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# Temporal variability of dew in a transition morpho-climatic zone in Southern Brazil

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ABSTRACT

The period in which leaves are exposed to dew is of extreme importance for epidemiological aspects, which affects the health and the final biomass production of plants. The objective of this study was to determine the main temporal characteristics of the dew occurrence in a preserved point of the transition morpho-climatic zone between the Pampa Biome and the Atlantic Forest Biome in Santa Maria, Rio Grande do Sul State, Brazil. Data were collected from June 2016 to May 2018 by a LWS-L sensor. Number of days with dew per month and the frequency histograms of the dew onset and dry-off times per season were determined. The leaf wetness duration (LWD, h) was calculated. Mean LWD per month and its monthly variability was determined. The minimum number of occurrences by month was 4 (January 2017), and the maximum was 29 (April 2018). The preferred onset and dry-off times were 6-9 PM, and 7-10 AM, respectively, although there were differences between seasons. The LWD tended to decrease during the warmer seasons (9.00-9.54 h), compared to the colder seasons (10.58-11.12 h), and presented a significantly monthly variability.



## Introduction

Wetting can be established by several factors that allow the formation of liquid water in different parts of the plants, preferably leaves, and is thus defined as leaf wetting. Factors can be meteorological such as rain or dew, or artificial such as irrigation. Dew provide long periods in which plants are with liquid water in its leaves (Sentelhas et al., 2008) and is often the main source for leaf wetness of the lower third of the plants (Schmitz & Grant, 2009; Alvares et al., 2015).

The period in which leaves are exposed to dew is of extreme importance for epidemiological aspects, which affects the health and productivity of plants (Igarashi et al., 2014). It can benefit the germination, infection and sporulation of pathogens as water is indispensable for the germination of spores and the penetration of their germinative tube in the host. The longer the leaf wetness duration, the greater its susceptibility to pathogens, with the increase of occurrence of diseases and its severity (Reis et al., 2004). Dew can interfere with the prevention of diseases, pests or invasive plants in agricultural crops. With liquid water on the leaf surface, there is a greater chance of spillage or dilution of the sprayed pesticides

(Roman et al., 2004). Considering the transpiration and photosynthetic processes, dew droplets reduces gas exchanges (water vapor and $CO_2$) between leaves and atmosphere when starts early in the evening and persists in the early morning (Ishibashi & Terashima, 1995; Hanba et al., 2004; Letts & Mulligan, 2005). It also increases leaf albedo and emissivity and reduces leaf temperature due to evaporation, interfering with the leaf energy balance (Gerlein-Safdi et al., 2018).

The air temperature and humidity, wind and radiation are the variables that most affect dew formation, directly influencing its onset and dry-off times and duration (Sharma, 1976). Dew occurs when the temperature of an exposed surface, such as a leaf, reaches the dew point temperature of the humid air close to the surface. In this case, condensation of the water vapor occurs on the exposed surface and not in the air. The leaf surface undergoes intense cooling, losing long-wave radiation on clean sky and windless nights (Monteith & Unsworth, 1990; Pereira et al., 2002).

Physically, dew formation is easily explained (Monteith & Unsworth, 1990; Pereira et al., 2002). However, it is not an easy variable to measure on a plant canopy as it depends on the interactions between the microclimatic conditions and the shoot architecture of the plants (Sentelhas et al., 2006; Alvares et al., 2015). In addition to microclimatic characteristics, the macroclimatic and topoclimatic scales also determine the dew formation. In macroclimatic terms, places of higher altitude and latitude where is colder than closer to the mean sea level and to the Equator experience more occurrences of dew. On the topoclimatic scale, lowland areas where the densest cold air accumulates and flat terrains where it is stagnant during the night are more prone to dew formation than the slopes and hills. The exposure and position of the terrain also determine the occurrence of dew on the topoclimatic scale. In the Southern Hemisphere, terrains facing South have lower air temperatures due to the less exposure to solar radiation and the incidence of colder winds and have a higher occurrence of dew. Also, dew evaporates earlier on the terrains facing East than on the facing West due to the earlier exposure to the Sun. Likewise, dew onset starts earlier on the East faces than on the West faces.

Weather stations of the national weather services usually do not measure dew occurrence (Madeira et al., 2002). There is no standard for dew measurements, both in terms of sensors and their own installation, making comparative studies of this variable unfeasible between locations under different climates, for example (Sentelhas et al., 2005; Durigon & De Jong van Lier, 2013). As a consequence, several methods have been developed to estimate it from weather data (Pedro Jr. & Gillespie, 1982; Gleason et al., 1994; Sentelhas et al., 2004; Durigon & De Jong van Lier, 2013; Alvares et al., 2015). However, the accuracy of these methods cannot always be tested due to de lack of field measurements.

