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Irrigation blades on the yield and quality of cotton seeds produced in Arenito Caiuá region

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ABSTRACT

To meet the growing demand for cotton production, it is necessary to adopt high-quality seeds. To ensure the production of high-quality seeds, it is essential to consider factors such as the amount of water supplied to the plant and the climate of the region. Therefore, this study aimed to assess the impact of different irrigation blades on the productivity and physiological quality of cotton seeds produced in the Arenito Caiuá region. Cotton seeds from FiberMax FM 911 GLTP cultivar were sown, and, after planting, four water depth treatments were applied: 0 (control, without irrigation), 50, 100 and 150% of crop evapotranspiration (ETc), being maintained until the end of the crop development. The cotton bolls were harvested and delinted manually and the weight of the bolls and seeds was measured. The seeds were subjected to moisture content, germination, and vigor tests. The different irrigation blades applied to the plants affect cotton productivity, with irrigation blades of 50 and 100% ETc providing greater productivity. The absence and excess of irrigation cause a significant reduction in the productivity of cotton and seed. The physiological quality of the formed seeds is not affected by the different irrigation blades applied to the plants.

Keywords: *Gossypium spp*, Seed quality, Seed vigor, Irrigation, Low altitude region.

Lâminas de irrigação na produtividade e qualidade de sementes de algodão produzidas no Arenito Caiuá

RESUMO

Para suprir a crescente demanda na produção de algodão é necessária a adoção de sementes de alta qualidade. Para obtenção de sementes de qualidade, deve-se considerar diversos fatores, como a quantidade de água fornecida à planta e o clima da região. Assim, este trabalho teve como objetivo avaliar o efeito de diferentes lâminas de irrigação na produtividade e qualidade fisiológica de sementes de algodão produzidas na região do Arenito Caiuá. Sementes de algodão da cultivar FiberMax FM 911 GLTP foram semeadas e, após o plantio, foram aplicados quatro tratamentos de lâmina de água: 0 (testemunha, sem irrigação), 50, 100 e 150 % da evapotranspiração da cultura (ETc), sendo estas lâminas mantidas até o final do ciclo da cultura. Os capulhos do algodão foram colhidos e deslintados manualmente e aferidos o peso dos capulhos e das sementes. As sementes foram submetidas aos testes de grau de umidade, germinação e a testes de vigor. As diferentes lâminas de água aplicadas às plantas apresentam efeito na produtividade do algodão, sendo que as lâminas de 50 e 100% da ETc propiciam maior produtividade. A ausência e o excesso de irrigação promovem redução significativa nas produtividades de algodão e de sementes. A qualidade fisiológica das sementes formadas não é afetada pelas diferentes lâminas de água aplicadas às plantas.

***Palavras-chave**: Gossypium spp.,* Qualidade de sementes, Vigor de sementes, Irrigação, Região de baixa altitude.

1. Introduction

The production of cotton seeds (*Gossypium hirsutum* L.) in Brazil has been increasing annually (Queiroga et al., 2022), accompanied by a growing demand for new areas where the production of high-quality seeds is feasible. Although high-altitude regions are the most recommended for seed production (Marcos-Filho, 2015), in the current situation, there is a need to expand crops to different areas, including low-altitude regions (Kedisso et al., 2023; Oliveira et al., 2021). In these locations, which were previously not recommended for seed production, it has been possible to produce high-quality seeds (Oliveira et al., 2021). Consequently, further studies are required to validate these areas as potential sources for seed producers (Kedisso et al., 2023).

The city of Umuarama is among the regions of Paraná that have historical prominence in the production of herbaceous cotton (Moura et al., 2020). The city is situated at an altitude of approximately 401 meters, within a humid subtropical climate zone, and is part of the "Arenito Caiuá" region (Peel et al., 2007). The soil of this region (sandstone soils) has a texture ranging from sandy to medium, low percentage of clay, high sand contents, and low water retention capacity (Fidalski et al., 2013). Generally, irrigation in these soils is recommended to ensure that the water demand of the plant is met.

