Climate and Rainfed Agriculture in Northeast Brazil

José Maria Brabo Alves[1], Jacques Servain[2] and José Nilson B. Campos[1]

[1]Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME)/ Departamento de Engenharia Hidráulica e Ambiental, Centro de Tecnologia, Universidade Federal do Ceará (UFC), Fortaleza, Ceará, Brazil
[2]Institut de Recherche pour le Développement (IRD), UMR-182, Paris, France. Currently visiting scientist at FUNCEME

ABSTRACT

The statistical relationship between the sea surface temperature variability over the tropical oceans and the 1952-2000 crops of beans and maize in the Ceará State of Brazil was investigated. This region receives precipitation only during February–May. The climatic indices over the tropics were the Niño-3 for the Pacific and the dipole index for the Atlantic. In a first series of diagnostic analyses, the climatic precursor variables were examined during November–January (years 0–1) for the Niño-3 index and during February–April (year 1) for the Atlantic dipole components. The agronomic variables were the planted area, annual production, yield (which showed a problematic negative linear trend during the study period), price, and aggregate value for year 1. A more robust statistical weight was obtained with the Atlantic dipole. The Pacific weight added to, or on the contrary decreased, the Atlantic effect. Ocean climatic conditions that generate drought episodes in the *Nordeste* are generally associated with bad harvests. The reverse effect is not systematic.

Key Words: Climate variability · Northeast Brazil (*Nordeste*) · Climatic impact · Rainfed agriculture

INTRODUCTION

Many studies worldwide have shown the importance of climatic variability in agricultural production and financial income from crops (Handler 1990, Semenov & Porter 1995, Carlson et al. 1996, Hansen et al. 1998, Sivakumar 2006). The techniques recently used in seasonal climate forecasting confront challenges in predicting the variations in crop production early enough to adjust critical decisions (Doblas-Reyes et al. 2006, Hansen & Sivakumar 2006, Rubas et al. 2006) that may, in turn, have a positive impact on rural society (Smit et al. 1996, Hansen et al. 2006, Adams et al. 1999). For emergent and developing countries, where the practice of soil conservation is often not widespread (Cane et al. 1994), and where the decision-making process is often deficient (Vogel & O'Brien 2006), this issue is not trivial. The socio-economic impact of forecasting is even more intense in areas where recurrent abnormal climatic variations prevent the annual regulation of crops (Garnet & Khandekar 1992), and where the small educated rural population has multiple difficulties to adapt (Brou et al. 2005). Among the areas in the world where such difficulties prevail, the Ceará State in the northern part of northeast Brazilian (hereafter called *Nordeste*) (Fig. 1) is an excellent academic example. There, the vulnerability of subsistence agriculture affects more than one million people, for whom it is the primary source of survival (Magalhães & Glantz 1992; Lemos et al. 2004).

Ninety-three percent of the Ceará State (146,300 km^2) is influenced by a semi-arid climate, with great seasonal and inter-annual variability in the rainfall regime. This rainy season is roughly limited to four months, with more than 60% of the total rainfall (about 650 mm/year on average) occurring in February-May. This is directly linked to the southward migration of the inter-tropical convergence zone (ITCZ), itself controlled to a large extent by the delayed feedback from the sea-surface temperature (SST) variability over the tropical oceans (*e.g.*, Hastenrath

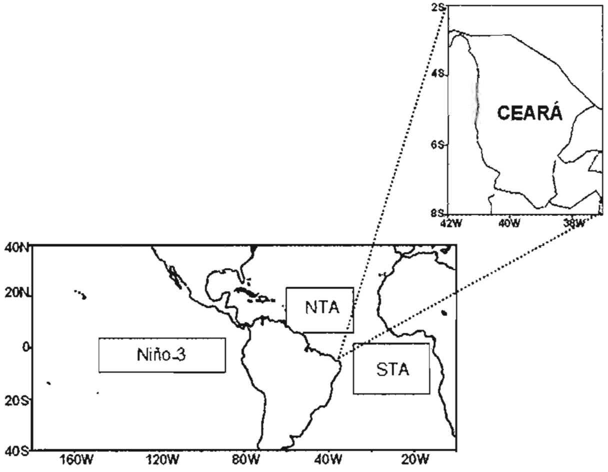

Figure 1 *– Niño-3, NTA, and STA areas used in this analysis of monthly SST anomaly indices. The Atlantic SST dipole index is the arithmetic difference in the SST anomalies between the NTA and STA areas. The Ceará State's limits are indicated on a zoom.*

& Greishar 1993). Any abnormal climatic event in these tropical oceans leads to an abnormal latitudinal displacement and/or intensity of the ITCZ. When such an anomalous climatic event occurs in the months around the end or beginning of a year, it may lead to a disruption in the seasonal rainfall of the *Nordeste* a few weeks later, with a consequent impact on rainfed crops.