The Pampa Biome extends throughout the southern half of the State of Rio Grande do Sul, Brazil, occupying about 63% of the state area (IBGE, 2004) and to other countries such as Argentina and Uruguay (Boldrini, 2009). It is located in a vast humid subtropical region with four well defined seasons and 8-10 rainy days per month. Pampa Biome vegetation is characterized by grasses, creeping and prostrate plants, and small trees with a high vegetable and animal diversity, and one of the main resources for fodder and livestock source of the region (Pillar et al., 2009). The remaining part of the state is occupied by the Atlantic Forest Biome which extends through the South, Southeast, Central-West and Northeast regions of Brazil, with smaller portions entering Paraguay and Argentina (IBGE, 2004). It is a tropical forest biome with high levels of biodiversity and variations in species richness due to factors such as latitude, altitude, rainfall and soil (Brazil, 2015). The highly dense vegetation varies from Atlantic Rain Forest in the lowest places (below 1000 m asl) located in coastal regions, and Atlantic Semi-deciduous Forest in the continental region of the country (above 600 m asl) (Morelatto & Haddad, 2000). While the Atlantic Rain Forest is found in very warm and rainy regions, the Atlantic Semi-deciduous Forest is located in regions with relatively severe dry seasons (Morelatto & Haddad, 2000).

As the transition region of the Pampa and Atlantic Forest Biomes is located in the subtropical region with well-defined seasons (Oliveira et al., 2017), the dew formation may occur differently throughout the year. In addition, it is located in a vast marginal region, where few national weather stations are available. So, the application of estimation models is mostly unfeasible, and measurements are restricted to short-term experimental studies. In this context, the objective of this study was to determine the main temporal characteristics of the dew occurrence in a preserved point of the transition morpho-climatic zone between the Pampa Biome and the Atlantic Forest Biome in Santa Maria, Rio Grande do Sul State, Brazil. There are few observational studies on dew in this region made with commercial plant species (Streck, 2006; Trentin et al., 2009) and none with native species, as is the case of the Pampa and Atlantic Forest Biomes vegetation.

## Material and Methods

Leaf wetness data were measured by a Leaf Wetness Sensor LWS-L from Decagon Devices installed in the experimental site located in Santa Maria, Rio Grande do Sul State, Brazil (latitude 29°43’27.502” S; longitude 53°45’36.097” W, and altitude 88 m). The experimental site is a preserved area used as pasture for beef cattle (Figure 1, left). The natural vegetation is dominated by well distributed *Andropogon lateralis*, *Paspalum notatum*, *Saccharum trinii*, *Sorghastrum pellitum* and *Aristida laevis* (Quadros & Pilar, 2001). According to the Köppen classification, the climate of the region is subtropical humid with hot summer (Cfa), with rain well distributed throughout the year (1500 to 1750 mm) and average annual air temperature from 17°C to 19°C (Heldwein et al., 2009). The soil of the experimental site is an Ultisol, sandy in the first 0.50 m layer, with a textural B horizon below (Santos et al., 2013).

The LWS-L sensor was kept at a constant height of 0.10 m above the surface with an angle of 20° to the soil surface (Figure 1, right). The sensor surface mimics a single-leaf blade of 11.2 cm length x 5.8 cm width x 0.075 cm thickness, and is white to reduce radiation absorption. It measures the dielectric constant of a printed-circuit in the sensor's upper surface modified by the presence of small amounts of liquid water. The sensor was connected to a CR1000 datalogger from Campbell Scientific by a cable of 5 m length. Measurements were stored every minute, and continuously collected for all days from June 2016 to May 2018. LWS-L data have three categories. The first one, represented by 0, indicates that the sensor surface was dry for 1 minute. A value of 0.5 indicates that there was some contamination by liquid water, and a value of 1 indicates that there was liquid water on the surface for 1 minute (Decagon, 2010). Data with a value equal to 1 were considered during the periods without rain to account only for wetting by dew.

The number of days with wetting by dew per month and season and the frequency histograms of the dew onset and dry-off times per season were determined. The leaf wetness duration (LWD, h), which is the time between the dew onset and dry-off, was calculated. The LWD per month and season, and its monthly variability were also determined. The monthly LWD data were submitted to the BoxPlot exploratory data analysis, to the analysis of variance using the F test and, when significant, to the Scott-Knott test at a level of 5% of probability. The statistical software SISVAR was used for the analyses (Ferreira, 2011).

