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Evaluation of the effect of nitrogen fertirrigation on productivity and efficiency of water use in broccolis

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ABSTRACT: Broccoli is attractive to consumers due to its high nutritional value. This study aimed to evaluate the crop yield components and water yield of the broccoli hybrid Centenário growing under different irrigation depths and nitrogen doses. The treatments consisted of no N fertilization (0 kg ha^{-1}), half dose (75 kg ha^{-1}), full dose (150 kg ha^{-1}), double dose (300 kg ha^{-1}), and triple dose (450 kg ha^{-1}). Irrigation depths tested were: 0, 75, 100, 125, and 150% of the crop evapotranspiration (ETc). The application of smaller water depths during the growth stage of the Centenário hybrid increased water yields. However, regardless of the nitrogen dose, irrigation depths greater than crop evapotranspiration resulted in better crop productivity.
Keywords: *Brassica oleracea* L.; irrigation management; sustainability; precision irrigation.

Avaliação do efeito da fertirrigação com nitrogênio na produtividade e eficiência do uso de água no brócolis

RESUMO: O brócolis é atraente para o consumidor devido ao seu alto valor nutricional. Este trabalho teve como objetivo avaliar os componentes do rendimento da cultura e da eficiência do uso da água no híbrido de brócolis Centenário, cultivado sob diferentes lâminas de irrigação e doses de nitrogênio. Os tratamentos consistiram de adubação sem N (0 kg ha^{-1}), meia dose (75 kg ha^{-1}), dose completa (150 kg ha^{-1}), dose dupla (300 kg ha^{-1}) e dose tripla (450 kg ha^{-1}). As lâminas de irrigação testadas foram: 0, 75, 100, 125 e 150% da evapotranspiração da cultura (ETc). A aplicação de lâminas de água menores durante a fase de crescimento do híbrido Centenário aumentou a eficiência de uso da água. No entanto, independentemente da dose de nitrogênio, lâminas de irrigação maiores que a evapotranspiração da cultura resultaram em melhores produtividades da cultura.
Palavras-chave: *Brassica oleracea* L.; manejo da irrigação; sustentabilidade; irrigação de precisão.

1. INTRODUCTION

Studies have shown that broccoli is a nutritionally rich food source and has the potential to protect against metabolic disorders, inflammatory diseases, and cancer (LÓPEZ-CHILLÓN et al., 2018).

Broccoli is a vegetable with a high water demand, which may decrease its productivity. Brassica production and quality are limited by soil water excess and deficit, which may decrease crop productivity (PEREIRA ET AL., 2018).

Moreover, nitrogen and potassium fertilization improves yield rates and the quality of broccoli inflorescences (BLIND et al., 2015).

Given the importance of broccoli and the lack of information on its water demands and proper nitrogen fertilization conditions, this study aimed to evaluate the effects of irrigation depths and nitrogen doses on the productivity components and water yields of the broccoli hybrid Centenário.

2. MATERIAL AND METHODS

The study was developed in the irrigation and drainage area of the Agricultural Engineering department of the Federal University of Viçosa, in Viçosa, MG, at UTM coordinates: 7701915.38 m S, 722542.99 m E, zone 23K. The cultivation period was from February to August 2019.

The broccoli hybrid Centenário has a compact bluish-green head and fine granulometry, with a crop cycle of about 72 days after transplantation (DAT). Seedlings produced in Styrofoam trays were transplanted 38 days after sowing. Planting rows were 0.7 m apart, and plants within rows were 0.5 m apart, resulting in a population of 28,570 plants ha^{-1}. Before transplantation, the experimental area was fertilized with 300 kg ha^{-1} P_2O_5, 20 kg ha^{-1} borax@, 20 kg ha^{-1} $ZnSO_4$, and 80 kg ha^{-1} K_2O.

We evaluated five nitrogen doses (N), which were chosen based on the recommendations for broccoli, i.e., 150 kg ha^{-1} (Vidigal; Pedrosa, 2007). The treatments consisted of no N fertilization (0 kg ha^{-1}), half dose (75 kg ha^{-1}), full dose (150

kg ha^{-1}), double dose (300 kg ha^{-1}), and triple dose (450 kg ha^{-1}). Nitrogen was supplied as urea and applied at three growth stages: 20% at 15 DAT, 40% at 30 DAT, and 40% at 45 DAT. Additionally, at topdressing, we also applied 80 kg ha^{-1} K2O, supplied as potassium chloride. Topdressings were performed by diluting the required urea and potassium chloride in water and applying the solution near the broccoli plants.

