Revista Brasileira de Agrometeorologia, Santa Maria, v. 7, n. 1, p. 127-138, 1999.
Recebido para publicação em 04/03/1999. Aprovado em 12/05/1999.

ISSN 0104-1347

ENSO INFLUENCES ON WHEAT CROP IN BRAZIL

INFLUÊNCIAS DO FENÔMENO ENSO SOBRE A CULTURA DE TRIGO NO BRASIL

Gilberto Rocca da Cunha[1], Genei Antonio Dalmago[2] and Valduino Estefanel[3]

SUMMARY

The El Niño-Southern Oscillation (ENSO) phenomenon or just El Niño, as commonly called, influences the climatic behavior in different areas of the world. In the case of Brazil, this phenomenon affects the northern part of the Northeast Region, the eastern Amazon (in the tropical area) and the extra-tropical area of the Southern Region. The climatic variability associated with the ENSO phenomenon phases, especially rainfall anomalies, may be quantified and this information can be effectively used by crop managers to reduce associated risks or to make better use of forthcoming favorable climatic conditions. The objective of this study was to identify the ENSO phases influencing wheat production in Brazil. The impact of these phases on grain yield was based on a historical series of yield data from 1920 to 1997. For 23 El Niño occurrences analyzed at national level, the deviations in wheat yield was negative in 61% of the cases. For 15 La Niña events, positive influences on wheat yields were observed in 73% of the cases. In the 40 neutral years, 55% of the time yield deviations were positive and 45% of the time were negative. Therefore, the ENSO phenomenon influences wheat yield in Brazil. In general, it causes positive impacts in La Niña years and negative impacts in El Niño years, particularly in the Southern part of the country.

Key words: El Niño, La Niña, ENSO, Southern Oscillation Index, climatic anomaly, wheat, Brazil.

RESUMO

O fenômeno El Niño-Oscilação do Sul (ENSO) influencia o comportamento do clima em diferentes regiões do mundo. No caso do Brasil, a parte norte da Região Nordeste e o leste da Amazônia (na faixa tropical) e a Região Sul (na faixa extra-tropical). Tendo em vista a possibilidade de quantificação da variabilidade climática associada às fases do fenômeno ENSO, vislumbra-se uma série de aplicações dessas informações no manejo de culturas, voltadas a reduzir riscos ou melhorar o aproveitamento de condições climáticas favoráveis. Este estudo teve por objetivo identificar a influência das fases do fenômeno ENSO sobre o rendimento da cultura de trigo no Brasil com base em análise da série histórica de 1920 a 1997. No país, para 23 episódios El Niño analisados, em 61% deles os desvios nos rendimentos foram negativos. Nos eventos La Niña (15 eventos) ocorreu o inverso, em 73% dos casos os desvios no rendimento de trigo foram positivos. E nos 40 anos considerados neutros, em 55% deles os desvios foram positivos e nos outros 45%, negativos. Portanto, na cultura de trigo, o fenômeno ENSO, em geral, causa impactos positivos, nos anos de La Niña, e negativos, nos anos de El Niño, particularmente no sul do país.

Palavras-chave: El Niño, La Niña, ENSO, Índice de Oscilação do Sul , anomalia climática, trigo, Brasil.

INTRODUCTION

The El Niño-Southern Oscillation (ENSO) phenomenon or just El Niño, as commonly referred, possesses two phases: a warm (El Niño) and a cold one (La Niña). The behavior of the sea surface temperature (SST) and deep oceanic waters over tropical Pacific Ocean (central and close to South American west coast) in association with pressure fields (represented by the Southern Oscillation Index) alters the pattern of general circulation of the atmosphere (Hadley and Walker cells), affecting consequently the climate in different areas of the world. General aspects of ENSO and its impacts in the global climate can be found, for example, in PHILANDER (1990), MOURA (1994), GLANTZ (1996) and NATIONAL RESEARCH COUNCIL (1996).

[1]Embrapa National Center for Wheat Research, Caixa Postal 451, CEP 99001-970 Passo Fundo, RS, Brazil. Fellow of CNPq-PQ.
[2]Fellow of CNPq – AP .
[3]University Federal of Santa Maria, 97105-900 Santa Maria, RS, Brazil.

Several areas in the world, whose climate is affected by the phases of ENSO, were identified by ROPELEWSKI & HALPERT (1987) and (1989). In the case of Brazil, the authors identify the northern part of the Northeast Region, eastern Amazon Region (in the tropical area) and the extra-tropical area of the Southern Region. The latest is inserted in a great area located in the southeastern South America, that also embraces Uruguay, and southeastern Paraguay and northeastern Argentina.

Several studies were performed to specifically study the impact of ENSO on Brazilian climate. ALVES & REPELLI (1992) and UVO et al. (1994) studied the Northeast Region of the country while GRIMM et al. (1996a), GRIMM et al. (1996b), and FONTANA & BERLATO (1997) addressed the impacts of the ENSO phenomenon phases on the South Region rainfall regime. The climatic anomalies caused by the ENSO phenomenon related to the rainfall regime are mostly studied and known for being of larger impact, although the thermal regime can also be modified by this phenomenon. In general, rainfall anomalies related to El Niño (warm waters in the tropical Pacific Ocean and negative Southern Oscillation Index) and to La Niña (cold waters in tropical Pacific Ocean and positive Southern Oscillation Index) reach the same areas in the same periods of the year (not necessarily covering the same exact months of the year in an opposite way, i. e., in those areas where there is excessive rainfall in El Niño years, drought periods can happen in La Niña years).

Particularly in the South of Brazil, excess of rainfall has occurred in El Niño years and drought in years of La Niña. There are two periods of the year which are mostly affected by the phases of ENSO: Spring and beginning of Summer (October, November and December) in the first year of the event, and end of Autumn and beginning of Winter (April, May and June) in the next year, as evidenced by GRIMM et al. (1996a) and (1996b) and FONTANA & BERLATO (1997). Consequently the chances of rainfall above of normal in these periods of the year are larger in the presence of the El Niño phenomenon, than for La Niña phenomenon, when the probability of rainfall below the normal is larger.

The non-predictable climatic variability is one of the main sources of risk to agricultural activities (HARDAKER et al., 1997). Most of the crop insurance clains in Brazilian agriculture are due to climatic causes. GÖEPFERT (1993) indicated rates of casualties of 16,27% in summer crops and of 21,64% in winter crops in Brazil.

It is possible to quantify the climatic variability associated to the ENSO phases, mainly rainfall anomalies, as pointed out by ROPELEWSKI & HALPERT (1996), STONE et al. (1996) and DIAZ et al. (1998), as well as forecasting ENSO indicators like Southern Oscillation Index through statistical schemes or physical models up to an year in advance (LATIF et al., 1994). This type of information can be applied on crop management, giving the possibility of reducing associated risks and improving the chances of better use of favorable climatic conditions.

