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INTERANNUAL VARIABILITY OF SOYBEAN YIELD IN THE ARGENTINE PAMPAS AND ITS RELATIONSHIP WITH SYNOPTIC WEATHER TYPES IN SOUTHERN SOUTH AMERICA

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1. INTRODUCTION

The Humid Pampas covers the country's most productive agricultural land where soybean is one of the most important grain crops followed by maize, wheat and sunflower.

Persistent synoptic conditions or larger scale events frequently occur in the region, causing extreme rainfall (Malaka and Nuñez, 1980; Casarin and Kousky, 1986; Minetti and Sierra, 1989; Alessandro, 1996, 2000; Labraga et al., 2002). Local daily scale variables that influence soybean yield directly depend on the larger scale atmospheric fields. Compagnucci and Vargas (1985, 1986), Compagnucci and Salles (1997) and Compagnucci et al. (2001) studied the objective identification and classification of synoptic patterns in southern South America and described spatial patterns using surface pressure. Solman and Menendez (2003) and Bischoff and Vargas (2003, 2006) used geopotential heights at the 500 hPa level while Bettolli et al. (2005 (Brazil), 2006) worked on the 1000 hPa level. These authors (2007) made a classification of geopotential height patterns at two levels (1000 and 500 hPa) and studied their relation to rainfall in the Humid Pampas. However, though the studies mentioned analysed the relationship of synoptic structures to different surface variables, no studies have been found relating these structures with any productive sector in particular using its relation to surface variables.

The main goal of the present study is to analyse soybean yield variability in the Argentine Humid Pampas in relation to the atmospheric circulation patterns in southern South America.

This study is proposed as a continuation of a research line whose main goal is the evaluation and quantification of the impact of climate variability on soybean production. It started with the detailed analysis of the spatial and temporal variability of soybean production in the Argentine Humid Pampas and quantified associations between soybean yield and climate variables (Penalba et al. 2007).

2. DATA

In order to conduct this study, two datasets were used:

a) Soybean yield series in 58 provincial districts in the Pampas region (Santa Fe, Entre Rios, Cordoba and Buenos Aires) supplied by the Secretaría de Agricultura, Ganadería, Pesca y Alimentación de la Nación (SAGPyA) for the 1979/80 - 1999/00 period. The geographic location of each provincial district is shown in Figure 1 b.

The yield series showed a significant positive linear trend (42 of the 58, 95% confidence level) during the period analysed (Penalba et al,. 2007). Since the trend could affect the stability of the results, this effect was removed and the analysis was carried out with the anomalies of the yield (regarding the linear trend or the mean, according to the case).

b) 1000 and 500 hPa geopotential height daily fields from the NCEP reanalysis II provided by the NOAA-CIRES Climate Diagnostics Center during the 1979-2001 period (5346 fields) (http://www.cpc.ncep.noaa.gov). The domain selected extends from 15ºS to 60º S latitude and from 30ºW to 90º W longitude. (2.5º latitude by 2.5º longitude) (Figure 1a). The study was carried out using the daily geopotential anomaly fields: the daily average field of the period analysed was subtracted from each day in order to remove the seasonal cycle.

The months analysed are considered to be within the average cycle of the crop for the region (November to May of the following year) including pre-sowing (October).

