

## DEFICIÊNCIA HÍDRICA VIA BALANÇO HÍDRICO EM DIFERENTES ÉPOCAS DE CULTIVO DA SOJA NA REGIÃO DE UBERLÂNDIA-MG

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### 1 RESUMO

Para que uma cultura alcance a sua capacidade máxima produtiva é necessária disponibilidade hídrica na zona radicular. Assim, o déficit hídrico é um dos fatores que mais limita o potencial desenvolvimento de uma lavoura. Nesse contexto, objetivou-se com esse estudo determinar a melhor época de cultivo da soja na região de Uberlândia-MG, levando em consideração uma série histórica de 40 anos (1980 a 2020) dados climáticos, através da análise dos déficits hídricos via balanço hídrico sequencial diário. Para os 40 anos agrícolas estudados calculou-se os balanços hídricos sequenciais diários, levando em consideração quatro diferentes datas de cultivo: 01 de novembro, 15 de novembro, 01 de dezembro e 15 de dezembro. Para cada data de cultivo analisaram-se os déficits hídricos ao longo de todo o ciclo da cultura, e em subperíodos fenológicos (S-V1/V2; V2-R1; R1-R5/R7; R7-R8). Para todas as datas de semeadura observaram-se deficiência hídrica em quase todos os subperíodos fenológicos da soja. Para a região de Uberlândia-MG as datas de plantio entre os dias 15 de novembro a 01 de dezembro apresentaram os menores déficits hídricos nas duas fases/subperíodos iniciais.

**Keywords:** balanço hídrico, evapotranspiração, demanda hídrica.

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**WATER DEFICIENCY VIA WATER BALANCE IN DIFFERENT SOYBEAN GROWING TIMES IN THE UBERLÂNDIA-MG REGION**

### 2 ABSTRACT

For a crop to reach its maximum productive capacity, water availability in the root zone is necessary. Thus, water deficit is a factor that most limits the potential development of a crop. In this context, this study aimed to determine the best time for soybean cultivation in the region of Uberlândia-MG, considering a historical series of 40 years (1980 to 2020) climatic data,

through the analysis of water deficits via water balance daily sequential. For the 40 agricultural years studied, the daily sequential water balances were calculated, considering four different cropping dates: November 1st, November 15th, December 1st, and December 15th. For each cultivation date, water deficits were analyzed throughout the crop cycle, and in phenological sub-periods (S-V1/V2; V2-R1; R1-R5/R7; R7-R8). For all sowing dates, water deficit was observed in almost all soybean phenological sub-periods. For the region of Uberlândia-MG, the planting dates between November 15th and December 1st showed the lowest water deficits in the two initial phases/sub-periods.

**Keywords:** water balance, evapotranspiration, water demand.

### 3 INTRODUCTION

Brazil is one of the most important soybean-producing countries worldwide, along with the United States and Argentina (SENTELHAS et al., 2015). With a production of approximately 117 million tons in the 2017/18 agricultural year (CONAB, 2019) and with an estimated increase of 9 million tons for the 2019/20 harvest, Brazil surpassed the United States to become the world's largest soybean producer (USDA, 2020). Among these regions, the Cerrado region is responsible for approximately 65% of total production (CONAB, 2019).

Climate is one of the most limiting factors for crop development, directly influencing productivity. Water deficit, for example, is considered one of the most limiting factors for soybean quality and productivity (GALÃO et al., 2014). Therefore, understanding a crop's water needs and replenishing evapotranspired water throughout its cycle are essential for successful crop production. With respect to water needs, soybean crops require approximately 450 to 800 mm of water, which is evenly distributed throughout the cycle (CARVALHO et al., 2013).

With respect to vegetative development, water requirements tend to increase, reaching the maximum amount during the flowering and grain-filling periods, requiring up to 7.4 mm day<sup>-1</sup> (GAVA et al., 2015). After this peak, the

values decrease until final maturation. Therefore, for nonirrigated crops, successful productivity depends on well-distributed rainfall throughout the production cycle, especially during critical periods of greatest evapotranspirometric demand (PARDO et al., 2015).

Water deficit is characterized by a potential evapotranspirometric demand greater than soil water availability. Depending on the level of this stress and the plant's physiological stage, different processes can be affected (TAVARES et al., 2013), leading to an irreversible reduction in productivity. In soybean, the most sensitive periods in relation to water availability are germination/emergence and flowering/grain filling (NEUMAIER et al., 2020).

