IMPACTS OF EL NIÑO AND LA NIÑA ON AGRICULTURAL PRODUCTION IN SOUTHERN BRAZIL AND THE USE OF CLIMATE FORECASTS IN AGRICULTURE

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Abstract

In southern Brazil the warm episodes of ENSO (El Niño) produce rainfall above the climatological mean, and the cold episodes of ENSO (La Niña) produce rainfall below the climatological mean. The period of the year with the greatest impact on rainfall, both for El Niño and La Niña, is spring and early summer. The study of the impacts of El Niño and La Niña on agriculture in the South Region of Brazil (Rio Grande do Sul) shows that El Niño is favorable to the non-irrigated spring-summer crops, such as soybean and maize, raising their mean yields, whereas the La Niña phenomenon is responsible for harvest losses of these two main grain-producing crops in the state. On the other hand, the La Niña phenomenon is favorable to the production of wheat and other winter cereals, and, in several cases, is favorable also to irrigated rice. El Niño may be unfavorable to the spring-summer crops (soybean, maize and rice, for instance) when there is a rainfall above

climatological mean in April and May of the second year of the phenomenon (the maturation and harvest time) as occurred during the great El Niño of 1982/1983. These initial results of the relationship between El Niño and La Niña, rainfall and agricultural production are encouraging. They indicate that seasonal climate forecasts may provide invaluable information for the management of crops, soil and water, and minimize risks in unfavorable situations, making better use of favorable situations. However, in order to make the best use of long-term forecasts, such as those based on El Niño and La Niña, it is necessary to perform further studies of the phenomenon and its impacts on the climate and agriculture in the region, as well as to establish mechanisms to evaluate the effects of decision-making on the agricultural productive process.

1. Introduction

The South Region of Brazil (Paraná, Santa Catarina and Rio Grande do Sul) produces approximately 50 % of the country's grain, 81 % of the fruit, 25 % of the meat, 25 % of the vegetables and 25 % of the milk. The state of Rio Grande do Sul, alone, accounts for around 23 % of the Brazilian grain production, the most important crops being soybean, maize, rice and wheat, with a mean production of 16.3 million tons during the 1993-1995 period (IBGE, 1996).

Although the mean climatic conditions in the South Region of Brazil (subtropical and temperate climates) are favorable to agriculture in general, the seasonal and annual variability of some meteorological elements, especially rainfall are responsible for the great variability in yields and production in most of this region (Berlato, 1987; Bergamaschi, 1989; Berlato, 1992; Berlato and Fontana, 1999).

As was showed for the first time by Ropelewski and Halpert (1987; 1989), in southeastern South America (southern Brazil, northeastern Argentina, Uruguay and southern Paraguay) there are clear signs of climatic variability associated with the El Niño-Southern Oscillation (ENSO) phenomenon, producing mainly rainfall anomalies.

Several other authors have confirmed and amplified the initial observations by Ropelewski and Halpert for the South Region of Brazil (Rao and Hada, 1990; Studzinski and Diaz, 1994; Studzinski, 1995; Fontana e Berlato, 1997; Grimm et al., 1996 a,b; Diaz et al., 1998). In this region, the warm episodes of ENSO (El Niño) produce rainfall above the climatological mean and the cold episodes of ENSO (La Niña) rainfall below the climatological mean. The greatest impact on rainfall, both in the case of El Niño and La Niña, occurs in spring and early summer.

This paper begins by presenting the impacts of climate variability on agricultural production in the far south of Brazil, especially the effects associated to El Niño and La Niña in grain production. It ends with some considerations regarding the use of climate forecasts in the decision-making process in agriculture.

2. Effects associated with El Niño and La Niña on Rio Grande do Sul agriculture

2.1. Soybean and maize

Soybean and maize are the two main crops in Rio Grande do Sul. Together, they cover 70 % of the cultivated area and account for 65 % of the total grain production in the State. Practically all these crops are farmed without irrigation (dry-farming) and their yields and production, consequently, depend on rainfall.

