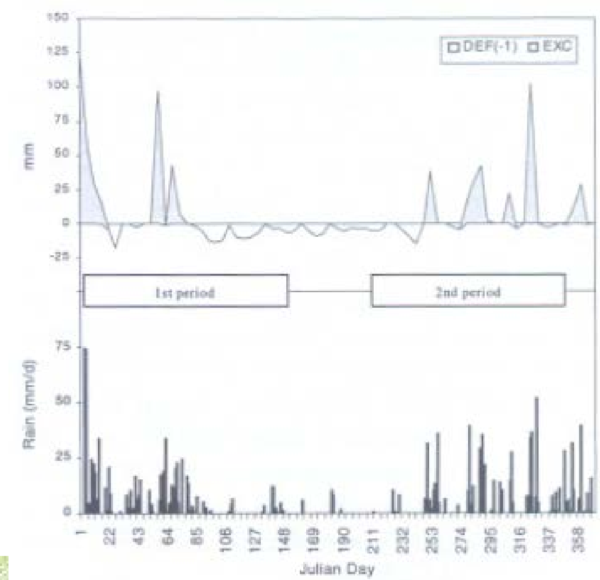
[5] Fellows of CNPq

Table 1. Averages and standard deviations of the mean (Avg. ± s.d.) of the weather elements at the automatic weather station, during the experiment (1996, Piracicaba, SP, BR).

Weather Elements	Period[1]	
	1 Jan – 24 May	2 Aug – 9 Dec
Rn ($MJ\ m^{-2}\ d^{-1}$)	12.22 ± 2.99	11.45 ± 2.92
Tmax (°C)	30.0 ± 3.1	29.0 ± 3.0
Tmin (°C)	18.1 ± 3.1	14.8 ± 3.8
RHmin (%)	48.2 ± 7.8	39.6 ± 12.9
RHmed (%)	78.8 ± 5.0	70.4 ± 8.7
Δe (kPa)	1.13 ± 0.31	1.28 ± 0.41
u_2 ($m\ s^{-1}$)	1.75 ± 0.47	2.09 ± 0.22
n/N[2]	0.68 ± 0.18	0.70 ± 0.22

[1] 41 days for the 1st period; 86 days for the 2nd period.
[2] from the CWS data set.



Avaliação de métodos de estimativa da ETo – Pós FAO 56

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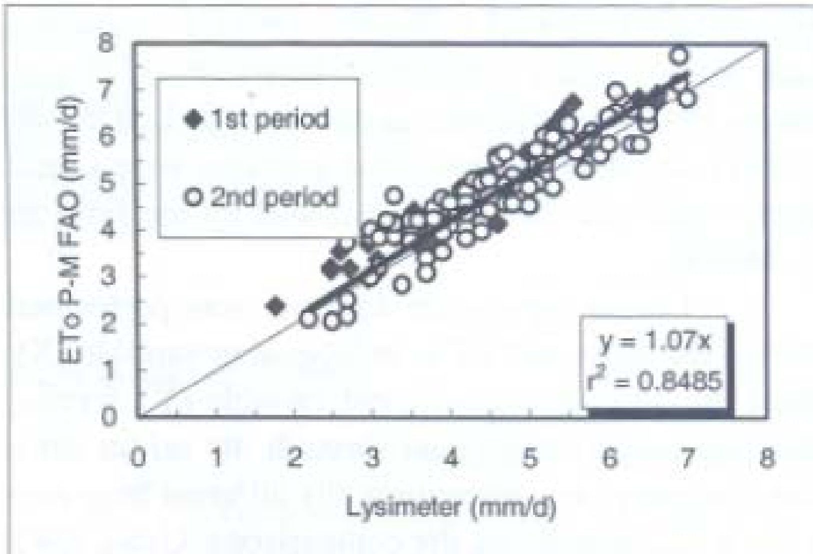

Figure 2. Daily FAO-56 reference evapotranspiration (ETo), with data from the automatic weather station (AWS) vs. daily lysimeter ET, at Piracicaba, SP, Brazil.

EMC

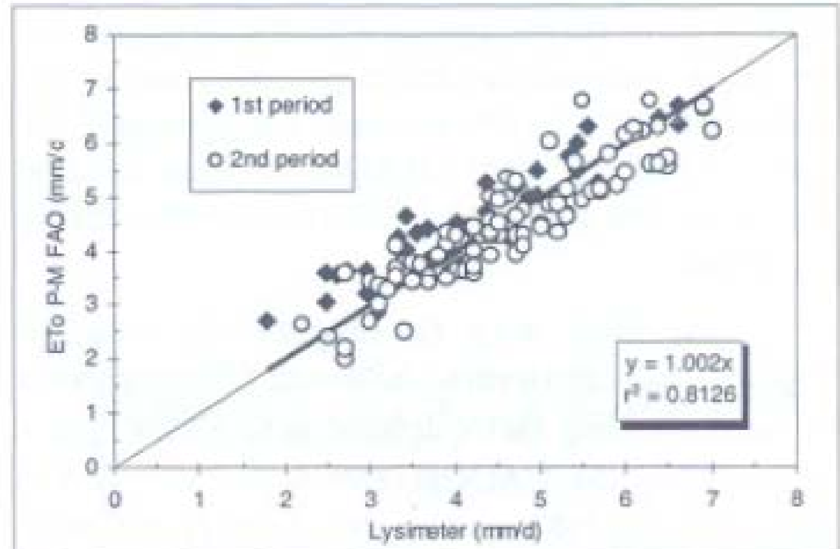

Figure 3. Daily FAO-56 reference evapotranspiration (ETo), with data from the conventional weather station (CWS) vs daily lysimeter ET, at Piracicaba, SP, Brazil

Avaliação de métodos de estimativa da ETo – Pós FAO 56

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Conclusions

The reference evapotranspiration given by the Penman-Monteith big leaf model parameterized by FAO-56 guidelines was very close to the lysimetric measurements obtained on an irrigated grass field
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In general, ETo
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Avaliar o desempenho de métodos alternativos frente à recomendação do Boletim FAO 56 para condições de dados faltantes.

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Evaluation of FAO Penman–Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada

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ABSTRACT

Grass reference evapotranspiration (*ETo*) is an important agrometeorological parameter for climatological and hydrological studies, as well as for irrigation planning and management. There are several methods to estimate *ETo*, but their performance in different environments is diverse, since all of them have some empirical background. The FAO Penman–Monteith (FAO PM) method has been considered as a universal standard to estimate *ETo* for more than a decade. This method considers many parameters related to the evapotranspiration process: net radiation (*Rn*), air temperature (*T*), vapor pressure deficit (Δe), and wind speed (*U*); and has presented very good results when compared to data from lysimeters populated with short grass or alfalfa. In some conditions, the use of the FAO PM method is restricted by the lack of input variables. In these cases, when data are missing, the option is to calculate *ETo* by the FAO PM method using estimated input variables, as recommended by FAO Irrigation and Drainage Paper 56. Based on that, the objective of this study was to evaluate the performance of the FAO PM method to estimate *ETo* when *Rn*, Δe, and *U* data are missing, in Southern Ontario, Canada. Other alternative methods were also tested for the region: Priestley–Taylor, Hargreaves, and Thornthwaite. Data from 12 locations across Southern Ontario, Canada, were used to compare *ETo* estimated by the FAO PM method with a complete data set and with missing data. The alternative *ETo* equations were also tested and calibrated for each location. When relative humidity (*RH*) and *U* data were missing, the FAO PM method was still a very good option for estimating *ETo* for Southern Ontario, with *RMSE* smaller than 0.53 mm day^{-1}. For these cases, *U* data were replaced by the normal values for the region and Δe was estimated from temperature data. The Priestley–Taylor method was also a good option for estimating *ETo* when *U* and Δe data were missing, mainly when calibrated locally (*RMSE* = 0.40 mm day^{-1}). When *Rn* was missing, the FAO PM method was not good enough for estimating *ETo*, with *RMSE* increasing to 0.79 mm day^{-1}. When only *T* data were available, adjusted Hargreaves and modified Thornthwaite methods were better options to estimate *ETo* than the FAO PM method, since *RMSE*s from these methods, respectively 0.79 and 0.83 mm day^{-1}, were significantly smaller than that obtained by FAO PM (*RMSE* = 1.12 mm day^{-1}).

1. Introduction

Evapotranspiration (*ET*) is the simultaneous process of transfer of water to the atmosphere by transpiration and evaporation in a soil–plant system (Rosenberg et al., 1983; Allen et al., 1998; Mavi and Tupper, 2004). In an agricultural field, when the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and the canopy completely covers the soil, transpiration becomes the main process of water loss. *ET* is an important parameter for climatological and hydrological studies, as well as for irrigation planning and management.

According to Allen et al. (1998), the main meteorological parameters affecting evapotranspiration are solar radiation, air temperature, vapor pressure deficit and wind speed. The crop type, variety, development stage, and plant density also affect crop evapotranspiration, since differences in resistance to transpiration, crop height, canopy roughness, reflection, ground cover and crop rooting characteristics result in distinct *ET* levels for different crops under the same meteorological and soil conditions.

As *ET* is influenced by several factors, its study, in a more comprehensive way, was made possible by the definition of some boundary conditions in terms of available weather data, which was done in 1948 by both Thornthwaite and Penman when defining

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Proc. Fla. State Hort. Soc. 123:189–195. 2010.

Evaluation of Methodologies to Estimate Reference Evapotranspiration in Florida

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Additional index words. Hargreaves, Penman-Monteith, Priestley and Taylor

The Penman-Monteith equation was considered by the United Nations Food and Agriculture Organization (FAO) as the standard method to calculate reference evapotranspiration (ETo). The lack of data availability, especially in long-term historical records, was the basic obstacle for a broader use of the FAO Penman-Monteith equation. Long-term records often included daily maximum and minimum temperatures and precipitation. In these circumstances empirical methods could be used but required calibration for local conditions and were not readily transferable to other regions. The main objectives of this study were to compare reference evapotranspiration estimated by the FAO Penman-Monteith equation to reference evapotranspiration estimated by the Priestley and Taylor and the Hargreaves empirical methods. The use of the FAO Penman-Monteith equation with estimated solar radiation, relative humidity, and wind speed was also evaluated. Daily, 10-d, and monthly values of reference evapotranspiration calculated by Penman-Monteith and the other methods were compared. The Priestley and Taylor method was found to be the best method to use when available long-term historical records included only daily temperature and precipitation. This methodology can be used in climatological studies for irrigation planning and to better understand the effects of seasonal climate variability on crop water requirements in Florida.

Evapotranspiration (ET) is the soil-plant system water requirement, which is the combination of two separate processes, soil surface evaporation and plant transpiration. ET is an important agrometeorological parameter for climatological studies, water resources planning, and irrigation scheduling (Bautista et al., 2009; Sentelhas et al., 2010; Wu, 1997). ET is influenced by several factors such as the environment, crop characteristics, and management practices. The concept of reference evapotranspiration (ETo) presented by Allen et al. (1998) is the evapotranspiration from a reference surface, which is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s·m^{-1} and an albedo of 0.23. It closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The ETo concept was introduced to evapotranspiration studies to eliminate the influence of soil type, crop characteristics and management in ET measurements. Therefore, ETo is calculated using only weather parameters.

The Food and Agriculture Organization of the United Nations (FAO) consider the FAO Penman-Monteith method (FAO-56) as the standard method to calculate ETo. This method is physically based and incorporates physiological and aerodynamic factors (Bautista et al., 2009; Sentelhas et al., 2010). However, FAO Penman-Monteith requires meteorological parameters which may not be available everywhere. The lack of data availability, especially in long-term historical records, is the basic obstacle for a broader use of the FAO Penman-Monteith equation. Long-term records often include only daily minimum and maximum temperatures, and precipitation. In these circumstances empirical methods can be used to estimate ETo.

Numerous equations have been created to estimate ETo. The standard method to estimate ETo, FAO Penman-Monteith, was also used to evaluate alternative methods (Allen et al., 1994 a, b). These alternative methods have the advantage of requiring few meteorological data. However, they were generally calibrated for local conditions and not readily transferable to other regions (Grismer, 2002). Priestley and Taylor is a radiation-based method and is a simplification of the original Penman equation (Priestley and Taylor, 1972). Under humid conditions, it has shown good results and acceptable estimates of ETo on an annual basis (Trajkovic and Kolakovic, 2009). Lu et al. (2005) studying six methods to estimate ETo in the southeastern USA using radiation and temperature-based equations, found good correlation between the methods, mainly between Priestley and Taylor and other empirical methods. In a study conducted in Georgia, Priestley and Taylor underestimated monthly average ETo during the winter in most locations across the state and overestimated during warm season months (Suleiman and Hoogenboom, 2007). Nevertheless the Priestley and Taylor equation was found to be a good method to estimate ETo after proper calibration in southern Ontario, Canada (Sentelhas et al., 2010).

The Hargreaves equation, presented by Hargreaves and Samani (1985), is temperature based and can be used when only temperature is available. This method generally provides more accurate ETo estimates for periods of 5 d or longer (Jensen et al., 1997). Under humid conditions Hargreaves generally overestimates ETo. However, after local calibration Trajkovic (2007) reported overestimation of about 1% when compared to ETo estimated by FAO Penman-Monteith.

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Avaliar o desempenho de métodos alternativos frente à recomendação do Boletim FAO 56 para condições de dados faltantes.

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Evaluation of FAO Penman–Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada

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ABSTRACT

Grass reference evapotranspiration (*ETo*) is an important agrometeorological parameter for climatological and hydrological studies, as well as for irrigation planning and management. There are several methods to estimate *ETo*, but their performance in different environments is diverse, since all of them have some empirical background. The FAO Penman–Monteith (FAO PM) method has been considered as a universal standard to estimate *ETo* for more than a decade. This method considers many parameters related to the evapotranspiration process: net radiation (*Rn*), air temperature (*T*), vapor pressure deficit (Δe), and wind speed (*U*); and has presented very good results when compared to data from lysimeters populated with short grass or alfalfa. In some conditions, the use of the FAO PM method is restricted by

In a similar way, the objective of this study was to evaluate the performance of the FAO PM method to estimate *ETo* with missing data in Southern Ontario, Canada, as well as to test alternative methods to determine this variable.

ETo when *U* and Δe data were missing, mainly when calibrated locally (*RMSE* = 0.40 mm day^{-1}). When *Rn* was missing, the FAO PM method was not good enough for estimating *ETo*, with *RMSE* increasing to 0.79 mm day^{-1}. When only *T* data were available, adjusted Hargreaves and modified Thornthwaite methods were better options to estimate *ETo* than the FAO PM method, since *RMSEs* from these methods, respectively 0.79 and 0.83 mm day^{-1}, were significantly smaller than that obtained by FAO PM (*RMSE* = 1.12 mm day^{-1}).

1. Introduction

Evapotranspiration (*ET*) is the simultaneous process of transfer of water to the atmosphere by transpiration and evaporation in a soil–plant system (Rosenberg et al., 1983; Allen et al., 1998; Mavi and Tupper, 2004). In an agricultural field, when the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and the canopy completely covers the soil, transpiration becomes the main process of water loss. *ET* is an important parameter for climatological and hydrological studies, as well as for irrigation planning and management.

According to Allen et al. (1998), the main meteorological parameters affecting evapotranspiration are solar radiation, air temperature, vapor pressure deficit and wind speed. The crop type, variety, development stage, and plant density also affect crop evapotranspiration, since differences in resistance to transpiration, crop height, canopy roughness, reflection, ground cover and crop rooting characteristics result in distinct *ET* levels for different crops under the same meteorological and soil conditions.

As *ET* is influenced by several factors, its study, in a more comprehensive way, was made possible by the definition of some boundary conditions in terms of available weather data, which was done in 1948 by both Thornthwaite and Penman when defining

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Table 7
Average *RMSE* ranking for reference evapotranspiration estimated by the Penman–Monteith (FAO PM) method with missing data, and by the Priestley–Taylor (PT Original and PT Adjusted), Hargreaves (H Original and H Adjusted), and Thornthwaite (TH Original and TH with effective temperature, *Tef*) methods in Southern Ontario, Canada.

Rank #	Method and Condition	Average RMSE (mm day^{-1})[a]
1	FAO PM ($-U$)	0.182 a
2	PT Adjusted	0.402 b
3	FAO PM ($-e_a$)	0.512 b
4	FAO PM ($-U$ and $-e_a$)	0.530 bc
5	PT Original	0.624 c
6	H Adjusted	0.704 c
7	FAO PM ($-SR$)	0.793 d
8	TH *Tef*	0.830 d
9	FAO PM ($-U$ and $-SR$)	0.835 d
10	H Original	1.103 e
11	FAO PM ($-e_a$ and $-SR$)	1.105 e
12	FAO PM ($-U$, $-e_a$ and $-SR$)	1.121 e
13	TH Original	1.194 e

[a] The averages followed by the same letter are not statistically different by the *t*-test (p = 0.05).

Avaliar o desempenho de métodos alternativos frente à recomendação do Boletim FAO 56 para condições de dados faltantes.

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Evaluation of Methodologies to Estimate Reference Evapotranspiration in Florida

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Additional index words. Hargreaves, Penman-Monteith, Priestley and Taylor

The Penman-Monteith equation was considered by the United Nations Food and Agriculture Organization (FAO) as the standard method to calculate reference evapotranspiration (ETo). The lack of data availability, especially in long-term historical records, was the basic obstacle for a broader use of the FAO Penman-Monteith equation. Long-term records often included daily maximum and minimum temperatures and precipitation. In these circumstances empirical methods could be used but required calibration for local conditions and were not readily transferable to other regions. The main objectives of this study were to compare reference evapotranspiration estimated by the FAO

The main objective of this study was to select a methodology to estimate ETo under Florida conditions when only temperature and precipitation data were available. Specific objectives were to compare ETo calculated by the FAO Penman-Monteith method to ETo estimated by empirical methods (Priestley and Taylor and Hargreaves) and to ETo calculated by the same FAO Penman-Monteith method but using estimated solar radiation, relative humidity, and wind speed.

height, actively growing and completely shading the ground. The ETo concept was introduced to evapotranspiration studies to eliminate the influence of soil type, crop characteristics and management in ET measurements. Therefore, ETo is calculated using only weather parameters.

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methods to estimate ETo in the southeastern USA using radiation and temperature-based equations, found good correlation between the methods, mainly between Priestley and Taylor and other empirical methods. In a study conducted in Georgia, Priestley and Taylor underestimated monthly average ETo during the winter in most locations across the state and overestimated during warm season months (Suleiman and Hoogenboom, 2007). Nevertheless the Priestley and Taylor equation was found to be a good method to estimate ETo after proper calibration in southern Ontario, Canada (Sentelhas et al., 2010).

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Table 4. Root mean square error (RMSE) and coefficient of determination (R^2) for different time periods (daily, 10-d, and monthly), regions (South, Central and North–Panhandle), and methods [FAO Penman-Monteith with estimated weather variables (ePM), Priestley and Taylor (PT), and Hargreaves (HA)].

