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SPECTRAL AGROMETEOROLOGICAL MODELING ADAPTED BY MEANS OF SIMPLIFIED TRIANGLE METHOD FOR SOYBEAN IN PARANÁ STATE – BRAZIL

MODELAGEM AGROMETEOROLÓGICA ESPECTRAL ADAPTADA POR MEIO DO MÉTODO DO TRIANGULO SIMPLIFICADO PARA CULTURA DA SOJA NO ESTADO DO PARANÁ – BRASIL

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ABSTRACT
Agriculture is an economic activity with high dependence on weather and climate. Special geotechnology and agrometeorological modeling can be used to optimize productivity in regional and national systems, while minimizing costs. The aim was to test the agrometeorological model for estimating crop soybean yield proposed by Doorenbos and Kassam (1979), using only spectral data as input variable in the model obtained by a simplified triangle method applied in Paraná state, for crop years 2002/03 to 2011/12. A high accuracy of the data was found, the model values for the parameter d_1 ("d_1" modified Willmott) were between 0.8 and 0.95, whereas the root mean squared error showed that there was low variation between 30.81 to 116.88 (kg ha^{-1}) and the p-value was used as the indicator significance of the model at the level of 5%, indicating that there was no statistically significant difference between the estimated and observed data, this means that the average of the data estimated by the model were statistically equal the average of the observed data. Thus, we can say that images of remote sensing can be used as tools in the absence of surface information, in agrometeorological modeling to estimate crop soybean yield.

Key-words: crop yield; MODIS image; remote sensing; vegetation index.

RESUMO
A agricultura é uma das atividades econômica com maior dependência do tempo e do clima. Geotecnologia espacial e a modelagem agrometeorológica associadas, podem ser utilizadas na otimização da produtividade agrícola tanto em escalas regionais e nacionais, minimizando custos. O objetivo deste trabalho foi testar o modelo agrometeorológico de estimativa da soja proposto por Doorenbos e Kassam (1979), utilizando apenas dados espectrais como variável de entrada, por meio do método do triângulo simplificado. Foram analisadas regiões do Estado do Paraná e os anos-safra de 2002/03 a 2011/12. Os dados mostraram alta precisão, sendo que os valores do parâmetro d1 ("d1" Willmott modificado) foram de 0,8 e 0,95, enquanto o erro médio quadrático mostrou que houve baixa variação entre 30,81 a 116,88 (kg ha^{-1}). Em relação ao p-valor, utilizado como indicador de significância do modelo ao nível de 5%, mostrou que não houve diferença estatisticamente significativa entre os dados estimados e observados, isto significa que a média dos dados estimados pelo modelo foi igual à média dos dados observados. Dessa forma, podemos dizer que as imagens de sensoriamento remoto podem ser utilizadas como ferramentas na ausência de informações superficiais, na modelagem agrometeorológica para estimar o rendimento da soja cultivada.

Palavras-chave: produtividade, imagem MODIS, sensoriamento remoto; índice de vegetação.

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1. INTRODUCTION

Agriculture is one of the most important segments of the production chain and is the most dependent on natural conditions, mainly climate and soil, which control the growth and development of plants. Agrometeorology aims at identifying and quantifying the relationship between development and yield of cultivated plants. Once identified, meteorological elements and the cycle period of the plants they limit, it is possible to achieve a derivation of realistic models for forecasting or assessing harvest production (BERLATO et al., 1992). The description of soybean phenology allows to identify and group the stages of development of the crop and to relate them to their specific needs during the cycle (NEPOMUCENO et al. 2001).

Due to the importance of grains in Brazil and internationally it is necessary to have a system of crop forecasting able to identify production numbers in advance, as well as avoid losses, and employ new technologies aimed at reducing risk. According to Carmello et.al., (2013) among the risks, come to the question of water availability, directly interfering with the harvesting results, reaching the socioeconomic profile of the area, with regard to the internal and external market, reaches food security and the generation of jobs and income

Based on this, the geotechnology applied to agriculture has a great potential because through remote sensing techniques it is possible to obtain information on estimated acreage, crop yield and vegetative vigor, on local, state, or country scale. Thus, the objective of studies in remote sensing are the estimates of spectral variables related to growing conditions, which can then be inserted into simulations of productivity models (HUANG et al., 2002).

Several studies have been developed in this area in order to improve and complement programs related to agriculture either based on meteorological data obtained from conventional weather stations, or even spectral models based on satellite images. As examples, work by Camargo et al. (1988) and Moraes et al. (1998), which are agrometeorological models designed to yield estimates of crop production are based on climate data obtained from conventional weather stations. These types of agrometeorological models are derived from small-scale experimental plots, which hinder the applicability to regional studies. Examples of these kinds of studies with spectral model are those of Labus et al. (2002), Mkhabela et al. (2005), Prasad et al. (2006), Dubreul (2005) and Er-Raki et al. (2007).

