ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

ADJUSTMENT OF PROBABILITY FUNCTIONS TO WATER EXCESS AND DEFICIT IN SOYBEANS CULTIVATED IN LOWLAND SOILS

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1 ABSTRACT

The objective of this study was to verify the fit of exponential, gamma, lognormal, normal and weibull probability density functions (pdf) to water deficit and excess accumulated data during soybean subperiods and development cycle. Historical series of meteorological data obtained from Pelotas and Santa Maria meteorological stations (RS) were utilized. The soybean development simulation was performed for cultivars from the relative maturity group (RMG) between 5.9-6.8, 6.9-7.3 and 7.4-8.0 on eleven sowing dates from September 21 to December 31. Daily sequential water balance was calculated with water excess (days) and water deficit (mm) data to adjust each pdf to the observed data. The better adjustment frequency for water excess data in the soybean cycle was obtained with normal pdf in Santa Maria and weibull and gamma in Pelotas. Regardless of the location, the lognormal pdf presented the best fit for the water deficit data in the soybean cycle. In both locations, normal and weibull pdf demonstrated the best performance for water excess in the subperiods gamma, lognormal and exponential pdf for the water deficit.

Keywords: *Glycine max*, risk analysis, sowing date, historical series.

BORTOLUZZI, M. P.; HELDWEIN, A. B.; TRENTIN, R.; NIED, A. H.; DA SILVA, J. R.; DA ROCHA, L.
AJUSTE DE FUNÇÕES DE PROBABILIDADE AO EXCESSO E DÉFICIT HÍDRICO NA SOJA EM TERRAS BAIXAS

2 RESUMO

O objetivo deste trabalho foi verificar o ajuste das funções densidade de probabilidade (fdp) exponencial, gama, lognormal, normal e weibull aos dados de déficit e excesso hídrico, acumulados durante subperíodos e ciclo de desenvolvimento da soja. Foram utilizadas séries históricas de dados meteorológicos obtidos das estações meteorológicas de Pelotas e de Santa Maria, RS. Foi simulado o desenvolvimento da soja, para cultivares de grupo de maturidade

Recebido em 14/07/2019 e aprovado para publicação em 13/05/2020
DOI: http://dx.doi.org/10.15809/irriga.2020v25n2p402-419

relativa (GMR) entre 5.9–6.8, 6.9–7.3 e 7.4–8.0 em onze datas de semeadura compreendidas entre 21 de setembro e 31 de dezembro. Calculou-se o balanço hídrico sequencial diário, sendo obtidos os dados de excesso hídrico (dias) e déficit hídrico (mm) para ajustar cada fdp aos dados observados. A maior frequência de ajuste para os dados de excesso hídrico no ciclo da soja foi obtida para a fdp normal em Santa Maria e fdp weibull e gama para Pelotas. A fdp lognormal foi a que melhor se ajustou aos dados de déficit hídrico no ciclo da soja, independentemente do local. Em ambos os locais, a fdp normal e a weibull apresentaram o melhor desempenho para o excesso hídrico nos subperíodos e as fdps gama, lognormal e exponencial para o déficit hídrico.

Palavras-chave: *Glycine max*, análise de risco, data de semeadura, séries históricas.

3 INTRODUCTION

The study of occurrence probability of adverse phenomena is elementary to reduce the risks of yield losses in agricultural crops. Official credit institutions and insurance companies condition the financing or insurance of agricultural activity only if the risk is quantified. Several years of expensive and time-consuming field trials generally do not consider the potential extreme meteorological conditions that characterize the interannual variability of a long data series. The risk measurement is more accurate when based on certain probability density functions (pdf), which are directly linked to the nature of the long data series under analysis.

The probability distribution is a mathematical adjustment of the frequency distribution. The probability distribution can be represented by a pdf. When integrated in a given interval, the pdf determines the occurrence probability of an event in this interval, being called the cumulative probability function.

In agrometeorology, there are studies with several variables including the occurrence of hail (BERLATO; MELO; FONTANA, 2000), frost (WREGE et al., 2018), solar radiation (BURIOL et al., 2001; ASSIS et al., 2004), rainfall (SILVA et al., 2007; KIST; VIRGENS FILHO, 2015), and air temperature (ARAÚJO et al., 2010), likewise for water excess in soybean (BORTOLUZZI et al., 2017) and water deficit in soil with grass or reference cover (SILVA et al., 2008) in maize (NIED et al., 2005) and common bean (SILVA et al., 2006). These studies enable improved planning of agricultural activities, since they generate information regarding the occurrence risk of determined values of adverse variables for the studied period, facilitating preventive decision-making to mitigate the crop yield reduction in function of adverse events.

The use of a long data series is required to perform this type of study (SILVA et al., 2008; TRENTIN et al., 2013). Moreover, the data must be representative to allow the use of pdf parameters adjusted for general use in the studied region. Furthermore, the use of pdf and parameters is only possible if they can estimate the observed frequency, which is verified by the adhesion tests (CATALUNHA et al., 2002). The most commonly used adhesion tests are Chi-square (χ^2), Kolmogorov-Smirnov (KS) and Lilliefors. The Lilliefors test is specific and limited to testing the data adherence to the normal distribution (ASSIS; ARRUDA; PEREIRA, 1996).

The identification of the pdf that best fit water excess and deficit is crucial in view of the relevance and harmful effects of water excess (BEUTLER et al., 2014; GUBIANI et al., 2018) and deficit

(WIJEWARDANA et al., 2018) for soybean cropping, which are intensified in lowland soils. The identified pdf generates information for a future inclusion of the probability analysis in the Agricultural Zoning of Climatic Risk. Therewithal, knowledge of the risk associated with the soybean sowing season can contribute to agricultural security, which has great potential for growth.

With the purpose of testing the hypothesis that the occurrence risk of water excess and deficit in soybean cultivated in lowland can be estimated from pdf, the objective of this study was to verify the fit of exponential, gamma, lognormal, normal and weibull probability density functions to data of water deficit and excess accumulated during soybean subperiods and development cycle. To meet the objective, we considered three sets of relative maturity groups of soybean cultivars cultivated in lowland soils of the Vacacaí and Piratini river basins respectively in Santa Maria and Pelotas, RS.

4 MATERIAL AND METHODS

Daily mean, maximum and minimum air temperature (°C), insolation (h), air relative humidity (%), wind speed (km·day^{-1}) and rainfall (mm) were obtained from Pelotas meteorological station located in the municipality of Capão do Leão, RS, southern Brazil (31º52'S, 52º21'W at 13.2 m altitude), from September 1971 to June 2017 and at the main meteorological station of Santa Maria, RS, Brazil (29°43'23''S, 53°43'15''W, at 95 m altitude), from September 1968 to June 2017, which totalized respectively 46 and 49 years of observations. The daily photoperiod for Pelotas and Santa Maria was calculated according to Kiesling (1982), considering the duration of the civil twilight of 6° below the horizon plane. According to the Köppen climate classification and the analyzed database, the climate of the two regions is subtropical humid Cfa without dry season defined.

The simulation of soybean development was performed according to the methodology proposed by Trentin et al. (2013). In this methodology, thermal time was calculated to estimate the emergence date (EM). Occurrence date of the first trifoliate leaf emission stage (V2) was estimated using the Soydev model (SETIYONO et al., 2007). The beginning of flowering (R1) and beginning of seed (R5) date were simulated with the models proposed by Sinclair et al. (1991) and Sinclair et al. (2007), respectively. The date of physiological maturity (R7) stage was obtained by calculating the thermal time and the date of harvest maturity (R8) was simulated by the model proposed by Sinclair (1986).

