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Water excess and its effect on cassava growth and yield

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ABSTRACT

Flooding periods directly interfere with the availability of oxygen in the soil, affecting the aerobic processes of the plants. In this study, we aimed to: (i) characterize the effects of water excess soil on cassava growth; (ii) identify management practices that reduce the impact of water excess on cassava yield; and (iii) to know the crop potential yield for the study region in order to quantify the yield loss caused by water excess. The effects of water excess were evaluated through experiments in pots and in the field. The physiological and morphological response of cassava plants under water excess in a controllable environment indicated greater damage to cassava after exposure of 96 and 120 hours of water excess. Every 24 hours of water excess, about 20% of the plants did not emerge and, after 96 hours of excess, the emergence was null. The use of raised seedbeds was a management practice that ensured 62.6% of plant establishment, allowing cassava yields of up to 16.9 Mg ha^{-1}. The potential yield to Santa Maria in the 2018/2019 crop year was 43.9 Mg ha^{-1} of cassava roots. The yield gap caused by water excess was up to 4.1 Mg ha^{-1}.

Keywords: raised seedbeds; oxygen; potential; yield gap; *Manihot esculenta* L. Crantz.

INTRODUCTION

Population growth and changes in the world economy force the adaptation of production systems and constant increases in yield to guarantee food security and sovereignty (Grassini *et al.*, 2014). Cassava culture stands out in this scenario for being a low-cost crop, which reduces hunger and rural poverty, contributing to socioeconomic development, having been elected by the United Nations Food and Agriculture Organization as food of the century XXI. (FAO, 2020; Tironi *et al.*, 2019, Tagliapietra *et al.*, 2019). The yields of tuberous roots in Brazil and Rio Grande do Sul are very low 15 and 17 Mg ha^{-1}, respectively (IBGE, 2021), compared to yields found in Colombia and India (75 and 90 Mg ha^{-1}), Africa Oriental (50 and 60 Mg ha^{-1}) and in experiments conducted in research institutions in Brazil (20 and 33 Mg ha^{-1}) (Cock *et al.*, 1979; Obiero, 2004; Ntawuruhunga *et al.*, 2006; Tironi *et al.*, 2015).

Water excess is one of the factors that affect plant growth and development, and long periods of flooding interfere with the availability of oxygen in the soil, may occur in hypoxia (low amount of O_2) or anoxia (absence of O_2) (Taiz, *et al.*, 2017). The most cassava producing regions in southern Brazil present water excess in the soil due to low atmospheric demand and high rainfall during the planting period (August to November). In Rio Grande do Sul, for example, in addition to the high rainfall during the planting period, the cultivation areas are usually in poorly drained soils, such as Hapludalf typic and Albaqualf typic (Streck, *et al.*, 2008; Stefanello *et al.*, 2017) maximizing water excess in cassava plant.

Under water excess conditions, the O_2 flux entering

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the soil is reduced. With the decrease in the intake flux, the remaining O_2 in the soil is quickly depleted by plants and/or microorganisms. The concentration of oxygen in the soil may decrease to zero around 24 hours after the onset of water excess (Drew, 1997; Marschner, 1995; Drew *et al.*, 2000; Liesack *et al.*, 2000). As cassava is a plant not adapted to flooded environments, the lack of O_2 gradually inhibits and it can paralyze cell respiration, which negative affect the glycolysis route and Krebs cycle and reduce yield (Taiz *et al.*, 2017; Tironi *et al.*, 2019). Losses in cassava yield due to waterlogging are frequently associated with challenges such as reduced sprouting of the cassava stakes after planting, the emergence of soil-borne diseases, and occurrences of root rot (Tironi *et al.*, 2019).

Currently, there is a gap in scientific knowledge regarding the period that causes the greatest damage to cassava crops, as well as the identification of management alternatives in areas with water excess. Research conducted with crops in the soybean, maize, and tobacco, by Sartori *et al.* (2015), Faraco *et al.* (2016), and Zaluski & Antonelli (2014), respectively, presents positive results in plant growth and development through the adoption of management practices such as the construction of drainage systems and the use of raised seedbeds to minimize the effects of water excess. Therefore, it is essential to deepen studies and investigations to develop effective water management strategies in cassava cultivation, aiming to increase yield and reduce damage caused by water excess in the soil. In this study, we aimed to: (i) characterize the effects of water excess soil on cassava growth; (ii) identify management practices that reduce the impact of water excess on cassava yield; and (iii) to know the crop potential yield for the study region in order to quantify the yield loss caused by water excess.

