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*Article*

# Growth and Commercial Productivity of Onion Crops Subjected to Different Irrigation Rates

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**ABSTRACT**

Onions are highly sensitive to water deficit, especially during the bulb formation stage. In organic systems, this characteristic is intensified, making irrigation management decisive for growth and productivity. This study aimed to evaluate the impact of different irrigation depths on the growth and commercial productivity of onions in an organic system, through two field experiments conducted in 2014 and 2015. The experimental design was randomized blocks, with five replicates and four irrigation depths (42%, 50%, 83%, and 100% of the total depth, controlled by an Automatic Irrigation Actuator - AAI). Plant dry biomass (PDB), leaf area index (LAI), leaf area (LA), crop growth rates (CGR) and net assimilation rates (NAR), and commercial bulb productivity were evaluated. In 2015, the highest irrigation depths (83% and 100% of the AAI) promoted significantly higher biomass accumulation, leaf area, and growth rate. Although in 2014 no significant effects of irrigation depths on vegetative growth parameters were observed, in both years, commercial bulb yield was higher with the use of greater irrigation depths. Reduced irrigation depths (42% and 50% of the AAI) resulted in lower crop growth and significant reductions in yield. It is concluded that the application of adequate irrigation depths is essential to optimize onion growth and productivity in organic systems, with water deficit being a severe limiting factor.

**Keywords:** water use efficiency; plant metabolism; stress adaptation; sustainable cultural practices; agroecosystem.

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**RESUMO**

A cebola apresenta alta sensibilidade ao déficit hídrico, principalmente na fase de bulbificação. Em sistemas orgânicos, essa característica é intensificada, tornando o manejo da irrigação decisivo para o crescimento e a produtividade. Este estudo teve como objetivo avaliar o impacto de diferentes lâminas de irrigação no crescimento e na produtividade comercial da cebola em sistema orgânico, ao longo de dois experimentos de campo conduzidos em 2014 e 2015. O delineamento experimental foi em blocos casualizados, com cinco repetições e quatro lâminas de irrigação (42%, 50%, 83% e 100% da lâmina total, controladas por Acionador Automático para Irrigação - AAI). Foram avaliadas a biomassa seca de planta (BSP), o índice de área foliar (IAF), a área foliar (AF), as taxas de crescimento da cultura (TCC) e de assimilação líquida (TAL), e a produtividade comercial de bulbos. Em 2015, as maiores lâminas de irrigação (83% e 100% do AAI) promoveram significativamente maior acúmulo de biomassa, área foliar e taxa de crescimento. Embora em 2014 não tenham sido observados efeitos significativos das lâminas sobre os parâmetros de crescimento vegetativo, em ambos os anos, a produtividade comercial de bulbos foi superior com o uso das maiores lâminas de irrigação. As lâminas reduzidas (42% e 50% do AAI) resultaram em menor crescimento da cultura e reduções expressivas na produtividade. Conclui-se que a aplicação de lâminas de irrigação adequadas é fundamental para otimizar o crescimento e a produtividade da cebola em sistemas orgânicos, sendo o déficit hídrico um fator limitante severo.

**Palavras-chave:** eficiência do uso da água; metabolismo vegetal; adaptação ao estresse; práticas culturais sustentáveis; agroecossistema.

## Introduction

The onion (*Allium cepa* L.) is a vegetable widely cultivated around the world, originating about 4,000 years ago in Egypt and introduced to Brazil during colonization, expanding in the South with Azorean immigrants (Oliveira 2022). Currently, its production is globally significant, totaling more than 92 million tons annually on approximately 4.5 million hectares, with an average yield of 19.3 t ha$^{-1}$. Among the world's largest producers are China, India, the United States, and Iran (UzDaily 2023). In Brazil, the crop also has great economic relevance, with a production of approximately 1.64 million tons on 49,300 hectares, an average yield of 33.2 t ha$^{-1}$ and a value of over R$ 4 billion in 2023, with Santa Catarina being the main producing state (IBGE 2023).

The high productive efficiency of onions depends on suitable environmental conditions, especially fertile soils, water availability, and an appropriate photoperiod. Irrigation management is crucial, since maintaining moisture close to field capacity favors seedling emergence, initial establishment, and maximization of productivity Feitosa et al. (2020a). In addition, longer photoperiods associated with high temperatures accelerate bulb maturation, shortening the crop cycle and contributing to increased yields Gabriel et al. (2022).