The main objective of this study was to present an analysis of the impact of the Pacific and Atlantic tropical SST variability on the quality and quantity of rainfed agriculture in the Ceará State. The period studied was 1952-2000, which includes a good sample of drought years, flood years, and years considered normal in the *Nordeste*. The economic responses are measured here in terms of various agricultural variables for the two major rainfed crops in Ceará State, beans (*Phaseolus vulgaris L.*) and maize (*Zea mays*), traditional species that have been grown for at least a century. These crops are mainly consumed by humans and animals on a regional level in the *Nordeste*, what strongly attenuates any unspecified effects of external markets.

DATA SETS AND FIRST DIAGNOSTIC ANALYSES

Agronomic Variables

Rainfed data were collected by the *Instituto Brasileiro de Geografia e Estatistica* and compiled by the *Instituto de Planjeamento do Ceará*. The variables used here were planted area, annual production, yield (or productivity, defined as the production divided by the entire agricultural area), price (corrected according to long-term monetary fluctuations), and aggregate value (price/yield) .

The planted area during the study period of 1952-2000 (Fig. 2a) strongly paralleled the growth rate of the rural population. It varied from about 150,000 ha in the middle of the 20th century for both maize and beans, to about 600,000 ha at the end of the century. However, two distinct periods are apparent. Whereas the increase in the planted area was virtually constant from the beginning of the 1950s until the end of the 1970s, that variable experienced large inter-annual changes during the last two decades of the 20th century. We will demonstrate that many of those changes can be directly related to climatic variability.

The production, yield, and aggregate values for maize and beans are given in Fig. 2b, 2c, and 2d, respectively. The general long-term behaviours of these variables definitely differ from the variability in planted areas (Fig. 2a). A slow increase (not significant at 95%) is observed for production across the full 1952-2000 time series. The yearly crop of maize varies from very small values (*e.g.*, 1958, 1981, 1983) to more than 600,000 tons (in 2000), but with strong inter-annual and multi-decadal changes. The yearly crop of beans is smaller with values ranging between very low (usually in the years when the maize crop is also low) and 300,000 tons (in 1994), and the inter-annual and multi-decadal changes are weaker than those of maize. As will be seen below, there were consecutive drought years at the beginning of the 1980s, and the immediate effect was an obvious dramatic fall in both maize and bean production during this period (Fig. 2b). This was also associated with the previously mentioned abrupt change in the areas planted (Fig. 2a).

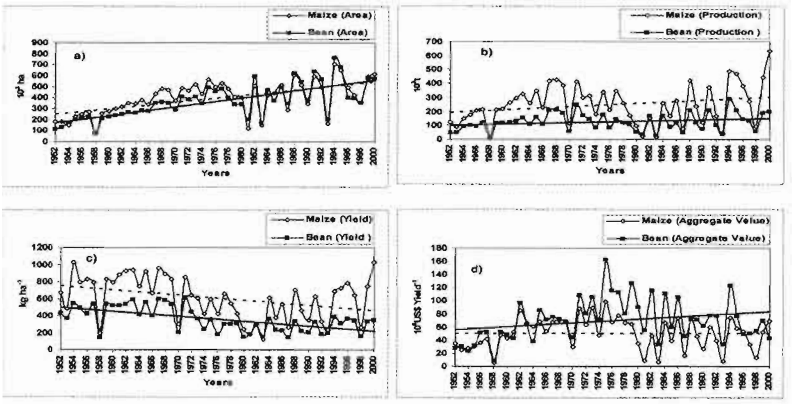

***Figure 2** – 1952-2000 planted areas (a), annual productions (b), yields (c), and aggregate values (d) for maize and bean crops in the Ceará State. The solid and dotted lines in the figures show the linear trends for beans and maize, respectively.*

In contrast to the planted areas and production time series, a negative trend (significant at 95%) is apparent in the yield time series for both maize and beans (Fig. 2c), confirming the problematic behaviour of rainfed agriculture in the *sertãos*. The yields were smaller for beans (about 50 to 600 kg ha^{-1}) than for maize (about 50 to 1050 kg ha^{-1}), with again higher inter-annual variability for maize. It is interesting to note that, except for isolated years such as 1958 and 1970, the yields for both species were best during the first half of the recorded data. After the half-decade episode around the drought years of the 1980s, during which the yield values were particularly low (very low production with strong changes in the areas planted), the yields increased again but without reaching their former values.

The yearly aggregate values (Fig. 2d) vary very greatly compared with the production and yield variables discussed above. A relatively regular increase in aggregate values (from $U 20 to 80 million yield^{-1}) was observed for both species during the first part of the record, with about the same values. A maximum profit occurred in the mid 1970s (*e.g.*, about $US160 million and $US100 million yield^{-1} in 1975 for beans and maize, respectively). The following decade (1975–1985) was marked by a reduction in aggregate values, especially for maize. The last 10 years of the record show a new increase for beans, with relative stability, at close to $US80 million yield^{-1}. During this time, the aggregate value for maize continued to show significant inter-annual variability. The worst years for aggregate values (*e.g.*, 1958, 1970, 1981, 1983, 1993, and 1998) were also the years with the lowest productions, the worst yields, and often a dramatic reduction in the planted area.