Region	Period	Equation	RMSE	R^2
South	Daily	ePM	1.057	0.360
		PT	0.890	0.495
		HA	0.983	0.376
		HA	0.195	0.966
Panhandle	Daily	ePM	0.704	0.7553
		PT	0.631	0.791
		HA	0.671	0.765
	10-d	ePM	0.272	0.955
		PT	0.211	0.968
		HA	0.216	0.967
	Monthly	ePM	0.238	0.967
		PT	0.169	0.980
		HA	0.171	0.979

Overall ETo estimated by the Priestley and Taylor equation had the highest correlation and lower RMSE when compared to ETo estimated by the FAO Penman-Monteith equation. However, in the case of 10-d and monthly time periods, results obtained using the Hargreaves equation were similar to the ones obtained using the Priestley and Taylor equation. Additionally, the fact that the calibration of the Hargreaves methodology requires only one empirical coefficient as opposed to Priestley and Taylor that requires four empirical coefficients provides an additional incentive to its use for estimating long-term 10-d and monthly ETo time series when only temperature and rainfall records were available.

Caracterização da disponibilidade hídrica no Brasil

Caracterização da disponibilidade hídrica no Brasil

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Water deficit and water surplus maps for Brazil, based on FAO Penman-Monteith potential evapotranspiration
(doi:10.4136/ambi-agua.59)

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ABSTRACT

The climatological water balance (CWB) proposed by Thornthwaite and Mather (1957) is a useful tool for agricultural planning. This method requires the soil water holding capacity (SWHC), rainfall (R) and potential evapotranspiration (PET) data as input. Among the methods used to estimate PET, the one proposed by Thornthwaite (1948) is the simplest and the most used in Brazil, however it presents limitations of use, which is caused by its empirical relationships. When Thornthwaite PET method is used into the CWB, the errors associated to PET are transferred to the output variables, mainly water deficit (WD) and water surplus (WS). As all maps of WD and WS for Brazil are based on Thornthwaite PET, the objective of this study was to produce new maps of these variables considering Penman-Monteith PET. For this purpose, monthly normal climate data base (1961-1990) from Brazilian Meteorological Service (INMET), with 219 locations in all country, was used. PET data were estimated by Thornthwaite (TH) and FAO Penman-Monteith (PM) methods. PET, from both methods, and R data were used to estimate the CWB for a SWHC of 100 mm, having as results actual ET (AET), WD and WS. Results obtained with PET from the two methods were compared by regression analysis. The results showed that TH method underestimated annual PM PET by 13% in 84% of the places. Such underestimation also led to AET and WD underestimations of 7% (in 69% of places) and 40% (in 83% of places), respectively. For WS, the use of TH PET data in the CWB resulted in overestimations of about 80% in 78% of places. The differences observed in the CWB variables resulted in changes in the maps of WD and WS for Brazil. These new maps, based on PM PET, provide more accurate information, mainly for agricultural and hydrological planning and irrigation and drainage projects purposes.

Keywords: climatological water balance; agricultural planning; irrigation projects.

Mapas de deficiência hídrica e excedente hídrico para o Brasil, baseados na evapotranspiração potencial de Penman-Monteith - FAO

RESUMO

O balanço hídrico climatológico (BHC) proposto por Thornthwaite e Mather (1957) é uma ferramenta muito útil para o planejamento agrícola. Esse método requer como variáveis de entrada a capacidade de água disponível do solo (CAD), a chuva (P) e a evapotranspiração

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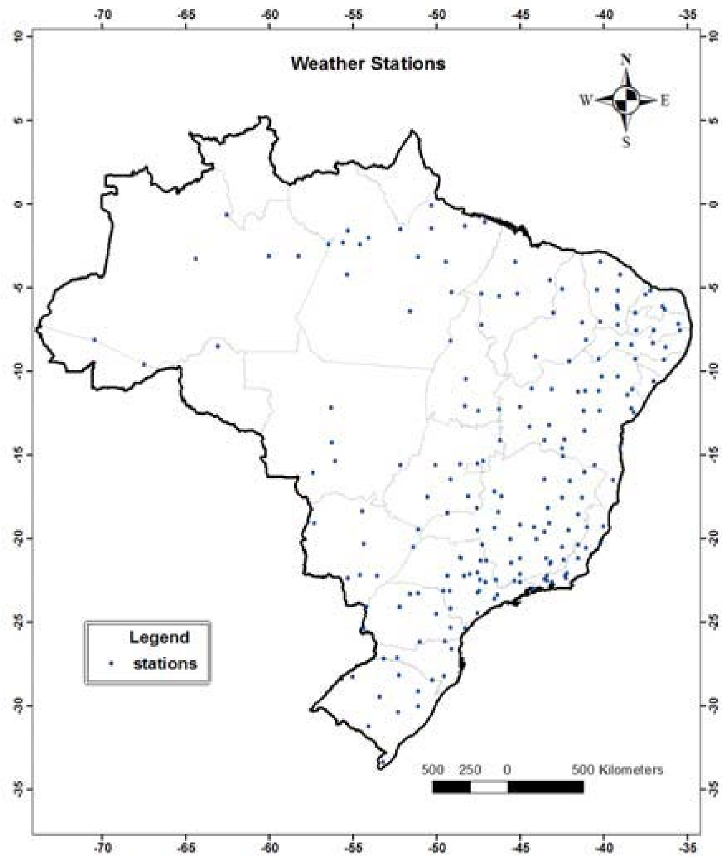
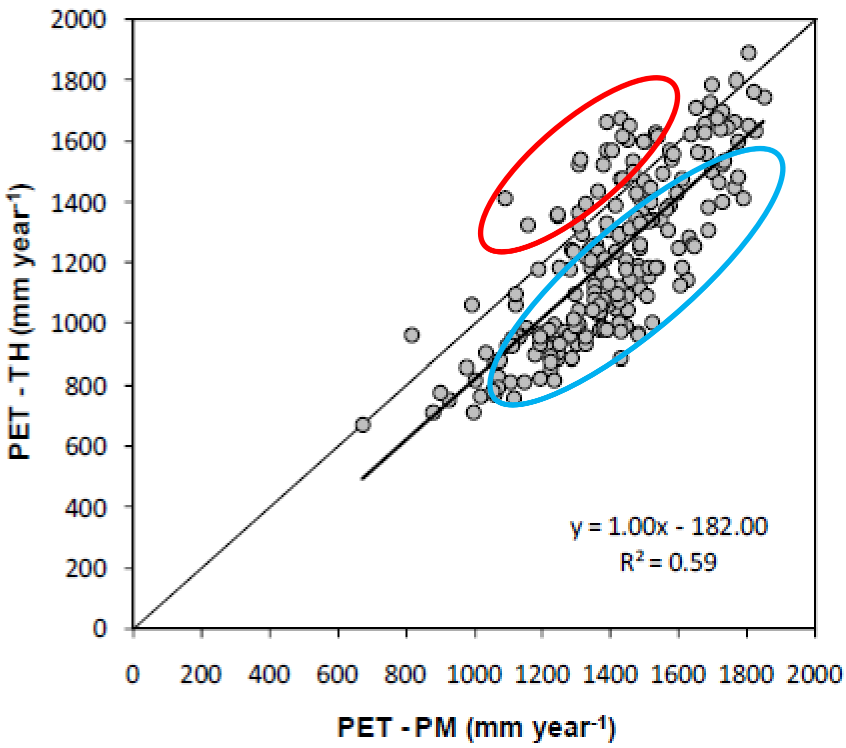
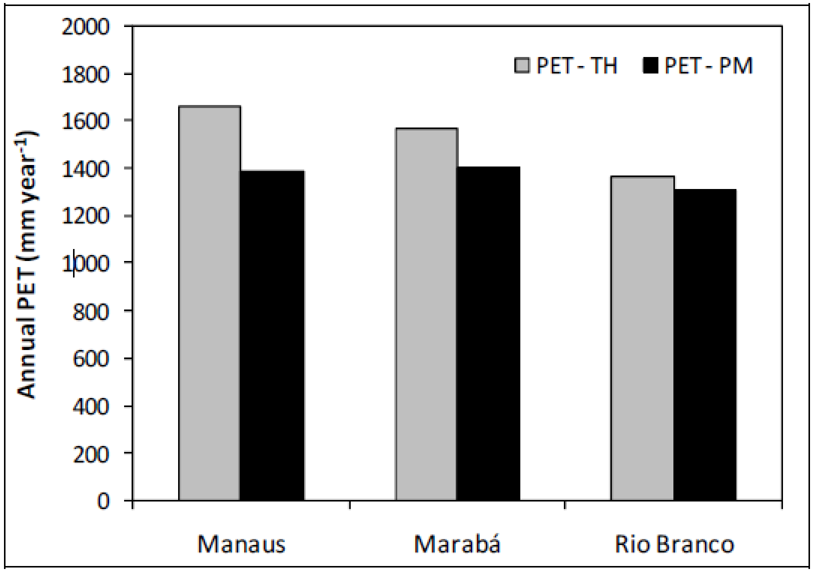
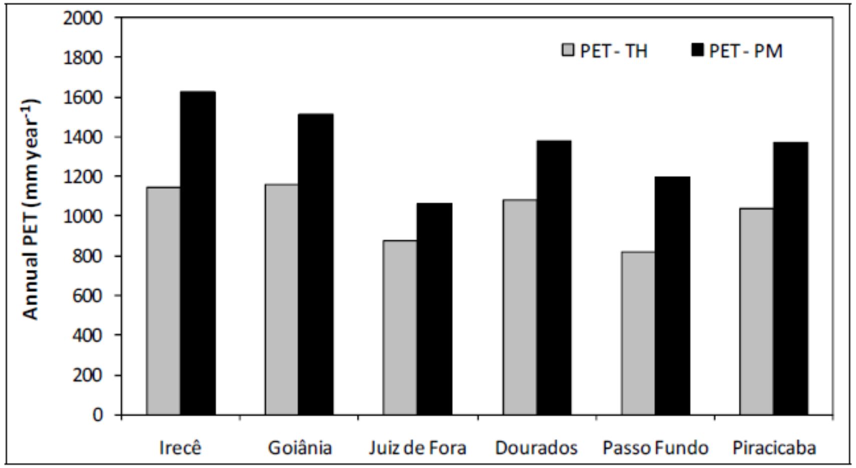
219 locations in the country



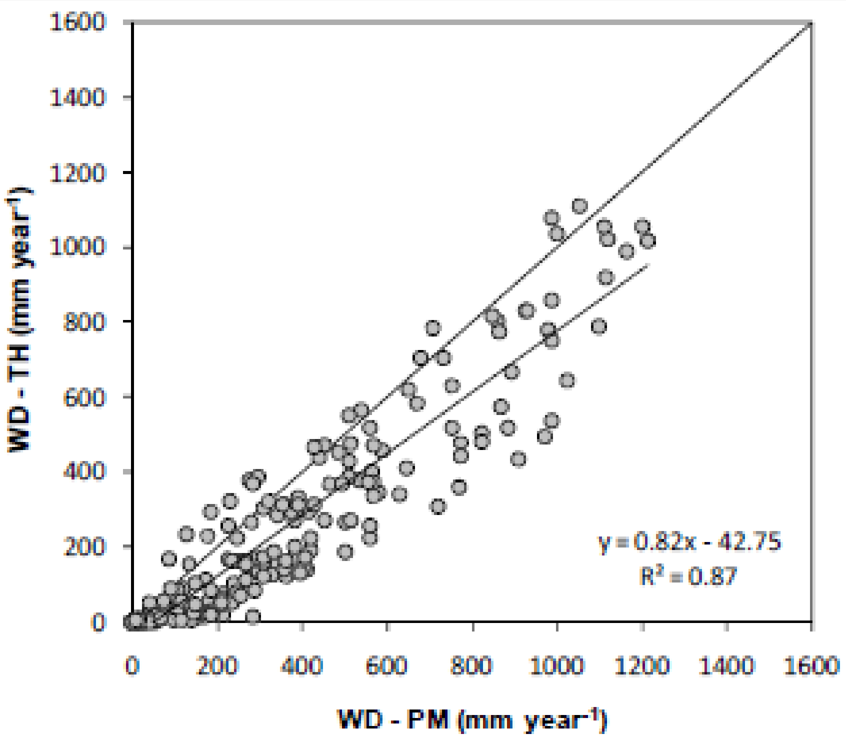
Comparação ETo Thornthwaite x Penman-Monteith

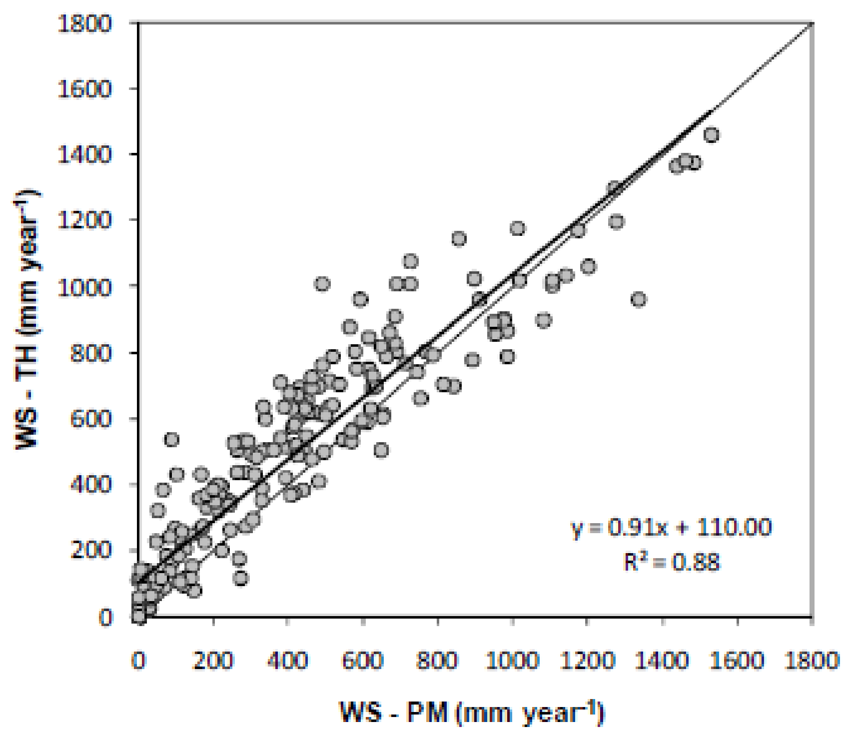






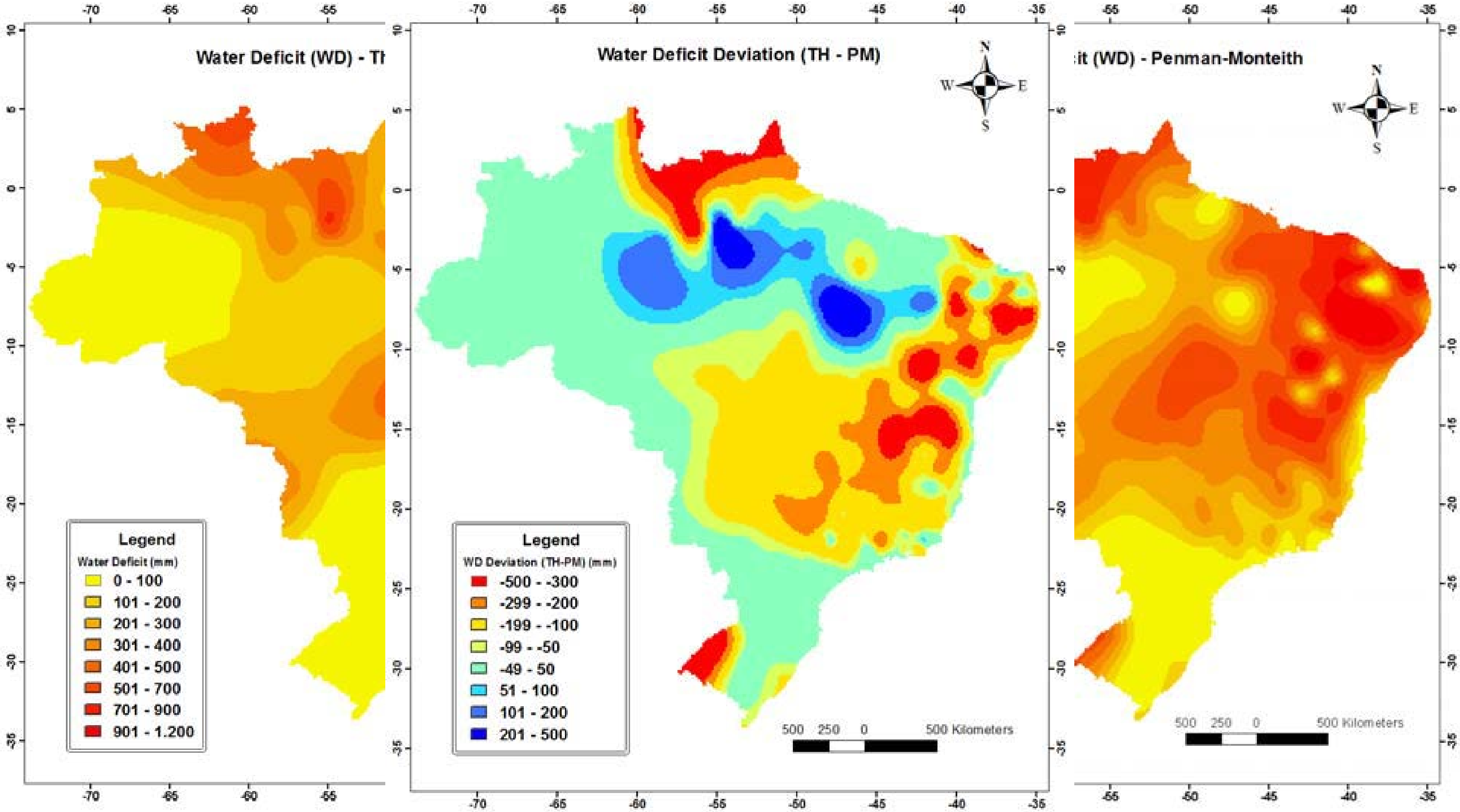
Comparação Balanço Hídrico
ETo Thornthwaite x ETo Penman-Monteith