In the production of cotton seeds, water supplementation via irrigation reduces the risks that the lack of rain can cause in different physiological phases of the crop (Cheng et al., 2021; Wu et al., 2024). Water deficit is detrimental to cotton throughout the crop cycle (Cheng et al., 2021). However, when it occurs in the flowering and development phases of bolls, it usually causes severe productivity losses, both in fiber and seeds (Wu et al., 2024).

On the other hand, excess water in the soil can be equally deleterious, especially in the initial development of the crop, as it leads to hypoxia, reduced root length, and efficiency, decreasing nutrient uptake by plants (Echer and Rosolem, 2022). In addition, water stress, caused by excessive rainfall during harvest, is one of the main factors that intensify the deterioration and consequently the reduction of the physiological quality of the seeds (Marcos-Filho, 2015).

Consequently, maintaining an appropriate quantity of water for the plant during crop development is of critical importance to the productivity and quality of the seeds produced (Bewley et al., 2013). Water deficiency in cotton leads to reduced photosynthesis and increased photorespiration, which can drastically reduce seed size (Kolahi et al., 2021). In addition, it can lead to changes in secretory cavities, a reduction in soluble protein, carbohydrates, and lipid content (Kolahi et al., 2020), a decrease in embryo size (Kolahi et al., 2020) and in the number of seeds per boll (Shavkiev et al., 2023).

Ensuring water availability through irrigation can increase germination potential (Bai et al., 2023) and vigor (Wijewardana et al., 2019) or not influence the physiological quality of the generated seed (Gama et al., 2021). This depends on the species, cultivar, cropping system, management, environmental conditions, and stress levels (Bewley et al., 2013). Studies involving these factors are still incipient for the production of cotton seeds.

Given the scarcity of information on seed production in low-altitude regions and on the impact of irrigation on the germination potential and vigor of the seeds formed, this study aims to evaluate the effect of different irrigation blades on the yield and physiological quality of cotton seeds produced in the Caiuá Sandstone region.

2. Material and Methods

The experiment was carried out at the Umuarama Regional Campus, CAU/CCA Farm, and at the Seed Laboratory of the State University of Maringá, in the - city of Umuarama – Paraná – Brazil, located at the geographic coordinates of 23°45' south latitude and 53°19' west latitude, altitude of 401m. According to the Köppen classification, the region's climate is of the Cfa type – humid subtropical climate, without a dry season (Peel et al., 2007).

The chemical characterization of the soil of the experimental area is presented in Table 1 and is obtained from composite samples collected in the 0-20 cm depth layer. According to the chemical conditions found in the analysis, soil correction was carried out with the application of 1.5 t $^{ha-1}$ of calcitic limestone with PRNT 80%, following the method based on the increase in base saturation, described by Pauletti and Motta (2019). Figure 1 shows the soil water retention curve, obtained by correlating the water contents in deformed samples and their respective stresses obtained using porous capsules (tensiometers).

Through the retention curve, it was possible to obtain the total porosity of the soil, calculated by the value of volumetric moisture at a tension of 0.7 kPa. The microporosity was considered equal to the water content retained at the 4.0 kPa tension and the macroporosity was obtained by the difference between the total porosity and the microporosity. The available water capacity was obtained considering the difference between the voltage (6 kPa) in the field capacity and the voltage of 60 kPa (Steduto et al., 2012). These values and the other physical properties of the soil are shown in Table 2.

Table 1. Chemical characterization of the soil in the experimental area of the Umuarama Campus of the State University of Maringá, year 2022.

pH	P	M.O.	Ca	K	Mg	Al	CTC	V
$CaCl_2$	mg dm^{-3}	g dm^{-3}	--------------------cmol$_c$ dm^{-3}--------------------					%
4.50	14.89	14.87	1.25	0.16	0.37	pH	P	M.O.

P and K were extracted with 0.05 mol L-1 HCl + 0.025 mol L-1 H2SO4; Ca, Mg, and Al were extracted with KCl mol $^{L-1}$. P = phosphor, MO= organic matter, Ca=calcium, K=potassium, Mg=magnesium, Al=aluminum, V=base.

