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CROP PRODUCTION

# Risk of water surplus in soybean crop on haplic planosol soil in the Central Depression of Rio Grande do Sul State, Brazil

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**ABSTRACT**: *The aim of this study was to identify soybean sowing dates on which there was low water surplus risk. The crop was raised on a Haplic Planosol soil in the Central Depression of Rio Grande do Sul, Brazil. Soybean development simulations and daily water balances were calculated for different sowing dates from August 1968 to July 2012. Water surplus data was subjected to BoxPlot analyses and Scott-Knott tests at a 5% error probability. Exponential, gamma, lognormal, normal and Weibull functions were tested and the best fits to the data were obtained for both subperiods and total cycle. The highest number of fits for the development cycle and subperiods were obtained using the gamma and weibull functions, respectively. For sowing carried out after November 1, there was a low water surplus risk in the sowing-emergence subperiod. The risk of water surplus during the development cycle decreased with the advance of the sowing date.*
**Key words**: ***Glycine max***, *water balance, numerical analysis, probability distribution function.*

## Risco de excesso hídrico para a cultura da soja em planossolo háplico na Depressão Central do Rio Grande do Sul

**RESUMO**: *O objetivo deste trabalho foi identificar as datas de semeadura com menor risco de ocorrência de excesso hídrico para a cultura da soja, em um Planossolo Háplico na Depressão Central do Rio Grande do Sul. A simulação do desenvolvimento da soja e o balanço hídrico sequencial diário foram realizados para diferentes datas de semeadura em cada ano do período de agosto de 1968 a julho de 2012. Os dados dos dias de excesso hídrico, obtidos para o ciclo da cultura, foram submetidos à análise BoxPlot e teste de Scott-Knott a 5% de probabilidade de erro. Foram testadas as funções exponencial, gama, lognormal, normal e weibull, verificando-se a de melhor ajuste aos dados obtidos para os subperíodos e ciclo total. O maior número de ajustes para o ciclo de desenvolvimento e para os subperíodos foram obtidos para as funções gama e weibull, respectivamente. As semeaduras, realizadas após o dia primeiro de novembro, apresentam menor risco de ocorrência de excesso hídrico no subperíodo semeadura-emergência. O risco de ocorrência de excesso hídrico para o ciclo de desenvolvimento é decrescente, conforme o avanço da data de semeadura.*
**Palavras-chave**: ***Glycine max***, *balanço hídrico, análise numérica, função de distribuição de probabilidade.*

## INTRODUCTION

In the State of Rio Grande do Sul, the cultivation of soybean crops on fields designated for rice cultivation has increased in recent years because of economic feasibility, intercropping, and red rice crop control. The 2014/2015 soybean crop covered approximately 300,000ha (IRGA, 2016). The Central Depression of the State of RS has mainly Haplic Planosol soil, which is hydromorphic due to a reduced infiltration capacity and high compaction rates (SARTORI et al., 2016). It has frequent water surplus periods when rainfall occurs (LINKEMER et al., 1998).

The harmful effects of water surplus are severe during some developmental stages and depend on the total number of days in which the plants are subjected to water surplus. Water surplus inhibits germination by causing rapid seed imbibition, embryonic cell membrane rupture, reduction of aerobic respiration, and production of toxic substances (WUEBKER et al., 2001; TIAN et al., 2005; KIRKPATRICK et al., 2006).

During the vegetative phase, the greatest losses due to water surplus occur at early development stages, when water surplus causes reductions in plant stand (LINKEMER et al., 1998; KIRKPATRICK et al., 2006) and in nitrogen fixation (BACANAMWO & PURCELL, 1999). Water surplus between flowering and early grain filling reduces the number of pods per plant, seeds per pod, and grain productivity (GRIFFIN

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& SAXTON, 1988; SCHÖFFEL et al., 2001; RHINE et al., 2010). Therefore, crops should be sown on dates with a low water surplus risk.