Figure 1 shows the function of the relationship between rainfall and soybean yield in the state of Rio Grande do Sul. It is found that the quadratic function has a good fit to the data observed, showing that rainfall from December to March accounts for almost 80 % (r^2=0.79) of the interannual variation in soybean yields. It is stressed that mean rainfall (6 stations) in the significant area of production (northwest of the state) accounts for much of the variability of soybean yields in the state. Through this function, the maximum soybean yield is achieved with a 848 mm rainfall, equivalent to 213 mm, on average, per month. This value is much higher than the monthly mean in the December-March period, even for the regions with the heaviest rainfalls in the state (Ávila, 1994).

A study of the water use of soybean carried out for several years in the climatic region of the Depressão Central (Berlato et al., 1986), shows that soybean require an average of approximately 827 mm of water for the whole cycle (approximately 4.5 months). Therefore, the 848 mm of rainfall over 4 months (December to March) needed to achieve the maximum soybean yield is quite realistic, taking into account that total rainfall, not effective rainfall was used in this study.

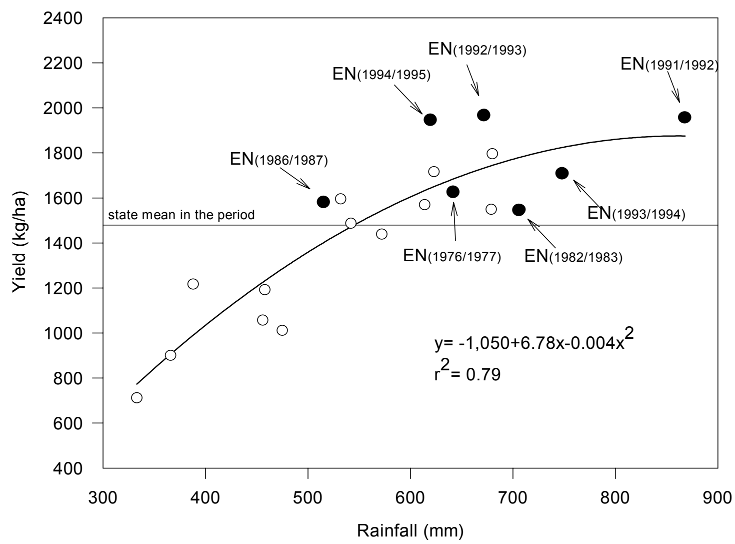


Figure 1. Relationship between the rainfall from December to March (mm) and soybean grain yield (kg/ha) in the state of Rio Grande do Sul, 1975/1976-1994/1995 period (Berlato and Fontana, 1999). EN- Years of occurrence of EL Niño.

Matzenauer and Fontana (1987), relating rainfall to data from experiments concerning maize yields in the Depressão Central region of the State, had already shown that the quadratic function is well fitted to the data observed, and that the rainfall that occurred during the reproductive period (tasseling-silking), accounts for much of the variability in the yields of this crop.

In Figure 1 are shown the El Niño events that occurred during the period from 1975/1966 to 1994/1995 (7 events). The mean soybean yields in the state during the 7 years when El Niño occurred was 1,763 kg/ha, 283 kg/ha (16 %) more than the average for the whole period. During the 1991/1992, 1992/1993 and 1994/1995 events, the mean yield was 1,958 kg/ha, 478 kg/ha (34 %) more than the mean for the whole period. In these three El Niño events the record mean yields for the soybean crops in the state of Rio Grande do Sul occurred for the period studied (1975/1976 to 1994/1995).

The La Niña events causing droughts in the south region of Brazil are, basically, very harmful to agriculture. However, during the period studied for soybean only two events occurred (1975/1976 and 1988/1989). The 1975/1976 event was relatively weak, with rainfall from December to March above the climatological mean. The 1988/1989 event was intense, but the drought occurred mainly during the winter months, with rainfall from December to March above the climatological mean.

Figure 2 shows the time distribution of rainfall in five-day periods, the means of six locations in the northwestern region of the state for the agricultural years of 1990/1991 and 1991/1992, as well as part of the average agricultural calendar for soybean. In 1990/1991 a drought occurred in the region, mainly during the period from end of December to March, coinciding with the whole period of flowering and a great part of the soybean grain filling period (critical periods for the crop as regards water) (Figure 2a). The mean soybean yield for that year was 712 kg/ha, one of the lowest in the history of this crop in the state. The following year, 1991/1992, thanks to the El

Niño phenomenon, there was plenty of rainfall in the region and in the same period and the mean yield in the state rose to 1,957 kg/ha (Figure 2b).