Several studies were performed concerning relationship between ENSO phenomenon phases, its associated climatic variability, and crop yield. CANE et al. (1994) found a correlation explaining more than 60% of the variance among El Niño, rainfall indexes and corn yield in Zimbabwe, South Africa; KEPPENE (1995) identified an ENSO signal in soybean futures prices; CARLSON et al. (1996) studied corn yield and weather in Midwestern USA in relation to extreme Southern Oscillation; FONTANA & BERLATO (1996) analyzed the influence of ENSO over rainfall and maize yield in the state of Rio Grande do Sul (Brazil); RAO et al. (1997) found strong positive correlation between Southern Oscillation Index (SOI) and corn yield in seven of the nine states of Northeastern Brazil; MJELDE & KEPLINGER (1998) examined the impact of Southern Oscillation extreme events in estimating and forecasting Texas (USA) sorghum and winter wheat yields; and HANSEN et al. (1998) evaluated the economic impact of ENSO events on the Southeastern United States agriculture.

In the wheat production region of Brazil, the following circumstances are often referred to as potential elements of weather-related risks for small grain crops: water excess and/or deficiency, frost, high temperatures, high relative humidity (favoring diseases), wind lodging, hail, etc. Therefore, the objective of this study was to determine the impact of ENSO phases and the climatic variability associated on wheat grain yield in Brazil.

MATERIAL AND METHODS

Historical series data of wheat grain yield in Brazil between 1920 and 1997, originated from IBGE (Brazilian Institute for Geography and Statistics), Bank of Brazil-CTRIN, and other Brazilian institutions like Conab/Dipla/Depos, were analyzed in relation to its variability according to the phases of El Niño-Southern Oscillation, El Niño, La Niña, and neutral years. The annual average yield of wheat (kg/ha) data was organized by state means (Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Mato Grosso do Sul and Minas Gerais) and country mean.

The original data for the wheat yield historical series (1920-1997) were initially submitted to regression analysis, where the year was considered as the independent variable in order to separate the effect of the technologies incorporated into the production system along the time on the wheat yield due to the climatic variability among years. Starting from the best adjusted regression model (the r^2 approach), the technological trend associated to the data was removed using the formula:

$$Yci = (Yi-(Y(Xi)-Y(Xo))) \quad (1)$$

Where, Yci = corrected yield of the year i, Yi = original yield of the year i, Y(Xi) = yield of the year i estimated by the regression model, and Y(Xo) = yield of the first year of the historical series estimated by the regression model.

The annual deviations of wheat yield in relation to the average of the historical series were calculated starting from the corrected yield values, i.e. after detrending the original series. This data were expressed in kg/ha and in units of standard deviation.

During the considered period, the years were classified in agreement with the ENSO phase (El Niño, La Niña, and neutral years), based on the SOI values (ROPELEWSKY & JONES, 1987). According to that, those years with SOI values smaller or equal to -0,5 during five or more consecutive months were considered as El Niño years and La Niña years were those with SOI values equal or larger than 0,5 for at least five consecutive months.

The time period contemplated in this study includes the following El Niño events (the starting year of the phenomenon): 1923, 1925, 1930, 1932, 1939, 1940, 1941, 1946, 1951, 1957, 1963, 1965, 1969, 1972, 1976, 1977, 1982, 1986, 1991, 1992, 1993, 1994, and 1997. La Niña grouped the following years (the starting year of the event): 1920, 1924, 1928, 1931, 1938, 1942, 1949, 1954, 1964, 1970, 1973, 1975, 1988, 1995, and 1996. All remaining years were classified as neutral years.

RESULTS AND DISCUSSION

Wheat in Brazil has been cultivated mainly in the Southern Region, where Paraná (PR) and Rio Grande do Sul (RS) are the main producing states. Wheat has also been grown in Santa Catarina State (SC), even though in a smaller scale. Wheat statistics are also available for Mato Grosso do Sul (MS), São Paulo (SP) and Minas Gerais (MG) states. Due to their importance for the total Brazilian wheat production, and considering the sensitivity of this area to climatic variations associated to the ENSO phenomenon phases, the results obtained for the states of the Southern Region (PR, RS and SC; in this order, for the importance of the crop) will be first presented and discussed. Afterwards, the effects on the average wheat yield in MS, SP, and MG, as well as at country level will be discussed.

The average wheat yielding variability in the states of Paraná, Rio Grande do Sul, and Santa Catarina, from 1920 to 1997, is shown in Figure 1. Parts (a), (c) and (e) of this figure contemplate the original historical series, showing a quadratic growth trend for the average yield as a function of the year, which could be explained by the incorporation of new technologies in the production system, such as cultivar with higher yielding potential and improvement of the crop management practices (mainly fertilization and diseases and pests control). From 1920 to 1940 wheat yields in Brazil were decreasing, mostly due to diseases and lack of adaptation to soil low pH. However, in the 40's with the release of improved cultivars (for instance the cultivar Frontana, released in 1940) this trend was reversed. A good review of the wheat breeding history in Brazil can be found in LAGOS (1983). Parts (b), (d) and (f) of Figure 1 contain the same historical yield series correcting for the technological trend associated to the data and stressing the effect of the climatic variability on the crop yield.

Figure 2, parts (a), (b) and (c), shows the deviations for the corrected average wheat yielding, i.e., without the technological trend effects, in the states of Paraná, Rio Grande do Sul, and Santa Catarina, respectively. These deviations are expressed in kg/ha and are positive or negative if the corrected yield the year was above or below the average of the historical series. The bars are black, white and gray colors, in agreement with El Niño's, La Niña's, and neutral years classification. In the time period considered in this study, 78 years, 23 El Niño events and 15 La Niña events were observed. The other 40 years were neutral years. The analysis of Figure 2 and the data presented on Table 1 demonstrate that the impacts of El Niño events are, most of the time, negative on the yield of wheat in the three states of the Southern Region of Brazil. The opposite happens during La Niña years, when the predominant impacts are positive. In neutral years, impacts are mainly positive. The Figure 2 also shows that mean deviation for the ENSO events in the 60's, the 70's, and the 80's were more pronounced than other periods. These events not only were more frequent in these periods but also were stronger, causing more impact on the interannual climatic variability.

