AGRICULTURAL RESILIENCE IN THE BRAZILIAN SEMI-ARID REGION: DEFICIT IRRIGATION AND PERFORMANCE OF ELEPHANT GRASS CV. BRS CAPIAÇU

RESILIÊNCIA AGRÍCOLA NO SEMIÁRIDO BRASILEIRO: IRRIGAÇÃO DEFICITÁRIA E DESEMPENHO DO CAPIM-ELEFANTE CV. BRS CAPIAÇU

RESILIENCIA AGRÍCOLA EN EL SEMIÁRIDO BRASILEÑO: RIEGO DEFICITARIO Y DESEMPEÑO DEL PASTO ELEFANTE CV. BRS CAPIAÇU

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ABSTRACT

This study reviews the main aspects related to the characterization of the Brazilian semi-arid region and agricultural resilience strategies, focusing on deficit irrigation and the physiological responses of plants subjected to water and saline stress. The semi-arid region presents high climatic variability and low-fertility soils, which limit agricultural productivity and reinforce the need for more efficient management practices. Deficit irrigation emerges as an alternative to optimize water use, allowing savings of up to 20% in water consumption and 30% in energy use, without significantly compromising production. Recent studies show that different crops respond differently to reductions in irrigation depth, making it possible to identify optimal application levels that reconcile productivity and water use efficiency. Elephant grass cv. BRS Capiaçu stands out among tropical forages due to its high biomass productivity and ability to adapt to adverse moisture and soil conditions. However, its performance is directly related to proper irrigation management, fertilization, and cutting frequency. Under water and saline stress conditions, plants activate antioxidant and osmotic defense mechanisms that contribute to maintaining homeostasis and physiological activity. Therefore, integrated water management and the use of adapted cultivars constitute essential tools for the sustainability of productive systems in the semi-arid region.

Keywords: Water Use Efficiency. Plant Physiology. Stress Tolerance. Photosynthesis. Forage Production. Climate Sustainability.

RESUMO

Este trabalho revisa os principais aspectos relacionados à caracterização do semiárido brasileiro e às estratégias de resiliência agrícola, com foco na irrigação deficitária e nas respostas fisiológicas de plantas submetidas a estresse hídrico e salino. A região semiárida apresenta alta variabilidade climática e solos de baixa fertilidade, o que limita a produtividade agrícola e reforça a necessidade de práticas de manejo mais eficientes. A irrigação deficitária surge como alternativa para otimizar o uso da água, permitindo economia de até 20% no consumo hídrico e 30% de energia, sem comprometer significativamente a produção. Estudos recentes evidenciam que diferentes culturas respondem de forma distinta à redução da lâmina de irrigação, sendo possível identificar níveis ótimos de aplicação que conciliam

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produtividade e eficiência no uso da água. O capim-elefante cv. BRS Capiaçu destaca-se entre as forrageiras tropicais pela elevada produtividade de biomassa e capacidade de adaptação a condições adversas de umidade e solo. Entretanto, seu desempenho está diretamente relacionado ao manejo adequado da irrigação, da fertilização e da frequência de corte. Sob condições de estresse hídrico e salino, as plantas ativam mecanismos de defesa antioxidante e osmótico que contribuem para a manutenção da homeostase e da atividade. Assim, o manejo integrado da água e o uso de cultivares adaptadas constituem ferramentas essenciais para a sustentabilidade dos sistemas produtivos no semiárido.

Palavras-chave: Eficiência Hídrica. Fisiologia Vegetal. Tolerância ao Estresse. Fotossíntese. Produção Forrageira. Sustentabilidade Climática.

RESUMEN

Este trabajo revisa los principales aspectos relacionados con la caracterización del semiárido brasileño y las estrategias de resiliencia agrícola, con énfasis en el riego deficitario y en las respuestas fisiológicas de las plantas sometidas a estrés hídrico y salino. La región semiárida presenta alta variabilidad climática y suelos de baja fertilidad, lo que limita la productividad agrícola y refuerza la necesidad de prácticas de manejo más eficientes. El riego deficitario surge como una alternativa para optimizar el uso del agua, permitiendo un ahorro de hasta un 20% en el consumo hídrico y un 30% de energía, sin comprometer significativamente la producción. Estudios recientes evidencian que diferentes cultivos responden de manera distinta a la reducción de la lámina de riego, siendo posible identificar niveles óptimos de aplicación que concilien productividad y eficiencia en el uso del agua. El pasto elefante cv. BRS Capiaçu se destaca entre las forrajeras tropicales por su elevada productividad de biomasa y capacidad de adaptación a condiciones adversas de humedad y suelo. Sin embargo, su desempeño está directamente relacionado con el manejo adecuado del riego, la fertilización y la frecuencia de corte. Bajo condiciones de estrés hídrico y salino, las plantas activan mecanismos de defensa antioxidante y osmótica que contribuyen al mantenimiento de la homeostasis y de la actividad fisiológica. Así, el manejo integrado del agua y el uso de cultivares adaptadas constituyen herramientas esenciales para la sostenibilidad de los sistemas productivos en el semiárido.