Climatic Variables

The intra-seasonal and inter-annual variability in ITCZ, and consequently the *Nordeste's* climate, are largely teleconnected with worldwide climate phenomena, such as the El Niño-Southern Oscillation (ENSO) in the equatorial Indo-Pacific Ocean (Philander 1990, Trenberth 1997), and the SST anomaly dipole in the tropical Atlantic (Moura & Shukla 1981, Servain 1991, Nobre & Shukla 1996). The El Niño/La Niña couple (Philander 1990) has multiple climatic and socio-economic consequences all over the world. Among these, El Niño is often associated with dry episodes over the *Nordeste*, whereas La Niña can lead to flooding in this semi-arid region (Uvo et al. 1998). The meridian mode of climate variability in the tropical Atlantic, usually called the "dipole" (Servain 1991), is represented by a latitudinal gradient in the SST anomaly pattern between the north and south of the tropical basin (Ayina & Servain 2003). The phases of the standard Atlantic dipole control the zonal band of cloudiness and precipitation associated with the ITCZ (Hastenrath & Greishar 1993). During a positive phase (*i.e.*, positive SST anomalies in the northern tropical basin and negative SST anomalies in the south), the thermal gradient points towards the northern hemisphere. Consequently, the ITCZ is predominantly located to the north of its climatological position, and rains are often below normal in the *Nordeste* (Hastenrath & Heller 1977, Hastenrath 1990). Conversely, during a negative phase of the dipole, the whole system is moved abnormally southwards, generally bringing more rain to *Nordeste* (Wagner 1996). We must also note that El Niño (La Niña) years are sometimes associated with positive (negative) occurrences of the SST dipole (Enfield & Mayer 1997), thus increasing the influence of the tropical Atlantic.

There is no universal single definition of ENSO (SCOR 1983, Trenberth 1997, Chen et al. 2002). Most of the time, this major ocean-atmosphere-coupled event is defined by either the surface pressure difference between Tahiti and Darwin (*e.g.*, Ropelewski & Jones 1987) or the SST anomaly in specified regions of the eastern tropical Pacific (Chen et al. 2002). Among these test regions, the Niño-3 area (5°N-5°S and 150°-90°W) (Fig. 1) and the Niño-3.4 area (5°N-5°S and 170°-120°W), both strongly correlated, are the most currently used. Based on previous similar analyses, as for instance that of Uvo et al. (1998), we choose the Niño-3 area as the more related with the *Nordeste's* climate. Here, we used an adaptation of the definition proposed by Trenberth (1997): positive PacPos (negative PacNeg) Pacific episodes are flagged when the SST anomaly, averaged in the Niño-3 area during November-January is greater (lower) than +0.5 °C (-0.5 °C); neutral Pacific episodes (PacNeu) are flagged when the Niño-3 SST anomaly remains at the |0.5| °C threshold.The months November-January were chosen here because this period, which overlaps Christmas, statistically represents the El Niño signal most adequately, and because it includes the possible 3-4 month delayed climatic connection between the eastern tropical Pacific, the Atlantic tropics (Enfield & Mayer 1997, Saravanan & Chang 2000), and the seasonal rainfall over the *Nordeste* (Uvo et al. 1998).

In the tropical Atlantic, where the variability is weaker than in the Pacific, a significant positive DipPos (negative DipNeg) dipole value is flagged when the difference in the SST anomalies of the northern tropical Atlantic (NTA) and the southern tropical Atlantic (STA) regions (Fig. 1), averaged during February-April, is greater (lower) than +0.2 °C (-0.2 °C); neutral Atlantic dipole episodes (DipNeu) are noted when the difference between the anomalies remains within the |0.2| °C threshold. The months February-April were chosen here because this period sees an almost immediate impact of the tropical Atlantic on the *Nordeste* climate (Servain 1991, Nobre & Shukla 1996), and it also corresponds to the first phase of plant growth in this semi-arid region. With these definitions, all the years during the study period were classified according to the nine possible combinations of Pacific and Atlantic climatic episodes, as either positive, negative, or neutral. Table 1 shows the years in each climatic category. The number of years varies from two (category DipNeg/PacNeu) to nine (category DipNeu/PacNeg).

Consequently, the statistical analysis was performed with precaution, using rigorous significance tests. For each group of years on Table 1, we calculated the averages, standard deviations, and anomalies (differences between averages for composite years and the long-term average calculated over the whole length of

DipNeg /PacNeg: 1957, 1974, 1984, 1985, 1986, 1989, 2000
DipNeg /PacNeu: 1991, 1994
DipNeg /PacPos: 1973, 1988, 1995

DipNeu /PacNeg: 1961, 1965, 1967, 1971, 1972, 1975, 1976, 1996, 1999
DipNeu /PacNeu: 1959, 1982, 1990, 1993
DipNeu /PacPos: 1964, 1977, 1987, 1998