Crop development models associated with water balance and the numerical risk have been used (SILVA et al., 2008; LUCAS et al., 2015). Nevertheless, as yet, no studies have shown water surplus event risks for different soybean developmental stages. Agricultural zoning does not factor in this variable when planning sowing calendars (BRASIL, 2015). The identification of the relative risk of water surplus in different soybean sowing seasons and critical subperiods is extremely important, particularly in areas traditionally cultivated with irrigated rice and pasture (grasses, forbs).

The objective of this study was to identify the dates at which there was the lowest risk of water surplus to three critical developmental stages and the total cycle of soybean cultivated on Haplic Planosol soils in the Central Depression of the State of Rio Grande do Sul.

## MATERIALS AND METHODS

Daily data for air relative humidity and temperature (9:00$^{AM}$, 3:00$^{PM}$, and 9:00$^{PM}$), maximum and minimum air temperature, insulation, wind speed, precipitation, and evaporation data (using a Piché evaporimeter [EvP]) were obtained from the main climatological station of Santa Maria, Brazil (ECPSM). Data archives from August 1968 to July 2012 were used. According to the Köppen classification, the regional climate is Cfa type, characterized as humid and subtropical, with warm summers and an undefined dry season (HELDWEIN et al., 2009).

Plant development was simulated according to TRENTIN et al. (2013) using only cultivars with a determined growth habit. Varieties were grouped by cycle based on their relative maturity group (RMG). For RMG 7.4-8.0, the sowing dates (SD) of the 1$^{st}$, 11$^{th}$, and 21$^{st}$ days of October, November, and December were selected. For RMG 5.9-6.8 and 6.9-7.3, SD between October 11 and December 21, and between October 21 and December 21 were chosen, respectively. For each year, cycle and subperiod were obtained the sowing dates (SD), emergence (EM), first trifoliate leaf (V2), flowering initiation (R1), grain filling initiation (R5), maturation initiation (R7), and full maturity (R8).

Daily sequential water balance (DSB) was determined according to methods proposed by THORNTHWAITE & MATHER (1955). The calculation script was similar to the one used by SILVA et al. (2008) and LUCAS et al. (2015). Reference evapotranspiration (ETo) estimation was performed using the Penman-Monteith method, in accordance to ALLEN et al. (1998). ETo was included in the calculation of crop evapotranspiration using the crop coefficients (Kc) recommended by the FAO for soybean cultivation (ALLEN et al., 1998). During the subperiod V2-R1, Kc varied in response to the relative development rate. During the subperiod R5-R7, Kc varied in response to the thermal time (TRENTIN et al., 2013).

The available water capacity (AWC) was calculated based on the root depth throughout the cycle in a Haplic Planosol soil, which belongs to the Vacacaí, Brazil mapping unit. An initial AWC of 23mm was used until sub-period V2 and the root depth was 0.10m. For the V2-R1 subperiod, a sigmoidal growth curve was used for the root system and depended on the relative development rate (TRENTIN et al., 2013). The final AWC (92mm) was applied after the R1 stage and the root depth was of 0.40m. Soils with frequent water surplus are not expected to accommodate further deepening of the root system (FIETZ & RANGEL, 2008).

Since some of the rainwater is lost mainly to surface runoff, the effective rainfall was calculated, according to LUCAS et al. (2015). Water surplus was analyzed using the number of days under water surplus (that is, soil water content>AWC). Two days were added after the end of rain event to account for the time required to drain the free water in soybean cultivation on Haplic Planosol soil (BORTOLUZZI, 2015).

Data of water surplus days for the crop cycle in each RMG were subjected to BoxPlot exploratory analysis, ANOVA, and mean comparison using the Scott-Knott's test at a 5% error probability level. Distribution and probability analyses were performed for the total number of water surplus days in the S-EM, EM-V2, and R1-R5 subperiods, and for the entire cycle, using the exponential, gamma, lognormal, normal, and Weibull functions of probability distribution. Functions were adjusted and tested using only data from years when water surplus occurred. Chi-square and Kolmogorov-Smirnov adherence tests were performed at a 10% significance level. The highest indicated that chi-square significance function was chosen when adjustments of two or more functions were present.