Meteorological data were collected at a conventional weather station from the 8$^{th}$ Meteorology District of the Instituto Nacional de Meteorologia (DISME/INMET), located approximately 3000 m from the experimental area. Monthly means of the maximum (Tmax, °C), mean (Tm, °C) and minimum (Tmin, °C) air temperature, relative humidity (RH, %), wind velocity (W, m/s), and the monthly total of sunshine duration (DI, h) were gathered from the INMET website from June 2016 to May 2018 (WMO: 83936; http://www.inmet.gov.br/portal/index.php?r=estacoes/estacoesConvencionais). Monthly anomalies were calculated considering the mean or total monthly value of each variable and its mean value during the entire considered period.

## Results and Discussion

From June 2016 to May 2018, the number of days of wetting by dew in the transition morpho-climatic zone between the Pampa and the Atlantic Forest Biomes varied

**Figure 1.** Micrometeorological station (left) and the Leaf Wetness Sensor LWS-L (right) of the experimental site located in Santa Maria, Rio Grande do Sul State, Brazil.

throughout the months (Figure 2). The minimum number of days of dew occurred in January 2017, with 5 occurrences, and the maximum in April 2018, with 29 occurrences. The mean greatest numbers of days with dew occurred in winter season (25.5, 26 and 22 days in July, August and September, respectively), which presents a more favorable climatic condition for its formation. These conditions are intense night cooling of the surfaces, and lower solar radiation and air temperature (Nery, 2005; Heldwein et al., 2009). The difference between the number of days with dew in May and June 2017 was equal to 2, but in July of 2017 the occurrences increased significantly (~ +10). The same occurred in 2016, when the occurrences in June were 13 and in July were 23 (we do not have data for May 2016). In studies conducted by Trentin et al. (2009) with potato in the same region. they of the Pampa Biome, they observed an increase in leaf wetness due to dew the closer to or after the Winter Solstice (June 21 – South Hemisphere), corroborating our findings. In summer (January to March – data of 2017 and 2018), the mean number of days with dew of each month decreased compared to winter, reaching a minimum of 9 days in January. In the transition seasons (fall and spring), it ranged between the higher winter and lower summer values (23 days in April and 13.5 days in December).

Variability in dew occurrence may be related to the great interannual variability of atmospheric conditions (Rubert et al., 2018). Figure 3 presents the monthly anomalies of air temperature, relative humidity, wind velocity and sunshine duration. The spring of 2016 and the summer of 2017 were warmer than the spring of 2017 and the summer of 2018 (Figure 3a). Winter of 2016 was colder than the fall and winter of 2017. As a consequence of the cooling, anomalies of relative humidity were closer to the mean or positive during these seasons, and most negative during spring and summer due to the warming (Figure 3b), indicating a closer air saturation condition in these seasons. Wind velocity was markedly higher during late winter, spring and early summer, but most positive anomalies were observed in spring of 2016 and the most negative ones (lightest winds) occurred in the early winter of 2016 (Figure 3c). Anomalies of sunshine duration were positive and higher during summer compared to winter, but in the winter of 2017 anomalies were positive (reaching 49.30 h in July) (Figure 3d). In general, the winter of 2017 was less cold, windy and cloudy, and more humid compared to the same period of 2016. The summer of 2018 was colder, drier, less windy and less cloudy than the summer of 2017. According to the ENSO Outlook of the Australian Bureau of Meteorology (2020), a La Niña event occurred from December 2017 and March 2018. The studied region was not under the influence of the ENSO in the remaining period (June 2016 to November 2017, and April and May 2018). In the South of Brazil, La Niña years are

**Figure 2.** Monthly number of days with leaf wetness by dew during the summer (a), fall (b), winter (c) and spring (d) (bars) in Santa Maria, Rio Grande do Sul State, Brazil, from June 2016 to May 2018. Black dots indicate the mean number of days of each month.

