

El Niño – Southern Oscillation influences on soybean yields in eastern Paraguay

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ABSTRACT: Soybean (*Glycine max.* L. Merrill) production in Paraguay has increased dramatically during the last decade and the country is now the fourth largest soybean exporter in the world, producing about 3% of the world's soybean production. This paper explored associations between soybean yield in eastern Paraguay and the El Niño Southern Oscillation (ENSO) phases. Historical soybean yield data from official government sources were detrended to remove the effects of technological advances, and yield residuals were computed. In addition, differences in mean precipitation among ENSO phases were investigated under the context of crop development phases. The CSM-CROPGRO soybean model was used to simulate soybean development for two locations representing the most important soybean producing areas in Paraguay. Influences of ENSO phases on mean precipitation during planting and blooming, blooming and seed podding, and from young pods to physiological maturity were explored through tests of differences in the central tendency. Relative yield residuals during El Niño years were positive six out of seven events and varied from -9.4 to $+24.2\%$ for the 1991/1992 and 2002/2003 cropping seasons, respectively. During La Niña years, calculated residuals were negative for three out of four events and varied from -37.9 to $+1.5\%$ for the 2005/2006 and 1988/1989 cropping seasons, respectively. Analysis of precipitation records showed significantly lower precipitation levels between planting and blooming during La Niña years than during El Niño years. Differences in mean precipitation during blooming and beginning of seed formation were found to be not significant. Mean precipitation between seed podding and crop maturity was found to be significantly lower during La Niña years than during El Niño years in one of the locations studied. Copyright © 2007 Royal Meteorological Society

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1. Introduction

Soybean (*Glycine max.* L. Merrill) production in Paraguay has increased dramatically during the last decade and the country is now the fourth largest soybean exporter in the world, producing about 3% of the world's soybean production (USDA-FAS, 2007a). According to the association of oilseed and cereal exporters of Paraguay (CAPECO, <http://www.capeco.org.py>), soybean production in Paraguay increased from 2.4 million metric tons during the 1995/1996 cropping season to about 4.0 million metric tons during the 2004/2005 season. A record production of 6.0 million metric tons is expected for the 2006/2007 cropping season (USDA-FAS, 2007b). Production is concentrated in the eastern region of the country where the departments of Itapúa, Alto Paraná,

and Canindeyu together are responsible for 80% of the total production (Figure 1).

Seasonal climate variability is a major source of production risks. The majority of crop failures are associated with either a lack or excess of rainfall. Climate variability is also associated with other sources of production risks such as pest and disease incidence. Weather patterns, including high temperature and humidity, and the potential for daily rainfall, can create a near-perfect environment for the outbreak of fungal diseases (Fraisse *et al.*, 2006a). The El Niño Southern Oscillation (ENSO) phenomenon is the strongest driver of inter-annual climate variability around the world (Ropelewski and Halpert, 1996; McPhaden *et al.*, 2006) and affects crop production in many regions. ENSO phases are characterized by sea surface temperature (SST) anomalies in the eastern equatorial Pacific Ocean. When SST is higher than normal the phenomenon is referred to as El Niño or warm events. Associated with the warmer surface temperatures is an

