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INFLUÊNCIA DO FENÔMENO EL-NIÑO OSCILAÇÃO SUL NO CULTIVO DE ARROZ IRRIGADO NA BACIA HIDROGRÁFICA MIRIM-SÃO GONÇALO

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1 RESUMO

O cultivo de arroz representa um dos destaques na economia da região Sul do Brasil, porém sua produção pode sofrer impactos negativos relacionados às variações climáticas. Nesse contexto, este trabalho tem como objetivo avaliar a produtividade média corrigida de arroz irrigado (PMCAI), assim como a influência do fenômeno El Niño Oscilação Sul (ENOS) e os índices *Standardized Precipitation Index* (SPI), *Standardized Precipitation Evapotranspiration Index* (SPEI) e *Oceanic Niño Index* (ONI) na bacia hidrográfica Mirim-São Gonçalo (BHMSG). Foram utilizados valores de PMCAI para a região a partir das safras de 1984/1985 até a safra 2019/2020. Os períodos de regência ENOS foram identificados a partir de dados obtidos pelo *National Weather Service*, compreendendo o período supracitado, através do índice ONI. Os dados de precipitação e evapotranspiração de referência foram utilizados para o cálculo dos índices SPI e SPEI. Os resultados mostram que a variável PMCAI não apresentou significância a nível de 5% em relação à regência do fenômeno ENOS. Por sua vez, a análise dos índices SPEI e SPI para o mês de dezembro e o ONI em grande parte dos meses, apresentaram uma correlação significativa com a PMCAI.

Palavras-chaves: irrigação, produtividade, ENOS, SPI, SPEI.

BOEIRA, L. S.; GONÇALVES, G. M. S.; BARTELS, G. K.; SILVEIRA, J. F.; COLLARES, G. L.
INFLUENCE OF EL NINO/SOUTHERN OSCILLATION (ENSO) ON RICE CROP YIELD IN THE MIRIM-SÃO GONÇALO WATERSHED

2 ABSTRACT

Rice cultivation represents one of the highlights in the economy of the southern region of Brazil; however, its production may suffer negative impacts related to climatic variations. This study aimed to evaluate the corrected average of crop yield irrigated rice (PMCAI), as well as, the influence of the El Nino/Southern Oscillation (ENSO) phenomenon and the Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI) and Oceanic Niño Index (ONI) indexes in the Mirim-São Gonçalo watershed. PMCAI values for this region were used from the harvest of 1984/1985 up to 2019/2020. The ENSO occurrence

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periods were identified from data obtained from the National Weather Service, within the same mentioned harvest period using the ONI. The reference precipitation and evapotranspiration data were applied to calculate the SPI and SPEI indexes. The results indicated that the PMCAI variable did not show significance at the level of 5% in relation to the occurrence of the ENSO phenomenon. In turn, the analysis of the SPEI and SPI indices for December and the ONI in most of the months, showed a significant correlation with the PMCAI.

Keywords: irrigation, crop yield, ENSO, SPI, SPEI.

3 INTRODUCTION

Brazil currently ranks 11th in the world for rice production, representing approximately 7 million tons per year, and 10th and 15th in the world rankings for annual rice exports and imports, respectively, representing a production of 650,000 tons in exports and 850,000 tons in imports (UNITED STATES DEPARTMENT OF AGRICULTURE, 2021). However, a considerable part of global rice production is highly dependent on the water supply in the river basins where these crops are grown, since, according to Lopes and Rocha (2006), more than 75% of global rice production comes from irrigated crops.

The Mirim-São Gonçalo River basin (BHMSG) has a total area of 62,250 km², which is shared between Brazil (29,250 km², corresponding to 47%) and Uruguay (33,000 km², or 53%), making the BHMSG a transboundary river basin (AGÊNCIA DE DESENVOLVIMEN TO DA LAGOA MIRIM, 2020). According to Arroz (2020), in the southern region of Brazil, rice cultivation is almost entirely irrigated and flooded. Notably, during the 2019/2020 harvest (the period between September and March), the average ionized rice productivity (PMAI) in the state of Rio Grande do Sul (RS) was 8,316 kg.ha-¹ (CONAB, 2018). Such cultivation is the main economic activity in the BHMSG region, and according to CONAB (2018), the state of RS was responsible for 76.5% of irrigated rice production in Brazil. Therefore, the main uses of water in the BHMSG are irrigation (OLIVEIRA et al., 2015) and human supply (AGÊNCIA DE DESENVOLVIMENTO DA LAGOA MIRIM, 2020).

