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Use of Climate Forecasts to Soybean Yield Estimates

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1. Introduction

The soybean is an annual legum that have many industrial, human, and agricultural uses. United States are the main producing and exporters of soybean grain, ranking as the first highest agricultural commodity of this specific agricultural cultural (FAO, 2008). Considering the total production of soybeans by the 20 highest producing countries in 2008 was 35% from US, 26% from Brazil and 20% from Argentine, having equivalent agricultural commodities values.

Some studies in agronomic experimental stations suggest that this culture was initially introduced in Bahia State, northeastern of Brazil, 1882. However, only after the 40's in southern of Brazil, the soybean crop became commercial in the country. Nowadays, this culture is considered the most important agricultural commodity in Brazil, and one of its main export products (Esquerdo, 2001).

The production of soybean has a great importance for the economy of Brazil. Historical data of soybean harvest for Brazil (IBGE, 2008) show a high correlation between soybean production economic value and productivity of this culture (Cardoso et al., 2010). According to IBGE, the Brazilian production in 2007 was 58 million tons, with Mato Grosso, Paraná and Rio Grande do Sul States adding higher crop production.

Soybean cultivars can be classified according to the duration of your cycle, being early (75 to 115 days), semi-early (116 to 125 days), medium (126 to 137 days), late medium (138 to 150 days) and late (over 150 days), according to Farias et al. (2000).

According to Camargo (1994), the climate is the main factor responsible by annual fluctuations in grain production in Brazil. The occurrence of drought is the main cause of harms (71% of cases), followed by excessive rainfall (22% of cases), hail, frost, pests and diseases (Göpfert et al., 1993).

The observations of weather conditions applied to the crop forecast models are useful to provide the most accurate crop simulations, and the importance of solar radiation, precipitation and air temperature variables is stood out (Hoogenboom, 2000).

Research has been conducted with the goal of exploring the climate patterns to improve the yield of this crop agriculture. The soybean production can be significantly affected by water

conditions, according to the intensity of water deficit (Thomas & Costa, 1994; Confalone & Dujmovich, 1999). The water necessity of the soybean crop will increase with plant development, reaching a maximum during the flowering and grain filling phases, decreasing after this period (EMBRAPA, 2004). Significant water deficits during flowering and grain filling, causing physiological changes in the plant, such as stomatal closure and winding sheets, consequently cause premature leaf drop and flower and pod abortion, resulting in decrement grain yield. Thus, precipitation over the planted area is an important determiner of crop yield, considering the high cost of effective irrigation being.

Studies developed by IPEA (Institute of Applied Economic Research) in 1992 indicated that 95% of Brazilian agricultural losses were due to events of drought or heavy rain. Based on these data, was established, in 1996, the zoning program in Brazil for climate risks, being the public policy currently adopted by Brazilian Ministry of Agriculture of Agrarian Development to direct credit and agricultural insurance in the country. The zoning established, statistically, the risk levels of the regions studied for various types of culture, assuming crop losses of up to 20%. This indirectly increased agricultural productivity. The agroclimatic zoning of risks is a tool that indicates what to plant, where to plant and when to plant according to the climatic region (Assad et al., 2008).

According to Farias et al. (1997), in modern agriculture, increases in income and reductions in costs and risks of failure ever more dependent of judicious use of resources. In this case, the farmer must make decisions based on available production factors and involved risk levels involving your activity, looking for in order to reach greater prosperity. Among the risk factors can be considered as the main the market uncertainties and the unpredictable climate conditions.

A way that can minimize the effects of drought is to plant only varieties adapted to the region, in appropriate period and soil condition. Farias et al. (2001) delimited areas with fewer risks for the soybean crop in Brazil, based on: sowing dates; water availability in each region; water consumption in the different stages of development of the soybean crop; soil type; and cultivar cycle. Results are presented in a map that represents the drought risk classification of different areas of the state for a given sowing date, as a function of the soil type and cultivar cycle.

Assad et al. (2007) evaluated the performance of soybean yield forecast system for Brazil that is based on the conceptual model proposed by Doorenbos & Kassam (1979), including some empirical adjustments for each Brazilian region. Statistical analysis was performed to evaluate the estimated soybean yield for harvests from 2000/2001 to 2005/2006. According to the results of correlation were not significant differences between the estimates and official data. Additionally it was observed that such system has a good performance in the soybean yield forecast in the Brazilian States of Mato Grosso, Paraná, São Paulo, Minas Gerais, Tocantins and Goiás, and a low performance in the soybean yield forecast in the Brazilian States of Rio Grande do Sul, Santa Catarina, Mato Grosso do Sul, Maranhão, Piauí and Bahia.