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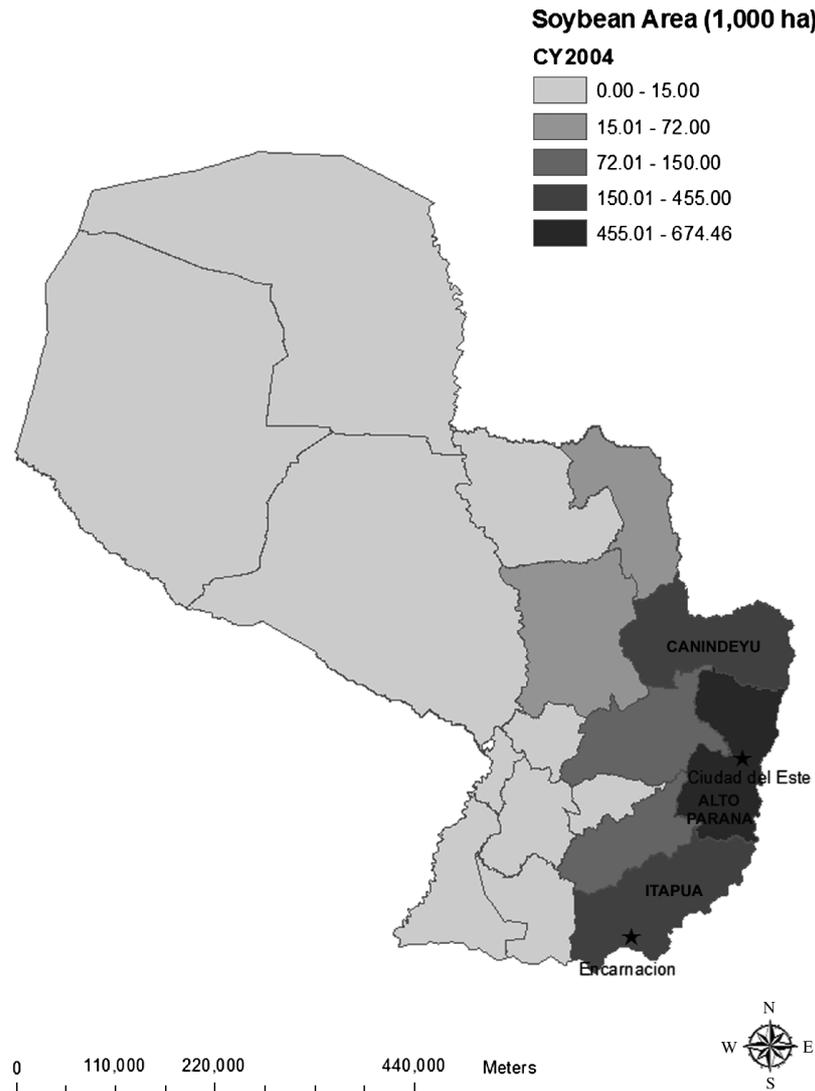


Figure 1. Soybean planted area (1000 ha) in Paraguay during the 2003/2004 cropping season (Source: Inter-American Institute for Cooperation in Agriculture – IICA).

increase in convective activity, and at a certain stage, a persistent reduction of the normally westward flowing winds (Cane, 2001). When the SST is lower than normal, the phenomenon is referred to as La Niña or cold events. During La Niña events, the equatorial trade winds strengthen, resulting in colder water being brought up from the ocean's floor. Neutral is the term for when neither El Niño nor La Niña are present in the Pacific. Under neutral conditions, trade winds blow from east to west near the Equator in the Pacific Ocean.

Paraguay is located in the Paraná-Plata basin where the seasonal cycle of precipitation is generally characterized by a rainy period in austral summer and a dry period over the winter. The rainy period is caused by a large-scale phenomenon recently called the South American Monsoon System (SAMS, Zhou and Lau, 1998). However, detailed analysis of month-to-month precipitation demonstrated that the rainfall regime over eastern Paraguay is characterized by two rainfall peaks observed during the transition seasons: autumn and spring (Rusticucci and

Penalba, 2000). Several studies have demonstrated the teleconnections between ENSO activity in the tropical Pacific Ocean and anomalies in the seasonal precipitation patterns in subtropical southeastern South America. Positive precipitation anomalies related to the El Niño event and negative anomalies during La Niña events have been found along southern Brazil, Uruguay, the pampas region and northeastern Argentina (Chu, 1991; Pisciotano *et al.*, 1994; Ropelewski and Halpert, 1996; Diaz *et al.*, 1998; Grimm *et al.*, 1998, 2000; Montecinos *et al.*, 2000).

ENSO impacts on agricultural output around the world have also been extensively documented. El Niño is known to cause low grain yields in south Asia and Australia, and high grain yields in the North American prairies (Garnett and Khandekar, 1992). Cane *et al.* (1994) associated ENSO-related SSTs with rainfall and corn yields in Zimbabwe, where SST, a full year before planting, explained 57% of the variability in yields. ENSO events have also been found to influence corn yields in the mid-western and southeastern

USA (Handler, 1990; Carlson *et al.*, 1996). Hansen *et al.* (1998) analysed the historical (1960–1995) response of total production value and its components (yield, area harvested and price) to ENSO phases, and quarterly SST for six crops (peanut, tomato, cotton, tobacco, corn and soybean) in the southeastern USA. ENSO phase significantly influenced corn and tobacco yields, the areas of soybean and cotton harvested, and the values of corn, soybean, peanut and tobacco. Podestá *et al.* (1999) investigated the association of grain crop yields and ENSO in central-Eastern Argentina. They concluded that the association between lower yields and La Niña events are usually stronger and less variable than corresponding yield increases during El Niño events. To our knowledge, there are no studies of ENSO impacts and soybean yields in Paraguay.