Irrigation depths tested were: 0, 75, 100, 125, and 150% of the crop evapotranspiration (ETc), which were applied during all crop cycles. At 71 DAT, broccoli plants were at the harvesting point, with well-developed dark green flower buds but no open flowers. At the time of harvest, we collected each inflorescence separately and measured for fresh weight, diameter, and height. We also determined inflorescence dry weights after drying samples at 60 ºC until constant weight. Total inflorescence yield - TIY (Kg ha-1) was estimated by multiplying fresh weights by the population number (28570 plants ha^{-1}). Irrigation water yields (IWY) were obtained by dividing TIY (kg ha^{-1}) by total irrigation water (IW) applied (m^3 ha^{-1}).

The experimental area had 8.40 m^2, with three rows of eight plants, totalizing 24 plants. Regression coefficient significance was checked by t-test at 0.05 probability.

3. RESULTS

We verified that broccoli yield components may have quadratic and linear responses to irrigation depths and nitrogen doses (Table 1). As consequence, different response surfaces were obtained to inflorescence diameter (ID) (Figure 1A) and inflorescence height (IH) (Figure 1B).

Inflorescence fresh weight (IFW) (Figure 2A) and total inflorescence yield (TIY) (Figure 2B) showed similar variations as in ID, evidencing the close relationship among these variables. We also investigated water-use efficiency through irrigation water yield (IWY) measures. Both irrigation and N fertilization had a significant effect ($p<0.05$) on IWY (Figure 3).

Additionally, we observed that IWY decreased as N doses were increased. This result was related to TIY decreases at higher N doses (Figure 3). This is because high N doses may have an unfavorable effect on broccoli production.

Table 1. Coefficients of regression equations for broccoli yield components.
Tabela 1. Coeficientes das equações de regressão para componentes de rendimento de brócolis.

Y	β_0[1]	β_1[1]	*P*-value	β_2[1]	*P*-value	β_3[1]	*P*-value	β_4[1]	*P*-value
ID[2]	10.00580	0.06600	0.01000	-0.00030	0.01000	0.01740	0.01000	0.00003	0.01000
IH[3]	10.45160	0.06110	0.01000	-0.00020	0.01000	0.00500	0.15000	-	-
IFW[4]	223.12330	4.74530	0.01000	-0.01980	0.05000	0.88800	0.01000	-0.00120	0.15000
TIY[5]	6374.95230	135.58190	0.01000	-0.56780	0.05000	25.37000	0.05000	-0.03490	0.15000
IWY[6]	104.46800	-1.75590	0.01000	0.00740	0.05000	-0.00120	0.44000	-	-

[1]Coefficients of the fitted regression as a function of irrigation depth (L) and nitrogen dose (N), following the model: $Y= \beta_0+ \beta_1L+ \beta_2L^2+ \beta_3D + \beta4D^2$; [2] inflorescence diameter (ID); [3] inflorescence height (IH); [4] inflorescence fresh weight (IFW); [5] total inflorescence yield (TIY); [6] irrigation water yield (IWY).
[1]Coeficientes da regressão ajustada em função da lâmina de irrigação (L) e dose de nitrogênio (N), seguindo o modelo: Y= β0+ β1L+ β2L.2+ β3D + β4D2; [2] diâmetros de inflorescência (DI); [3] altura da inflorescência (AI); [4] massa fresca de inflorescência (FIW); [5] produtividade total de inflorescências (TIY); [6] rendimento de água de irrigação (IWY).