Palabras clave: Eficiencia Hídrica. Fisiología Vegetal. Tolerancia al Estrés. Fotosíntesis. Producción Forrajera. Sostenibilidad Climática.

1 INTRODUCTION

The Brazilian semi-arid region, recognized as the most extensive and humid in the world, is characterized by scarce and irregular rainfall, high evapotranspiration rates and long periods of drought, factors that strongly condition water availability and agricultural productivity (Vicente-Serrano *et al.*, 2015; Santos *et al.*, 2024). Described by the predominance of Caatinga vegetation and heterogeneous soils, often shallow and susceptible to erosion (Inácio Silva *et al*., 2024; Souza *et al*., 2022). Such conditions impose severe limits on agriculture, increasing the risks of food insecurity and requiring more resilient production systems (Begizew, 2021; Rathore, 2024).

To mitigate these challenges, it is necessary to adopt practices that allow soil and water conservation, such as efficient irrigation and the use of species adapted to water stress, which constitutes a promising alternative for strengthening agricultural sustainability in these regions (Lankford *et al*., 2023). Although irrigation is a vital technique for plant production in dry areas, its improper application can result in soil salinization and waste of resources (Cunha, 2019; Silva & Neves, 2020).

Thus, deficient irrigation emerges as a technique for rational water management, allowing better efficiency in the use of water and energy resources (Levien *et al.*, 2021). In addition, the cultivation of adapted forage grasses, such as elephant grass cv. BRS Capiaçu, has high production potential and tolerance to water deficit, and is indicated for animal feed supplementation in semi-arid environments (Pereira *et al*., 2016; Moura *et al*., 2024). However, understanding the physiological and biochemical responses of plants under conditions of water and saline stress is essential to optimize management and ensure production in the semi-arid region (Araújo *et al*., 2010).

Thus, this literature review aims to synthesize the current knowledge on agricultural resilience strategies in the Brazilian semi-arid region, with emphasis on deficient irrigation, plant physiology under water and saline stress, and elephant grass performance cv. BRS Capiaçu as a productive and sustainable alternative.

2 CHARACTERIZATION OF THE BRAZILIAN SEMI-ARID REGION AND AGRICULTURAL RESILIENCE STRATEGIES

Semi-arid regions have scarce and irregular rainfall, high evapotranspiration and prolonged periods of drought, which results in scarcity of water resources and significant climate variability over time and space (Vicente-Serrano et al., 2015) . The intensity and irregularity of extreme rainfall is evident, contributing to prolonged droughts and the increase in the number of consecutive days without precipitation. The soils of these areas are quite heterogeneous, with physical and chemical properties that vary according to land use, topography, and management practices, with the presence of shallow soils, low fertility, and susceptible to erosion being common. (Santos et al., 2024) (Inácio Silva et al., 2024)

In Brazil, the semi-arid region is considered the wettest and most extensive in the world, with annual rainfall ranging from 400 to 800 mm. The predominant vegetation is the Caatinga, which presents different physiognomies, from hyperxerophilous formations to enclaves of dry forest and savannah, reflecting the interaction between climate and soil attributes, in higher areas, more acidic soils and rich in organic carbon predominate, while in lower regions more alkaline and less developed soils are common. Second, the delimitation of the Brazilian semi-arid region covers 1,427 municipalities (Figure 1). (Silva et al., 2021) (Oliveira et al., 2019; Souza et al., 2022) Bezerra et al. (2021)

Agriculture in the semi-arid region faces severe limitations due to the scarcity and irregularity of rainfall, high temperatures, poor soils, and frequent drought events, which reduces productivity and increases the risk of food insecurity. Among the main constraints are the limitation of water for irrigation, soil degradation, vulnerability to climate extremes, and low resilience of traditional agricultural systems. (Begizew, 2021) (Rathore, 2024)

To overcome these challenges, resilient practices have been adopted, such as soil and water conservation, rainwater harvesting, efficient supplemental irrigation (such as drip irrigation), and the use of reservoirs for water storage, which increase the capacity to cope with periods of drought. The use of species adapted to water stress, such as resistant grasses and legumes and local varieties of native plants, is essential to ensure production even in dry years. The integration of traditional practices and technological innovations, combined with the strengthening of cooperation networks and access to information, is essential to increase the resilience of farmers in the semi-arid region. (Lankford et al., 2023) (Begizew, 2021) (Rathore, 2024)