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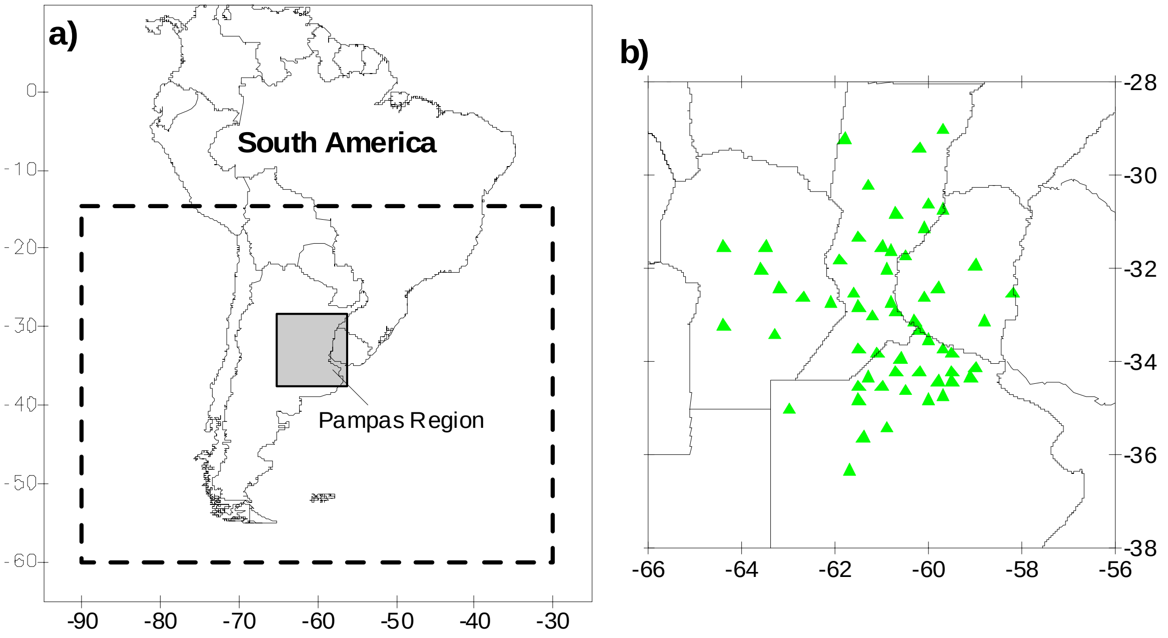

Figure 1. Spatial domain of geopotential height fields (a) and location of provincial districts for the analysis of soybean yields (b).

3. RESULTS

3.1 *Soybean yield inter-annual variability*.

The spatial and temporal structure of soybean yield in the Argentine Humid Pampas was analysed in detail by Penalba et al. (2007). These authors found that soybean yield has a low spatial coherence and is representative only in localised areas. This suggests that for each crop season, the average regional yield cannot represent the whole region. Therefore, in order to characterise each soybean season regionally, the following index was considered:

NYI: the number of provincial districts per crop season with negative yield anomalies.

In consequence, the high (low) value of the index implies that many provincial districts presented negative (positive) yield anomalies, thus giving a regional characterisation of each soybean growing season. The temporal series of this index is presented in Figure 2 a, showing a high temporal variability.

3.2 *Weather Types*

The weather types (WTs) resulting from the synoptic classification shown in Figure 3 taken from Bettolli et al. (2007) will be used. These WTs were obtained by combining the Principal Component Analysis with the k-means cluster analysis.

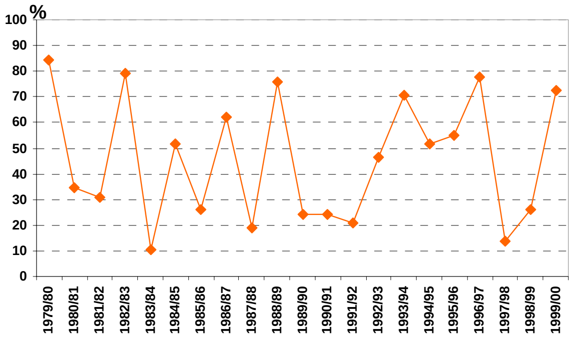

Figure 2. Temporal NYI series (a)

This synthesis of the daily circulation in southern South America includes 7 spatial structures which are representative of the 1000 hPa geopotential height anomalies and 5 at the 500 hPa level. These spatial fields constitute the most frequent anomalies in the atmospheric circulation of the region. They represent atmospheric flow anomaly configurations of larger scale than the regional ones, which "lead" or "condition" the processes at smaller scales and temperature and humidity advections at lower levels (Bettolli et al., 2007).