Three sets of soybean cultivars belonging to the relative maturity groups (RMG) between 5.9-6.8, 6.9-7.3 and 7.4-8.0 were considered. The RMG refers to the development cycle duration and this RMG amplitude was used to represent most of the cultivars currently used in lowland areas in the southern portion of Rio Grande do Sul, The eleven sowing dates were simulated at intervals of 10 or 11 days within the sowing date period among September 21 and December 31.

Daily sequential water balance (SWB) was calculated according to the methodology described by Pereira, Villa Nova e Sediyama (1997). Daily values of rainfall, soybean crop evapotranspiration (ETc) and water storage capacity (WSC) of the soil were used to obtain real evapotranspiration (ETr) and water deficit. Water excess was considered when soil water content was greater than WSC. The estimation of reference evapotranspiration (ETo) is required for SWB and was estimated using the Penman-Monteith method (ALLEN et al., 1998). Values of the crop coefficient (Kc) recommended by the FAO for soybean crop were used to calculate crop evapotranspiration (ETc) (ALLEN et al., 1998).

The WSC was calculated for the Planosol Haplic Eutrophic vertisolic in the coverage area of Pelotas and for the Planosol Haplic Eutrophic arenic in the Santa Maria region, using microporosity and permanent wilting point data obtained respectively from Ribeiro et al. (2016) and Gubiani et al. (2018). The initial WSC (WSCi) obtained for the 0-10 cm layer was 23 mm for both locations and was considered for the S-EM subperiod. The final WSC (WSCf) calculated for the 0-30 cm layer was 63 and 66 mm respectively for the Pelotas and Santa Maria soils and was used since stage R1. For the V2-R1 subperiod, a sigmoidal growth curve of the root system proposed by Dourado Neto et al. (1999) was used.

From the SWB, data on water excess (days) and water deficit (mm) were obtained throughout the soybean cycle and development subperiods comprised between sowing (S), EM, V2, R1, R5, R7 and R8 for each sowing date of each year of the historical series. Data were submitted to analysis of probability distribution and adherence test to verify the pdf that best represented the data distribution. Probability density functions (pdf) were used for continuous variables, since the variables water excess (days) and water deficit (mm) were counted in totals by subperiod and in the total soybean development cycle, analogous to Silva et al. (2007) for total rainfall over a given period.

The adjustments of the exponential, gamma, lognormal, normal and weibull pdf were tested using SAS software and reduced to two parameters, according to the recommendation of Assis, Arruda e Pereira (1996) and Catalunha et al. (2002). The adhesion tests used were Chi-square (χ^2) and Kolmogorov-Smirnov at $p > 0.10$ probability. The χ^2 test compares the observed and theoretical frequencies for each frequency class of the sample. Meantime, the KS test compares only the largest difference module with a tabulated value according to the number of observations in the series, which in this case corresponds to the number of studied years. When two or more functions were adjusted, the one with greatest significance level indicated by the χ^2 test was chosen.

5 RESULTS AND DISCUSSION

Considering the total soybean development cycle with 66 scenarios, the pdf normal, weibull and gamma were the ones with the highest adhesion frequency to the variable number of days with excess water for the coverage region of Santa Maria (Vacacaí river basin) and Pelotas (Piratini river basin) meteorological stations (Table 1). In Pelotas, the weibull pdf exhibited better adherence to water excess data (days) in the total cycle in 15 out of 33 sowing dates. In addition, the Weibull pdf presented the greatest adjustment frequency (45.5%), followed by the gamma pdf with fit for 39.4% of the sowing dates (Table 1).

Meanwhile, the normal pdf demonstrated better adherence to the water excess results in the lowland conditions of the Vacacaí river basin in the Santa Maria coverage region, obtaining a better data fit in 20 sowing dates (60.6%), followed by the weibull pdf in eight sowing dates (Table 1). Moreover, the normal pdf showed a significant fit for all sowing dates at this location, being deprecated at the time of choice because of the lower significance values in the adhesion tests.

For the water deficit data (mm) accumulated in the soybean development cycle in lowland areas of the Vacacaí river basin, lognormal pdf presented better adjustment in most of the sowing dates, except for five dates where no pdf adjustment was obtained (Table 1). The lack of adjustment on these five dates, with sowing between November 21 and December 31, was probably due to the favorable water condition to soybeans as was also verified for maize (NIED et al., 2005). The lognormal pdf also presented the greatest frequency of data adjustment for soil water deficit in the conditions of grass coverage in meteorological station for decendial and monthly scale in Santa Maria (SILVA et al., 2008).

Table 1. Adjustment frequency (%) of the probability density functions (pdf) for the variables water excess and water deficit during the soybean cycle for Vacacaí and Piratini river basins. Santa Maria, RS, 2019.

Pdf	**Water excess (% of n*)**		**Water deficit (% of n)**	
	Vacacaí	**Piratini**	**Vacacaí**	**Piratini**
Exponential	0	0	0	0
Gamma	15.2	39.4	0	36.4
Lognormal	0	3.0	84.8	51.5
Normal	60.6	12.1	0	0
Weibull	24.2	45.5	0	12.1
Lack of fit	0	0	15.2	0
Total*	n=33	n=33	n=33	n=33
n=132	n=66		n=66	

*n = Total number of adhesion tests of each pdf

For lowlands of the Piratini river basin in the coverage region of Pelotas, at least one pdf was adjusted in all 33 simulated sowing dates for the three soybean RMG. The highest adjustment frequency was also obtained with lognormal pdf, being selected because of the better fit than the others in more than 50% of the cases, followed by gamma (36.4%) and weibull (12.1%). Similar to the adjustment of the normal pdf for water excess data in lowlands of the Vacacaí river basin, the lognormal pdf also exhibited fit to the water deficit data for all sowing dates. Therefore, we can infer that the lognormal pdf better represents the water deficit data distribution, regardless of the considered location.

The exponential pdf did not fit the data for any sowing date or considered variable. For the water excess data (days) throughout the cycle, the lognormal pdf presented better fit only for the September 21 sowing date with RMG 6.9-7.3 for the lowlands of the Piratini river basin (Table 2). On the other hand, the normal pdf did not fit properly the water deficit data at any sowing date for both locations (Table 3). Therefore, we clearly demonstrated that the normal pdf cannot be employed properly to describe the water deficit occurrence risks. Furthermore, the lognormal pdf does not exhibit a satisfactory fit to evaluate the occurrence risk of a determined number of days with water excess for soybean cultivated in lowlands of the two studied rivers basins as a function of the data asymmetric distribution. Therefore, even with the soil buffering effect as a function of its water storage capacity, the characteristics of distribution of rainfall precipitation (SILVA et al., 2007) are transferred in an attenuated form to the resulting daily SWB data, such as water excess (days) and water deficit (mm) accumulated in the cycle.

Table 2. Probability density functions (pdf) and adjusted coefficients for water excess during the soybean cycle in Vacacaí and Piratini river basins in 11 simulated sowing dates (SD). Santa Maria, RS, 2019.