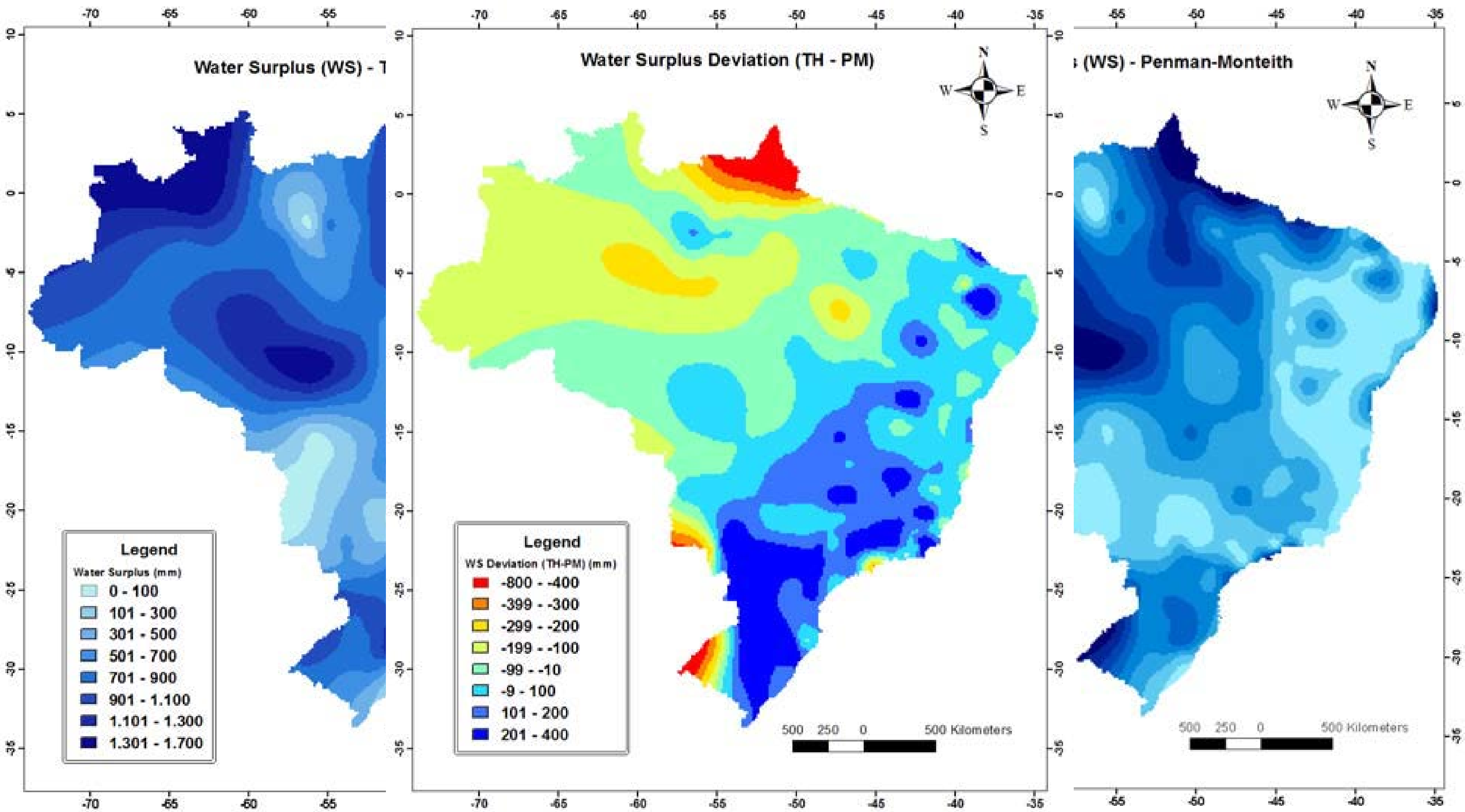


Maior efeito na Deficiência hídrica do que no Excedente hídrico

Comparação Deficiência hídrica – BH T&M (1955) Thornthwaite x Penman-Monteith



Comparação Excedente hídrico – BH T&M (1955)
Thornthwaite x Penman-Monteith

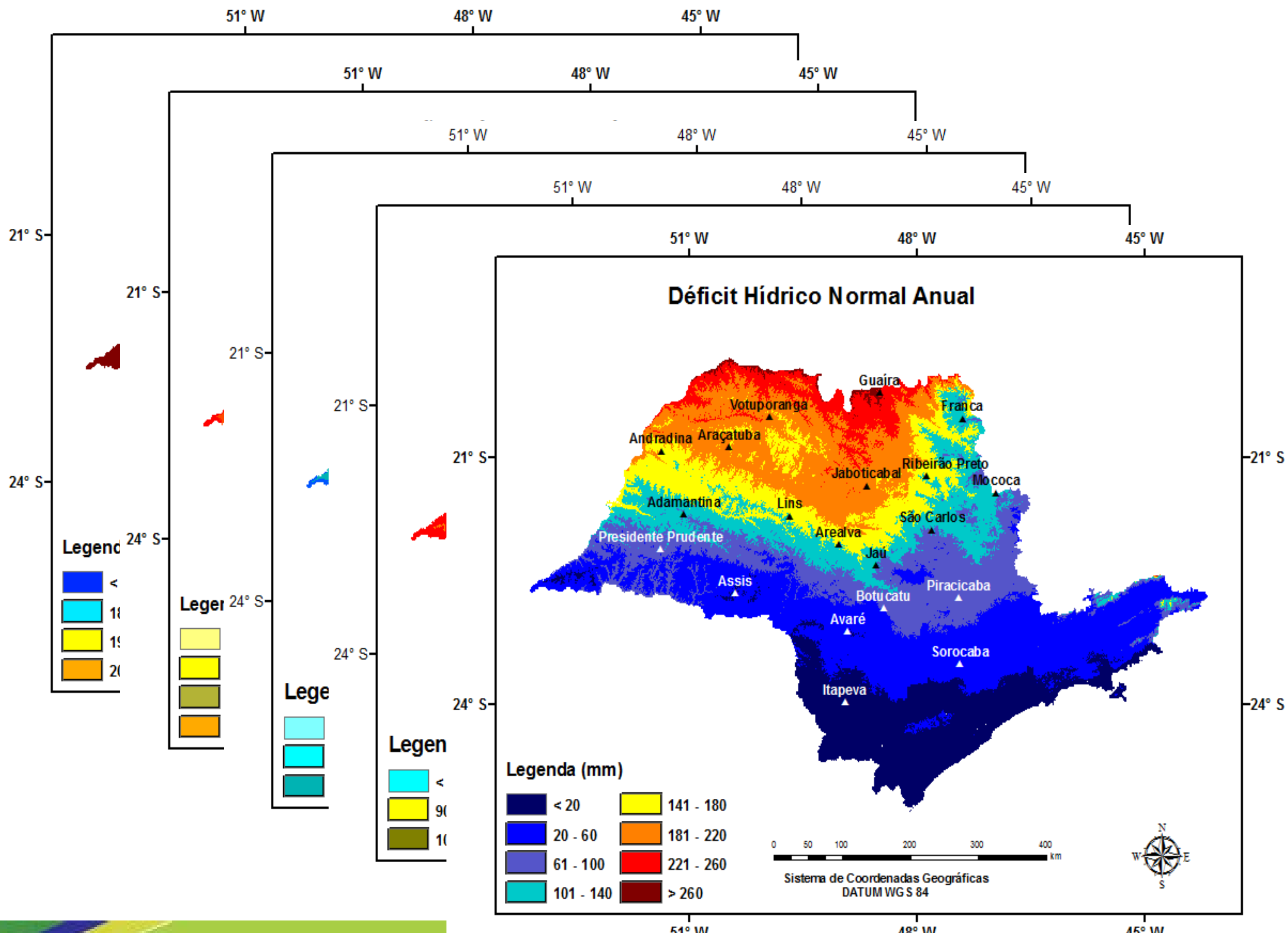


Aplicações na determinação de lâminas de irrigação para outorga

Determinação da Lâmina de Irrigação para fins de Projeto, com base no Balanço Hídrico Diário

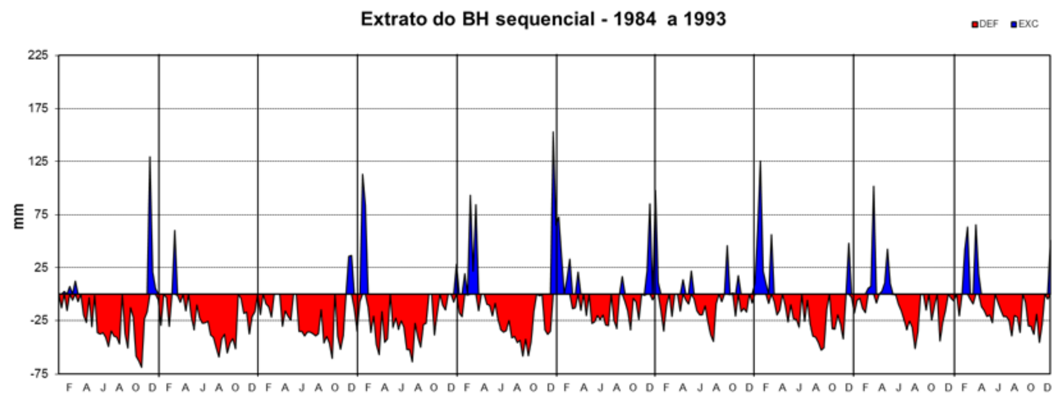
O caso da região de Andradina, SP

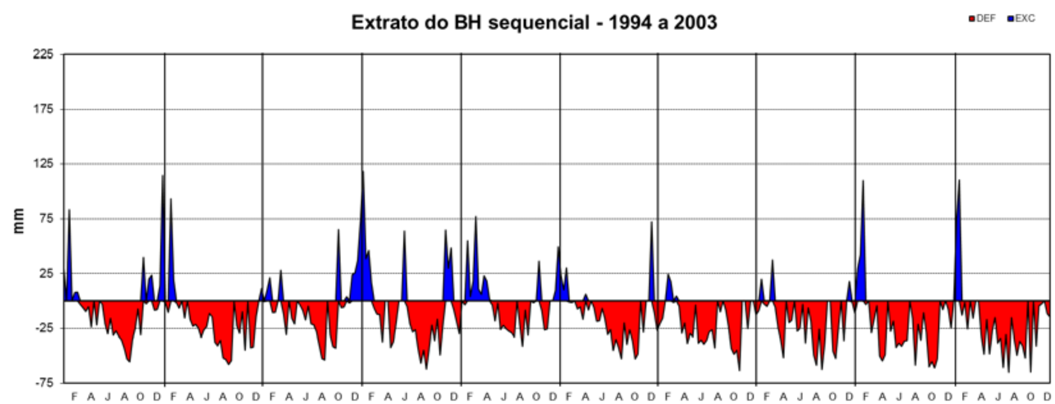
Por que irrigar a cana-de-açúcar na no oeste Paulista?

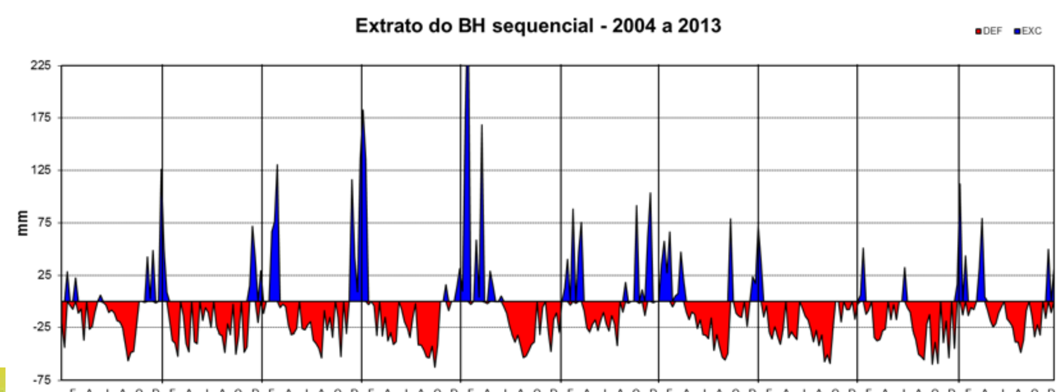


Balanço Hídrico Sequencial Andradina, SP 1984 a 2013 CAD = 67 mm

ETo estimada por Penman-Monteith FAO56





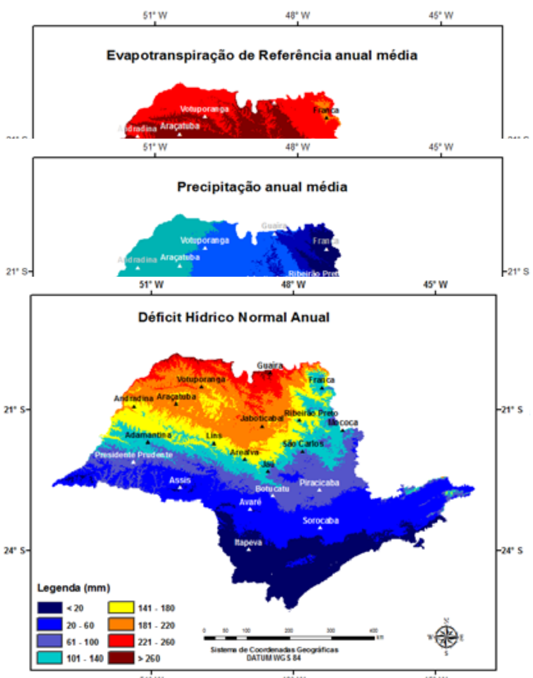


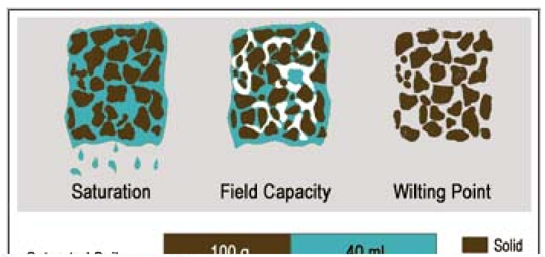
Ano		DEF	EXC
		(mm)	
1	1984	835,7	178,8
2	1985	837,9	60,3
3	1986	796,1	72,3
4	1987	893,0	196,8
5	1988	752,3	400,1
6	1989	397,0	367,2
7	1990	386,2	208,8
8	1991	637,0	330,7
9	1992	437,4	179,8
10	1993	548,1	241,1
11	1994	536,1	227,4
12	1995	770,5	227,4
13	1996	483,4	226,9
14	1997	673,1	501,2
15	1998	387,7	259,4
16	1999	602,3	192,3
17	2000	738,3	46,4
18	2001	698,1	75,4
19	2002	899,8	181,9
20	2003	841,5	183,8
21	2004	507,4	151,2
22	2005	770,2	314,3
23	2006	587,9	470,4
24	2007	726,0	485,4
25	2008	560,7	787,9
26	2009	350,7	551,2
27	2010	556,4	387,6
28	2011	789,7	110,4
29	2012	808,1	89,6
30	2013	488,5	368,9
Mínima		350,7	46,4
Média		643,2	269,2
Máxima		899,8	787,9

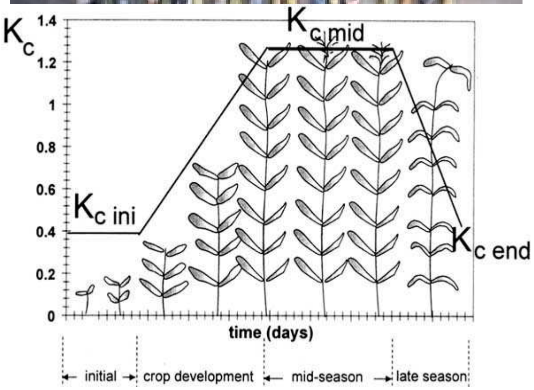
Quanto irrigar a cana-de-açúcar no oeste Paulista?

Depende

Clima	Solo	Cultura/Variedade





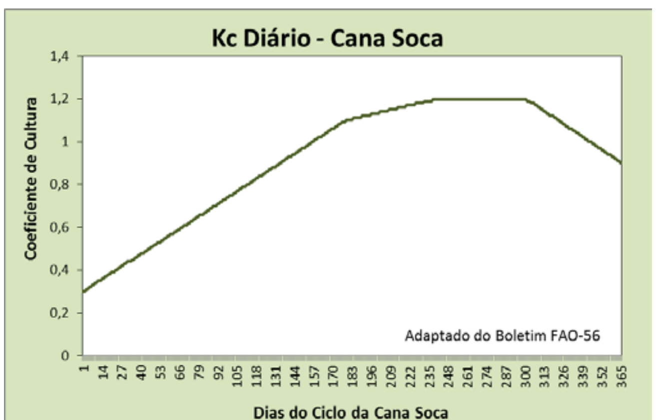


Determinação da Lâmina de Irrigação Provável para Projeto

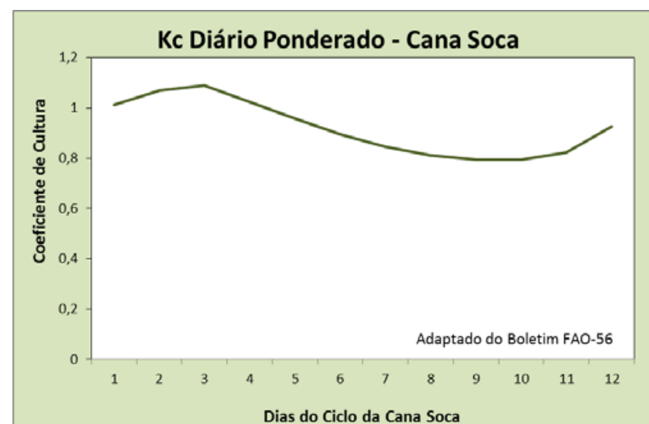
Estimativa da Evapotranspiração da Cultura – Kc ponderado

ETo Penman-Monteith (Allen et al., 1998)

Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez
1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20
1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18
1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13
1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05
1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92
0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78
0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64
0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50	0,64	0,78	0,92	1,05	1,13	1,18	1,20	1,20	1,11	0,97	0,37	0,50
1,01	1,07	1,10	1,03	0,96	0,90	0,85	0,81	0,79	0,80	0,82	0,93	1,01	1,07	1,10	1,03	0,96	0,90	0,85	0,81	0,79	0,80	0,82	0,93

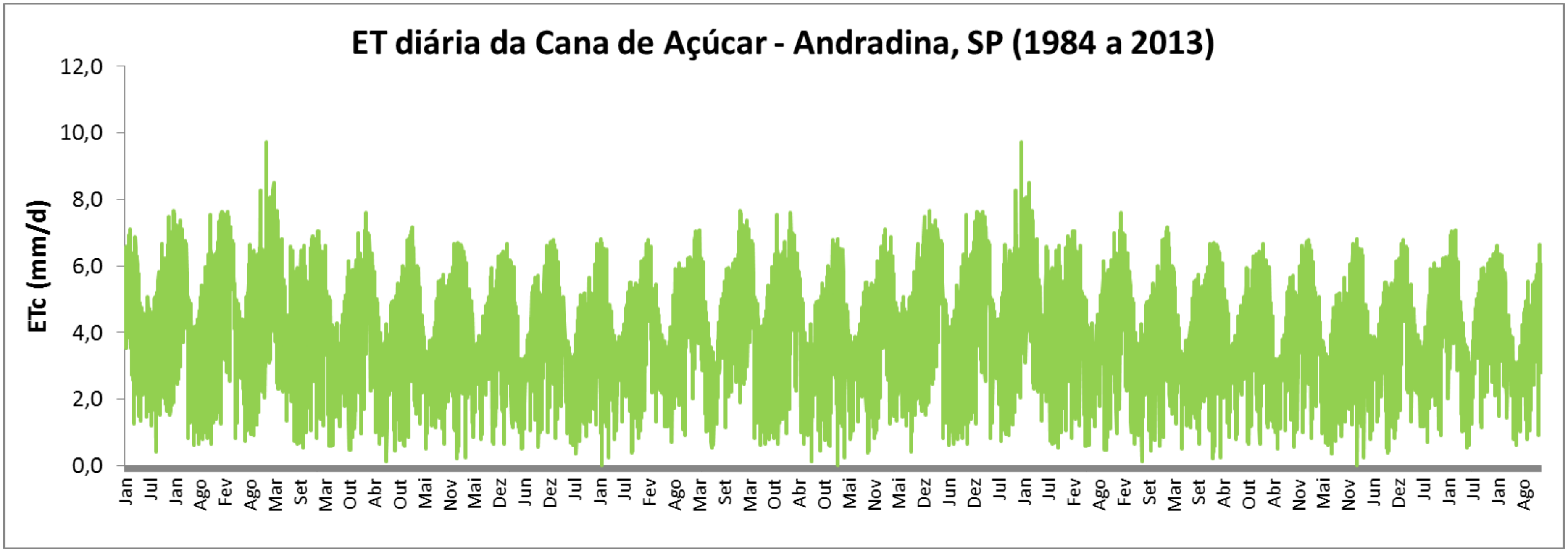


Kc Ponderado na Escala Diária



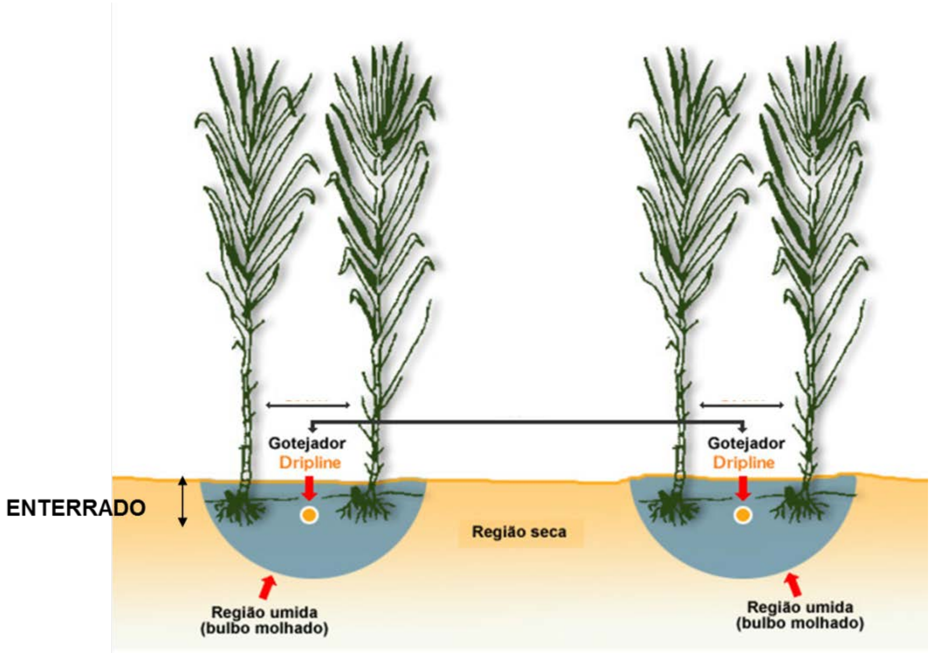
Determinação da Lâmina de Irrigação Provável para Projeto