Productivity in irrigated rice cultivation is influenced mainly by adverse weather conditions (low temperatures, low solar radiation and low water availability), which can be identified through analysis of the Niño oscillation index (*OIB)*, *standardized precipitation index* (ONI), standardized precipitation index (SPI) and *standardized precipitation and evapotranspiration index* (SPEI). These indices are generally applied on a monthly scale and are used to assess how wet or dry a given period is. The SPI (MCKEE; DOESKEN; KLEIST, 1993) is probably the most widely used index worldwide (SOBRAL et al., 2018) and is recommended by the World Meteorological Organization (WMO) for its simplicity of application, requiring only precipitation data (CHEN et al., 2013). More recently, Vicente-Serrano et al. (2010) proposed the SPEI, an index based on the climatic water balance (the difference between precipitation and reference evapotranspiration) (POTOP, 2011). Both indices have the advantage of being able to be calculated on different time scales to monitor the beginning, end, duration, and intensity of each wet or dry period (POTOP, 2011).

One of the main climatic phenomena that interferes with the occurrence and magnitude of these climatic elements is the El Niño–Southern Oscillation (ENSO)

(SOCIEDADE SUL-BRASILEIRA DE ARROZ IRRIGADO, 2016), which is even mentioned in studies carried out by Arsego et al. (2020) and Carmona (2001), who related the ENSO phenomenon with rice cultivation in the state of the RS.

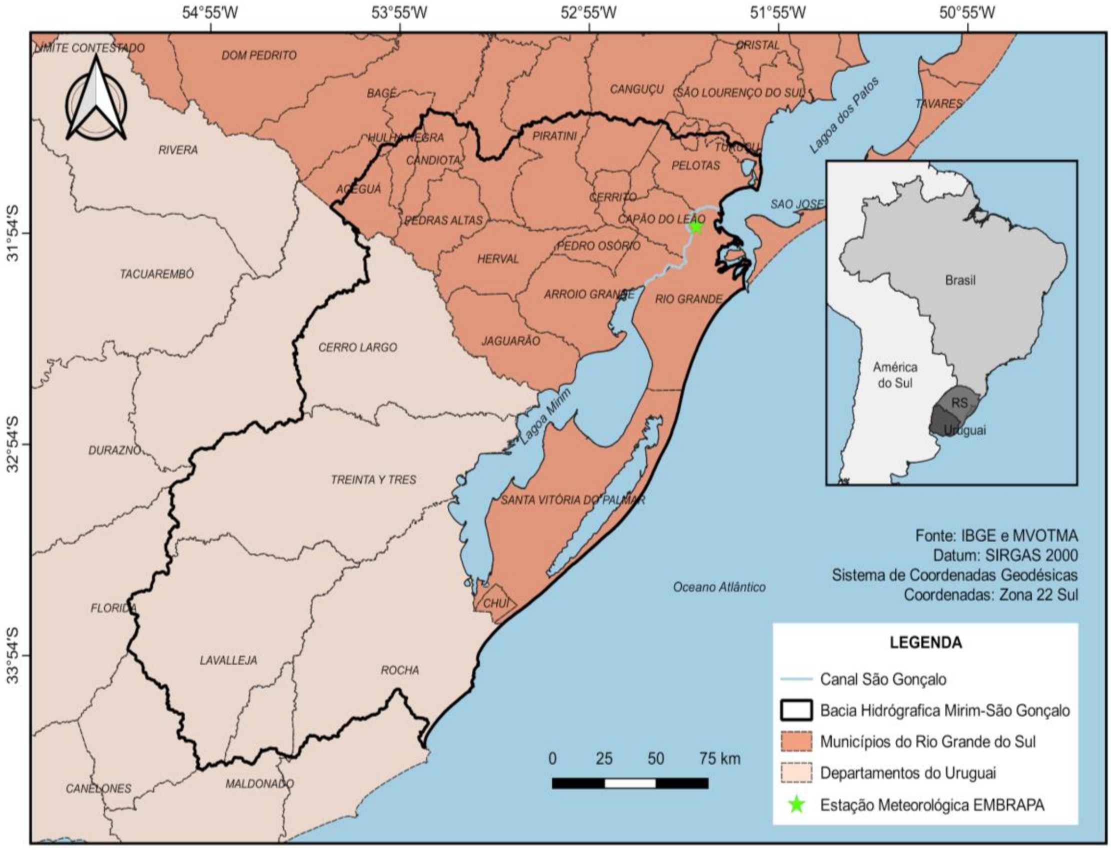
According to ARROZ (2020), rice production in 2020 was estimated to be approximately 11.2 million tons, of which 10.3 million tons were cultivated in irrigated areas, representing a total growth of 6.6% compared with the previous harvest, a fact made possible by the record harvest that Brazil experienced in 2020, with special emphasis on favorable climatic conditions in the southern region of the country.