During the germination/emergence period, both lack and excess water affect soybean establishment and plant population uniformity. During the reproductive period, a lack of water can cause stomatal closure and leaf curling, resulting in premature leaf, flower, and pod drop (EMBRAPA, 2013).

Sowing time is also a factor of utmost importance, as it affects yield, architecture, and plant behavior and is directly related to photoperiod, temperature and water availability (FRIGERI et al., 2019). In this sense, studies have been carried out to determine the best planting times for soybean crops, such as Silva et al. (2018) and Carmo et al. (2018).

Arantes et al. (2010), when studying soybean cultivation in the central region of

Brazil, with an emphasis on the Triângulo Mineiro region, reported that the ideal period ranges from the second week of October to the second week of December. More specifically, for the Uberlândia-MG region, Amorim et al. (2011), who studied seven soybean cultivars in the field during the 2001/02 harvest, determined that the best growing season was between November 15 and December 14. However, this study does not consider rainfall variability over time, which can influence the best growing season.

In this context, the objective of this study was to determine the best time for planting soybeans in the Uberlândia-MG region, taking into account a historical series of 40 years of climate data, through the analysis of water deficits via daily sequential water balance.

#### 4 MATERIALS AND METHODS

The work was developed on the basis of a series of meteorological data from the municipality of Uberlândia, Minas Gerais. The database consisted of a 40-year historical series (from January 1980--May 2020) obtained from a meteorological station belonging to the National Institute of

Meteorology (INMET), with geographic coordinates of 18° 55'S, 48° 15'W and an average altitude of 869 m. The climate of the Uberlândia region, according to the Köppen classification, is type Aw (tropical climate with higher rainfall in summer than in winter).

The daily meteorological variables used were precipitation; maximum, average and minimum air temperatures; average relative humidity; and wind speed and global radiation.

The sequential daily climatological water balance and water deficit of soybeans under the soil and climate conditions of Uberlândia, Minas Gerais, were performed via the methodology of Thornthwaite and Mather (1955). For the purposes of water balance, a soybean variety with an average cycle of 120 days was considered. The calculations and graphs were developed in Microsoft Excel® spreadsheets.

Crop evapotranspiration was calculated by multiplying the reference evapotranspiration (mm day<sup>-1</sup>) by the crop coefficient (Kc) for each phenological phase. From the daily meteorological data, the reference potential evapotranspiration, ETo, was calculated via the Penman-Monteith equation (Equation (1)) (ALLEN et al., 1998):

$$ETo = \frac{0,408 \Delta (Rn - G) + \gamma \frac{900}{T_{med} + 273} v^2 (es - ea)}{\Delta + \gamma (1 + 0,34 v^2)} \quad (1)$$

where:

ETo - reference evapotranspiration, mm day<sup>-1</sup>;

Rn - total net radiation of the lawn, MJ m<sup>-2</sup> day;

G - soil heat flux density, MJ m<sup>-2</sup> day<sup>-1</sup>;

Tmed - average daily air temperature, °C;

v 2 - average daily wind speed at 2 m height, ms<sup>-1</sup>;

es - vapor saturation pressure, kPa;

ea - partial vapor pressure, kPa;

Δ - slope of the vapor pressure curve, kPa C<sup>-1</sup>;

γ - psychrometric coefficient, kPa C<sup>-1</sup>.

Soybean water deficiency was simulated for four different sowing dates in the municipality of Uberlândia-MG, namely, November 1, November 15, December 1, and December 15. These dates were selected because they represent the period when soybean is usually sown in the region (AMORIM et al., 2011). To represent the

variation in the phenological phases of the crop, four subperiods were generated, considering the variation in  $K_c$  and the

effective depth of the soybean root system (Table 1).

**Table 1.** Representation of the duration of the phenological stages of a soybean cultivar with a 120-day cycle with their respective cultivation coefficients ( $K_c$ ) and effective depths of the root system.