	Region of coverage	SD	Relative Maturity Groups								
			5.9-6.8			6.9-7.3			7.4-8.0		
			pdf	a*	b*	pdf	a*	b*	pdf	a*	b*
Water excess (days)	Vacacaí	21/sep	N	46.755	14.933	N	46.857	14.839	W	54.061	3.899
		01/oct	N	43.346	15.250	N	43.653	15.032	G	6.945	6.558
		11/oct	G	5.446	7.437	W	44.892	2.898	G	5.849	7.382
		21/oct	G	5.537	6.707	G	5.501	7.200	W	48.486	3.096
		01/nov	W	39.217	2.862	W	42.953	2.958	N	41.612	15.670
		11/nov	N	33.000	13.333	N	36.571	14.214	W	44.826	3.040
		21/nov	N	34.625	13.257	N	35.632	13.842	N	40.530	13.817
		01/dec	N	32.857	12.614	W	38.167	3.100	N	40.612	13.590
		11/dec	N	31.000	12.337	N	33.959	12.556	N	39.306	13.118
		21/dec	N	30.469	11.841	N	33.224	11.962	N	38.591	13.970
		31/dec	N	31.204	11.293	W	36.145	3.000	N	37.795	13.049
	Piratini	21/sep	W	50.719	3.098	LN	3.763	0.391	G	5.506	8.680
		01/oct	W	48.819	3.029	W	49.817	3.159	G	5.545	8.762
		11/oct	N	42.500	16.057	W	49.911	3.009	N	49.545	17.232
		21/oct	W	47.592	3.118	W	50.227	3.301	W	54.243	3.308
		01/nov	G	5.745	7.120	W	49.272	3.131	G	5.121	9.319
		11/nov	G	4.849	8.037	G	4.777	8.477	G	4.909	9.197
		21/nov	G	5.665	6.454	G	5.975	6.587	W	48.467	2.971
		01/dec	G	5.736	6.184	N	38.181	14.730	N	42.454	15.163
		11/dec	W	39.902	3.071	W	41.693	2.853	G	7.380	5.614
		21/dec	W	38.843	2.798	W	39.796	2.674	G	6.866	5.894
		31/dec	W	39.510	2.888	W	40.149	2.855	G	7.350	5.574

*The parameters of pdf G= Gamma, W= Weibull and LN= Lognormal are denominated “scalar” and “shape” and the ones of pdf N=Normal are denominated mean and standard deviation. LF = lack of fit. RMG = relative maturity groups.

Regarding the water excess (days) data in lowlands of the Vacacaí river basin, the mean (a) and standard deviation (b) parameters of the normal pdf, which had the highest adjustment frequency, presented great association with sowing dates of sowing, counted in days after September 20 for the three RMG (Figure 1). Furthermore, the parameter “a” (mean) was more modified as a function of the sowing date than “b” (standard deviation). For parameter “a” of normal pdf, a quadratic regression adjustment was obtained, with $R^2 > 0.97$ for all RMG analyzed in isolation, while for parameter “b” a linear regression fit was obtained with R^2 of 0.97, 0.87 and 0.65 respectively for RMG 5.9-6.8, 6.9-7.3 and 7.4-8.0.

The data set including all RMG of parameter “a” of normal pdf resulted in a quadratic regression ($a = 0.001123\ x^2 - 0.2348\ x + 46.60$), decreasing since September 20 and with $R^2 = 0.65$. Meanwhile, the parameter “b” exhibited a negative linear function ($b = -\ 0.3072\ x + 15.41$) with $R^2 = 0.68$. Nevertheless, there were small differences between the RMG especially regarding the “a” coefficient, which was slightly larger for RMG 7.4-8.0. Fitting the linear function, we obtained $R^2 = 0.94$ (Figure 1C). Quadratic functions were fitted for RMG 5.9-6.8 and 6.9-7.3 with $R^2 \geq 0.98$ (Figure 1A and 1B). The parameter "b" did not present differences between RMG, maintaining the negative linear regression for the three RMG (Figure 1A, B and C).

Table 3. Probability density functions (pdf) and adjusted coefficients for water deficit during the soybean cycle in Vacacaí and Piratini river basins in 11 simulated sowing dates (SD). Santa Maria, RS, 2019.

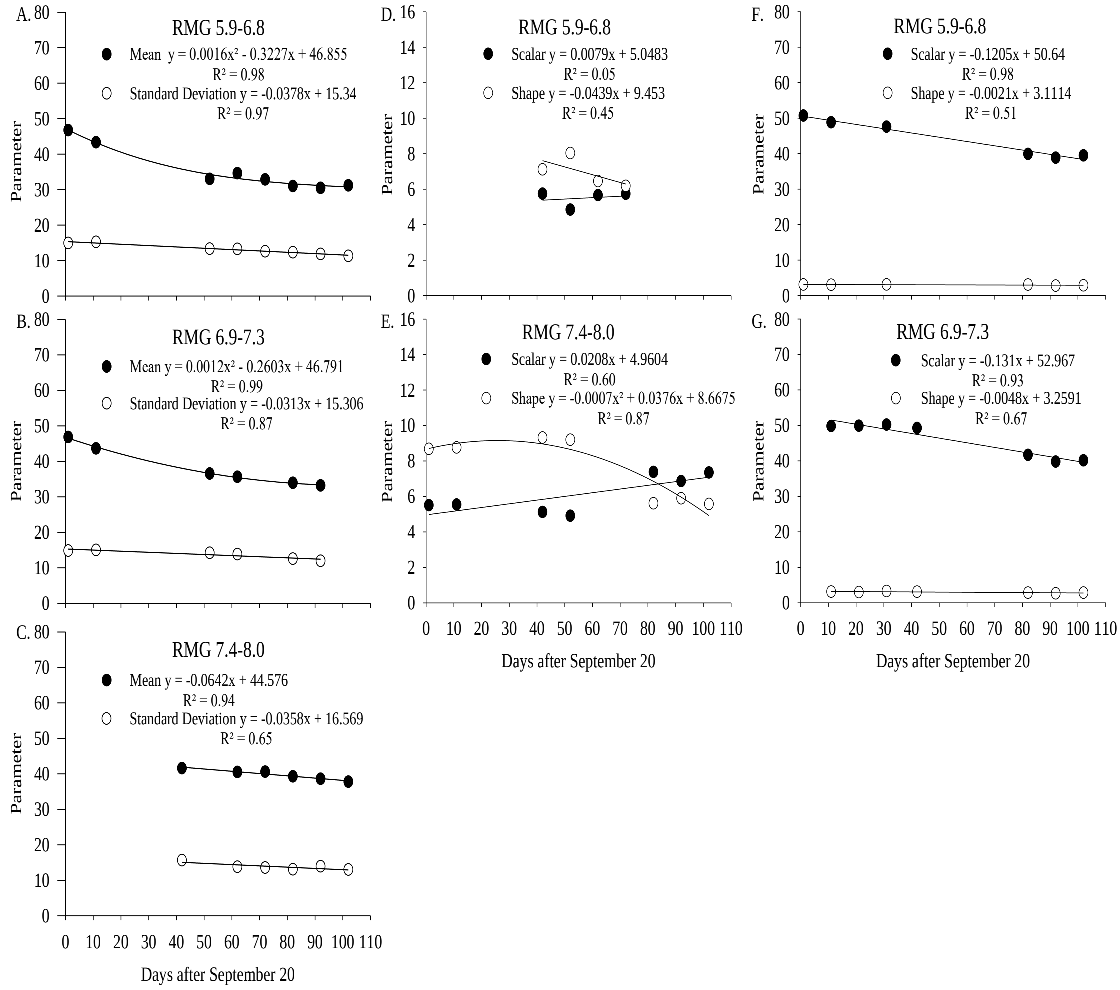
	Region of coverage	SD	Relative Maturity Groups								
			5.9-6.8			6.9-7.3			7.4-8.0		
			pdf	a*	b*	pdf	a*	b*	pdf	a*	b*
Water deficit (mm)	Vacacaí	21/sep	LN	5.028	0.371	LN	5.050	0.369	LN	5.031	0.360
		01/oct	LN	5.076	0.360	LN	5.099	0.359	LN	5.078	0.362
		11/oct	LN	5.086	0.361	LN	5.114	0.361	LN	5.091	0.367
		21/oct	LN	5.060	0.365	LN	5.082	0.367	LN	5.058	0.367
		01/nov	LN	5.013	0.375	LN	5.024	0.371	LN	5.005	0.360
		11/nov	LN	4.939	0.376	LN	4.960	0.368	LN	4.944	0.347
		21/nov	LN	4.839	0.389	LN	4.861	0.368	LF	---	---
		01/dec	LF	---	---	LN	4.749	0.358	LF	---	---
		11/dec	LF	---	---	LN	4.629	0.365	LN	4.605	0.361
		21/dec	LN	4.496	0.381	LN	4.512	0.375	LN	4.476	0.380
		31/dec	LF	---	---	LN	4.373	0.394	LN	4.346	0.397
	Piratini	21/sep	G	15.532	9.565	G	15.794	9.681	LN	4.947	0.338
		01/oct	LN	4.945	0.343	LN	4.974	0.336	LN	4.942	0.339
		11/oct	LN	4.930	0.339	LN	4.948	0.340	G	15.180	9.428
		21/oct	G	15.349	8.979	W	154.68	3.336	G	14.479	9.256
		01/nov	G	15.429	8.240	LN	4.783	0.363	G	14.525	8.376
		11/nov	W	129.44	3.133	W	129.55	3.165	LN	4.646	0.357
		21/nov	G	13.465	7.771	LN	4.587	0.365	LN	4.548	0.368
		01/dec	LN	4.466	0.377	LN	4.469	0.371	G	11.027	8.141
		11/dec	LN	4.326	0.379	LN	4.338	0.375	G	9.224	8.635
		21/dec	G	10.017	7.137	W	80.887	2.991	G	8.713	8.035
		31/dec	LN	4.037	0.374	LN	4.061	0.373	LN	4.046	0.365