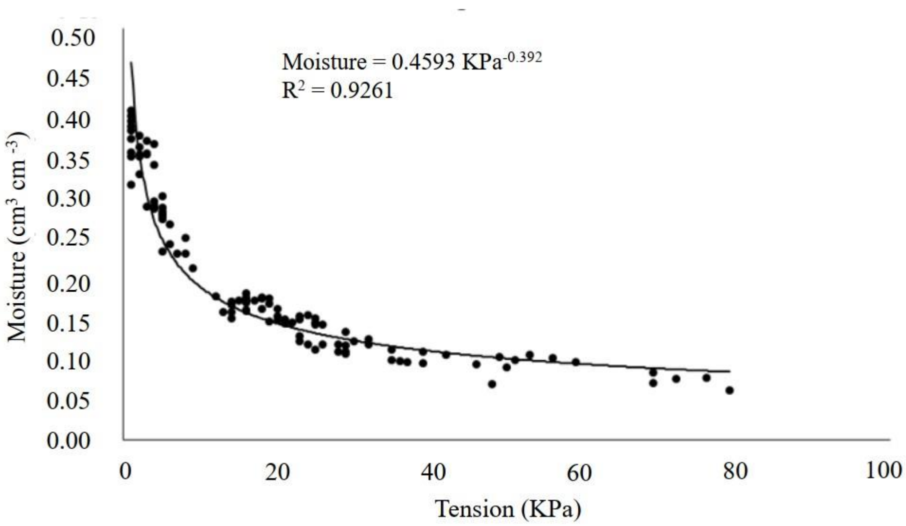

Figure 1. Soil water retention curve.

Table 2. Physical-water characterization of the soil used in the experiment.

HFC	CH	AWC	Porosidade (%)			SD	PD	Granulometry (%)		
cm^3	cm^{-3}	(mm)	Micro	Macro	Total	g cm^{-3}		Sand	Silt	Clay
0.258	0.135	21.80	26.70	26.10	52.80	1.31	2.65	83.25	2.70	13.55

*HFC – Humidity in field capacity; CH – Critical humidity; AWC – available water capacity SD – soil density (method of (BOUYOUCOS, 1951)); -PD – particle density (pycnometer method).

The sowing of the seeds of the Fibermax FM 911 GLTP cultivar was conducted in January 2022. Following the planting process, four distinct water depth treatments were implemented, namely: 0% (control - without irrigation), 50%, 100%, and 150% of the crop evapotranspiration (ETc). Each treatment was allocated in 5 rows, and the three central rows and the two peripheral rows were considered borders. The experiment was arranged in a randomized block design, with four blocks.

Throughout the development of the crop, fertilization was carried out, considering the chemical analysis of the soil (table 1) and the recommendation for the crop (Pauletti and Motta, 2019). A total of 12 and 5 kg $^{ha-1}$ of N and K2O were applied, respectively. In addition, herbicide, insecticide, and fungicide application management was adopted, when necessary. Irrigation in the area was implemented soon after sowing. The irrigation method used was localized, by drip system. The drip tape had a nominal flow rate of 2 L $^{h-1}$ and was spaced 0.15 m apart. The drip tapes were placed in 15 rows with a division of 5 rows of 50, 100, and 150% of the ETc, individually connected to the irrigation control head. Irrigation management was carried out via climate, with reference evapotranspiration calculated by the method proposed in the FAO Bulletin 56 (Allen et al., 1998), with a methodology adapted from the Penman-Monteith method.

Meteorological data were obtained through the use of an automatic meteorological station installed next to the experimental area. With the reference evapotranspiration data, it was possible to obtain the crop evapotranspiration (ETc) using the ETo product with the crop coefficient (kc) for the cotton crop, available in the FAO Bulletin 56 (Allen et al., 1998).

Thus, the applied irrigation depth was found employing the ratio between ETc and application efficiency b (Ea), and Ea was considered to be 0.95. Cotton harvesting was carried out manually. After harvesting, the weight of the total production was measured by plot. The seeds were manually delinted and after delinting, the weight of the seed yield was measured. The data were extrapolated to kg $^{ha-1}$, considering a population of 122 thousand plants per hectare.

After weighing, the tests and determinations were performed. The determination of moisture content was performed using four replicates of 25 seeds per treatment. This determination was performed by the greenhouse method at 105 °C for 24 hours (Brasil, 2009). The weight of one thousand seeds was determined using eight replicates of 100 seeds per treatment, which were weighed on a precision analytical balance (0.001 g) (Brasil, 2009). For the germination test, four replicates of 50 seeds were used per treatment, using germitest paper moistened with distilled water in the proportion 2.5 times its weight. The seeds were sown on moistened paper, rolls were made and placed to germinate in a germinator at a temperature of 25 °C.