The curves of yield deviations accumulated probability, expressed in percentage of the average yield, are shown in Figure 3. The behavior of the curves in the El Niño years (▬▬), La Niña years (——) and in the years considered without distinction among El Niño, La Niña or neutral years (········) reinforces the indication that the worst years for wheat production (larger probabilities of negative yield deviations) are those classified as years of El Niño. On the other hand, La Niña years are the most favorable ones, for they are associated with larger probabilities of positive yield deviations. The separation among the curves of accumulated probability, where the one that represents La Niña years moved more to the right of the figure further than the one that represents years of El Niño, reinforces the inference that stochastically La Niña years are dominant in relation to El Niño years. In other words, there are greater chances of having positive deviations in wheat yield in the years of La Niña and

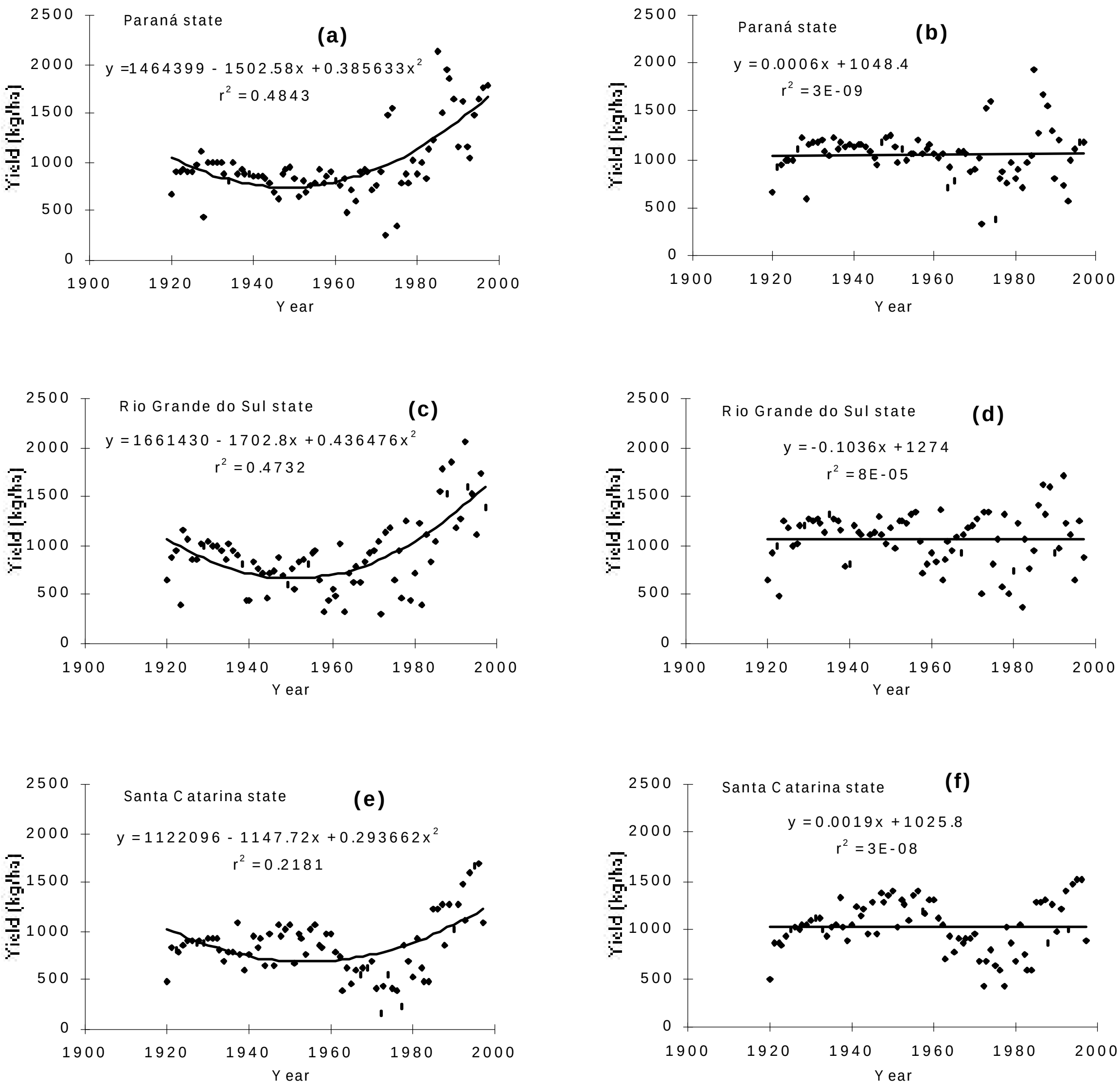

Figure 1. Wheat yield (kg/ha) time series [(a), (c), and (e)] and resulting detrend time series [(b), (d), and (f)], from 1920 to 1997, for Paraná, Rio Grande do Sul, and Santa Catarina states, respectively.

greater chances of having negative yield deviations in El Niño years.

The original historical wheat yield series for the states of Mato Grosso do Sul (from 1971 to 1997), São Paulo (from 1952 to 1997), and Minas Gerais (from 1976 to 1997) are presented in Figure 4, parts (a), (c) and (e) respectively. The data indicate a linear trend of average yield growth in these states as a function of the year. The same historical series, without technological trend, is presented in parts (b), (d) and (f) of this figure, as well as the yield variability due to no technological causes.

The deviations of the corrected yield for the states of Mato Grosso do Sul, São Paulo, and Minas Gerais in relation to the average of the historical series are shown at part (a), (b) and (c), respectively, of Figure 5. The ENSO events are identified by the colors of the bars where El Niño is shown in black, La Niña in white, and neutral year in gray.

In these three states, the regional influence of the phases of ENSO on the climate is not as evident as it is in Southern Brazil. However, since this later analysis is based on a shorter historical series of yield data, such results should be seen with some caution. Nevertheless, the deviations observed in Figure 4 and the data presented in Table 1 indicate larger occurrence

