UNIVERSIDADE FEDERAL DE SANTA MARIA
CENTRO DE CIÊNCIAS RURAIS
DEPARTAMENTO DE FITOTECNIA
PROGRAMA DE PÓS-GRADUAÇÃO EM AGRONOMIA

RELATÓRIO CIRCUNSTANCIADO DAS ATIVIDADES DESENVOLVIDAS NO PERÍODO DE PÓS-DOUTORADO

Projeto: Análise numérica de favorabilidade climática à ferrugem asiática da soja na região central do Rio Grande do Sul

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Santa Maria/RS, dezembro de 2020.

1. INTRODUÇÃO

Este Relatório Circunstanciado visa descrever as atividades realizadas durante o período de realização do pós-doutorado no Programa de Pós-Graduação em Agronomia (PPGA), da Universidade Federal de Santa Maria (UFSM), no período de janeiro à dezembro 2020, sob a orientação do Professor Doutor Arno Bernardo Heldwein.

O projeto apresentado para a execução do Pós-doutorado apresentava como título: - Análise numérica de favorabilidade climática à ferrugem asiática da soja na região central do Rio Grande do Sul, sendo o objetivo simular épocas de semeadura para a cultura da soja e seus subperíodos de desenvolvimento, obter os valores de severidade de ferrugem asiática acumulados nos subperíodos por sistema de previsão agrometeorológica/fitossanitária para essas diferentes épocas em 51 anos e, com base nesses resultados, determinar a época de semeadura de menor risco de ocorrência dessa doença na região central do Rio Grande do Sul.

No decorrer do projeto, houveram modificações, incorporando às análises outros três locais de estudo (Cruz Alta, Passo Fundo e São Luiz Gonzaga), ampliando a abrangência do projeto, visando a maior robustez das produções

2. DESENVOLVIMENTO DAS ATIVIDADES DO PROJETO

Em função da Pandemia Mundial de COVID-19, o planejamento inicial do estágio pós-doutoral precisou ser ajustado, com muitas atividades sendo desenvolvidas à distância, visando evitar o contágio pelo novo coronavírus. Assim, após 16 de março de 2020, os encontros com o supervisor e o grupo de pesquisa foram realizados majoritariamente por teleconferência, visando delinear os experimentos e análises, discutir o tratamento de dados e também a redação das produções decorrentes do projeto. Ressalta-se que, apesar das dificuldades inicialmente imaginadas, a qualidade das atividades não foi prejudicada, pois a equipe desenvolveu uma rotina e adaptou-se à mesma, de forma a produzir resultados satisfatórios.

O estudo foi desenvolvido utilizando os dados meteorológicos de temperatura do ar e umidade relativa do ar de quatro locais do estado do Rio Grande do Sul (Cruz Alta, Passo Fundo Santa Maria e São Luiz Gonzaga). Estes locais são representativos das principais regiões produtoras de soja no estado. Conforme a classificação climática de

Köppen, no Rio Grande do Sul ocorrem os climas dos tipos Cfa e Cfb, que não tem estação seca definida, com verões quentes e moderadamente quentes, respectivamente. O tipo Cfa prevalece na maior parte do Estado e o Cfb ocorre nas partes mais altas da Serra do Nordeste, Planalto e Serra do Sudeste. Dentre os locais estudados, apenas Passo Fundo está próximos ao limite do clima Cfb. Porém, ainda é classificado como Cfa (KUINCHTNER; BURIOL, 2001).

Os dados meteorológicos utilizados neste trabalho foram fornecidos pelo Instituto Nacional de Meteorologia e coletados em estações meteorológicas automáticas e convencionais, no período de 1961-2020. Quando disponíveis dados de ambas as estações, optou-se por utilizar os dados das estações automáticas, por terem disponibilidade horária. No caso dos dados das estações convencionais, foram realizadas estimativas de temperatura e umidade relativa do ar a cada hora, de acordo com Radons (2012). Os períodos com falhas de registro de dados foram excluídos da análise. Os anos agrícolas (agosto-julho) foram classificados em El Nino (EN), La Niña (LN) e Neutros (N) de acordo com a fase de ocorrência do fenômeno El Niño Oscilação Sul (ENOS), tendo por base os dados do NOAA (2020).

O ciclo de desenvolvimento da soja foi simulado para datas de semeadura em intervalos de aproximadamente 10 dias, compreendendo todo o período recomendado pelo Zoneamento Agrícola de Risco Climático para cada local de estudo. Em Cruz Alta e São Luiz Gonzaga, o período de semeadura inicia em 21 de setembro. Já em Passo Fundo e Santa Maria, inicia em 01 de outubro. Foram considerados três grupos de maturidade relativa (GMR): precoce (até 6.3), médio (6.4–7.4) e tardio (7.5 ou maior) (KARSTER; FARIAS, 2011).

A data de emergência foi estimada pelo o acúmulo de soma térmica (temperatura base 10 ºC), assumindo o valor acumulado de 92,5 ºC dia (SCHNEIDER et al., 1987). O estágio de emissão da quinta folha trifoliada (V5) foi estimado pelo modelo Soydev (SETIYONO et al., 2007) com coeficientes de Streck et al. (2009). A estimativa do início da floração (R1) foi feita pelo modelo de Sinclair et al. (1991), utilizando coeficientes interpolados de acordo com o GMR. O início do enchimento de grãos (R5) foi estimado de acordo com Sinclair et al. (2007) e o início da maturação (R7) foi considerado quando atingida a soma térmica acumulada de 554 ºC dia (temperatura base 10 ºC) a partir do estágio R5 (MARTORANO et al., 2012).

Foram calculados, diariamente, os valores de favorabilidade climática para a ocorrência da ferrugem asiática da soja, obtidos pelo produto das as funções de resposta ao tempo de molhamento foliar e à temperatura do ar durante o período de molhamento, ambas com variação entre 0 e 1 (ENGERS, 2019). Foi considerada a presença de molhamento foliar quando a umidade relativa do ar era superior a 85% (STRECK, 2006). A função de resposta ao tempo de molhamento foliar (f(W)) é descrita a seguir:

$$f(W) = \frac{1}{1 + e^{(W-12)}}$$

Em que W é o tempo de molhamento foliar, em horas. A função de resposta à temperatura do ar (f(T)) é assim descrita:

$$f(T) = \frac{2\ (\mathrm{T} - 8)\alpha\ (\ 22{,}75 - 8)\alpha\ -\ (\mathrm{T} - 8)2\alpha}{(22{,}75 - 8)2\alpha} \qquad \alpha$$

$$= \frac{\ln 2}{ln[(42 - 8)/(22{,}75 - 8)]}$$

Os valores de 42, 22,75 e 8 indicam, respectivamente, as temperaturas do ar máxima, ótima e mínima para o desenvolvimento da doença.

O número de aplicações por ciclo foi calculado dividindo-se o número de valores de favorabilidade acumulados ao longo do período de proteção pelo intervalo de aplicações de fungicidas, considerado de 9 valores de favorabilidade acumulados. O período de proteção foi considerado entre a emissão da quinta folha trifoliada (V5) e o início da maturação (R7). O intervalo entre aplicações de fungicidas (dias) foi calculado dividindo-se a duração do período de proteção pelo número de aplicações de fungicidas (ENGERS, 2019).

Os dados foram analisados por meio da análise de variância pelo teste F em 5% de probabilidade de erro para verificar a existência de efeito significativo da data de semeadura, ciclo e fase do fenômeno ENOS, bem como de interação entre os fatores. Foram realizadas análises de regressão (médias) e box plot (percentis 5, 25, 50, 75 e 95) para interpretação dos resultados.

2.1 Considerações do artigo

Da execução deste projeto de pós-doutorado resultou a produção de um artigo científico, enviado para publicação na revista *Tropical Plant Pathology*, intitulado "**Climatic risk of Asian soybean rust occurrence in the state of Rio Grande do Sul, Brazil**", que se encontra anexo a este relatório.