*The parameters of pdf G= Gamma, W= Weibull and LN= Lognormal are denominated "scalar" and "shape" and the ones of pdf N=Normal are denominated mean and standard deviation. LF = lack of fit. RMG = relative maturity groups.

The parameters of the gamma pdf fitted for the number of days with water excess in the soybean development cycle cultivated in lowlands of the Piratini river basin exhibited a trend of inverse variation throughout the sowing calendar when considering RMG 5.9-6.8 (Figure 1D). A positive linear relation for parameter "a" (scalar) with $R^2 > 0.60$ was obtained for RMG 7.4-8.0 cultivars. For the parameter "b" (shape), a quadratic equation inverse of the parameter "a" was fitted with $R^2 > 0.87$ (Figure 1E). In addition, there was a better fit of the gamma pdf for only two sowing dates when RMG 6.9-7.3 cultivars were considered. Therefore, no regression analysis was performed for the parameters "a" and "b" regarding the sowing date.

The scalar (a) and shape (b) parameters of the weibull pdf for Pelotas were decreasing for sowing dates from September 21 to December 31, presenting a negative linear relation and obtaining values for parameters “a” and “b” respectively of R^2 = 0.98 and 0.51 for RMG 5.9-6.8 (Figure 1F) and respectively of R^2 = 0.93 and 0.67 for RMG 6.9-7.3 (Figure 1G). There was better fit of the weibull pdf for only two sowing dates for RMG 7.4-8.0 and therefore no regression analysis was performed.

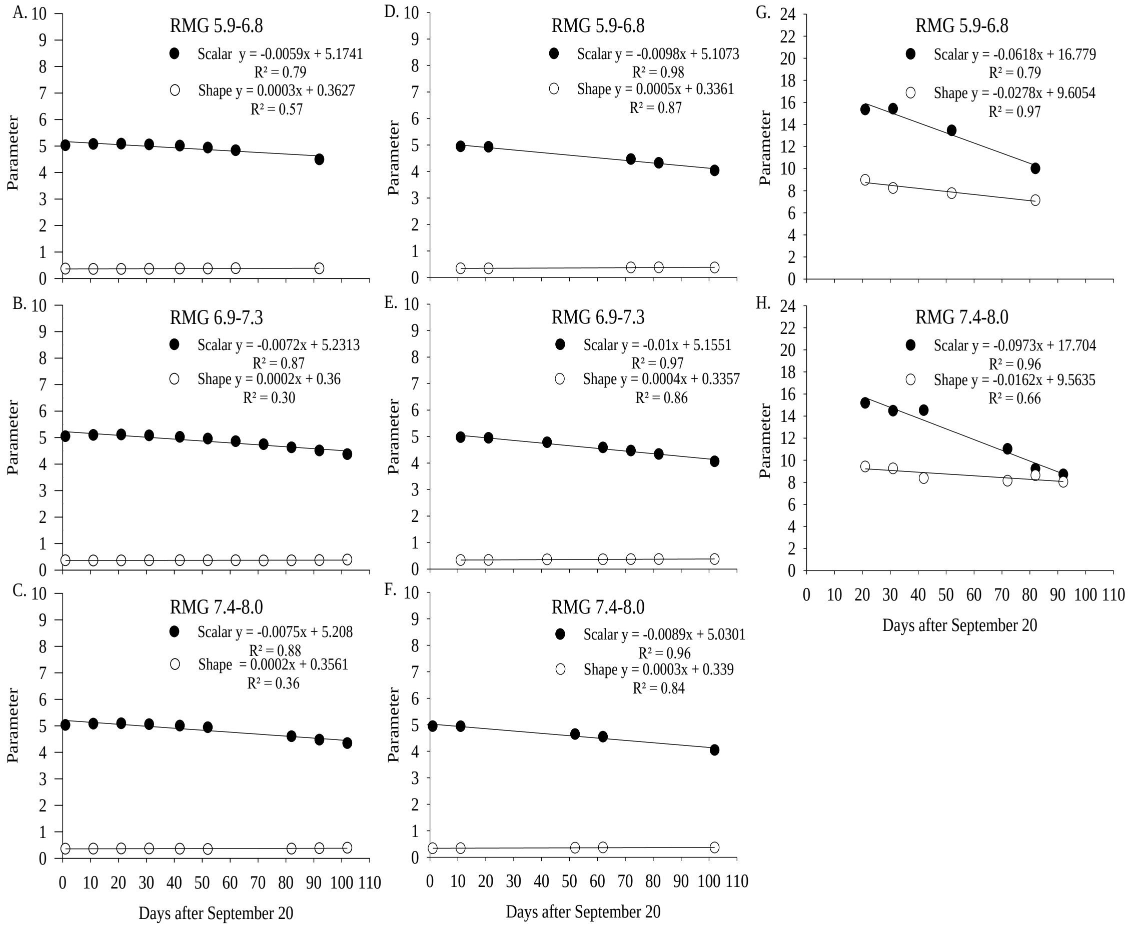
Figure 1. Parameters of probability density functions (pdf) normal (a, b and c) adjusted to determine the water excess in the soybean cycle in Vacacaí river basin and gamma (d and e) and weibull (f and g) in Piratini river basin. Santa Maria, RS, 2019.



The parameter “a” (scalar) of the lognormal pdf fitted for water deficit presented a negative linear relation in function of the sowing dates for the soils of the Vacacaí river basin, with R^2 values between 0.78 and 0.88, according to the considered RMG (Figure 2A, 2B and 2C). Similarly, the negative linear relation occurred for soil in the lowland of the Piratini river basin with $R^2 \geq 0.96$ for all RMG (Figure 2D, 2E and 2F). The parameter “b” (shape) did not exhibit great variation throughout the sowing calendar. Furthermore, a positive linear regression was fitted for all RMG with low R^2 (between 0.30 and 0.57) for the lowlands of the Vacacaí river basin and with $R^2 \geq 0.84$ for the Piratini river basin.