Sophisticated and complex mathematical models are being increasingly used to provide representations of the physical processes that characterize the interactions at the land surface. Attempts to describe these mechanisms and physical processes with greater realism led to the development of the land surface modeling systems proposed for application, for example, using images of surface radiant temperature (Ts) and fractional vegetation cover (Fr), to provide moisture content in the soil surface (Mo), and fractional evapotranspiration (EF, the ratio of evapotranspiration ET to net radiation Rn), through a methodology known as the "triangle method". The approach of the triangle method is based on a contextual interpretation of a scatter plot derived from the relationship between radiant surface temperature (Ts) and vegetation index (IV, specifically the normalized difference vegetation index NDVI) (Figure 1).

The discovery that the pixel envelope in Ts/NDVI (or Fr) space tends to form a triangle or a trapezoid is very important since the triangular shape of the graph dispersion Ts / IV arises from Ts being less sensitive to water content at the surface in vegetated areas, than in areas of exposed soil Gillies et al. (1995; 1997), Symanzik et al. (2000), Goward et al. (2002), Sun et al. (2005), Arvor et al. (2007), and Brunsell and Anderson (2011). These authors used different spatial datasets to demonstrate that the limits of the triangular shape (the pixel envelope depicted as the small circles in Figure 1) can be used to infer the physical limits for solutions of flows of surface energy and the availability of soil moisture with a minimum of external data.

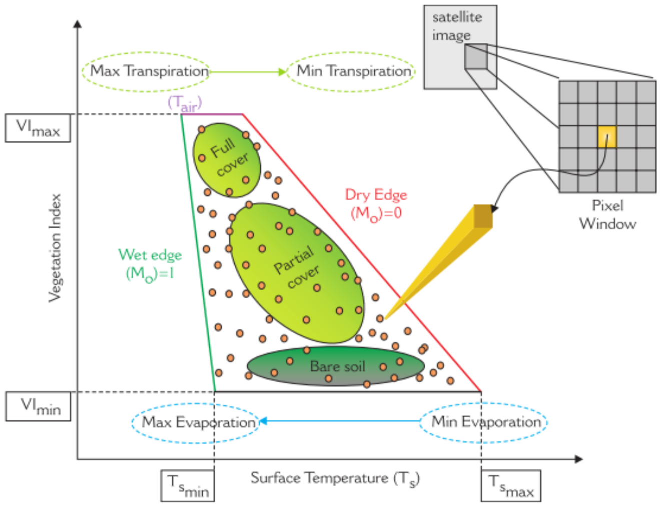

Figure 1-. Schematic graph of dispersion of the pixel values of NDVI as a function of surface temperature (Ts) of a satellite image. Source: Adapted from Petropoulos et al (2009), and Ehrlich Lambin (1996), Sandholt et al. (2002) and Nishida et al. (2003).

According to Carlson (2013), many efforts have been invested in complex mathematical methods to obtain surface parameters such as water content in soil and evapotranspiration; some of these methods discussed in the literature are unnecessarily complex. Based on this, Carlson developed a new methodology based on simple and purely geometric, physical arguments obviating the use of complex models. This new methodology is termed herein as "simplified triangle method".

Para Dubreuil et al. (2010), the nature of the spectral behavior of the plants a simple relationship between NDVI and evapotranspiration can be established by means of stomatal resistance to the transfer of water vapor.

Therefore, it is justified that a good estimate of crop yield requires modeling the environmental effects on physiological processes, determinants of crop yield, a quantity that is not only an important tool for farmers but also for the food industry and for the planner, leading to the implementation of appropriate public policies. The aim of this article was to test the agrometeorological model for soybean yield estimates modify the conventional agro-meteorological model (variable relative evapotranspiration - actual evapotranspiration / potential evapotranspiration, ETr/ETp), by spectral variables obtained through the simplified triangle method to the counties of Campo Mourao, Luiziana, Roncador, Apucarana, Marilândia do Sul, Lidianópolis, Ivaiporã and Manoel Ribas, in the years crop.

2. MATERIALS AND METHODS

The universe of analysis encompasses the state of Paraná, Campo Mourao, Luiziana, Roncador, Apucarana, Marilândia do Sul, Lidianópolis, Ivaiporã and Manoel Ribas, located in the southern region of the country between latitudes 22°29'S and 26°43'S and the meridians 48°2'W and 54°38'W (Figure 2), where the prevailing climate is temperate mesothermal and super-humid, Cfa - according to Köeppen climate classification with moderate temperatures, well distributed rainfall and hot summers. The state is located in a region of climatic transition from a subtropical climate with milder north to a condition that approaches the south temperate climates, where winters are severe and the season of plant growth is better defined.