Figure 1

Municipalities included in the 2021 Semi-arid Delimitation

Source: Bezerra et al. (2021)

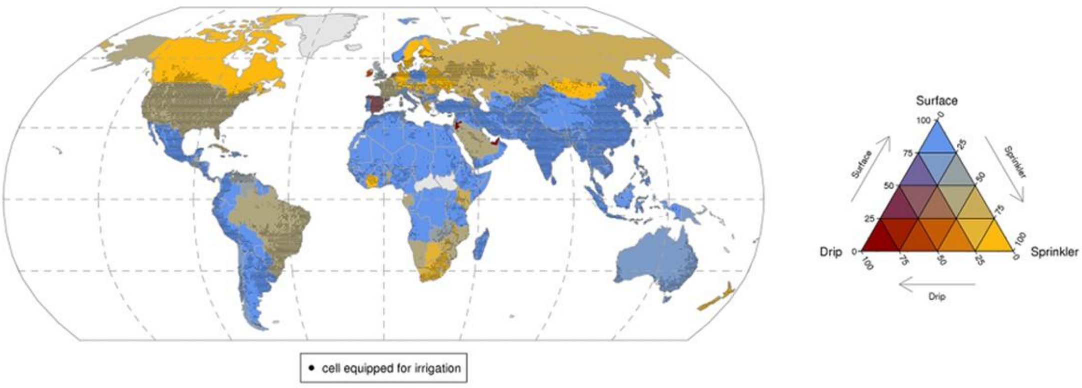
1. Use of deficient irrigation

Soil moisture is an extremely important factor for plant development, the ideal amount of this resource enables greater crop productivity. Therefore, the producer should adopt the irrigated agriculture model when the availability of water is lower than what is necessary for the crop or when there is irregular rainfall. Thus, irrigation is a method that helps in the production of vegetables, especially in regions that have water scarcity. However, the application of water in the wrong way can cause negative consequences for both the plant and the environment, such as soil saturation that prevents aeration of the roots, cause high evaporation, provides leaching of nutrients and salinizes the soil, in addition to forming a favorable microclimate for the development of diseases. (Carvalho et al., 2017) (Levienetal., 2021) (Cruz, 2019) (Cunha, 2019; Silva & Neves, 2020)

According to the Food and Agriculture Organization of the United Nations (FAO), irrigated areas correspond to less than 20% of the total cultivated area of the planet, with the consumption of about 70% of water, but produce more than 40% of food, fibers and bioenergy crops (FAO, 2011). Jägermeyr et al. (2015) estimated the global water use in agriculture based on three irrigation systems (surface, sprinkler and drip) in a model of the biosphere and agrosphere (Figure 2), resulting in a gridded world map of irrigation efficiencies, which represents the water consumption that results in crop production, it was observed that the lowest values (< 30%) in South Asia and Sub-Saharan Africa and the highest values (> 60%) in South Asia and Sub-Saharan Africa. Europe and North America. They also estimated that 2,469 km3 of water per year is withdrawn for irrigation, with 1,212 km3 returning to the place of origin and 1,257 km3 being effectively consumed in irrigation. In view of this scenario and the fact that water is a limited resource, it is necessary to optimize its use, so that it allows irrigated agriculture to be rational and efficient, through advances in technology and the use of crops resistant to water deficit. (Levienet et al., 2021)

Figure 2

Global distribution of irrigation systems at the national level, based on AQUASTAT statistics. The cells that include irrigated areas are hatched, based on Siebert et al. (2015)



Source: Jägermeyr et al. (2015).

In agricultural systems, it is possible to save approximately 20% of the water and 30% of the energy consumed if irrigation is carried out correctly (Lima, Ferreira, Christofidis, 1999). Through practices that involve everything from planning to application, such as the adoption of localized irrigation systems, which have greater application efficiency, associated with the amount of water that the plant needs at the time of irrigation, for this, it is necessary to know the phenological phase of the crop and the climatic conditions. (Coelho et al., 2005)