Evaluations of the percentage of normal seedlings were performed on the 4th and 12th days after sowing (Brasil, 2009). The first germination count was performed together with the germination test, with an evaluation of the percentage of normal seedlings on the fourth day after sowing (Brasil, 2009). For the accelerated aging test, the seeds were distributed in a single and uniform layer on stainless steel screens and placed in sealed germination boxes (11 x 11 x 3.5 cm) with 40 mL of distilled water at the bottom. They were kept in a germination chamber at 41°C for 48 hours. Subsequently, four replicates of 50 seeds were submitted to the germination test, and the evaluation of the percentage of normal seedlings was performed on the fourth day after sowing (Krzyzanowski et al., 2020).

Seedling length: Four replicates of 20 seeds were used per treatment. The seeds were sown on *germitest* paper half the length of the traditional paper, and moistened with distilled water at the rate of 2.5 times the weight of the dry paper. Rolls were made and placed in a germination chamber at 25 °C for 7 days (Krzyzanowski et al., 2020). After this period, the seedlings were measured for length with the aid of a graduated ruler. For field seedling emergence test, four replicates of 50 seeds per treatment were used. The seeds were sown in soil, at a depth of 3 cm, at the experimental station of the Umuarama Regional Campus (sandstone region). Seedling emergence was counted daily and when emergence stabilized at 12 days, the percentage of emergence was measured (Krzyzanowski et al., 2020) and the emergence speed index (ESI) was calculated (Maguire, 1962).

The experiment in the field was carried out in randomized blocks and in the laboratory, to measure the physiological quality of the seeds, it was conducted in a completely randomized design, using four treatments of water depth, and four replications. The data were submitted for analysis of variance, using the F test at 5% significance, and the means were compared by the Tukey test at 5% probability, with the aid of the R Software, Core Team, 2023.

3. Results and Discussion

The crop cycle lasted 210 days, and there was a sudden change between maximum, average, and minimum temperatures during cotton development (Figure 2). The optimal temperature range for cotton development is 20 to 30 °C (Echer, 2014). However, during most of the crop cycle, a maximum temperature above 30 °C and a minimum temperature below 20 °C were observed, in addition to a high amplitude between day and night temperatures (Figure 2).

Snider and Oosterhuis (2012) state that sudden fluctuations in temperature impair the reproductive development of the crop. Heat stress can affect productivity through the aborting of flower buds and the non-viability of sexual reproduction, being one of the most sensitive processes to high temperatures (Lohani et al., 2020). Therefore, temperatures above the optimum can cause significant losses in productivity due to decreased fertilization rate and seed formation (Cheng et al., 2021; Lohani et al., 2020).

The weight of the boll is defined by the weight of crude fiber and, mainly, by the number of seeds per fruit (Shavkiev et al., 2023). In this way, the number of seeds per boll is an important component of cotton production and, for seed production, it is even more essential. Many researchers have demonstrated that high-temperature stress is one of the main factors negatively affecting seed development. In cotton, temperatures above 26 °C can increase the frequency of seeds that are not fully (Echer, 2014), possibly due to inhibition of pollen development, egg abortion, or the inviability of sexual reproduction (Echer, 2014; Lohani et al., 2020). During crop development, rainfall was well distributed among crop phases (Figure 3).