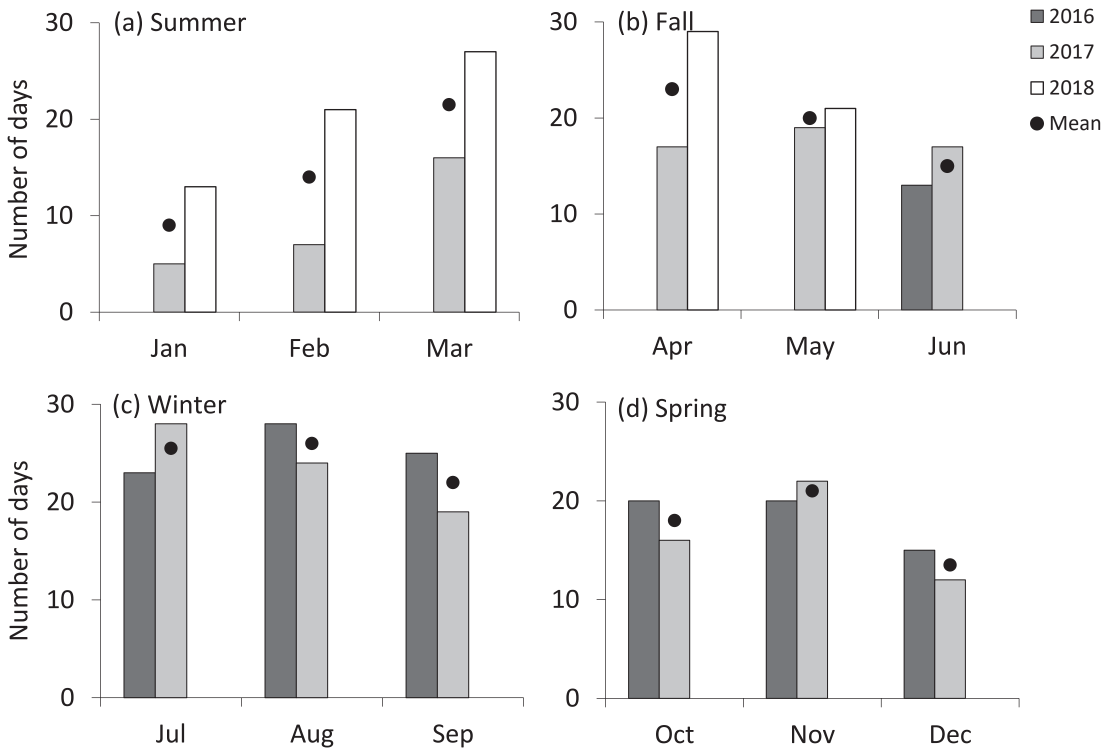
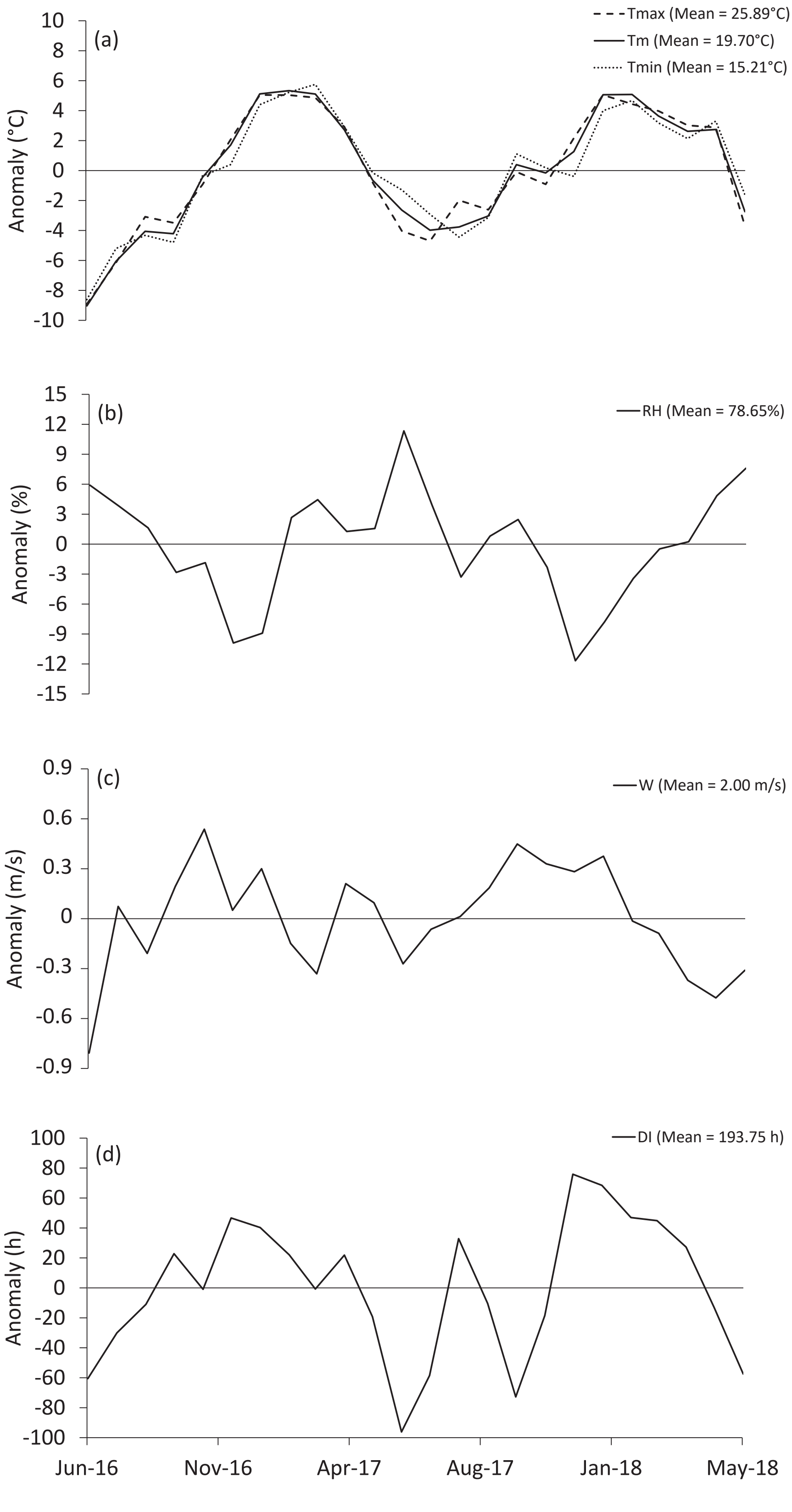