DipPos/PacNeg: 1955, 1956, 1963, 1968, 1997
DipPos/PacNeu: 1953, 1954, 1960, 1962, 1978, 1979, 1980, 1981
DipPos/PacPos: 1952, 1958, 1966, 1969, 1970, 1983, 1992

Table I *– Composite years cla\ssified according to the definition of the observed climatic events in the Pacific and Atlantic tropical oceans. The acronyms are defined in the text.*

the 1952-2000 time series) of the four agricultural variables previously defined (production, yield, aggregate value, and price for the maize and bean crops). The 95% confidence interval for statistical significance was calculated with the following formulae:

$$\mu \pm t_c\left(\frac{\sigma}{n}\right)$$

$$\text{and } \sigma \pm t_c\left(\frac{\sigma}{\sqrt{2n}}\right),$$

where t_c is defined according to Student's t distribution, in agreement with n, the number of years in each composite group; μ and σ indicate the mean and standard deviation (S.D) of the sample, respectively. The statistical significance of the anomalies at 95% was calculated according to Harrison and Larkin (1998). Significant anomalies were those whose absolute value exceeded

$$(t_{95}(n).\sigma)/(n)^{\frac{1}{2}},$$

where t_{95} is Student's t value for n degrees of freedom.

These Pacific and Atlantic climatic indices are the observed monthly SST data from the Comprehensive Atmospheric-Ocean Data Set (COADS) (da Silva et al. 1994).

Not directly used in this study, we present the obvious relationship between subsistence harvests and precipitation over the *Nordeste*, a time series of the Ceará rainfall index, averaged during the mean rainy season (February–May) in the same study period (1952-2000). This index was constructed using the daily rainfall observations obtained at the weather station network of Ceará State (60–150 weather stations, according to time period) under the auspices of *FUNCEME*. In Figure 2, we can see that most of the worst years for production, yield, and aggregate values for the two rainfed species (*i.e.*, 1958, 1970, 1983, 1993, 1998) occurred during the driest years, and were also very often associated with El Niño years (for instance, the two big El Niño years in 1983 and 1998) and positive Atlantic dipole occurrences. Such a relationship is less clear during flood years (*e.g.*, 1974 and 1985), which are sometimes associated with La Niña years or with negative values of the Atlantic dipole index.

In a simple correlation analysis between the precipitation time series and the agronomic variables (production and yield) shown in Figure 2, the correlation coefficients were as follows: maize: +0.52 and +0.38 for production and yield, respectively; bean: +0.46 and +0.22 for production and yield, respectively. Values up to 0.30 are significant at the 95% level. Therefore, it seems that the climatic response of maize was slightly higher than that of beans.

MAIN RESULTS

Diagnostic Analysis of Climatic Impact

Our first objective was to investigate how agronomic variables are directly related to climatic variables. To do that, we mainly used the diagnostic analysis below.

For each composite in Table 1, Figure 3 shows the mean, standard deviation (S.D), and the upper (U.L.) and lower (L.L.) 95% confidence limits for yearly production, yield, and price for the bean and maize crops. Means and S.D are also given for the full series, independently of the climate categories. The two production variables show similar behaviour (Fig. 3a and 3b) and the S.D values, which remain relatively stable, are strongly dependant on the yearly composites. Thus, the greatest mean values for both crops (up to 250,000 and 430,000 tons for beans and maize, respectively) clearly occur when a significant negative Atlantic dipole (cold NTA, warm STA) is associated with neutral conditions over the eastern equatorial Pacific. However, this yearly composite is marked by the highest ranges between the upper and lower 95% confidence limits. The intermediate values for production (about 140,000 and 300,000 tons for beans and maize, respectively) are associated with a negative Pacific SST, generally independently of the Atlantic surface conditions. The worst harvest quantities (less than 80,000 and 100,000 tons for beans and maize, respectively), also marked by a minimum 95% confidence interval, commonly appear when a neutral or positive Atlantic dipole is associated with neutral or positive Pacific events.

Contrary to the production variables, the yield variables for beans (Fig. 3c) and maize (Fig. 3d) do not show this sort of dispersion according to the yearly composites (means, S.D, and 95% confidence intervals remain relatively stable), although the highest mean values are clearly noted when a cold Pacific episode is associated with a positive or neutral Atlantic dipole (about 480 and 800 kg ha^{-1} for beans and maize, respectively). However, the behaviour of the worst yields according to the yearly composites differs somewhat for beans and maize. Thus, the worst yield is noted for beans (255 kg ha^{-1}) when neutral conditions over the Atlantic are associated with a positive Pacific event. For maize, the two lowest yields, of similar magnitudes (about 400 kg ha^{-1}), were observed when the Atlantic and Pacific were neutral, and a positive Atlantic dipole occurred during a positive Pacific episode. To summarize, cold SST over the tropics generates rather good yields, whereas warm SST produces rather bad yields.