Onion productivity is closely linked to the interaction between physiological factors, such as photosynthetic rate and stomatal conductance, and environmental conditions, varying according to the characteristics of each variety in bulb formation Bachie et al. (2019). Among the main factors that influence onion growth and productivity are population density, nutrition, water availability, and photoperiod. The latter plays a central role, as it regulates bulb initiation and development, determining the moment when the leaves cease to act primarily as photosynthetic organs and begin to direct photoassimilates for storage in the bulbous structure Terán-Chaves et al. (2023a).

However, irrigation management and soil water availability have often been neglected by producers, compromising onion growth, productivity, and quality. Irrigation is often carried out without planning, with indiscriminate application of water and a lack of knowledge about the soil-water-plant relationship, making it essential to know when and how much to irrigate to optimize yield and efficient water use (Tolossa 2021).

Knowledge of onion responses to available soil water levels allows for the improvement of production systems, increasing production efficiency. Thus, the objective of this study was to evaluate, over two years, the growth and commercial productivity of onions grown under different irrigation depths in an organic system in the Baixada Fluminense region of Rio de Janeiro.

**Materials and Methods**

Two experiments were conducted between May and October 2014 and 2015 at the Fazendinha Agroecológica do Km 47, located in the municipality of Seropédica, in the Baixada Fluminense region of the state of Rio de Janeiro, at coordinates 22º45` S and 43º41`W, at an altitude of 33 m. The region's climate is tropical, classified as Aw according to Köppen. Figure 1 shows the climatic conditions during the study period for both years.

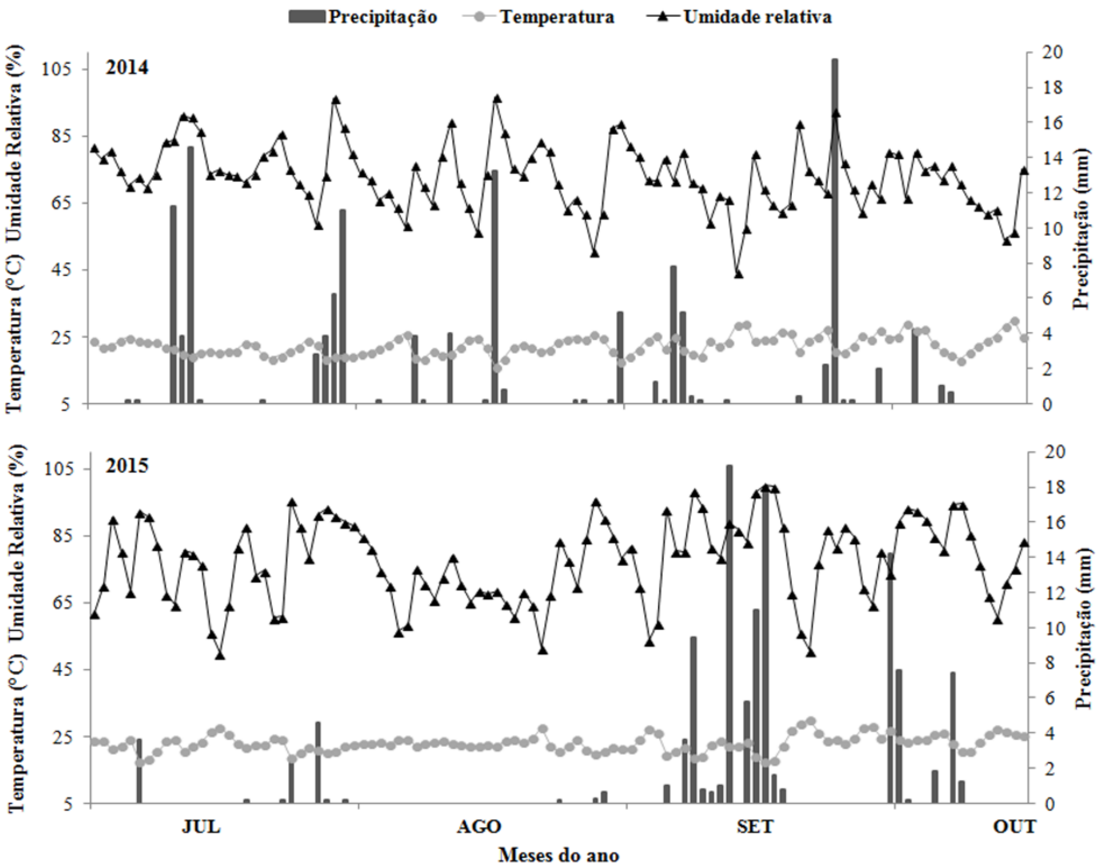



Figure 1. Meteorological data during the study period. Source: prepared by the authors

The soil in the experimental area is classified as Red-Yellow Argisol, sandy loam texture (Embrapa, 2006). Chemical analysis of the soil in the 0-20 cm layer showed the following values in 2014 and 2015, respectively: pH 6.2 and 6.5; Al 0.0 and 0.0 cmolc.dm$^{-3}$, Ca 3.7 and 3.2 cmolc dm$^{-3}$ , Mg 1.6 and 1.2 cmolc dm$^{-3}$ , K 120 and 152 mg dm$^{-3}$ , P 54 and 64 mg.dm$^{-3}$.