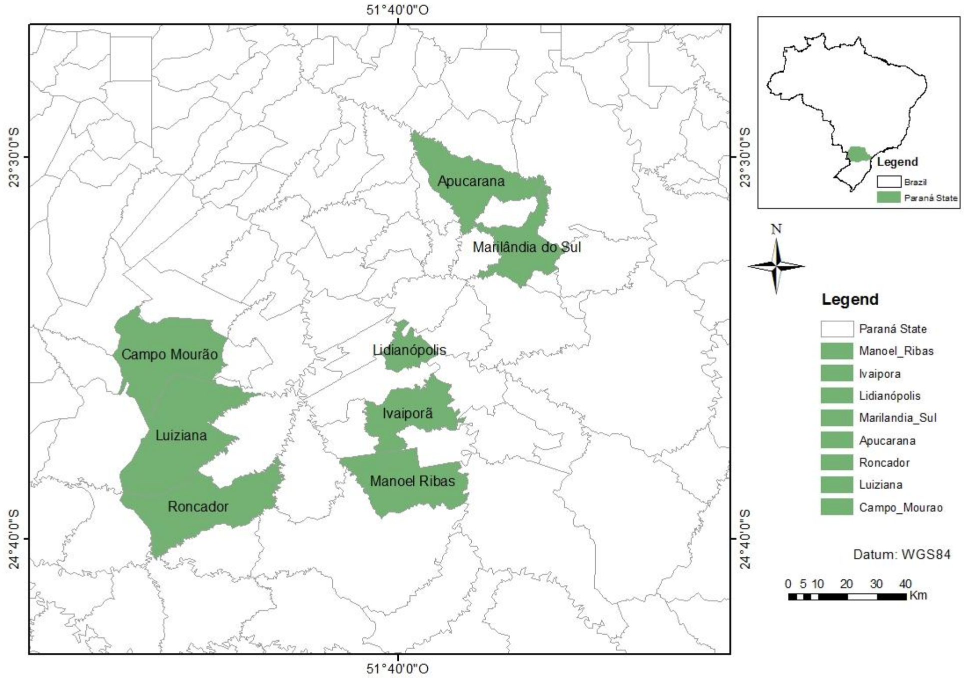

Figure 2 - Location of the study area. Source. Silva-Fuzzo, D.F.

The counties selected were based on data from the SEAB (Department of Agriculture and Supply of State of Paraná). As such, eight counties that showed high levels of average productivity (kg ha^{-1}) in the 10 years analyzed were selected, namely the agricultural years from 2002/2003 to 2011/2012, totaling a period of 10 years, with soybean.

To estimate relevant parameters using the triangle method, images from sensor MODIS, products MOD13A2 and MOD11A2, tile h13v11, were used. These products are the compositions of images of 16 days of Vegetation Index NDVI and images of 8 days with surface temperature Ts, respectively, with spatial resolution of one kilometer. These images can be obtained from the NASA <https://wist.echo.nasa.gov/api/> site, being originally in sinusoidal projection and in HDF format (Hierachical Data Format). These were processed at first by MRTool tool (Modis Reprojection Tool <https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool) and were redesigned to WGS-84 projection and GeoTIFF format.

In all, 14 NDVI images and 14 Ts images were composed from 16 and 8 days, respectively. These were therefore selected for the same dates of satellite for the passage of the two quantities, Ts and NDVI, i.e., the date of the NDVI image is the same image data for Ts (scenes 257, 273, 289, 305, 321, 337 353, 001, 017 033 049 065 081 and 097, representing respectively the dates, 09/14 09/30 10/16 11/01 11/17 12/03 12/19 01/01 01/17 02/02 02/18 03/06 03/22. Were selected the 14 images of each composition comprising the agricultural period of soybean growth (September to April) totaling 28 images for each year. Mathematical operations were made by changing the digital values of the image pixels, the MOD11A2 products are for 16-bit images, and are converted primarily expressed in Kelvin temperature, and then for values in degrees Celsius (°C) through the following equations 1 and 2.

$$T(K) = MOD11A2\ X\ 0{,}002 \quad (1)$$

$$T(°C) = TK - 273{,}1 \quad (2)$$

The MO13A2 products,=16-bit images**,** were converted to and scale of -1 to 1 by dividing 10,000 by the image, according to equation 3. These procedures were performed using IDL .

$$NDVI = MOD13A2/10.000 \quad (3)$$

With the NDVI values converted from the digital product and the raw temperatures converted to degrees Celsius, calculations of the important boundary parameters, NDVIs, NDVIo, NDVImax, and NDVImin, were performed from the NDVI images, where NDVIs and NDVIo are, respectively, the highest values represent 100% coverage of vegetation and the lowest values represent by bare soil. Similarly, the extraction of Tmax values are obtained, for the warmest pixels with bare soil or urban area while Tmin represents the lowest temperatures appropriate to areas with well watered dense vegetation as, proposed by Carlson, 2007. Subsequent scatterplots are shown with axes representing scaled quantities, T* and fractional vegetation cover, Fr, where T* is defined as equation 4 :

$$T* = \{\frac{Ts - Tsmin}{Tsmax - Tsmin}\} \quad (4)$$

Ts, as defined above, is surface radiant temperature, Tsmin is the value of Ts for wet bare soil or dense well watered vegetation, and Tsmax is the corresponding value of Ts for dry, bare soil characteristic of an urban center, for example. Fractional vegetation cover is obtained from NDVI through the equation 5 (Carlson, 2007).