The main objective of this study is to characterize the influence of ENSO events on soybean yields in Paraguay. The influence of ENSO on precipitation patterns during soybean developmental stages is also analysed. We hypothesized that El Niño events would have a positive effect on soybean yields and that the opposite would occur during La Niña events.

2. Methods and data

Historical soybean yield data from official government sources are used to investigate the influence of ENSO phases on yield. Soybean yield data are detrended to remove the effects of technological advances and yield residuals are computed. The relatively short period of soybean yield records available for this study are not sufficient to reach a good understanding of ENSO influences on yields in eastern Paraguay. In addition, longer series of weather records are used to investigate differences in mean precipitation among ENSO phases under the context of crop development phases. Influences of ENSO phases on mean precipitation during crop planting and blooming, blooming and seed podding, and seed podding and physiological maturity are explored through tests of differences in the central tendency. The length of each development phase is determined using the CSM-CROPGRO-Soybean model (Boote *et al.*, 1998; Jones *et al.*, 2003). This approach differs from the traditional approach of investigating differences based on monthly totals such as in the study by Rusticucci and Penalba (2000), and can potentially better explain the influence of ENSO phases on soybean growth and development.

2.1. Soybean yield data

Soybean growth, development and yield are dependent on the genetic potential of a given variety and the environment. The genetic yield potential is only obtained when the environmental conditions are perfect for a determined genetic make-up and, since that is not possible under normal field conditions, environmental stresses such as water and nutrient deficiencies, extreme temperatures, pests and diseases are the main factors determining yield

fluctuations (Ritchie *et al.*, 1996). In this study, historical records of countrywide mean soybean per-hectare yield estimates from 1982 to 2007 compiled from Paraguay's Ministerio de Agricultura y Ganadería were used to represent the variability of soybean yield in the study area. National averages are a useful proxy for Alto Parana and Itapúa yields as, historically, these two departments have been responsible for more than 75% of the country's production and only recently has any significant expansion occurred relating to other departments (MAG, 2002).

Historical yield records can provide a valuable perspective of the possible influence of ENSO on crop yield. However, in addition to climate variability, historical crop yield data integrates a number of factors such as technological advances (improved varieties or management, shifts from rain fed to irrigated production) and price cycles. The data need to be processed to separate the effects of seasonal climate variability from other factors that tend to change more slowly. Long-term trends need to be removed from the dataset to allow the analysis of more frequent shifts related to climate variability (Fraise *et al.*, 2006b).

Soybean yields in Paraguay have increased in a non-linear fashion over the time-period studied. Therefore, instead of using a parametric functional form (e.g. linear), a low-pass spectral smoothing filter (Press *et al.*, 1992) was used. The premise of data smoothing is that one is measuring a variable that is both slowly varying and also affected by random noise. The spectral or Fourier transform method used removes variation above a specified frequency and then applies the inverse Fourier transformation to generate the low-frequency yield trend. Although the choice of smoothing period is subjective, we used a 10-year smoothing, as suggested by Hansen and Ines (2004) in their study to analyse crop yield impacts of seasonal climate variability in the State of Gujarat, India. A potential problem with the removal of trends is that the estimated long-term trend may also reflect long-term climate effects (Podestá *et al.*, 1999). Conversely, the variability after removal of the trend may not entirely be climate related.

Soybean yield residual for each year was computed by subtracting the trend line or expected yield from the annual yields. Relative yield residuals, defined as the ratio (%) of yield residuals to expected yields, were computed to facilitate the comparison and analysis of ENSO influences on soybean yield.

2.2. Weather data

According to Caffera and Berbery (2006), eastern Paraguay is a humid subtropical region with annual mean precipitation between 1500 and 1900 mm, depending on the locations. Based on the availability and completeness of the dataset, weather observations from two weather stations (Figure 1), Encarnación (27°12'S, 56°00'W), located in the Department of Itapúa, and Ciudad del Este (25°24'S, 54°49'W), located in the Department of Alto Paraná, were compiled to represent the main

soybean producing areas. The compiled data sets included daily weather observations of maximum and minimum air temperature and precipitation from 1951 (Encarnación) and 1965 (Ciudad del Este) to 2006.