MATERIAL AND METHODS

The present study consisted of experiments in pots and in the field carried out in the experimental area of the Department of Phytotechnics of the Federal University of Santa Maria (29°41'S, 53°43'W, altitude 113 m). The region's climate is humid subtropical, type Cfa, according to the Koppen classification (Alvares *et al.*, 2013), with an average temperature above 22 °C in summer, with an average annual precipitation greater than 1600 mm (Facco *et al.*, 2012). Cassava was cultivated in soil classified as Hapludalf typic, which had 18% clay (medium texture), 1.5% organic matter and a water pH of 5.5. In humid conditions, these soils are classified as hydromorphic.

The study in pots was carried out in the agricultural years of 2018/19 and 2019/20 and in the field experiment in 2018/19. The pots used had dimensions of 23.5 cm in diameter at the upper edge, 19 cm at the lower edge, and 22 cm in height, resulting in a total volume of 9 liters. Were filled with characteristic soil of typical Hapludalf, ensuring homogenization and the same soil mass in all pots. The planting was carried out in the second half of September, where the pots were placed on benches with a height of 0.7 m from the surface, in the center of a greenhouse covered with a transparent plastic film with semi-open sides that had dimensions of 9 m in length, 6 m in width and 3 m in height, with East - West orientation. Homogeneous vegetative stakes were selected, with five buds of Vassourinha cultivar as it is the most planted in southern Brazil; the planting depth was 5 cm, planted horizontally. On the day before planting, the pots were irrigated until saturation so that on the day of planting the soil had moisture close to the field capacity.

The study, in pots, had imposition of the water excess in different stages of development. Two studies were evaluated separately: (I) water excess imposed immediately after cassava planting, before plant emergence (8 days after planting), aiming to assess the interference of water excess on the stakes; and (II) water excess imposed at the beginning of development, when the plants had reached nine leaves (38 days after planting), and are no longer dependent on stakes reserves. According to Tironi *et al.* (2019), planting carried out in August and September offers the highest yield potential. However, due to the occurrence of high rainfall during these months, damage can occur to the cuttings and the plants that are initiating their development. In each experiment, six treatments with five replications were applied: Control = zero hours or without application of water excess; T1 = 24 hours of water excess; T2 = 48 hours of water excess; T3 = 72 hours of water excess; T4 = 96 hours of water excess and T5 = 120 hours of water excess. Each vase was considered as an experimental unit (EU), and the treatments were randomly selected and arranged in a completely randomized design.

The conduction of both experiments lasted 69 days after planting. In the EUs before and after the implantation of treatments was carried out through daily irrigations, in order to keep the humidity in the pots close to the field capacity. During the treatment period, a water layer around 5 cm above ground level was maintained to ensure the necessary excess moisture.

The soil in the field study area was classified as Hapludalf typic, hydromorphic and poorly drained, with a sandy surface horizon and alluvial clay accumulation. The planting of the cassava cuttings was carried out in the second half of September of 2018. Tillage soil preparation was carried out, using a rotary tiller to create raised seedbeds with a base of 0.8 m, height of 0.6 m and upper width of 0.4 m. Fertilization was carried out according to the crop demand and soil analysis results and applied straight at the planting hole. The planting density was 15.625 plants ha^{-1} arranged in 0.8 m between rows and 0.8 m between plants. Each experimental plot was composed of six rows or six raised seedbeds, with 10 plants per row or per raised seedbed. The cassava cultivar used was Vassourinha, selecting homogeneous cuttings with 5 buds, at a planting depth of 0.05 m. In the present study, a randomized block design with split plots was employed, with four replications. The qualitative factor under assessment was the treatment of "in" or "out" of raised seedbed, while the quantitative factor considered was the duration of water excess (0, 48, 96, and 144 hours) with water supply initiated 8 days after planting and before emergence. To ensure water excess in the treatments lasting 48, 96, and 144 hours, the surface irrigation method was employed, in which water was applied to the plots through a pumping system until forming a layer on the soil surface. The harvesting took place on May 29, 2019.

The variables measured in the pots study were date of emergence (EM), emergence rate (ER), percentage of establishment (PE), final plant density (FPD), number of leaves (NL), plant height (PH), leaf area (LA), leaf dry mass (LDM), stem dry mass (SDM) and root dry mass (RDM). The variables measured for the analysis in the field study were date of emergence (EM), emergence rate (ER), percentage of establishment (PE), final plant density (FPD), number of leaves (NL), leaf area index (LAI), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM) and root yield (Mg ha^{-1}).