In both experiments, a randomized block design was adopted, with four levels of water replacement (42, 50, 83, and 100% of the irrigation depth determined to meet the crop's water requirements) and five replicates. Irrigation was performed by microirrigation, automatically controlled by the Automatic Irrigation Actuator (AAI) (Medici et al. 2010). The different depths were obtained using "iDrop normal" emitters (Irritec), with nominal flow rates of 2.0 and 4.0 L $^{h^{-1}}$, adjusted at different spacings on the side rows of each bed. The replacements corresponding to 42, 50, 83, and 100% of the determined rainfall, applied by the AAI and added to natural precipitation, resulted in 204, 224, 278, and 321 mm in 2014, and 278, 302, 397, and 444 mm in 2015.

The cultivar used was Alfa tropical, sown in 288-cell polystyrene trays in April in both years of the experiment. The seedlings were transplanted at the end of June, using cattle manure as a base fertilizer at a rate of1,0 kg $m^{-2}$ of dry matter as a . The plots were arranged in beds and had1 $m^2$ , with 40 plants cultivated per plot. The spacing adopted for the crop was0,10 m between plants and0,25 m between rows. Cultural practices consisted of weeding, phytosanitary control, and top dressing at 30 and 55 days after transplanting (DAT) with castor bean cake at a dose of150 g $^{m^{-2}}$, which is equivalent to 102 kg N $^{ha^{-1}}$.

Two contiguous plants were collected per plot, including the root system, at 16-day intervals between 8 and 88 days after transplanting (DAT), for a total of 6 collections. At the end of the cycle, in October, the plants and bulbs were collected in the usable area of each plot, disregarding the border rows and considering only the area designated for evaluation.

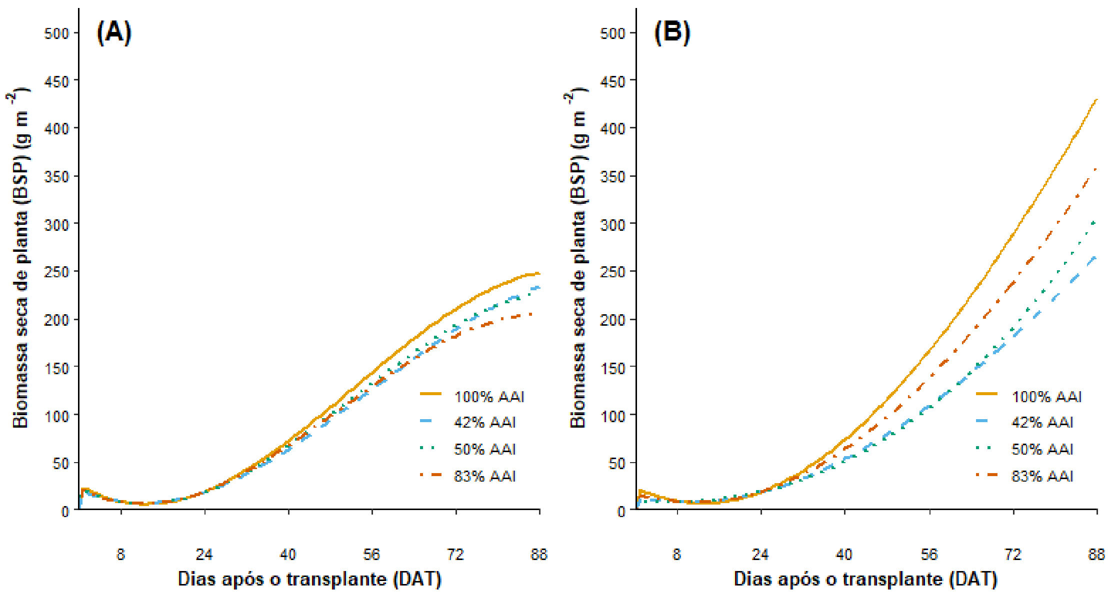
In each biomass sampling, the plants were divided into aerial parts, bulbs, and roots. The leaf area was determined by a photoelectric meter (Licor 3100, Licor Inc., USA), with the readings of the device multiplied by two due to the tubular leaves. The plant samples were dried in an oven at70 °C , and weighed. The data were converted to leaf area index (LAI) and total plant biomass per unit area of land, considering the area occupied by the two sampled plants. The data were transformed into natural logarithms to homogenize the variances of the different collection periods (Araújo 2003).