The ENSO index developed by the Japan Meteorological Agency (JMA) that is based on regional SST was used in this study. The JMA index is a temperature-based index and uses mean SSTs within the equatorial Pacific region that extends from 4°N–4°S to 150–90°W. The JMA definition of a warm (cold) ENSO event requires the SST in this region to be greater than 0.5 °C (less than –0.5 °C) for 6 consecutive months and the months must include October, November and December (Hanley *et al.*, 2003).

2.3. Soybean varieties and development stages

Soybean varieties are classified for their morphological growth habit, and for their day length and temperature requirements to initiate floral or reproductive development. The indeterminate growth habit is characterized by a continuation of vegetative growth after flowering begins. Determinate soybean varieties have finished most of their vegetative growth when flowering begins (Ritchie *et al.*, 1996).

The classification for maturity is based upon the adaptability of a soybean variety to effectively utilize the growing season in a given region. In the United States, soybean varieties adapted to a particular region are given a group number from 00 for the northernmost region in Minnesota and South Dakota to 8.0 for the southernmost region in the country. In South America, soybean varieties are generally classified as short-cycle, medium-cycle, or late-cycle genotypes, depending on the length of time it takes to reach physiological maturity in a given location. In lower latitudes, closer to the Equator, the days are shorter during the summer than in higher latitudes, and soybean plants tend to flower earlier, shortening their vegetative cycle. To minimize this negative aspect, varieties adapted to lower latitudes are generally indeterminate or have a longer vegetative period. Soybean is grown in Paraguay between 25 and 28 degrees of latitude south and the varieties are mostly determinate (L. Cubilla, F. Olmedo and E. Ojeda, personal communication, 2006). A soybean variety corresponding to maturity group 7.0 was chosen to represent a typical medium-cycle variety grown in the study area.

The stages of development of a soybean plant are divided into vegetative (V) and reproductive (R) (Ritchie *et al.*, 1996). Subdivision of the V stages are designated numerically as V1, V2 and V3 through V (*n*) except for the first two stages, which are designated as VE (emergence) and VC (cotyledon stage). The last V stage is designated as V (*n*), where (*n*) represents the number for the last node stage of the specific variety. The reproductive phase is subdivided into 8 stages, two flowering stages (R1 and R2), two pod stages (R3 and R4), two seed stages (R5 and R6), and two maturity stages (R7 and R8). Developmental phases used in this study to analyse precipitation patterns were grouped into three main

phases: (1) Vegetative phase between planting and commencement of blooming (Plant–R1); (2) Reproductive phase between commencement of blooming and beginning of seed formation (R1–R5); and (3) Seed-filling phase between beginning of seed formation and physiological maturity (R5–R8).

Soybean planting in Paraguay starts in mid-October and extends through the end of November. A typical planting date, November 1st, was selected for the analysis of precipitation patterns. The duration of the soybean life cycle and duration of the individual phases of development within the life cycle are dependent on photoperiod and temperature. Soybeans are short-day plants and, therefore, they flower earlier under short day-lengths. The rate of plant development is directly related to temperature, so the length of time between the different stages will vary as the temperature varies both between and within the growing season (Ritchie *et al.*, 1996). In addition, deficiencies of nutrients, moisture or other stress conditions may lengthen the time between vegetative stages, but shorten the time between reproductive stages.

2.4. Crop model simulations

In order to correctly analyse precipitation patterns during specific developmental stages, the CSM-CROPGRO-Soybean model was used to simulate soybean development during the growing season. CSM-CROPGRO is part of the Decision Support System for Agrotechnology Transfer (DSSAT) suite of crop models (Jones *et al.*, 2003). The DSSAT package is specifically designed to answer ‘what-if’ questions frequently asked by policy makers and farmers concerned with sustaining an economically and environmentally safe agriculture (Tsuji *et al.*, 1994). DSSAT simulates crop growth, development and yield as well as changes in soil water, carbon and nitrogen that take place under the cropping system over time.

The model uses species and cultivar parameters such as base temperatures and optimum temperatures for developmental processes (rate of emergence, rate of leaf appearance and rate of progress towards flowering and maturity), growth progress (photosynthesis, leaf expansion, pod addition, etc), and day-length sensitivity traits to simulate soybean growth and development. Simulation of the life cycle progress through any given developmental phase depends on a physiological day accumulator as a function of temperature and day length. A physiological day can be thought of as equivalent to one calendar day if temperatures are optimum 24 h per day and day length is below the critical short-day requirement. Typical cultivar-specific parameters (genetic coefficients) provided in DSSAT by the model developers for maturity group 7.0, were used to predict soybean development responses to temperature, photoperiod and water or nitrogen deficits. Most cultivar coefficients are generally similar for cultivar within a maturity group (Boote *et al.*, 1997). This provides the possibility of simulating soybean development during the season, as

approximate values are known for all maturity groups. However, using the model to simulate soybean yields would require additional calibration and validation for local conditions.