Estimativa da Evapotranspiração da Cultura – Kc ponderado

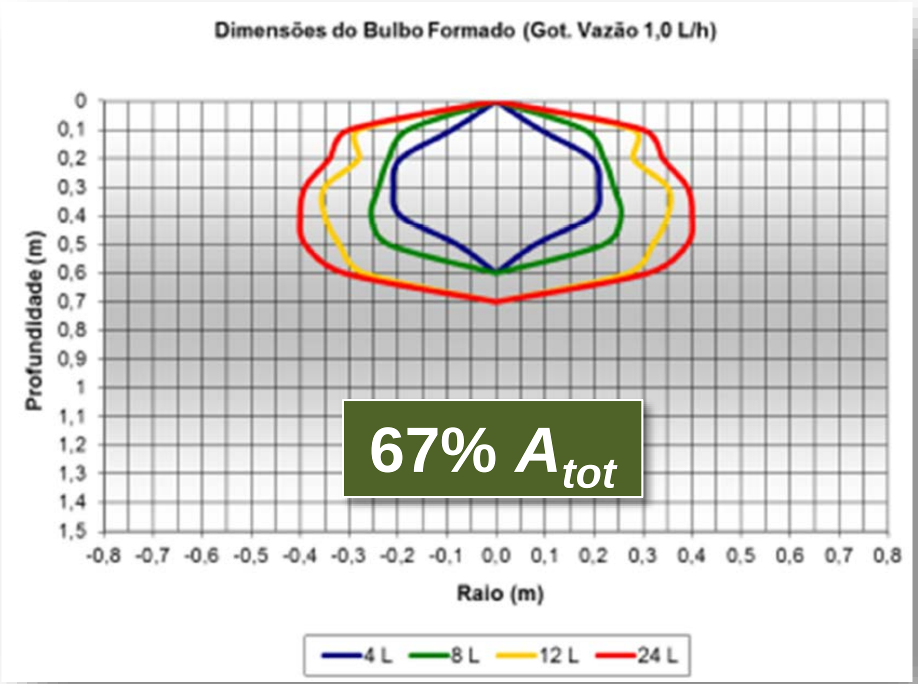


Determinação da Lâmina de Irrigação Provável para Projeto

Determinação da Área de Contribuição do Solo para Captação da Chuva

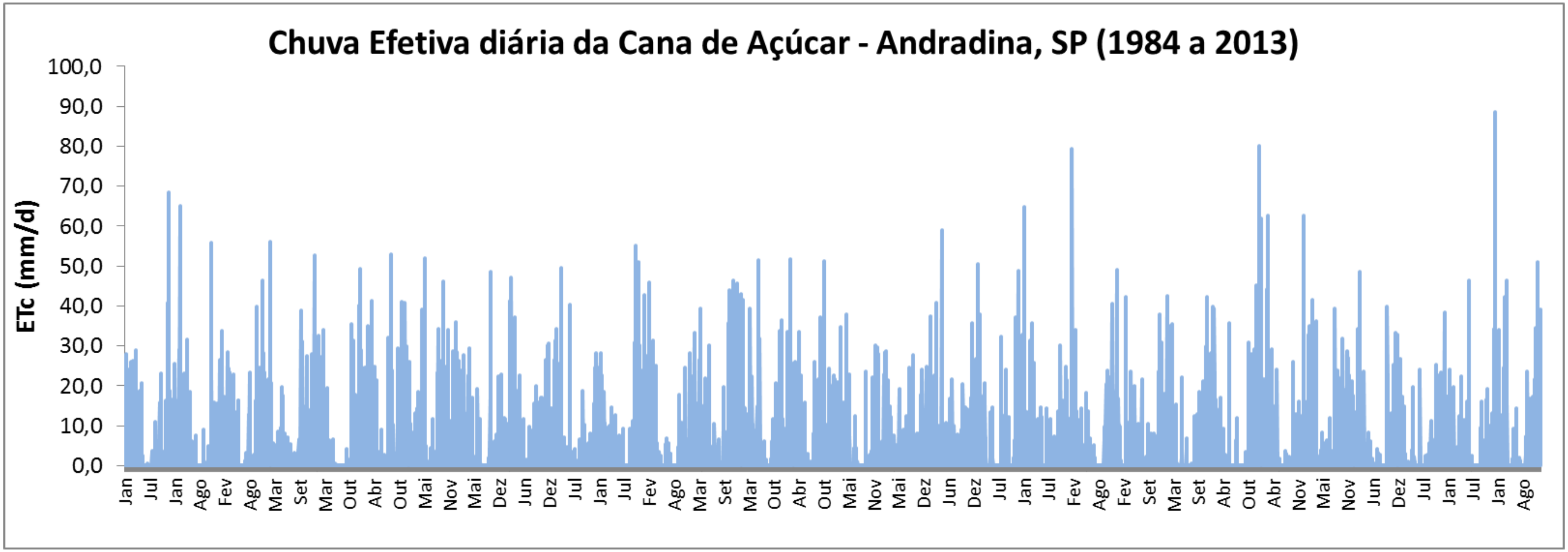


Cedido por Daniel Pedroso - Netafin



Determinação da Lâmina de Irrigação Provável para Projeto

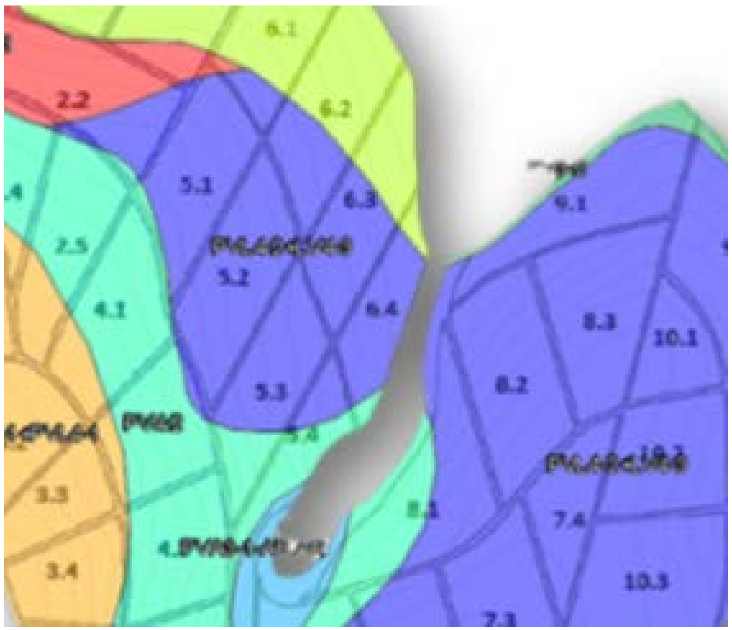
Determinação da Área de Contribuição do Solo para Captação da Chuva



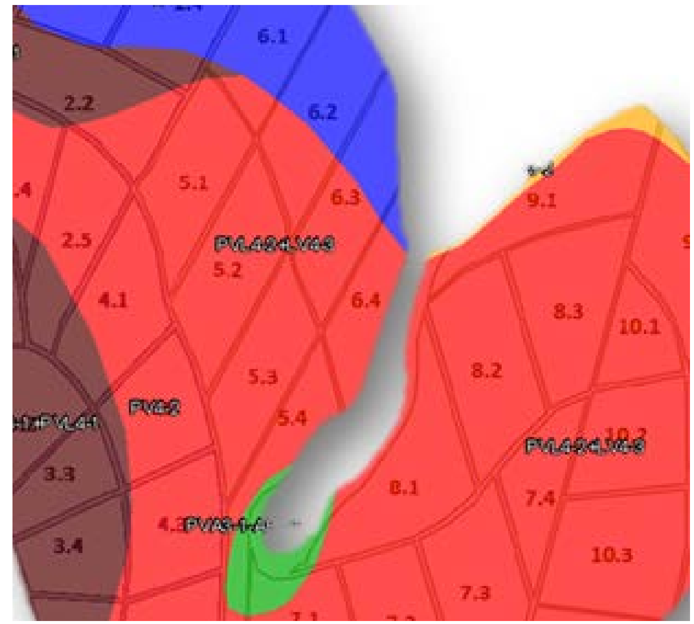
Pefetiva = [(Ptotal -2) * 0,67] * 0,8 → Descontos para a interceptação das folhas e palha + escorrimento sup.

Determinação da Lâmina de Irrigação Provável para Projeto

Determinação da CAD para fins de Irrigação por Gotejamento



- LV4-1 + PVL4-1
- PV3-2
- PV4-2
- PVL4-2 + LV4-3
- PVA3-1-AB,AR
- CX2-1 + PV2-1
- NV2-1

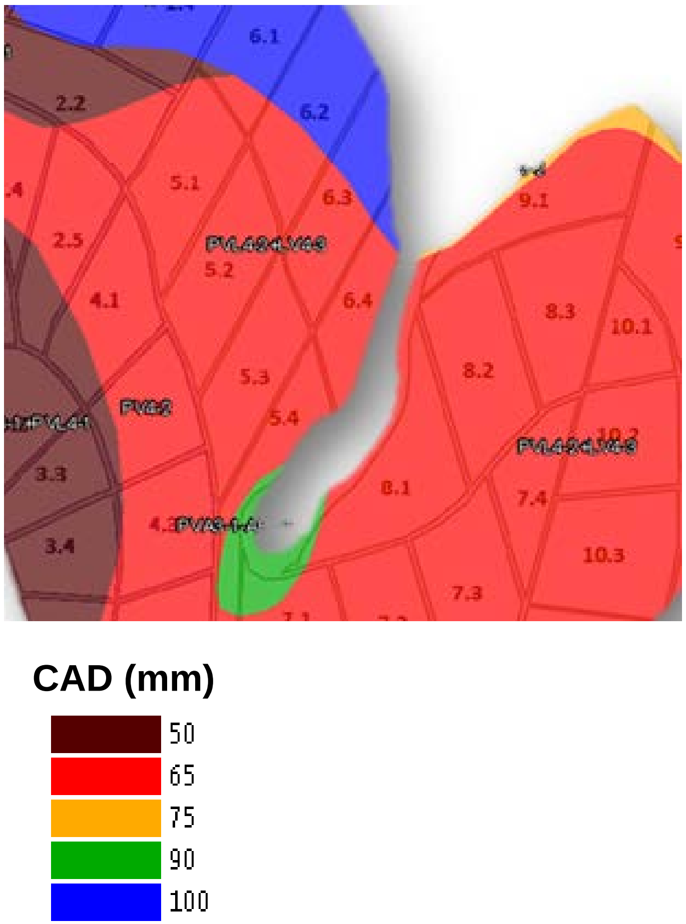


CAD (mm)

- 50
- 65
- 75
- 90
- 100

Determinação da Lâmina de Irrigação Provável para Projeto

Determinação da CAD para fins de Irrigação por Gotejamento

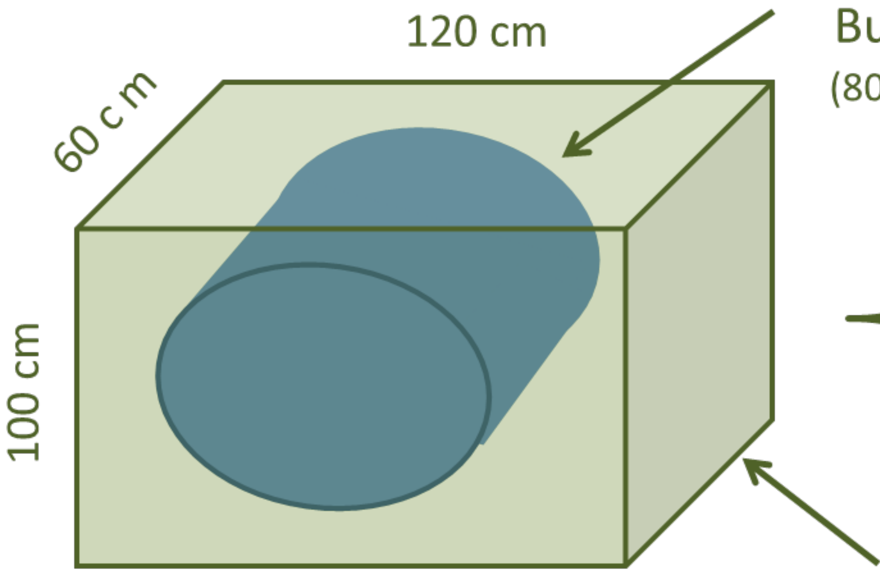


CAD Ponderada pela
Área de Contribuição
de cada Classe de CAD

$CAD_{Ponderada}$ = 67 mm
(para 1 m de profundidade)

Determinação da Lâmina de Irrigação Provável para Projeto

Determinação da CAD para fins de Irrigação por Gotejamento

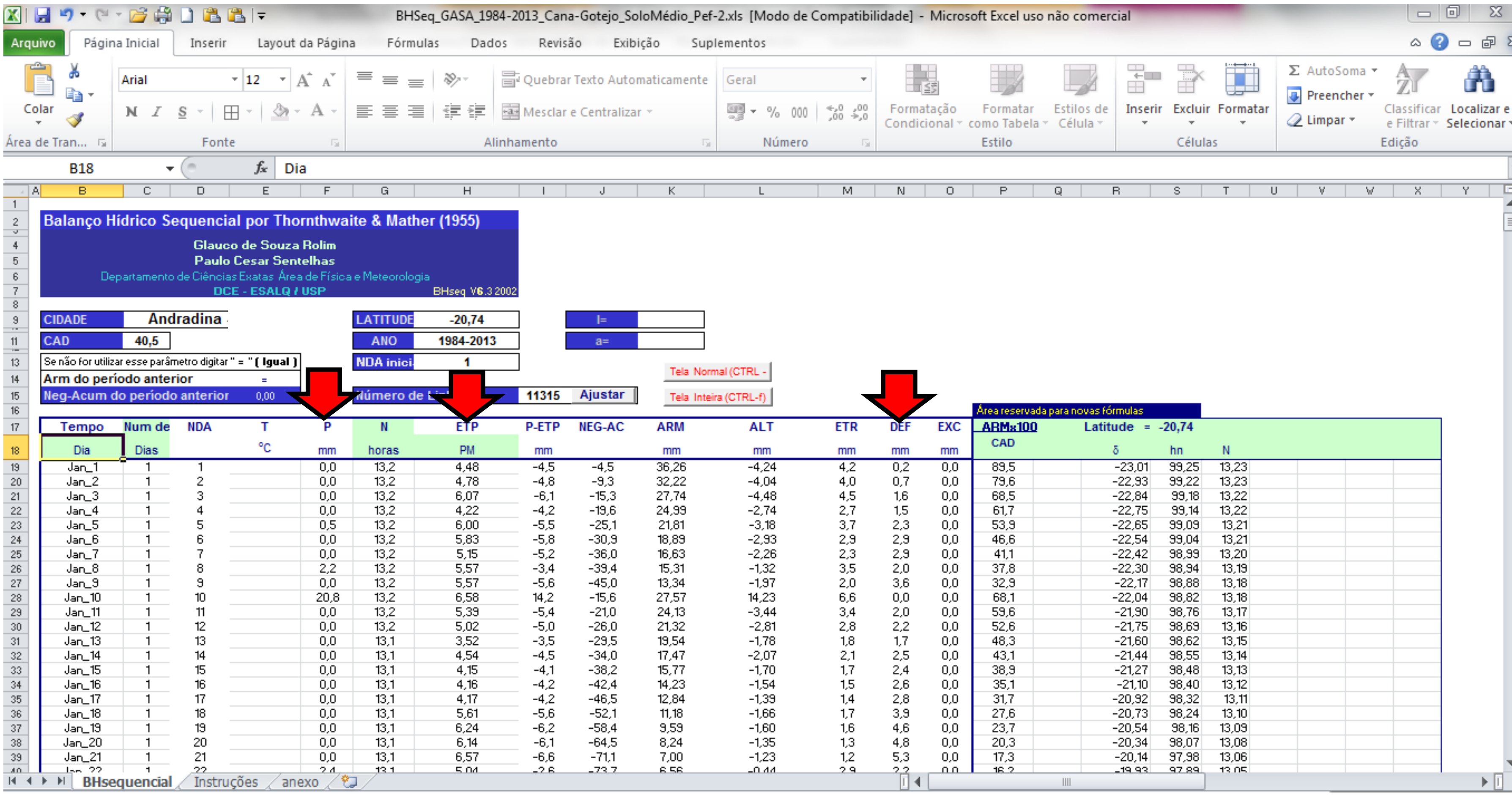


Proporção $V_{Bulbo} / V_{total} = 0,6045$

$CAD_{Bulbo} = 67 * 0,6045 = 40,5$ mm

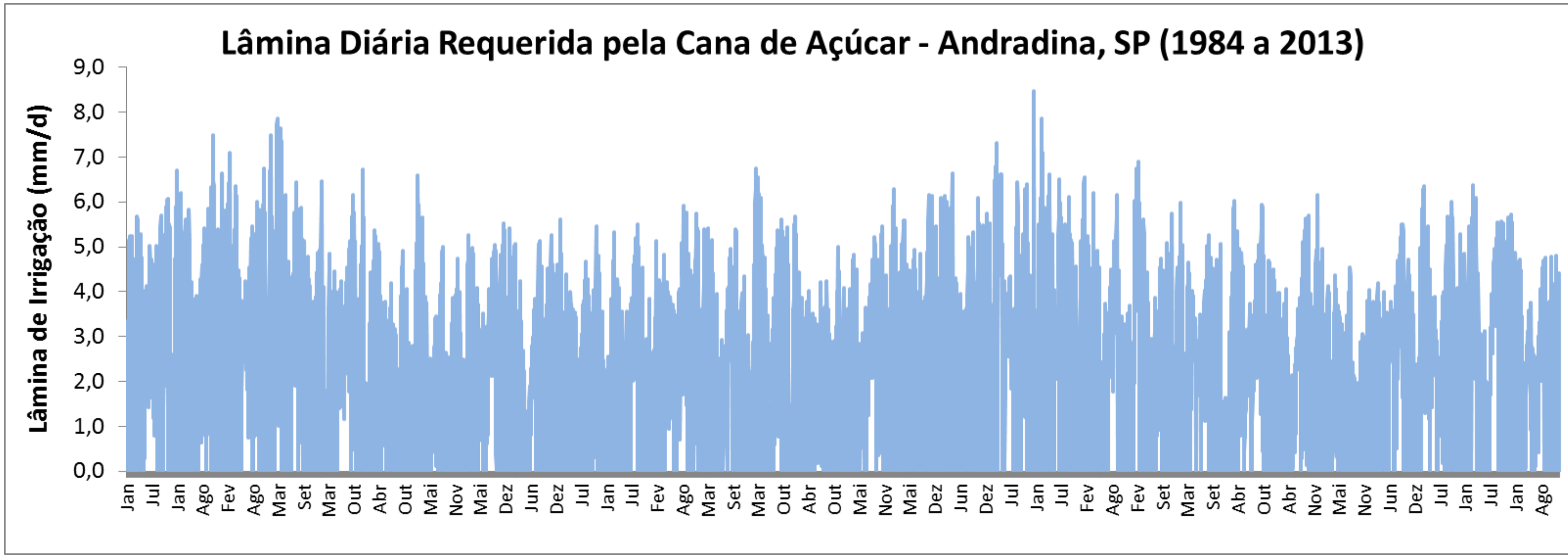
Determinação da Lâmina de Irrigação Provável para Projeto