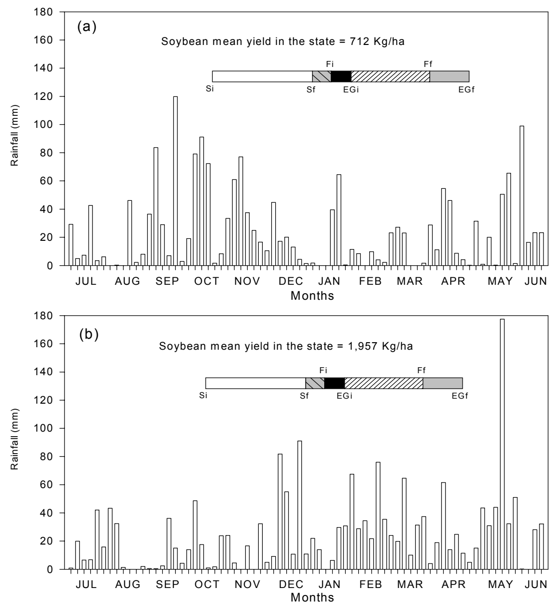


Figure 2. Rainfall (mm) for five-day periods in the northwest of the state of Rio Grande do Sul (mean of 6 localities) in 1990/1991(drought) (a), in 1991/1992 (El Niño) (b) and mean soybean yield in the state. Source of data: 8th DISME/FEPAGRO/EMATER-RS. The horizontal bar represents part of the mean agricultural calendar of soybean. Si and Sf represent the beginning and end of the sowing, respectively; Fi and Ff, represent the beginning and end of flowering, respectively; Egi and Egf represent the beginning and end of grain filling, respectively.

Figure 3 shows the time distribution of rainfall in the same region previously mentioned (northwest of the state) for the La Niña year of 1995/1996. This La Niña, considered weak, was very similar, in terms of rainfall, to the climatological mean of the phenomenon in the state, i.e., producing a drought at the end of spring and beginning of the summer of the year when the phenomenon began and the end of autumn of the following year. The drought in the first period, especially in November and December, was the main reason for the modest yields of soybean and maize in the state that year, 1,565 kg/ha and 2,097 kg/ha, respectively.

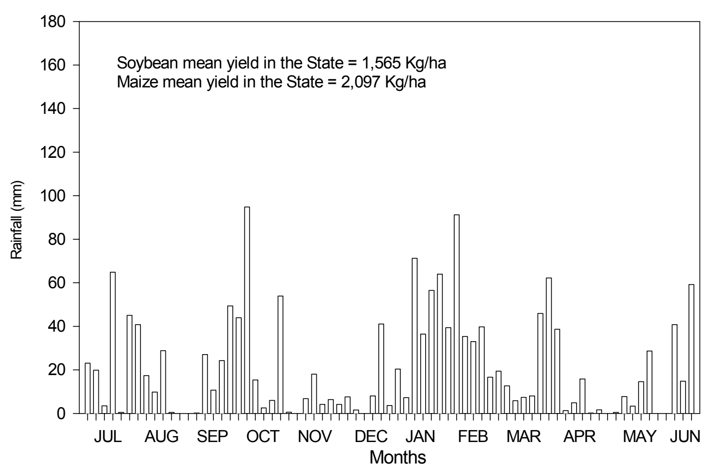


Figure 3. Rainfall (mm) for five-day periods in the northwest of the state of Rio Grande do Sul (mean of 6 localities) during the La Niña phenomenon of 1995/1996 (July to June) and mean yield of soybean and maize in the state of Rio Grande do Sul. Source of data: 8th DISME/FEPAGRO/EMATER-RS.