The LFA and biomass data were adjusted to 2nd-degreeand 3rd-degree polynomial models, which presented similar results in statistical terms, with the 2nd-degree model being chosen due to its greater simplicity. From this model, instantaneous values of crop growth rate and net assimilation rate were obtained by derivation (Hunt 1982).

The data obtained were submitted to analysis of variance (ANOVA), considering the irrigation layers as treatments and the blocks as replicates. When significance was found by the F test ($p \leq 0.05$), regression models were adjusted between the growth and productivity variables and the applied water replacement levels. The leaf area index (LAI) and total dry biomass data were adjusted to second-degree polynomial models, while the net assimilation rate (NAR) and crop growth rate (CGR) were obtained by derivation from these equations. For the commercial productivity of the bulbs, a linear model was adjusted as a function of irrigation depths.

**Results and Discussion**

The accumulation of biomass in onion plants was initially slow, especially up to 40–60 DAT, a period in which low vegetative growth and limited nutrient absorption are observed (Figures 2A and 2B). At this stage, the plants accumulated, on average, 17.4 to 28.5% of the total biomass of the 2014 and 2015 cycles. From 61 DAP onwards, growth intensified, concentrating in the bulbification phase, when up to 84% of dry matter and 73–89% of total nutrients accumulated, highlighting the importance of this phase for the final crop yield Kurtz et al. (2016).

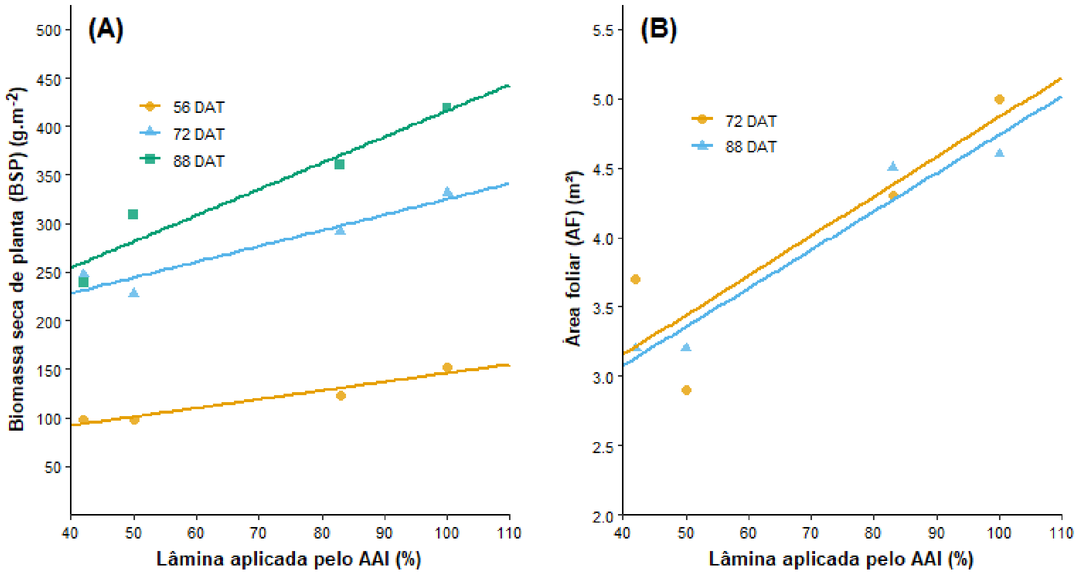



| | Treatments | Equations | $R^2$ |
|---|---|---|---|
| 2014 | 100% AAI | -0.000575 DAT² + 0.100417 DAT + 1.126372 | 0.95 |
| | 83% AAI | - 0.000588 DAT² + 0.009928 DAT + 1.129957 | 0.96 |
| | 50% AAI | - 0.000563 DAT² + 0.098231 DAT + 1.143728 | 0.96 |
| | 42% AAI | - 0.000512 DAT² + 0.093618 DAT + 1.179207 | 0.95 |
| | **Treatments** | **Equations** | **$R^2$** |
| 2015 | 100% AAI | - 0.000441 DAT² + 0.094019 DAT + 1.203769 | 0.97 |
| | 83% AAI | - 0.000388 DAT² + 0.086326 DAT + 1.288455 | 0.96 |
| | 50% AAI | - 0.000276 DAT² + 0.073079 DAT + 1.434422 | 0.94 |
| | 42% AAI | - 0.000348 DAT² + 0.078694 DAT + 1.358069 | 0.94 |

Figure 2 and Table 1. Total biomass of onion plants during the growth cycle, under different irrigation rates, in crops in 2014 (A) and 2015 (B) and their respective regression equations. Legend: BSP = dry plant biomass (g $m^{-2}$); DAT = days after transplanting; AAI = water applied by irrigation; $R^2$ = coefficient of determination. All equations were statistically significant ($p < 0.05$). Source: authors (2025).