After function adjustment, the probability values were calculated. The maximum number of days of probable water surplus during the crop cycle was calculated using 25%, 50%, 75%, 90%, and 95% probabilities. For the subperiods, occurrences of at least 2, 4, 8, and 12 d of water surplus were considered. Percentage of years were also calculated wherein water surplus was reported for the different sowing dates for the soybean developmental subperiods.

## RESULTS AND DISCUSSION

Considering the 25 sowing dates of the total crop cycle, the gamma probability distribution function performed best. Water surplus data adjustments were provided for nine sowing dates. There was no function adjustment for the November 1 sowing simulation of RMG 6.9-7.3; and therefore, in this case, the empirical frequency distribution was used.

Among the seventy-five combinations of sowing dates and the subperiods S-EM, EM-V2, and R1-R5, at least one function was significantly adjusted in fifty-five cases. The Weibull function was best adjusted for the subperiod frequency distribution (32.8%), followed by the gamma (22.4%), normal (19.2%), lognormal (16.8%), and exponential (8.8%) functions. The gamma and Weibull functions gave higher adjustments than that by the others for rainfall frequency in Santa Maria, Brazil (SILVA et al., 2007). An elevated dispersion of water surplus days was observed around the median. There was also a significant number of atypical values (Figures 1A, 1C, and 1E), which indicated high interannual variability in meteorological conditions and water surplus. Despite nonsignificant differences, the average number of water surplus days tended to decrease at the start and end of the sowing calendar (Figures 1A, 1C, and 1E).

At the 90% probability level, the estimated number of days with water surplus varied from 35-44 (Figure 1B), 38-48 (Figure 1D), and 42-52 (Figure 1F) for RMG 5.9-6.8, 6.9-7.3, and 7.4-8.0 respectively. As an example, it was observed that in 90% of the cases or agricultural years, the RMG 5.9-6.8 cultivars will encounter a maximum of 44 days of water surplus during their development cycle when they are sown between October 21 and November 11, and 38 days after November 21 (Figure 1B). This analysis can be extrapolated to the remaining probability levels, relative maturity groups, and sowing dates.

For RMG 6.9-7.3 and 7.4-8.0, the early sowing dates had the highest number of days with probable occurrence of water surplus, mainly because of longer cycle duration (TRENTIN et al., 2013) and lower evapotranspiration rates in October (HELDWEIN et al., 2009). Probabilities were 90% and 95% (Figures 1D, 1F).

Whereas water surplus was observed on almost all the sowing dates of the years studied, this was not the case for subperiods, mainly because of their shorter duration. The number of years for which water surplus was reported varied between sowing dates and RMG (Table 1). On average, water surplus occurred in about 73% of the years during the subperiods S-EM and EM-V2. In other words, only in a quarter of the years were there no water surplus issues during these subperiods.

For the R1-R5 subperiod, water surplus damage was highly significant (SCHÖFFEL et al.,

Table 1 - Percentage of years with water surplus reported for subperiods S-EM (sowing–emergence), EM-V2 (emergence - first trifoliate leaf), and R1-R5 (flowering initiation–beginning of grain filling) on Haplic Planosol soil. Three relative maturity groups (RMG) were considered, and the sowing dates (SD) were in the period from October 1 to December 31 and were simulated in each year of the period between 1968 and 2012.