Influenced by the COVID-19 pandemic, there was an increase in the price of rice in Brazil, resulting in increases of more than 30% in the value of the raw material, representing final prices 290% higher than the minimum price established by the federal government (BRAZILIAN RICE INDUSTRY ASSOCIATION, 2020). Therefore, the objective of this study was to evaluate the influence of ENSO and the SPI, SPEI, and ONI indices between 1984 and 2020 on the corrected average productivity of irrigated rice (PMCAI) in the Mirim-São Gonçalo River Basin.

4 METHODOLOGY

According to Oliveira et al. (2015, 2019), the Patos–Mirim Lagoon Complex is considered the largest lagoon system in Latin America. According to Corrêa et al. (2015), this complex is located in extremely southern Brazil and encompasses Lagoa Mirim and Laguna dos Patos, which together have a total area of nearly 10,000 km² and are connected by the 76.6 km long São Gonçalo Canal. The BHMSG is inserted in this context, having in its drainage area all the waters of Lagoa Mirim and the São Gonçalo Canal and the southern part of Laguna dos Patos (Figure 1). Of interest for this study is the Brazilian portion of the BHMSG, which encompasses 21 municipalities, the São Gonçalo Canal, and part of Lagoa Mirim.

Figure 1. Location of the study area, showing the Mirim-São Gonçalo River Basin, comprising its Brazilian and Uruguayan portions.



The climate of the region, according to the Köppen climate classification, is of the "Cfa" type, that is, humid temperate with hot summers, with rainfall well distributed throughout the year (PEEL; FINLAYSON; MCMAHON, 2007). The reference precipitation and evapotranspiration (ETo) data via the Penman–Monteith method (ALLEN et al., 1998) were obtained from data from the meteorological station of the Brazilian Agricultural Research Corporation (Embrapa) temperate climate located in the municipality of Capão do Leão, RS (Figure 1). Two indices are used: the standardized precipitation index (SPI) (MCKEE; DOESKEN; KLEIST, 1993) and the standardized precipitation and evapotranspiration index (SPEI) (VICENTE-SERRANO; BEGUERÍA; LÓPEZ-MORENO, 2010).

These indices can be applied at different time scales; therefore, in this work, time scales of 1, 3, 6 and 12 months were used, which were named SPI-1 (SPEI-1), SPI-3 (SPEI-3), SPI-6 (SPEI-6), and SPI-12 (SPEI-12), respectively. To calculate the SPEI, the log-logistic distribution was used, whereas the gamma distribution was applied to calculate the SPI index, as detailed by Vicente-Serrano, Beguería and López-Moreno (2010). In the original formulation, the SPEI uses the Thornthwaite equation (THORNTHWAITE, 1948) to calculate the ETo. As recommended by Beguería et al. (2014), we used the more robust Penman–Monteith equation (ALLEN et al., 1998) to calculate the ETo.

The values of the two indices at all scales were calculated for the different months of the year (January–December). Using the beginning of the harvest in March as a basis (KLERING et al., 2016), the values of the indices in the months of January to March were related to the productivity obtained in the same year, whereas the values of the indices obtained in the months of April to December were correlated with the productivity of the following year.

The time scale (1, 3, 6 or 12 months) and the most appropriate month for each of the indices to describe the variability in rice productivity were selected on the basis of Pearson's correlation coefficient, considering significance levels of 0.1 and 0.05.

The productivity data of the crops used in the study were obtained from the Rio Grande do Sul Rice Institute (IRGA) through harvest reports from 1984/1985--2019/2020; 36 harvests were analyzed, with the exception of the 2006/2007 harvest, which is unavailable in the IRGA database (INSTITUTO RIO GRANDENSE DE ARROZ, 2020).