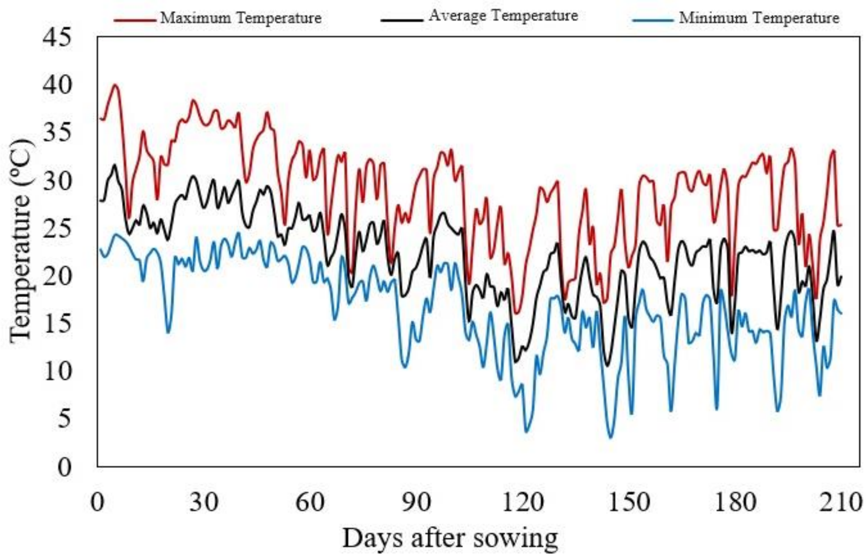

Figure 2. Maximum, average and minimum temperature during the development of cotton seeds (*Gossypium hirsutum* L), cultivar FiberMax FM 911 GLTP.

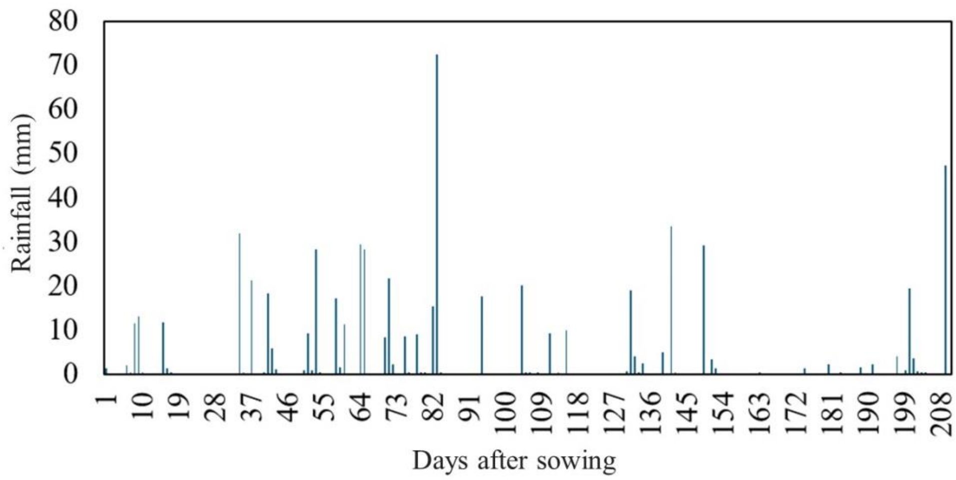

Figure 3. Rainfall regime during the development of cotton seeds (Gossypium hirsutum L), cultivar FiberMax FM 911. GLTP.

The water requirement of the cotton crop varies from 400 to 700 mm per cycle, depending on the climatic conditions and the length of the cultivar's cycle (Zonta et al., 2016). However, recent studies indicate that the seasonal water consumption of 1079 mm ha^{-1} was what provided higher productivity of cotton seeds (Shareef et al., 2018). The amount of water to be used by the plant varies in each phase that the plant is in, and in each physiological phase it demands a specific amount of water, depending on the conditions of the environment (Wu et al., 2024).

Thus, water needs must be met throughout the crop cycle (Coelho, 2023), based on crop evapotranspiration (Shareef et al., 2018). In this experiment, low rainfall intensity was observed at the beginning of the cycle (Figure 3). Water is extremely important for tissue development and resumption of seed embryo growth (Bewley et al., 2013). Water deficit at this stage leads to a decrease in seed germination rate, stand failure, and a reduction in crop productivity (Echer and Rosolem, 2022).

However, although water is important for seedling germination and growth, the largest amount of water required by the plant is in the flowering and development phase of bolls (Wu et al., 2024), which consume 50 to 60% of all water required by the crop during the season (Echer and Rosolem, 2022). As the water demand required by the crop is higher during this period, the lack of water during this period leads to a significant reduction in productivity, as it can make the production of flowers and/or the formation of apples unfeasible (Wu et al., 2014).