In order to characterise the temporal evolution of the daily circulation, an index was defined for each level, taking into consideration the seasonal and monthly frequencies of each WT.

SFWTi-x: seasonal frequency of the occurrence of pattern WTix

MFWTi-x: monthly frequency of the occurrence of pattern WTix where x is the level of the atmosphere (1000 or 500 hPa) and i is the pattern number for level x: i=1, ..., 7 if x = 1000; i = 1, ... , 5 if x = 500.

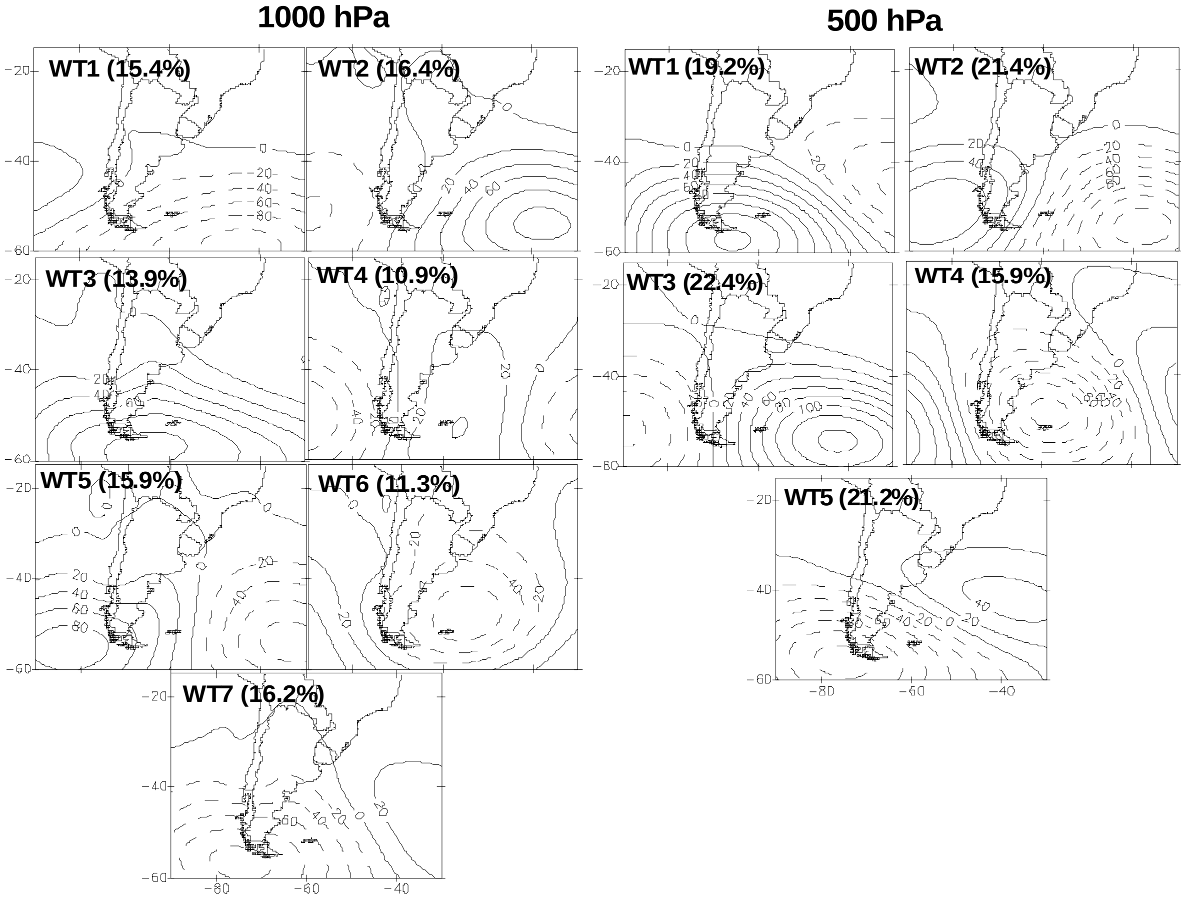

Figure 3. Spatial patterns of geopotential height anomalies at 1000 and 500 hPa. In brackets: frequency of each pattern in percentage