$$Fr = \{\frac{NDVI - NDVIo}{NDVIs - NDVIo}\}^2 \quad (5)$$

Here, NDVIo is the NDVI value corresponding to bare soil; and NDVIs is the value corresponding to the maximum coverage of vegetation (bare soil) (Gillies and Carlson, 1995). According to Carlson, some of these methods discussed in the literature are unnecessary since the triangle method can be evaluated without the use of complex models but perhaps with equal accuracy from simple, purely geometric formulae based on physical arguments. This simplification uses the configuration of the pixel envelope in T*/Fr space, specifically the boundaries of the envelope, to constrain the solutions. In so doing, the method's power is that it does not require any external data for the atmosphere or the surface. The key parameters that define these boundaries are Tsmax, Tsmin, NDVIs and NDVIo and the two key features are the warm (dry) and cold (wet) edges, shown in Figure 1. Thus, the method of the triangle, determined from its simple geometric form, yields the availability of surface soil moisture (Mo) and the evapotranspiration (ET) expressed as a fraction of the net radiation (Rn), referred to as the evapotranspiration fraction (EF), as exemplified in Carlson (2013). Equations 6 and 7 define these terms as follows:

$$MO = 1 - \frac{T*(pixel)}{T*warmedge} \quad (6)$$

$$Ftotal = EFsoil*(1 - Fr) + Fr(pixel) \quad (7)$$

where, EF_{veg} is the value appropriate for vegetation alone, the potential evapotranspiration (assumed to be equal to 1.0), and T* is the scaled surface radiant temperature evaluated along the warm edge. Thus. EF_{soil} = Mo and EF_{veg} = 1

These formula are based on the assumption that the soil surface evaporation and surface soil moisture availability (Mo) are at maximum (the potential (Mo =1) along the cold edge of the pixel envelope and are zero (Mo = 0) along the warm edge. The transpiration from just the plants is assumed to be always at potential, unless the leaves are wilting. Transpiration and evaporation are blended together depending on the fractional vegetation cover to yield the total evapotranspiration expressed as EF.

The original agrometeorological model comes from the multiplicative model based on Doorenbos and Kassam (1979), as proposed by Rao et al. (1988). This model (Equation 8) considers the product of the ratio, ETr / ETp, reducing production as the water requirement of soybean ceases to be met during the phenological stages considered, in order that:

$$\frac{Ya}{Yp} = \prod_{i=1}^{4}[1 - Ky_i\left(1 - \frac{ETr}{ETp}\right)i \quad (8)$$

Where, Ya is the estimated yield (kg ha^{-1}); Yp, the potential yield (kg ha^{-1}); ETr, the actual evapotranspiration (mm); ETp, the potential evapotranspiration (mm); and kyi is the coefficient of penalization productivity due to water deficiency for each developmental stage. Phenological stage (ky) are, Vegetative Development = 0.2, Flowering = 0.4, Grain Filling = 0.8, Maturation = 0.2. It can be seen that ETr / ETp, being a relative evapotranspiration, is very similar to the evapotranspiration fraction EF, which is estimated by the triangle method. Typically, in agrometeorological modeling, the ETr and ETp values are obtained with the calculation of climatic water balance, with data obtained from conventional meteorological stations. Here, were test the use of EF in place of this ratio by replacing the ETr/ETp values in the agrometeorological model with EF.

Thus, the ETr / ETp were replaced by the value of EF, estimated by the simplified triangle method, consequently the model was modified according to Eq.9. Where, EF is fractional evapotranspiration.

$$\frac{Ya}{Yp} = \prod_{i=1}^{4}[1 - Ky_i\ (1 - EF)i \quad (9)$$

The Water Balance aims to calculate the water storage in the soil taking into account both the type of vegetation and its stage of growth and development, allowing one to monitor the water storage of the soil by means of the principle of conservation of mass in a volume of vegetated soil (Pereira et al., 2002). The estimated water balance is based on the method of Thornthwaite and Mather (1955), in decendial scale, which provides estimates of actual evapotranspiration (ETR), the water storage in the soil (ARM), the water deficit (DEF) and water surplus (EXC).

Subsequently, the estimated values of rainfall from the TRMM satellite (Tropical Rainfall Measuring Mission) were also obtained, as well as the average air temperature from the Global Atmospheric Model ECMWF (European Centre for Medium-Range Weather Forecasts), because this large data set allows for increased coverage of the county, for the years from 2002/03 to 2010/11 were obtained for Campo Mourão and Apucarana city for data comparison. The TRMM data are available for free online access through the NASA website: <http://trmm.gsfc.nasa.gov/data_dir/data.html>. The data comes in xls format, geographic coordinates, and temperature data obtained from ECMWF air. Images are available free of charge in raster format (tif geo) in the JRC site, http: //mars.jrc.ec.europa .eu / mars / Aboutus / FOODSEC / Data-Distribution.

The obtaining agro-meteorological data can be made by networks of meteorological stations which record atmospheric data. However, given the size of the country, there is not a network of stations with sufficient coverage to meet this need, especially at the local level. Thus it is necessary to use data estimated by meteorological satellites such as TRMM for precipitation and ECMWF to the air temperature.