Subperiod	Duration (days)	Crop coefficient ( $K_c$ )	Depth (cm)
S-V1/V2	15	0.56	15
V2-R1	35	1.21	30
R1-R5/R7	40	1.50	40
R7-R8	30	0.9	40

**Source:** Adapted from FARIAS et al. (2001) and FIETZ and URCHEI (2002). S - sowing; V2 - second node; R1 - beginning of flowering; R5 - beginning of grain filling; R7 - beginning of physiological maturation; and R8 - full maturation.

The values of the cultivation coefficients ( $K_c$ ) used were recommended by Farias et al. (2001), whose periods were adapted to the phenological stages proposed by Costa (1996). The effective depth for each stage throughout its development was determined by Fietz and Urchei (2002) (Table 1). The total water deficit of soybean in each subperiod was determined via the water balance, which consisted of the sum of the daily differences between the reference potential evapotranspiration ( $E_{To}$ ) and the actual evapotranspiration of the crop ( $E_{Tr}$ ).

To determine the soil water storage capacity (SSC), the physical attributes of a Dystrophic Red Latosol present on the Uberlândia campus of the Instituto Federal do Triângulo Mineiro (IFTM) were considered. This soil type is representative because it is the most abundant in the region (EMBRAPA, 2018).

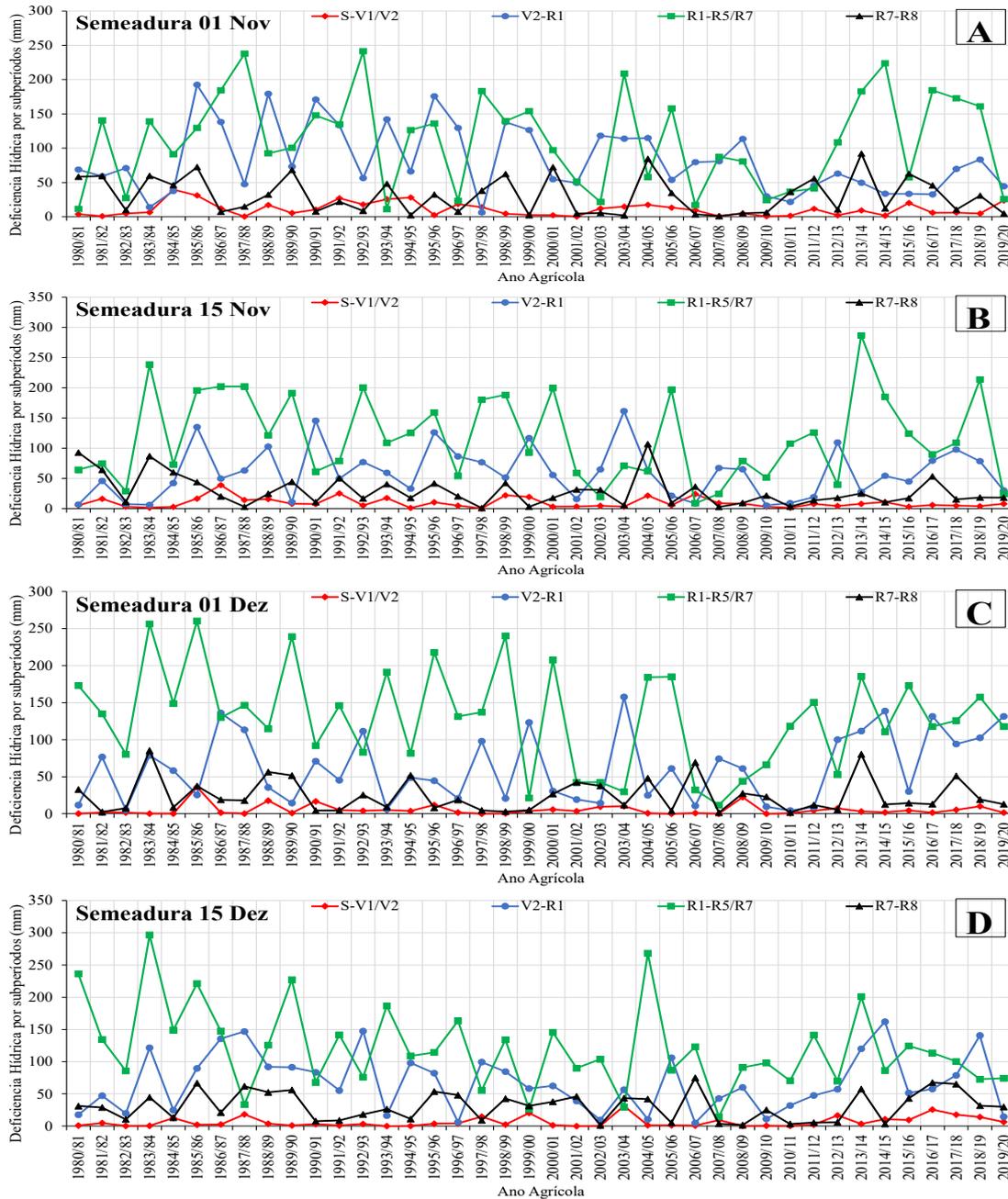
To begin the water balance, the soil was considered at field capacity. The soil moisture values based on volume at field capacity (stress 33 kPa) and at the permanent wilting point (stress 1500 kPa) were 39.6% and 29.1%, respectively, and the soil density was 1.15 g cm<sup>-3</sup>. Both analyses were performed in the soil laboratory of the IFTM-Uberlândia Campus.