Figure 4 shows the standard deviations of the maize yields in the state and the rainfall of the period from October to February, an average of 17 meteorological stations located in the most significant region for the production of that crop (northern region of Rio Grande do Sul), for the same period of 20 years of soybean. Firstly, it is found that there is a strong positive association between yield and rainfall during the crop growth season. The figure also shows that of the seven El Niño events that occurred during this period, in five the crop was favored as far as regards yield. Similar results had already been observed by Fontana and Berlato (1996) for two localities in the same region (Cruz Alta and Passo Fundo). In the two La Niña events, rainfall for the most important period involving maize (October to February) was below the meteorological mean (negative deviations), but the mean maize yield was only lower than average in the year 1975/1976.

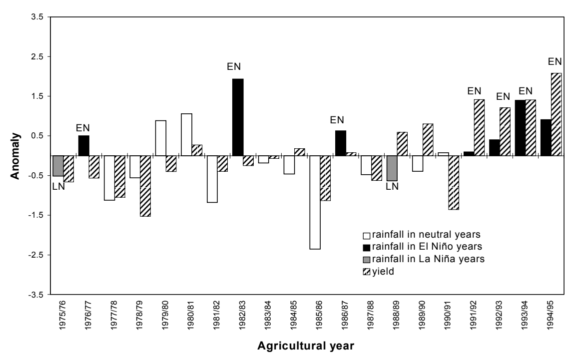


Figure 4. Anomalies standardized (by standard deviation) of maize yield and rainfall from October to February in the state of Rio Grande do Sul, 1975/1976-1994/1995 period (Fontana and Berlato, 1996). EL-years of occurrence of El Niño: LN-years of occurrence of La Niña.

Table 1 shows the mean yields of soybean and maize in Rio Grande do Sul in the last four events of El Niño and La Niña, not included in Figures 1 and 4. These data confirm the tendency for modest yields in these crops in the La Niña years (1995/1996, 1998/1999 and 1999/2000), but they also confirm the gains in mean yields of the state obtained in the El Niño years. In the case of soybean, for instance, the mean yield of 2,088 kg/ha and the total production of 6,605,743 tons in the El Niño year 1997/1998, represent, in physical terms, the best result of the whole history of this crop in Rio Grande do Sul.

Table 1. Mean soybean and maize yields in the state of Rio Grande do Sul, during the most recent El Niño and La Niña events.

Crop	La Niña (1995/1996) Kg/ha	El Niño (1997/1998) Kg/ha	La Niña (1998/1999) Kg/ha	La Niña (1999/2000) Kg/ha
Soybean	1,704	2,088	1,459	1,593
Maize	2,170	2,961	2,422	2,644

Source of the data: IBGE/EMATER-RS

The reason for the positive response of the non-irrigated spring-summer crops, in terms of yield, to El Niño, is that normal rainfall at the end of spring and summer in the state is generally insufficient to cover the water needs of these crops, limiting their yields (Berlato et al., 1986; Berlato, 1992; Fontana and Berlato, 1996; Berlato and Fontana,1999). This also goes for some forage plants such as, for instance, alfalfa, as shown by Bergamaschi et al. (1997).

In addition to the fact that normal summer rainfall is insufficient for non-irrigated agriculture, the droughts with rainfall well below the mean, that occur more frequently in spring and summer, make the situation worse.

Table 2 shows the “big numbers” of the physical and economic impacts of droughts on agricultural production in the state of Rio Grande do Sul. The last six droughts caused losses on the order of 19.1 million tons of grain, for the soybean and maize crops, a total value of more than 3 billion dollars. This loss of 19.1 million tons of soybean and maize represents more than the total production of all grain obtained in a normal year (no drought) in the state of Rio Grande do Sul.

An interesting study by the Empresa de Assistência Técnica e Extensão Rural (EMATER-RS, 1998) on the reasons for harvest losses in the State during the 1992-1997 period, shows the importance of the droughts. Table 3 illustrates the case of soybean and maize, the two main non-irrigated crops in the state. It is found that the droughts accounted for approximately 93 % of the soybean harvest losses and 88% of the maize harvest losses. It should be stressed that no severe droughts occurred in the state during the period studied, the most significant being that of 1995/1996, due to a weak La Niña event.