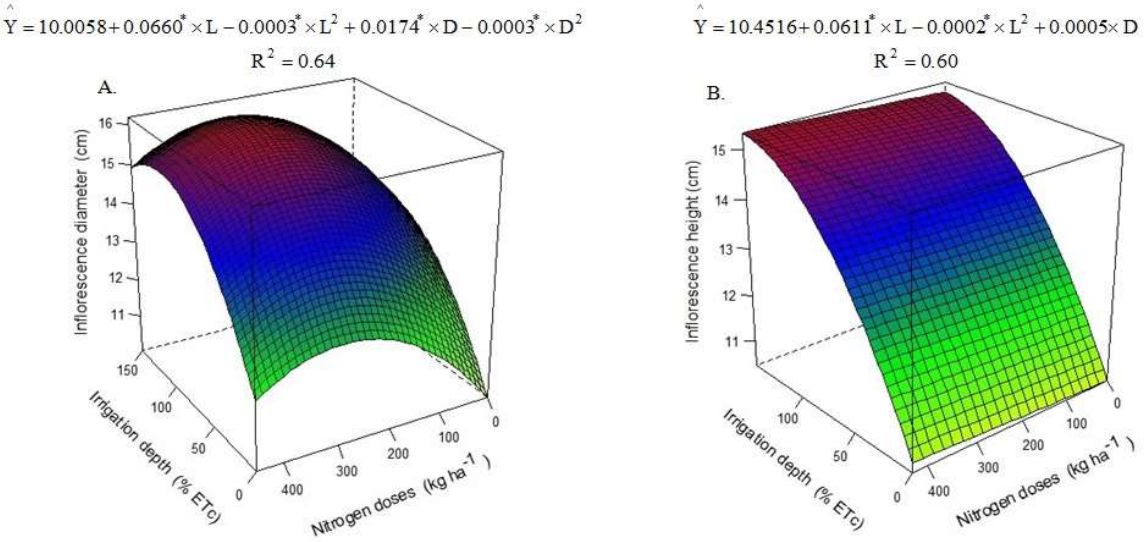

Figure 1. Response surface for inflorescence characteristics: (A) inflorescence diameter - ID and (B) inflorescence height - IH (in centimeters) as a function of irrigation depth (L) and nitrogen doses (N). *Significant at $p \leq 0.05$ by the t-test.
Figura 1. Superfície de resposta para características da inflorescência: (A) diâmetro da inflorescência - ID e (B) altura da inflorescência - IH (em centímetros) em função da lâmina de irrigação (L) e das doses de nitrogênio (N). *Significativo para $p \leq 0,05$ pelo teste t.

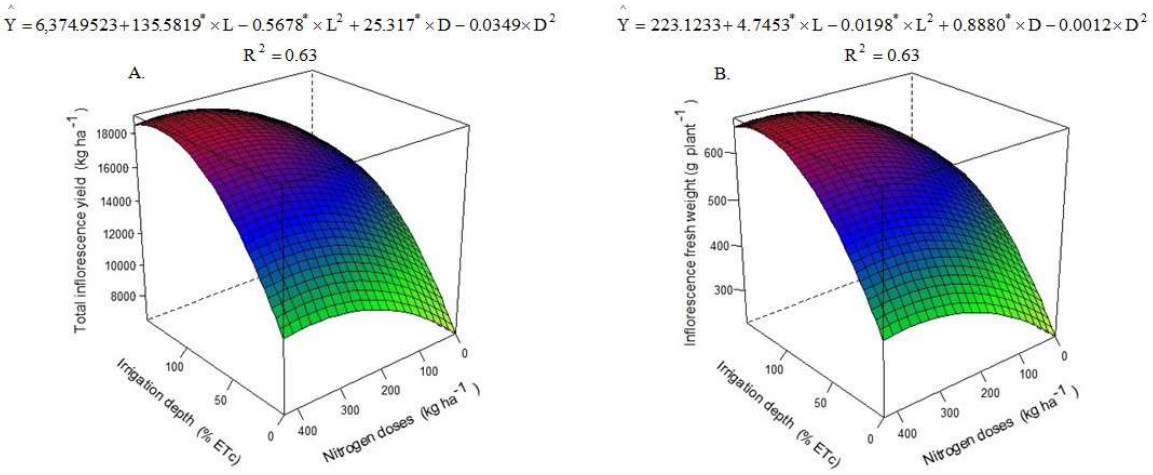

Figure 2. Response surface for inflorescence productive characteristics: (A) total inflorescence yield – TIY and (B) inflorescence fresh weight – IFW as a function of irrigation depth (L) and nitrogen dose (N). *Significant at $p \leq 0.05$ by the t-test.
Figura 2. Superfície de resposta para características produtivas da inflorescência: (A) produtividade total da inflorescência – TIY e (B) massa fresca da inflorescência – IFW em função da lâmina de irrigação (L) e dose de nitrogênio (N). *Significativo para $p \leq 0{,}05$ pelo teste t.