3.3 *Relationship between WTs and soybean yield*

3.3.1 Seasonal Frequencies

As a first step in the analysis of the relationship between WTs and soybean yield, the seasonal correlation coefficients between the two indices were calculated. The results show that these correlations are not significant (Table 1). The frequencies of the groups with equal correlation coefficient sign were summed. This is the case of WT2-1000, WT4-1000 and WT7-1000 at the 1000 hPa level which presented positive correlations. The correlation between the sum of the indexes and the NYI reaches a value of 0.42 (significant at 90%). This would indicate that the combined presence of these three WTs during the crop season would induce an adverse effect on the yield. On the contrary, the sum of the indexes SFWT1-1000 + SFWT3-1000 + SFWT5-1000 shows a correlation of -0.45 with the NYI (significant at 95%). This would indicate that the years with low values in this index (positive yield anomalies in regional terms) are accompanied by high frequencies of these daily patterns.

For the 500 hPa level, the SFWT1-500 and SFWT2-500 indexes show negative, though not significant, associations with the NYI. This result indicates that the higher seasonal frequencies in these patterns correspond to a lower number of districts with negative yield anomalies. On the other hand, the negative impact on yield in regional terms could be favoured by higher seasonal frequencies of pattern WT5-500.

These results show that soybean yield inter-annual variability may be related to atmospheric circulation structure in seasonal terms. However, the surface conditions generated by a given WT may be either favourable or not for the crop. This will depend on the stage of the crop cycle in which they occur. For this reason, a monthly analysis was made of the temporal evolution of the correlation coefficient between the MFWTix and the NYI indexes.

3.3.2 Monthly Frequencies

The soybean yield is an amount which summarizes simplistically the characteristics of the crop seasons and the NYI is a value which characterises each crop season at regional level. Consequently, the demand of statistical significance in the correlation could become very rigorous in terms of the analysis of the WTs-soybean yield relationship. On the other hand, the circulation of one particular month is not exclusively explained by a single atmospheric pattern. For these reasons, the correlation coefficient is considered as a primary indicator of a possible relationship between WTs and the NYI, beyond its significance. In all cases, the joint temporal evolution of the MFWTix and the NYI indexes are taken into consideration in this analysis.

The correlation coefficients between the monthly frequency series of each WT and the NYI are presented in Figure 4. For the 1000 hPa level, the higher frequencies of the WT1-1000 would favour yield particularly in the second half of the growing season. The WT2-1000 shows a positive anomaly with an NW-SE axis over the Pampas region (see Figure 3) which significantly favours dry days. This pattern would have a positive impact on the yield when it occurs with higher frequency in April as it makes harvest easier. WT3-1000 does not seem to show a preferential month or period of influence (Figure 4). WT4-1000 shows a positive anomaly centre in the geopotential, with its axis to the east of the continent. This configuration favours stability at low levels and warm and humid advection from the subtropical zones, increasing significantly the probability of dry days in the Pampas region (Bettolli et al., 2007). This situation has a negative effect on the yield during flowering, pod set and pod filling stages (January and February). WT5-1000 favours the entry of cold air from the south (see Figure 3). This pattern shows an adverse effect during sowing time (November) and then the effect is reverted during the remaining crop season, mainly in January and February (Figure 4). The higher frequency of this WT during seed germination and early vegetative growth stages (sensitive stages to low temperatures) would affect the yield adversely. However, if this WT occurs more frequently in January and February it would affect the yield as it reduces the thermal stress conditions during flowering and pod setting. WT6-1000 increases the probability of rainfall in the region ((Bettolli et al., 2007) showing favourable effects during the first half of the season and adverse effects during the second half, particularly in April). WT7-1000 shows negative effect on the crop mainly towards the end of the season (April) (Figure 4). This WT induces intensified westerlies over middle latitudes and cyclonic disturbances in the centre of the country (see Figure 3) and could be associated with days of intense rainfall in the region (Bettolli et al., 2007). Considerable rainfall and days with excessive environmental humidity during harvest time may cause losses in quantity and quality of the crop.