Sowing dates were obtained according to Johann (2012), who estimated date of planting soybeans for the State of Paraná, considering the type of farming, the best conditions of water service in the phenological phases, and showing the regions with higher or lower weather risk for the development of this vegetation.

To evaluate the reliability of the data estimated by agrometeorological model, first the multitemporal compositions were made in RGB images of NDVI, to highlight only a summer crop and extract the pixels of an urban area. Thus, the period with the highest vigor were placed on the R channel, then the images with less vigor in G and B channels. This procedure was operationalized by 4.5 ENVI (The Environment for Visualizing Images), and the composition of these scenes were the image 001 (refers to January, 1st), image 285 (refers to October, 16th), image 305 (refers to November, 1st), the year 2010/11 were used.

And with the aim to separate the pixels for summer crops from other crops, a procedure was developed in IDL (Interactive Data Language) the extraction system data / pixel of RGB composite image in grayscale, i.e. through that system were chosen the gray values between 0 and 255, in which for the R channel were considered the largest gray level values and G and B channel values lower levels of gray. Thus, the pixels are extracted (removed) at lower gray values, creating the mask for the summer crop. These were taken as the basis for comparison of LANDSAT 5/ TM images mosaics as ground reference.

In the making of masks, were separated areas with summer crops (soybeans and corn) from the other cover crops. Among the various simulations of cuts of gray levels, for channels of RGB color composition, it was found that the one with the best masking properties was obtained with R-180 and GB -110 for crop years, i.e., were selected pixels with gray levels > 180 in R and gray levels < 110 in GB channels . So, did not include urban areas on the agro-meteorological model estimated harvest. Later, the average was calculated from the pixels obtained by vegetation mask for each of the 8 counties, (pixels estimated by agrometeorological model with productivity values). This was necessary because the productivity values observed in the field, corresponds a total value for the entire county area.

To investigate the method, the values estimated by the modified agrometeorological model were compared using data from fractional evapotranspiration (EF), with the conventional model using the values of relative evapotranspiration (the radio of actual evapotranspiration to potential evapotranspiration (ETr/ETp) obtained by the climatological water balance of Thornthwaite and Mather (1955) for estimated data TRMM and ECMWF. In order to the satellite image data be compatible with the crop measurements, satellite estimates of EF for individual pixels were averaged over each county.

Statistical analyzes were performed to verify the correctness and accuracy of the data, using a simple linear regression model and its coefficient of determination (R^2), which shows the ratio or percentage of variance in one variable that can be explained variance from the other. It is noteworthy that the accuracy refers to the degree of conformity of an estimated quantity to the true (measured directly in the field) value. The precision is the degree of variation in the results of a measurement and is based on the standard deviation of a number of repetitive values generated from the same analysis. The MAE (mean absolute error) may be most appropriate for checking the correctness or accuracy of estimated scalar data (e) in relation to the (measured) data (o) (Eq.10). The RMSE (root square error) is used to estimate the quality of the classifier, as in Eq. 11.

$$MAE = N^{-1} \sum_{I=1}^{N} | O_I - e_i | \quad (10)$$

$$RMSE = \sqrt{(\frac{1}{n} x \sum_{i=1}^{N} (Yobs - Yest)^2} \quad (11)$$

To verify the final quality of the estimator model, as described by Willmott et al. (1985) propose an adaptation called index Willmott modified, expressed in Eq.12, given by:

$$d_1 = 1 - \left[\sum (e_i - o_i)^2 / (|e_i - o| + |o_i - o|)\right] \quad (12)$$

where d_1 is the concordance index and the subscripts are defined as in Eq. 10.

The confidence index "c" indicates the model performance according to Sentelhas and Camargo (1997) through the index of precision and accuracy, expressed by the Eq. 13.

$$C = R^2 * d \quad (13)$$

This criterion was also applied to the data set, the Mann-Whitney (1947). A criterion of 5% or less is used, in order to ascertain whether there was any significant difference between the mean and the distribution of the measured crop productivity data and those derived from the simplified triangle method. In addition, the average systematic error (Es) and the (non-systematic) random mean error (Ea) were calculated.

3. RESULTS AND DISCUSSION

Estimates of EF and Mo, using the simplified triangle method, were obtained from the images T * and Fr, in the form of the approximately triangular-shaped scatterplots for the eight counties of the state of Paraná, for 10 years of crop data (2002/03 to 2011/12). As an example, the counties of Campo Mourão and the agricultural year 2011 -12, show a scattering of pixels for each satellite image, representing the entire phenological cycle of soybean. In Figure 3 were observe the dispersion of pixels in their typical triangular configuration the dashed red line indicating the warm (dry) edge of the triangle, and the dotted line in blue the cold (wet) edge. Hot and cold ends, respectively, correspond to the driest and wettest pixels for a given value of Fr (Jiang et al, 2001; Petropoulos et al, 2009; Garcia et al, 2014).