With the onset of the bulbification process from 40 DAT, biomass accumulation was intense until 72 and 88 DAT, respectively, in 2014 (Figure 2A) and 2015 (Figure 2B). These periods accounted for 59.1 and 82.6% of the total biomass. Recent studies also highlight the bulbification phase as a determinant for the accelerated increase in onion biomass, especially when associated with adequate water availability conditions (Terán-Chaves et al., 2023b). In 2014, biomass increased from 72 DAT onwards, with this period accounting for 12.5% of the total biomass; however, this increase was lower than that observed in 2015 (Figure 2B), when it reached 32.6%. At the end of the two growing cycles, the dry biomass of the aerial part (BSP) in 2015 was 49.8% higher than in 2014 (Figure 2).

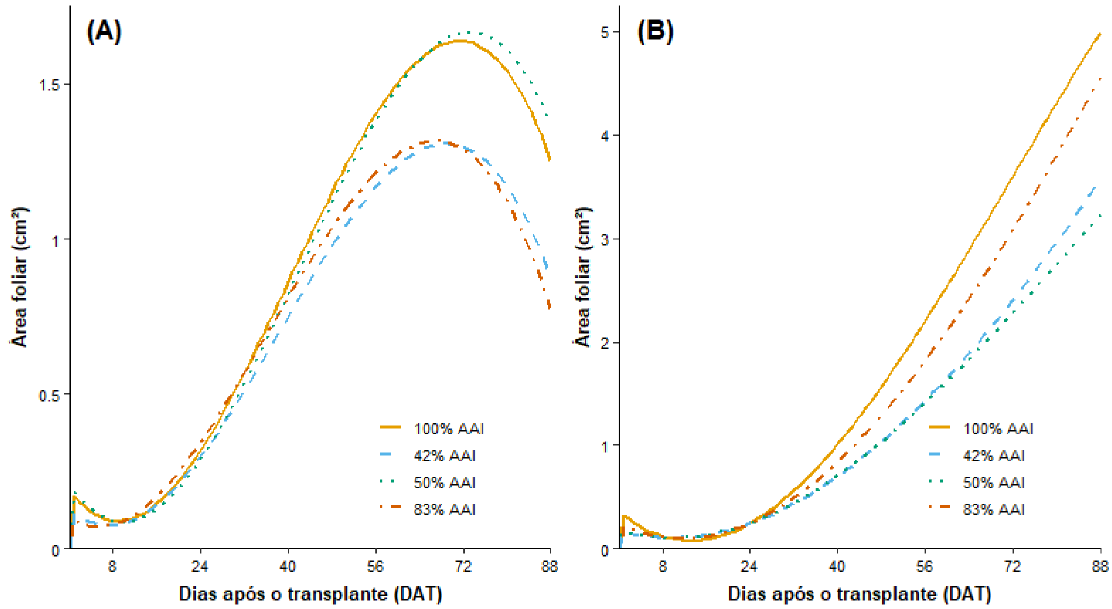
Irrigation depths significantly influenced biomass accumulation only in 2015, in the assessments carried out at 56, 72, and 88 DAT (Figure 3A), with the 100% water replacement depth responsible for the highest biomass. Similar results were observed by Souza et al. (2017) and Feitosa et al. (2020b), who reported a significant increase in onion growth and productivity due to adequate water supply, while irrigation deficits reduced biomass accumulation. This response is associated with physiological mechanisms of water stress, which directly affect cell turgidity and limit plant growth (Zegeye et al., 2024).




| | Treatments | Equations | $R^2$ |
|---|---|---|---|
| BSP | 56 DAT | -0.000575 DAT² + 0.100417 DAT + 1.126372 | 0.944 |
| | 72 DAT | - 0.000588 DAT² + 0.009928 DAT + 1.129957 | 0.9084 |
| | 88 DAT | - 0.000563 DAT² + 0.098231 DAT + 1.143728 | 0.9251 |
| AF | **Treatments** | **Equations** | **R** |
| | 88 DAT | 0.028(%AAI) + 1.9404 | 0.9406 |
| | 72 DAT | 0.0286(%AAI) + 1.9838 | 0.7849 |