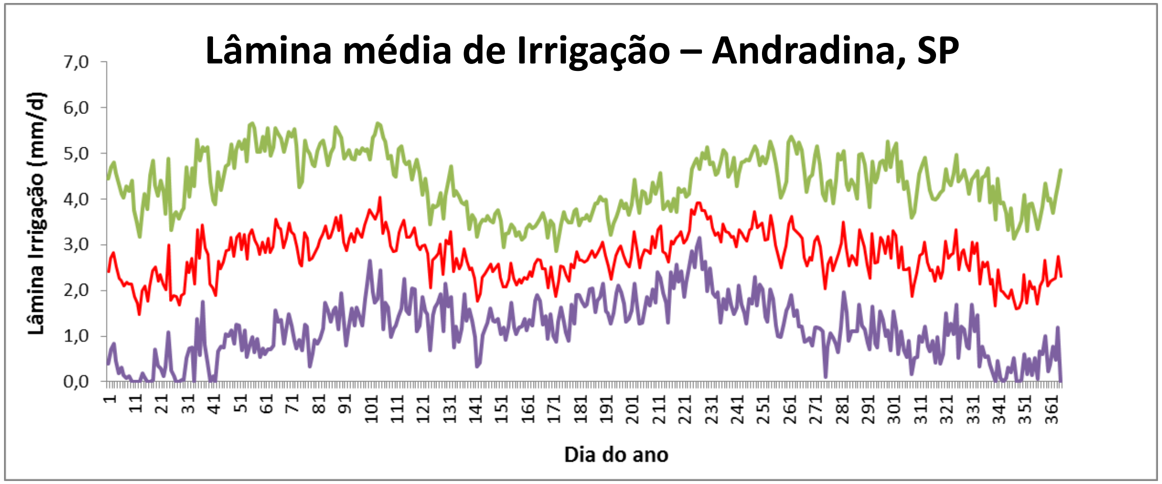
Balanço Hídrico Diário e Determinação da Lâmina Provável



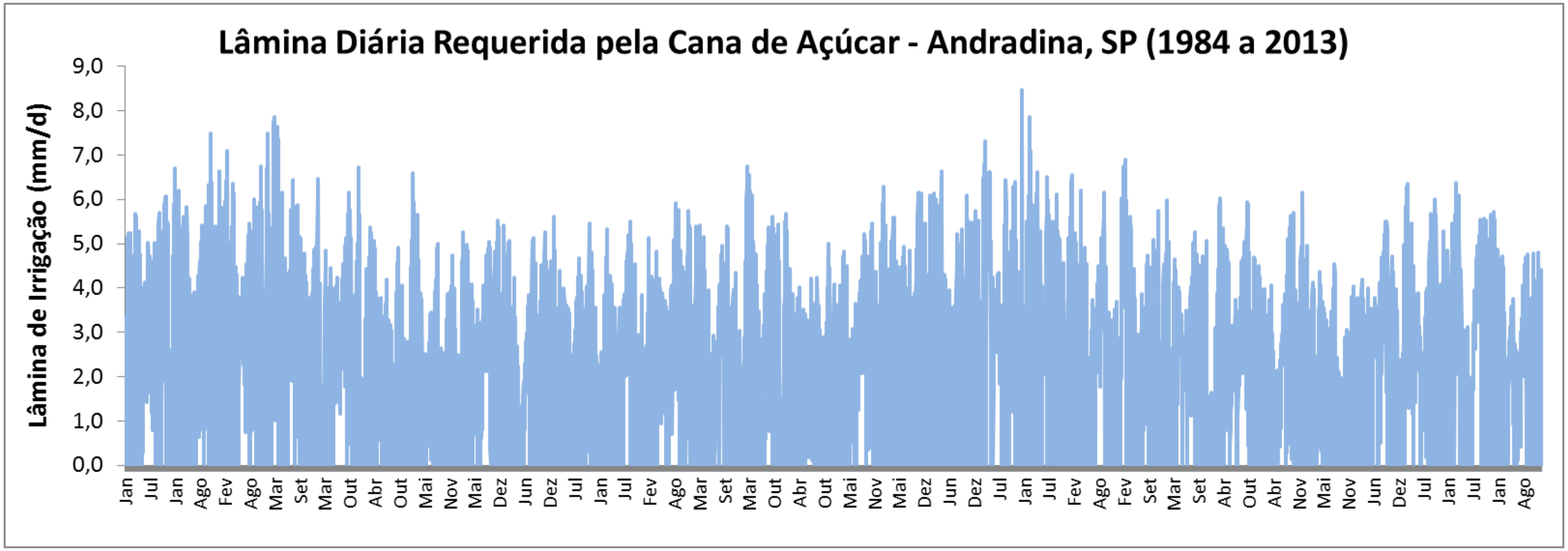
Tempo Dia	Num de Dias	NDA	T °C	P mm	N horas	ETP PM	P-ETP mm	NEG-AC	ARM mm	ALT mm	ETR mm	DEF mm	EXC mm	ARMx100 CAD	δ	hn	N
Jan_1	1	1		0,0	13,2	4,48	-4,5	-4,5	36,26	-4,24	4,2	0,2	0,0	89,5	-23,01	99,25	13,23
Jan_2	1	2		0,0	13,2	4,78	-4,8	-9,3	32,22	-4,04	4,0	0,7	0,0	79,6	-22,93	99,22	13,23
Jan_3	1	3		0,0	13,2	6,07	-6,1	-15,3	27,74	-4,48	4,5	1,6	0,0	68,5	-22,84	99,18	13,22
Jan_4	1	4		0,0	13,2	4,22	-4,2	-19,6	24,99	-2,74	2,7	1,5	0,0	61,7	-22,75	99,14	13,22
Jan_5	1	5		0,5	13,2	6,00	-5,5	-25,1	21,81	-3,18	3,7	2,3	0,0	53,9	-22,65	99,09	13,21
Jan_6	1	6		0,0	13,2	5,83	-5,8	-30,9	18,89	-2,93	2,9	2,9	0,0	46,6	-22,54	99,04	13,21
Jan_7	1	7		0,0	13,2	5,15	-5,2	-36,0	16,63	-2,26	2,3	2,9	0,0	41,1	-22,42	98,99	13,20
Jan_8	1	8		2,2	13,2	5,57	-3,4	-39,4	15,31	-1,32	3,5	2,0	0,0	37,8	-22,30	98,94	13,19
Jan_9	1	9		0,0	13,2	5,57	-5,6	-45,0	13,34	-1,97	2,0	3,6	0,0	32,9	-22,17	98,88	13,18
Jan_10	1	10		20,8	13,2	6,58	14,2	-15,6	27,57	14,23	6,6	0,0	0,0	68,1	-22,04	98,82	13,18
Jan_11	1	11		0,0	13,2	5,39	-5,4	-21,0	24,13	-3,44	3,4	2,0	0,0	59,6	-21,90	98,76	13,17
Jan_12	1	12		0,0	13,2	5,02	-5,0	-26,0	21,32	-2,81	2,8	2,2	0,0	52,6	-21,75	98,69	13,16
Jan_13	1	13		0,0	13,1	3,52	-3,5	-29,5	19,54	-1,78	1,8	1,7	0,0	48,3	-21,60	98,62	13,15
Jan_14	1	14		0,0	13,1	4,54	-4,5	-34,0	17,47	-2,07	2,1	2,5	0,0	43,1	-21,44	98,55	13,14
Jan_15	1	15		0,0	13,1	4,15	-4,1	-38,2	15,77	-1,70	1,7	2,4	0,0	38,9	-21,27	98,48	13,13
Jan_16	1	16		0,0	13,1	4,16	-4,2	-42,4	14,23	-1,54	1,5	2,6	0,0	35,1	-21,10	98,40	13,12
Jan_17	1	17		0,0	13,1	4,17	-4,2	-46,5	12,84	-1,39	1,4	2,8	0,0	31,7	-20,92	98,32	13,11
Jan_18	1	18		0,0	13,1	5,61	-5,6	-52,1	11,18	-1,66	1,7	3,9	0,0	27,6	-20,73	98,24	13,10
Jan_19	1	19		0,0	13,1	6,24	-6,2	-58,4	9,59	-1,60	1,6	4,6	0,0	23,7	-20,54	98,16	13,09
Jan_20	1	20		0,0	13,1	6,14	-6,1	-64,5	8,24	-1,35	1,3	4,8	0,0	20,3	-20,34	98,07	13,08
Jan_21	1	21		0,0	13,1	6,57	-6,6	-71,1	7,00	-1,23	1,2	5,3	0,0	17,3	-20,14	97,98	13,06

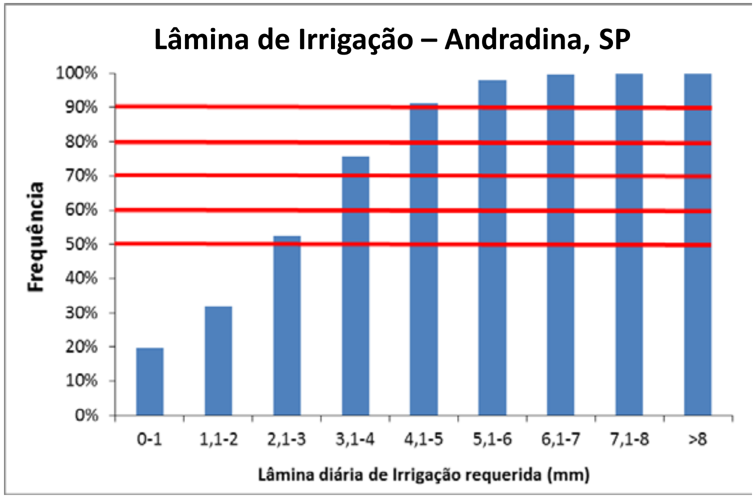
Determinação da Lâmina de Irrigação Provável para Projeto





Determinação da Lâmina de Irrigação Provável para Projeto

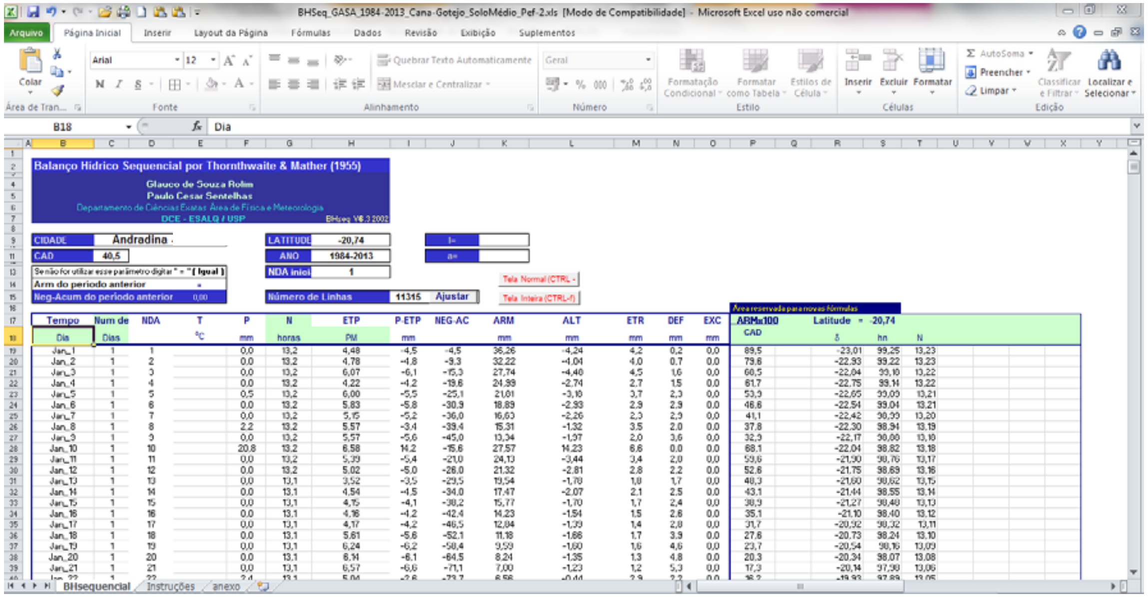




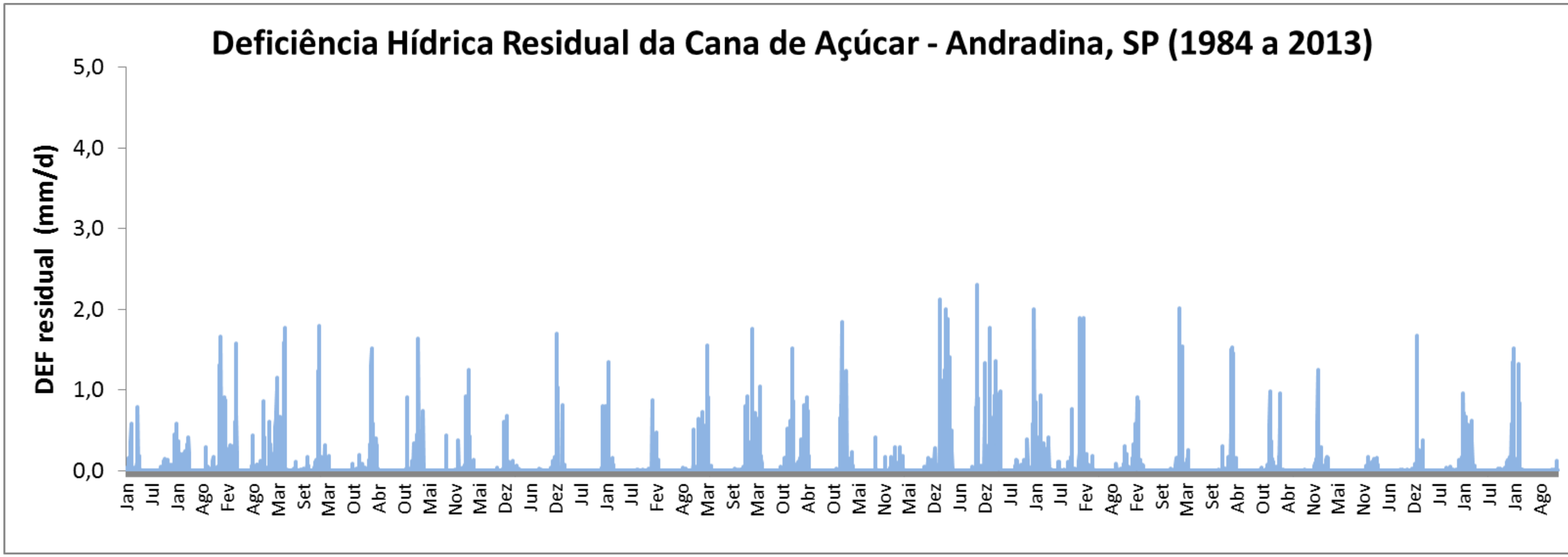
Probabilidade de Cobertura dos Eventos					
50	**60**	**70**	**80**	**90**	**100**
ETc Provável (mm/d)					
2,9	3,3	3,7	4,2	4,9	8,9

Determinação da Lâmina Diária de Irrigação

P+I		Lâm.Max.	4,91			
Solo:	Ponderado					
Ano	**Data**	**Prec**	**ETc**	**P-ETc**	**P+I**	**I**
1984	01/jan	0,0	4,5	-4,5	4,5	4,5
1984	02/jan	0,0	4,8	-4,8	4,8	4,8
1984	03/jan	0,0	6,1	-6,1	4,9	4,9
1984	04/jan	0,0	4,2	-4,2	4,2	4,2
1984	05/jan	0,5	6,0	-5,5	4,9	4,4
1984	06/jan	0,0	5,8	-5,8	4,9	4,9
1984	07/jan	0,0	5,2	-5,2	4,9	4,9
1984	08/jan	2,2	5,6	-3,4	5,6	3,4
1984	09/jan	0,0	5,6	-5,6	4,9	4,9
1984	10/jan	20,8	6,6	14,2	20,8	0,0
1984	11/jan	0,0	5,4	-5,4	4,9	4,9
1984	12/jan	0,0	5,0	-5,0	4,9	4,9
1984	13/jan	0,0	3,5	-3,5	3,5	3,5
1984	14/jan	0,0	4,5	-4,5	4,5	4,5
1984	15/jan	0,0	4,1	-4,1	4,1	4,1
1984	16/jan	0,0	4,2	-4,2	4,2	4,2
1984	17/jan	0,0	4,2	-4,2	4,2	4,2
1984	18/jan	0,0	5,6	-5,6	4,9	4,9
1984	19/jan	0,0	6,2	-6,2	4,9	4,9
1984	20/jan	0,0	6,1	-6,1	4,9	4,9
1984	21/jan	0,0	6,6	-6,6	4,9	4,9
1984	22/jan	2,4	5,0	-2,6	5,0	2,6
1984	23/jan	0,0	5,7	-5,7	4,9	4,9
1984	24/jan	0,0	6,2	-6,2	4,9	4,9
1984	25/jan	0,0	5,0	-5,0	4,9	4,9
1984	26/jan	11,7	3,9	7,9	11,7	0,0
1984	27/jan	11,9	5,8	6,1	11,9	0,0
1984	28/jan	17,6	5,9	11,6	17,6	0,0
1984	29/jan	0,0	6,0	-6,0	4,9	4,9
1984	30/jan	0,0	5,3	-5,3	4,9	4,9
1984	31/jan	0,0	6,4	-6,4	4,9	4,9



Balanço Hídrico Diário e Determinação do DEF Residual



Eventos DEF > 0 = 2704 (≈ 25%)
Eventos DEF > 0,1 = 821 (≈ 7,5%)
DEF média anual = 14,4 mm