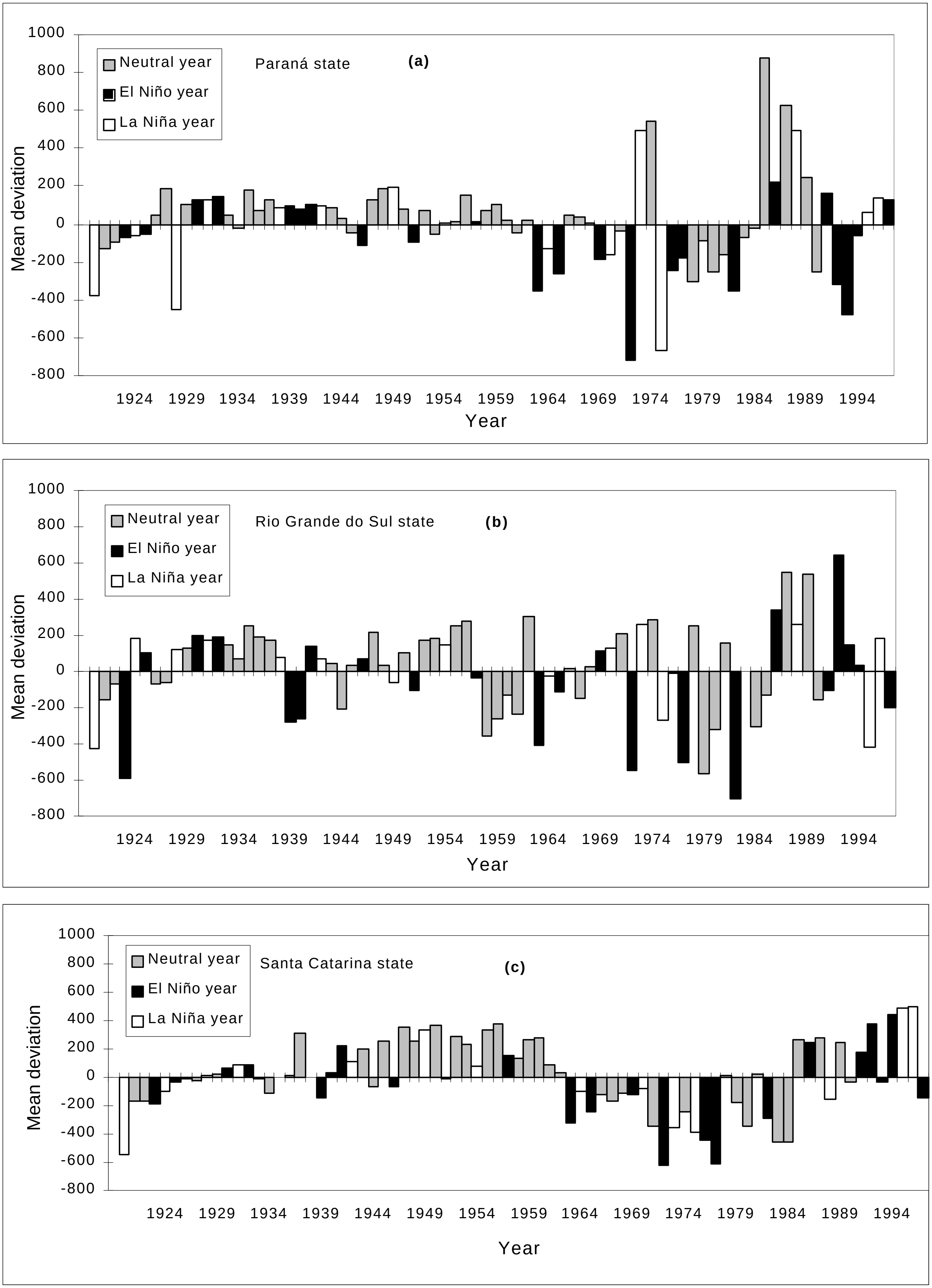

Figure 2. Wheat yield mean deviation (kg/ha) resulted to ENSO phenomenon phase for Paraná (a), Rio Grande do Sul (b), and Santa Catarina (c) states, from 1920 to 1997.

Table 1 . Positive and negative ocurrences of mean deviation in wheat yield from Brazil related to ENSO Phenomenon phases, 1920 to 1997.

State	Period	El Niño years +	El Niño years -	El Niño years Total	La Niña years +	La Niña years -	La Niña years Total	Neutral years +	Neutral years -	Neutral years Total	Total years
Paraná	1920-1997	9 (39%)	14 (61%)	23 (29%)	9 (60%)	6 (40%)	15 (19%)	26 (65%)	14 (35%)	40 (52%)	78 (100%)
Rio G. do Sul	1920-1997	10 (43%)	13 (57%)	23 (29%)	10 (67%)	5 (33%)	15 (19%)	25 (63%)	15 (37%)	40 (52%)	78 (100%)
Santa Catarina	1920-1997	9 (39%)	14 (61%)	23 (29%)	8 (53%)	7 (47%)	15 (19%)	22 (55%)	18 (45%)	40 (52%)	78 (100%)
Mato G. do Sul	1971-1997	3 (30%)	7 (70%)	10 (37%)	2 (40%)	3 (60%)	5 (18%)	8 (67%)	4 (33%)	12 (45%)	27 (100%)
São Paulo	1952-1997	6 (43%)	8 (57%)	14 (30%)	6 (75%)	2 (25%)	8 (17%)	12 (50%)	12 (50%)	24 (53%)	46 (100%)
Minas Gerais	1976-1997	4 (44%)	5 (56%)	9 (41%)	3 (100%)	0 (0%)	3 (14%)	3 (30%)	7 (70%)	10 (45%)	22 (100%)
Brazil	1920-1997	9 (39%)	14 (61%)	23 (29%)	11 (73%)	4 (27%)	15 (19%)	22 (55%)	18 (45%)	40 (52%)	78 (100%)

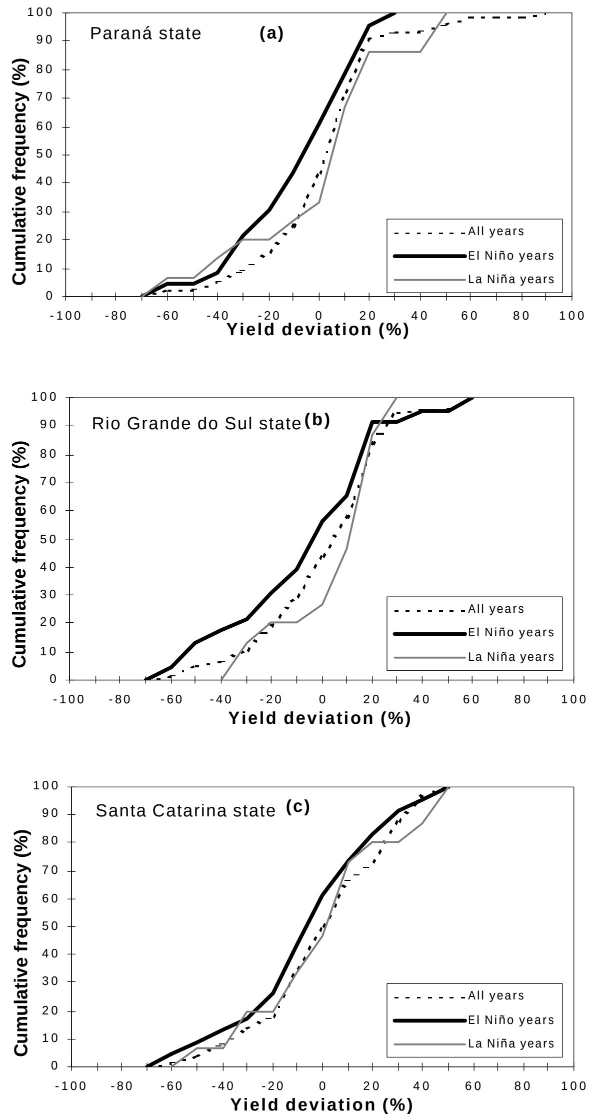

Figure 3. Cumulative frequency (%) of wheat yield deviations in response to ENSO phase for Paraná (a), Rio Grande do Sul (b), and Santa Catarina (c) states, time series from 1920 to 1997.