For the formation of quality seeds, water is highly required from flowering to the physiological maturity of the seeds (Bewley et al., 2013). From this point, a dry environment is expected to be harvested. The presence of rainfall at harvest is extremely deleterious to the quality of the seeds. As observed in this experiment, there was low rainfall intensity during seed maturation and heavy rainfall at harvest (Figure 3), which harmed seed quality (Table 3).

Although there was a well-distributed rainfall regime during the development of the crop (Figure 3), the high temperatures reached during the cycle (Figure 2) promoted an unfavorable water balance to the crop, which culminated in a situation of water deficit in most of the plant development and seed formation, in the rainfed condition (0% ETc treatment). On the other hand, when there was supplementary irrigation, water storage was identified in the soil during almost the entire crop cycle, except for a peak deficit on the fourth day after sowing (Figure 4).

In the area without irrigation, for most of the cycle there was a water deficit in the soil (Figure 4), which caused a significant reduction in total and seed productivity (Table 3). According to Cheng et al. (2021), water deficit when imposed from the vegetative period is highly detrimental to the cotton crop. This is because a lack of water during germination can reduce the plant stand; during the vegetative phase it reduces net photosynthesis; and in the reproductive phase, it affects the formation and viability of the floral structures that form the seeds (Kolahi et al., 2021; Kolahi et al., 2020; Koudahe et al., 2021; Shavkiev et al., 2023).

There was a significant effect of irrigation blades on total and seed yield, and the highest yields were obtained for the irrigation blades of 50 and 100% of ETc, with no significant difference between them (Table 3). When these blades were applied, the average total yield was 4006 kg ha^{-1} and the seed yield was 2404 kg ha^{-1}. According to Conab (2023), in Paraná, the average total productivity of cotton and seed, for the 22/23 harvest, was 3068 kg ha^{-1} - 1810 kg ha^{-1}, respectively, being 23% lower than those obtained in this study (Table 3). Thus, it is a fact that the caiuá sandstone region has the potential to produce cotton, especially if it provides an ideal amount of water for the plant.

When the water depth corresponding to 150% of the ETc was applied, lower productivity was obtained than when the irrigation blades of 50 or 100% were applied, indicating a possible stress suffered by the plant due to excess water. Excess water harms cotton crops, as high soil moisture can stimulate the rapid expansion of leaves and stem cells and, thus, increase excess vegetative growth (Echer and Rosolem., 2022). The supply of assimilates to the fruit can be reduced in favor of vegetative structures. Excessive vegetative growth is likely to occur when cotton is grown in well-drained soils (Echer and Rosolem, 2022), such as those of the Caiuá sandstone.

However, although the plant may have suffered from overwatering, in the absence of irrigation (0% of ETc), there was an even more pronounced loss of productivity (Table 3). Although cotton has some drought tolerance (Cheng et al., 2021; Shareef et al., 2018; Shavkiev et al., 2023), as evidenced in this study, by the higher productivity obtained (4060 kg ha^{-1}) when 50% of the ETc is irrigated, the importance of water for crop development is evident (Table 3). In the rainfed condition, a 40% reduction in productivity was observed, compared to the 50 or 100% ETc condition (Table 3).

Thus, these results demonstrate that water supplementation, via irrigation, in the region of the caiuá sandstone is extremely necessary so that there is no reduction in crop productivity, as also described by Fidalski et al. (2013). After the quantification of the yield, the determinations of the moisture content, weight of a thousand seeds, and the tests of the first count of germination, germination, seedling length, accelerated aging, emergence, and seedling emergence speed index in the field were carried out (Table 3), to verify if the different irrigation blades applied to the crop could reflect on the physiological quality of the seeds formed.

It was found that there was no difference in the physiological quality of the seeds that were formed under the different irrigation blades, as evidenced by the tests of the first count of germination, germination, seedling length, accelerated aging, emergence, and seedling emergence speed index (Table 3). Each of these tests aims to determine whether the seeds have vigor, that is, whether they have the potential to develop normal and vigorous seedlings in the field (Krzyzanowski et al., 2020). Seed vigor is not a single measurable property, but is the result of a sum of taxes that must be analyzed together (Bewley et al., 2013). The occurrence of seed deterioration in the field can be considered the main cause of reduced seed vigor (Bewley et al., 2013).