Aplicações na simulação da produtividade e do "yield gap" de culturas agrícolas

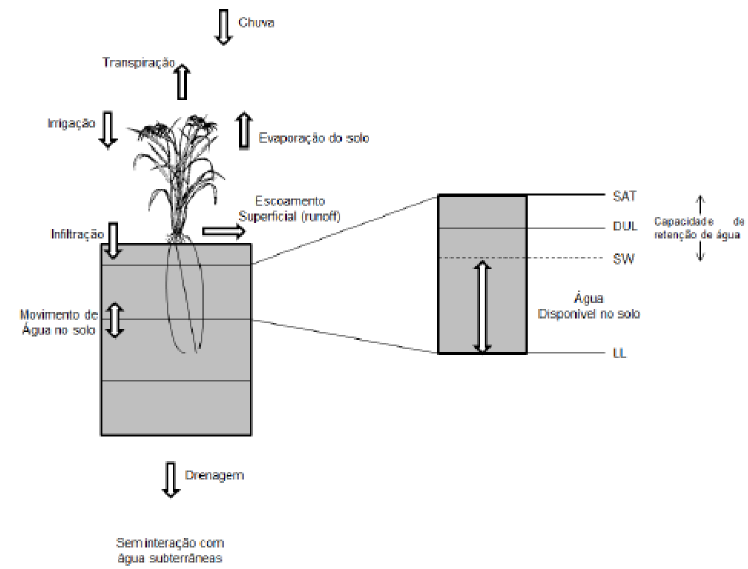
Universidade de São Paulo
Escola Superior de Agricultura "Luiz de Queiroz"

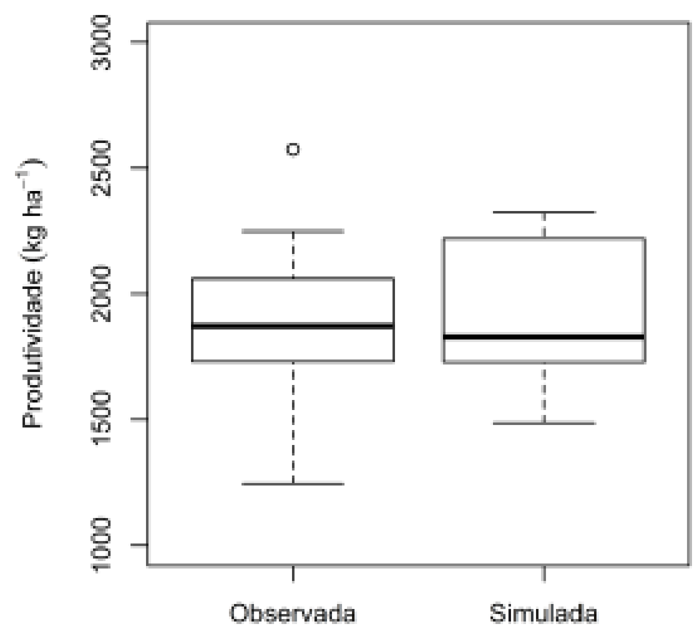
Aplicação do modelo ORYZA-DSSAT para a estimativa da produtividade do arroz de terras altas como subsídio ao zoneamento de risco climático no Estado de Goiás, Brasil

Lucas Fernandes de Souza

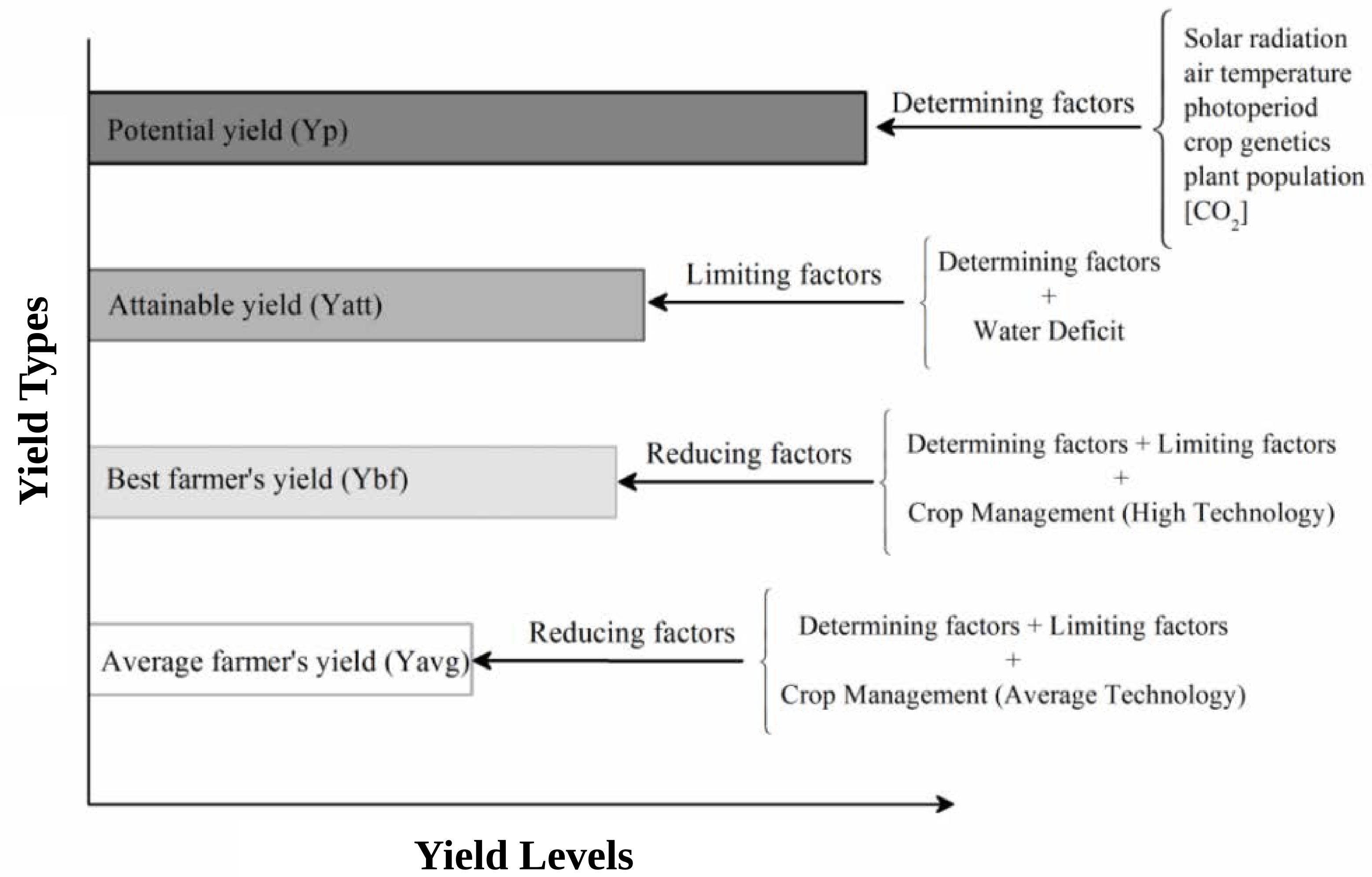
Tese apresentada para obtenção do título de Doutor em Ciências. Área de concentração: Física do Ambiente Agrícola

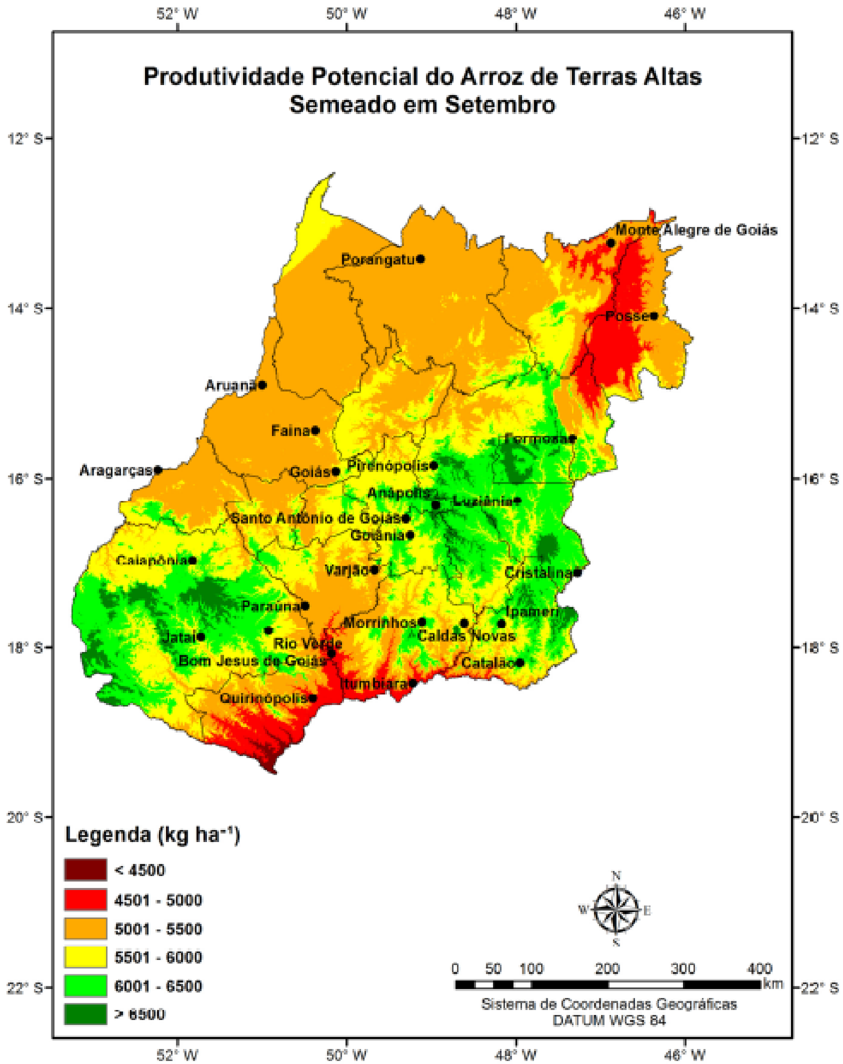
Piracicaba
2013



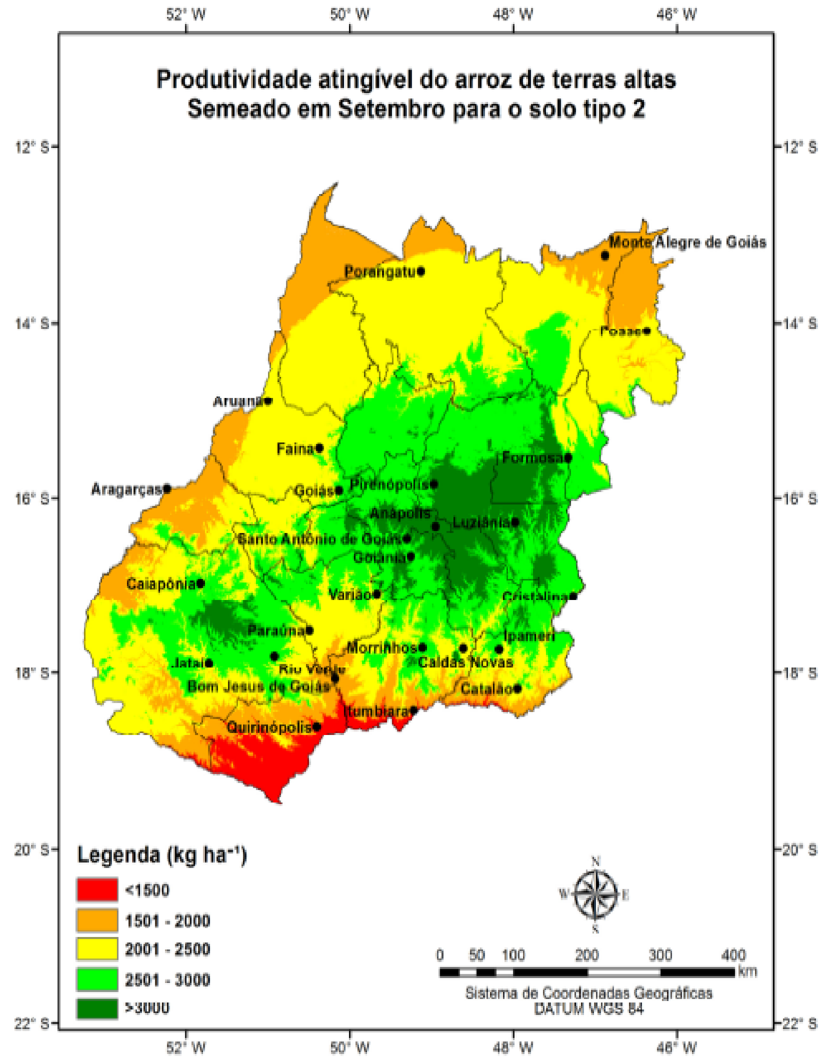


Tipos e Níveis de Produtividade e seus Fatores





YG ≈ 3000 kg ha^{-1}



PP = 4500 a 6500 kg ha^{-1}

PA = 1500 a 3000 kg ha^{-1}

Souza (2013)

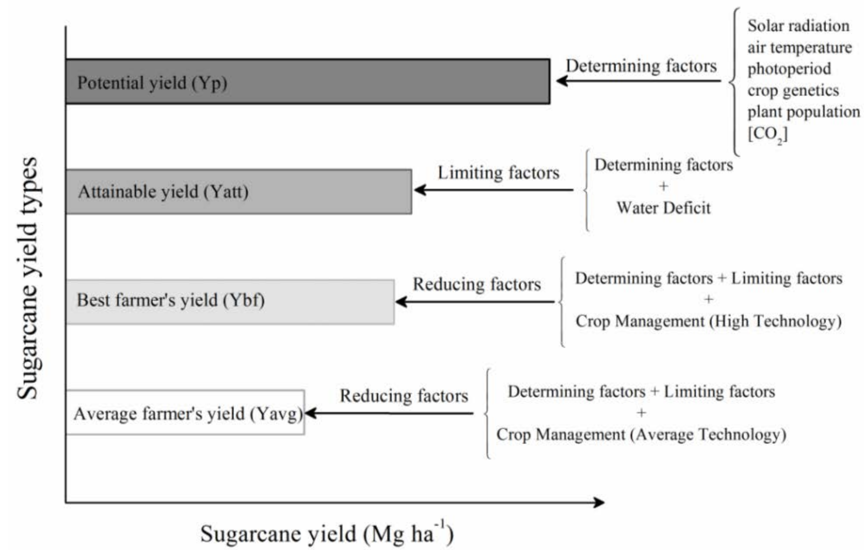
University of São Paulo
"Luiz de Queiroz" College of Agriculture

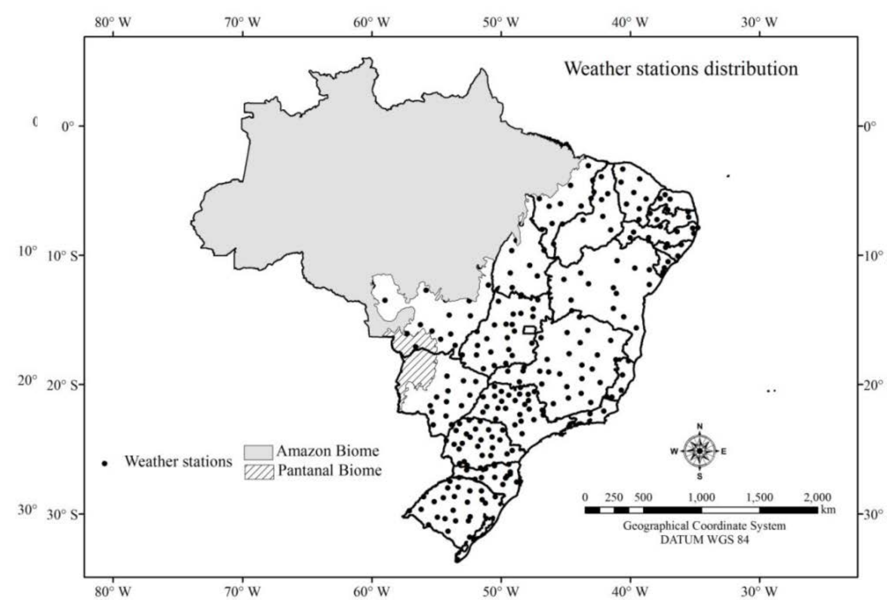
Sugarcane yield gap in Brazil: a crop modelling approach

Leonardo Amaral Monteiro

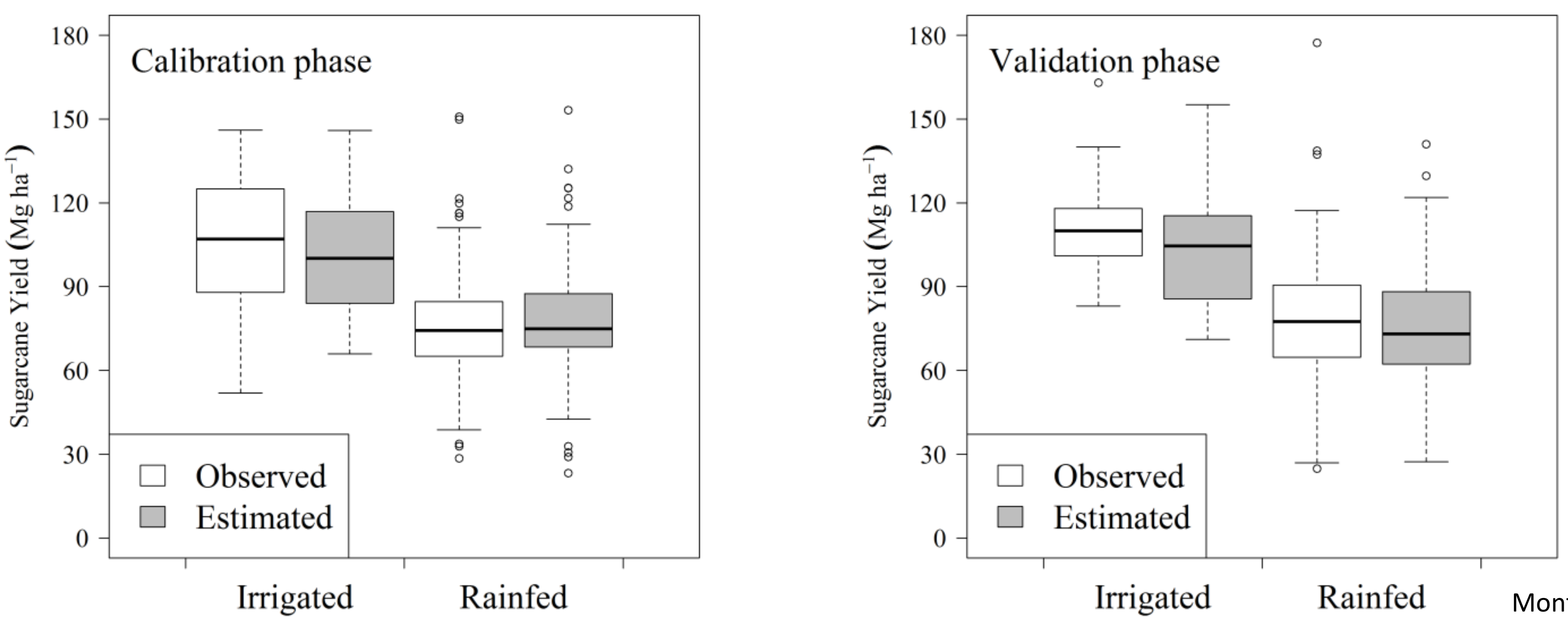
Thesis presented to obtain the Doctor degree in Science.
Area: Agricultural Systems Engineering