Studies focused on the correct management of irrigation water have grown in the literature, such as studying the cultivation coefficient (Kc) and the efficiency of water use for eggplant crops, the experiment was carried out in the dry and rainy season of the region and the treatments were irrigation depths of 100%, 80%, 60%, 40% and 20% of the reference evapotranspiration (ET Dantas et al. (2025) $_0$ - mm $^{day-1}$), the results showed that the Kc is higher in the sandy loam soil than in the loam soil, and the best water use efficiency and productivity was in the 100% depth of ET0. They have already evaluated the growth, productivity, economic viability of forage plants submitted to irrigation depths of 25%, 50%, 75% and 100% of ET Santos et al. (2025) $_0$, and observed that BRS Capiaçu presented better development in the depth of 100%. studied the biomass production of Tanzania grass in five irrigation depths (40, 60, 80, 100 and 120% of the actual evapotranspiration), it was observed that the 120% depth provided better production, however, the 80% depth had only 5% less biomass production. Cajá et al. (2023)

2.1 ELEPHANT GRASS CV. BRS CAPIAÇU

The elephant grass (*Pennisetum purpureum* Schumach.), has its origin in the African continent, specifically in Tropical Africa, was discovered by Colonel Naiper in 1905 and in 1920 was introduced in Brazil, coming from Cuba. Being widely cultivated in tropical and subtropical regions, this grass stands out for its great biomass productivity per hectare. Among the perennial tropical crops used for biomass production, elephant grass has a high capacity for dry matter accumulation compared to the others, as it is highly efficient in fixing atmospheric (Saraiva & Konig, 2013) (Pereira et al., 2021) CO_2, due to its high photosynthetic efficiency metabolism (C4 metabolism) (Marafon et al., 2023).

In view of this, in 2015, Embrapa Dairy Cattle developed the BRS Capiaçu cultivar, as an alternative for bulky supplementation for the herd. The cultivar has characteristics of tall size (4.20m), wide and long leaves, erect clumps, thick stalks and late flowering, standing out from other elephant grass cultivars, such as BRS kurumi and the Roxo elephant, due to the ease of mechanical harvesting, good resistance to damping-off, absence of joçal (hairs) and tolerance to water deficit (Pereira et al., 2016) (Figure 3). The biomass production is 50 t $^{ha-1\ year-1}$ of dry matter or 300 t $^{ha-1\ year-1}$ of fresh matter, about 30% higher than the others, and can be supplied to the animal in the form of silage or chopped in natura in the trough. Due to the high productivity, it has a high extraction of nutrients in the soil and, consequently, frequent fertilization. However, fertilization is not the only factor that can interfere with plant growth and nutritive value, the frequency of cutting being short or long also affects. In short intervals, productivity is compromised and in long intervals the material loses nutritional quality. (Pereira et al., 2021) (Retoreet et al., 2021)

Figure 3

Mechanized harvesting of elephant grass cv. BRS Capiaçu

Source: Pereira et al., 2016.

BRS Capiaçu is demanding in terms of edaphoclimatic conditions, needs deep soils and good fertility, does not support waterlogged soils, and planting should be carried out at the beginning of the rainy season, with furrows 20 to 30 cm deep and spaced between 0.80 to 1.20 m, propagation is by means of whole or cut stalks (stalks with 4 or 5 nodes). In addition, this cultivar is not resistant to grasshoppers (*Deois flavopicta*), so the implementation of the crop in regions with a history of this pest should be avoided. (Moura et al., 2024; Pereira, et al., 2021)

Monção et al. (2019) studied the productivity of BRS capiaçu submitted to five cutting intervals (30, 60, 90, 120 and 150 days), and concluded that with the advance of the age of BRS Capiaçu grass, there was an increase in dry matter production per unit area. On the other hand, this resulted in a decrease in the nutritional value, evidenced by the decrease in the digestibility and degradability of the dry matter fractions, as well as in the digestibility of the fibrous fraction. While they sought to relate the productive and nutritional characteristics of BRS Capiaçu managed at five cutting heights (1.03, 1.93, 3.43, 4.50 and 4.98 meters), the results indicated that the equilibrium point between productivity and nutritional value occurred at the height of 3.43 m. They have already evaluated the height of BRS Capiaçu plants subjected to saline stress by irrigation (0.6, 1.8, 3.0, 5.0 and 10.0 dS Leal et al. (2020) Lisboa et al. (2023) $^{m-1}$), and observed that the height was higher in the 0.6 treatments; 1.8

and 3.0 dS $^{m-1}$ and those that were irrigated with 10.0 dS $^{m-1}$ had the lowest height, thus concluding that the initial phase of the grass is tolerant to salinity of up to 3.0 dS $^{m-1}$.