There are evidences that the accuracy of yield forecast models increases when the meteorological forecast information is used (Challinor et al., 2003; Cantelaube & Terres, 2005). Reliable meteorological forecasts having considerable lag may contribute to anticipate the productivity estimates and give good estimates of crop yield losses. Using the ensemble forecast – where the initial condition (IC) uncertainties are explored by making a certain number of IC disturbed forecasts – had a positive impact on increasing the predictability (Gneiting & Raftery, 2005; Sivillo et al., 1997). Mendonça & Bonatti (2004) compared the

performance of ensemble weather forecasts from the Center for Weather and Climate Prediction of National Institute for Space Research (CPTEC/INPE) for the period from October 2001 to September 2003 and found out that the average ensemble performance is higher than that of the control forecast.

Analyses of soybean yield estimate models, showing that water is the factor that has greater influence on soybean grain yield could be incorporated into programs forecasting the crop harvest (Fontana et al., 2001).

Recent studies of Cardoso et al. (2010) show that the use of accurate meteorological forecasts can be useful to improve the productivity prediction and consequently contribute to agricultural planning. According to the results the use of up to 15 day meteorological forecasts lead to more reliable crop productivity estimates than those generated using only climatological information. The combination of precipitation forecasts by the CPTEC ensemble system combined with climatology date after the end of the forecast cycle already show significant improvement of the final productivity forecast compared to estimates solely based on past observed data and climatology. Highlighting the importance to turn meteorological forecasts available for periods as longer as possible in real time, primarily in periods when the crop is more sensitive to water deficit.

1.1 The interannual variability

El Niño–Southern Oscillation (ENSO) is a phenomenon of the coupled atmospheric–ocean that forms the link with the anomalous global climate patterns, being a dominant source of interannual climate variability. The atmospheric component tied to El Niño is termed the Southern Oscillation. El Niño corresponds to the warm phase of ENSO, consisting of a basinwide warming of the tropical Pacific. The term La Niña is applied to the cold phase of ENSO, associated with a cooling of the tropical Pacific (Trenberth, 1997).

The La Niña and El Niño phenomenons influence the precipitation over some regions of the South America such as Northeast Brazil, eastern Amazônia, Southern Brazil, Uruguay and NE Argentina (Ropelewski & Halpert, 1987, 1989). Studies have suggested that sea surface temperature (SST) positive anomalies in the equatorial Pacific, related El Niño events, favours to increase of precipitation in the South of Brazil (Grimm et al.,1998; Coelho et al., 2002) and decrease of precipitation in the Brazilian Northeast (Rao & Hada, 1990; Moura & Shukla, 1981). There is a general behavior towards opposite signals in the precipitation anomalies over southern South America during almost the same periods of the El Niño and La Niña cycles, indicating a large degree of linearity in the precipitation response to these events.

Peak rainfall in central-east Brazil during part of spring holds a significant inverse correlation with rainfall in peak summer monsoon, especially during ENSO years (Grimm et al., 2007). As shown by the latter paper, a surface–atmosphere feedback hypothesis is proposed to explain this relationship: low spring precipitation leads to low spring soil moisture and high late spring surface temperature; this induces a topographically enhanced low-level anomalous convergence and cyclonic circulation over southeast Brazil that enhances the moisture flux from northern and central South America into central-east Brazil, setting up favorable conditions for excess rainfall. Antecedent wet conditions in spring lead to opposite anomalies.

Marques et al. (2005) observed that part of the variability of rainfall and air temperature in the state of Rio Grande do Sul (southern Brazil) is associated with the variability of Sea Surface Temperature (SST) in the Pacific and Atlantic oceans. This knowledge is of great relevance, given the importance of these elements on vegetation growth. Also was verified

the existence of the association between SST in the Pacific and Atlantic oceans and NDVI (Normalized Difference Vegetation Index) in the Rio Grande do Sul State, which is dependent on season and region of the state. NDVI is correlated to SST of the Pacific Ocean during the summer, while for the winter period the SST of the Atlantic Ocean shows greater correlation.

Berlato & Cordeiro (2005) studied the variability of soybean yield in Rio Grande do Sul State, southern Brazil, noting that the variability in yields coincides with higher rainfall variability. They observed that the increasing trend of yields between 1990 and 2000 years coincides with the increasing trend of rainfall from October to March, caused by the merger of El Niño events that cause positive anomalies of precipitation in spring and early summer, in Rio Grande do Sul State. The risk of El Niño be prejudicial to non-irrigated summer crops is restricted to "rebound" phenomenon in the fall of the second year of the event, especially if the months of April and May are wet anomalous can harmful the final maturation and harvest, as was the case of the large El Niño of 1982/1983.