Water deficit data were subjected to analysis of variance (ANOVA) via a randomized block design, with treatments consisting of sowing periods and replicates/blocks across the 40 agricultural years studied. The means were compared via Tukey's test at the 0.05 probability level via SISVAR® software (FERREIRA, 2019).

## 5 RESULTS AND DISCUSSION

Figure 1 shows the simulated water deficit values for the soybean crop over 40 agricultural years at different sowing dates and phenological stages (subperiods). According to the sequential daily water balance simulations of the crop, throughout the 40 agricultural years studied, there was a water deficit in most subperiods/stages (Figure 1). However, as shown in Figure 1, in all phenological stages of the plants, there were years without water deficit, mainly between S-V1/V2 and R7-R8. Examples of harvests without water deficit for S-V1/V2 can be observed in the 2005/06 harvest, when sowing occurred on December 1st (Figure 1 C), and in the 1993/94 harvest (Figure 1 B), when sowing occurred on December 15th.

**Figure 1.** Water deficiency (mm) for soybean crops at different phenological stages and different sowing dates, namely, November 1 (A), November 15 (B), December 1 (C) and December 15 (D), in the municipality of Uberlândia, MG, during 40 agricultural years.



Source: Authors

Fietz and Urchei (2002) obtained similar results in simulations of the soil water balance via Dourados-MS. These authors reported water deficiency in all phases (subperiods) and planting seasons studied (November 15 and December 15). Thus, water deficit can cause changes in

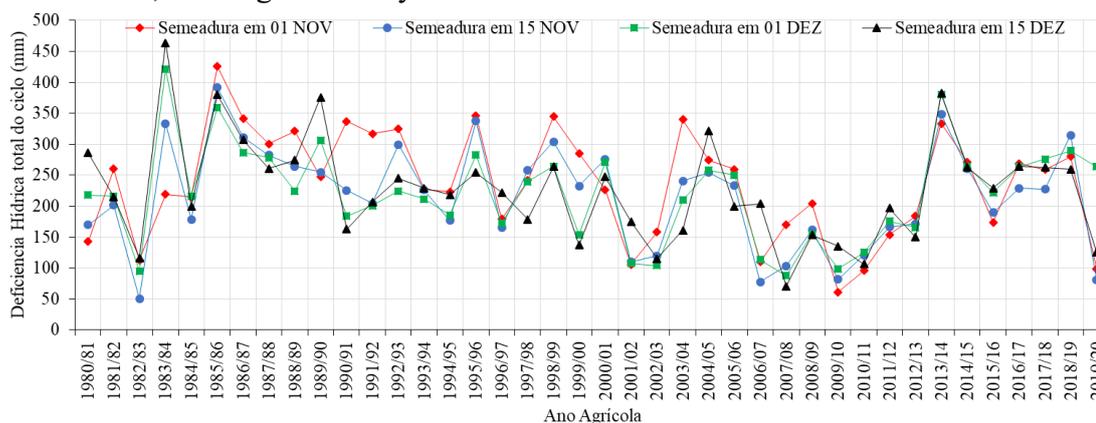
soybean leaves, directly influencing the reduction in the photosynthetic rate, stomatal conductance and plant transpiration (ZHANG et al., 2016).