of negative yield deviations in years of El Niño, than in La Niña or neutral years, while negative yield deviations prevailed in El Niño episodes as well as in La Niña episodes in the state of Mato Grosso do Sul . This uncertainty is better demonstrated through the analysis of the curves of accumulated probability yield deviations (Figure 6). In this Figure, part (b), the largest chances of negative yield deviations in years of El Niño (curve moves to the left) and of positive deviations (curve moves to the right) in years of La Niña are defined

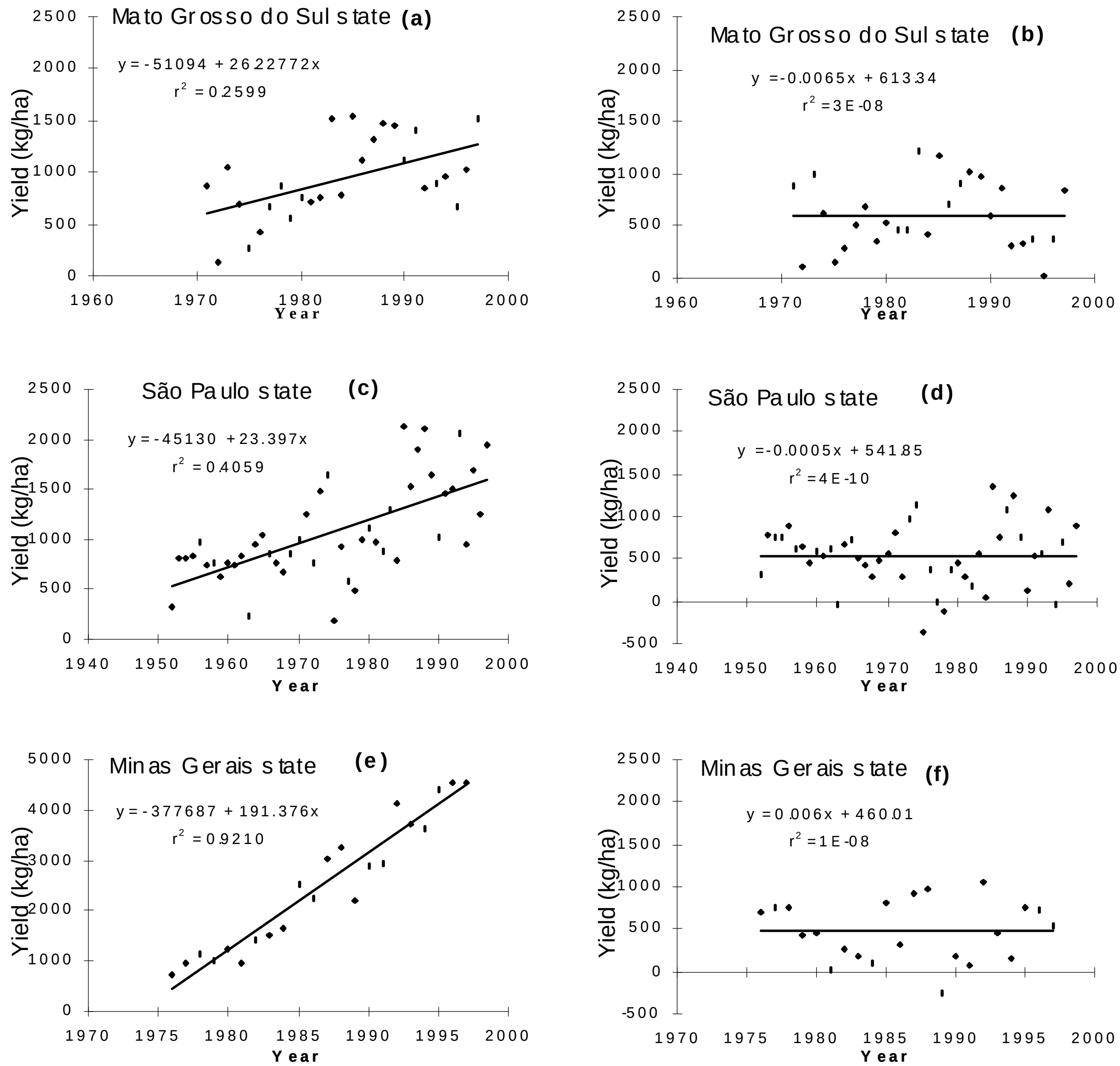

Figure 4. Wheat yield (kg/ha) time series [(a), (c), and (e)] and resulting detrend time series[(b), (d), and (f)], from 1952 to 1997, for Mato Grosso do Sul, São Paulo and Minas Gerais states, respectively.

stochastically just for the state of São Paulo.

Considering the whole set of wheat yield data for the period between 1920 and 1997 for the entire country presented in Figure 7, part (a), a quadratic trend in the elevation of the mean yield in function of the year can be observed. This tendency can be attributed to technological progresses incorporated into Brazilian wheat crop. Part (b) of the Figure 7 shows the variability of wheat yield in Brazil due to non-technological reasons, since this trend detected on the original series was now removed.

The states of Rio Grande do Sul and Paraná have the largest influence in the composition of wheat statistics at national level. This fact could account for the fact that the curves for, national yield deviations in relation to the historical average presented on Figure 7, part (c) and the representation of the curves of accumulated national yield deviations probabilities showed on Figure 7, part (d) are very similar to the same curves obtained for those two states, Rio Grande do Sul and Paraná. Stochastically, there is a dominance of first order (accumulated curves of probability do not cross, Figure 7, part (d)) of La Niña events in relation