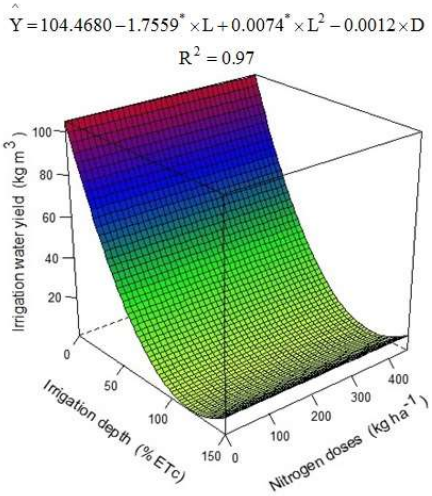

Figure 3. Response surface for irrigation water yield: Irrigation water yield - IWY as a function of irrigation depth (L) and nitrogen doses (N). *Significant at $p \leq 0.05$ by the t-test.
Figura 3. Superfície de resposta para produção de água para irrigação: Produção de água para irrigação - IWY em função da lâmina de irrigação (L) e das doses de nitrogênio (N). *Significativo para $p \leq 0{,}05$ pelo teste t.

4. DISCUSSION

The highest ID was 16.3 cm at an irrigation depth of 110.0% of ETc and N dose of 290.0 kg ha^{-1}. The highest water availability (150% of the ETc) combined with the highest fertilization dose (450 kg ha^{-1} N) led to a better IH, which was 15.34 cm (Figure 1B). It is known that broccoli inflorescence heights decrease as irrigation depths are reduced. We also observed this behavior, regardless of the N dose. On the other hand, due to the crucial importance of N in broccoli growth and development, we expected size increases at higher N doses (BIKA et al., 2018). However, high N doses can lead to environmental problems and groundwater pollution. Therefore, the benefits of higher inflorescences based on higher N doses should be better evaluated.

Vidigal et al. (2021) reported increased inflorescence weights at N doses above 300 kg ha^{-1}. Water supply is considered a favorable factor for broccoli development, as plants under water stress can show loss of growth. Based on the fitted model, the cultivar Centenário showed the best IFW (671.7 g plant^{-1}) at an irrigation depth of 119.4% of the ETc and N dose of 370 kg ha^{-1}. This result is greater than the finding of Lalla et al. (2010), which was 568.7 g. The largest TIY estimated here was 19078 kg ha^{-1} at an N dose of 370 kg ha^{-1} and irrigation depth of 119.4% of the ETC.

Applying irrigation depths of 150, 125, 100, 75, and 0% of the ETc at an N dose of 150 kg ha^{-1} resulted in yields of 16,900; 17,500; 17,200; 16,300, and 9,400 kg ha^{-1}, respectively. However, the TIY of broccolis may be quite variable depending on the production system and crop management.

It decreased linearly as the N dose increased and had a quadratic effect with irrigation depths. At each fertilization level, IWY had a minimum value at an irrigation depth of 118.64% of the ETc (Figure 3). The highest IWY values were reached at N doses close to 0 kg ha^{-1}, while the lowest ones were at 450 kg N ha^{-1}. This reduction with increasing irrigation depths may be explained by the occurrence of twelve rainfall events, totaling 59 mm, during the growing period. These rains supplied enough water to produce broccoli inflorescence at the lowest irrigation depth, and productivity did not increase much with the applied water.

Regarding irrigation, IWY varied with the water depth studied. Although the highest TIY (19,060 kg ha^{-1}) was observed at 316.54 mm irrigation depth (Figure 2A), this treatment had lower efficiency in terms of water use, resulting in the lowest IWY (0.60 kg m^{-3}) (Figure 3). On the other hand, the treatment with the lowest TIY (6,375 kg ha^{-1}), using only 8.63 mm irrigation depth (Figure 2A) during crop establishment, improved water-use efficiency, showing a higher IWY (104.46 kg m^{-3}) (Figure 3). This trend has also been observed in other studies, in which the highest IWY is found at smaller irrigation depths (GEISENHOFF et al., 2015).

5. CONCLUSIONS

Variations in irrigation depth and nitrogen dose influence crop yield of the broccoli hybrid Centenário. The critical irrigation depth with the best yield components was above 100% of the ETc. Moreover, the nitrogen fertilization dose that results in the best yield components is higher than the recommended. Under conditions similar to ours, the best nitrogen fertilization doses are 370 kg ha^{-1}, but its economical availability should be yet evaluated.

Higher yields are obtained at an irrigation depth of 119.40% of the ETc. The greater the water-use efficiency, the smaller the irrigation depth within each nitrogen fertilization dose.

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Review by institutional committee: Not applicable.

Ethics Committee: Not applicable.

Data availability: Study data can be obtained by request to the corresponding author or the second author, via e-mail. It is not available on the website as the research project is still under development.

Conflicts of Interest: The authors declare no conflict of interest. Supporting entities had no role in the study's design; in the collection, analysis, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.