Deterioration is strongly influenced by genetics and the environment in which the seeds are grown (Marcos-Filho, 2015). In this experiment, it was evident that extreme temperatures, above 30 °C and below 20 °C (Figure 2), and the high intensity of rainfall at harvest (Figure 3) impaired seed quality (Table 2). Seeds from plants that were irrigated with 100% ETc were the ones with the highest moisture content. On the other hand, those that were not irrigated (0% ETc) or over-irrigated (150% ETc) were the ones with the lowest moisture. Under water stress conditions, water uptake by seeds can be reduced (Silva et al., 2019) and can affect seed development (Marcos-Filho, 2015). Thus, these stresses imposed on the plants may have interfered with water uptake and seed formation and reflected in the low moisture content of the seeds.

Table 3. Total (crude fiber + seeds) and seed (Seeds) productivity, moisture content (MC), weight of one thousand seeds (WTS), first germination count (FC), germination (GER), seedling length (SL), accelerated aging (AA), emergence (EM) and emergence speed index (ESI) when different irrigation blades were applied to cotton (*Gossypium hirsutum* L), cultivar FiberMax FM 911 GLTP.

Irrigation blades (% ETc)	Productivity		MC	WTS	FC
	Total	Seeds			
0	2418c	1451c	10c	84.13ab	80a
50	4060a	2436a	11b	82.56b	77a
100	3953a	2372a	12a	85.37a	80a
150	3529b	2117b	10c	82.96b	85a
CV (%)	2418c	1451c	10c	84.13ab	80a
Irrigation blades	GER	SL	AA	EM	ESI
0	86a	11.27a	72a	55a	8.28a
50	85a	12.25a	62a	54a	7.89a
100	85a	11.97a	59a	57a	7.74a
150	81a	11.90	58a	46a	5.27a
CV (%)	5,02	6.83	10.67	7.03	9.94