The soybean yields statistics in the last three decades (a large part of the history of this crop in the State), showed a frequency of 32 % reduction of yield due to drought. In other words, on average, approximately for one out of every three crops there is loss of yield due to this climatic adversity.

Table 2: Physical and economic impacts of droughts on agricultural production in the state of Rio Grande do Sul (soybean and maize).

Agricultural year	Losses of grain (millions of tons)	Value US$ millions
1987/1988	3.6	709.3
1990/1991	5.5	797.0
* 1995/1996	2.8	522.5
1996/1997	2.1	402.8
* 1998/1999	2.8	335.4
* 1999/2000	2.3	307.8
Total	19.1	3,074.8

Source of data: EMATER-RS * Years of La Niña

Table 3. Causes of losses in harvests in the State of Rio Grande do Sul (1992/1997 period)

Crop	Total loss (millions of tons)	Causes	
		Drought	Excessive rainfall, hail, pests, diseases etc.
Soybean	3,3	92,6 %	7,4 %
Maize	3,5	88,4 %	11,6 %

Source of data: EMATER-RS

In the El Niño years, there is no possibility of the occurrence of long periods of drought and the spring-summer rainfall is generally higher than the climatological mean, leading to higher yields and, thus, higher production.

The risk that El Niño could be harmful to the non-irrigated summer crops is limited to autumn of the second year of phenomenon , especially if April and May are very rainy, and could create problems for the end of the maturation process and harvesting activities. During the intense El Niño in 1982/1983, the frequent excessive rainfall, beginning in April, determined losses of approximately 994 thousand tons of soybean and 196 thousand tons of maize. The negative impact of the intense 1982/1983 event could have been significantly reduced if, at the time, there had been the knowledge and forecasts of the phenomenon, that are already available to decision-makers in agriculture and to the farmers themselves, before sowing began.

2.2. Paddy Rice

Figure 5 shows the anomalies of irrigated rice yields as compared to the historical mean in the last five decades (1944/1945 to 1999/2000) in the State, where we can also see the years when El Niño and La Niña occurred. This figure was constructed after removing the technological trend of the original series that is highly significant in the case of rice. After removing the effects of new technologies (cultivars, management etc.), deviations from the mean of the new series are due to the environmental elements, especially meteorological ones. In Figure 5 it is seen that of the 17 El Niño events, 9 were harmful (53 %) in terms of yield (negative deviations) and 8 (47 %) were beneficial (positive deviations).

One of the possible reasons why El Niño is harmful to irrigated rice is the smaller amount of hours of sunlight caused by this phenomenon during the growing season of this crop, especially from October to February (Figure 6). As regards the La Niña event, of the 10 events that occurred during the period in 6 (60 %) yields were higher than average and in 4 (40 %) lower. These data show that there is a tendency for El Niño events to lower the yield of irrigated rice and a stronger tendency for La Niña events to be favorable.