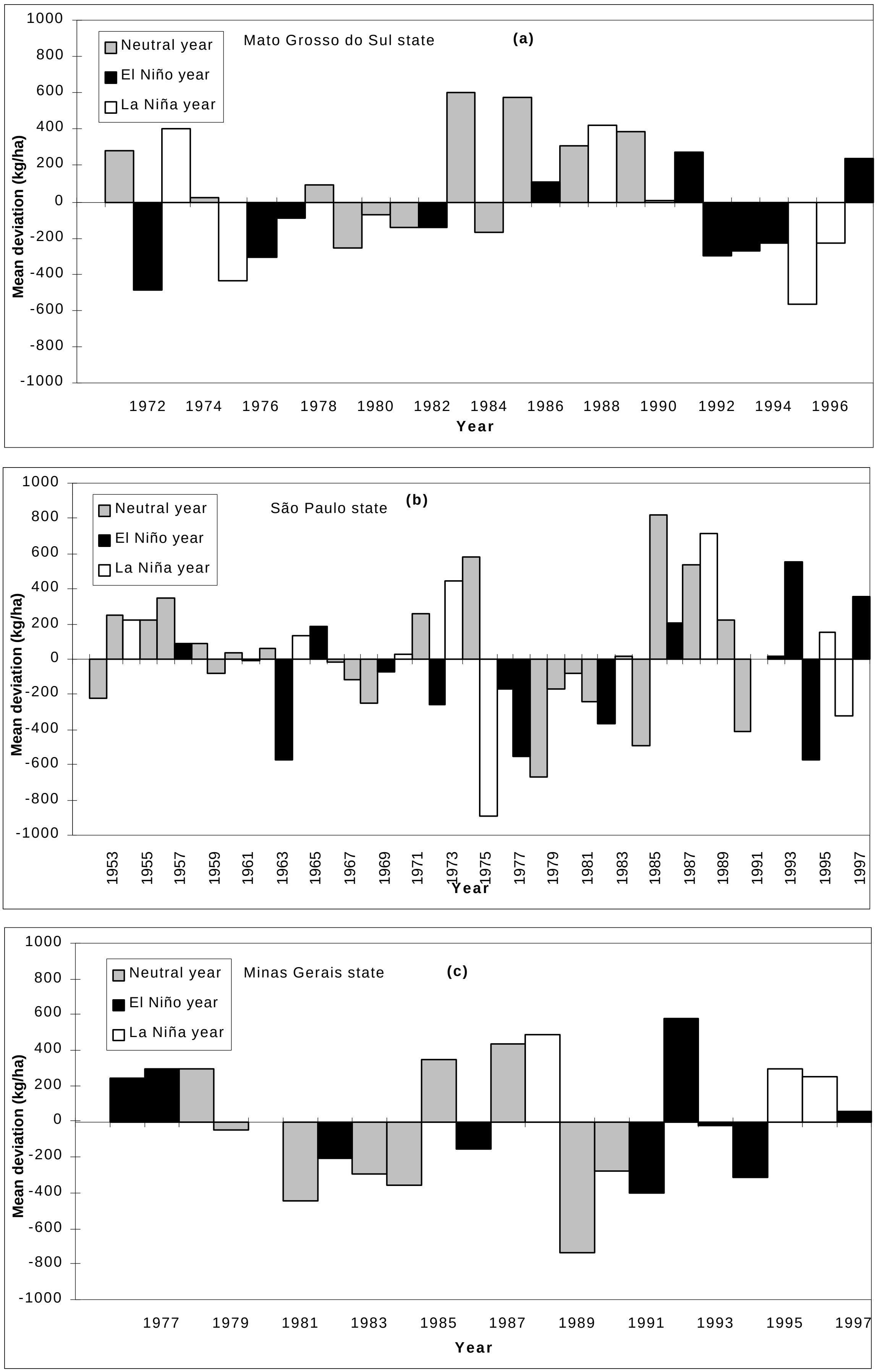

Figure 5. Wheat yield mean deviation (kg/ha) related to ENSO phenomenon phase for Mato Grosso do Sul (a), São Paulo (b), and Minas Gerais (c) states,

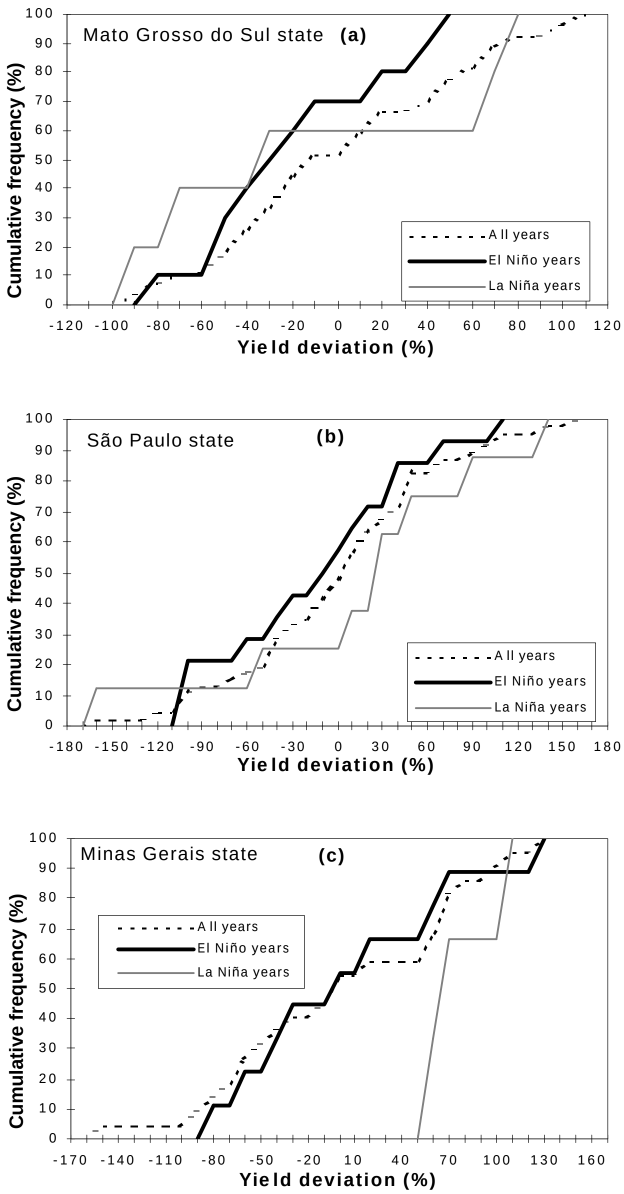

Figure 6. Cumulative frequency (%) of wheat yield deviations in reponse to ENSO phase for Mato Grosso do Sul (a), São Paulo (b), and Minas Gerais (c) states, time series from 1952 to 1997.

to El Niño events regarding the chances of bringing positive impacts on wheat yield in Brazil.

The data presented on Table 1 reinforces what is observed in Figure 7. In 23 El Niño episodes analyzed, the deviations in wheat yields were negative in 61% of the cases. In 15 La Niña considered events, the inverse was true, i. e., in 73% of the cases the deviations in yield were positive, i. e. above the expected yield. And in 40 neutral considered years, the deviations were positive in 55% of the years, remaining negative in the other 45%.

The behavior of the variability of wheat yield in Brazil in relation to the phases of the phenomenon ENSO can be explained by its influence on rainfall anomalies in the spring period and beginning of summer in the South of Brazil (GRIMM et al., 1996a and 1996b and FONTANA & BERLATO, 1997). Great part of the national wheat production is concentrated in this area, where the states of Paraná and Rio Grande do Sul are located. Excess of rainfall during the wheat growing season, as observed in years of El Niño, creates favorable environmental condition for the development of diseases. Besides the saturation of the soil with water and the reduction of sunshine period duration verified in rainy days, a reduction on the root system and aerial part (dry mass) growth are also observed, having a negative effect on wheat yield components, according to studies accomplished in the Southern Brazil by WENDT & CAETANO (1985) and SHEEREN et al. (1995a, 1995b). For the El Niño event of 1997, BERLATO & FONTANA (1997) estimated losses of 568,681 tons of grains in this region, where 82% would be due to losses of wheat yield. Nevertheless, the negative impact of El Niño on wheat yield in Brazil depends mainly on the intensity of the phenomenon and the anomaly caused in the rainfall regime. According to GALVANI & PEREIRA (1997), the episodes can be classified as weak, moderate or strong (based on SOI annual mean).