This increasing trend of soybean yields is also present in the productivity historical data of Brazil (Figure 1). When compared the productivity historical data of the productivity with El Niño and La Niña events occurrences the relationship is unclear, except for the El Niño episodes of 1988, 1992, 2003 and 2007 that indicate a positive relation. This can see by Figure 1 that presents the Oceanic Nino Index (ONI), based 3 month running mean of sea surface temperature anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W) to quarterly november-december-january (NDJ). Several studies discuss the impact of El Niño and La Niña phenomena on rainfall patterns in some regions of Brazil, however it is observed that the response on soybean yield in years of these events is not linear, probably due the distribution of rain throughout the development of the crop, that varies in different events.

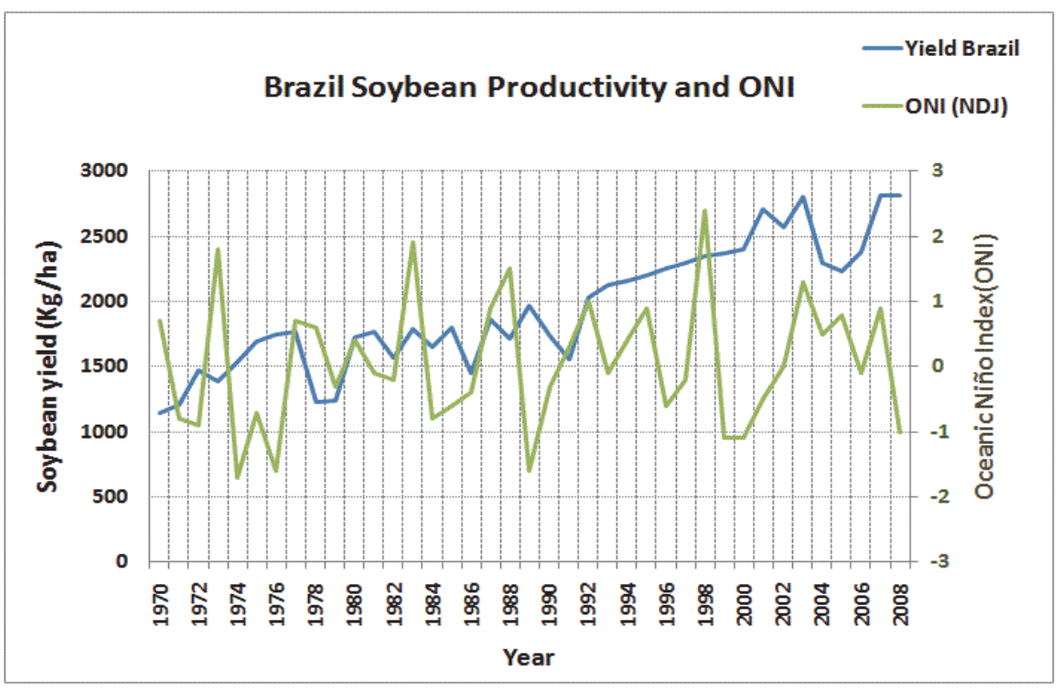

Fig. 1. Data yearly productivity (kg/ha) for Brazil for the period 1970 to 2008 (Source: IBGE) and data quarterly (november-december-january) Oceanic Niño Index (Source: NOAA).

1.2 Climate forecasts for estimative of soybean productivity

The climatic condition in the critical phases of the plant vegetative development influences the crop productivity, thus being a basic parameter for crop forecast. It is important to evaluate the possibility to use of climate forecasts in estimating the productivity given that rainfall patterns on Brazil are influenced by climate variability, as in other areas of the globe.

The Center for Weather and Climate Prediction of the National Institute for Space Research (CPTEC/INPE) develops, produces and disseminates weather forecasts as well as seasonal climate forecasts since early 1995. This Center is part of the research network of the Ministry of Science and Technology of Brazil. The model used for seasonal climate predictions is the COLA-CPTEC Atmospheric Global Circulation Model (AGCM) which was originally derived from the National Center for Environmental Prediction (NCEP) model by COLA. The same model is used at CPTEC for medium-range.