One effect to be considered is the inherent and gradual increase in agricultural productivity caused exclusively by the insertion and improvement of technologies applied to the field. Therefore, for comparison purposes between the harvests surveyed, the effects of increased technology on the PMAI data in the basin were smoothed, applying Equation (1), as proposed by Arsego et al. (2019).

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

where Yci is the corrected average productivity of irrigated rice for year i; Yi is the original productivity of year i; $Y(Xi)$ is the productivity estimated for year i via the regression model; and $Y(Xf)$ is the productivity of the previous year estimated via linear regression.

Information on the periods of the ENSO phenomenon was obtained from the *National Weather Service (*NWS) (CLIMATE PREDICTION CENTER INTERNET TEAM , 2020), covering the period related to the harvests analyzed, from 1984--2020, through the ONI index.

The PMCAI values of the region were related to the periods governed by El Niño, La Niña and climate neutrality. Therefore, the statistical analysis of these results was carried out through the analysis of variance of the data (F test) at 5% significance, and when there was a significant difference between the treatments, the data were submitted to the mean test (Scott--Knott) via the statistical program Sisvar 5.6® (FERREIRA, 2008).

5 RESULTS AND DISCUSSION

According to information obtained from Embrapa's meteorological station, from 1971--2020, the average monthly precipitation ranged from 103 mm (December) to 150 mm (February), with an annual average of 1,399 mm (Figure 2). The ETo ranged from 36 mm in June to 150 mm in December, with an average annual total of 1,080 mm (Figure 2). The ETo variation for the Southern Hemisphere increases in the summer months and decreases in the winter months. As analyzed by Hallal et al. (2013), the ETo variation throughout the year is directly related to the availability of solar energy. Unlike ETo, precipitation in BHMSG presents greater variability during the months of the year and is well distributed throughout the year, corroborating the results of other studies (BOEIRA et al., 2020; GONÇALVES; BACK, 2018).

Figure 2. Temporal variation in precipitation and reference evapotranspiration (ETo) for the Mirim-São Gonçalo River basin region from 1971--2020

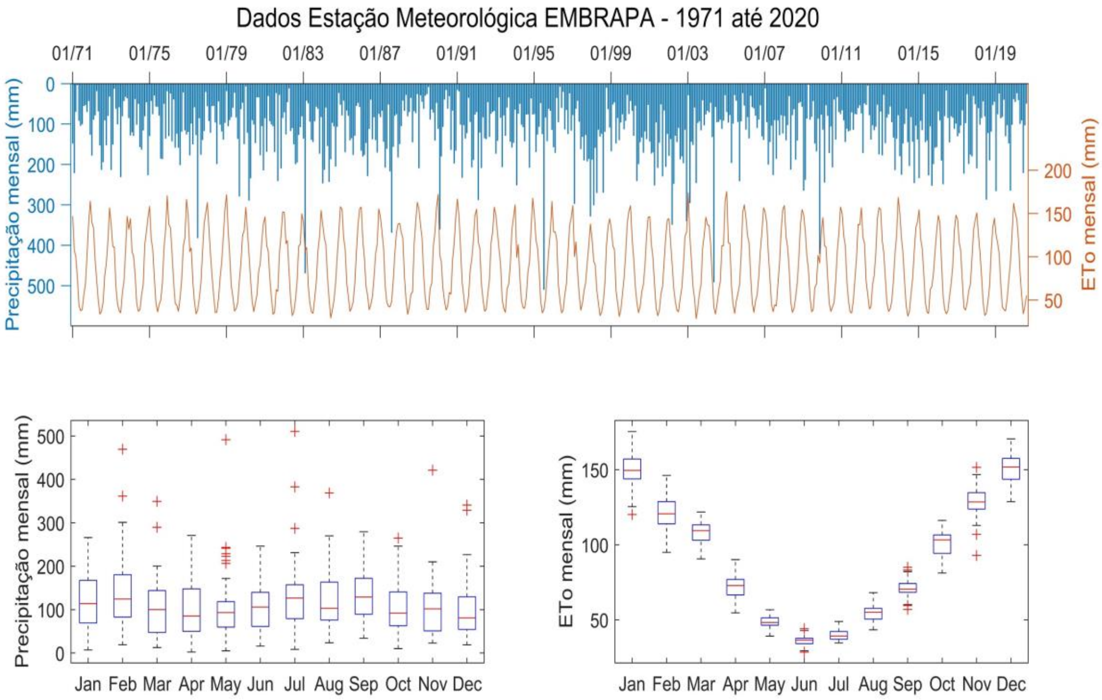


Table 1 shows the occurrence of the ENSO phenomenon in the harvests (through colors) between 1984 and 2020, together with the PMAI and PMCAI values, with harvests governed by El Niño periods presented in red, those governed by La Niña periods presented in blue and those of climate neutrality represented in gray.