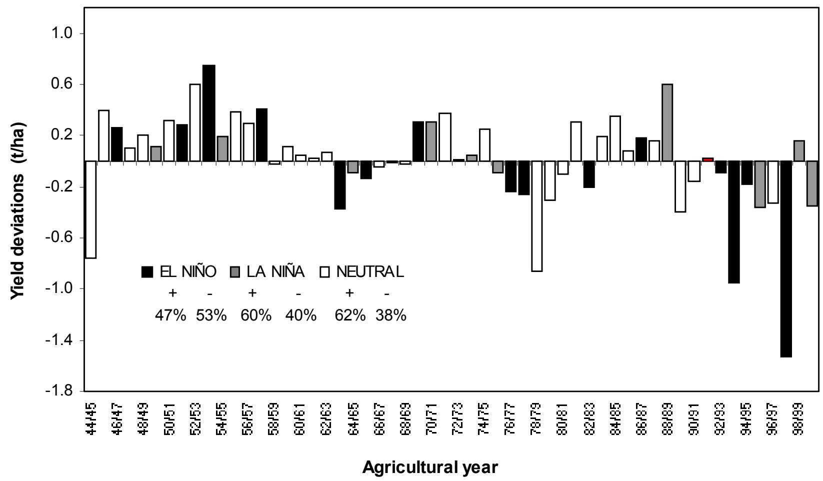
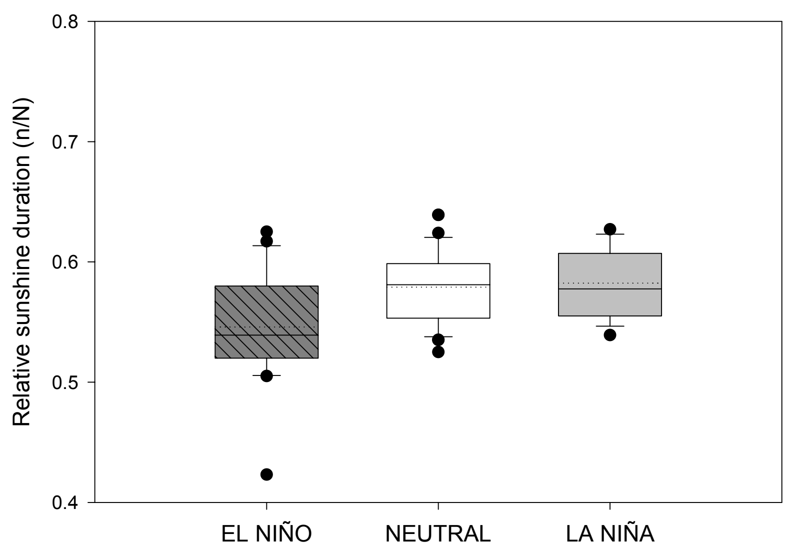


Figure 5. Anomalies in irrigated rice yields (t/ha) in the state of Rio Grande do Sul, 1944/1945-1999/2000 period (Carmona and Berlato,2001). Source of data: IRGA-RS.



0.8
0.7
0.6
0.5
0.4
Relative sunshine duration (n/N)
EL NIÑO
NEUTRAL
LA NIÑA

Figure 6. Distribution of relative sunshine duration (n/N), from October to February, associated to the years of El Niño, La Niña and neutrals, 1944/2000 period, for the rice-growing region of the state of Rio Grande do Sul (Carmona and Berlato, 2001). The full horizontal line inside the boxes represents the percentile 50 (median), the dashed line represents the mean, the end of the boxes the percentiles 25 and 75, the bar the percentiles 10 and 90, and the full circles the extreme values. Source of data: FEPAGRO/RS and 8th DISME/INMET.

The La Niña years in the State are characterized by below normal rainfall, especially in spring and the beginning of summer, as has already been seen, but also by less nebulosity, more hours of sunlight (Figure 6) and, possibly, more solar radiation. If there is no lack of water in the reservoirs (dams), these meteorological conditions are excellent for rice growth and development, in fact, in this case the motto of rice growers, that “rice is a plant that enjoys sun on its head and water on its feet” is valid. Under these circumstances, La Niña may provide the opportunity for above average yields. This could occur, for instance, when La Niña follows an El Niño; in this case, the reservoirs (dams) have maximum water storage in spring. This is what happened in the agricultural year 1998/1999. After an intense El Niño (1997/1998), came La Niña. According to IBGE-EMATER (EMATER, 1999), the rice harvest of 1998/1999 had an average yield of 5,552 kg/ha, and a production of 5,403,100 tons, considered one of the bests harvests in the last few years in the State. However, in the case of very intense and extensive episodes of La Niña, even rice can be harmed by lack of water.

2.3. Wheat

Figure 7 shows the deviation from the mean of wheat yields in the state of Rio Grande do Sul over a 78-year period, after the removal of the technology trend (Cunha et al., 1999). During this period, 23 events of El Niño and 15 events of La Niña occurred (marked on the graph). In 57 % of the El Niño years the deviations were negative, and in 43 % they were positive. Of the La Niña events, 67 % presented positive deviations and 33 %, negative deviations. These results of observations show a strong tendency of the La Niña years to favor wheat crops in the State, whereas the El Niño years are generally unfavorable.