*CV = Coeficiente of variation ***ETc = crop evapotranspiration,

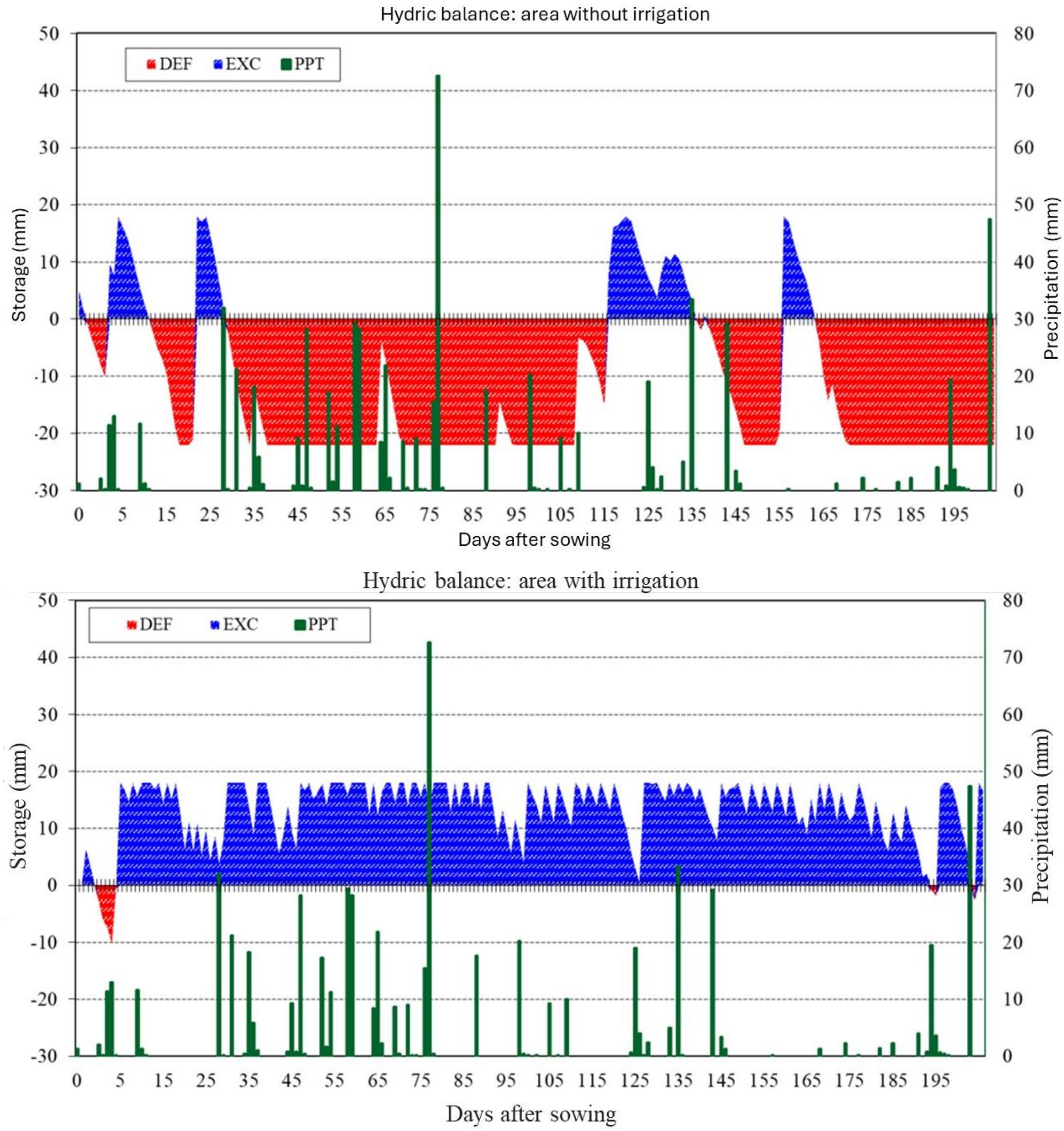

Figure 4. Water storage in the soil (left axis), precipitation (right axis and green bars - PPT), which led to a situation of deficit (in red – DEF) or accumulation (in blue – EXC) of water in the soil, during the development of cotton (*Gossypium hirsutum* L), cultivar FiberMax FM 911 GLTP, in non-irrigated or irrigated areas.

The weight of one thousand seeds was higher in the treatments 0 and 100% of ETc. The higher weight of these seeds is due to the higher accumulation of dry matter. In the irrigated condition (100% ETc), the availability of water to the plants helps in the mobilization of plant reserves for the seeds and can provide the maximum dry matter content at the point of physiological maturity (Bewley et al., 2013). On the other hand, when under water deficit (0% ETc), plants can invest in a smaller number of seeds with higher dry mass (Moura et al., 2023).

Even though there were sudden fluctuations in temperature (Figure 2) and rainfall at harvest (Figure 3), the seeds produced showed more than 80% germination (Table 3), a rate higher than the minimum recommended for the production and commercialization of cotton seeds, which is 75% (Brasil, 2013). However, the effects of bad weather on seed vigor were evident, with a low percentage of emergence (Table 3).

The volume of rainfall added to the applied irrigation blades of 50 or 100% of the ETc was sufficient to meet the plant's water needs, which culminated in productivity higher than the average for the state of Paraná (CONAB, 2023). The generated seeds showed germination higher than the minimum for commercialization (Brasil, 2013). However, they did not present high physiological quality (mean emergency of 53%). It is believed that the high temperatures and the occurrence of rain at harvest were the main factors that led to the reduction of the physiological quality of the cotton seeds produced in the Caiuá Sandstone.

4. Conclusions

Irrigation with a water depth of 50 and 100% of ETc provides a higher yield of cotton and seeds. The absence and excess of irrigation promote a significant reduction in total and seed yield. Irrigation does not affect the physiological quality of the seeds.

Authors' Contribution

Caio Henrique Marques Lima did the conception of the idea, execution of the experiment, data analysis, preparation of the article, bibliographic review and writing of the article. Martha Freire da Silva coordinated in the conception of the idea, statistics, execution of the experiments and review of the article writing. Alini Silva Souza supported in the execution of the experiment and data analysis. Cleverton Timoteo De Assunação helped in the execution of the experiment, data analysis and literature review. Jõao Paulo Francisco helped in the orientation of irrigation blades and dada colect. Nátally Emanuelly dos Santos supported in the execution of the experiment and literature review.

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