The model requires daily weather data to simulate crop development and growth, including minimum and maximum air temperature, solar radiation, and precipitation. Solar radiation was generated using the program WGENR, a solar radiation generator based on the approach of Hodges *et al.* (1985). A typical soil profile representative of the red, clayey soils derived from basalt soils that are found in the region was used in the simulations. Results from the model were used to determine the length of development phases, allowing the estimation of precipitation amounts during each phase.

2.5. Analyses of precipitation patterns

Statistical analyses of precipitation distributions by the ENSO phase and crop development stage were performed using SAS statistical software version 9.1 (SAS Institute, Cary, NC). Precipitation distributions were checked for normality with PROC UNIVARIATE, and when not normally distributed were analysed with PROC NPAR1WAY (SAS Institute, 1999). General linear model analyses were conducted with PROC MIXED (SAS Institute, 1999) on each location by crop development stage. Duncan's new multiple range tests were used to separate precipitation means at a 0.05 after significance had been determined.

3. Results and discussion

3.1. Soybean yield trend and anomalies

Table I shows soybean yield, residual and ENSO phases from the 1981/1982 to the 2006/2007 cropping seasons. The yield series is not long since soybean cultivation in Paraguay as a commercial crop is a relatively new phenomenon. The earliest commercial plantings have been undertaken in the mid-to-late 1970s. The series includes 26 crop years of which 15 are neutral years, 7 are El Niño years and 4 are La Niña years. According to the official records, the maximum mean per-hectare yield (3008 kg ha⁻¹) was obtained during the 1994/1995 cropping season, a neutral year, and the minimum (1497 kg ha⁻¹) in 1982/1983, an El Niño year. In terms of relative residuals, the maximum (24.2%) was calculated for the 2002/2003 cropping season, an El Niño year, and the minimum (-37.9%) for the 2005/2006, a La Niña year. Figure 2 shows the time series of soybean yields and the low-frequency trend estimated by the smoothing process.

3.2. Precipitation during soybean development phases

Descriptive statistics for precipitation observed at the Ciudad del Este and Encarnación weather stations during soybean development phases are shown in Table II. In the case of Ciudad del Este, weather observations from 1965 to 2006 included 21 neutral years, 10 El Niño years and 11 La Niña years. Weather observations for Encarnación

Table I. Historical soybean yield series (Source: Ministerio de Agricultura y Ganadería), residuals, and ENSO classification.

Cropping season	Yield (kg ha ⁻¹)	Residual (%)	ENSO phase in season
1981/1982	1506	5.3	Neutral
1982/1983	1497	2.4	El Niño
1983/1984	1527	2.0	Neutral
1984/1985	1631	5.8	Neutral
1985/1986	1228	-23.2	Neutral
1986/1987	1750	4.7	El Niño
1987/1988	1830	3.9	El Niño
1988/1989	1897	1.5	La Niña
1989/1990	1994	0.2	Neutral
1990/1991	1868	-11.8	Neutral
1991/1992	2036	-9.4	El Niño
1992/1993	2825	19.4	Neutral
1993/1994	2587	4.91	Neutral
1994/1995	3008	18.36	Neutral
1995/1996	2875	-3.0	Neutral
1996/1997	2841	1.5	Neutral
1997/1998	2629	0.5	El Niño
1998/1999	2619	-2.41	La Niña
1999/2000	2533	-2.6	La Niña
2000/2001	2601	6.7	Neutral
2001/2002	2770	3.1	Neutral
2002/2003	2852	24.2	El Niño
2003/2004	1916	-13.7	Neutral
2004/2005	2024	-14.5	Neutral
2005/2006	1820	-37.9	La Niña
2006/2007	2800	12.1	El Niño