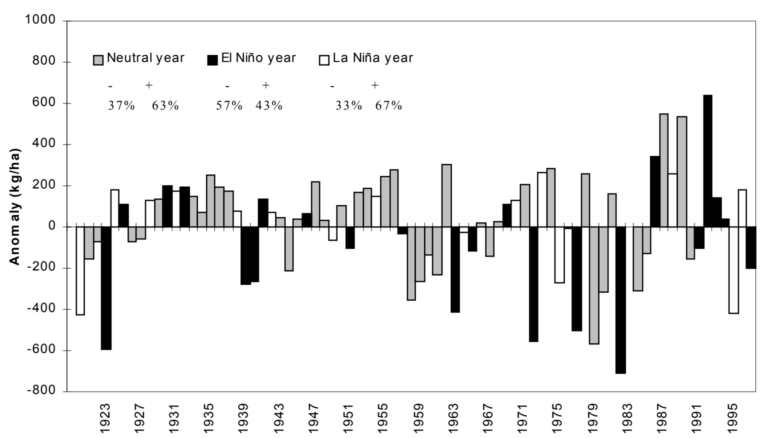


Figure 7. Wheat yield anomalies (kg/ha) in the state of Rio

Grande do Sul, 1920-1997 period (Cunha et al., 1999).

El Niño is unfavorable to wheat and, certainly, to the other winter cereals, especially considering that the intense, frequent rainfalls provoked by this phenomenon at the end of spring coincide with the period of maturation and harvesting of these cereals. According to data from the official agencies that perform surveys of Rio Grande do Sul agriculture (IBGE/EMATER-RS), the loss of wheat production attributed to the last El Niño in 1997/1998, was on the order of 316 thousand tons, representing 35 % less than estimated for the state at the beginning of the harvest. The winter crops, however, represent less than 10 % of the total grain production of Rio Grande do Sul.

Table 4 shows a qualitative summary of the effects associated to El Niño and La Niña in the main Rio Grande do Sul crops. As discussed previously, El Niño tends to be favorable to the spring-summer crops, except for rice, and unfavorable to winter crops. The opposite behavior is observed for the La Niña events.

Table 4. Qualitative summary of the effects associated to El Niño and La Niña in agricultural production in the state of Rio Grande do Sul.

CropP	El Niño	La Niña
Soybean	Favorable	Unfavorable
Maize	Favorable	Unfavorable
Rice	Unfavorable (intense event)	Favorable (weak event)
Wheat and other winter cereals	Unfavorable	Favorable
Forage plants	Favorable	Unfavorable

In order to minimize the impacts of the climatic adversities on agriculture, climate risk zonings for risk and irrigation, whenever possible, are appropriate strategies in the case of droughts. For the climatic variability associated with El Niño and La Niña, the seasonal climate forecasts currently available, become invaluable information in the decision-making process regards the management of crops, soil and water.

3. Climate forecasts applications in agriculture

According to data shown in the previous items, El Niño, which produces above normal rainfall in spring-summer, is favorable to soybean and maize crops, raising their mean yields, whereas the La Niña phenomenon, which produces droughts in spring-summer, is responsible for losses in the harvest of these two main grain-producing crops in the region. On the other hand, the La Niña phenomenon is favorable to the production of wheat and other winter cereals and, in several cases, it is also favorable to irrigated rice. These initial results of the relationship between indicators of climate variability, rainfall and agricultural production are encouraging. They indicate that seasonal climate forecasts may constitute invaluable information for crop management, insofar as they minimize risks under unfavorable conditions and make good use of favorable situations.

In the state of Rio Grande do Sul, forecasts and warnings of the occurrence of the latest El Niño event (1997/1998) enable several decisions to be made, such as harvesting the wheat earlier and faster and hurrying up with sowing the rice, in order to minimize risks. During the La Niña event of 1998/1999, a Work Group (WG) with representatives of several organizations, including universities, technical aid agencies and farmers organizations (cooperatives and federations) was instituted under the coordination of the Secretaria da Agricultura e Abastecimento (SAA/RS), to follow the monitoring and forcasting of the La Niña phenomenon made by national and international weather and climate forecasting institutes, analyze this information and provide technical advice to the farmers. This WG constituted an interesting experience of regional integration to apply climate forecasts in agriculture, for the purpose of minimizing the impacts of droughts that are well-known to occur during the La Niña years. The WG produced a technical document containing information about the evolution of the phenomenon, the forecasts for the next season and the technical advice based on agricultural and agrometeorological research to reduce losses. This document was disseminated to the whole State by conventional and electronic means.