From the exposed, the largest risk for wheat cultivation in Brazil in years when the phenomenon El Niño occurs is evident as function of the importance of the Southern states for the brazilian wheat production. The larger chances of positive climatic impacts occur in La Niña years, followed by neutral years. That is due to the behavior of the rainfall distribution in the South Region of Brazil in association with the phases of the ENSO phenomenon. In a similar study performed in Argentina, GRONDONA et al. (1997) found an erratic answer for the wheat yield in relation to the phases of ENSO. However, the largest yield increase was verified in an year of La Niña and the largest yield reduction was verified in an year of El Niño. The ENSO phenomenon causes similar impact on the rainfall distribution of the Pampeana Region of Argentina as the one observed in the South Region of Brazil.

CONCLUSION

The ENSO phenomenon influences the yield of the wheat crop in Brazil. In general, it causes a positive impact in La Niña years, and a negative impact in El Niño's years; particularly in the South Region of Brazil.

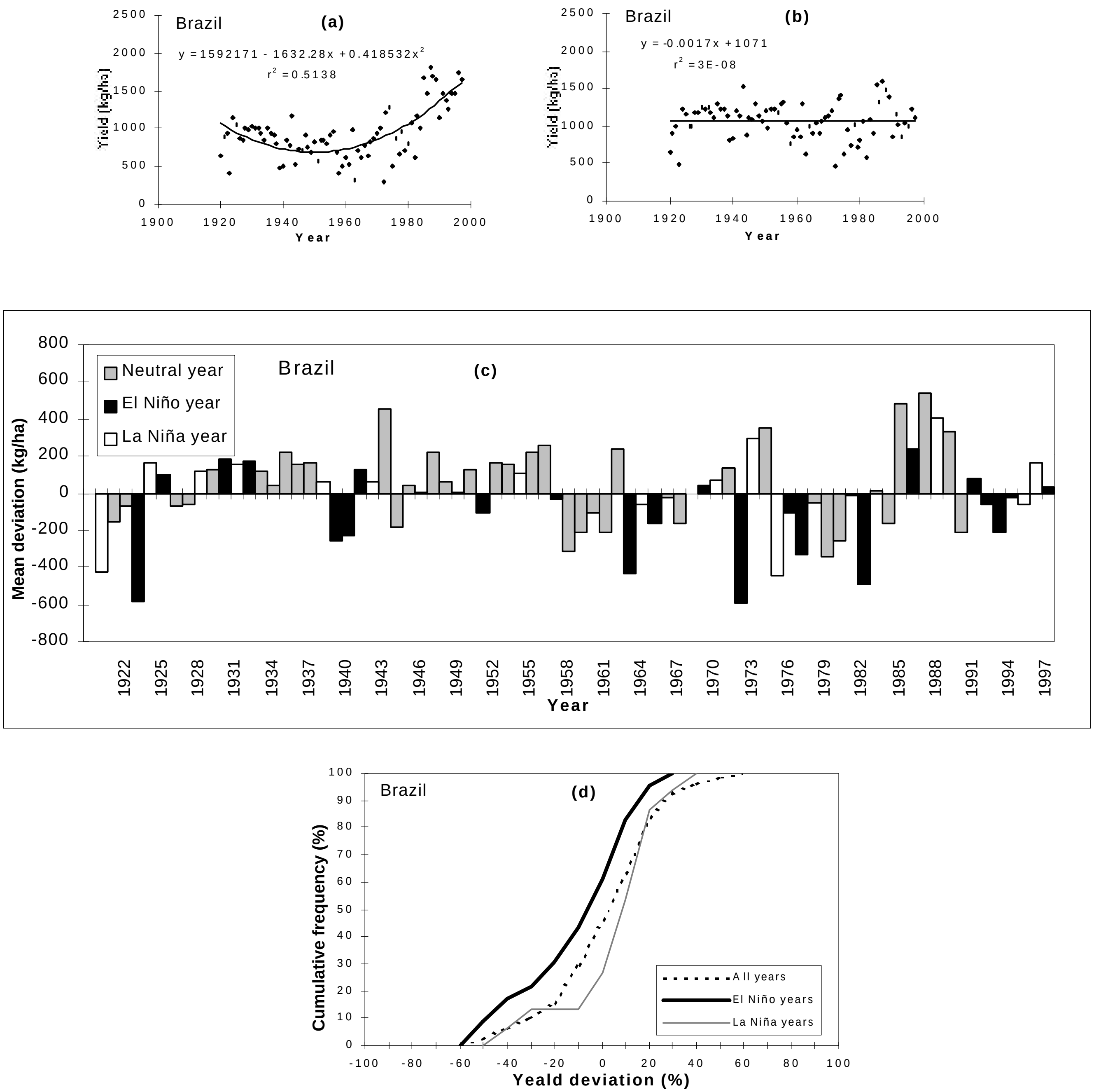

Figure 7. Wheat yield (kg/ha) original (a) and detrend (b) time serie, wheat yield mean deviation (kg/ha) (c), and cumulative frequency (%) of wheat yield in Brazil (d) related to ENSO phenomenon phase, from 1920 to 1997.

ACKNOWLEDGMENT

Our special thanks to dr. Ana Christina Albuquerque Zanatta and dr. Erivelton Scherer Roman for revising the translation of this paper.

REFERENCES

ALVES, J.M.B., REPELLI, C.A. A variabilidade pluviométrica no setor norte do nordeste e os eventos El Niño - oscilação sul (enos). **Revista Brasileira de Meteorologia**, São Paulo, v. 7, n. 2, p. 583-592, 1992.

BERLATO, M.A., FONTANA, D.C. El Niño oscilação sul e a agricultura da região sul do Brasil. In: BERRI, G.J., comp. **Efectos de El Niño sobre la variabilidad climática, agricultura y recursos hídricos en el sudeste de sudamérica**. [Buenos Aires] : Ministerio de Cultura y Educación - Secretaría de Ciencia y Tecnología, [1997]. 39 p. p. 27-30. (Taller y Conferencia sobre El Niño 1997/98, Montevideo, Uruguay, 1997)

CANE, M.A., ESHEL, G., BUCKLAND, R.W. Forecasting zimbabwean maize yield using eastern equatorial Pacific sea surface temperature. **Nature**, London, v. 370, p. 204-205, july 1994.