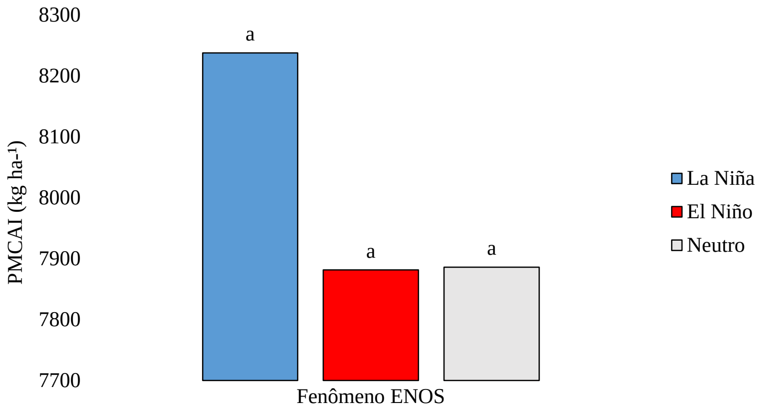
Table 1. History of the analyzed harvests with their respective average rice productivity values and El Niño Southern Oscillation (ENSO) phenomenon

Harvest	PMAI (kg.ha $^{-1}$)	PMCAI* (kg.ha $^{-1}$)	Harvest	PMAI (kg.ha $^{-1}$)	PMCAI* (kg.ha $^{-1}$)
1984/1985	5,000.00	8,839.5	2002/2003	4,828.2	6,693.1
1985/1986	4,600.0	8,329.8	2003/2004	5,658.6	7,413.8
1986/1987	4,634.3	8,254.4	2004/2005	5,615.0	7,260.5
1987/1988	5,230.0	8,740.4	2005/2006	5,927.7	7,463.5
1988/1989	4,904.7	8,305.4	2006/2007	-	-
1989/1990	5,020.0	8,311.0	2007/2008	6,992.7	8,309.1
1990/1991	4,381.3	7,562.6	2008/2009	7,257.6	8,464.3
1991/1992	5,254.5	8,326.1	2009/2010	6,847.2	7,944.2
1992/1993	5,412.5	8,374.4	2010/2011	7,965.4	8,952.7
1993/1994	4,737.5	7,589.7	2011/2012	7,511.8	8,389.4
1994/1995	5,112.5	7,855.0	2012/2013	7,705.8	8,473.7
1995/1996	5,325.0	7,957.8	2013/2014	7,200.5	7,858.7
1996/1997	5,422.8	7,945.9	2014/2015	8,279.8	8,828.3
1997/1998	4,360.6	6,774.0	2015/2016	7,134.1	7,572.9
1998/1999	5,330.7	7,634.4	2016/2017	8,215.4	8,544.5
1999/2000	5,546.8	7,740.8	2017/2018	7,728.1	7,947.5
2000/2001	5,909.9	7,994.2	2018/2019	7,911.2	8,020.9
2001/2002	4,872.0	6,847.1	2019/2020	8,308.8	8,308.8

*Values corrected from Equation 1; PMAI = average productivity of irrigated rice; PMCAI = corrected average productivity of irrigated rice; El Niño; La Niña; climate neutrality.

According to the results shown in Table 1, most harvests (13 harvests) were periods of climate neutrality (neutral), followed by harvests governed by the El Niño (12 harvests) and La Niña (11 harvests) phenomena. The relationships between the PMCAI in the study region and the ENSO phenomenon are presented in Figure 3.

Figure 3. Relationship between the PMCAI in the 1984/1985 harvests and that in the 2019/2020 harvest, with the exception of 2006/2007, and the ENSO phenomenon



Averages followed by the same letter do not differ according to the Scott–Knott test at the a=0.05 level.

Figure 3 shows that the PMCAI variable was not significant under the El Niño and La Niña regimes or under periods of climatic neutrality. For the periods governed by La Niña, the PMCAI was greater than that of the other periods (close to 4.3%), with a value of 8,237.7 kg.ha $^{-1}$, followed by El Niño periods (7,881.6 kg.ha $^{-1}$) and periods of climatic neutrality (7,886.2 kg.ha $^{-1}$). Studies such as those by Arsego et al. (2020), Carmona (2001) and Mota (2000) reported that La Niña events are associated with increased rice productivity in southern RS.