2.2 PLANT PHYSIOLOGY UNDER WATER AND SALT STRESS

Water deficit causes changes in the anatomy, physiology, and biochemistry of plants, and the intensity of these changes varies according to the plant and its degree of tolerance and resistance. The visible effects in forages are smaller, dry and/or withered leaves, modification in the number of tillers and longer roots, in physiology there is less turgidity of cells, modification of stomatal closure and structure of chloroplasts, acceleration of the senescence process, as well as reduction of transpiration and rate of assimilation of carbon dioxide. (Araújo et al., 2010) (Campos et al., 2021; Zampirolloet et al., 2021)

With the detection of water stress, a series of physical and chemical signals are triggered that promote changes in plant development, among the acclimatization mechanisms, stomatal closure stands out, which occurs due to the loss of turgor of the guard cells. This closure plays a crucial role in reducing water loss through transpiration, but it also has significant consequences, such as decreased stomatal conductance, photosynthesis rate, and CO_2 assimilation, directly impacting metabolism and plant growth (Mak et al., 2014; Reis et al., 2022; Yang et al., 2021) .

The decrease in the level of CO2 in cell structures causes a reduction in the activity of the enzyme ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco). Consequently, to repair this reduction in carboxylation, NADPH (nicotinamide adenine dinucleotide phosphate) accumulates and the NADP+ electron acceptor becomes unavailable, causing electron agglomeration at the end of the photochemical step. These electrons are transferred to molecular oxygen, resulting in (Campos et al., 2019) reactive oxygen species (ROS), such as hydrogen peroxide (H2O2) and superoxide anion ($O2^{\bullet-}$), which can deteriorate the photosynthetic apparatus, as well as the peroxidation of lipid membranes and chlorophylls. To contain the imbalance caused by low photosynthetic assimilation and other physiological processes that cause the formation of ROS, plants protect cells from possible oxidative damage through the antioxidant defense system, which is composed of enzymes such as superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT) and non-enzymatic components such as ascorbate, glutathione, carotenoids and phenolic compounds, which act to neutralize ROS. (Martins et al., 2024) (Campos et al., 2019; Sharma et al., 2012)

In addition to these modifications, changes in the photosynthetic apparatus are one of the main responses of plants under conditions of water deficit, an indirect way to evaluate this damage is by measuring the fluorescence of chlorophyll *a*, and the water deficit causes an imbalance between the production and use of electrons in photosystem II (PSII), affecting the maximum quantum yield of the PSII reaction centers (Fv/Fm ratio), ranging from 0.78 to 0.85. Another modification is the visual appearance and color of the leaves, which is directly affected by this stress, in addition to reducing the availability of energy in the plant, due to the lower photosynthetic activity and carbohydrate production. (Toscano et al., 2019) (Martins et al., 2024)

Salt stress triggers a series of adverse effects on plants, including the reduction of relative water content, the closure of stomata, the decrease in photosynthetic rate and plant growth, in addition, it causes modifications in leaf anatomy, as a strategy to limit water loss and preserve the efficiency of the photosynthetic process. In the photochemical realm, salinity directly compromises the functionality of photosystem II (PSII) by reducing the quantum efficiency of photosynthesis, altering chlorophyll fluorescence patterns, and in more severe cases, damaging the components of photosynthetic machinery, these damages result in the drop in photosynthetic pigment content and the consequent suppression of photosynthetic activity. (Acosta-Motos et al., 2017; Shahid et al., 2020) (Jańczak-Pieniążek et al., 2022; Stefanov et al., 2024)

As a form of defense against stress, plants activate a series of physiological and biochemical mechanisms. Among them, the increase in the activity of antioxidant enzymes, such as superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD), which act in the elimination of reactive oxygen species, in parallel, there is the accumulation of compatible osmolytes, such as proline and soluble sugars, which contribute to osmotic adjustment, in addition to the activation of toxic ion exclusion mechanisms, aiming at the maintenance of cellular homeostasis (Jańczak-Pieniążek et al., 2022; Shahid et al., 2020; Shahid et al., 2022) .

3 FINAL CONSIDERATIONS

The analysis of the literature shows that the Brazilian semi-arid region, although marked by water and soil restrictions, has high productive potential when managed with adaptive technologies and efficient water use practices. Deficient irrigation, associated with the choice of tolerant cultivars, such as elephant grass cv. BRS Capiaçu, is a viable strategy to promote sustainability and productive stability in regional agricultural systems.

The physiological responses of plants to water deficit and salinity highlight the importance of understanding the biochemical and photochemical mechanisms involved in acclimatization to stress. Such knowledge guides the development of more precise management techniques, which reconcile conservation of water resources and increased productivity. Thus, the integration between traditional practices and technological innovations is essential to strengthen agricultural resilience and mitigate the impacts of climate change in Brazil's semi-arid areas.

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