Emergence was evaluated daily until the number of emerged plants stabilized, and the date of emergence was considered when 50% of the total stakes planted in each treatment presented the first visible sprouting above ground. The emergence rate was calculated using the following calculation:

$$ER\ (plant\ day^{-1}) = ({}^{N1}/_{D1}) + ({}^{N2}/_{D2}) + \dots ({}^{Nn}/_{Dn}) \quad (1)$$

In which N1 is the number of plants emerged in the first count; D1 is the number of days after planting for the first count; Nn is the number of plants emerged in the last count; Dn is the number of days after planting for the last count;

To assess the percentage of establishment (PE), the number of plants per treatment which emerged and established with two leaves or more was considered. PE was calculated using the following expression:

$$PE(\%) = \frac{(100 * NPE)}{NSP} \quad (2)$$

In which NPE is the number of established plants (with more than two open leaves) in the treatment; NSP is the total number of stakes planted in the treatment.

The final plant density was determined by subtracting the number of stakes planted in each experimental unit from the total number of plants that did not emerge and establish themselves. The number of leaves count was performed weekly, considering the first leaf from the base to the last open leaf of the apex. The PH was measured using a ruler. It was considered the distance from the ground level to the plant apex, while the LA was performed according to the methodology of Trachta *et al.* (2020):

$$LA = 0.1335x^{2.2376} \quad (3)$$

In which x is the longitudinal length of the central lobe.

The LAI was calculated by dividing the sum of the LA of each plant by the soil area it covered. To obtain LDM, SDM and RDM, the plant of each EU was collected. In the field study, five random plants were collected. The samples were partitioned into roots, stem and leaves, and these materials were dried in an oven at 60 ºC for 20 days (time necessary to reach constant mass). The yield of each treatment in the field study was calculated according to the final density in each treatment. The yield loss, that is, the yield gap (YG) was determined by the difference between the potential yield and the average yield of treatments in the field experiment. The potential yield was simulated by the Simanihot model according to the methodology described by Tironi *et al.* (2017).

$$YG\ (Mg\ ha^{-1}) = YP - YMn \quad (4)$$

In which YG is the yield gap; YP is the potential yield estimated by the model in the 2018/19 crop year; YMn is the average yield of the evaluated treatment.

To assess the effect of water excess on cassava growth and yield, data were subjected to analysis of variance by the F test at 5% probability. For the effect of hours of water excess on growth and development variables, regression analyzes were performed and for the effect of growing cassava "in" or "out" of a raised seedbed, Student's and Tukey's t test was used for comparisons of means in case of statistical significance. The software used for all statistical analyzes was SISVAR version 5.7.

RESULTS AND DISCUSSION

The water excess imposed in the planting phase before emergence caused a delay in emergence and reductions in emergence rate, establishment percentage and final plant density (Figure 1). These results are in agreement with studies carried out on sweet maize (Marinho *et al.*, 2019), soybean (Gazolla-Neto *et al.*, 2012), and beans (Custódio *et al.*, 2009), which observed a delay in the emergence, energy expenditure and non-emerged plants due to imposed water excess. Figure 1a shows that, as the hours of water excess increased, there was a delay in the emergence of cassava plants. In the treatment of 72 hours of water excess, the time required for emergence was 32 days, while in the treatments with 96 hours or longer of water excess were applied, there was not emergence. Under favorable conditions, for Santa Maria, the first shoots emerge within 15 days after planting (Alves, 2006; Tironi *et al.*, 2019).

The rate of loss in emergence was about 20% for each 24 after water excess (Figure 1C). The non-emergence of plants in these treatments occurred due to cell death in the vegetable tissue of the stakes, inhibiting the sprouting and generation of a new plant. This fact can be explained due to the excess of water providing very low oxygen levels in the soil (Sairam *et al.*, 2008; Dias Filho, 2012), may cause the cell death due to the lack of O_2. The lack of O_2 paralyzes and gradually inhibits the aerobic respiration of cells, reducing the production of heat and energy from 36 to 2 ATP (Taiz *et al.*, 2017). This energy decrease, together with the increase of toxic products (ethanol and lactate) generated by fermentative respiration, end up blocking the biochemical work. Fermentative respiration generates cellular acidity due to the production of lactic acid in the cytosol, which acidosis ends up irreversibly disrupting the metabolism in the cytoplasm, and all these aspects that occur due to the lack of O_2 end up resulting in the death of cells (Taiz *et al.*, 2017).