Figure 3 and Table 2. Dry biomass and leaf area (LA) in response to different irrigation depths at 56, 72, and 88 DAT in 2015, and their respective regression equations. Legend: LA = leaf area ($dm^2$ $plant^{-1}$ ); %AAI = percentage of water applied by irrigation in relation to reference evapotranspiration; $R^2$ = coefficient of determination. Linear equations with statistical significance ($p < 0.05$). Source: prepared by the authors

From this period onwards, the increase in LAI intensified in both years; however, in 2014 this increase was only observed up to 72 DAT, due to the onset of plant senescence, while in 2015 growth continued until 88 DAT (Figure 3B). These results reflect the differences in cycle conditions and demonstrate the importance of irrigation depth in maintaining photosynthetic activity for longer in 2015.




| | Treatments | Equations |
|---|---|---|
| 2014 | 100% AAI | IAF=-0.000774 DAT² + 0.107498 DAT- 3.233912 |
| | 83% AAI | IAF=-0.000881 DAT² + 0.112356 DAT - 3.297499 |
| | 50% AAI | IAF=-0.000738 DAT² + 0.105759 DAT - 3.274529 |
| | 42% AAI | IAF=-0.000831 DAT² + 0.110149 DAT - 3.381481 |
| 2015 | Treatments | Equations |
| | 100% AAI | IAF=-0.000493 DAT² + 0.097367 DAT - 3.146379 |
| | 83% AAI | IAF=-0.000400 DAT² + 0.087048 DAT - 3.045261 |
| | 50% AAI | IAF=-0.000363 DAT² + 0.078585 DAT - 2.930102 |
| | 42% AAI | LAI=-0.000336 DAT² + 0.077356 DAT - 2.934725 |

Figure 4 and Table 3. Leaf area index (LAI) as a function of days after transplanting (DAT) under different irrigation rates and their respective regression equations.

Legend: LAI = leaf area index; DAT = days after transplanting; AAI = water applied by irrigation; $R^2$ = coefficient of determination. Second-degree polynomial equations with statistical significance ($p < 0.05$). Source: prepared by the authors

LAI was significantly influenced by irrigation rates only in 2015, in the evaluations performed at 72 and 88 DPT (Figure 4B). The irrigation rate corresponding to 100% of the total irrigation rate promoted the highest LAI values in both evaluation periods, while the 42% and 50% irrigation rates resulted in significant reductions of 41.3% and 30.9% in leaf area at 72 and 88 DAT, respectively. These results highlight the sensitivity of onions to water deficit, since the reduction in water supply directly compromised vegetative growth.

Corresponding to 50% of the blade applied by the AAI, there was an anticipation of the stagnation period, in relation to the other blades applied, which began at 40 DAT and continued until 48 DAT (Figure 4A). In 2015, the highest irrigation depths (100 and 83% of the depth applied by the AAI) showed decreasing TALs throughout the growing season. The blade corresponding to 50% of the blade applied by the AAI showed an increase in TAL until 16 DAT with a subsequent decrease, and the blade corresponding to 42% of the blade applied by the AAI showed a decreasing behavior until the end of the cycle, and after the beginning of the decrease in TAL, this behavior was not as intense when compared to the larger blades applied (Figure 4B).

The net assimilation rate (NAR) was directly affected by the irrigation blades, as they influenced the leaf area index (LAI) and biomass (Figures 5A and 5B). In 2014, no significant differences in NAR were observed, as the blades did not alter vegetative growth. In 2015, the larger blades increased the LAI and, consequently, the biomass, due to greater light interception. The smaller blades, on the other hand, presented a higher NAR due to a compensatory effect, demonstrating greater photosynthetic efficiency per unit of leaf area under conditions of lower water availability. This behavior was also described by (Mitku and Adamite 2025), who emphasize that moderate water deficits can improve water use efficiency and photosynthesis, although they reduce total production, highlighting the importance of water management to balance leaf area and physiological performance.