These scatterplots can be interpreted in the context of Eqs 6 and 7 as follows: Each pixel within these triangles represents a different value of surface soil water content (Mo) and evapotranspiration fraction (EF). The former varies linearly (along any straight line at constant Fr) from zero (dry) at the warm edge (the sloping red line) to 1.0 (wet) at the cold edge (the vertical blue line). EF varies linearly from zero at the lower right hand vertex to 1.0 along the cold edge. Fractional vegetation cover varies linearly from zero at the base of the triangle to 1.0 at the upper vertex.

In Figure 3, the pixels tend to form a more dense grouping on top of the scatter plot in the months of higher vegetative peak of soybeans, whereas in the months of vegetative growth more pixels are dispersed within the triangular shape, as would be expected according to the physiological cycle for soybeans. It is also very important to analyze the upper vertex of the triangle, because this is relevant to the distribution of the pixel envelope, the greater the number or pixels accumulated at the top of the triangle, the higher the concentration of vegetation for that image, ie, during the time representing the greatest crop development.

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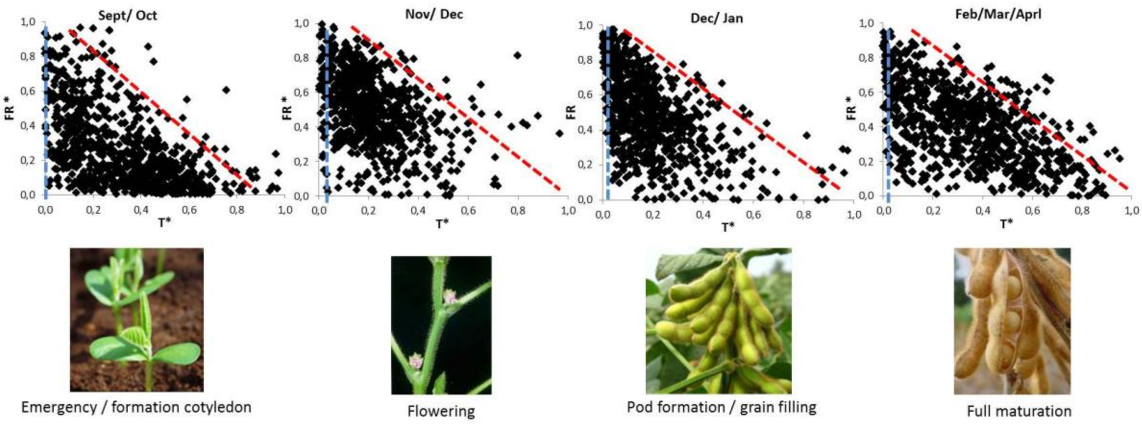

Figure 3 - Schematic representation of triangle method and phenological cycle of the soybean crop. Source. Silva-Fuzzo, D.F.

According to Carlson (2013), the sloping warm side of the triangle (the warm edge) indicates higher bare soil temperature than in areas of higher vegetation, because the soil is more shielded from the sun by the vegetation. Were note with triangular graphs that the warm edge has many more pixels near the lower part of the warm edge (signifying more dry, canopy visible to the radiometer), for the months with the greatest amount of exposed soil, i.e. the months of sowing (Sept / Oct) and months regarding the harvesting season (Mar / Apr).

It is worth pointing out that some sensitivity to T* does exist near the upper vertex in some of the triangles, indicating the soil is not always invisible to the satellite sensor under the dense vegetation. When there is not a group of pixels at the top of the triangular space, this may indicate that there are few patches of dense vegetation within the triangle space, (Fr) less than 1.0. Although the temperature of the leaves themselves is assumed not to vary significantly, the temperature of the vegetation canopy (soil plus crop) varies with soil moisture, so that months with less vegetation have a greater exposure to bare soil. Recall, that the basic assumption in the triangle method is that the temperature of the leaves does not vary in space unless the crop is experiencing significant water stress.

Then were tested the agrometeorological model of Doorenbos and Kassam (1979), which includes EF values obtained from the simplified triangle method. Agricultural productivity of the soybean crop was evaluated by considering the estimated values of EF using the simplified triangle method, and substituting these for the values of ETr/ETp (ratio between actual evapotranspiration/potential evapotranspiration) previously used in the original model, whose input was based on surface, rainfall and climate data as described earlier in this paper). The model performance was evaluated by means of statistical analyzes presented below, the index " d_1" and " d_2" Willmott, coefficient of determination Rsquared, index "c", and MAE, RMSE, Ea and Es errors, and the Mann-Whitiney (1947) test (Table 1).

Table 1 express the differences between measured and estimated yield is expressed as a percentage 100 (b-a)/a, $d_{1,}$ are the concordance indices, which indicates the model performance, R^2 is the coefficient of determination, (the correlation coefficient). The parameter “c” is a confidence index; it is a measure of the model performance. MAE is the mean absolute error, RMSE is the root squared error, Ea is the systematic error, Es is the non-systematic error, and the p-value is an assessment of the significance significant difference between the mean values of the estimated data and the mean values of the measured data. Error here is defined as the difference between estimated and measured crop productivity.