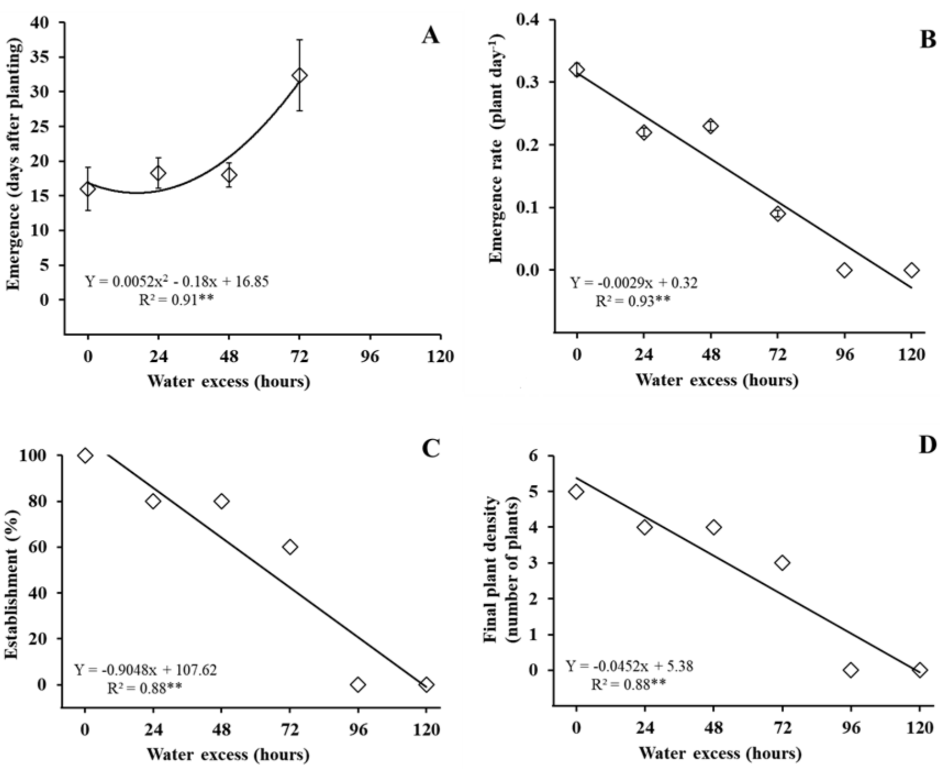

Figure 1: Emergence (A), emergence rate (B) percentage of establishment (C) and final plant density (D) submitted to hours of water excess in the planting phase to pre-emergence in pots. The initial density was five stakes planted in each treatment.

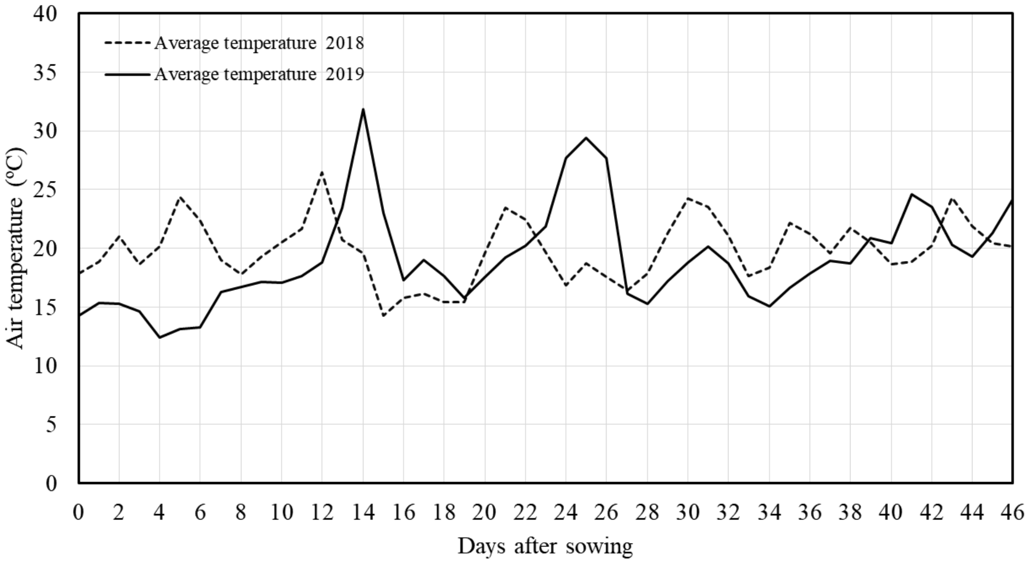

Figure 2: Average air temperature in 2018 and 2019.

Air temperature plays a crucial role in regulating the growth and development of the cassava crop. When analyzing Figure 2, it is noted that, during the treatment period, they remain within the range of cardinal temperatures of the culture, as reported by Matthews & Hunt, 1994. Thus, temperatures close to 14 ºC (base temperature) can affect the rate of growth and development, delaying the emergence and growth of new organs. However, during the treatment period, it was observed that, as we increased the hours of water excess, the temperatures also increased (Figure 2).