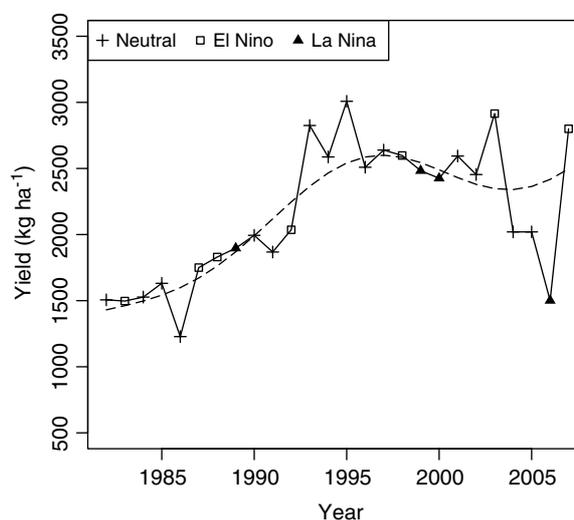


Figure 2. Time series of soybean yields, 1982–2005. Crosses correspond to neutral years. El Niño years are shown as open squares and La Niña years as filled triangles. The dashed line corresponds to the estimated low-frequency trend.

from 1951 to 2006 included 29 neutral years, 13 El Niño years and 14 La Niña years.

Simulated length of the growing season varied from 117 to 136 days for Ciudad del Este and from 128 to 144 days for Encarnación. Total precipitation during

Table II. Descriptive statistics for total precipitation (mm) observed at the Ciudad del Este and Encarnación weather stations during soybean development phases.

Weather Station	Stage ENSO (mm)	Plant–R1			R1–R5			R5–R8			Growing Season			
		Neutral	El Niño	La Niña	Neutral	El Niño	La Niña	Neutral	El Niño	La Niña	Neutral	El Niño	La Niña	All Years
Ciudad del Este	Min	16	127	64	94	117	112	36	44	49	414	408	275	275
	Max	436	506	358	519	302	400	600	609	430	1010	1158	867	1158
	Median	182	215	140	215	220	268	233	317	236	662	784	689	692
	Mean	207	261	151	248	212	255	228	319	243	683	793	649	699
Encarnación	Min	61	118	106	123	161	96	41	92	64	407	454	334	334
	Max	466	586	361	466	634	315	383	903	390	865	1675	895	1675
	Median	209	277	176	213	239	171	180	361	123	663	861	563	654
	Mean	234	304	192	234	263	202	176	372	169	645	939	563	683

the growing season varied from 275 mm in Ciudad del Este during the 1967/1968 growing season (La Niña) to 1675 mm in Encarnación during the 1957/1958 growing season (El Niño). Total precipitation during the growing season was, on average, lower during La Niña years and higher during El Niño years.

Figure 3 shows mean precipitation values observed in Ciudad del Este and Encarnación during each development phase. Duncan's test results indicated that precipitation means are significantly ($p < 0.05$) different between El Niño and La Niña years during the vegetative phase of development (Plant–R1) in Ciudad del Este and Encarnación. During the early reproductive phase between blooming and beginning seed formation, observed mean precipitation values were not significantly different between El Niño and La Niña years. During the seed-filling phase between beginning of seed formation and physiological maturity (R5–R8), mean precipitation during El Niño years was significantly different of La Niña years in Encarnación but not in Ciudad del Este. Nevertheless, mean precipitation observed in Ciudad del Este during El Niño years (319 mm) was 31.3% above the mean precipitation observed during La Niña years (243 mm).

Figures 4 and 5 show precipitation probability of exceeding graphs for Ciudad del Este and Encarnación, respectively. They demonstrate that in both locations the distribution of precipitation during the vegetative (Plant–R1) and the seed-filling (R5–R8) phases indicate higher probabilities of exceeding different precipitation levels during El Niño years, as compared to neutral and La Niña years. During initial reproductive stages, between blooming and commencement of seed stage (R1–R5), probability of exceeding different precipitation levels is less distinct among ENSO phases, both in Ciudad del Este and Encarnación.

3.3. Discussion and conclusions

Soybean yields in Paraguay have not followed the typical upward low-frequency trend resultant of technological improvements. By the end of the 1990s the trend reversed downward due to adverse weather in 2004, 2005