Table 1 - Statistical Analysis performance of the agro-meteorological model (Eq. 9) modified for simplified triangle method, from 2002/03 to 2011/12 in kg ha^{-1}, and data measured by SEAB. Note which "Obs" means observed productivity and "Est" estimated productivity.

	Apucarana			Campo Mourão			Luiziana			Roncador		
Anos	Obs	Est	Diff %	Obs	Est	Diff %	Obs	Est	Diff %	Obs	Est	Diff %
2002/03	2700	2793	-3,3	3000	3060	-2,0	3300	2921	13,0	3200	3059	4,6
2003/04	3000	2985	0,5	3160	2975	6,2	2750	3034	-9,4	3100	3076	0,8
2004/05	3300	3256	1,4	2750	2658	3,5	2355	2606	-9,6	2100	1710	22,8
2005/06	2660	2980	-10,7	2280	2242	1,7	2700	2856	-5,5	2850	2755	3,4
2006/07	2700	2600	3,8	2727	2689	1,4	2851	3108	-8,3	3200	3156	1,4
2007/08	3200	3156	1,4	3180	3000	6,0	2988	3044	-1,8	2500	2365	5,7
2008/09	3060	3032	0,9	3000	2986	0,5	2580	2800	-7,9	2900	2468	17,5
2009/10	2800	2685	4,3	2500	2457	1,8	3322	2986	11,3	3200	3059	4,6
2010/11	2900	2859	1,4	3300	3256	1,4	3200	3103	3,1	3480	3325	4,7
2011/12	2800	2512	11,5	3173	3080	3,0	2726	2645	3,1	3071	2089	47,0
d_1		0,87			0,98			0,73			0,82	
R²		0,60			0,95			0,42			0,71	
c		0,53			0,93			0,30			0,58	
MAE		108,80			78,70			211,70			253,90	
RMSE		47,30			30,81			66,47			116,88	
Ea		45,41			26,22			64,43			115,00	
Es		13,22			16,17			16,34			20,90	
p-valor		0,85			0,43			0,16			0,19	

	Marilândia			Lidianópolis			Ivaipora			Manoel Ribas		
Anos	Obs	Est	Diff %	Obs	Est	Diff %	Obs	Est	Diff %	Obs	Est	Diff %
2002/03	3120	2963	5,3	3250	3015	7,8	3200	2986	7,2	3200	3156	1,4
2003/04	3360	3059	9,8	3000	2910	3,1	3000	3097	-3,1	3100	3160	-1,9
2004/05	2780	3159	-12,0	2600	2441	6,5	2650	2689	-1,5	2650	2693	-1,6
2005/06	2800	2823	-0,8	2650	2701	-1,9	2700	2612	3,4	2650	2569	3,2
2006/07	3300	2900	13,8	3000	2986	0,5	3000	2955	1,5	3000	2928	2,5
2007/08	3200	2985	7,2	3223	3156	2,1	2950	2900	1,7	3250	3103	4,7
2008/09	2800	3058	-8,4	2900	2674	8,5	3400	3206	6,1	3000	3055	-1,8
2009/10	2900	2598	11,6	3100	2980	4,0	3100	3327	-6,8	3200	3106	3,0
2010/11	3600	3200	12,5	3350	3156	6,1	3400	3063	11,0	3435	3215	6,8
2011/12	2479	2100	18,0	2231	2430	-8,2	3300	3176	3,9	2987	2569	16,3
d_1		0,74			0,93			0,89			0,89	
R²		0,42			0,87			0,62			0,69	
c		0,31			0,81			0,55			0,62	
MAE		281,40			135,50			141,50			123,40	
RMSE		87,14			39,88			47,68			48,05	
Ea		84,60			36,17			44,03			44,31	
Es		20,90			16,80			18,29			18,59	
p-valor		0,52			0,63			0,47			0,52	

*Significant at 5% for the p-values.

By analyzing the coefficients of confidence "c", the values ranged from 0.9 (c>0.85) for some counties as Campo Mourão. Apucarana and Ivaiporã showed low values of this index 0.53 and 0.55, respectively, indicating the poor performance of these models, for these counties. Analyzing the MAE it was found that the values were underestimated by 78.70 kg ha^{-1} in Campo Mourão, and 281.40 kg ha^{-1}in Marilândia. The RMSE showed that on average there was variation between 30.81 kg ha^{-1} to 116.88 kg ha^{-1}. The R^2 values ranged from 0.42 in Marilândia and Luiziana to 0.95 in Campo Mourão. There was no statistically significant difference ($p > 0.05$) between the estimated and measured data, meaning the averages of the data estimated by the modified model were statistically equal to the averages of the measured data by the SEAB.

Ren et al. (2008) have generated regional spectral models for estimating yield of winter wheat based on MODIS NDVI profiles for 11 counties in China from 2002 to 2004, noting that the linear relationship between NDVI and productivity values was significant, with R^2 values being 0.66 to 0.88., These data were compared with official field data, showing good accuracy of the estimated data. Random errors were higher than those of systematic errors, indicating that the exactness of the measurements was better than the accuracy.