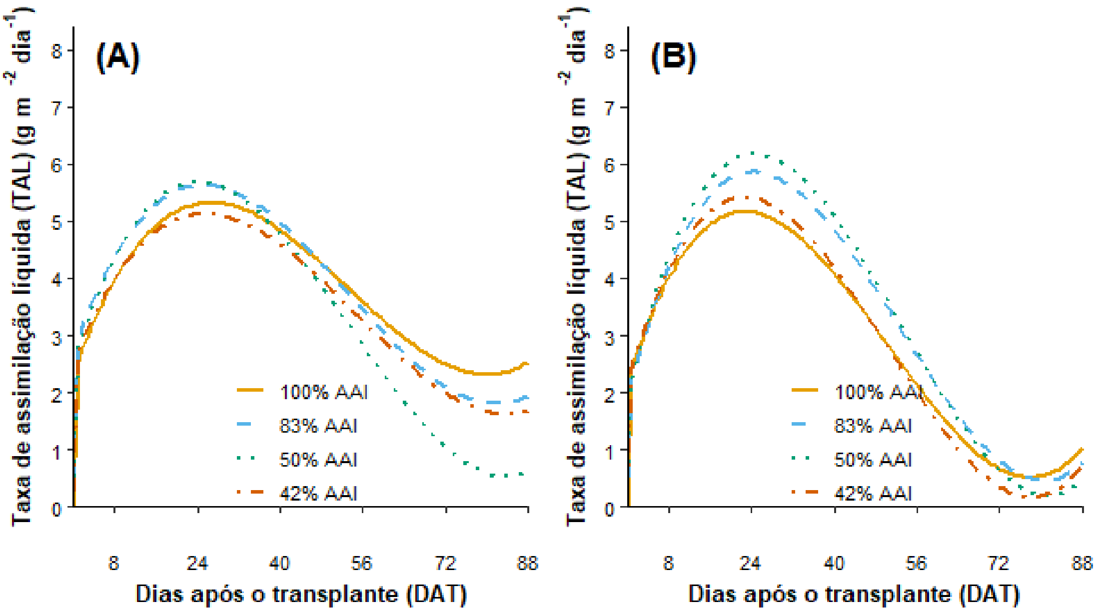



Figure 5. Net assimilation rate (NAR) for different irrigation depths during the six assessments carried out in 2014 (A) and 2015 (B). Source: prepared by the authors

The crop growth rate (CGR) showed different behaviors between the two years of cultivation (Figures 6A and 6B). In 2014, a similar pattern was observed between the irrigation depths applied by the AAI, with no significant differences in CGR values, which increased up to 56 DAT and decreased until the end of the cycle. In 2015, clear differences were observed between treatments: the blades corresponding to 100 and 83% of the blade applied by the AAI resulted in the highest CGRs up to 72 DAT, but with a sharp drop after that period. The 50% blade showed intermediate values, reaching its peak later, at 88 DAT, while the 42% blade maintained the lowest values throughout the cycle, reaching a maximum at 72 DAT, about 58% lower than that obtained with the 100% blade. These results show that the higher water replenishment applied by AAI anticipates and maximizes TCC, but for a shorter time, while the reduced blades provide lower growth intensity, but sustained for a longer period.

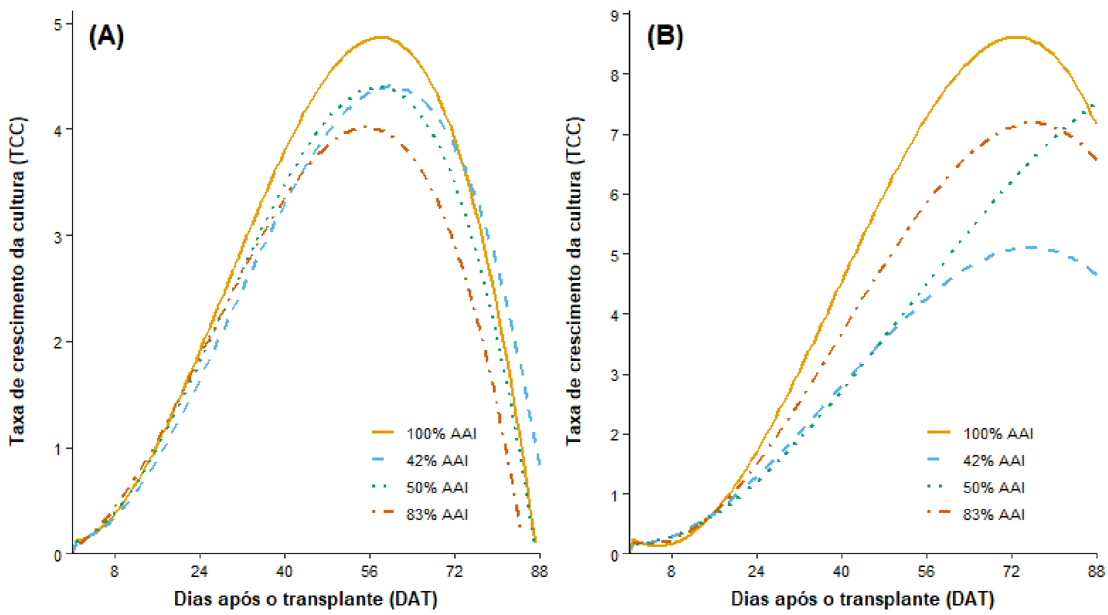



Figure 6. Crop growth rate for different irrigation depths during the six assessments carried out in 2014 (A) and 2015 (B). Source: prepared by the authors