The gamma pdf also presented a proper adjustment frequency for the water deficit data for the lowlands of the Piratini river basin. In addition, a marked linear decrease of parameter "a" (scalar) was verified with the advance of the sowing date from October 11. The regression equations obtained showed $R^2 = 0.79$ for RMG 5.9-6.8 (Figure 2G) and $R^2 = 0.96$ for RMG 7.4-8.0 (Figure 2H). There was also a negative linear regression equation fit for parameter "b" (shape), with $R^2 = 0.97$ and $R^2 = 0.66$, respectively (Figure 2G, 2H). For the RMG 6.9-7.3 cultivars, the gamma pdf was the best fit only for two sowing dates and no regression analysis was performed.

Figure 2. Parameters of probability density functions (pdf) lognormal (a, b and c) adjusted to determine the water deficit in the soybean cycle in Vacacaí river basin and lognormal (d, e and f) and gamma (g and h) in Piratini river basin. Santa Maria, RS, 2019.



For the six soybean development subperiods, 792 scenarios were obtained for the pdf adjustment test for the water excess and deficit data obtained from the combination of 11 sowing dates, six subperiods, three RMG and two studied locations. At least one function was significantly adjusted in 328 of the 396 possible cases for the variable "number of days with excess water". There was no significant difference in the adjustment of functions between the two locations when considering the summary of the frequency of adjustments of the pdf to the obtained values (Table 4).

Table 4. Adjustment frequency (%) of probability density functions (pdf) for the variables water excess and water deficit in six soybean development subperiods for Vacacaí and Piratini river basins. Santa Maria, RS, 2019.

pdf	Water excess (% of n*)		Water deficit (% of n*)	
	Vacacaí	**Piratini**	**Vacacaí**	**Piratini**
Exponential	1,5	1,5	26,3	31,3
Gamma	10,6	12,1	32,3	21,2
Lognormal	5,3	4,1	26,8	23,2
Normal	32,8	34,8	0,5	2,0
Weibull	33,2	29,8	14,1	19,7
Lack of fit	16,6	17,7	0,0	2,6
Total	n=198	n=198	n=198	n=198
n=792	n=396		n=396	

*n = Total number of adhesion tests of each pdf

The weibull pdf predominated in the frequency distribution fitted for the subperiods (33.2%), followed by normal (32.8%) for the Santa Maria data applied to the lowland soil conditions of the Vacacaí river basin. Normal and weibull pdf were also the ones that better fitted the water excess data in the lowlands of the Piratini river basin, with a total fit respectively of 34.8% and 29.8%. Considering the two locations, in only 68 of the 792 cases (8.6%) there was a lack of fit for any pdf (LF) (Table 4), being necessary to choose the empirical frequency distribution. Thus, this finding reinforces the strong possibility of using probability in the analysis of climate risk zoning.

The gamma and weibull functions exhibited the best fit in the rain frequency distribution analysis in Santa Maria (SILVA et al., 2007), in Parana State (KIST; VIRGENS FILHO, 2015) and for monthly rainfall data in Bento Gonçalves, RS (RODRIGUES; SANTOS FILHO; CHAVES, 2013). Therefore, we can infer that also for the subperiods, as for the whole crop cycle, the water excess occurrence is more dependent on rainfall distribution than on evapotranspiration, based on the better fit of the same pdf for rainfall data (SILVA et al., 2007) and water excess.

Considering the water deficit data (mm) by subperiod for the lowland of the Vacacaí river basin (Santa Maria), there was a fit for at least one pdf at all sowing dates (Table 4). The gamma pdf presented the highest adjustment frequency (32.3%), followed by lognormal (26.8%) and exponential (26.3%). These pdf were also the predominant ones for the lowlands of the Piratini river basin, but the exponential (31.3%) present the highest adjustment frequency (Table 4). The better exponential adjustment was probabily due to the high data asymmetry as was also verified for rainfall data in the dry season of Ceará State (SILVA et al., 2013).

There was no fit of any pdf for water deficit data for the Pelotas (Piratini river basin) coverage area only for five sowing dates (Table 4). Therefore, we can affirm there was a higher adjustment frequency of pdf to the water deficit data in comparison to water excess data. This is probably due to the greater interannual variability of water excess occurrence, generating extreme values that difficult the fit of a pdf.

The pdf that best fitted the frequency distribution for the variable number of days with water excess in the six developmental subperiods at the 11 different sowing dates, with the respective coefficients for the three RMG are presented in Table 5 for Santa Maria and in Table 6 for Pelotas.

Table 5. Probability density functions (pdf) adjusted to determine the water excess and water deficit accumulated in the subperiods of the soybean crop (Subp) for Vacacaí river basin in 11 simulated sowing dates (SD). Santa Maria, RS, 2019.

WC		Subp.	Sowing dates										
			1	2	3	4	5	6	7	8	9	10	11
Water excess	RMG 5.9-6.8	S-EM	N	N	N	N	N	LF	LF	W	LF	LF	N
		EM-V2	N	LF	N	W	N	LF	N	W	N	N	N
		V2-R1	N	G	W	W	W	G	LF	W	W	W	LF
		R1-R5	LF	W	N	W	LN	LF	W	EX	N	G	G
		R5-R7	W	N	LN	W	W	N	W	N	W	G	N
		R7-R8	G	LN	G	N	LN	N	W	LF	LF	N	G
	RMG 6.9-7.3	S-EM	N	N	LF	LF	N	LF	LF	N	G	N	W
		EM-V2	N	N	N	W	LF	LF	N	W	W	LF	N
		V2-R1	N	LN	W	W	W	N	N	W	N	N	N
		R1-R5	W	W	W	LN	W	W	W	LF	N	N	W
		R5-R7	W	W	G	W	N	W	N	W	G	W	G
		R7-R8	W	LF	G	G	N	W	N	N	LN	W	W
	RMG 7.4-8.0	S-EM	N	LF	N	LF	N	LF	W	N	LF	N	LF
		EM-V2	N	LF	N	W	LF	LF	N	N	W	LF	LF
		V2-R1	W	G	W	G	N	W	W	W	N	N	W
		R1-R5	EX	G	W	G	LF	EX	W	N	W	W	LN
		R5-R7	G	G	LF	N	W	W	LN	W	W	W	W
		R7-R8	W	N	LN	W	W	LF	N	G	N	N	N
Water deficit	RMG 5.9-6.8	S-EM	LN	EX	EX	G	EX	G	W	LN	EX	W	EX
		EM-V2	LN	EX	W	G	LN	EX	EX	G	EX	EX	EX
		V2-R1	LN	LN	G	G	G	G	G	G	EX	W	LN
		R1-R5	W	G	G	W	G	G	G	LN	G	G	LN
		R5-R7	G	G	W	LN	LN	G	LN	LN	LN	G	W
		R7-R8	EX	LN	EX	EX	LN	LN	LN	EX	EX	G	LN
	RMG 6.9-7.3	S-EM	EX	EX	EX	EX	EX	EX	G	W	EX	W	EX
		EM-V2	LN	G	LN	LN	LN	EX	EX	G	W	G	EX
		V2-R1	LN	G	G	G	LN	LN	G	LN	W	LN	G
		R1-R5	G	G	G	G	W	G	LN	LN	W	G	LN
		R5-R7	G	LN	LN	G	W	LN	LN	LN	LN	W	W
		R7-R8	EX	EX	EX	EX	EX	EX	EX	EX	EX	LN	EX
	RMG 7.4-8.0	S-EM	LN	EX	EX	G	EX	W	G	LN	EX	G	G
		EM-V2	LN	G	G	G	LN	EX	G	G	W	G	G
		V2-R1	G	W	W	LN	G	LN	G	LN	G	G	G
		R1-R5	G	W	W	W	G	W	G	W	G	LN	LN
		R5-R7	G	W	LN	LN	LN	LN	G	LN	G	N	G
		R7-R8	EX	EX	LN	EX	EX	EX	EX	EX	EX	W	EX

WC = Water condition; G = Gamma, W = pdf Weibull and LN = pdf Lognormal; N = pdf Normal; EX = pdf exponential; LF = lack of fit. RMG = relative maturity groups. 1 = 21/sep; 2= 01/oct; 3= 11/oct; 4 = 21/oct; 5 = 01/nov; 6 = 11/nov; 7 = 21/nov; 8 = 01/dec; 9 = 11/dec; 10 = 21/dec; 11 = 31/dec.