| RMG | SD | --------------------Subperiod----------------- | | |
|---|---|---|---|---|
| | | S-EM | EM-V2 | R1-R5 |
| | Oct 1 | - | - | - |
| | Oct 11 | - | - | - |
| | Oct 21 | 86 | 84 | 41 |
| | Nov 1 | 84 | 75 | 38 |
| | Nov 11 | 65 | 59 | 43 |
| 5.9-6.8 | Nov 21 | 65 | 70 | 36 |
| | Dec 1 | 79 | 72 | 36 |
| | Dec 11 | 72 | 68 | 48 |
| | Dec 21 | 68 | 61 | 41 |
| | Dec 31 | - | - | - |
| | | | | |
| | Oct 1 | - | - | - |
| | Oct 11 | 82 | 84 | 41 |
| | Oct 21 | 86 | 84 | 36 |
| | Nov 1 | 84 | 75 | 38 |
| | Nov 11 | 66 | 61 | 36 |
| 6.9-7.3 | Nov 21 | 66 | 70 | 41 |
| | Dec 1 | 79 | 72 | 50 |
| | Dec 11 | 73 | 68 | 43 |
| | Dec 21 | 68 | 64 | 45 |
| | Dec 31 | - | - | - |
| | | | | |
| | Oct 1 | 82 | 86 | 32 |
| | Oct 11 | 82 | 84 | 34 |
| | Oct 21 | 86 | 84 | 36 |
| | Nov 1 | 84 | 75 | 32 |
| 7.4-8.0 | Nov 11 | 66 | 64 | 32 |
| | Nov 21 | 66 | 70 | 41 |
| | Dec 1 | 79 | 73 | 36 |
| | Dec 11 | 73 | 73 | 43 |
| | Dec 21 | 68 | 66 | 48 |
| | Dec 31 | 68 | 73 | 59 |

(-) Sowing dates not recommended on the basis of technical indications for soybean cultivation in the states of Rio Grande do Sul and Santa Catarina.