This model is able to simulate the main features of the global climate, and the results are consistent with analyses of other AGCMs. The seasonal cycle is reproduced well in all analyzed variables, and systematic errors occur at the same regions in different seasons. The Southern Hemisphere convergence zones are simulated reasonably well, although the model overestimates precipitation in the southern portions and underestimates it in the northern portions of these systems. The high and low level main circulation features such as the subtropical highs, subtropical jet streams, and storm tracks are depicted well by the model, albeit with different intensities from the reanalysis (Cavalcanti et al., 2002).

The CPTEC-COLA AGCM simulates the broad aspects of the observed El Nino Southern Oscillation (ENSO) variations reasonably well, as may be expected since these variations are primarily driven by prescribed SST. Some regions, such as Northeast Brazil, Amazonia, southern Brazil-Uruguay exhibit better predictability due to the large skill of the AGCM in reproducing interannual variability of climate in those regions (Marengo et al., 2000).

Occurs monthly at CPTEC a forum to develop a consensus seasonal forecast. The participants were climate experts and operational forecasters, who reached a consensus forecast for the coming 3-month season (Berri et al., 2005). In general the consensus forecast shows better results than the operational purely forecasts of the CPTEC-COLA AGCM (Camargo Jr. et al., 2004). This type of prediction can be useful in estimating crop productivity.

This chapter present an study about the investigate of possible contribution of climate forecasts for soybean productivity forecast, considering quarterly rain forecasts updated monthly, due the importance of this variable to the yield of soybean. The improvement of estimated soybean productivity may give a contribution to agribusiness sector, in order to turn more realistic expectations available and assist on the strategic planning.

2. Investigating the possibility of improving crop forecast

Several studies indicate that Southern Region of Brazil is the main area of the country affected by interannual climate variability, as commented above. As the climate predictability tends to be better in ENSO years over regions affected by this phenomenon, it is important to investigate the potential role of precipitation climate forecast as a partial substitute for the usual climatological data in crop forecast models.

The Southern Region of Brazil is included in the areas with low climatic risk for soybean production (AGRITEMPO, 2007), participating with 32% of the total production of soybeans in Brazil (IBGE, 2009). The Rio Grande do Sul State (RS) is the second main producer state of

this region, being its rainfall regime strongly affected by impacts ENOS (Grimm et al.,1998; Coelho et al., 2002; Berlato & Cordeiro, 2005). Thus, were studied productivity cases on a municipality of RS in three years corresponding to different phases of ENSO: 2005/2006 harvest (neutral year), 2006/2007 harvest (El Niño year) and 2007/2008 harvest (La Niña year). The municipality evaluated is located in the interest area and has longs historical data series, being a reliable reference for studies on agricultural productivity.

2.1 Model description

The FAO model proposed by Doorenbos & Kassam (1979) was applied to estimate the crop agricultural productivity. This is an empirical model that includes the following components: soil, with its water balance; plant, with its development, growth and yield processes; and atmosphere, with its thermal regime, rainfall and evaporative demand. This model correlates the relative yield drop to the relative evapotranspiration deficit, being formulated by the Equation (1). Therefore, it is necessary to first estimate the potential productivity (Yp) that represents the maximum crop yield in suitable conditions and then estimate YR accounting the relative water deficiency that is weighed by a crop sensitivity factor for the water deficit.

$$YR/YP = 1 - ky \cdot (1 - ER/EP), \quad (1)$$

being: YR the actual productivity;
YP the potential productivity;
ER the actual crop evapotranspiration;
EP the potential crop evapotranspiration;
ky the productivity penalization coefficient per water deficit, variable with the crop phenological stage.

The actual crop evapotranspiration (ER) is determined by the sequential water balance based on daily temperature and precipitation data. The potential evapotranspiration (EP), or maximum crop evapotranspiration, is given by the product between the reference evapotranspiration (ETo), and the crop coefficient (Kc) for each phenological stage, as recommended by FAO, considering temperature information in its estimate. The Thornthwaite equation is a simpler method for estimating ETo, since it just requires mean temperature data. As there are limitations of this method to some climatic conditions, Camargo et al. (1999) proposed an adjust of Thornthwaite method using the concept of an effective temperature, which is a function of the local thermal amplitude. In this work was used the adjusted Thornthwaite's method was used, also considering the effective temperature corrected by photoperiod (Pereira et al., 2004). The penalization coefficient ky is an empirical adjustment factor that is specific for each crop, each phenological stage and each region of Brazil, considering the regional particularities of the varieties and the used production systems, according to values recommended by FAO (Assad et al., 2007). The potential productivity Yp represents the maximum value that can be obtained in each region and presupposes in its estimate that the phyto-sanitary, nutritional and water crop requirements are met and that the productivity is conditioned only by crop characteristics and the environmental conditions that are represented by solar radiation, photoperiod and air temperature.