Considering the sowing simulation on November 1st, the total water deficit of the soybean cycle ranged from 61.1 mm

(2009/10 harvest) to 425.6 mm (1985/86 harvest), with an average of 236.1 mm (Figure 2). The greatest water deficit occurred between V2 and R1 (Figure 1A), at approximately 200 mm. Notably, between R1 and R5/R7, the water deficit was lower than that between V2 and R1. This behavior

was also observed by Souza et al. (2016) in an experiment carried out in the 2007/08 harvest in the municipality of Paragominas-PA, in which the maximum evapotranspiration of the crop comprised the same period mentioned above, concentrating mainly in the grain-filling phase (R5).

**Figure 2.** Total water deficiency (mm) for soybean crops on different sowing dates: November 1; November 15; December 1; and December 15, in the municipality of Uberlândia, MG, in 40 agricultural years.



Source: Authors

For sowing on November 15th, the total water deficiency of the cycle ranged from 50.8 mm (1982/83 harvest) to 391.4 mm (1985/86 harvest), with an average of 215.9 mm (Figure 2). In most agricultural years, the subperiods with maximum water deficiency indices correspond to subperiods R1 to R5/R7, beginning of flowering, passing through grain filling and extending to the beginning of maturation, and the vegetative phase, from the second node to the beginning of flowering (V2 to R1) (Figure 2). This behavior can be explained by the phenological stages occurring between the end of November and the beginning of February, months with high evapotranspiration demands in the municipality (average monthly ETo ranging from 187 to 133 mm/month in November and February, respectively). According to Figure 1, only in three harvests (1980/81, 2004/05 and 2006/07) did the maximum deficits occur in subperiods R7--R8.

The analysis of total water deficiencies for sowings carried out in December revealed that when sowings were sown on December 1st, water deficits varied from 87.7 mm (2007/08 harvest) to 420.7 mm (1983/84), with an average of 220.6 mm (Figure 2). For the sowings on December 15th, the water deficiency varied from 70.5 mm (2007/08) to 463.5 mm (1983/84), with an average of 225.5 mm (Figure 2). The behavior was the same as that observed in the sowings in November, with the maximum deficit values concentrated in subperiods R1 to R5/R7 and V2 to R1, with higher values in the first.

However, in December 2005–06 and 2009–10 harvests for planting on the first day of the month and in the 1993–94 harvest sown on the fifteenth day, no water deficits were observed in the first subperiod of the crop cycle. The sowing time results in differences in most of the agronomic characteristics of the crop, with a decrease in plant height and the number of days to

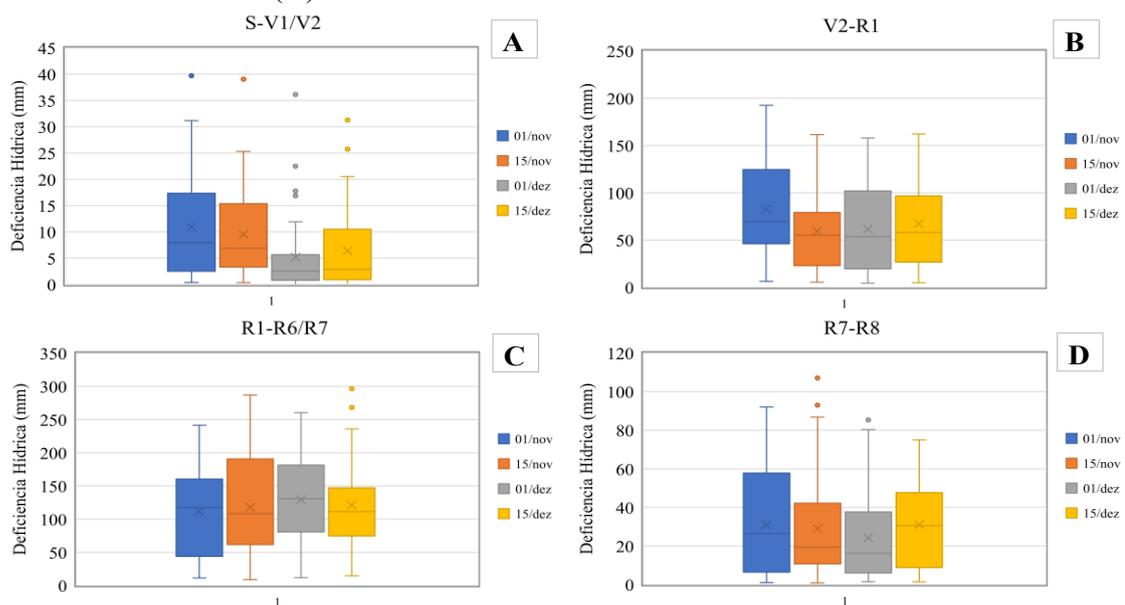
flowering, as sowing is delayed (AMORIM et al., 2011).