Piracicaba
2015



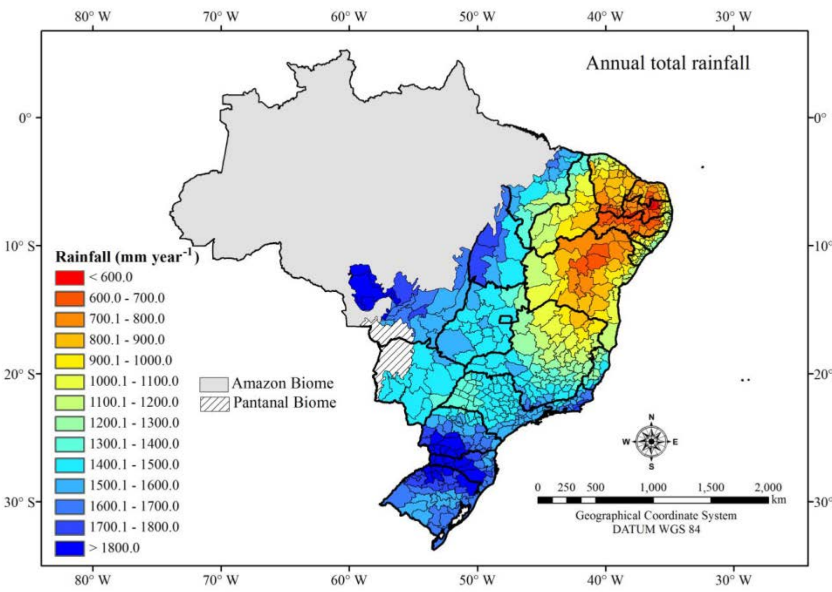


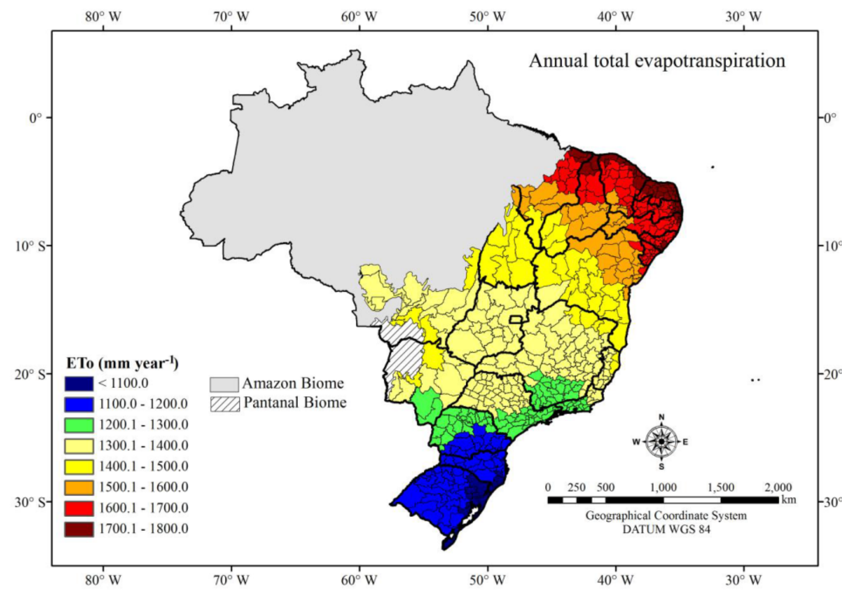
A computational routine was developed in R language code (R CORE TEAM, 2014) in order to collect the daily weather inputs referent to each VWS provided by NASA/POWER system (STACKHOUSE, 2010). The rainfall data from the gridded platform were replaced by those from National Water Agency (ANA) database, available for each location. Wind speed (U10) data were adjusted for 2-m height (U2) through the wind profile equation, which resulted in a correction factor (f = 0.748), as suggested by Allen et al. (1998). **The reference evapotranspiration (ETo), was estimated according to Penman-Monteith method (ALLEN et al., 1998).** All dataset were adjusted to a 10-day time scale to be applied as inputs in the water balance and sugarcane yield model.

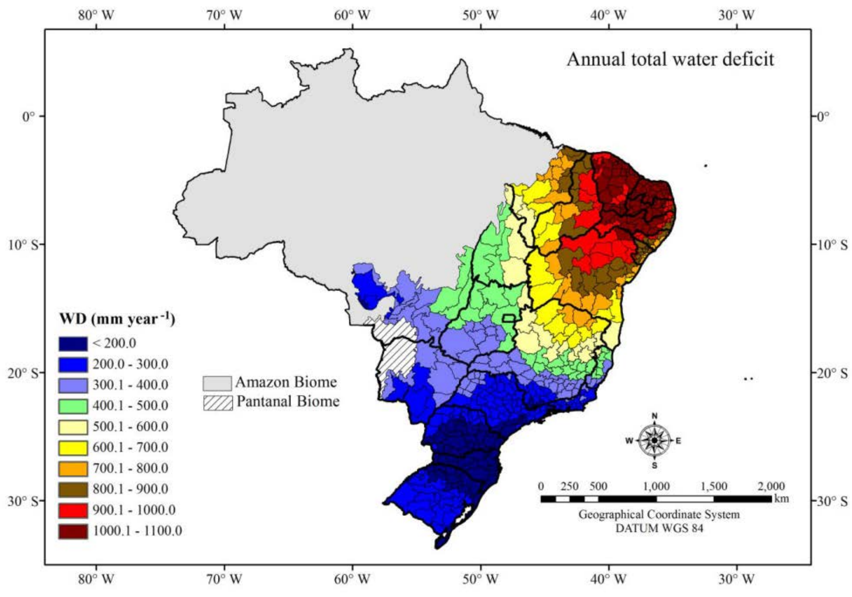


Monteiro (2015)

4° Mesa Redonda - Utilização da FAO 56 no Brasil e na América do Sul

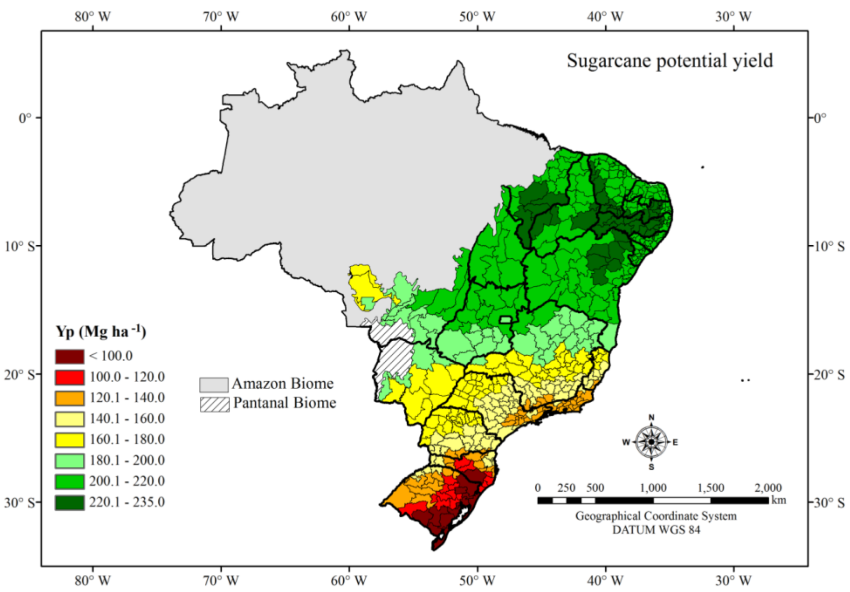


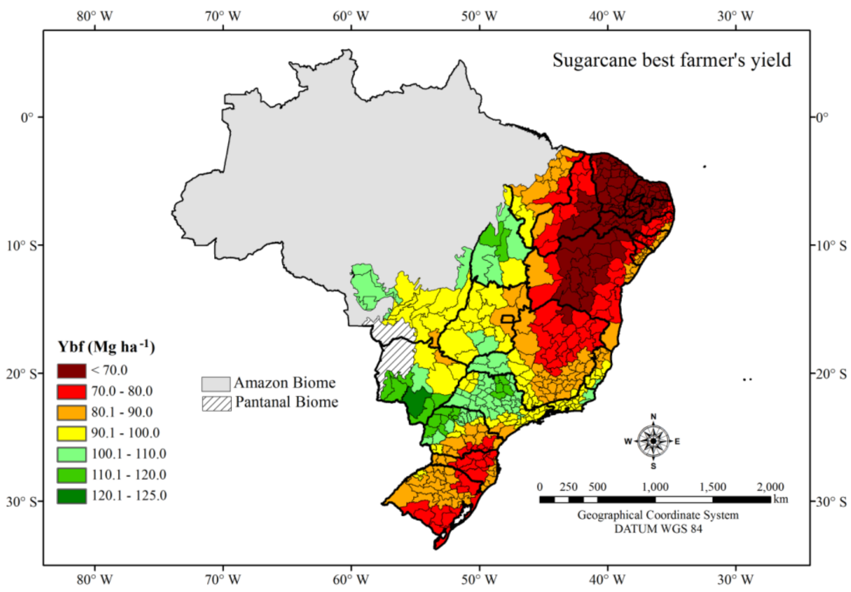


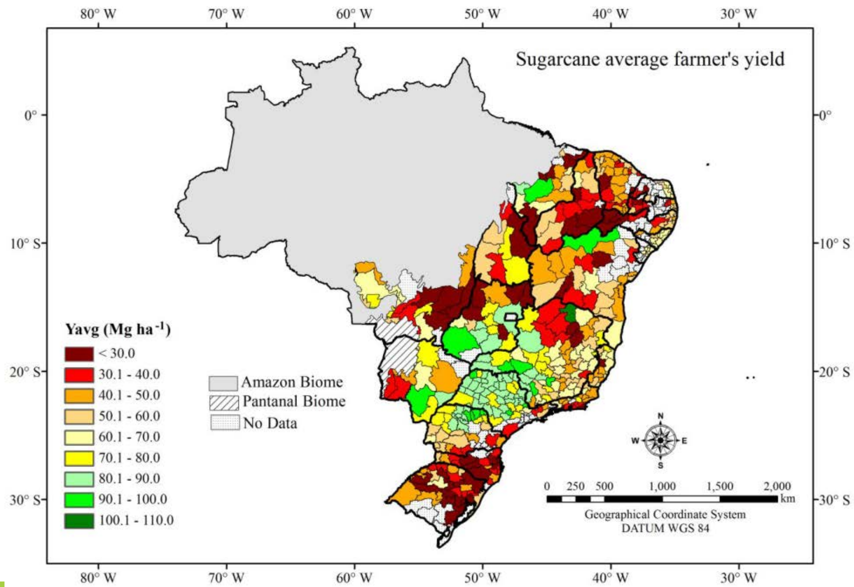


Monteiro (2015)

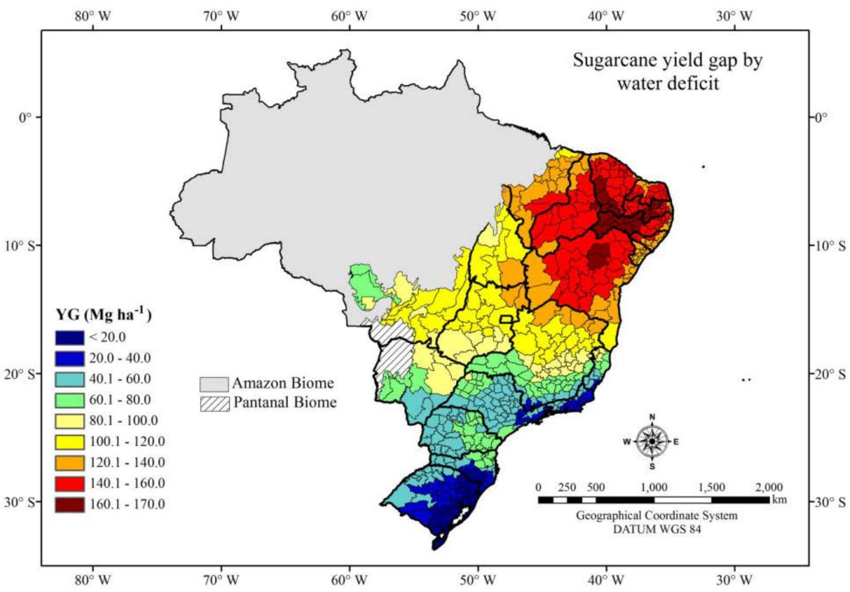
4° Mesa Redonda - Utilização da FAO 56 no Brasil e na América do Sul

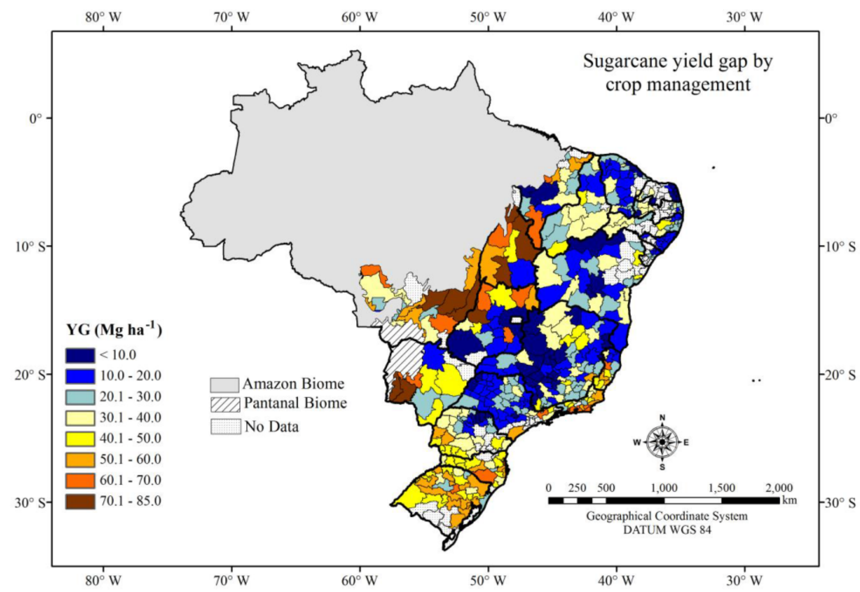


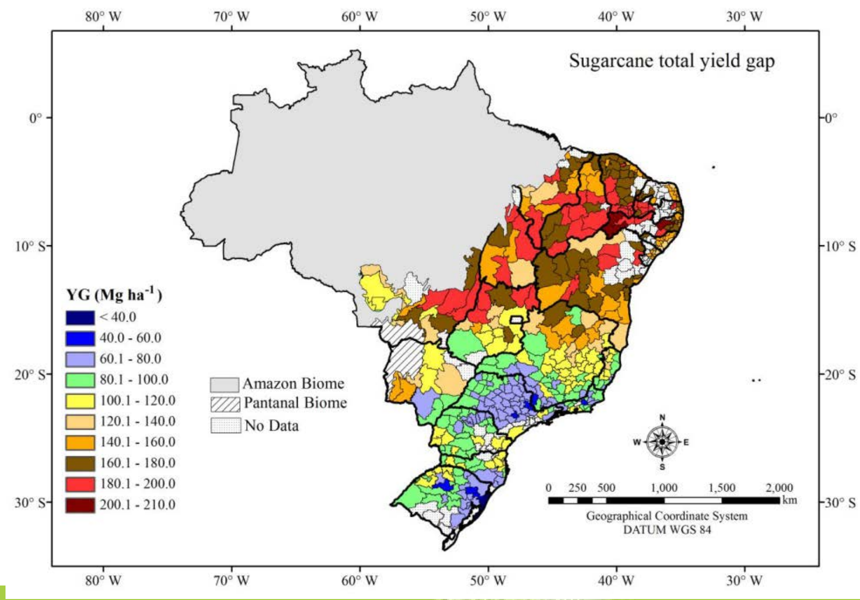




Monteiro (2015)

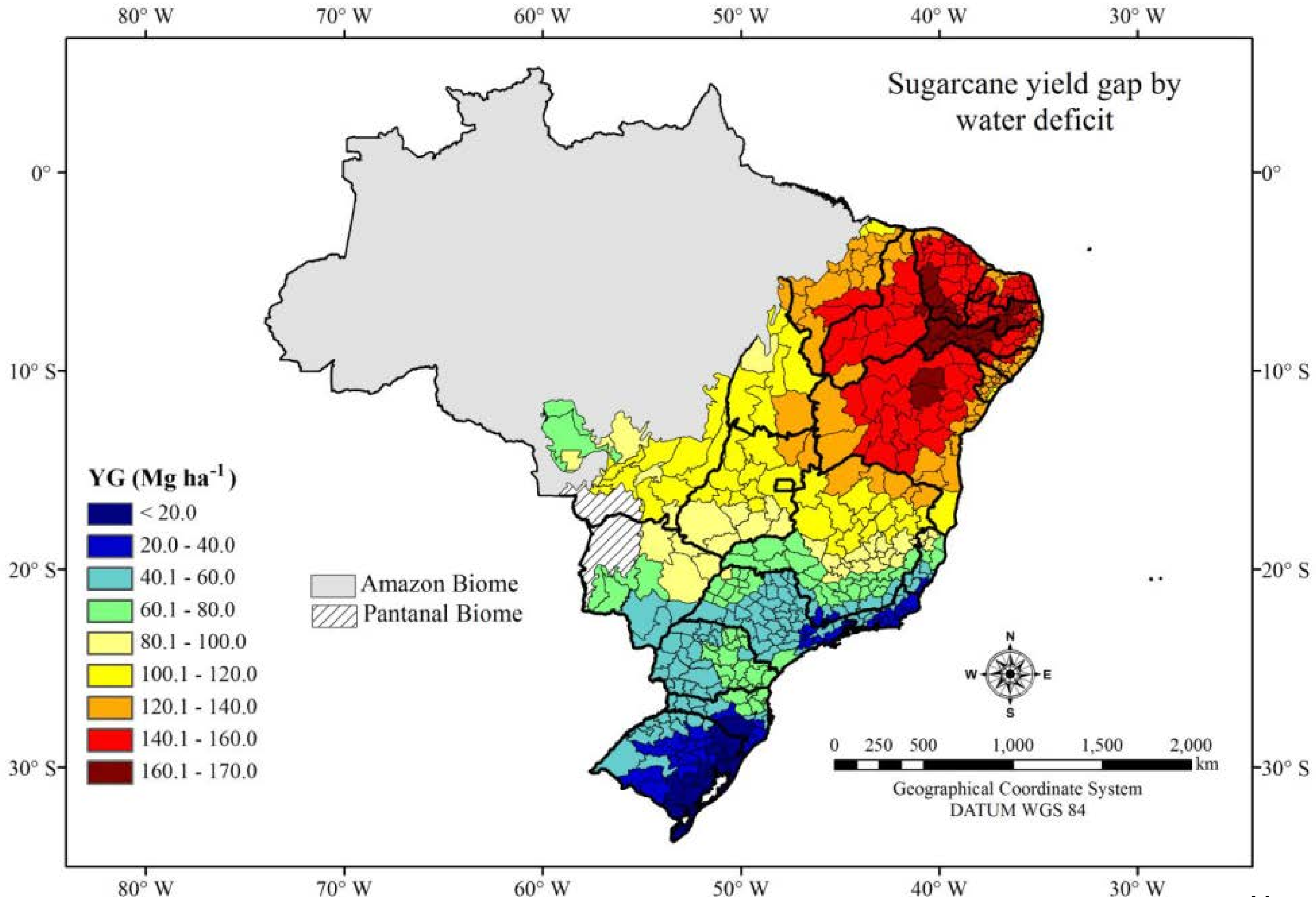






Monteiro (2015)