Os resultados deste estudo permitem fazer inferências práticas sobre o controle da FAS no Rio Grande do Sul. Cultivares precoces, semeadas no início do período recomendado pelo zoneamento agrícola, geralmente tem em seu ciclo condições meteorológicas menos favoráveis para a ocorrência da FAS e menor variabilidade interanual. O efeito do fenômeno ENOS, no entanto, varia entre os locais estudados, com tendência de prevalência de condições mais favoráveis para a ocorrência da doença em anos de El Niño. Porém, os anos de neutralidade são os que apresentam maior variabilidade interanual da favorabilidade para ocorrência da doença.

3. DEMAIS ATIVIDADES REALIZADAS

- Publicação de artigo em periódico científico: BRAND, S. I.; HELDWEIN, A. B.; RADONS, S. Z.; MALDANER, I. C.; HINNAH, F. D.; GUSE, F. I.; SILVA, J. R. Effect of Alternaria and Septoria spot on sunflower yield. **International Journal of Biometeorology**, v. 64, p. 2153–2160, 2020. http://dx.doi.org/10.1007/s00484-020-02006-8 (comprovação anexa)

- Envio de artigo para publicação em periódico científico: Visando o aproveitamento do banco de dados disponível, foi elaborado o artigo "*Hours of occurrence of daily extreme air temperature and relative humidity in Santa Maria, RS*", submetido para publicação na revista **Agrometeoros** (comprovação anexa)

- Envio de artigo para publicação em periódico científico: Visando o aproveitamento do banco de dados disponível, foi elaborado o artigo "*Climatic favorability for agricultural spraying in the state of Rio Grande do Sul*", submetido para publicação na revista **Agricultural and Forest Meteorology** (comprovação anexa)

4. CONSIDERAÇÕES FINAIS

A realização do estágio pós-doutoral significa um aprofundamento em um determinado tema de pesquisa, no caso o foco da realização deste no PPGA/UFSM foi aprimorar as técnicas de tratamento e análise de dados, bem como o desenvolvimento de simulações de desenvolvimento da cultura da soja. Durante estes dois semestres, a colaboração de demais pesquisadores, em um trabalho em equipe, foi fundamental para execução deste projeto demostrando a importância da cooperação entre pesquisadores como algo benéfico para a ciência. E na ciência temos a imprevisibilidade, e está foi observada ao surgir, no início do período pós-doutoral, uma Pandemia, que paralisou as atividades presenciais na Universidade Federal de Santa Maria e fez a população se recolher nas suas casas e desenvolver o trabalho em formato remoto.

5. AGRADECIMENTOS

Registro meus agradecimentos mais sinceros ao Professor Dr. Arno Bernardo Heldwein, pelo acolhimento, convívio e ensinamentos ao longo de mais esta etapa. Ao PPGA/UFSM e a Universidade Federal da Fronteira Sul (*Campus* Cerro Largo, RS) pela oportunidade de cursar este estágio pós-doutoral como parte da minha formação docente.

6. REFERÊNCIAS

ENGERS, L. B. O. Sistema de previsão para o manejo da ferrugem asiática em soja. 2019. **Dissertação de Mestrado**. Universidade Federal da Fronteira Sul. 60 f. https://rd.uffs.edu.br/handle/prefix/3592

KASTER, M.; FARIAS, J. R. B. Regionalização dos testes de VCU-Valor de Cultivo e Uso de cultivares de soja-terceira aproximação. In: 32º Reunião de pesquisa de soja da região central do Brasil, São Pedro, SP. **Anais**.., p. 231-235, 2011.

KUINCHTNER, A.; BURIOL, G. A. Clima do Estado do Rio Grande do Sul segundo a classificação climática de Köppen e Thornthwaite. **Disciplinarum Scientia Naturais e Tecnológicas**, v. 2, n. 1, p. 171-182, 2001. https://doi.org/10.37779/nt.v2i1.1136

MARTORANO, L. G.; BERGAMASCHI, H.; FARIA, R. T.; DALMAGO, G. A. Decision Strategies for Soil Water Estimations in Soybean Crops Subjected to No-Tillage and Conventional Systems, in Brazil. In: INTECH. **Problems, perspectives and challenges of agricultural water management**. 1 ed. 2008. https://doi.org/10.5772/29711

NOAA. **Historical El Nino/ La Nina episodes (1950-present)**. Disponível https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Acesso em outubro de 2020.

RADONS, S. Z. Análise numérica de risco climático de ocorrência de requeima na cultura da batata na região central do Rio Grande do Sul. Santa Maria: UFSM, 2012. 115 p. **Tese de Doutorado**.

https://repositorio.ufsm.br/bitstream/handle/1/3211/RADONS%2c%20SIDINEI%20ZWICK.pdf

SCHNEIDER, F. M.; BURIOL, G. A.; HELDWEIN, A. B.; MANFRON, P. A.; SACCOL, A. V.; ESTEFANEL, V. Temperatura base e soma térmica do subperíodo semeadura emergência para algumas cultivares de soja (Glycine max (L.) Merrill). **Revista do Centro de Ciências Rurais**, v. 17, n. 4, p. 299-308, 1987. http://coral.ufsm.br/revistaccr/index.php/RCCCR/article/viewFile/639/636

SETIYONO, T. D.; WEISS, A.; SPECHT, J.; BASTIDAS, A. M.; CASSMAN, K. G.; DOBERMANN, A. Understanding and modeling the effect of temperature and day length on soybean phenology under high-yield conditions. **Field Crops Research**, Amsterdam, v.100, p.257-271, 2007. https://doi.org/10.1016/j.fcr.2006.07.011

SINCLAIR, T. R.; KITANI, S.; HINSON, K.; BRUNIARD, J.; HORIE, T. Soybean flowering date: linear and logistic models based on temperature and photoperiod. **Crop Science**, v. 31, n. 3, p. 786-790, 1991. https://doi.org/10.2135/cropsci1991.0011183X003100030049x

STRECK, L. Determinação da duração do período de molhamento foliar em cultivos de batata Tese de Doutorado, Universidade Federal de Santa Maria. 2006, 107 f. https://repositorio.ufsm.br/bitstream/handle/1/3270/Tese%20StreckLuciano.pdf

STRECK, N. A.; PAULA, G. M.; OLIVEIRA, F. B.; SCHWANTES, A. P.; MENEZES, N. L. D. Improving node number simulation in soybean. **Pesquisa Agropecuária Brasileira**, v. 44, n. 7, p. 661-668, 2009. https://doi.org/10.1590/S0100-204X2009000700002

7. Anexos

Tropical Plant Pathology

Climatic risk of Asian soybean rust occurrence in the state of Rio Grande do Sul, Brazil

--Manuscript Draft--

Manuscript Number:	
Full Title:	Climatic risk of Asian soybean rust occurrence in the state of Rio Grande do Sul, Brazil
Article Type:	Original Article
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Abstract:	One of the greatest challenges for the sustainability of soybean production in Brazil is the control of Asian Soybean Rust (ASR). This study aimed to assess the climatic risk of Asian soybean rust occurrence throughout the period recommended for sowing in four locations of Rio Grande do Sul, considering different soybean relative maturity groups and the phases of the El Niño–Southern Oscillation phenomenon. The soybean development cycle and the climatic favorability for ASR occurrence were simulated for the recommended sowing dates in the period from 1961 to 2020 in four locations of Rio Grande do Sul. Early cultivars, sown at the beginning of the period recommended by agricultural zoning, usually exhibit less favorable climatic conditions for ASR occurrence and less interannual variability in their cycle. The effect of the ENSO phenomenon varies across the studied locations, with the prevalence of more favorable conditions for ASR occurrence during El Niño years. However, neutrality years show greater interannual variability for the risk of ASR occurrence.
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Author Comments:	Dear Editor-in-chief: I am pleased to submit an original research article entitled “Climatic risk for soybean Asian rust occurrence in Rio Grande do Sul state, Brazil” for consideration for publication in Tropical Plant Pathology. In this manuscript, we evaluate the climatic risk for the Asian soybean rust occurrence over the period recommended for sowing in four locations in Rio Grande do Sul State, Brazil. We consider the different relative maturity groups, El Niño South Oscilation phenomenon phases and soybean development cycle and sowing dates during the recommended period. Favorable weather conditions for the FAS occurrence were simulated in four locations in Rio Grande do Sul, in the 1961-2020 period. Early maturing cultivars, sown at the beginning of the period recommended by agricultural zoning, generally have less favorable weather conditions for the occurrence of FAS in their cycle and less interannual variability. The effect of the ENSO phenomenon, however, varies among the studied locations, with a tendency for the prevalence of more favorable conditions for the disease occurrence in El Niño