In general at the 500 hPa level, the WTs show smaller correlations with the NYI than at the lower level. WT1-500, which favours rainy days, would have a positive influence during the February-March period. WT2-500 shows weak associations, however the negative correlations towards the end of the crop season would indicate that higher frequencies of this WT would favour the yield as it produces favourable conditions for harvesting the crop. WT2-500 is characterised by a positive anomaly over the Pacific which intensifies the wedges to the west of the Andes and induces subsidence at mid-levels over the Pampas region and the consequent stability and dry conditions (Bettolli et al., 2007). WT3-500 does not show a defined pattern of associations with the NYI. WT4-500 shows negative geopotential anomalies centered in the Malvinas Islands (Figure 3). This configuration of anomalies benefits rising motions and instability mechanisms over the Pampas region favouring rainfall conditions (Bettolli et al., 2007). In particular, the positive correlation observed in February would suggest that this WT has negative effect on the soybean yield. However, when the joint behaviour of temporal series is observed, a direct association appears in only one crop season (1996/97) (not shown). Something similar occurs with the positive correlation in March. Nevertheless, during the critical period corresponding to the flowering and pod setting (December-January), the higher frequency of this pattern favours the yield. WT5-500 shows a negative effect towards the end of the season (April) (Figure 4). This may be due to this WT favours significantly the days with intense and generalised rainfall (Bettolli et al., 2007), an adverse situation during harvest time. On the other hand, WT5-500 would show an adverse effect on the yield (positive correlations during the critical period of December, January and February). However, the analyses of the temporal series show that the association is only due to a few isolated years.