The actual productivity (YR) calculation by the Equation 1 is normally made with the daily data obtained in surface stations or by climatology data. In the studied cases, one considered

the values listed in the Table 1 for the ky and Kc coefficients were considered. Using extended weather forecast data may allow the actual productivity (YR) estimates to be made with the same anticipation and accuracy of meteorological models. The more accurate and anticipated will the productivity estimate be, more useful and strategic it will be.

	Duration (days)	Kc	ky
1 – Establishment	10	0.30	0.10
2 – Vegetative Development	35	0.70	0.20
3 – Flowering	40	1.10	0.80
4 – Fructification	30	0.70	1.00
5 – Maturation	10	0.40	0.10

Table 1. Values of ky and Kc coefficients per phenological stage that are considered in calculating the actual productivity.

2.2 Data

In this study, we used forecast and observed precipitation daily data in Passo Fundo/RS (28.23ºS; 52.31ºW) and observed temperature daily data, both from October 20 to February 21 of years: 2005/2006, 2006/2007, 2007/2008, related harvest periods according drought risk sowing date recommended (AGRITEMPO, 2007). This is a municipality of Rio Grande do Sul State (RS), is located in southern Brazil, presenting humid subtropical local climate (Cfa) according to the Koppen's classification.

The climatologic values of daily precipitation that were calculated for each year's month, on the basis of a 40-year observation period (1961 to 2000). Were also analyzed precipitation historical data to found the precipitation thresholds associated with the range that each precipitation tercile for the coming 3-month season. These values was used to represent qualitatively the precipitation climate forecast.

The climate forecasts of precipitation were obtained by consensus seasonal forecast developed monthly at CPTEC, based in forecasts of CPTEC-COLA AGCM compared with results of other models climate, being presented by maps on the CPTEC web. As the precipitation seasonal forecast are available by tercile maps displays the probability of occur above normal, normal and below normal precipitation. The use of tercile probabilities provides both the direction of the forecast relative to climatology, as well as the uncertainty of the forecast. The probability that any of the three outcomes will occur is one-third, or 33.3%. Recall that for each location and season, the tercile correspond to actual precipitation ranges, based on the set of historical observations. Thus, were used the values of observed precipitation thresholds to represent the forecasts precipitation of the category forecasts most likely. Based on values of seasonal precipitation were obtained forecast daily precipitation. These values were updated monthly to each new climate forecast, as well as is possible on real-time situation.

The observed soybean productivity data was obtained by the Brazilian Geographical and Statistical Institute (IBGE) for harvests studied.

2.3 Simulations

The simulations were developed considering the possibility of its real-time replicating. Thus to evaluate the possible contribution of precipitation climate forecasts, the actual productivity was estimated in three different ways, changing only the precipitation data set, as follows:

i. A suitable model simulation for the productivity estimate, using the observed precipitation and temperature data (October to February);
ii. Productivity estimates using series that are composed of climatologic and observed precipitation – containing observed precipitation values from the first cycle day – on different periods (ends extended at each 1 day) that are completed by climatologic values until the crop cycle ends;
iii. Productivity estimates considering precipitation series that are respectively composed by observation, climate forecast (3-month season) and climatology on different periods of the crop cycle that are extended at each 1 day in the same way as in the previous case. In this case, the values corresponding values of climatic forecasts were updated monthly.

Thus, to accomplish the second and third types of simulation was necessary to process the crop forecast model 125 times, that corresponds to the cycle day number, since the observed data is updated daily.

3. Results and discussion

In regard to climatology precipitation in the studied region is well known that the Rio Grande do Sul State presents a double peak in the wet season: from summer to spring and then to late winter, presenting a phase discontinuity (Grimm et al, 1998). In the location of Passo Fundo, at the northern part of the state of Rio Grande do Sul, the peak rainy season is the austral spring, with the largest volume in September (206 mm) and the lowest in April (118 mm). In general, the precipitation in Passo Fundo is well distributed throughout the year. There is a marked seasonal cycle of temperatures in Passo Fundo, with maximum temperatures around 28 ºC (17 °C) in January (July) and minimum temperatures near 17 ºC (7 ºC) in January (July).