	years. However, neutral years are those that present the greatest interannual variability in risk for the disease occurrence. We believe that this manuscript is appropriate for publication by Tropical Plant Pathology because it addresses one of the typical topics in the journal, more specifically strategies for plant protection. This topic has been widely discussed by scientific society, as environmental contamination by drift has been frequent around the world and has caused great environmental and economic damage. Thus, knowing the climatic risk for the Asian soybean rust occurrence over the period recommended for sowing can help to reduce this damage and make agriculture a more sustainable activity. Finally, studies like this are rarely seen in the scientific literature, making our study expected to be highly visible and serve as a basis for other similar studies development. We want to make it clear, as stated in the journal's instructions to authors, that (i) all authors have approved the submission of the manuscript; (ii) the findings have not been published or are not under consideration for publication elsewhere; (iii) authors transfer copyright to the Brazilian Phytopathological Society. Thanks you for your consideration! Sincerely, Dr. Sidinei Zwick Radons Corresponding author Federal University of Fronteira Sul
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Climatic risk of Asian soybean rust occurrence in the state of Rio Grande do Sul, Brazil

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ABSTRACT

One of the greatest challenges for the sustainability of soybean production in Brazil is the control of Asian Soybean Rust (ASR). This study aimed to assess the climatic risk of Asian soybean rust occurrence throughout the period recommended for sowing in four locations of Rio Grande do Sul, considering different soybean relative maturity groups and the phases of the El Niño–Southern Oscillation phenomenon. The soybean development cycle and the climatic favorability for ASR occurrence were simulated for the recommended sowing dates in the period from 1961 to 2020 in four locations of Rio Grande do Sul. Early cultivars, sown at the beginning of the period recommended by agricultural zoning, usually exhibit less favorable climatic conditions for ASR occurrence and less interannual variability in their cycle. The effect of the ENSO phenomenon varies across the studied locations, with the prevalence of more favorable conditions for ASR occurrence during El Niño years. However, neutrality years show greater interannual variability for the risk of ASR occurrence.

KEYWORDS

Phakopsora pachyrhizi, favorability, fungicides, El Niño–Southern Oscillation.

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ORIGINAL PAPER

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Effect of *Alternaria* and *Septoria* spot on sunflower yield

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Abstract

Leaf diseases affect crop yields. In sunflower crops, leaf spot severity can reach 100%, but the magnitude of the yield loss caused by the disease is not known. This study aimed to evaluate the effect of *Alternaria* and *Septoria* leaf spot severity on sunflower yield across different years in a humid subtropical climate. We conducted 37 experiments in Santa Maria, RS, Brazil, over 7 years. The hybrids Embrapa 122, Helio 358, Aguará 03, and Altis 99 were sowed and managed according to national crop recommendations. Severity assessments for *Alternaria* and *Septoria* spots were performed at 2- to 7-day intervals using a diagrammatic scale. We evaluated the effects of *Alternaria* and *Septoria* leaf spot severity on crop yield using upper limit graphs. The 37 experiments comprised 13 normal season crops (August to October) and 24 late season crops (November to February). The results were also classified according to the contemporaneous phases of the ENSO (El Niño Southern Oscillation): El Niño, La Niña, and Neutral. In normal season crops, severities of up to 24% do not result in yield decrease. After this, each 1% increment in disease severity produces a decrease of 66 kg ha^{-1} on sunflower yield. In late season crops, the reduction in productivity occurs at severities greater than 34%, with a decrease of 50 kg ha^{-1} for each 1% increase in combined disease severity. The highest severity values and lowest yields, both in the normal and late season crops, occurred in El Niño years.

Keywords *Septoria helianthi* · *Alternaria helianthi* · *Helianthus annuus* · Severity · Production

Introduction

Sunflower leaf diseases are mostly of fungal origin (Leite et al. 2005). In humid subtropical climates, *Alternaria* (*Alternaria helianthi*) and *Septoria* (*Septoria helianthi*) leaf spots are most common. *Septoria* leaf spot was first reported in 2007 in Rio Grande do Sul (Maldaner et al. 2009b), with high incidence and severe occurrences under some conditions (Maldaner et al. 2009a; Radons 2010; Hinnah 2014; Brand et al. 2018). In a span of only a few years, it has become a cause of immense economic damage in the southern region of Brazil, due to humid climate conditions.

As fungal pathosystems are favored by higher air humidity and leaf wetness (AGRIOS 2004; Leite and Amorim 2002a), these will have greater expression in rainy years. In addition, rainfall is a pathogen spore dispersion route (Amorim and

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Pascholati 2011), which accelerates epidemic spread in the cropped area.

Rainfall, and especially water surpluses, are very frequent from winter, to June until August, to early October in Rio Grande do Sul (Buriol et al. 1980; Heldwein et al. 2009). Thus, leaf wetness tends to be more prolonged and frequent during this period (Streck 2006), favoring fungal diseases. In El Niño years, this favorable condition generally extends from October to December in southern Brazil, due to increased rainfall (Iizumi et al. 2014).

Management practices aim to improve the crop condition and yield of agricultural crops. In sunflowers, there are no hybrids resistant to leaf spots, requiring that control actions be taken when environmental conditions favor the causal pathogens. However, as sunflower plants reach great heights by the beginning of anthesis, application of chemical, physiological, or biological control products is difficult and results in substantial mechanical damage to plants (Radons 2010). Thus, the most appropriate technique is aerial application or the use of self-propelled sprayers.

Registration of fungicides in Brazil for sunflower crop has occurred, since there was not until 2009 (Radons 2010), and currently there is already registration for some leaf diseases (AGROFIT 2018). This is due to this crop expansion in Brazil, the historical damage already caused by leaf diseases in sunflower (Leite et al. 2007) and the consequent necessity to control diseases that occur when weather conditions were favorable.

Quantification of the damage caused by different leaf diseases in sunflower is therefore needed. They cause reduction of plant photosynthetic tissue, leading to lower photoassimilate production and thus decreased yield (Calvet 2001; Mello et al. 2011). However, such quantification is not yet available to support farmers' decision-making. Therefore, this study aimed to evaluate the effect of *Alternaria* and *Septoria* spot severity on sunflower yield under different weather conditions in a humid subtropical climate.

Materials and methods

The experiments were conducted in Santa Maria, RS, Brazil (29°43′23″ S, 53°43′15″ W and 95 m above sea level). The climate is characterized as subtropical humid, with a hot summer and no defined dry season (Cfa under the Köppen classification) (Alvares et al. 2013). The soil type is a Red Ultisol (EMBRAPA 2006).

The experiments were conducted across 7 years: from 2007/2008 to 2012/2013, and 2015/2016 (see also Guse 2009; Maldaner 2009; Radons 2010; Hinnah 2014; Brand 2017 for additional information) (Table 1). The hybrids Embrapa 122, Helio 358, Aguará 03 and Altis 99 were sowed and managed according to national crop recommendations (CQFS-RS/SC 2016; EMBRAPA 2000; AGROFIT 2018).