Incremento de Produtividade com Irrigação Plena

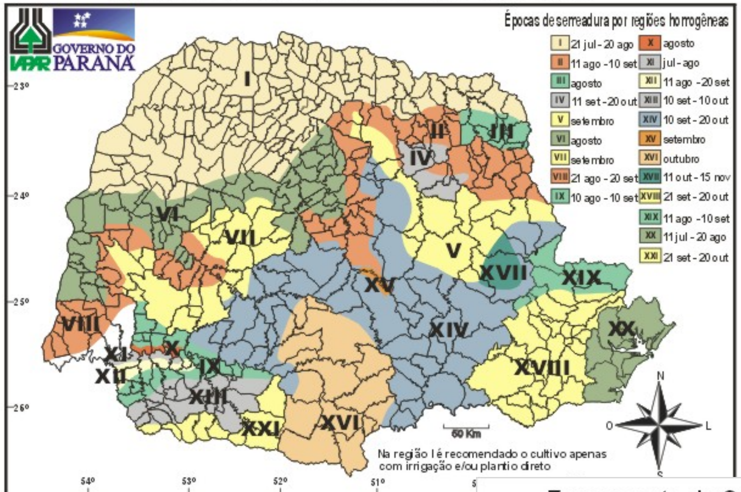


Monteiro (2015)

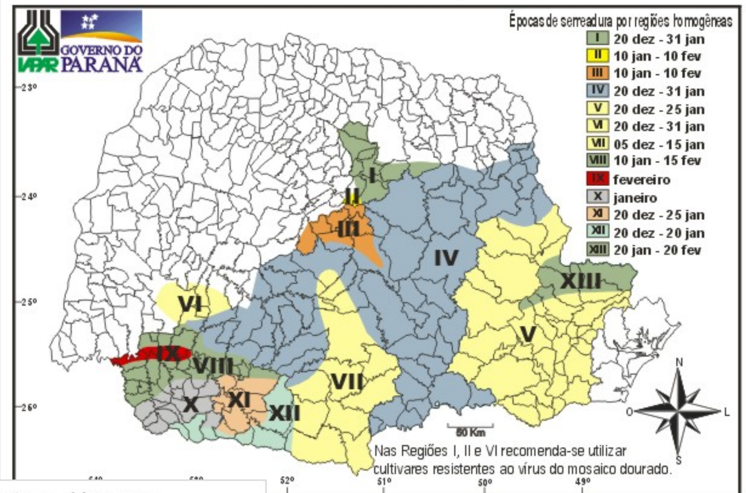
Outros Tipos de Aplicação

Zoneamento Agroclimático/Risco Climático

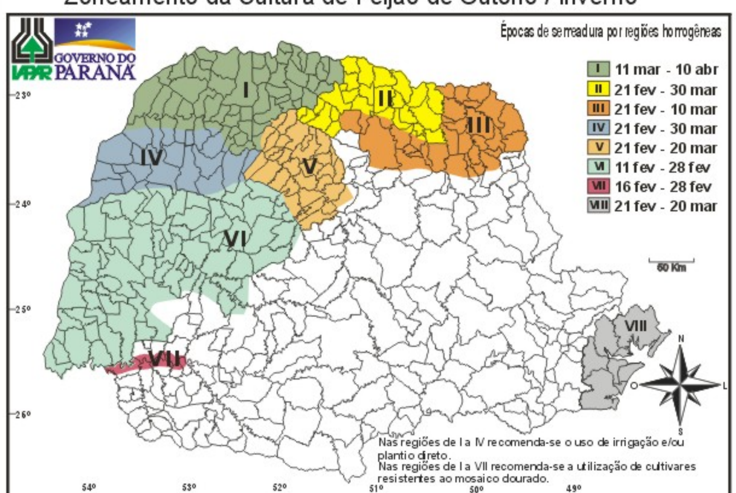
Zoneamento da Cultura de Feijão das Águas



Zoneamento da Cultura de Feijão da Seca

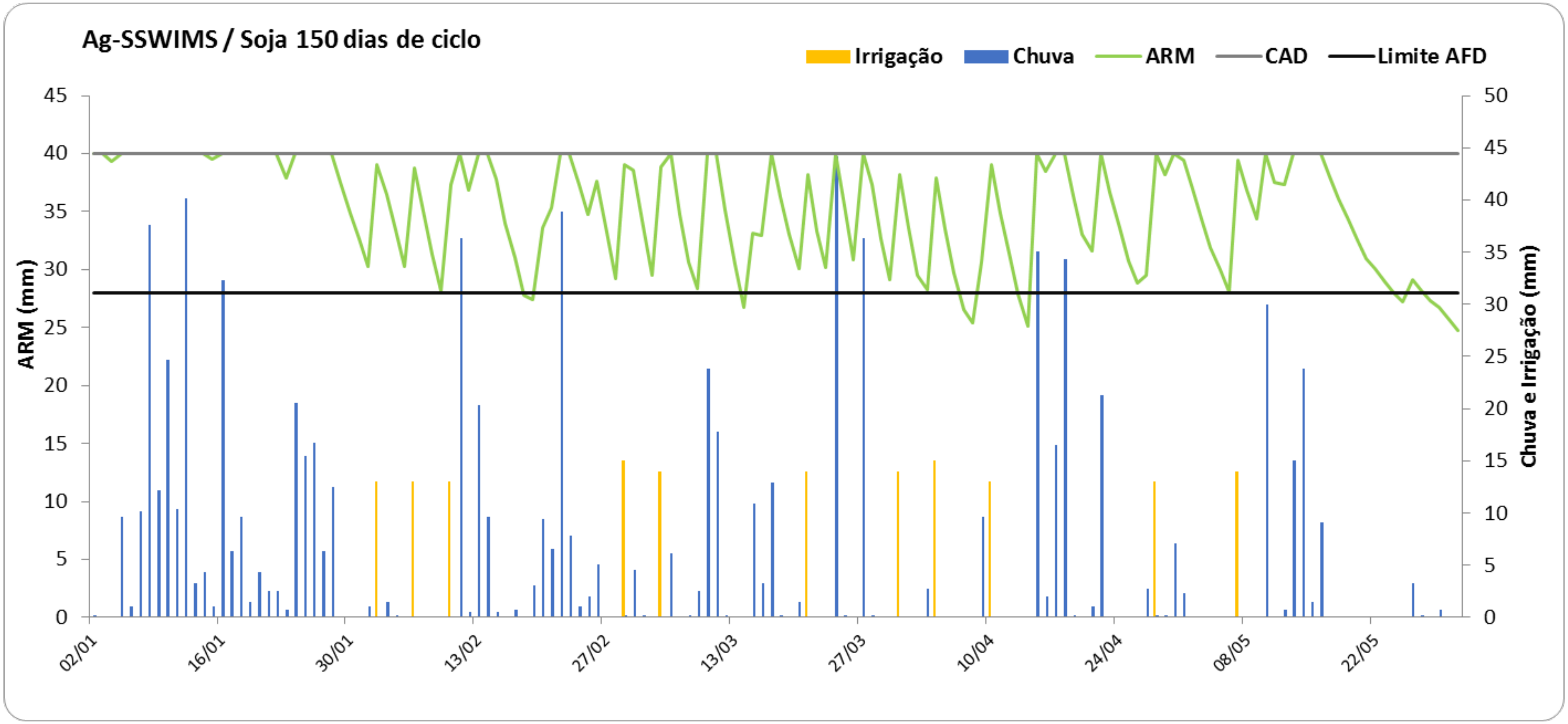


Zoneamento da Cultura de Feijão de Outono / Inverno



Outros Tipos de Aplicação

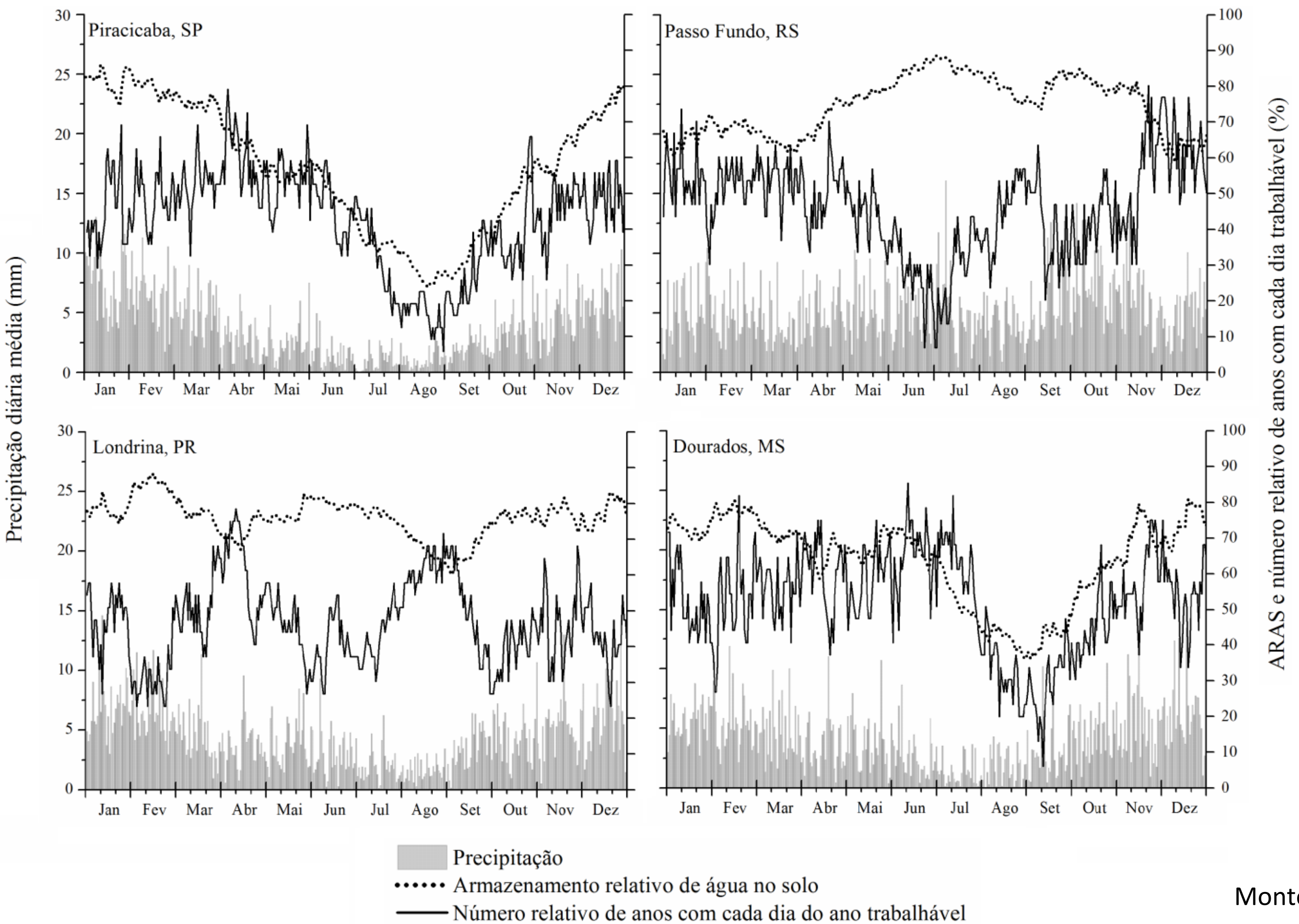
Manejo da irrigação



Sentelhas (2015)

Outros Tipos de Aplicação

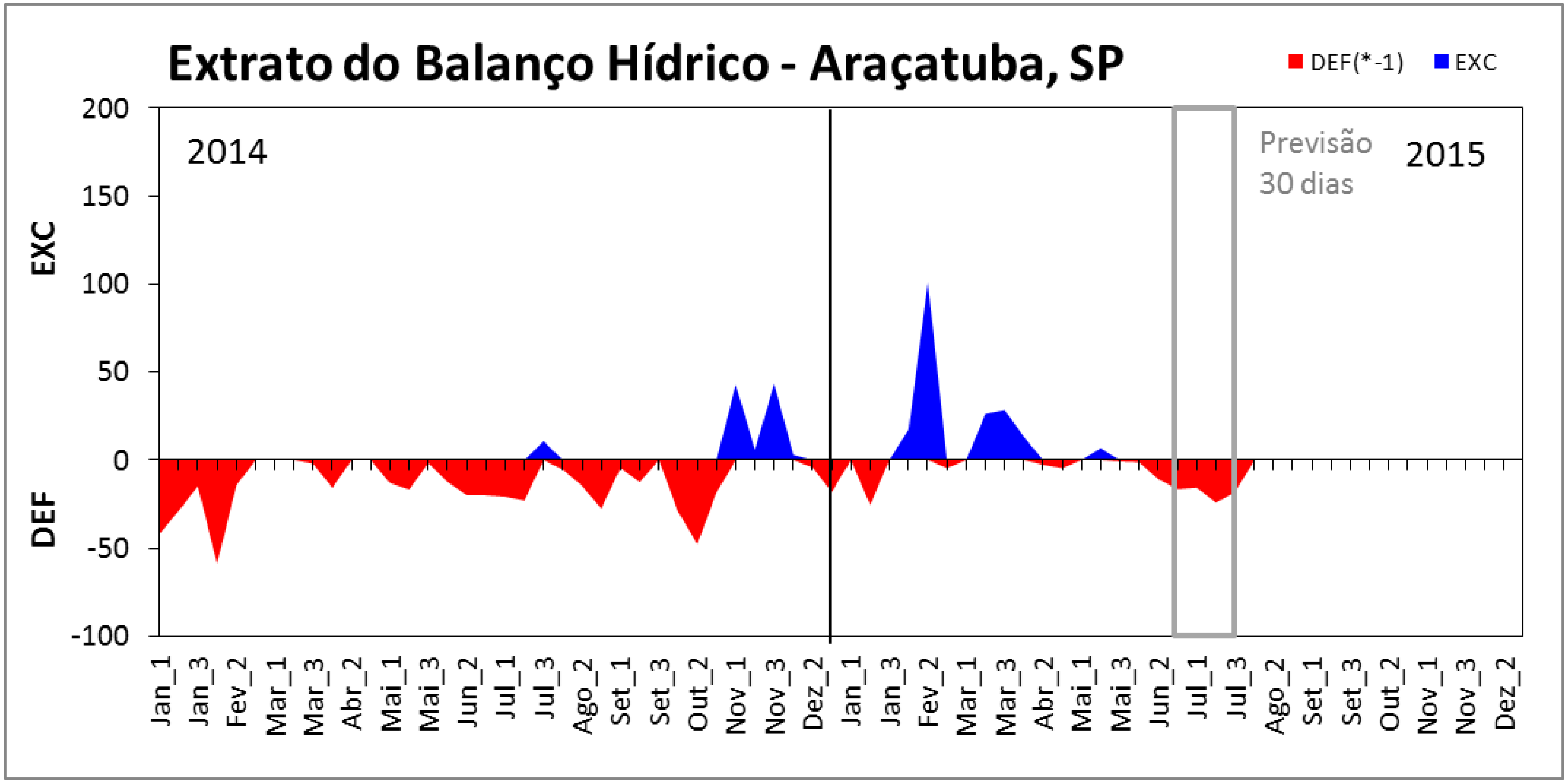
Definição de dias trabalháveis



Monteiro et al. (2015)

Outros Tipos de Aplicação

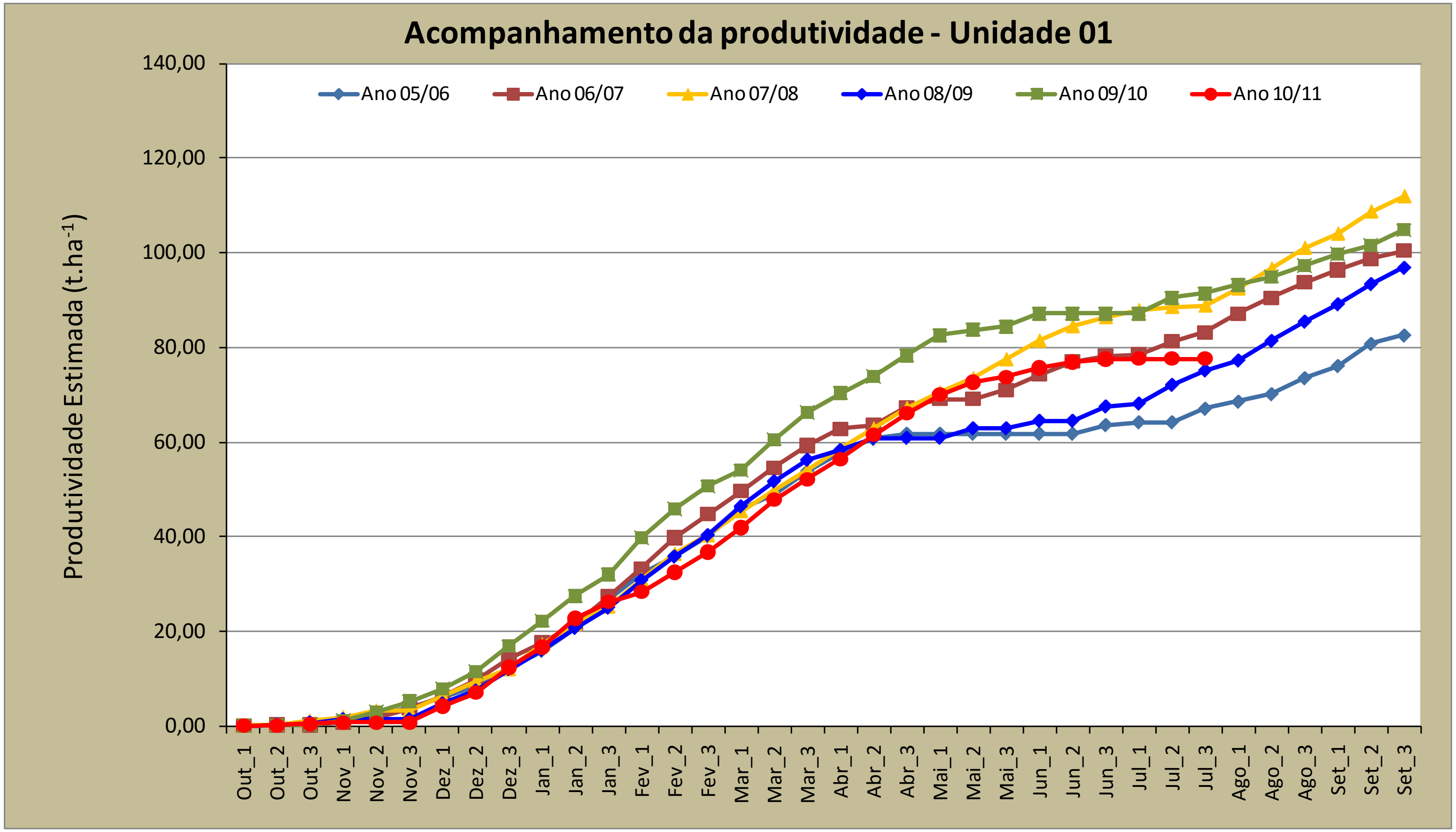
Monitoramento Agroclimático



Sentelhas (2015)

Outros Tipos de Aplicação

Previsão de safra



Sentelhas (2012)

Obrigado

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