**Figure 3.** Anomaly of maximum (Tmax, °C), mean (Tm, °C) and minimum (Tmin, °C) air temperature (a), relative humidity (RH, %) (b), wind velocity (W, m/s) (c) and sunshine duration (DI, h) (d) in Santa Maria, Rio Grande do Sul State, Brazil, from June 2016 to May 2018. Mean values of each variable are between parentheses.




characterized by a reduction in cloudiness and rain during spring and summer (Rao & Hada, 1990), what may increase the night cooling, and slightly lower air temperatures.

Dew onset started during the late afternoon and early evening (Figure 4), with preferential times of 6 PM (12.53%), 7 PM (11.21%), 8 PM (10.33%) and 9 PM

(10.55%), with isolated cases of daytime onset. This result corroborates that found by Baier (1966), who states that the onset of dew occurs 2 to 3 hours after sunset. The preferred time for dew dry-off occurred was in the early morning after sunrise and the consequent surfaces and air heating by the incidence of solar radiation. The most frequent times for dew dry-off were 7 AM (14.34%), 8 AM (19.16%), 9 AM (24.67%) and 10 AM (13.22%). Streck (2006) observed in potato grown in Santa Maria, RS, Brazil, that dew dry-off started around 7 and 8:30 AM in the fall and spring of 2004. Dew onset was later in summer and spring, mostly between at 8 and 7 PM, respectively (Figure 4a and 4d), and earlier at 6 PM in fall and winter (Figure 4b and 4c). The dry-off time presented an opposite behavior, as dew dissipated mostly between 7 and 9 AM during summer and spring, respectively, and between 8 to 11 AM during fall and winter. Dew occurrences in the afternoon (12 AM to 5 PM) were much lower during the warmer seasons (6) compared than during the colder seasons (18), a period in which surface of leaves and air heats up, hindering water vapor condensation and rising the vapor pressure deficit, what favors evaporation.

Considering the onset and dry-off times of each dew occurrence during the studied period, the leaf wetness duration (LWD) was calculated (Figure 5). During the warmer seasons (spring and summer) (Figure 5a and 5d) the LWD decreased, with lowest mean LWD been observed in January 2018 (5.64 h). In colder seasons LWD tended to increase (Figures 5b and 5c), and the highest mean LWD occurred in the end of fall - early winter (14.35 h in June 2016) which is related to lower wind and incident solar radiation of the winter Solstice period (Sentelhas et al., 2005; Sentelhas et al., 2008; Paula et al., 2012). Although the number of days of wetting by dew was lower in June than in May (in 2017) and July (in 2016 and 2017), the wetness in June was the longest observed in the entire data series (~ 14 h, Figure 5). Alvares et al. (2015) simulated mean monthly LWD in Brazil through interpolated relative humidity data by kriging. They reached a LWD of 2-6 h from October to December (spring), and 6-10 h during the remaining seasons, with a maximum of ~ 10 h in June in the Pampa Biome region where our data was measured. Although their simulated LWDs were lower than the observed ones of our study, both had the same time trend. In the winter the mean LWD was 10.58 h and in the summer the mean LWD was 9.54 h. During the transition seasons, mean LWD were 9.00 h for spring and 11.12 h for fall. Although the summer of 2018 presented a greater number of days with dew than the summer of 2017 (33 cases more), differences of mean LWD between the two periods were slightly higher than 2 h (LWD longer in 2018). On the other hand, winter of 2016 had only 5 days more of dew than the winter of 2017, and mean LWD of 2017 was 2.95 h longer than the 2016.