Meteorological data were obtained at the National Institute of Meteorology (INMET) automatic weather station at Santa Maria, RS, located 50 m from the experiments. Daily mean air temperature (°C), air relative humidity (%), wind speed ($m\ s^{-1}$), and sum of daily solar radiation ($MJ\ m^{-2}\ day^{-1}$) values were used to calculate the reference evapotranspiration (mm) by the Penman–Monteith method. Crop coefficients were selected in accordance with phenological stage (Allen et al. 1998).

To calculate the daily water balance, adapting the Thornthwaite and Mather (1995) method, we used daily rainfall ($mm\ day^{-1}$) and an available water storage capacity value of 122 mm, determined for the experimental area by Loose (2016).

Alternaria (*Alternaria helianthi*) and *Septoria* (*Septoria helianthi*) leaf spot severity assessments were performed at intervals of 2 to 7 days. We used the diagrammatic scale proposed by Leite and Amorim (2002b), which estimates the sick tissue percentage, i.e., the area that presents visible symptoms and/or disease signs.

Harvesting occurred when plants reached the R8 stage. After harvesting, heads were manually threshed and then dried in an oven at 60 °C for 72 h. After drying, the grain mass was determined, moisture content measured, and mass corrections made to 13% moisture to obtain yield ($kg\ ha^{-1}$).

Each year's rating as La Niña, Neutral, or El Niño was obtained from the US Climate Prediction Center (2016). According to Berlato et al. (2005), the period of the ENSO phenomenon begins at July 1 of a year and ends at June 30 of the following year.

The results analysis was performed by correlating the graphically determined maximum yield with the final observed disease severities, in El Niño, La Niña, and Neutral years across the 37 experiments.

Results

In normal season crops, the average yield was higher than in late season crops, mainly in response to a higher severity of *Alternaria* and *Septoria* spots in late season crops (Fig. 1). In normal season crops, the highest observed yield of 5252.6 $kg\ ha^{-1}$ occurred at a severity value of 24%; at higher severities, yield decreased with increasing severity. We found that for each 10% increase in severity, there was a reduction of 663.3 $kg\ ha^{-1}$ in sunflower yield for severities greater than 24%. In late season crops, yield decreased from its highest observed value of 3712.5 $kg\ ha^{-1}$ at 32% severity. For severity greater than 34%, a 10% increase in leaf spot severity decreased yield linearly by 504.5 $kg\ ha^{-1}$ (Fig. 1).

Table 1 Experimental specifications, indicating sowing months, row and plant spacing, year, El Niño Southern Oscillation (ENSO) condition classification, growing season (normal or late season crop), sunflower hybrid(s), and evaluated disease in 37 experiments

Month of sowing	Spacing (m) (rows × plants)	Year	ENSO	Normal/late season	Hybrid	Disease
Jul, Aug, and Oct	0.9 × 0.25	2007/08	La Niña	Normal	Helio 358, Aguará 03, Embrapa 122	*Alternaria* leaf spot
Nov, Dec, Jan, and Feb	0.9 × 0.25	2007/08	La Niña	Late season	Helio 358, Aguará 03, Embrapa 122	*Alternaria* leaf spot
Sep	0.9 × 0.25	2007/08	La Niña	Normal	Helio 358, Aguará 03	*Alternaria* leaf spot
Feb	0.9 × 0.25	2007/08	La Niña	Late season	Helio 358, Aguará 04	*Alternaria* leaf spot
Sep	0.9 × 0.25	2008/09	Neutral	Normal	Helio 358	*Septoria* leaf spot
Feb	0.9 × 0.25	2008/09	Neutral	Late season	Helio 358	*Septoria* leaf spot
Oct	0.9 × 0.25	2007/08	La Niña	Normal	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Nov and Jan	0.9 × 0.25	2007/08	La Niña	Late season	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Aug and Sep	0.9 × 0.25	2008/09	Neutral	Normal	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Nov and Feb	0.9 × 0.25	2008/09	Neutral	Late season	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Oct	0.9 × 0.25	2009/10	El Niño	Normal	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Nov, Dec and Jan	0.9 × 0.25	2009/10	El Niño	Late season	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Nov and Dec	0.9 × 0.25	2010/11	La Niña	Late season	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Sep and Oct	0.9 × 0.25	2011/12	La Niña	Normal	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Nov, Jan, and Feb	0.9 × 0.25	2011/12	La Niña	Late season	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Sep and Oct	0.9 × 0.25	2012/13	Neutral	Normal	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Nov, Dec, Jan, and Feb	0.9 × 0.25	2012/13	Neutral	Late season	Aguará 03, Helio 358	*Alternaria* and *Septoria* leaf spot
Nov and Feb	0.7 × 0.33	2015/16	El Niño	Late season	Altis 99	*Septoria* leaf spot

Air temperature and relative humidity varied throughout the experiments, with greater variation in the experiments of 2007/2008 and 2008/2009 (Fig. 2). In the 2009/2010, 2010/2011, 2011/2012, and 2012/2013 crops, the air temperature variation was smaller. The highest average air relative humidity values were recorded in the years 2009/2010, 2012/2013, and 2015/2016. The year 2015/2016 had the highest frequency periods in which relative humidity values were higher than 90%, but this threshold was not reached in other years. This condition favors leaf wetness, and relative humidity can be a measure used to estimate leaf wetness duration (Sentelhas et al. 2008). Precipitation was variable within the analyzed years, and generally the lowest cumulative quantities were in La Niña years and the highest in El Niño years. The smallest cumulative value in most years occurred in the later sowing, that is, in the late season crop.

In El Niño years of 2009/2010 and 2015/2016, it was observed that the water deficit was smaller, that of the agricultural year 2015/2016 being the lowest in any of our experiments. Over the seven experimental years, the highest water deficit (cumulatively over 125 mm) and the lowest ETr (real evapotranspiration) ETc (crop evapotranspiration)$^{-1}$ fraction occurred in 2011/2012, which was a La Niña year. The smallest deficit value occurred in the El Niño year 2015/2016, with only 4 mm in 5 months.

Discussion

The highest yield obtained in the normal season crop was 5252.6 kg ha^{-1} at a severity level of 24% (Fig. 1), sown in October 2012. This yield occurred in a Neutral year in which rainfall was 565 mm in the complete cycle, and most of the rainfall occurred during the reproductive phase, providing a good water supply at this most demanding of the sunflower's growth stages (Castro and Farias 2005), resulting in a high yield. In this experiment, disease control was not performed. Above 24%, increasing severity resulted in decreasing crop yield; with each 1% increase in *Alternaria* and *Septoria* leaf spot severity, yields reduced by approximately 66 kg ha^{-1}.

We also observed that lower productivity tends to occur in La Niña years, even when disease severity is lower. In La Niña years, the effect of water stress is most likely to occur during early spring and summer (Fontana and Berlato 1997; Iizumi et al. 2014). Thus, higher water deficit occurs during the crop's reproductive phase, as shown by lower relative crop evapotranspiration (ETr ETc^{-1}) (Table 2), which affects the grain filling stage, leading to lower yield. The 2011/2012 crop had the lowest relative evapotranspiration and, therefore, the greatest water limitation for the crop throughout the growth cycle (Table 2), affecting yield. In an experiment in a La Niña year in which irrigation was performed, in addition to disease control management, higher yields were achieved.