The results obtained for biomass, LAI, TAL, and TCC show that the 2015 crop showed better onion crop development compared to 2014. This result may be related to the higher occurrence of leaf diseases such as "seven-fold disease" (*Colletotrichun* sp) and "purple spot" (*Alternaria porri*) in 2014, which caused leaf drying of the crop from the beginning of cultivation. A higher number of rainfall events in the 2014 crop compared to the 2015 crop (Figure 1) may have promoted a more favorable environment for the occurrence of diseases. The higher incidence of diseases in the 2014 crop also led to an acceleration of the leaf senescence process compared to the 2015 crop (Figure 4).

Although significant effects of irrigation depths on plant biomass and leaf area were observed only in the 2015 crop, commercial bulb productivity was influenced in both years (Figure 7). Depths corresponding to 100% and 42% of the total depth provided the highest and lowest commercial productivity, respectively. The increase in productivity obtained with 100% replacement compared to 42% of the rainfall was approximately 39.8% in 2014 and 54.5% in 2015, evidencing the significant response of the crop to greater water availability. This behavior was also observed by Andrade et al. (2022), who verified an increase in bulb productivity under higher irrigation levels. In contrast, Carvalho et al. (2017), evaluating the crop in an organic system, found no significant differences in productivity due to irrigation management, emphasizing that the response of onions to water availability may vary depending on the cultivation system and environmental conditions.

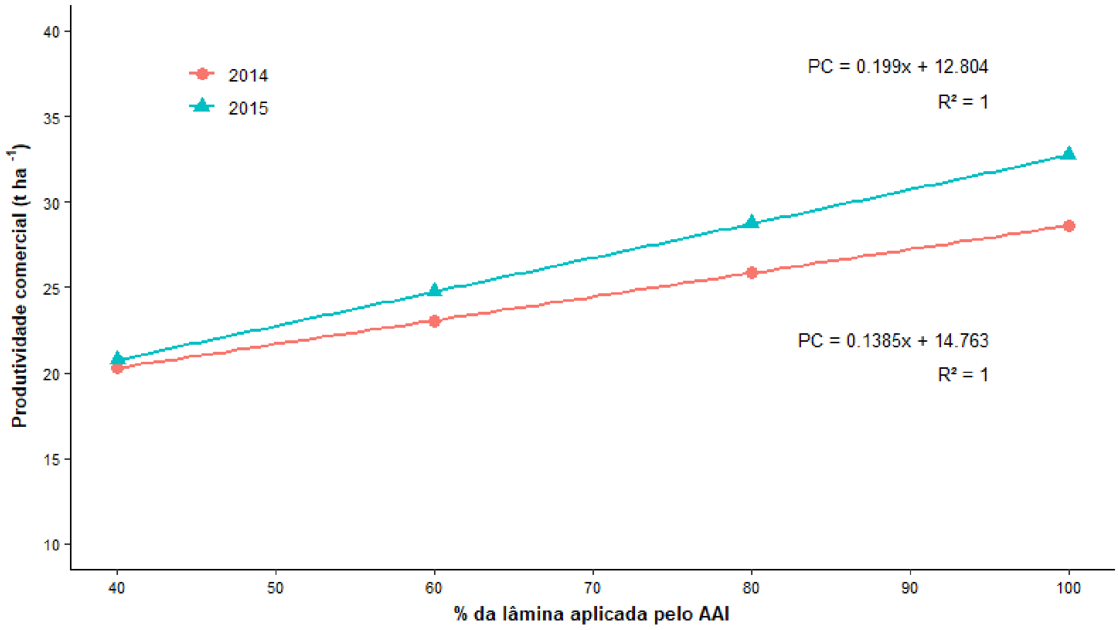



Figure 7. Commercial onion bulb productivity in response to different irrigation depths in 2014 and 2015 and their respective regression equations for commercial productivity (CP) as a function of the percentage of water applied by irrigation in two years of cultivation. Legend: CP = commercial productivity (t ha$^{-1}$ ); %AAI = percentage of water applied by irrigation in relation to reference evapotranspiration; $R^2$ = coefficient of determination. Linear equations with statistical significance ($p < 0.05$). Values represent the average of four replicates per treatment. Source: prepared by the authors

## Conclusions

Onions grown organically showed high sensitivity to water deficit. The 100% water requirement, determined by tensiometric monitoring, provided the highest biomass and productivity values, while lower replacements significantly reduced crop performance. Thus, full replacement of water demand is essential to maximize productivity and water use efficiency in tropical organic systems.

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