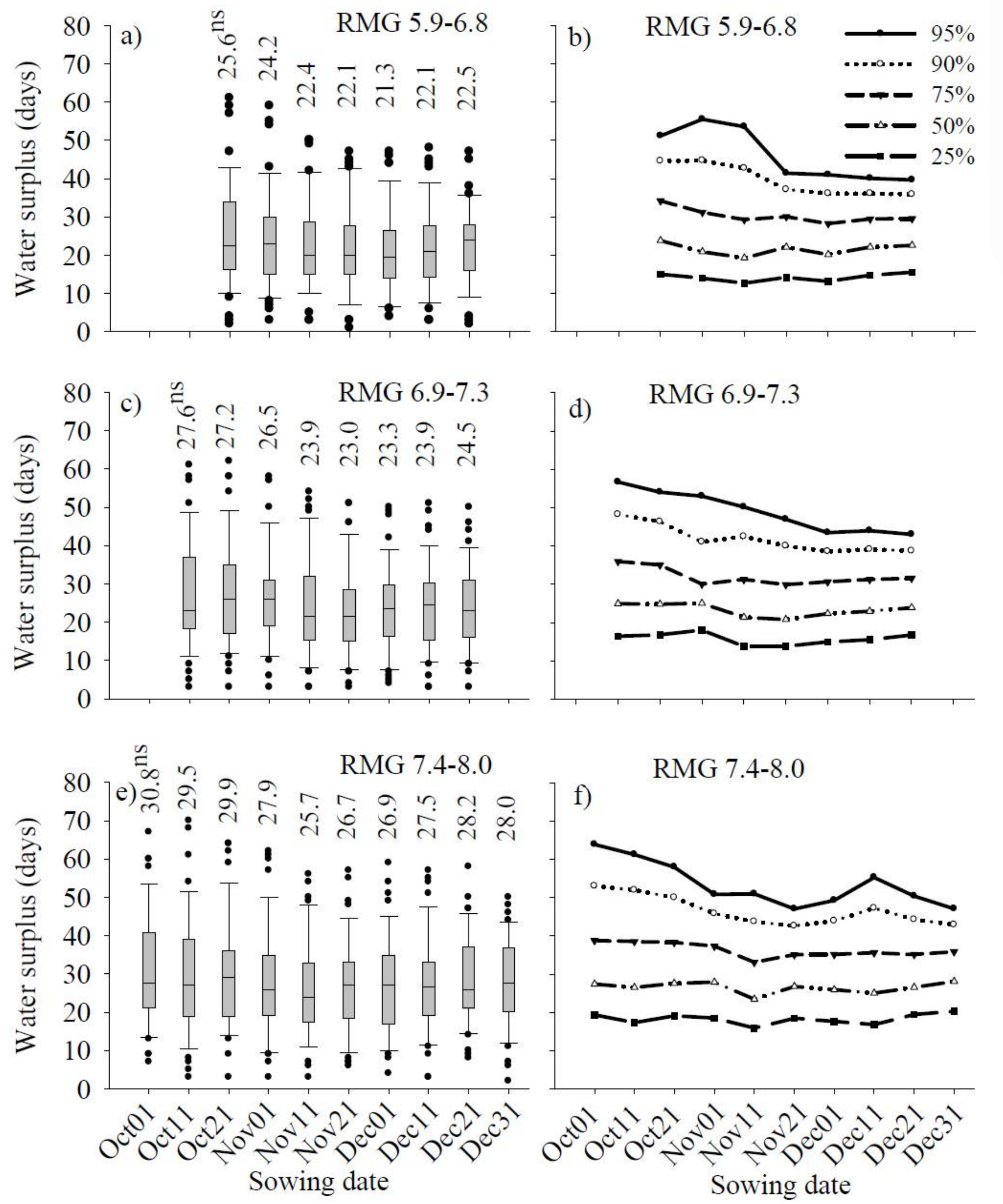


Figure 1 - Occurrence and average number of days of water surplus (A, C, E), and maximum number of days of water surplus during the soybean crop development cycle (B, D, F) in the relative maturity groups (RMG) 5.9-6.8, 6.9-7.3, and 7.4-8.0 on Haplic Planosol soil for the simulated sowing dates of October 1 and December 31 in each period from 1968-2012. ns, Non-significant.

2001; RHINE et al., 2010), yet water surplus occurred in only 38% of the years during that subperiod (Table 1). This is explained by the higher daily water requirement by the plants during this phase (ALLEN et al., 1998), which, for most sowing dates, coincides with the period of highest atmospheric demand,