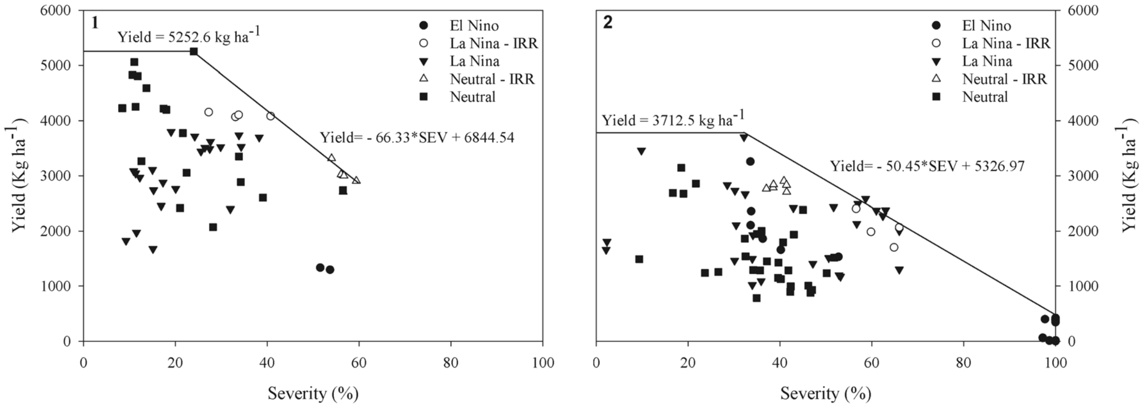

Fig. 1 Sunflower yield in relation to final observed severity of *Alternaria* and *Septoria* leaf spots in El Niño, La Niña, and Neutral years; (1) 15 experiments with normal season crops and (2) 24 with late season crops, in Santa Maria, RS, Brazil. IRR—Irrigated experiment

In El Niño years, the higher rainfall, higher air humidity, and lower solar radiation availability (Fontana and Berlato 1997; Iizumi et al. 2014) favor phytopathogen development and spread, promoting greater disease severity, which results in lower yields. In El Niño years yield was less than 1300 kg ha^{-1}, mainly due to higher leaf spot severity (Fig. 1).

In late season crops, the maximum yield (3704 kg ha^{-1}) occurred at an *Alternaria* and *Septoria* spot severity of 34%. However, yield in normal crops was higher than in late season crops, despite the same disease severity values (Fig. 1). Even so, the highest late season crop yield occurred in a La Niña year, unlike that observed in the normal crops. In this case, even under La Niña conditions, we observed that the lowest water deficit and ETr ETc^{-1} ratio was higher (Table 2), especially at the end of the crop cycle, during the more susceptible grain filling stage (Castro and Farias 2005). Thus, water limitation was lower than in other La Niña years (2007/2008 and 2011/2012).

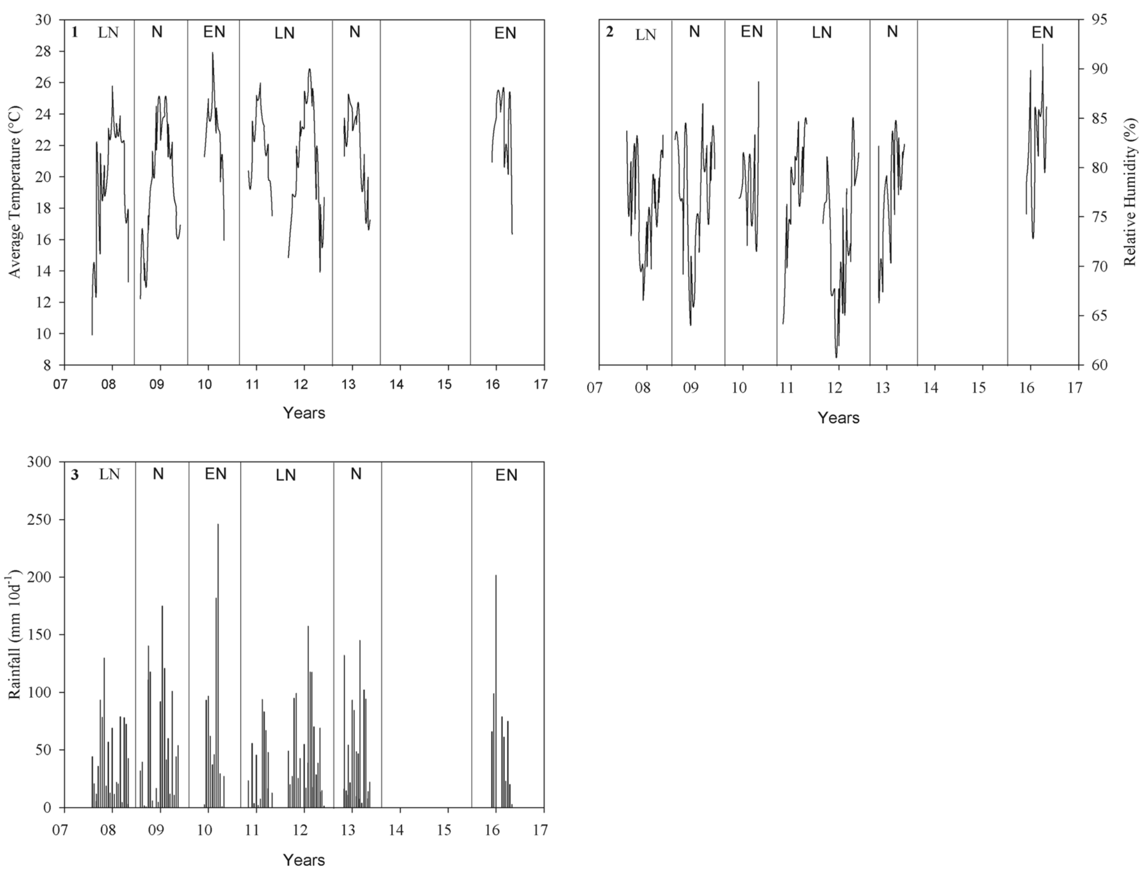

Fig. 2 (1) Average air temperature, (2) air relative humidity, and (3) precipitation, for Santa Maria, RS, during the 37 experiments, in the periods 2008 to 2013 and 2015 to 2016

The highest *Alternaria* and *Septoria* spot severities occurred in a late season crop during an El Niño year (2015/2016), with a reduction of 3509 kg ha^{-1} compared with the highest observed yield, due to a disease severity close to 100%. However, it is noteworthy that in this experiment, in addition to the conditions of higher water surplus and an ETr ETc^{-1} ratio close to 1 (Fig. 1 and Table 2), the crop was inoculated with *Septoria helianthi*. In La Niña years with higher severities, lower yields were obtained. In the normal season crop of 2007/2008, in addition to higher severity (near 60%), water deficit (Fig. 1 and Table 2) reduced the yield in the late season crop.

As regards the effect of the ENSO phenomenon, we found higher severity values for *Septoria* and *Alternaria* leaf spots in El Niño years, corroborating the results of Loose et al. (2012). According to these authors, for earlier-sown crops, the

Table 2 Accumulated water excess (AWE), accumulated water deficit (AWD), and minimum relative evapotranspiration value (Min ETr ETc^{-1}) during sunflower flowering (F), grain filling (GF), and maturation (M) phases in 36 experiments (Exp) conducted in Santa Maria, RS, in La Niña (LN), El Niño (EN), and Neutral (N) years