Whereas, that the suitable productivity estimate is reached by using the data observed throughout the period, that is, simulating a yield forecast model with the data observed throughout the crop cycle period, this type of simulation was used as basis comparison. The estimated soybean productivity for Passo Fundo using observed meteorological data was of 2588 Kg/ha in 2005/2006, 2525 Kg/ha in 2006/2007 and 2652 Kg/ha in 2007/2008. The verified soybean productivity was of 2500 kg/ha, 3000 kg/ha and 2450 kg/ha for the harvest of 2005/2006, 2006/2007 and 2007/2008, respectively (IBGE, 2008). The estimate productivity using data observed was better adjusted to 2005/2006 and 2007/2008 harvest than 2006/2007 period.

It is important to estimate the productivity estimate gain at different forecast periods, using whatever precipitation forecasts are available in a real-time application. To develop real-time productivity estimates in different periods of the crop cycle, there are observed data until the day of estimative, 3-month season of climate forecast and climatology for the remainder. Thus, various soybean productivity estimates were made in Passo Fundo, assuming that such estimates had been made in different crop periods, considering that there were observed data up to the beginning of the process, completed by forecasts and climatology from the end of the precipitation forecast period until harvest. Results are presented in form of graphics in Figures 2 to 4.

When comparing the results of the productivity estimated by the observed precipitation with that based on the precipitation climate forecasts throughout the crop cycle and with the climatological precipitation, it is verified that the estimate based on the precipitation forecasts is closer to the observed productivity than the estimate based on the climatological rainfall to

2005/2006 and 2007/2008 harvest (Figure 2 and Figure 4), in the period of between 40th and 70th day of the cycle. This is a period that of plant is most affected by water necessity is higher, being the estimative of productivity sensitive to variations of precipitation. This demonstrates the importance of using precipitation climate forecasts accurate to attain the productivity estimates, main in this cycle periods. Cardoso et al. (2010) found similar results by use of up to 15 day wheather forecasts to improve the soybean productivity prediction.

For the cases of 2005/2006 harvest (neutral year) and 2007/2008 harvest (La Niña year) was verified gain when using precipitation climate forecasts, because the climate forecast hit the category of precipitation occurred between November and January, periods when the crop is more sensitive to water deficit. In these two years was verified below normal precipitation in November and December, persisting until February in case of La Niña year.

There were no differences between estimate productivity using forecasts precipitation and only climatology information to 2006/2007 harvest, because although it is an El Niño year the climate forecast indicated normal to all period, being observed above normal precipitation from November by the end of the period. Maybe the forecast climate wrong because it was a weak El Niño, making more difficult the estimation of their impacts. However the error of climate forecast no harmful the estimate crop, because was forecast normal precipitation, ie, climatology that is data used when there is not climate forecast.