After removing water excess in the pre-emergence planting phase, the cassava plants that emerged and established themselves showed normal growth evolution. When performing the analysis of variance, the variables NL, PH, LA, did not show significant difference with the periods of imposed water excess, with the exception of the dry matter of the parts of the plant that presented statistical difference. Although there was no statistical difference, we can observe a tendency of reduction in the values in the NL, PH and LA in the 72 hours period of water excess, being explained by the delay in the emergence of the plants in this treatment (Figure 2). Considering the 48 hours treatment of water excess, there was a trend of NL, PH, LA, LDM, SDM e RDM similar to the treatment without imposition of water excess (Figure 3).

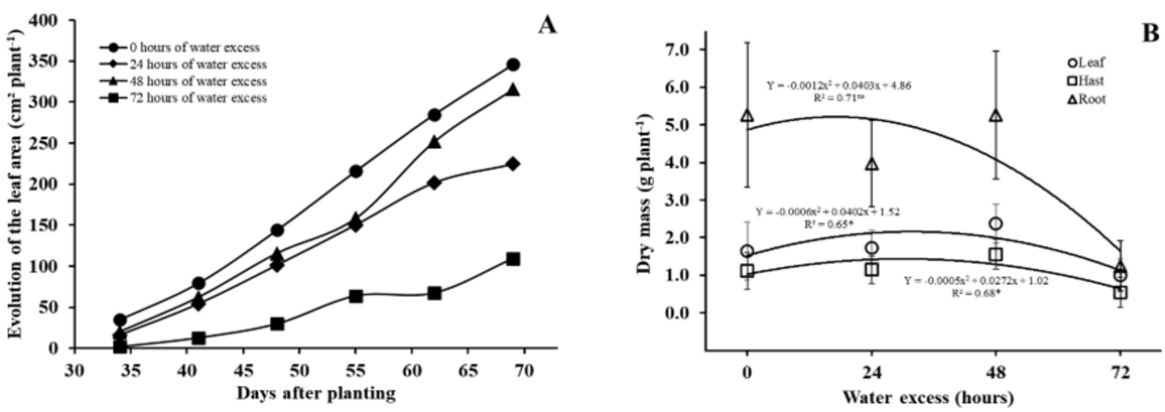

Figure 3: Evolution of the leaf area (A) and regression dry mass of leaf, stem and root (B) at 69 days after planting, submitted to hours of water excess, in the planting phase to the pre-emergence (study in pots). *Significant at 5% probability by the F. ns = not significant.