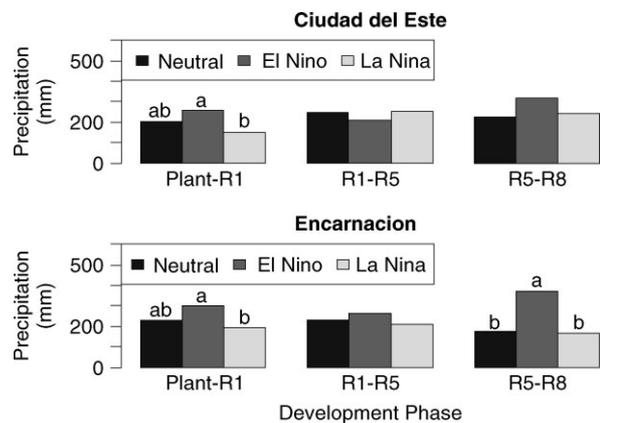


Figure 3. Mean precipitation for Ciudad del Este (top) and Encarnación (bottom) during neutral, El Niño and La Niña events. Soybean development phases 1: Planting to blooming stage (Plant–R1), 2: Blooming stage to start of seed stage (R1–R5), and 3: Start of seed stage to physiological maturity (R5–R8). Duncan's test grouping (a, b, ab), $p < 0.05$.

and 2006, and possibly, additional factors, such as the expansion to new areas and disease pressure. During the 2003/2004 and 2004/2005 growing seasons, classified as neutral years, total precipitation during the growing season amounted to 60 and 82%, respectively, of the long-term averages for each location. Most of the observed precipitation was measured during the vegetative phase of the crop development, resulting in stress during the reproductive phases. During the La Niña event of 2005/2006, total precipitation amounted to 70% of the long-term averages, but the deficit occurred primarily during the vegetative phase. Observed precipitation between planting and blooming in Ciudad del Este and Encarnación totaled 76 and 168 mm, respectively, corresponding to 37 and 72% of long-term averages observed during the vegetative phases in these locations. Soybean rust (*Phakopsora pachyrhizi*), a serious disease causing severe crop losses in many parts of the world, may have also depressed yields in the early 2000s. It was first detected in Paraguay in 2001, primarily affecting late planted soybean (Morel *et al.*, 2005). More recently, the yield trend has shown signs of improvement, sustained

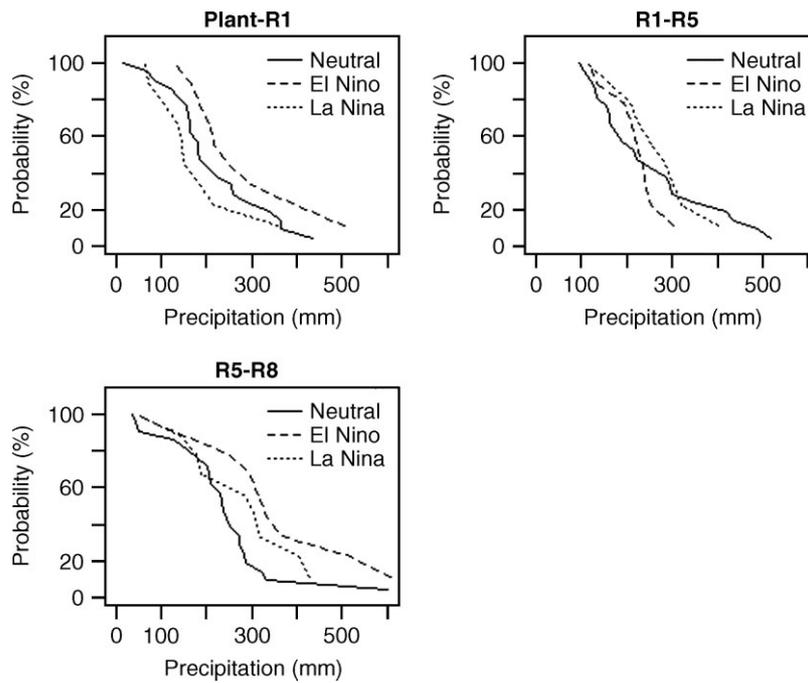


Figure 4. Precipitation probabilities of exceeding during planting to start of blooming (Plant–R1), blooming to commencement of seed stage (R1–R5), and seed stage to physiological maturity (R5–R8) for Ciudad del Este.