The LWD showed significant monthly variability (Figure 6). In general, the LWD of the late fall of 2016 and 2017, winter of 2017 and fall of 2018 did not present significant differences and was higher (from 10.70 to 14.35 h). LWD data from July 2016 to April 2017, September and October 2017, and December 2017 to February 2018 were significantly lower and ranged from 5.64 h to 10.25 h.

## Final considerations

Our study presents the possibility of knowing the temporal dynamics of dew formation in the vegetation of in the transition morpho-climatic zone between the Pampa and the Atlantic Forest Biomes in the South of Brazil. Although some dew is formed during the day-time, especially in the fall-winter seasons, most events occurs during the night. The LWD in shows a significant monthly variability. The observational dew data set of our study also is the first published this transition zone. In this sense, it can be readily used to calibrate and validate simulation models for LWD on monthly and seasonal time scales, such as, for example, the models described by Pedro Jr. & Gillespie (1982), Gleason et al. (1994), Sentelhas et al. (2004), and Durigon & De Jong van Lier (2013). Also, LWD simulations presented by Alvares et al. (2015), the only published work of LWD which includes the region, can be validated. However, to broaden the discussion of our study which includes 24 months, it would be indicated to analyze a longer observational data set in the same experimental site and in other sites of the region, and to include the wetting caused by rain.

## Author contributions

L. M. Jorge, D. M. Salvadé and J. R. da Silva conceived and performed the analysis, wrote the paper; D. R. Roberti designed and performed data collection and wrote the paper; and A. Durigon designed the study, performed the analysis and wrote the paper.

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**Figure 4.** Histograms of the dew onset (grey bars) and dry-off (black bars) times during the summer (a), fall (b), winter (c) and spring (d) in Santa Maria, Rio Grande do Sul State, Brazil, from June 2016 to May 2018.