This WG is now institutionalized under the general coordination of the Secretaria da Agricultura e Abastecimento (SAA-RS) as a "Fórum Permanente de Monitoramento do Tempo e Clima para Agricultura no Rio Grande do Sul". This Forum holds monthly meetings and is already on its fifteenth edition (March 2001).

However, in order to be able to profit most from long-term forecasts (climatic forecasts), such as those based on El Niño and La Niña, it is necessary to go ahead with studying the phenomenon and its impacts on the climate and on the agriculture in the region, as well as to establish mechanisms to assess the effects of decision-making on the agricultural production process.

A permanent, possibly useful system to apply to climate forecasts based on El Niño and La Niña in agriculture should consider at least the following items:

- The existence and availability of the climatic forecasts on time and space scales appropriate to agricultural activities;
- The most detailed studies possible regarding the impacts of El Niño and La Niña on the climate in the region;
- Studies on the impacts of El Niño and La Niña on agriculture in the region;
- Generation of "products" of climate forecasts with an added agrometeorological and agricultural value;
- Dissemination of these "products" in the form of technical recommendations;
- Use of technical recommendations by farmers;

- Assessment of the result of the decision to use or not use the technical recommendations.

The latter item is crucial, since it represents system feedback. It is necessary to know whether the technical recommendations resulted in the minimization of the negative impacts of adverse meteorological phenomena on agricultural production, and also whether favorable climate forecasts proved useful. Finally, it is necessary to know whether the "climate input" used or not used made a difference to the farmer's income. But this must be quantitatively demonstrated by follow-up and statistical evaluations.

Figure 8 shows a simplified flowchart of the proposed System of Application of Climate Forecasts to Agriculture for regions that present strong signs of the El Niño and La Niña phenomenon, as is the case in southern Brazil.

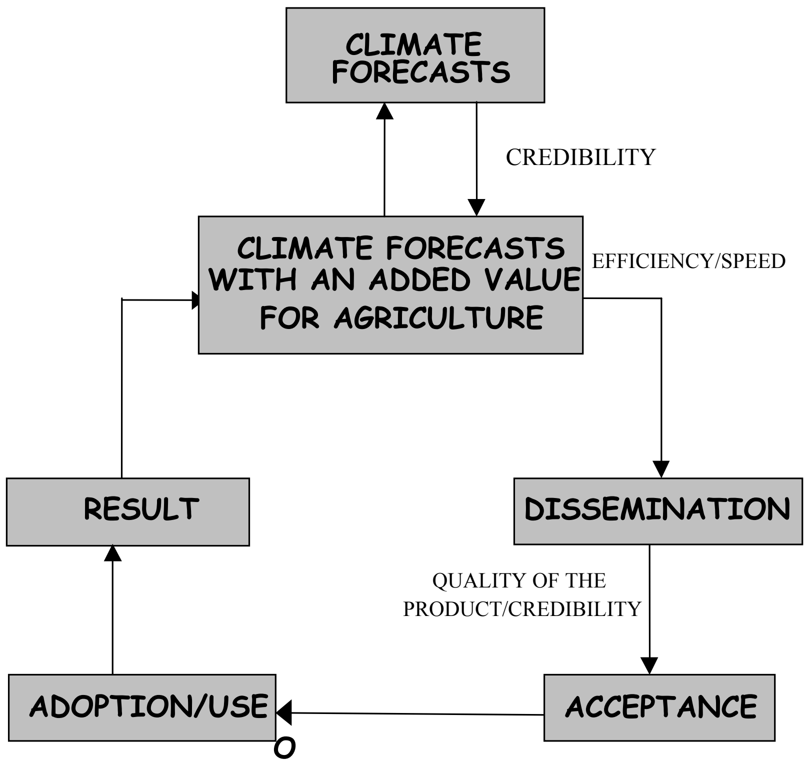


Figure 8. Flowchart of a System of Application of Climate Forecasts to Agriculture

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