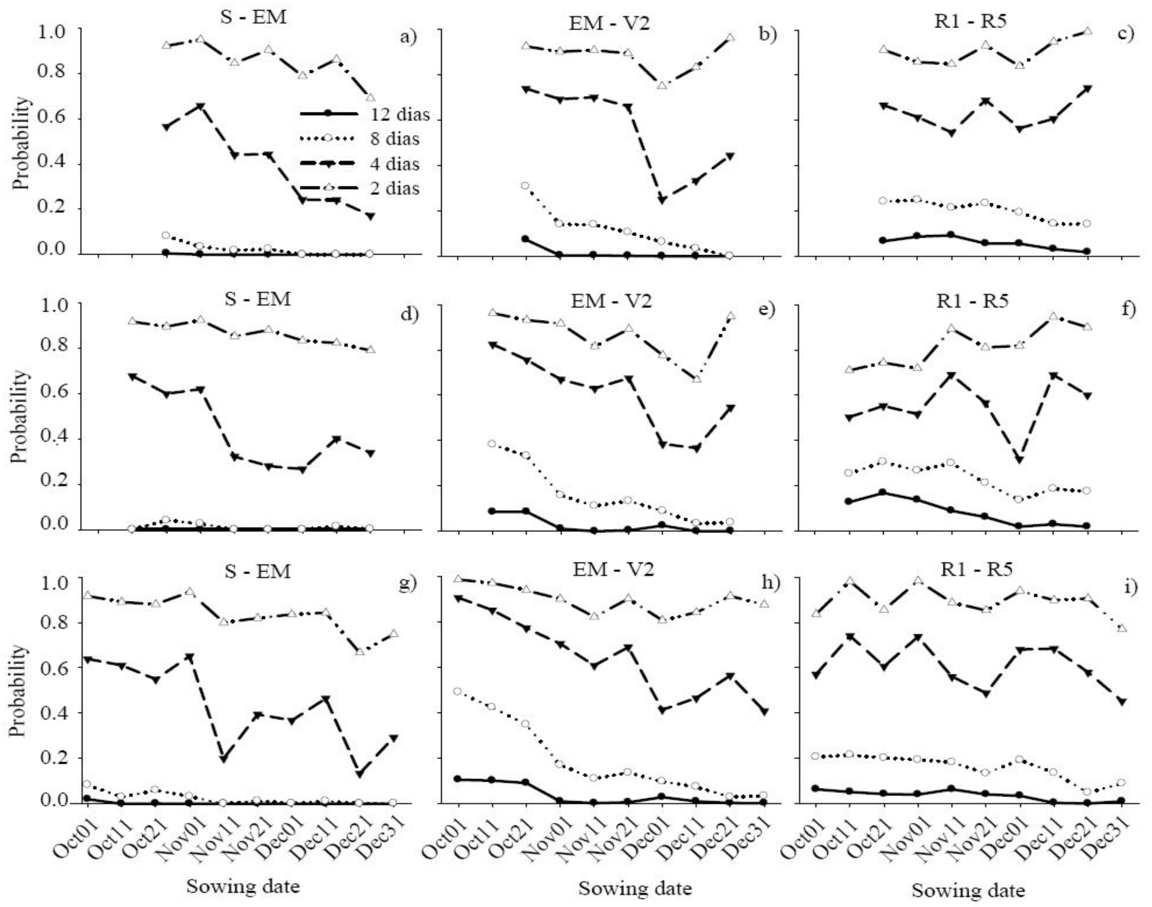


Figure 2 - Probability of occurrence of a water surplus for at least 2, 4, 8, and 12 days, accumulated during the S-EM (sowing–emergence), EM-V2 (emergence–first trifoliate leaf), and R1-R5 (flowering initiation–grain filling initiation) subperiods of soybean plants development for relative maturity groups (RMG) 5.9-6.8 (A, B, C), 6.9-7.3 (D, E, F), and 7.4-8.0 (G, H, I) on Haplic Planosol soil on ten simulated sowing dates between 1968 and 2012.

namely, the months between December and February (HELDWEIN et al., 2009).

For all RMG and sowing dates in the S-EM period, the probability of two or more water surplus days is >0.6%. This value was obtained by the adjusted functions (Figures 2A, 2D, and 2G). For the soybean sowing dates up to and including November 1, at least four water surplus days occurred in greater than half of the trial years. This level of water surplus is detrimental to seed germination (WUEBKER et al., 2001). Because of the short duration of this subperiod, the probability of greater than eight water surplus days is very low (TRENTIN et al., 2013).

For the EM-V2 subperiod, the risk of water surplus decreased from the first to the last sowing dates (Figures 2B, 2E, and 2H). Stress during the plant's initial development stages might impede normal, healthy root system development in soybean plants as well as root nodulation, which results from symbiosis between the host plant and ***Bradyrhizobium*** spp. bacteria. These bacteria have an elevated oxygen demand, and nitrogen fixation is reduced in hypoxic conditions (BACANAMWO & PURCELL, 1999), which in turn lowers crop productivity (BOARD, 2008).

There was a probability >0.5 that at least four water surplus days occurred for RMG 5.9-6.8 during the R1-R5 subperiod on all sowing dates (Figure 2C). This condition poses a significant risk (GRIFFIN & SAXTON, 1988). Starting from the December 11 SD, the risk of water surplus increased during the R1-R5 subperiod despite the decreased duration of this subperiod as the sowing calendar approached month end (TRENTIN et al., 2013). The SD with the lowest water surplus risk during this subperiod were November 11 and December 1.

For RMG 6.9-7.3 (Figure 2F) and RMG 7.4-8.0 (Figure 2I), the water surplus probabilities in the R1-R5 subperiod varied much between sowing dates. It was; therefore, impossible to determine sowing dates or RMG with clearly lower water surplus risks. Nevertheless, the SD of December 1 and November 21 had slightly lower water surplus risks for RMG 6.9-7.3 and RMG 7.4-8.0, respectively.

## CONCLUSION

In Haplic Planosol soils from the Central Depression of the State of RS, water surplus occurred in about 75% of the years during the S-EM and EM-V2 subperiod, and in about 40% of the years during the R1-R5 subperiod.

The risk of water surplus throughout the crop cycle of soybeans raised on Haplic Planosol soil in the Central Depression of the State of RS, which decreased from the beginning to the end of the sowing calendar.

The risk of water surplus during the subperiod between soybean sowing and emergence on Haplic Planosol soil in the Central Depression of the State of RS was lowest for sowings after November 1.

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