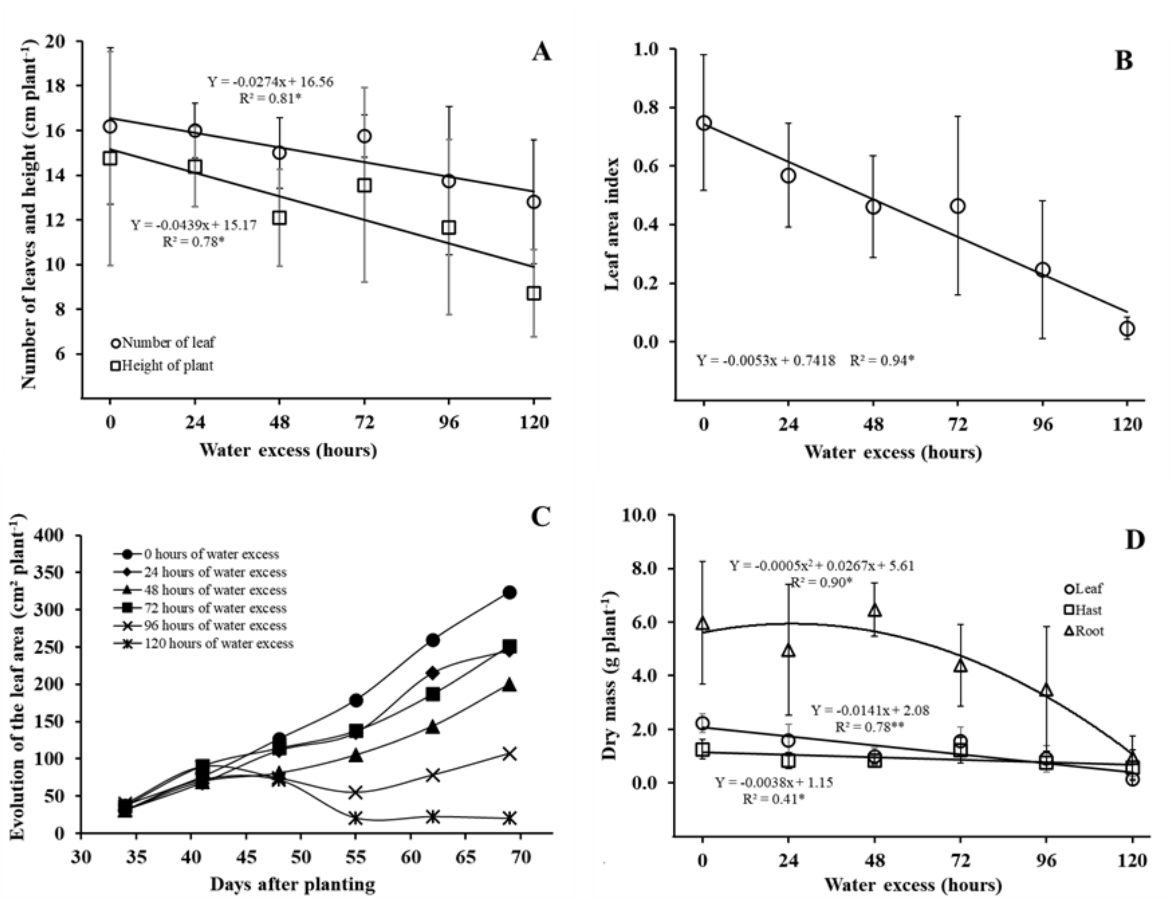

Figure 4: Regression of the number of leaves and plant height (A), leaf area index (B) and dry mass of leaf, stem and root (D) at 69 days after planting, and evolution of leaf area (C) of cassava plants subjected to hours of water excess, in the early development stage (study in pots). ** Significant at 1% probability and * Significant at 5% probability by the F test.

Regarding the trend of dry matter of plant parts in the 48 hours treatment, compared to the 24 and 48 hours of water excess, it can be inferred through studies reported that cassava plants under water excess conditions tend to increase the leaf area, producing new leaves quickly after releasing stress, exceeding plants under normal conditions (Figure 3). Due to the imposed water excess, the growth potential of the aerial part is more restricted than the capacity of the first leaves to assimilate atmospheric carbon, allowing carbohydrates to be relocated in greater quantity to the roots. After the release of stress, there was a rapid expansion and renewal of the canopy, where reserves accumulated in the storage roots play an important role in the recovery of the plant after some stress that it may suffer (Baker *et al.*, 1989; Connor *et al.*, 1981; Cours, 1951).

The imposition of water excess in the initial stage of development, when the plants reached 9 leaves, caused a decrease and paralysis of the growth and development of the plants, being more accentuated in the 96 and 120 hour treatments. Every 24 hours of water excess remaining in the soil, the number of leaves per plant gradually decreases by 0.66 leaves (Figure 4A), the PH by 1.05 cm (Figure 4A), the LA by 53.94 cm^2 (Figure 4B), LDM at 0.34 g, SDM at 0.03 g and RDM 0.22 at 1.95 g (Figure 4D). It can also be observed that in the evolution of the leaf area, shown in figure 4C, the growth of the plant is negatively affected by water excess, mainly in treatments of 96 and 120 hours of water excess, in which the smallest increments of leaf area were observed. As a form of physiological defense of the plant, the imposition of 96 and 120 hours of water excess resulted in a reduction of 38% and 71% in leaf area, respectively, due to growth limitation and leaf senescence (Figure 4C). However, it is noteworthy that in an attempt to survive the water excess, some plants showed total senescence of their aerial part and started their development again through a new sprouting after water excess.

Table 1: Summary of joint variance analysis for the variables: emergence (EM), emergence rate (ER), percentage of establishment (PE) and final plant density (FPD) of cassava plants as function of the sources of variation

	Mean square			
Sources of variation	**EM**	**ER**	**PE**	**FPD**
BLOCK	61.54^{ns}	6.28*	144.56^{ns}	3544648.66^{ns}
A	560.66**	0.93*	16102.89**	392316548.16 **
B	13.88^{ns}	6.28^{ns}	97.95^{ns}	2450097.00^{ns}
A x B	2.11^{ns}	0.04^{ns}	118.01^{ns}	2828235.38^{ns}
Overall average	34.66	0.72	36.70	5744.16
Coefficient of variation (%)	12.18	22.64	25.83	26.05

A = management (with and without raised seedbeds); B = water excess in hours; A x B = interaction between management and water excess. **Significant at 1% probability and *Significant at 5% probability of error in the F test. ns = not significant.

In the study of cassava plants under water excess at field level, there was no interaction between the management carried out (with and without raised seedbeds) and the hours of water excess imposed (Table 1). However, when we compare only the management “in” or “out” of raised seedbed, there was a significant difference for all analyzed variables.

According to the comparison of means, it appears that for the variables EM, ER, PE, FPD, the management with raised seedbeds is the most suitable one where the management without raised seedbeds management did not present enough plants to proceed with the evaluations of the NL, LAI, LDM, SDM and RDM (Figure 5). As already discussed in this study, possibly the emergence of plants was compromised due to the lack of O_2 in the soil due to water excess. The use of raised seedbeds in hydromorphic soils helps in surface water drainage, reduces the time the soil is saturated, promoting an environment of greater aeration for the roots (Silva *et al.*, 2007; Fiorin *et al.*, 2009; Zaluski & Antonelli, 2014; Sartori *et al.*, 2015; Faraco *et al.*, 2016), enabling the cultivation of cassava.