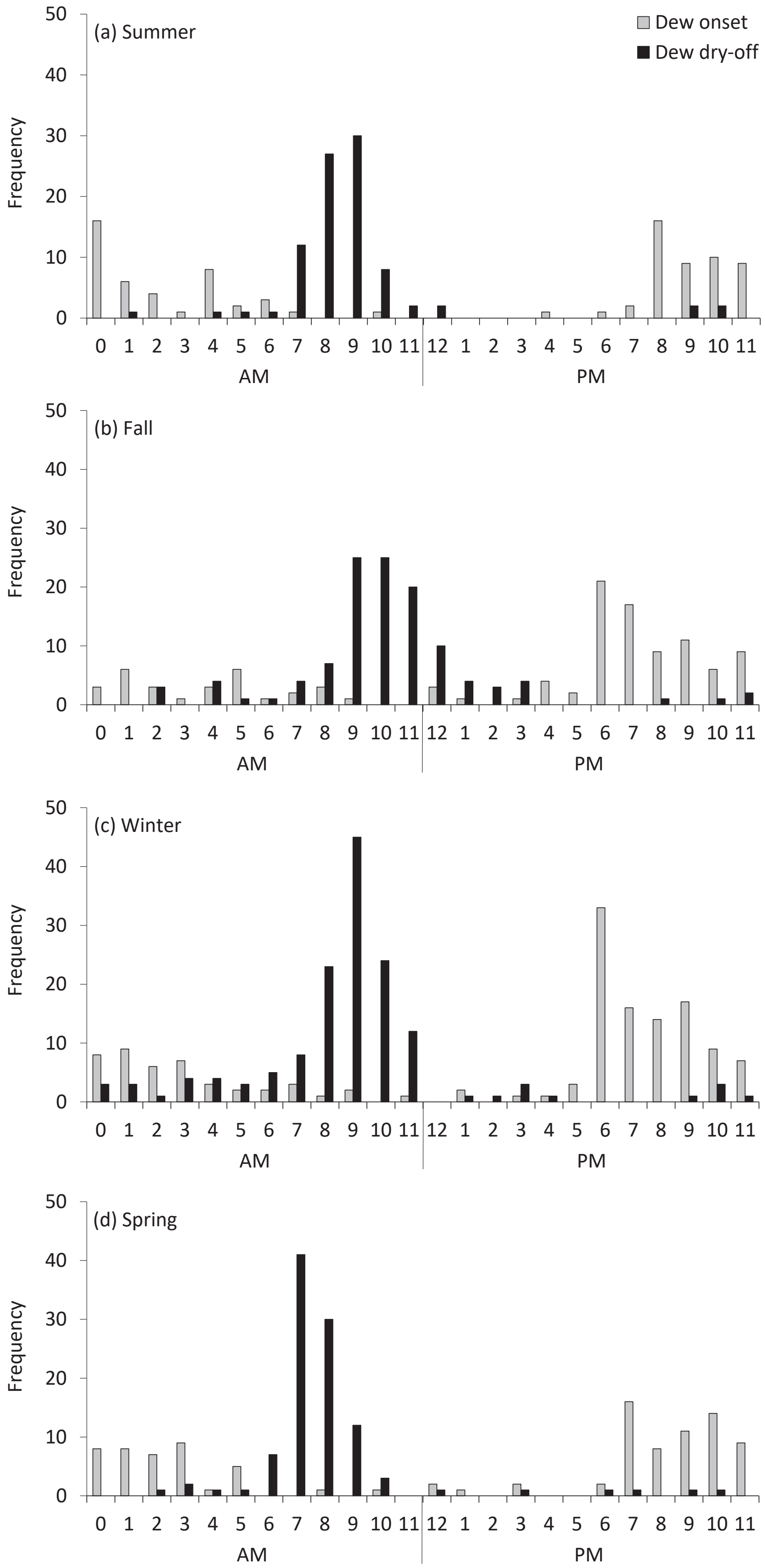


**Figure 5.** Monthly mean leaf wetness duration (LWD, h) in summer (a), fall (b), winter (c) and spring (d) in Santa Maria, Rio Grande do Sul State, Brazil, from June 2016 to May 2018 (bars). Black dots indicate the monthly mean leaf wetness duration considering all measurements of each month.

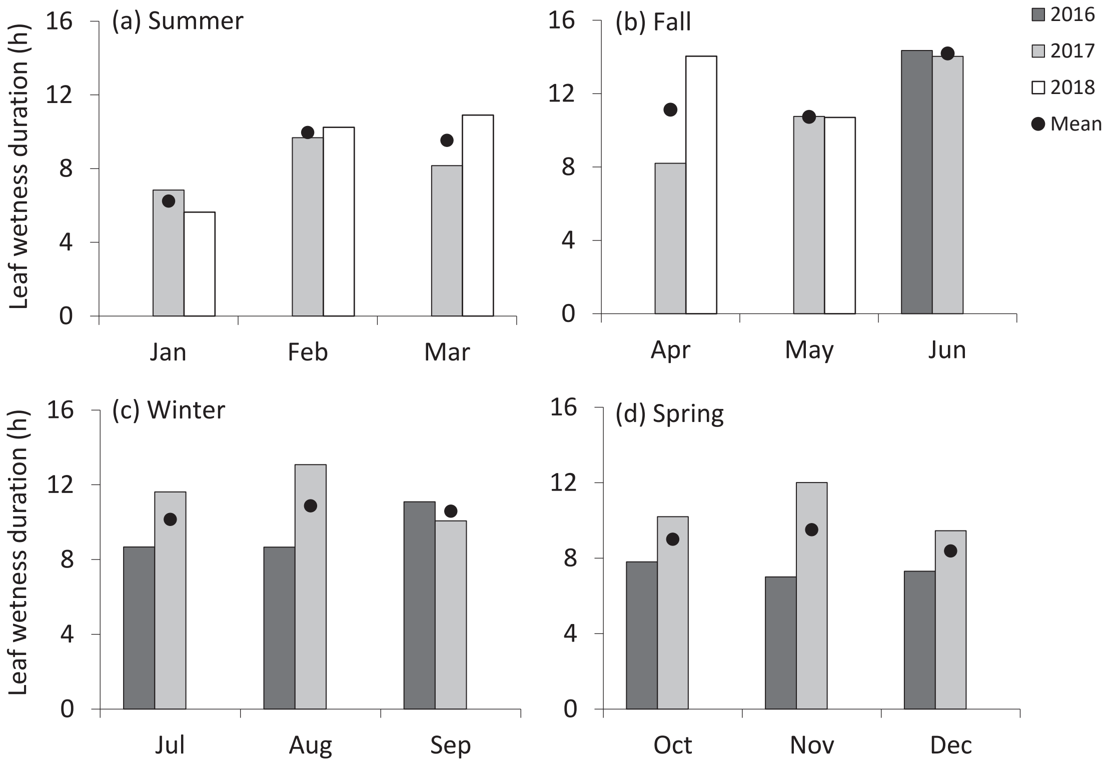
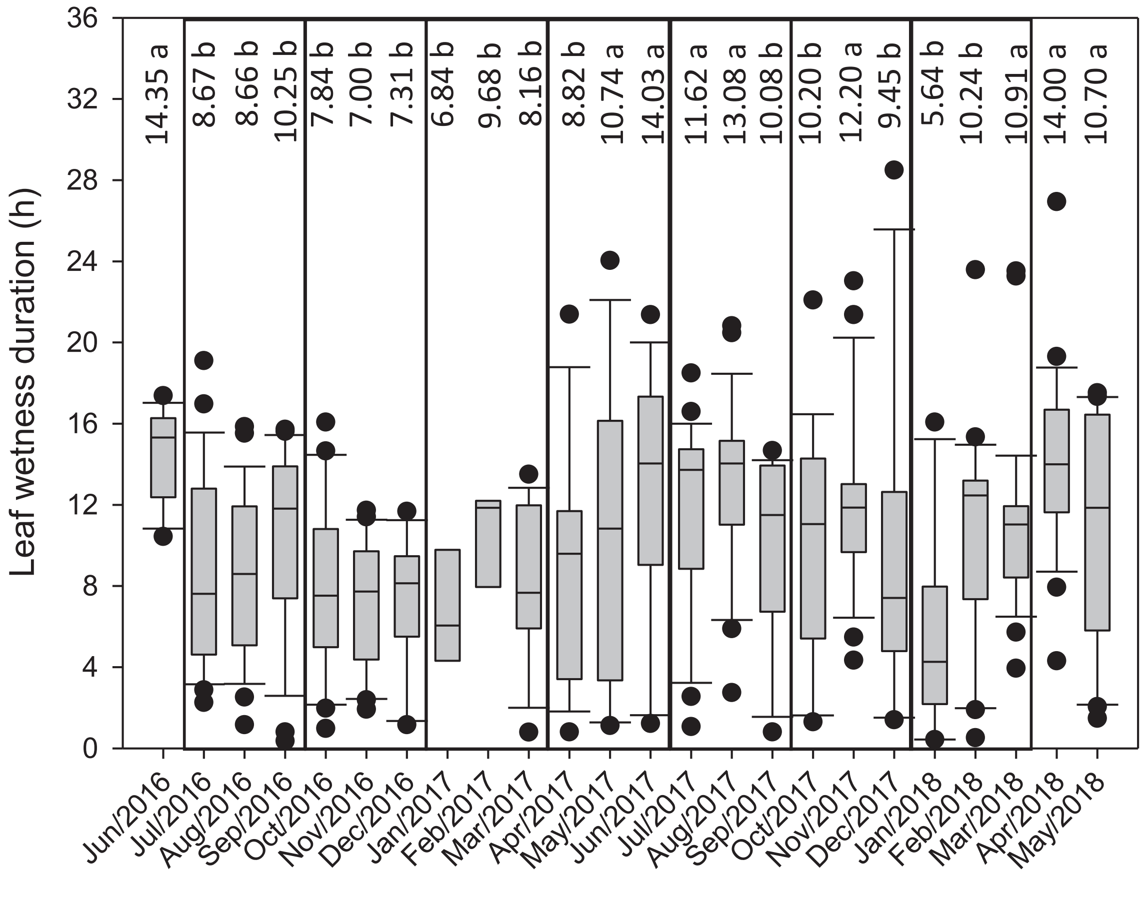