Table 6. Probability density functions (pdf) adjusted to determine the water excess and water deficit accumulated in the subperiods of the soybean crop (Subp) for Piratini river basin in 11 simulated sowing dates (SD). Santa Maria, RS, 2019.

WC		**Subp.**	**Sowing dates 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Water excess	RMG 5.9-6.8	S-EM	N	N	LF	N	N	LF	LF	LF	LF	LF	LF
		EM-V2	N	N	N	N	LF	LF	N	LF	N	W	N
		V2-R1	N	N	N	LN	W	G	N	N	N	N	W
		R1-R5	G	EX	LF	LN	LF	W	W	G	W	W	W
		R5-R7	G	G	G	W	N	W	W	W	W	W	W
		R7-R8	N	G	N	N	LF	W	LF	N	LF	N	N
	RMG 6.9-7.3	S-EM	N	LF	LF	N	W	N	LF	N	LF	LF	LF
		EM-V2	N	N	N	G	W	LF	N	N	N	N	N
		V2-R1	N	W	W	LN	W	W	N	LF	N	LF	N
		R1-R5	G	LN	LN	W	N	W	W	G	W	EX	G
		R5-R7	LN	W	W	LF	G	W	W	G	W	W	W
		R7-R8	W	W	W	LF	N	LF	W	N	N	G	G
	RMG 7.4-8.0	S-EM	LF	N	N	N	LF	N	G	G	LF	LF	N
		EM-V2	N	N	N	W	W	LF	N	N	N	N	LF
		V2-R1	W	W	G	W	W	W	N	N	W	N	N
		R1-R5	W	G	G	LF	N	W	G	W	G	W	G
		R5-R7	EX	W	W	W	W	W	W	W	W	W	LN
		R7-R8	LN	G	W	LF	N	N	N	N	N	N	N
Water deficit	RMG 5.9-6.8	S-EM	EX	LN	EX	EX	EX	EX	EX	G	EX	EX	EX
		EM-V2	W	LN	EX	W	LN	G	G	W	EX	G	LN
		V2-R1	G	W	G	G	G	LN	G	LN	G	LN	LN
		R1-R5	W	W	W	N	W	W	LN	G	W	G	G
		R5-R7	W	G	W	W	W	G	G	LN	LN	LN	G
		R7-R8	G	EX	EX	LN	EX	EX	G	EX	EX	EX	EX
	RMG 6.9-7.3	S-EM	EX	EX	EX	LN	LF	EX	EX	W	EX	G	EX
		EM-V2	LN	EX	EX	G	LF	G	W	G	EX	EX	LN
		V2-R1	W	N	G	G	G	G	W	LN	LN	EX	G
		R1-R5	W	G	N	W	LN	LN	LN	W	G	G	LN
		R5-R7	G	G	LN	LN	W	G	LN	G	LN	W	LF
		R7-R8	EX	EX	EX	LN	EX	EX	EX	EX	EX	EX	EX
	RMG 7.4-8.0	S-EM	EX	EX	LN	EX	EX	EX	EX	W	EX	EX	EX
		EM-V2	W	LN	EX	EX	LN	G	G	G	EX	W	LN
		V2-R1	LF	W	LN	G	W	W	G	LN	LN	G	LN
		R1-R5	W	LF	W	LN	W	LN	W	N	W	LN	W
		R5-R7	W	LN	LN	G	W	LN	LN	LN	LN	W	W
		R7-R8	EX	EX	LN	EX	EX	EX	EX	EX	EX	EX	LN

WC = Water condition; G = Gamma, W= pdf Weibull and LN= pdf Lognormal; N= pdf Normal; EX = pdf exponential; LF = lack of fit. RMG = relative maturity groups. 1 = 21/sep; 2= 01/oct; 3= 11/oct; 4 = 21/oct; 5 = 01/nov; 6 = 11/nov; 7 = 21/nov; 8 = 01/dec; 9 = 11/dec; 10 = 21/dec; 11 = 31/dec.

The exponential pdf fitted better than the others in only three sowing dates at each location and five of those were exclusively for the R1-R5 subperiod. The lognormal pdf also presented low frequency of better fit, with only eight and nine selections respectively for Santa Maria and Pelotas, randomly distributed into the three RMG in all four subperiods after the V2 stage. Similar randomness of better fit was also observed with gamma pdf for the same stages as for the lognormal in the two locations, but with a higher frequency, totaling 6, 14, 11 and 10 selections respectively in the V2-R1, R1-R5, R5-R7 and R7-R8 subperiods. The normal and weibull pdf presented a predominance of cases of better fit for certain subperiods and for a sequential set of sowing dates in some cases, which also occurred for the cases of lack of fit (LF).

For S-EM, EM-V2, V2-R1 and R7-R8 subperiods, the best fit of the normal pdf predominated to describe the data distribution of “number of days with excess water” at both locations. In the S-EM subperiod, the normal pdf predominated until the sowing date of November 1st at both locations. There was a similar trend until the sowing date of Oct 11 for the EM-V2 subperiod both for Santa Maria (Table 5) and Pelotas (Table 6). This finding infers clear evidence of greater water excess occurrence in the first 60 days of spring, which improves the homogeneity of frequency distribution in the form of normal function, even for short duration subperiods. Considering the two initial subperiods for November 11, the normal pdf was fitted only for RMG 6.9-7.3 and 7.4-8.0 in the S-EM subperiod in Pelotas (Table 6). There was no fit of any pdf for this date in either of the two locations for RMG 5.9-6.3 in the same subperiod and for the three RMG in the EM-V2 subperiod. When analyzing the rainfall data of all days of the 45 and 49 years, we verified that daily rainfall is significantly lower in the period of 01 to 10 and 11 to 20 of November than in the other days of the year. This results in lower occurrence of water excess in the S-EM and EM-V2 subperiods for soybean sown on November 1 and November 11 at both locations and implies lower chances of fitting some pdf for these short duration subperiods.

The weibull pdf showed a better data fit in comparison to the other tested functions in the subperiods of V2-R1 (sharing the highest frequency with normal pdf), R1-R5 and R5-R7. These are the reproductive subperiods and are determinants of yield formation. In addition, they have the longest duration, with more regular water excess distribution, which improves the condition for some pdf to fit the data distribution. In these three subperiods, weibull totaled 46 cases of better data fit for Santa Maria and 50 cases for Pelotas, being these random for sowing dates and RMG of soybean cultivars. Among these three subperiods, the weibull pdf had the highest number of fit in the R5-R7 subperiod, with 16 cases in Santa Maria and 23 in Pelotas. In compensation for the four later sowing dates (December), there was a lack of fit for the weibull pdf in the R7-R8 subperiod for Pelotas and only two of the 12 possible for Santa Maria.