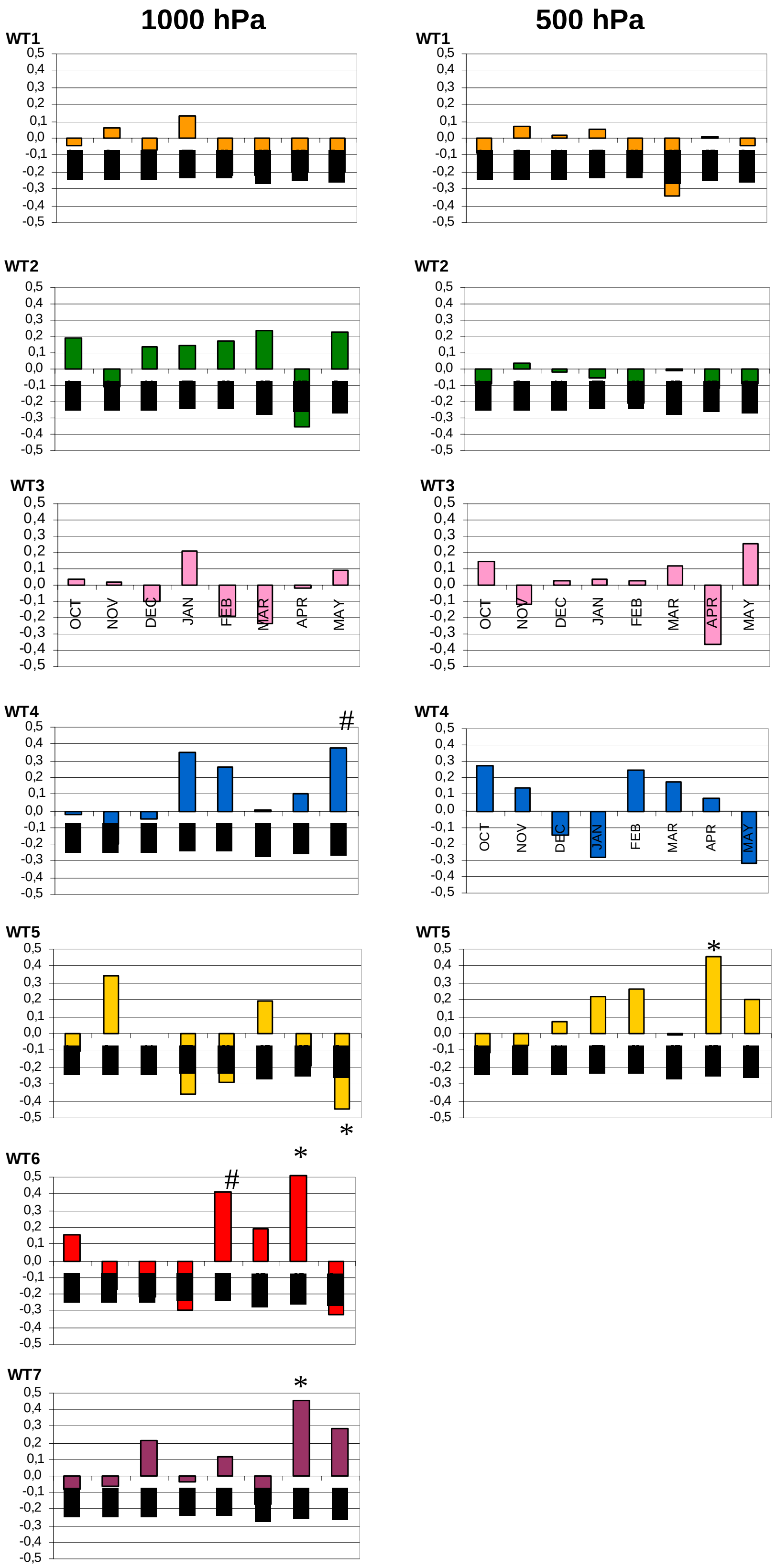

Figure 4. Correlation coefficients between the monthly frequencies of 1000 and 500 hPa WTs and the NYI. * (#) Significant coefficients at 5% (10%).

In general, although the two levels are not independent from each other, the WTs of 1000 hPa level have a clearer relationship with the NYI than the 500 hPa ones. This could be partly due to that the surface level patterns, more immediately, contain the information of humidity and temperature advections, variables which are very important for crop growth.

4. CONCLUSIONS

This work focused on soybean yield variability in the Argentine Humid Pampas and its relation to daily atmospheric circulation in the south of South America at low and middle levels. The region studied is the main soybean production area in Argentina and contributes a high percentage to world trade in soybean and its by-products.

Classification of the atmospheric circulation structures and knowledge of its main properties are a basic element for diagnosis and forecast. This paper identifies synoptic structures which are related to inter-annual yield variability. In general terms, the results suggest that particular circulation patterns on a regional scale may have good or adverse effects on soybean yield. Therefore, they could be introduced as a potential diagnostic and monitoring element of the yield variability.

Adverse impacts on final yield may be mainly associated to circulation patterns related to intense rainfall during harvest time (April and May) (patterns WT6 and WT7 at 1000 hPa and WT5 at 500 hPa) and to structures at lower levels (WT4 at 1000 hPa) which favour stability and warm advection in the summer (flowering, pod setting and grain filling time). On the other hand, the thermal effect may be observed in the WTs whose anomaly configuration favours the incursion of cold air at the lower levels (WT5 at 1000 hPa), contributing to low temperatures during seed germination and early vegetative growth stages, sensitive stages to low temperatures. This WT also induces anomalies in the flow which reduces thermal stress during flowering and pod set stages (austral summer) producing a positive effect on the yield. The WT, which favours stability at harvest time (April) (positive anomaly axis in the 1000 hPa geopotential with NW-SE direction over the Pampas, WT2-1000), shows a positive relationship with yield. During this period, these favourable conditions may also be generated by the higher frequency of the 500 hPa structures which intensify wedges to the west of the Andes and induce subsidence at middle levels over the region (WT2-500).

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