The use of raised seedbeds for the cultivation of cassava in this study provided about 60% of the emergence and establishment of plants. On the other hand, in the management without raised seedbeds, the emergence and establishment of plants were approximately 10% (Figure 5C). After removing the water excess, the cassava plants that emerged and established themselves presented normal growth evolution. When performing the analysis of variance, the NL, LAI, LDM, SDM and RDM variables showed no significant difference with the periods of imposed water excess. This can be explained by the occurrence of rainfall (81mm) that occurred in the planting phase to pre-emergence, causing a water surplus of 71 mm, mainly in treatments of 0 and 48 hours of water excess.

Studies of the potential yield and yield gap allow identifying the main factors that limit the increase in yield, directing new lines of research, in addition to improving current management practices (Van Ittersum *et al.*, 2013). The potential yield of cassava roots for Santa Maria in the 2018/2019 crop year was 43.9 Mg ha^{-1}, resulted in a yield gap of 27 Mg ha^{-1} of cassava roots (Figure 6).

It is noteworthy that, as mentioned above, the treatment with 0 and 48 hours of water excess presented unwanted rainfall and water excess in the period tested, explaining the yields similar to other treatments. Therefore, in the raised seedbeds treatment, when we compare 0 hours of water excess, the yield gap caused by water excess was up to 4.1 Mg ha^{-1} (Figure 6). These losses, above 50% in yield, are directly related to the smaller number of plants that emerged and established in the area (Figure 5D). However, the yields found in this study are close to the average yields of 15 and 17 Mg ha^{-1} in Brazil and Rio Grande do Sul, respectively (IBGE, 2021).

Cassava roots have high energy value, being the part of the plant with the highest commercial value in the market, and numerous derivatives can be obtained (Tagliapietra *et al.*, 2019), and the greater the production of roots on the property, the greater the producer profitability. As it is a perennial crop, the longer its time in the field, and under favorable conditions, the higher its shoot and root yield will be (Sagrilo *et al.*, 2002; Alves, 2006). However, planting in August and September in Rio Grande do Sul, where it expresses the greatest potential yield (Tironi *et al.,* 2019), can become a problem for the emergence and establishment of the crop, because, according to the