There was a fit of at least one pdf in 82.8% of the cases and the fit of normal and weibull pdf were predominant. However, the set of all results indicated that a clear characterization was not obtained for which pdf best fits the data distribution for the number of days with water excess, considering the different sources of variation such as the development subperiod and the soybean RMG, in addition to the sowing dates. For longer periods, such as the total development cycle, there is a clearer trend in the definition of the best fitted pdf to the data.

The pdf coefficients obtained from the respective fit to the frequency distribution of water deficit (mm) accumulated in the six development subperiods at the 11 different sowing dates for the three RMG considering the Santa Maria (Table 5) and Pelotas (Tables 6) data indicated the predominance of exponential pdf adjustment in the two shorter subperiods (S-EM and R7-R8). In the V2-R1, R1-R5 and R5-R7 subperiods, the gamma and lognormal pdf predominated for Santa Maria, while gamma, lognormal and weibull predominated for Pelotas.

There was a certain equilibrium in the number of best pdf fitted with exponential, gamma, and lognormal for the EM-V2 subperiod. Normal pdf presented the best adjustment only for the sowing date of December 01 for RMG 7.4-8.0 in Santa Maria (Table 5). Except for some random exceptions, there was no clear influence of RMG on the adjustment frequency of each pdf for water deficit in both locations.

The significantly higher frequency of exponential fpd in the developmental subperiods between sowing and emergence (S-MS) and physiological maturity and harvest maturity (R7-R8) at the two studied locations is related to the shorter duration of these subperiods during the soybean cycle in comparison to the others (TRENTIN et al., 2013). This condition generates water deficit values with smaller magnitude and narrow distribution range, leading to a better fit of the exponential pdf.

We highlight that the obtained pdfs and their respective parameters cannot be recommended and used universally for other studies. However, the knowledge generated on the function fit to the data obtained from the numerical analysis allows the use of them to determine the associated risk of excess and water deficit. Furthermore, the risk assessment information is important for growers and financial agents who can subsidize soybean cropping based on a known risk, contributing to increased soybean acreage in lowland areas.

6 CONCLUSIONS

Risk analysis of days of water excess and deficit can be performed by means of probability density function (pdf) in both the full cycle and subperiods of soybean development.

The greatest adjustment frequency for the water excess data throughout the soybean development cycle was obtained with normal pdf for soils of the Vacacaí river basin, while weibull and gamma were obtained for soils of the Piratini river basin.

The lognormal pdf best fitted to water deficit data throughout the soybean cycle, independently of the soils of the Vacacaí and Piratini river basins.

The normal and weibull pdf presented the best performance for water excess data in the soybean development subperiods for both locations. Meanwhile for water deficit, the best fit was obtained with gamma, lognormal and exponential pdf.

The magnitude of the adjusted lognormal probability density function (pdf) parameters to determine the water deficit in the soybean cycle in lowland soils of the Vacacaí river basin and lognormal and gamma in the soils of the lowland of the Piratini river basin demonstrated variation. They can be estimated according to the sowing dates considered in days accumulated after September 20 for three relative maturity groups (RMG).

7 ACKNOWLEDGEMENTS

The authors are thankful to the National Council for Scientific and Technological Development (CNPq) and the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting the scholarships respectively of research productivity and doctorate degree.

8 LITERATURE

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M**. Crop evapotranspiration**: guidelines for computing crop water requirements. Rome: FAO, 1998.

ARAÚJO, E. M.; SILVA, I. N.; OLIVEIRA, J. B.; CAVALCANTE JUNIOR, E. G.; ALMEIDA, B. M. Aplicação de seis distribuições de probabilidade a séries de temperatura máxima em Iguatu – CE. **Revista Ciência Agronômica**, Fortaleza, v. 41, n. 1, p. 36-45, 2010. DOI: http://dx.doi.org/10.5935/1806-6690.20100005. Disponível em: https://www.scielo.br/pdf/rca/v41n1/1806-6690-rca-41-01-0036.pdf. Acesso em: 24 jun. 2020.

ASSIS, F. N.; ARRUDA, H. V.; PEREIRA, A. R. **Aplicações de estatísticas à climatologia:** teoria e prática. Pelotas: UFPEL, 1996.

ASSIS, J. P.; DOURADO NETO D.; MANFRON, P. A.; MARTIN, T. N.; SPAROVEK, G.; TIMM, L. C. Ajuste de series históricas de temperatura e radiação solar global diária às funções densidade de probabilidade normal e log-normal, em Piracicaba, SP. **Revista Brasileira de Agrometeorologia**, Santa Maria, v. 12, n. 1, p. 113-121, 2004.

BERLATO, M. A.; MELLO, R. W.; FONTANA, D. C. Risco de ocorrência de granizo no estado do Rio Grande do Sul. **Revista Brasileira de Agrometeorologia**, Santa Maria, v. 8, n. 1, p. 121-132, 2000.

BEUTLER, A. N.; GIACOMELI, R.; ALBERTO, C. M.; SILVA, V. N.; SILVA NETO, G. F.; MACHADO, G. A.; SANTOS, A. T. Soil hydric excess and soybean yield and development in Brazil. **Australian Journal of Crop Science**, Brisbane, v. 8, n. 10, p. 1461-1466, 2014. Disponível em: https://search.informit.com.au/documentSummary;dn=752595525258902;res=IELHSS. Acesso em: 24 Jun. 2018.

BORTOLUZZI, M. P.; HELDWEIN, A. B.; TRENTIN, R.; LUCAS, D. D. P.; RIGHI, E. Z.; LEONARDI, M. Risk of water surplus in soybean crop on haplic planosol soil in the Central Depression of Rio Grande do Sul State, Brazil. **Ciência Rural**, Santa Maria, v. 47, n. 2, p. 1-7, 2017. DOI: http://dx.doi.org/10.1590/0103-8478cr20160170. Disponível em: https://www.scielo.br/pdf/cr/v47n2/1678-4596-cr-47-02-20160170.pdf. Acesso em: 24 jun. 2020.

BURIOL, G. A.; HELDWEIN, A. B.; ESTEFANEL, V.; MATZENAUER, R.; MARCON, I. A. Probabilidade de ocorrência de valores de radiação solar prejudiciais ao cultivo do pepineiro na região do baixo vale do Taquari, RS. **Pesquisa Agropecuária Gaúcha**, Porto Alegre, v. 7, n. 1, p. 97-104, 2001. Disponível em: http://www.fepagro.rs.gov.br/upload/1398887236_art__10.pdf. 25 Jun. 2019. Acesso em: 24 jun. 2020.

CATALUNHA, M. J.; SEDIYAMA, G. C.; LEAL, B. G.; SOARES, C. P. B.; RIBEIRO, A. Aplicação de cinco funções densidade de probabilidade a séries de precipitação pluvial no

Estado de Minas Gerais. **Revista Brasileira de Agrometeorologia**, Santa Maria, v. 10, n. 1, p. 153-162, 2002.

DOURADO NETO, D.; GARCIA, A. G.; FRANCELLI, A. L.; FRIZZONE J. A.; REICHARDT, K. Balance hídrico ciclico y secuencial: estimación de almacenamiento de agua en el suelo. **Scientia Agrícola**, Piracicaba, v. 56, n. 3, p. 537-546, 1999. DOI: http://dx.doi.org/10.1590/S0103-90161999000300005. Disponível em: https://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-90161999000300005. Acesso em: 24 jun. 2020.

GUBIANI, P. I.; MÜLLER, E. A.; SOMAVILLA, A.; ZWIRTES, A. L.; MULAZZANI, R. P.; MARCHESAN, E. Transpiration reduction factor and soybean yield in low land soil with ridge and chiseling. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 42, p. 1-14, 2018. DOI: http://dx.doi.org/10.1590/18069657rbcs20170282. Disponível em: https://www.scielo.br/pdf/rbcs/v42/0100-0683-rbcs-42-e0170282.pdf. Acesso em: 24 jun. 2020.