Similar to the yield variables, the price variables (Fig. 3e and 3f) do not show strong variability according to the yearly composites, and here too the ranges between the upper and lower 95% confidence limits are relatively large (and stable) for both species. The overall averages of the means were $US0.63 kg^{-1} (S.D = 0.33) for beans and $US0.22 kg^{-1} (S.D = 0.06) for maize. The prices for beans and maize were lowest for the combination DipNeg/PacNeu, *i.e.*, when the productions were at their highest values (Fig. 5a and 5b). Other low values for price occurred for the combination DipPos/PacNeg, which corresponds to modest productions but the highest yield. Conversely, high prices for beans and maize generally appear with Atlantic–Pacific combinations associated with low values for production (*e.g.*, DipPos/PacNeu). These characteristics, which balance price against production, must be related to the laws of the local market, as mentioned by Chimelli et al. (2002).

Figure 4 shows, for the nine types of yearly composites of Table 1, the early-defined anomalies in production, yield, and price for the bean and maize crops. Obviously, there is great consistency with the results presented in Figure 3 (although the use of the statistical tests described previously implies that some of the preceding conclusions must be accepted with caution). Thus, for the production anomalies (Fig. 4a and 4b), the very largest harvests definitively occurred for the composite years when a negative Atlantic dipole was associated with a neutral situation over the eastern equatorial Pacific (about +125,000 tons for beans, +250,000 tons for maize). Such a distinct yearly composite does not exist for the worst harvests, which usually occurred when the Pacific and Atlantic dipoles were neutral or positive, and were around –50,000 tons for beans and –100,000 tons for maize. Although not very high, but nevertheless marked, is the modest positive production anomaly for both species when a positive dipole was associated with a cold event over the Pacific (*i.e.*, the simultaneous occurrence of two antagonist climate effects to good rainfall over the *Nordeste*). The illustration of yield anomalies (Fig. 4c and 4d) qualitatively confirms the previous results obtained from the raw values (Fig. 4c and 4d). It is interesting to note, however, and contrary to the production anomalies, that there was a very similar balance between the positive and negative extreme values for these yield anomalies (~80 kg ha^{-1} for beans, ~190 kg ha^{-1} for maize), according to the different yearly composites. As seen previously (Fig. 3e and34f), the price anomalies generally vary in a way clearly opposite the variability in the production anomalies.

Figure 5, which shows the aggregate value anomalies (in \$US millions $yield^{-1}$), better illustrates the balance between the Pacific and Atlantic in their mutual climatic impact on the agrarian quantities. Independently of the Pacific index, the three climatic combinations on the right (on the left), which include a significant negative (positive) dipole in the Atlantic, are associated with positive (negative) aggregate value anomalies. During neutral climatic conditions over the Atlantic, cold Pacific events are associated with positive excess aggregate values, whereas for similar neutral Atlantic conditions, neutral and warm Pacific episodes imply a deficit for the farmers. It is also noteworthy that, even if the qualitative responses of maize and beans are completely similar for the nine index combinations, there are some significant differences in the absolute values.

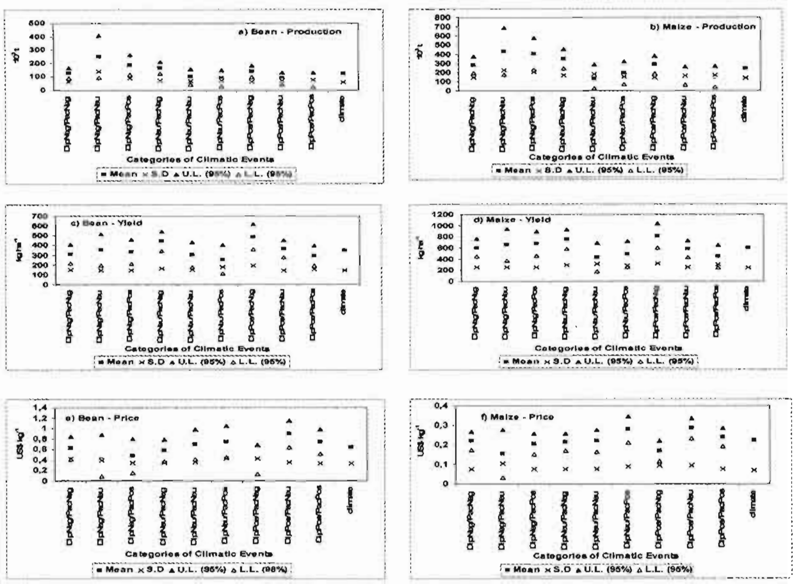

***Figure 3** – Means, standard deviations (S.D), and 95% confidence limits (U.L., L.L.) for the composite years of Table I for bean and maize crops: production (a, b), yield (c, d) and price (e, f). Values for the total means and S.D (independently of composite years) are indicated on the extreme right.*

For beans, the best profit ($US30.6 million yield^{-1}) was achieved with the combination DipNeg/PacNeu (see Fig. 6: the largest production, about normal yield, modestly good price), whereas the largest deficit ($US –22.6 million yield^{-1}) occurred during the combination DipPos/PacPos (low production and yield, modestly good price). For maize, the best profit ($US 22.8 million yield^{-1}) was associated to the combination DipNeg/PacPos (the second largest production, modest yield, bad price), whereas the greatest losses occurred with the combination DipPos/PacPos (low production and yield, good price), and especially ($US –16.4 million yield^{-1}) during neutral SST conditions over the two oceans (DipNeu/PacNeu) (modest production, very bad yield, modestly positive price).