ENSO	Exp number and year	Phases			Phases			Phases		
		F AWE	GF	M	F AWD	GF	M	F Min. ETr ETc^{-1}	GF	M
LN	Exp 1 2007/08	9.7	123.5	0.0	0.2	0.7	2.5	0.9	0.9	0.8
LN	Exp 2 2007/08	7.5	0.0	112.6	0.6	8.5	3.2	0.9	0.7	0.8
LN	Exp 3 2007/08	0.0	104.7	9.4	4.1	8.3	6.1	0.8	0.8	0.8
LN	Exp 4 2007/08	9.0	0.0	42.9	6.7	31.4	18.2	0.7	0.5	0.4
LN	Exp 5 2007/08	0.0	35.7	0.0	28.2	35.0	29.8	0.4	0.4	0.4
LN	Exp 6 2007/08	0.0	0.0	0.0	33.3	49.8	8.3	0.4	0.4	0.5
LN	Exp 7 2007/08	0.0	0.7	0.0	8.6	19.5	3.8	0.4	0.5	0.8
LN	Exp 8 2007/08	7.5	0.0	111.2	1.0	9.0	2.3	0.9	0.7	0.8
LN	Exp 9 2007/08	0.0	0.0	0.0	19.0	44.7	12.7	0.4	0.4	0.6
LN	Exp 10 2008/09	0.0	0.0	0.0	5.8	18.0	8.0	0.7	0.5	0.5
LN	Exp 11 2008/09	0.0	0.0	0.0	8.2	18.9	10.3	0.6	0.5	0.5
LN	Exp 12 2007/08	0.0	112.9	0.0	3.5	8.6	9.0	0.8	0.8	0.7
LN	Exp 13 2007/08	9.0	0.0	42.9	32.5	51.2	9.4	0.7	0.5	0.4
LN	Exp 14 2007/08	0.0	0.0	0.3	32.5	51.2	9.4	0.4	0.4	0.5
LN	Exp 15 2008/09	78.6	15.4	0.0	2.6	12.2	10.8	0.8	0.7	0.6
LN	Exp 16 2008/09	0.0	206.7	8.6	0.7	1.4	0.9	0.9	0.9	0.9
LN	Exp 17 2008/09	0.0	0.0	0.0	8.7	33.7	18.8	0.6	0.5	0.5
EN	Exp 18 2009/10	103.6	403.0	80.6	0.4	0.7	0.2	0.9	0.9	0.9
EN	Exp 19 2009/10	91.8	103.8	0.0	0.7	0.5	5.8	0.9	1.0	0.7
EN	Exp 20 2009/10	77.3	0.0	0.0	0.3	14.5	6.0	1.0	0.6	0.7
EN	Exp 21 2009/10	0.0	36.9	63.2	5.9	12.0	2.3	0.7	0.6	0.9
LN	Exp 22 2010/11	30.6	86.4	47.7	0.9	1.4	2.0	0.9	0.9	0.8
LN	Exp 23 2010/11	62.9	0.0	6.3	0.9	8.4	3.0	0.9	0.7	0.7
LN	Exp 24 2011/12	0.0	0.0	0.0	0.9	5.6	5.5	0.9	0.7	0.7
LN	Exp 25 2011/12	0.0	0.0	84.4	2.6	10.3	3.4	0.8	0.7	0.8
LN	Exp 26 2011/12	0.0	81.2	94.3	3.2	7.5	4.9	0.8	0.7	0.8
LN	Exp 27 2011/12	0.0	0.0	0.0	27.5	55.3	44.1	0.4	0.4	0.3
LN	Exp 28 2011/12	0.0	23.8	0.0	32.7	90.6	21.9	0.4	0.2	0.5
N	Exp 29 2012/13	40.1	171.5	183.3	0.8	1.9	1.8	0.9	0.9	0.9
N	Exp 30 2011/12	141.8	113.3	0.0	0.9	7.6	12.6	0.9	0.7	0.6
N	Exp 31 2011/12	0.0	0.0	69.3	11.6	34.6	18.0	0.6	0.5	0.4
N	Exp 32 2011/12	0.0	52.4	77.4	23.0	20.7	19.5	0.5	0.5	0.5
N	Exp 33 2011/12	0.0	55.0	0.0	29.0	31.6	29.3	0.5	0.5	0.4
N	Exp 34 2011/12	0.0	0.0	69.9	25.3	61.0	13.2	0.5	0.3	0.3
EN	Exp 35 2015/16	83.3	91.2	41.0	0.1	1.2	1.0	1.0	0.9	0.9
EN	Exp 36 2015/16	124.1	103.9	42.0	0.1	1.2	1.4	1.0	0.9	0.9

severity in El Niño years is higher than in Neutral and La Niña years. In this study, the severity was lower in normal season crops compared with late season crops. In late season crops, in addition to the higher air humidity in the canopy, plants were inoculated with *Septoria helianthi*, resulting in the highest severity and negatively impacting sunflower yield.

Overall, in both normal and late season crops, the highest severity and the lowest productivity occurred in El Niño years. In such years, there is greater precipitation in the southern region (Fontana and Berlato 1997). Due to higher relative humidity and rainfall in these years, there is an increased pathogen dispersal in fields and more frequent epidemics are seen (AGRIOS 2004).

Rainfall is an important mechanism of pathogen dispersal; it also increases air humidity and leaf wetness duration, which are important for the spread of fungal epidemics (AGRIOS 2004). The presence of water droplets or films on the aerial part of the plant favors the germination of fungal spores, hyphal penetration of the host tissue, and colonization (AGRIOS 2004); the high humidity favors sporulation. The higher severity of *Alternaria* and *Septoria* leaf spots and lower yield in El Niño year (2015/2016) are due to the inoculation of the late season crops against *Septoria helianthi*, in addition to the leaf spot-favoring conditions already described in this study.

Such inoculations promoted greater severity, which in turn reduced the area of healthy photosynthetic tissue (HPT) of the plant. In addition, the presence of non-visible lesions, which are caused by *Alternaria helianthi* in sunflowers, could result in elevated respiration at the edge of such lesions, so that the photosynthesis rate is lowered even in the remaining green tissue of the leaf (Calvet 2001; Mello et al. 2011). There is thus a yield reduction due to lower photoassimilate production (Taiz and Zeiger 2017). Therefore, when severity was close to 100%, photoassimilate production may have stopped, drastically reducing grain filling. The yield obtained probably came from the reserves of the still-living tissues head and stem.

The leaf area index (LAI), which varies with the crop leaf area, indicates the photoassimilate production capacity, which influences crop yield (Taiz and Zeiger 2017). Leaf disease, in turn, results in leaf area decrease, by leading to premature senescence in higher severity conditions, thus decreasing productivity. As disease severity increases, LAImax (leaf area index maximum) decreases as a result of premature leave fall, which results in their presenting chlorotic and necrotic lesions that promote senescence more quickly. According to Martins et al. (2004), who evaluated septoriosis and *Cercospora* leaf blight in soybean, severity greater than 66% led to faster leaf senescence. This relationship also depends on the developmental stage of the host plant when disease occurs. Lucas et al. (2012) found that when 25%, 50%, 75%, and 100% leaf injury was applied, sunflower plants tended to show decreasing yield, the degree being dependent on the phenological stage at which artificial injury was inflicted such that earlier-stage injury caused relatively greater loss. Early stage losses result in lower LAImax; disease severity will be higher, and senescence occurs early.

The water balance in the experiments in different years shows that there was a difference in water availability for crop development, and there was also a relationship with the ENSO phenomenon (Table 2). In two La Niña (2007/2008, 2011/12) and Neutral (2008/2009, 2012/2013) years, there were major water deficit events. However, in the La Niña year 2010/2011, the water deficit was smaller, which demonstrates that although ENSO events have a clear effect in Rio Grande do Sul, there is variation; there is not always a marked deficit, as demonstrated by Berlato et al. (2005). But in general, rainfall is higher in El Niño years, variable in Neutral years and lower in La Niña years (Berlato et al. 2005). Regardless of the magnitude of the water deficit, it usually occurs at the end of the plant cycle, which for most sowing dates is from February to May. However, in the 2 years 2008/2009 (Neutral) and 2011/2012 (La Niña), there was a deficit already present during the sowing period from August to October.

The magnitude of water surplus was the inverse of that for water deficit. The years with the lowest excess values were La Niña (2007/2008, 2010/2011, 2011/2012) and Neutral (2012/2013, 2008/2009). The largest surpluses occurred in the El Niño years of 2009/2010 and 2015/2016. In the former, the excess was concentrated at the beginning of the cycle, and in the latter, it occurred throughout the experimental period. A severe excess value of 1239 mm was observed in 2009/2010; the lowest (106 mm) was in 2007/2008. Lucas et al. (2015) identified that consecutive days of water excess caused limitation of sunflower development, and that this varies according to the sowing date and the crop cycle duration.