CARLSON, R.E., TODEY, D.P., TAYLOR, S.E. Midwestern corn yield and weather in relation to extremes of the southern oscillation. **Journal of Production Agriculture**, Madison, v. 9, n. 3, p. 347-352, 1996

DIAZ, A.F., STUDZINSKI, C.D., MECHOSO, C.R. Relationships between precipitation anomalies in Uruguay and southern Brazil and sea surface temperature in the pacific and atlantic oceans. **Journal of Climate**, Boston, v. 11, n. 2, p. 251-271, 1998.

FONTANA, D.C., BERLATO, M.A. Relação entre El Niño oscilação sul (ENOS), precipitação e rendimento de milho no estado do Rio Grande do Sul. **Pesquisa Agropecuária Gaúcha**, Porto Alegre, v. 2, n. 1, p. 39-45, 1996.

FONTANA, D.C., BERLATO, M.A. Influência do El Niño oscilação sul sobre a precipitação pluvial no estado do Rio Grande do Sul. **Revista Brasileira de Agrometeorologia**, Santa Maria, v. 5, n. 1, p. 127-132, 1997.

GLANTZ, M.H. **Current of change: El Niño's impact on climate and society.** Cambridge : University of Cambridge, 1996. 194 p.

GRIMM, A.M., TELEGINSKI, S.E., COSTA, S.M.S. da, et al. Anomalias de precipitação no sul do Brasil em eventos La Niña. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 9.,1996, Campos do Jordão, SP. **Anais**..., Rio de Janeiro : Sociedade Brasileira de Meteorologia / Universidade Federal do Rio de Janeiro, 1996a. v. 2. 1499 p. p. 1113-1117.

GRIMM, A.M., TELEGINSKI, S.E., FREITAS, E.D. de, et al. Anomalias de precipitação no sul do Brasil em eventos El Niño. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 9., 1996, Campos do Jordão, SP. **Anais**..., Rio de Janeiro : Sociedade Brasileira de Meteorologia / Universidade Federal do Rio de Janeiro, 1996b. v. 2. 1499 p. p. 1098-1102.

GÖEPFERT, H., coord. **Eventos generalizados e securidade agrícola**. Brasília: IPEA, 1993. 65 p.

GRONDONA, M.O., MAGRIN, G.O., TRAVASSO, M.I., et al. Impacto del fenomeno "El Niño" sobre la produccion de trigo y maiz en la region pampeana Argentina. In: BERRI, G.J., comp. **Efectos de El Niño sobre la variabilidad climática, agricultura y recursos hídricos en el sudeste de sudamérica**. [Buenos Aires]: Ministerio de Cultura y Educación - Secretaría de Ciencia y Tecnología, [1997]. 39 p. p. 13-18. (Taller y Conferencia sobre El Niño 1997/98, Montevideo, Uruguay, 1997)

HANSEN, J.W., HODGES, A.W., JONES, J.W. ENSO influences on agriculture in the southern United States. **Journal of Climate**, Boston, v. 11, n. 3, p. 404-411, 1998.

HARDAKER, J.B., HUIRNE, R.B.M., ANDERSON, J.R. **Coping with risk in agriculture**. Oxon : CAB International, 1997. 274 p.

LAGOS, M.B. **História do melhoramento do trigo no Brasil**. Porto Alegre: Instituto de Pesquisas Agronômicas, 1983. 80 p. (Boletim Técnico, 10)

LATIF, M., BARNETT, T.P., CANE, M.A., et al. A review of ENSO prediction studies. **Climate Dynamics**, Berlin, v. 9, p. 167-179, 1994.

MJELDE, J.W., KEPLINGER, K. Using the southern oscillation to forecast Texas winter wheat and sorghum crop yields. **Journal of Climate**, Boston, v. 11, n. 1, p. 54-60, 1998.

MOURA, A.D. Prospects for seasonal-to-interannual climate prediction and applications for sustainable development**. World Meteorological Organization Bulletin**, Geneva, v. 43, n. 3, p. 207-215, july 1994.

KEPPENNE, C.L. An ENSO signal in soybean futures prices. **Journal of Climate**, Boston, v. 8, n. 6, p. 1685-1689, 1995.

NATIONAL RESEARCH COUNCIL. **Learning to predict climate variations associated with El Niño and the southern oscillation**. Washington : National Academy Press, 1996. 171 p.

PHILANDER, S.G. **El Niño, La Niña, and the southern oscillation**. San Diego: Academic Press, 1990. 293 p.

RAO, V.B., SÁ, L.D.A., FRANCHITO, S.H., et al. Interannual variations of rainfall and corn yields in northeast Brazil. **Agricultural and Forest Meteorology**, Amsterdam, v. 85, n. 1/2, p. 63-74, 1997.

ROPELEWSKI, C.F., HALPERT, M.S. Global and regional scale precipitation associated with El Niño/southern oscillation. **Monthly Weather Review**, v. 115, p. 1606-1626, 1987.

ROPELEWSKI, C.F., HALPERT, M.S. Precipitation patterns associated with the high index phase of the southern oscillation. **Journal of Climate**, v. 4, p. 268-284, 1989.

ROPELEWSKI, C.F., HALPERT, M.S. Quantifying southern oscillation - precipitation relationships. **Journal of Climate**, Boston, v. 9, n. 5, p.1043-1059, 1996.

ROPELEWISKY, C.F., JONES, P.D. Na extension of the Tahiti-Darwin southern oscillation index. **Monthly Weather Review, Washington**, v. 115, p. 2161-2165. 1987.

SCHEEREN, P.L., CARVALHO, F.I.F. de, FEDERIZZI, L.C. Respostas do trigo aos estresses causados por baixa luminosidade e/ou excesso de água no solo. I. Teste em casa de vegetação. **Pesquisa Agropecuária Brasileira**, Brasília, v. 30, n. 8, p. 1041-1048, 1995.

SCHEEREN, P.L., CARVALHO, F.I.F. de, FEDERIZZI, L.C. Respostas do trigo aos estresses causados por baixa luminosidade e/ou excesso de água no solo. II. Teste no campo. **Pesquisa Agropecuária Brasileira**, Brasília, v. 30, n. 5, p. 605-619, 1995.

STONE, R.C., HAMMER, G.L., MARCUSSEN, T. Prediction of global rainfall probabilities using phases of the southern oscillation index. **Nature**, London, v. 384, p. 252-255, nov., 1996.

UVO, C.B., REPELLI, C.A., ZEBIAK, S., et al. **A study on the influence of the pacific and atlantic SST on the northeast Brazil monthly precipitation using singular value decomposition (SVD)**. São José dos Campos: INPE, 1994. 30 p. (Report of I International Training Course on Practical and Theoretical Aspects of Short Term Climate Prediction, Columbia, apr. 1993 - jan. 1994)

WENDT,W.,CAETANO,V.R. **Efeito do sombreamento artificial em trigo**. [S.1.: s.n.], 1985. 7 p. Trabalho apresentado no IV Congresso Brasileiro de Agrometeorologia, 1985, Londrina, PR.