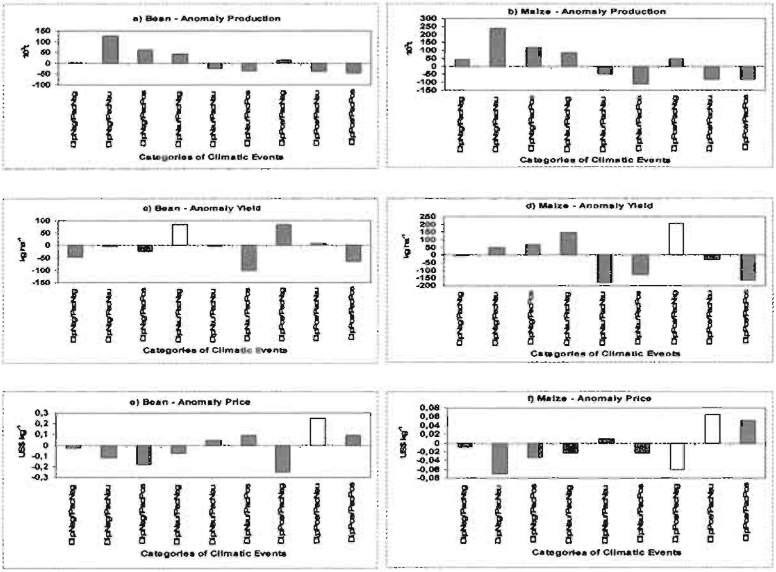

Figure 4 – *Bean and maize crop anomalies in production (a, b), yield (c, d), and price (e, f) for the composite years in Table 1. The shaded (blank) bars have a statistical significance above (below) 95%.*

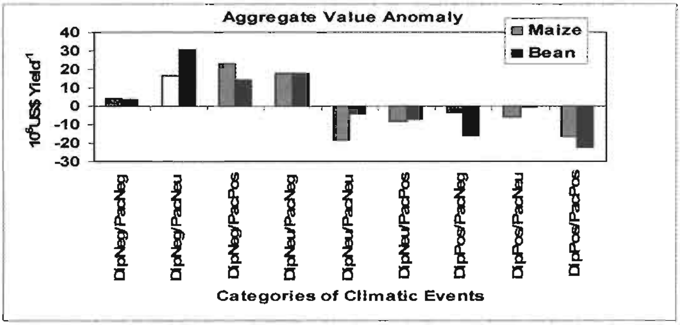

Figure 5 – *Aggregate value anomalies for maize and bean crops according to the composite years in Table 1. Black (bean) and grey (maize) bars are significant at 95% according to Student's t test. The blank bar (DipNeg/PacNeu with only two events) is not significant at this level.*

It must be noted that the most theoretically favourable situation for a good rainy season over the *Nordeste* (*i.e.*, the couple DipNeg/PacNeg) does not imply an exceptionally good harvest. The production anomalies are just above normal for beans (Fig. 4a) and modestly positive for maize (Fig. 4b). The behaviour is different for the yields: they are modestly negative for beans (Fig. 4c) and just below normal for maize (Fig. 4e). The prices are just below normal (Fig. 4e and 4f) and the aggregate value anomalies are slightly positive for both species (Fig. 5).

CONCLUSIONS AND PERSPECTIVES

There is a real statistical relationship between the climatic variability of the tropical oceans (Pacific and Atlantic) and the traditional rainfed crops in the Nordeste. Most of the climatic responses were very similar for bean and maize cultures, with a general (but not inevitable) advantage for maize. Although there are discrepancies for different climatic scenarios, good harvests of both crops were usually associated with cold SST over the tropics, whereas warm SST produced bad crops.

We observed that the role of the tropical Atlantic (the dipole) is, at the very least, as important as the role of the equatorial Pacific (ENSO). The climatic impact of the Atlantic dipole is more robust and organized than that of ENSO. The occurrence of a negative dipole in the Atlantic (i.e., a north-to-south positive gradient in SST anomalies over the tropics) correlated well with increases in the aggregate values (in \$US yield^{-1}) for both agricultural species. This positive economic effect increased, especially for beans, during neutral climatic conditions over the Pacific. Conversely, the occurrence of a positive dipole in the Atlantic is related to a deficit in these aggregate values, regardless of the sign of the Pacific event. With neutral conditions over the Atlantic, the aggregate values seem to be more dependent on the Pacific conditions, especially during cold Pacific events. Series of oceanic events inducing severe drought in the Nordeste (i.e., El Niño events linked to positive Atlantic dipoles) are generally associated with very bad harvests. Paradoxically, an "ideal" series of oceanic events inducing significant precipitation in the Nordeste (i.e., La Niña events linked to negative Atlantic dipoles) are not necessarily the most appropriate for planting. Indeed, strong excess precipitation, which is often associated with bacteriological epidemics and/ or insect proliferation, is not inevitably the best condition for a good harvest. Furthermore, equivalent quantities of precipitable water can produce harvests of different quantity and quality according to whether the precipitation is well distributed during the rainy season.