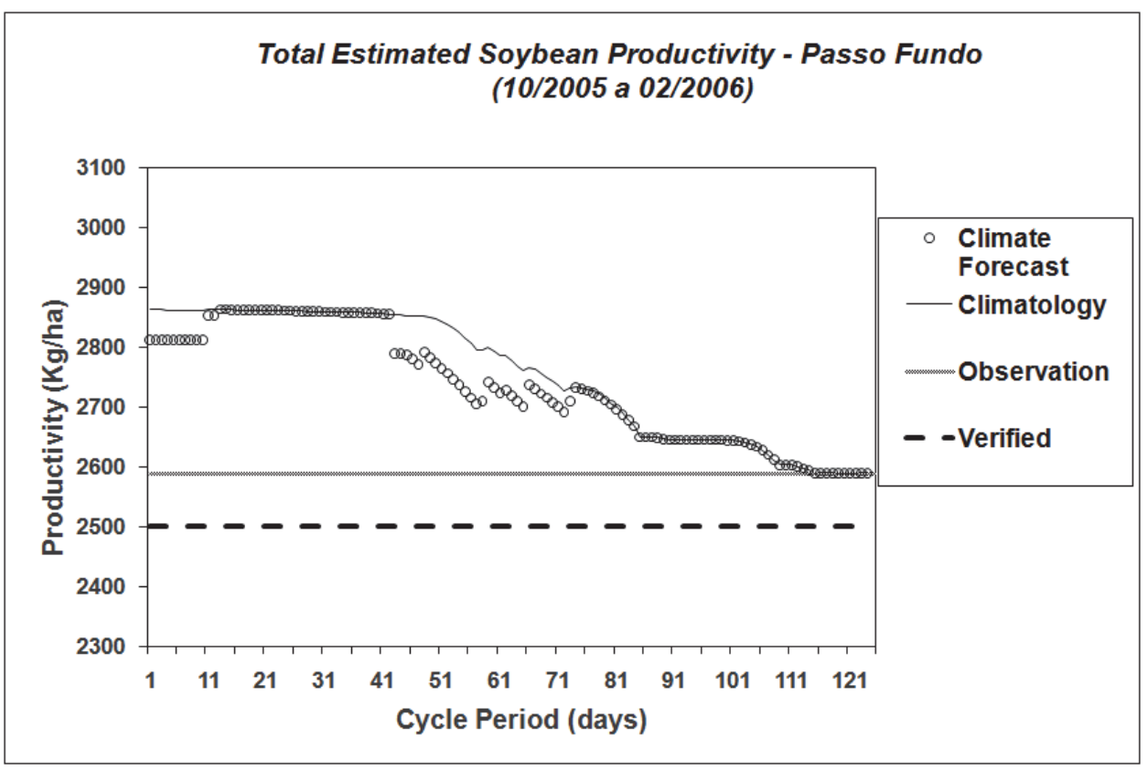

Fig. 2. Values of the total estimated productivity of soybean in Passo Fundo, 2005/2006 harvest, from the data observed throughout the cycle period (black dotted line) and from the series composed respectively by observation-climatology (black line) and observation-forecast-climatology (circles). It is highlighted that these composed series contain observed precipitation values from the first cycle day in different periods (extended at each 1 day). This also includes the value of the verified productivity (black thick line) published by the IBGE.

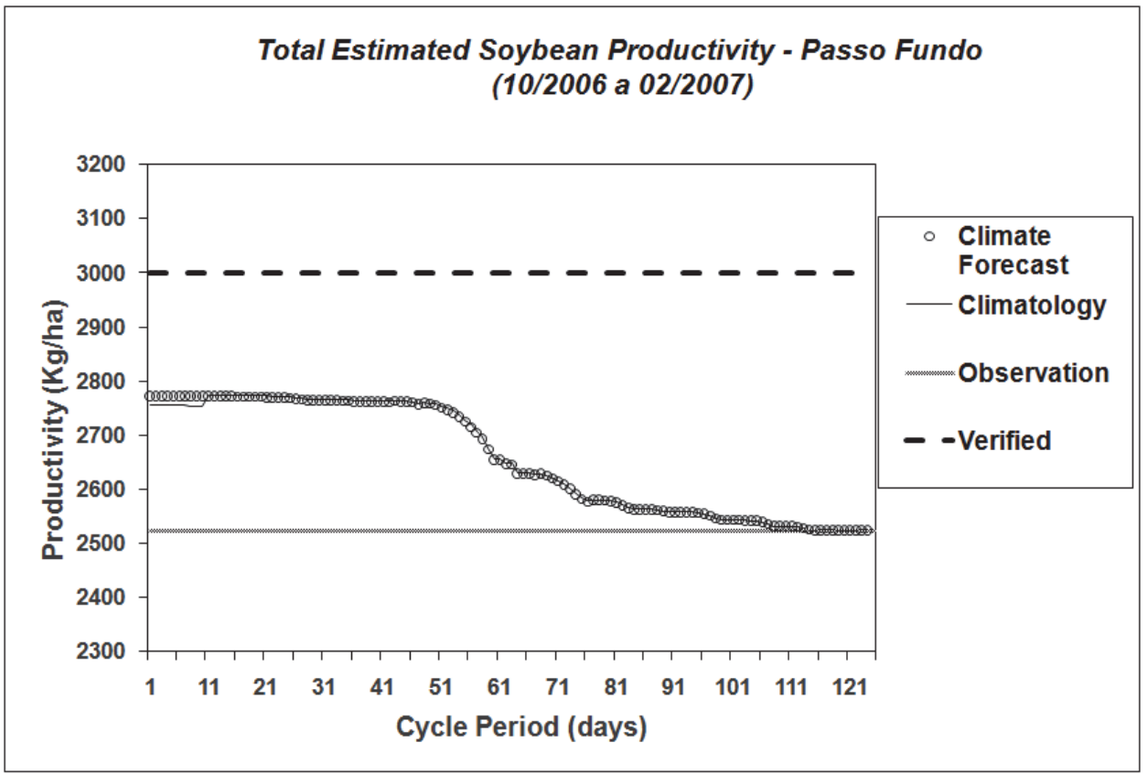

Fig. 3. Values of the total estimated productivity of soybean in Passo Fundo, 2006/2007 harvest, from the data observed throughout the cycle period (black dotted line) and from the series composed respectively by observation-climatology (black line) and observation-forecast-climatology (circles). It is highlighted that these composed series contain observed precipitation values from the first cycle day in different periods (extended at each 1 day). This also includes the value of the verified productivity (black thick line) published by the IBGE.