The ratio of real evapotranspiration (ETr) to maximum crop evapotranspiration (ETc), called relative evapotranspiration ($ETr\ ETc^{-1}$), was directly related to water deficit and inversely to water excess (Table 2). The lowest $ETr\ ETc^{-1}$ fractions occurred in the experiments of 2008/2009 (Neutral) and 2011/2012 (La Niña). The 2007/2008 (La Niña) and 2012/2013 (Neutral) years had similar water conditions, with the lowest $ETr\ ETc^{-1}$ values at the end of the crop cycle, and probable impairment of grain filling in late sowing dates. The most water-demanding phase in sunflowers is flowering, corresponding to an evapotranspiration rate of 6 mm day^{-1} to 8 mm day^{-1} (Castro and Farias 2005). Thus, depending on local water demand, there is a greater probability of water restriction at this stage, for a given level of precipitation. In contrast, the lowest $ETr\ ETc^{-1}$ values occurred in 2009/2010 (El Niño) and 2010/2011 (La Niña) years, occurring at the beginning and end of the development cycle and resulting in compromised crop establishment and grain filling.

The average $ETr\ ETc^{-1}$ over the years in the different experiments showed variation between sowing dates and experimental periods throughout the sunflower crop cycle. The highest value of 0.98 occurred in an El Niño year. The greatest difference between ETr and ETc was in a La Niña year, corresponding to an average ETr ETc^{-1} of 0.86, with daily values lower than 0.4. We therefore infer that there was a significant decrease in crop evapotranspiration, by more than 50%, in the most susceptible phase (Castro and Farias 2005), which compromised grain yield because the negative effects on yield are greater during this phase.

In normal season crops, the highest yields occurred in Neutral years. For example, in 2012/2013, the first sowing dates had the lowest water deficit values and the largest surpluses during the normal season crop. In contrast, in late season crops, the highest yields occurred in La Niña years. In the 2010/2011 normal season crop, when the water deficit was smaller than the excess water, especially in the period that encompasses the development cycle in the late season crop, thus yield was not harmed. Therefore, water availability is a decisive factor for higher yields, and water stress in the grain filling period negatively affects yield (Zobiole et al. 2010). With the shortest water excess period, the severities of *Alternaria* and *Septoria* leaf spots are lower and, at this lower incidence, do not decrease sunflower yield.

Neutral years had different productivity and severity values. Thus, in the Neutral year 2008/2009, yield was affected by the end-of-cycle water deficit even with *Alternaria* and *Septoria* leaf spot severity close to 34%. In the 2012/2013 crops, the last sowing dates were the most affected by water deficit, causing a yield limitation, but disease severity was higher, and this also affected the yield. Therefore, there was a double penalty on sunflower yield in this year.

Conclusions

Sunflower yield is reduced under damage by *Alternaria* and *Septoria* leaf spots. In normal season crops, a 1% increase in disease severity above 24% reduced yield by 66 kg ha^{-1}. In late season crops, each 1% increase in severity above 34% led to a decrease of 50 kg ha^{-1}.

Sunflower yield was lower in late season crops than in normal season crops, even with lower *Alternaria* and *Septoria* leaf spot severity values.

Septoria and *Alternaria* leaf spot severity was higher in El Niño years, and productivity was lower in those years.

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Compliance with ethical standards

Competing interest The authors declare that they have no competing interest.

References

AGRIOS GN (2004) Plant disease epidemiology, in: Plant Pathology.5 edn. Academic Press, San Diego, pp 265–291

AGROFIT (2018) Sistema de Agrotóxicos Fitossanitários. http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons. Accessed 29 July 2018

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome

Alvares CA, Stape JL, Sentelhas PC, De Moraes G, Leonardo J, Sparovek G (2013) Köppen's climate classification map for Brazil. Meteorol Z 22(6):711–728. https://doi.org/10.1127/0941-2948/2013/0507

Amorim L, Pascholati SF (2011) Ciclo relação patógeno-hospedeiro. In: Amorim L, Rezende JAM, Bergamin Filho A (eds) Manual de fitopatologia: Princípios e conceitos, 4th edn. Agronômica Ceres, São Paulo, pp 59–98

Berlato MA, Farenzena H, Fontana DC (2005) Associação entre El Niño Oscilação Sul e a produtividade do milho no Estado do Rio Grande do Sul. Pesq Agrop Brasileira 40(5):423–432. https://doi.org/10.1590/S0100-204X2005000500001

Brand SI (2017) Manchas foliares de alternária e septória em girassol: Modelagem da severidade e redução da produtividade. Dissertation, Universidade Federal de Santa Maria

Brand SI, Heldwein AB, Radons SZ, Silva JR, Puhl AJ (2018) Severity of Septoria Leaf Spot and Sunflower Yield Due to Leaf Wetness Duration. J Agric Sci 10:178–188. https://doi.org/10.5539/jas.v10n10p178

Buriol GA, Estefanel V, Saccol AV, Heldwein AB, Schneider FM (1980) Disponibilidades hídricas do solo possíveis de ocorrerem no estado do Rio Grande do Sul. Revista do Centro de Ciencias Rurais 10(supl):1–141

Calvet NP (2001) Lesão virtual causada pela mancha de *Alternaria helianthi* em diferentes genótipos de girassol (*Helianthus annuus* L.), e sua relação com a fotossíntese. Dissertation, Universidade de São Paulo. https://doi.org/10.11606/D.11.2019.tde-20190821-132046

Castro C, Farias JRB (2005) Ecofisiologia do girassol. In: Leite RMVBDeC, Brighenti AM, Castro CDe Girassol no Brasil. Londrina: EMBRAPA-CNPSo, pp. 163–218

CLIMATE PREDICTION CENTER (2016) Nacional Weather Service, Climate Prediction Center. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. Accessed 04 August 2016

Comissão DE Química E Fertilidade DO SOLO – RS/SC (2016) Sociedade Brasileira de Ciência do Solo. Manual de adubação e calagem para os Estados do Rio Grande do Sul e Santa Catarina. 11 edn. Porto Alegre

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (2000) Cultivo do girassol. Embrapa Soja, n. 1. http://www.cnpso.embrapa.br/producaogirassol/index.htm. Accessed15 January 2019

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (2006) Sistema Brasileiro de Classificação de Solos. Centro Nacional de Pesquisa em Solos. Embrapa – SPI, Brasília, Embrapa – Solos, Rio de Janeiro

Fontana DC, Berlato MA (1997) Influência do El Niño Oscilação Sul sobre a precipitação pluvial no estado do Rio Grande do Sul. Rev Bras Agrometeorol 5(1):127–132

Guse FI (2009) Produtividade, severidade de mancha de Alternária e deficiência hídrica em diferentes épocas de semeadura do girassol em Santa Maria - RS. Dissertation, Universidade Federal de Santa Maria

Heldwein AB, Buriol GA, Streck NA (2009) O clima de Santa Maria. Cienc Ambient 38(1):43–58

Hinnah FD (2014) Análise numérica de risco de ocorrência de mancha de alternária e septória em girassol para diferentes datas de semeadura, em Santa Maria - RS. Dissertation, Universidade Federal de Santa Maria

Iizumi T, Luo JJ, Challinor AJ, Sakurai G, Yokozawa M, Sakuma H, Brown ME, Yamagata T (2014) Impacts of El Niño Southern Oscillation on the global yields of major crops. Nat Commun 5: 3712. https://doi.org/10.1038/ncomms4712

Leite RMVBC, Amorim L (2002a) Influência da temperatura e do molhamento foliar no monociclo da mancha de alternária em girassol. Fitopatol Bras 27(2):193–200. https://doi.org/10.1590/S0100-41582002000200012

Leite RMVBC, Amorim L (2002b) Elaboração e validação de escala diagramática para mancha de alternária em girassol. Summa Phytopathol 28:14–19

Leite RMVBC, Brighenti AM, Castro C (2005) Girassol no Brasil. 1 edn. Embrapa Soja, Londrina