As mentioned, under all conditions, relatively high water deficit values were observed in the reproductive phase (R1 to R5/R7). According to Embrapa (2013) and Farias et al. (2007), this behavior is explained by the increase in water demand due to crop development, which reaches the highest values during flowering and grain filling and can consume between 7 and 8 mm day<sup>-1</sup>. After this period, the water demand tends to decrease, as observed under all the conditions analyzed. Suyker and Verma (2008) also reported peaks in the maximum evapotranspiration and leaf area index (LAI)

of soybean in the reproductive phase. The same behavior was reported by Zanon et al. (2015), who observed higher peaks between R1 and R5.

The sowing date with the highest risk of water deficiency or water stress for subperiods S to V1/V2 for soybean crops in the Uberlândia region was November 1st, with the highest deficiency values, the highest median, and the greatest dispersion of annual data (Figure 3A). For this phase or subperiod, the second largest dispersion and median were observed for crops on November 15th, and the third largest dispersion and median were observed for crops on December 15th.

**Figure 3.** Boxplot of the variability in water deficiency (mm) for soybean crops on different sowing dates (November 1; November 15; December 1 and December 15) and different development subperiods: S to V1--V2 (A); V2 to R1 (B); R1 to R5/R7 (C); and R7 to R8 (D).



Source: Authors

In the initial phase of the crop, both lack and excess water are considered a problem, with the former being more detrimental to the crop, affecting both soybean establishment and plant population uniformity (FARIAS et al., 2009). Therefore, considering this initial phase of the crop for the studied region, planting on December 1st is more advantageous because

of the lower water scarcity over the 40 years studied (Table 2). When the average water deficit values were statistically compared, lower water deficit values were observed on December 1st than on November 1st, which contributed to improving the initial development of the crop (Table 2 and Figure 3A).

**Table 2.** Average water deficit (mm) of soybeans according to their phenological phases and different sowing periods for the Uberlândia-MG region.

Sowing	Phenological stages of soybeans				Total
	S-V1/V2	V2-R1	R1-R6/R7	R7-R8	
01/Nov	10.93 a	82.84 a	111.31 a	31.01 a	236.09 a
15/Nov	9.55 ab	59.33 b	118.03 a	29.02 a	215.94 a
December 1st	5.21 b	61,61 ab	129.53 a	24.20 a	220.56 a
December 15th	6.40 ab	67.14 ab	120.95 a	30.98 a	225.46 a

Deficit values are in mm. The mean values followed by the same letter in the same column do not differ significantly according to the Tukey test ( $p < 0.05$ ).

When the second subperiod (V2 to R1) was analyzed, the most advantageous cultivation dates were 15/Nov and 01/Dec (Table 2) because they presented the lowest medians, with 55 and 53.5 mm of water deficit, respectively, and lower values in the 25% percentile (Figure 3B). In this subperiod, the lack of water reduces the number and size of pods and seeds due to the shortening of the stages (KRISHNAN et al., 2014). Furthermore, for the date of 15 November, there were lower values of water deficit and a smaller amplitude of the interquartile range in the boxplot (Figure 3B). Statistically, the sowing date of 15/Nov (lowest average water deficit) differed from the early sowing date of 01/Nov in V2-R1 (Table 2), with the aforementioned sowing date (01/Nov) being responsible for the greatest risk of water stress, with a high data amplitude and a 25% percentile value (46.1 mm) close to the median of the other sowing dates (Figure 3B).

When the third subperiod (R1 to R6/R7), which covers the flowering and grain-filling periods, was analyzed, lower median values of water deficiency were observed for the sowing dates of November 15 and December 15, with values of 108.2 and 111.3 mm, respectively (Figure 3C), although there was no significant difference in the means (Table 2). For this subperiod, the interquartile ranges were reduced as the sowing dates were later, presenting lower values for December 15. Although this is

one of the most critical phases of crop water stress, there were no significant differences in the dispersion of the water deficiency data (Figure 3C). Therefore, it is necessary to observe the behavior in the previous subperiods.