4. Conclusion

This chapter approached the importance of using climate forecasts to etimative of agricultural productivity and presented case studies of soybean productivity estimative, evaluating the possible contribution this type of information.

Was verified that in general the precipitation climate forecasts contribution to the improvement of estimated soybean productivity, primarily in periods when the crop is more sensitive to water deficit. For this period is important that the category of forecast precipitation be the same of observed precipitation. Thus, to achieve a gain by the use of climate forecast is necessary to know the skill of climate model used, preferring to apply this type of information in periods of greater reliability.

The improvement of estimated soybean productivity may give a contribution to agribusiness sector, in order to turn more realistic expectations available and assist on the strategic planning. This demonstrates the importance develop research that aim at better understanding the potential use of climate forecasts to estimate agricultural productivity, over the globe.

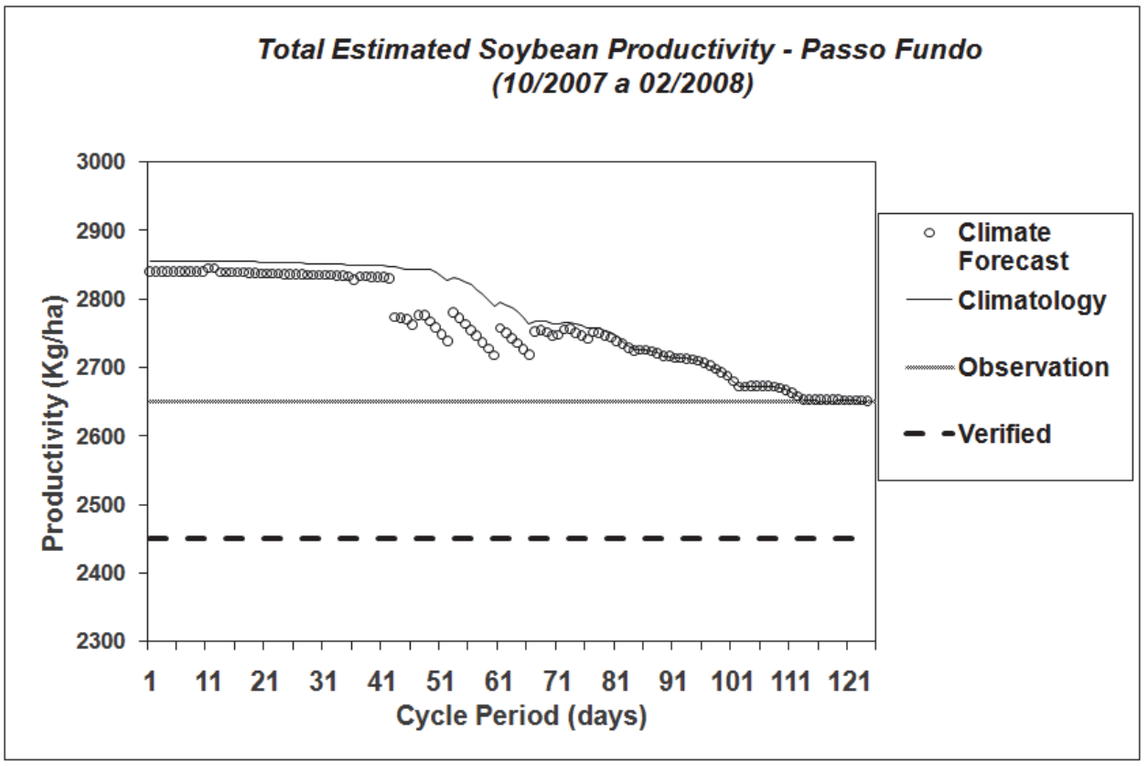

Fig. 4. Values of the total estimated productivity of soybean in Passo Fundo, 2007/2008 harvest, from the data observed throughout the cycle period (black dotted line) and from the series composed respectively by observation-climatology (black line) and observation-forecast-climatology (circles). It is highlighted that these composed series contain observed precipitation values from the first cycle day in different periods (extended at each 1 day). This also includes the value of the verified productivity (black thick line) published by the IBGE.

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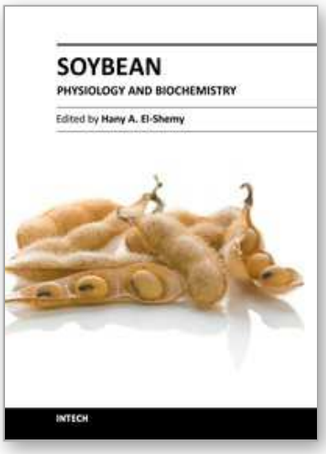

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