Usually in world agriculture, yields increase with time, indicating a continuous improvement in agricultural techniques. This is not the case for the *sertãos*. The *Nordeste's* bean and maize yield time series are quite unique because they both show a negative trend during the years 1952-2000. Although not fully explained in this paper, such a negative trend could have its origin in continuous impoverishment and desertification of the soil.

This study forms part of a broad scientific plan of *FUNCEME*, currently under development (*e.g.*, Souza Filho & Lall 2003, Sun et al. 2005, Sun et al. 2005, 2007) based on a complete arsenal of regional climatic statistical and numerical modelling (using various types of downscaling techniques). In collaboration with other national and worldwide institutes (*e.g., CPTEC/INPE, INMET, IRI, ECMWF*)[6], this plan has as its prime objective to improve the forecast of the rainy season across the entire *Nordeste* (Hammer et al. 1996). The second objective, which depends largely on the success of the first, is to identify relevant and valid

---

[6] - *CPTEC/INPE: Centro de Previsão de Tempo e Estudos Climáticos/Instituto Nacional de Pesquisas Espacias*
- *INMET: Insituto Nacional de Meteorologia*
- *IRI: International Research Institute for Climate and Society*
- *ECMWF: European Centre for Medium-Range Weather Forecasts*

elements that will allow medium-scale forecasting of the socio-economic conditions that are associated with the intra-seasonal variability in the regional climate. The anticipated identification of these conditions should facilitate better planning of public policies, to minimize agricultural losses (Risbey et al. 1999) and thus improve the living conditions of the "*sertanejos*" vis-à-vis climatic adversity.

ACKNOWLEDGEMENTS:

This work is part of the CNPq-IRD Project "Climate of the Tropical Atlantic and Impacts on the Northeast" (CATIN), No. CNPq Process 492690/2004-9. The authors thank the Fundação Cearense de Meteorologia e Recursos Hidricos (FUNCEME) and the Fundação Cearense para o Apoio Científico e Tecnológico (FUNCAP).

LITERATURE

Adams RM, Chen CC, McCarl BA, Weither RF (1999) Economic consequences of ENSO for agriculture. *J Clim* 13:165–172

Ayina L-H, Servain J (2003) Spatial–temporal evolution of the low frequency climate variability in the tropical Atlantic. Interhemispheric Water Exchange in the Atlantic Ocean (Elsevier Oceanographic Series), Edited by G. J. Goni and P. Malanotte-Razzoli, 475–495

Brant S (2007) Assessing the vulnerability to drought in Ceará, Northeast Brazil. Thesis in Master of Science, School of Natural Resources and Environment, University of Michigan, http://deepblue.lib.umich.edu/bitstream/2027.42/57432/1/Brant_thesis.pdf

Brou YT, Akindés F, Bigot S (2005) Climatic variability in Côte d'Ivoire: Between social perceptions and agricultural responses. *Cahiers d'Etudes et de Recherches Francophones / Agricultures* 14:533-540

Campos JNB, Studart TMC (2008) Drought and water policies in Northeast Brazil: backgrounds and rationale. *Water Policy* 10:425–438

Cane MA, Eshel G, Buckland RW (1994) Forecasting Zimbabwean maize yield using eastern equatorial Pacific sea surface temperature. *Nature* 370:204–205

Carlson RE, Todey DP, Taylor SE (1996) Midwestern maize yield and weather in relation to extremes of the southern oscillation. *J Prod Agric* 9:2003–2009

Chen CC, McCarl BA, Hiel HSJ (2002). Agricultural Value of ENSO Information under Alternative Phase Definition *Clim Change* 54:305–325

Chimelli AB, Mutter CZ, Ropelewski C (2002) Climate fluctuations, demography and development: insights and opportunities for Northeast Brazil. *J Inter Affairs* 56:213–234

Da Silva AAM, Young CC, Levitus S (1994) Atlas of surface marine data. Vol. 1: Algorithms and procedures. NOAA ATLAS NESDIS 6, U.S. Department of Commerce, NOAA, NESDIS, 83 pp.