In the last subperiod (R7 to R8), because it is the grain drying phase, the plant is no longer as sensitive to water stress. Furthermore, it is interesting that harvest occurs during a period of lack of rain (SOUZA et al., 2016). Figure 3D shows that in subperiods R7 to R8, the smallest water deficiencies occurred in crops on the sowing dates of December 1 and November 15, with medians of 16.6 and 19.3 mm, respectively (Figure 3D), although there was no significant difference in the means (Table 2). For these dates, better grain quality is possible; however, there is a greater risk of rain at the time of harvest.

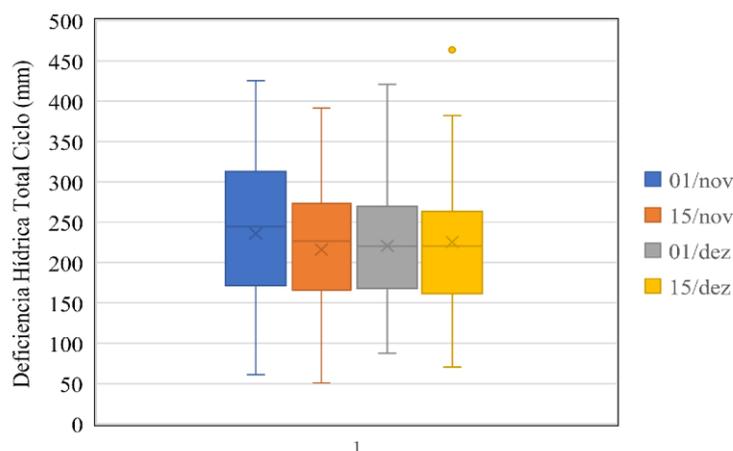
Water deficit during the reproductive period, more specifically during the final flowering phase and pod formation, can lead to flower and pod abortion, in which this lack of water can also trigger a second flowering, which is normally infertile, resulting in leaf retention (MUNDSTOCK and THOMAS, 2005; SILVA; CANTERI; SILVA, 2013). Simeão et al. (2018) reported that water deficit during the flowering and pod-filling phases inhibited the growth of the BRS Sambaíba RR cultivar, contributing to reductions of up to 33.2, 34.7, 41.3, and 13.7% in plant height, number of leaves, leaf

area index, and total dry mass, respectively, compared with those of the control.

An analysis of the data from the four subperiods (Figure 3) and the variability of the total water deficit of the cycle (Figure 4) revealed that the cultivation dates between November 15th and December 1st presented the lowest water deficits in the two initial

phases/subperiods, thus presenting greater potential for cultivation in the Uberlândia region. The very early sowing on November 1st, in addition to greater dispersions of the water deficit data observed in some subperiods (Figure 3), presents a larger interquartile range when the complete crop cycle is considered (Figure 4).

**Figure 4.** Boxplot of variability of total water deficiency of the cycle (mm) for soybean crops on different sowing dates (November 1; November 15; December 1 and December 15) over 40 years in Uberlândia-MG.



Source: Authors

For planting dates after November 15, the median values of total water deficiency are lower than those in earlier planting (November 1), thus generating lower water deficiency in most of the years studied (Figure 4), in absolute values. However, statistically, the averages are the same, as shown in Table 2. Water deficit is considered one of the limiting factors for soybean quality and productivity (GALÃO et al., 2014; TAVARES et al., 2013; FIETZ and URCHEI, 2002).

## 6 CONCLUSION

Water deficits were observed in all the phenological subperiods studied for soybean crops at all the sowing times studied in the Uberlândia region. Therefore, the duration of the water deficit and the phase or subperiod in which it occurs are potentially

the main limiting factors on productivity in nonirrigated soybean crops.

The highest water deficit values found in the initial and reproductive phases of the soybean crop were the main indicators for recommending the best sowing time, taking into account a long series of meteorological data (40 years).

For the Uberlândia-MG region, the planting dates between November 15th and December 1st presented the lowest water deficits in the two initial phases/subperiods.

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