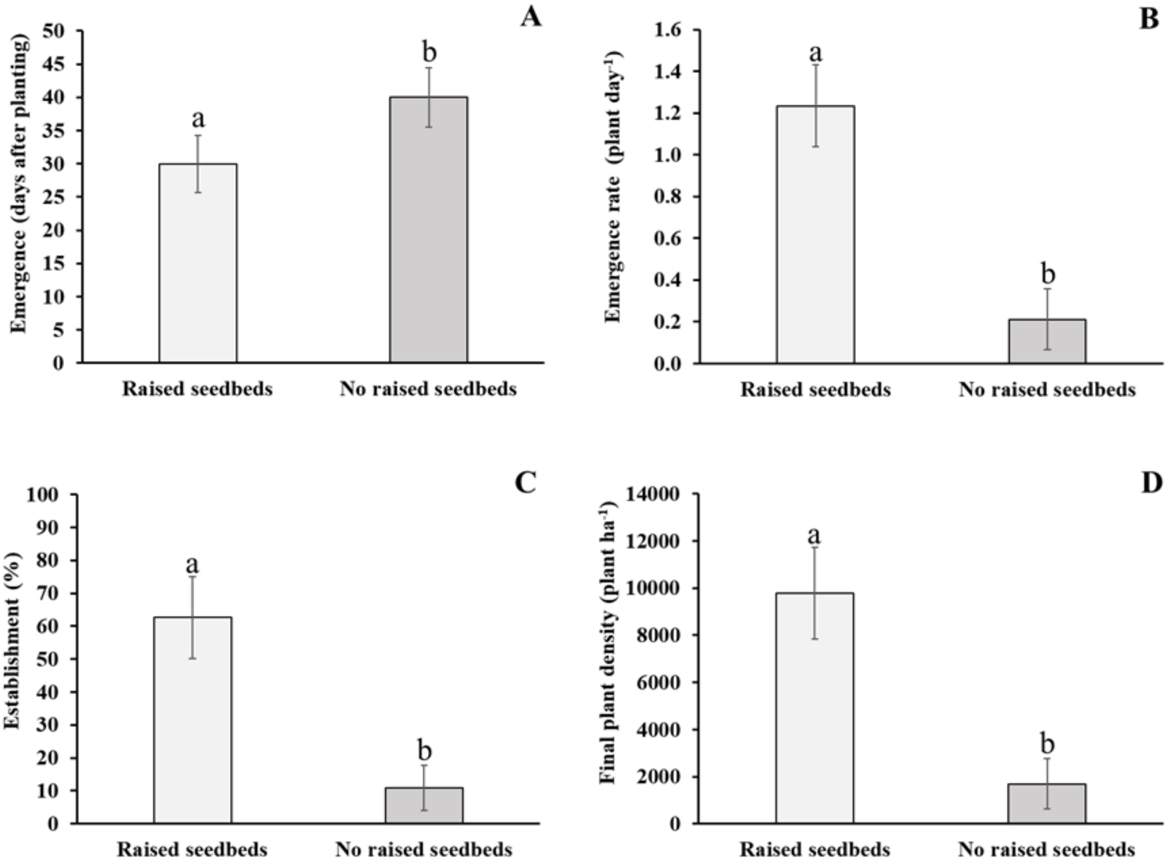

Figure 5: Comparison of means of emergence (A), emergence rate (B), percentage of establishment (C) and final plant density (D) of cassava in management with and without raised seedbeds subjected to hours of water excess. Mean values followed by the same letter do not differ significantly from each other by Student's t test ($p < 0.05$).

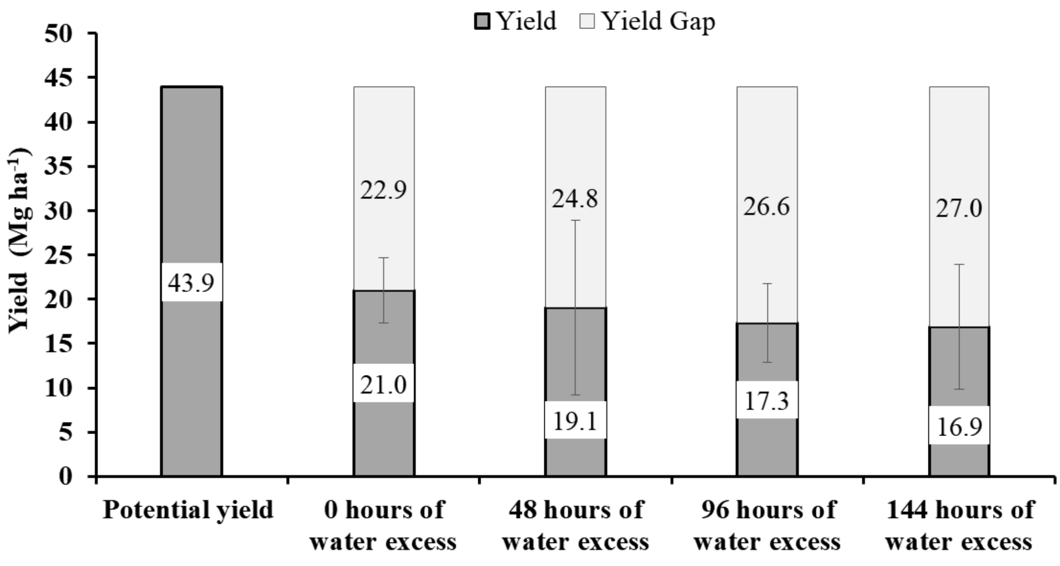

Figure 6: Simulated potential yield for the month of planting in September in the 2018/2019 crop year, yield and yield gap of treatments subjected to hours of water excess in raised seedbeds management.

history of the climatological water balance for the region of study (INMET, 2021), these months have water excess, due to low evaporative demand. The search for high yields the importance of knowing the behavior of the crop in the face of water excess, requiring management strategies for cultivation. This study is also valid for the main producing regions in the country, such as Pará, Paraná and São Paulo, which are leaders in the cultivation of cassava and also present a water excess in the main months of planting.

CONCLUSIONS

In the pre-emergence phase, after 24 hours of water excess, about 20% of the cassava stakes did not emerge, and after 96 hours, the emergence of plants does not occur. In the phase early of cassava development (stage V9), after the first 24 hours of water excess the plants showed a significant reduction in growth, but it is after 96 hours, and mainly in the 120 hours of water excess, that caused the severe damage to the crop cassava, reducing 38% the 71% of leaf area, taking place premature senescence of the plant's organs. The use of raised seedbeds was a management practice that ensured 62.6% of plant establishment, allowing cassava yields of up to 16.9 Mg ha^{-1}. The potential yield to Santa Maria in the 2018/2019 crop year was 43.9 Mg ha^{-1} of cassava roots, which resulted in a total yield gap of 27 Mg ha^{-1}. The yield gap caused by water excess was up to 4.1 Mg ha^{-1}.

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