**Figure 6.** Monthly variability of the leaf wetness duration (LWD, h) in Santa Maria, Rio Grande do Sul State, Brazil, from June 2016 to May 2018. *Means followed by the same letter did not differ among themselves by Scott-Knott test at 5% probability.



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# Variabilidade temporal do orvalho em uma zona morfo-climática de transição no Sul do Brasil

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RESUMO

O período em que as folhas são expostas ao orvalho é importante para processos epidemiológicos que afetam a sanidade e a produção final de biomassa. O objetivo deste estudo foi determinar as principais características temporais da ocorrência de orvalho em um ponto preservado da zona morfo-climática de transição entre o Bioma Pampa e o Bioma Mata Atlântica em Santa Maria, Rio Grande do Sul, Brasil. Os dados foram coletados entre junho 2016 e maio de 2018 por um sensor LWS-L. O número de dias com orvalho por mês e os histogramas de frequência dos momentos de início e secagem por estação foram determinado. A duração do período de molhamento (DPM, h) foi calculada. Os valores médios de DPM por mês e sua variabilidade mensal foram determinadas. O número mínimo de ocorrências de orvalho por mês foi 4 (janeiro de 2017), e o máximo foi 29 (abril de 2018). Os horários preferenciais de início do orvalho e de sua secagem foram 18-21 h e 7-10 h, respectivamente, embora tenham havido diferenças entre as estações. A DPM tendeu a diminuir durante as estações mais quentes (9,00-9,54 h), em comparação com as estações mais frias (10,58-11,12 h), e apresentou variabilidade mensal significativa.



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