In turn, the correlations between the PMCAI and the SPI, SPEI, and ONI at all time scales were predominantly negative (Figure 4). The SPI and SPEI can be grouped into seven categories, from extremely dry (SPI and SPEI ≤ -2.0) to extremely wet (SPI and SPEI ≥ 2.0) (POTOP et al. 2014). Thus, for the BHMSG, negative correlations indicate an increase in the PMCAI in drier periods, as indicated by the SPEI and SPI indices.

Figure 4. Pearson correlation matrix between the indices (SPEI-1 to SPEI-12, SPI-1 to SPI-12 and ONI) and the corrected average productivity of irrigated rice for the Mirim-São Gonçalo River basin

*p ≤ 0.10; **: p ≤ 0.05; SPI-1 = Standardized precipitation index at the 1-month time scale; SPEI-1 = Standardized precipitation and evapotranspiration index at the 1-month time scale; SPI-3 = Standardized precipitation index at the 3-month time scale; SPEI-3 = Standardized precipitation and evapotranspiration index at the 3-month time scale; SPI-6 = Standardized precipitation index at the 6-month time scale; SPEI-6 = Standardized precipitation and evapotranspiration index at the 6-month time scale; SPI-12 = Standardized precipitation index at the 12-month time scale; SPEI-12 = Standardized precipitation and evapotranspiration index at the 12-month time scale; ONI = Niño Oscillation Index.

The distribution of months with significant correlations is uniform for both indices (SPI and SPEI), with an emphasis on December, in which all time scales in which the indices were applied showed significant correlations (p ≤ 0.1). In this month, the highest correlations were obtained with the SPI-1 and SPI-3 indices (-0.40). Prabnakorn et al. (2018) also reported greater correlations (in magnitude) between rice yield and the SPEI with aggregation periods of one and three months in a river basin in northeastern Thailand. Apparently weak correlation values between the SPI and SPEI indices and irrigated rice yield were also reported by Chen et al. (2016) in a province of China. The authors reported higher correlation values between the analyzed indices and rainfed crops, such as corn and sorghum. The indices can be applied to different time scales, with the three-month scale being one of the most relevant for agriculture (POTOP et al., 2014). Therefore, indices that present significant correlations, especially in the final sowing period in the BHMSG, such as the SPEI-3 calculated for November, can be considered important predictors of irrigated rice productivity for future harvests. Because of the time lag between the vegetation response to precipitation, Ji and Peters (2003) suggested the use of the SPI-3 index to assess the effects of dry and wet periods on vegetation cover.

Por sua vez, a distribuição dos meses com correlação significativa é destaque para o índice ONI, apresentando correlações significativas ($p \leq 0,1$) for two-thirds of the months analyzed, except February, March, April, and May. The months with the highest correlations between the ONI and rice productivity were August and September (-0.37), October (-0.36), and November (-0.35). These are periods at the beginning of the cultivation period, in which situations that present high solar radiation and lower intensity and frequency of rainfall in the spring allow farmers to sow at the appropriate time, which is highly important for the farmer (MENEZES et al., 2012). Arsego et al. (2020) reported similar correlations between rice productivity and the ONI index for 47 rice-producing municipalities in the state of RS, highlighting the negative correlations during the crop development period and the importance of analyzing such variables.

Another important point raised by Arsego et al. (2020) is that the signal associated with the ONI persists with significant correlations, thus being linked to the persistence of a drier weather pattern during the crop development period that favors increased productivity due to the greater availability of solar radiation, as confirmed by the negative correlation.

6 CONCLUSIONS

From this study, the following conclusions are drawn:

1. The PMCAI, which considers the smoothing of the effects due to the increase in technology in BHMSG for the period from 1984/1985--2019/2020, was 7,995.1 kg.ha $^{-1}$.

2. The ENSO phenomenon was not significant for the PMCAI variable in the study region.

3. The SPEI and SPI indices with lags of 1, 3, 6 and 12 months calculated for the month of December are commonly those with the greatest correlation with irrigated rice productivity, demonstrating that they can be used to analyze the performance of agricultural activity.

4. The ONI index showed, for most months, significant correlations with irrigated rice productivity, particularly in the months at the beginning of cultivation.

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