Leite RDC, Castro CD, Brighenti AM, De Oliveira FA, De Carvalho CGP, De Oliveira ACB (2007) Indicações para o cultivo de girassol nos Estados do Rio Grande do Sul, Paraná, Mato Grosso do Sul, Mato Grosso, Goiás e Roraima. Embrapa Soja, Londrina

Loose LH (2016) Respostas agronômicas e morfológicas do girassol ao déficit e excesso hídrico em dois solos. Thesis, Universidade Federal de Santa Maria

Loose LH, Heldwein AB, Maldaner IC, Lucas DDP, Hinnah FD, Bortoluzzi MP (2012) Severidade de ocorrência das manchas de alternária e septoriose em girassol semeado em diferentes épocas no Rio Grande do Sul. Bragantia 71(2):282–289. https://doi.org/10.1590/S0006-87052012005000012

Lucas DDP, Heldwein AB, Maldaner IC, Dalcin JS, Loose LH (2012) A diagrammatic scale for the quantification of hail damage in sunflower leaves. Rev Ciênc Agron 43(4):822–826. https://doi.org/10.1590/S1806-66902012000400026

Lucas DDP, Heldwein AB, Maldaner IC, Trentin R, Hinnah FD, Silva JR (2015) Excedente hídrico em diferentes solos e épocas de semeadura do girassol no Rio Grande do Sul. Pesq Agrop Brasileira 50(6):431–440. https://doi.org/10.1590/S0100-204X2015000600001

Maldaner IC (2009) Irrigação e aplicação de fungicida na ocorrência de doenças e produtividade do girassol. Dissertation, Universidade Federal de Santa Maria

Maldaner IC, Heldwein AB, Blume E, Lucas DDP, Grim EL, Cabrera IC (2009a) Primeiro relato de *Septoria helianthi* em girassol no Brasil. In: Reunião Nacional da Pesquisa do Girassol. Anais, Embrapa Clima Temperado, Pelota, p 282–287

Maldaner IC, Heldwein AB, Loose LH, Lucas DDP, Guse FI, Bortoluzzi MP (2009b) Modelos de determinação não-destrutiva da área foliar em girassol. Cienc Rural 39(5):1356–1361. https://doi.org/10.1590/S0103-84782009000500008

Martins MC, Guerzoni RA, Cámara GDS, Mattiazzi P, Lourenço SA, Amorim L (2004) Escala diagramática para a quantificação do complexo de doenças foliares de final de ciclo em soja. Fitopatol Bras 29:179–184. https://doi.org/10.1590/S0100-41582004000200009

Mello FE, Xavier SA, Dorighello DV, Leite RMVBC (2011) Alteração na fotossíntese causada pela mancha de alternaria (*Alternaria helianthi*) em girassol. Trop Plant Pathol 36:1087

Radons SZ (2010) Severidade de ocorrência de mancha de septória e produtividade do girassol irrigado. Dissertation, Universidade Federal de Santa Maria

Sentelhas PC, Dalla Marta A, Orlandini S, Santos EA, Gillespie TJ, Gleason ML (2008) Suitability of relative humidity as an estimator of leaf wetness duration. Agric For Meteorol 148(3):392–400. https://doi.org/10.1016/j.agrformet.2007.09.011

Streck L (2006) Determinação da duração do período de molhamento foliar em cultivos de batata. Thesis, Universidade Federal de Santa Maria

Taiz L, Zeiger E, Møller IM, Murphy, A (2017) Fisiologia vegetal. Artmed, Porto Alegre

Thornthwaite CW, Mather JR (1995) The Water Balance. Centerton, Drexel Institute of Technology-Laboratory of Climatology, Publications in climatology 8:1

Zobiole LHS, Castro CD, Oliveira FAD, Oliveira Junior AD, Moreira A (2010) Curva de crescimento, estado nutricional, teor de óleo e produtividade do girassol híbrido BRS 191 cultivado no Estado do Paraná. Rev Bras Ol Fibros 14(2):55–62

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Agricultural and Forest Meteorology

Climatic favorability for agricultural spraying in the state of Rio Grande do Sul

--Manuscript Draft--

Manuscript Number:	
Article Type:	Research Paper
Section/Category:	Climate Data, Weather data, Data Generator
Keywords:	spray drift; pesticides; air temperature; relative air humidity; wind speed
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	Eduardo Schepke
	Atawana Vitória da Silva
Abstract:	This study aimed to determine, on a temporal scale, how favorable weather conditions are for agricultural spraying in the state of Rio Grande do Sul, Brazil. Hourly data from automatic weather stations from 12 locations were used, totaling 56,500 days and 1,356,009 hourly observations. The values of wind speed up to 10 km h $^{-1}$, air temperature up to 30 °C, and relative humidity above 55% were considered favorable. Considering the condition in which the three elements were simultaneously favorable, 60.5% of the moments were favorable for spraying in Rio Grande do Sul. Air temperature was the meteorological element with the greatest favorability. The wind speed, in turn, was the most limiting meteorological element. The months that showed the greatest favorability for agricultural spraying were May and June. On the other hand, the lowest favorability was obtained in November. The range of the most favorable times occurred from 12:00 a.m. to 7:00 a.m., and the most unfavorable range occurred from 1:00 p.m. to 4:00 p.m. Elevation showed a moderate negative correlation with wind speed favorability. On the other hand, longitude correlated strongly with air temperature and relative air humidity favorability for spraying.
Suggested Reviewers:	Homero Bergamaschi, Ph.D Researcher Professor, Universidade Federal do Rio Grande do Sul homerobe@ufrgs.br Internationally renowned researcher in Agrometeorology
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Claudia Wagner-Riddle, PhD
Editor-in-Chief
Agricultural and Forest Meteorology

November 17, 2020

Dear Editor-in-chief:

I am pleased to submit an original research article entitled "Climatic favorability for agricultural spraying in the State of Rio Grande do Sul" for consideration for publication in Agricultural and Forest Meteorology. In this manuscript, we determine, on a temporal scale, how favorable weather conditions are for agricultural spraying in the state of Rio Grande do Sul, Brazil. We show that elevation has a moderate negative correlation with wind speed favorability and longitude correlated strongly with air temperature and relative air humidity favorability for spraying. Considering the three meteorological elements, 60.5% of the moments were favorable for spraying in Rio Grande do Sul. May and June showed the greatest favorability for agricultural spraying were and the lowest favorability was obtained in November. The most favorable times for agricultural spraying occurred from 12:00 a.m. to 7:00 a.m., and the most unfavorable range occurred from 1:00 p.m. to 4:00 p.m.

We believe that this manuscript is appropriate for publication by Agricultural and Forest Meteorology because it addresses one of the typical topics in the journal, more specifically aerobiology, particularly the dispersion of pesticides. This topic has been widely discussed by scientific society, as environmental contamination by drift has been frequent around the world and has caused great environmental and economic damage. Thus, knowing the times when the risk of drift in agricultural spraying is lower can help to reduce this damage and make agriculture a more sustainable activity. Finally, studies like this are rarely seen in the scientific literature, making our study expected to be highly visible and serve as a basis for other similar studies development.

This manuscript has not been published and is not under consideration for publication elsewhere.

Thank you for your consideration!

Sincerely,

Dr. Sidinei Zwick Radons
Federal University of Fronteira Sul

It was determined, on a temporal scale, how favorable weather conditions are for agricultural spraying in the state of Rio Grande do Sul, Brazil

Elevation showed a moderate negative correlation with wind speed favorability and longitude correlated strongly with air temperature and relative air humidity favorability for spraying

Considering the three meteorological elements, 60.5% of the moments were favorable for spraying in Rio Grande do Sul.

May and June showed the greatest favorability for agricultural spraying were and the lowest favorability was obtained in November.

The most favorable times for agricultural spraying occurred from 12:00 a.m. to 7:00 a.m., and the most unfavorable range occurred from 1:00 p.m. to 4:00 p.m.

Climatic favorability for agricultural spraying in the state of Rio Grande Do Sul

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