Johann (2012) tested a spectral agrometeorological model based on MODIS EVI for the state of Paraná - Brazil, from 2004/05 to 2007/08 seasons. Altogether 317 counties were analyzed, using two statistical methods, "stepwise" and "best subset", showing correlations ranging from 0.57 to 0.85 and R^2 set values ranged between 33.31 and 66.90% for the same data set. The reliability values "d" shown that the values estimate straight lines approximating 1:1, showing the absence of systematic error in the estimates.

The agro-meteorological model developed by Doorembos and Kassam (1979) which considers the ETr / ETp also has been tested. In order to evaluate and compare the performance of the agrometeorological model based in simplified triangle method (that used the EF). For this comparison of the models, were used two approached, the first with point data, the surface meteorological stations (data from SIMEPAR), and the second with the data from the TRMM and ECMWF, with spatial resolution of 0.25° x 0 25° (about 25 km), through the climatic water balance of Tohrntwaite and Mather (1945).

Table 2 present statistics for the 3 counties with TRMM and ECMWF, both employing the d_2, d_1, R^2, c, MAE, RMSE, Ea, Es data analysis, and Mann-Whitney (1947), in the same way that the agrometeorological model based in simplified triangle method was evaluated.

Table 2 - Statistical Analysis performance of the with TRMM and ECMWF, both employing the d_2, d_1, R^2, c, MAE, RMSE, Ea, Es data analysis, and Mann-Whitney (1947), in the same way that the agrometeorological model based in simplified triangle method was evaluated. Note which "Obs" means observed productivity and "Est" estimated productivity.

	Apucarana			Campo Mourão			Lidianópolis		
Anos	Obs	Est	Diff %	Obs	Est	Diff %	Obs	Est	Diff %
200203	2700	2985	-9,5	3000	3104	-3,4	3250	3408	-4,6
200304	3000	3156	-4,9	3160	2985	5,9	3000	3256	-7,9
200405	3300	3256	1,4	2750	2689	2,3	2600	2864	-9,2
200506	2660	2630	1,1	2280	2189	4,2	2650	2540	4,3
200607	2700	2956	-8,7	2727	3100	-12,0	3000	2869	4,6
200708	3200	3058	4,6	3180	3256	-2,3	3223	3182	1,3
200809	3060	3121	-2,0	3000	2985	0,5	2900	2828	2,5
200910	2800	2900	-3,4	2500	2863	-12,7	3100	3552	-12,7
201011	2900	3059	-5,2	3300	3257	1,3	3350	3521	-4,9
201112	2800	2900	-3,4	3173	3106	2,2	2231	2569	-13,2
d1		0,83			0,91			0,88	
R²		0,63			0,70			0,71	
c		0,53			0,63			0,62	
MAE		133,30			136,80			199,30	
RMSE		47,50			74,48			76,42	
Ea		31,47			57,29			69,40	
Es		35,57			47,58			32,01	
p-valor		0,38			1,00			0,27	

*Significant at 5% for the p-values.

According to Fuzzo-Silva et. al (2015) the use of rainfall data estimated by the TRMM satellite, can be a tool in the absence of climatological information surface, and serve as input to support in agrometeorological modeling, agricultural monitoring, research assistance and the farmer, because it free data and easy access. Statistical performance of the agrometeorological model by Doorembos e Kassan (1979), based on TRMM and ECMWF data (25 km) for the years 2002/03 to 2011/12.

Comparing the tests (Table 1 on the modified model with EF method triangle, Table 2, and agro-meteorological Doorembos Kassan with TRMM and ECMWF data), were can say for Apucarana counties, Campo Mourao, that are repeated in the analyzes showed similar statistical performance. Regarding the concordance index "d_1", which measures the dispersion of data and accuracy, were can say that it showed better agreement (values 0,7 - 0.9) using EF obtained from the simplified triangle method (in agrometeorological model) than for the other two tests. The city of Lidianópolis showed better results with the modified model in relation to the TRMM and ECMWF data.

4. CONCLUSIONS

The variable fractional evapotranspiration (EF), developed with a simplified method for treating remote sensing measurements of vegetation index and radiometric surface temperature (referred to here as the simplified triangle method), can be used in replacement of relative evapotranspiration (ETr/ETp), obtained from the method of climatic water balance, often used in agrometeorological models to estimate agricultural productivity.

The agrometeorological model for the estimation of agricultural productivity of soybean showed better performance when (EF) is used in place of the ratio of actual evapotranspiration and potential evapotranspiration (ETr/ETp).

Thus the use of remotely sensed variables such as NDVI and surface radiant temperature, as obtained, for example from MODIS, can be used as reliable tool to calibrate agrometeorological models, such as for predicting soybean yield estimates. This type of data source is especially useful in the absence of ancillary data or surface information for monitoring and forecasting of agricultural crop yields.

The objective of this work was reached because positive results were obtained when the agrometeorological soybean estimation model proposed by Doorenbos and Kassam (1979) was tested, using only spectral data as input variable, using the simplified triangle method

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