KIESLING, T. C. Calculation of the length of the day. **Agronomy Journal**, Madison, v. 74, n. 4, p. 758-759, 1982. DOI: http://dx.doi.org/759.10.2134/agronj1982.00021962007400040036x. Disponível em: https://acsess.onlinelibrary.wiley.com/doi/epdf/10.2134/agronj1982.00021962007400040036x. Acesso em: 24 jun. 2020.

KIST, A.; VIRGENS FILHO, J. S. Análise probabilística da distribuição de dados diários de chuva no estado do Paraná. **Revista Ambiente e Água**, Taubaté, v. 10, n. 1, p. 172-181, 2015. DOI: https://doi.org/10.4136/ambi-agua.1489. Disponível em: https://www.scielo.br/pdf/ambiagua/v10n1/1980-993X-ambiagua-10-01-00172.pdf. Acesso em: 24 jun. 2020.

NIED, A. H.; HELDWEIN, A. B.; ESTEFANEL, V.; SILVA, J. C.; ALBERTO, C. M. Épocas de semeadura do milho com menor risco de ocorrência de deficiência hídrica no município de Santa Maria, RS, Brasil. **Ciência Rural**, Santa Maria, v. 35, n. 5, p. 995-1002, 2005. DOI: http://dx.doi.org/10.1590/S0103-84782005000500003. Disponível em: https://www.scielo.br/pdf/cr/v35n5/a03v35n5.pdf. Acesso em: 24 jun. 2020.

PEREIRA, A. R.; VILLA NOVA, N. A.; SEDIYAMA, G. C. **Evapo(transpi)ração**. Piracicaba: FEALQ, 1997.

RIBEIRO, P. L.; BAMBERG, A. L.; REIS, D. A.; OLIVEIRA, A. C. B. Condições físico-hídricas de Planossolo cultivado com soja em plantio direto. **Pesquisa Agropecuária Brasileira**, Brasília, v. 51, n. 9, p. 1484-1491, 2016. DOI: http: //dx.doi.org/10.1590/s0100-204x2016000900047. Disponível em: https://www.scielo.br/pdf/pab/v51n9/0100-204X-pab-51-09-1484.pdf. Acesso em: 24 jun. 2020.

RODRIGUES, J. A.; SANTOS FILHO, J. dos; CHAVES, L. M. Funções densidade de probabilidade para a estimativa de precipitação mensal. **Semina**: Ciências Exatas e Tecnológicas, Londrina, v. 34, n. 1, p. 03-08, 2013. DOI: http://dx.doi.org/10.5433/1679-0375.2013v34n1p03. Disponível em:

http://www.uel.br/revistas/uel/index.php/semexatas/article/view/10771/13260. Acesso em: 24 jun. 2020.

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, n. 2-3, p. 257-271, 2007. DOI: https://doi.org/10.1016/j.fcr.2006.07.011. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0378429006001560. Acesso em: 24 jun. 2020.

SILVA, J. C.; HELDWEIN, A. B.; MARTINS, F. B.; MAAS, G. F. Simulação para determinação das épocas de semeadura com menor risco de estresse hídrico para o feijão na região central do Rio Grande do Sul. **Irriga**, Botucatu, v. 11, n. 2, p. 188-197, 2006. DOI: https://doi.org/10.15809/irriga.2006v11n2p188-197. Disponível em: http://irriga.fca.unesp.br/index.php/irriga/article/view/3245. Acesso em: 24 jun. 2020.

SILVA, J. C.; HELDWEIN, A. B.; MARTINS, F. B.; TRENTIN, G.; GRIMM, E. L. Análise de distribuição de chuva para Santa Maria, RS. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 11, n. 1, p. 67-72, 2007. DOI: http://dx.doi.org/10.1590/S1415-43662007000100009. Disponível em: https://www.scielo.br/pdf/rbeaa/v11n1/v11n1a09.pdf. Acesso em: 24 jun. 2020.

SILVA, J. C.; HELDWEIN, A. B.; TRENTIN, G.; STRECK, N. A.; MARTINS, F. B. Funções de distribuição de probabilidade decendial e mensal para a deficiência hídrica no solo. **Ciência Rural**, Santa Maria, v. 38, n. 7, p. 1893-1899, 2008. DOI: http://dx.doi.org/10.1590/S0103-84782008000700014. Disponível em: https://www.scielo.br/pdf/cr/v38n7/a14v38n7.pdf. Acesso em: 24 jun. 2020.

SILVA, Í. N.; OLIVEIRA, J. B.; FONTES, L. O.; ARRAES, F. D. D. Distribuição de frequência da chuva para região Centro-Sul do Ceará, Brasil. **Revista Ciência Agronômica**, Fortaleza, v. 44, n. 3, p. 481-487, 2013. DOI: http://dx.doi.org/10.1590/S1806-66902013000300009. Disponível em: https://www.scielo.br/pdf/rca/v44n3/a09v44n3.pdf. Acesso em: 24 jun. 2020.

SINCLAIR, T. R. Water and nitrogen limitations in soybean grain productivity. I. Model development. **Field Crops Research,** Amsterdam, v. 15, n. 2, p. 125-141, 1986. DOI: https://doi.org/10.1016/0378-4290(86)90082-1. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/0378429086900821. Acesso em: 24 jun. 2020.

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,** Berlin, v. 31**,** n. 3, p. 786-790, 1991. DOI: http://dx.doi.org/10.2135/cropsci1991.0011183X003100030049x. Disponível em: https://pubag.nal.usda.gov/catalog/1335980. Acesso em: 24 jun. 2020.

SINCLAIR, T. R.; SALADO-NAVARRO, L. R.; SALAS, G.; PURCELL, L. C. Soybean yields and soil water status in Argentina: Simulation analysis. **Agricultural Systems**, Amsterdam, v. 94, n. 2, p. 471-477, 2007. DOI: https://doi.org/10.1016/j.agsy.2006.11.016. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0308521X06001958. Acesso em: 24 jun. 2020.

TRENTIN, R.; HELDWEIN, A. B.; STRECK, N. A.; TRENTIN, G.; SILVA, J. C. Subperíodos fenológicos e ciclo da soja conforme grupos de maturidade e datas de semeadura. **Pesquisa Agropecuária Brasileira**, Brasília, v. 48, n. 7, p. 703-713, 2013. DOI: http://dx.doi.org/10.1590/S0100-204X2013000700002. Disponível em: https://seer.sct.embrapa.br/index.php/pab/article/view/16151/12254. Acesso em: 24 jun. 2020.

WIJEWARDANA, C.; ALSAJRI, F. A.; IRBY, T.; KRUTZ, J.; GOLDEN, B. Quantifying soil moisture deficit effects on soybean yield and yield component distribution patterns. **Irrigation Science**, New York, v. 36, n. 4-5, p. 241-255, 2018.

WREGE, M. S.; FRITZSONS, E.; SOARES, M. T. S.; PRELA-PÂNTANO, A.; STEINMETZ, S.; CARAMORI, P. H.; RADIN, B.; PANDOLFO, C. Risco de ocorrência de geada na Região Centro-Sul do Brasil. **Revista Brasileira de Climatologia**, Curitiba, v. 22, p. 524-553, 2018. DOI: http://dx.doi.org/10.5380/abclima.v22i0.57306. Disponível em: https://core.ac.uk/download/pdf/229663009.pdf. Acesso em: 24 jun. 2020.