Doblas-Reyes FJ, Hagedorn R, Palmer TN (2006) Developments in dynamical seasonal forecasting relevant to agricultural management. *Clim Res* 33:19–26

Enfield DB, Mayer DA (1997) Tropical Atlantic sea surface temperature variability and its relation to El Niño–Southern Oscillation. *J Geophys Res* 102:929–945

Garnett ER, Khandekar ML (1992) The impact of large-scale atmospheric circulations and anomalies on Indian monsoon droughts and floods and on world grain yields—A statistical analysis. *Agr Forest Meteorol* 61:113–128

Hammer GL, Holzworth DP, Stone R (1996) The value of skill in seasonal climate forecasting to wheat crop management in a region with high climatic variability. *Aust J Agr Res* 47:717–737

Handler P (1990) USA maize yields, the El Niño and agricultural drought: 1867–1988. *Int J Climatol* 10:819–828

Hansen JW, Hodges AW, Jones JW (1998) ENSO influence on agriculture in the Southeastern United States. *J Clim* 11:404–411

Hansen JW, Sivakumar MVK (2006) Advances in applying climate prediction to agriculture. *Clim Res* 33:1–2

Hansen JW, Challinor A, Ines A, Wheeler T, Moron V (2006) Translating climate forecasts into agricultural terms: Advances and challenges. *Clim Res* 33:27-41

Harrison DE, Larkin NK (1998) El Niño-Southern Oscillation sea surface temperature and wind anomalies, 1946–1993. *Rev Geophys* 36:353-399

Hastenrath S (1990) Prediction of Northeast Brazil rainfall anomalies. *J Clim* 3:893–904

Hastenrath S, Heller L (1977) Dynamics of climatic hazards in northeast Brazil. *Q J R Meteorol Soc* 103:77–92

Hastenrath S, Greischar L (1993) Circulation mechanisms related to Northeast Brazil rainfall anomalies. *J Geophys Res* D. 98:D35093–5102

Lemos MCT, Finan TJ, Fox RW, Nelson DR, Tucker J (2004) The use of seasonal climate forecasting in policymaking: Lessons from Northeast Brazil. *Clim Change* 55:479–507

Magalhães AR, Glantz MH (1992) Socio-economic impacts of climate variations and policy response in Brazil. Esquel Brazil Foundation, Brasília, 155 pp.

Moura AD, Shukla J (1981) On the dynamics of droughts in northeast Brazil: Observations, theory and numerical experiments with a general circulation model. *J Atmos Sci* 38:2653–2675

Nelson DR (2005) The public and private sides of vulnerability to drought, an applied model of participatory planning in Ceará, Brazil. The University of Arizona, Tuscon p.217.

Nobre P, Shukla J (1996) Variations of sea surface temperature, wind stress and rainfall over the tropical Atlantic and South America. *J Clim* 10:2464–2479

Philander SG (1990) El Niño, La Niña, and Southern Oscillation. Academic Press, London, UK, 289 pp.

Risbey J, Kanlikar M, Dowlatabadi H, Granetz D (1999) Scale, context, and decision making in agricultural adaptation to climate variability and change. *Mitigation and Adaptation Strategies for Global Changes* 4:137-165

Ropelewski CF, Jones PD (1987) An extension of the Tahiti-Darwin Southern Oscillation index. *Mon Weather Rev* 15:2161-2165

Rubas DJ, Hill HSJ, Mjelde JW (2006) Economics and climate applications: Exploring the frontier. *Clim Res*, 33:43-54

SCOR (1983) Prediction of El Niño Proc. No. 19, Paris, France, Scientific Committee for Ocean Research Working Group 55:47-51

Semenov M, Porter JR (1995) Climatic variability and the modelling of crop. *Agr Forest Meteorol* 73:265-283

Saravan R, Chang P (2000) Interactions between tropical Atlantic variability and El Niño-Southern Oscillation. *J Clim* 13:2195-2216

Servain J (1991) Simple climate indices for the tropical Atlantic Ocean and some applications. *J Geophys Res* C 96:15137-15146

Sivakumar MVK (2006) Climate prediction and agriculture: Current status. *Clim Res* 33:3-17

Smit B, McNabb D, Smithres J (1996) Agricultural adaptation to climatic variation. *Clim Change* 33:7-29

Souza Filho FA, Lall U (2003) Seasonal to interannual ensemble streamflow forecasts for Ceará, Brazil: Applications of a multivariate semiparametric algorithm. *Water Resour Res* 39:1307, doi:10.1029/2002WR001373

Sun L, Moncunnil DF, Li H, Moura AD, Filho FDDS (2005) Climate downscaling over Nordeste Brazil using NCEP RSM97. *J Clim* 18:551-567

Sun L, Li H, Ward MN, Moncunnil DF (2007) Climate variability and maize yields in semi-arid Ceará Brazil. *J Appl Meteorol Clim* 46:226-240

Trenberth KE (1997) The definition of El Niño. *Bull Am Meteorol Soc* 78:2771–2777

Uvo CB, Repelli CA, Zebiak SE, Kushnir Y (1998) The relationship between tropical Pacific and Atlantic SST and Northeast Brazil monthly precipitation. *J Clim* 11:551–562

Vogel C, O'Brien K (2006) Who can eat information? Examining the effectiveness of seasonal climate forecast and regional climate-risk management strategies. *Clim Res* 33:111–122

Wagner RG (1996) Mechanisms controlling variability of the inter-hemispheric sea surface temperature gradient in the tropical Atlantic. *J Clim* 9:2010–2019

Wang B (1995) Interdecadal changes in El Niño onset in the last four decades. *J Clim* 8:267–285.