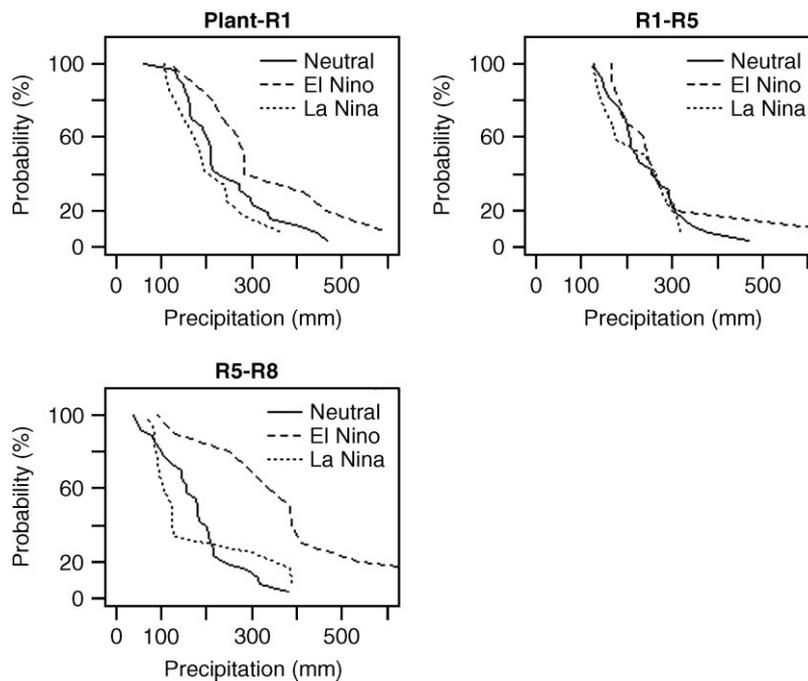


Figure 5. Precipitation probabilities of exceeding during planting to start of blooming (Plant–R1), blooming to start of seed stage (R1–R5), and start of seed stage to physiological maturity (R5–R8) for Encarnación.

by above-average yields obtained during the 2002/2003 and 2006/2007 El Niño seasons.

The analysis of relative yield residuals indicated that positive and negative residuals occurred in all ENSO phases. In the case of El Niño, calculated relative residuals were positive six out of seven events and varied from –9.4 to +24.2% for the 1991/1992 and 2002/2003

cropping seasons, respectively. During the strong El Niño events of 1982/1983 and 1997/1998, calculated relative residuals were 2.4 and 0.5%, respectively. Excessive rainfall was probably the reason for the modest gain in average yield. High moisture can depress yields by delaying planting, decreasing plant population, enhancing disease pressure, and causing harvest losses. Above

average precipitation was observed during the strong El Niño event of 1997/1998, totaling 1017 (45% above the long-term average), and 1304 mm (91% above the long-term average), for Ciudad del Este and Encarnación, respectively. During the high-yielding 2002/2003 El Niño season, observed precipitation gains in the two locations were less extreme, averaging 958 mm, 38% above the long-term averages, and well distributed throughout the season.

During La Niña years, calculated residuals were negative three out of four events and varied from -37.9 to $+1.5\%$ for the 2005/2006 and 1988/1989 cropping seasons, respectively. Lower precipitation during La Niña events, especially during the vegetative phase, is probably the main reason for lower yields. Average precipitation observed between planting and blooming during La Niña events corresponded to 74 and 83% of the long-term averages for the same time period in Ciudad del Este and Encarnación, respectively. At the time of planting, dry soils can prevent good germination with consequent low plant population and yield. Less than optimum canopy development can also enhance weed infestation problems. In addition, some pests and diseases such as slugs in no-till soybeans, and development of spotted spider mite problems are more prevalent during drought years.

This study explored the influences of ENSO on soybean yields and precipitation patterns during soybean development phases. Results confirmed our initial hypothesis that El Niño events are generally associated with above average soybean yields in eastern Paraguay, while La Niña events tend to result in lower yielding seasons. Analyses of precipitation patterns observed at Ciudad del Este, located in the Department of Itapúa, and Encarnación, located in the Department of Alto Paraná, demonstrated that El Niño (La Niña) events are associated with above (below) average precipitation during the cropping season, reinforcing previous findings in studies that analysed precipitation patterns in the region (e.g. Pisciotano *et al.*, 1994; Diaz *et al.*, 1998; Grimm *et al.*, 1998, 2000; Montecinos *et al.*, 2000). Mean precipitation during El Niño and La Niña events were significantly different during the vegetative phase of crop development both in Ciudad del Este and Encarnación and during the seed-filling phase in Encarnación.

We believe that this study is an important step towards better understanding soybean yield risks associated with climate variability in eastern Paraguay, however, it is somewhat limited by using a unique planting date and genotype to analyse production risks. Future research will explore the use of the CSM-CROPGRO-Soybean model to optimize soybean yield expectations under distinct ENSO phase scenarios, planting dates and genotypes.

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