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Crop Science/ Original Article

Production of green cowpea beans fertigated by continuous and pulse drip irrigation

Abstract – The objective of this work was to evaluate the production of green cowpea beans under conventional fertilization, different fertigation depths, and replacement of crop evapotranspiration (ETc) through continuous and pulse drip irrigation. The experimental design was a randomized complete block with 12 treatments distributed in a 5x2+2 factorial arrangement, with five ETc replacement irrigation depths (40, 60, 80, 100, and 120%), combined with two types of fertigation application (pulse and continuous) plus two additional treatments with pulse (control 1) and continuous (control 2) irrigation at 100% of ETc under conventional fertilization. The analyzed variables were: number of pods, number of grains, fresh and dry mass of pods and grains, and total shoot fresh and dry mass. Cowpea showed a better productive performance at the fertigation depths between 80 and 100% of ETc. Moreover, pulse fertigation promotes higher yields for all production variables analyzed. Regardless of the type of application (pulse or continuous), the productive variables show better results at the fertigation depths estimated for maximum physical efficiency than in the treatments with conventional fertilization and irrigation with a depth of 100% of ETc.

Index terms: *Vigna unguiculata*, evapotranspiration, grain yield, water management.

Produção de grãos verdes de feijão-caupi fertirrigado por gotejamento contínuo e pulsado

Resumo – O objetivo deste trabalho foi avaliar a produção de grãos verdes de feijão-caupi sob adubação convencional, diferentes lâminas de fertirrigação e reposição da evapotranspiração da cultura (ETc) por gotejamento contínuo e pulsado. O delineamento experimental foi em blocos ao acaso, com 12 tratamentos distribuídos em arranjo fatorial 5x2+2, com cinco lâminas de reposição da ETc (40, 60, 80, 100 e 120%), combinadas com dois tipos de aplicação de fertirrigação (pulsada e contínua) mais dois tratamentos adicionais com irrigação pulsada (testemunha 1) e contínua (testemunha 2), com lâmina de 100% da ETc sob adubação convencional. As variáveis analisadas foram: número de vagens, número de grãos, massa fresca e seca das vagens e dos grãos, e massa fresca e seca total da parte aérea. O feijão-caupi apresentou melhor desempenho produtivo nas lâminas de fertirrigação entre 80 e 100% da ETc. Além disso, a fertirrigação pulsada promove maiores rendimentos para todas as variáveis de produção analisadas. Independentemente do tipo de aplicação (pulsado ou contínuo), as variáveis produtivas apresentam os melhores resultados nas lâminas de fertirrigação estimadas para máxima eficiência física do que nos tratamentos com adubação convencional e irrigação com a lâmina de 100% da ETc.

Termos para indexação: *Vigna unguiculata*, evapotranspiração, rendimento de grãos, manejo da água.

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Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is a legume rich in nutrients and proteins, standing out for its socioeconomic importance in semiarid regions (Melo et al., 2018). However, there may be a decrease in cowpea grain yield depending on the intensity of water deficit and the stage of development that the plant is at when this deficit occurs (Ndiso et al., 2016; Toudou Daouda et al., 2018).

For improvements in crop yield, Busato et al. (2011) highlighted the use of tools and techniques that provide support for crop development, contributing to an intensive and sustainable agriculture. In this scenario, the drip irrigation method associated with fertigation stands out due to an efficient application of water and nutrients to the plants, allowing of adjustments during the addition of fertilizers at different phenological stages of the crop, resulting in a more economic and efficient fertilizer use (Costa et al., 2015).

Zamora et al. (2019) concluded that, among the existing technologies to support irrigation management, pulse irrigation has shown significant effects on the productivity of several crops. In this irrigation system, the application of an irrigation depth is fractionated in order to add water and nutrients close to the root zone of the plant, reducing the risks of nutrient leaching and water loss through percolation (Madane et al., 2018; Zamora et al., 2019).

In the literature, a positive effect of the appropriate irrigation and fertilization management on cowpea crop yield has been observed by Guimarães et al. (2020), Mota et al. (2020), and Soares et al. (2021). However, there are no known studies focusing on the production of cowpea beans fertilized conventionally and fertigated by continuous and pulse drip irrigation.

The objective of this work was to evaluate the production of green cowpea beans under conventional fertilization, different fertigation depths, and replacement of ETc through continuous and pulse drip irrigation.

Materials and Methods

The experiment was carried out in a greenhouse (13.20 m length x 4.5 m width) located at the Carpina sugarcane experimental station of Universidade Federal Rural de Pernambuco, in the municipality of Carpina, in the state of Pernambuco, Brazil (07º51'13"S', 35º14'10"W, at 180 m altitude).

In the greenhouse, 48 pots, each with an 85 L capacity, were placed at a height of 0.20 m from the soil surface. To facilitate drainage, each pot was filled initially with a layer of gravel with a 25 mm granulometry, totaling a volume of 0.48 m^3. Afterwards, the entire upper surface of the gravel was covered with a geotextile blanket to keep the particles from the upper layer from going to the lower layer and drainage system.

The soil used to fill the pots is classified as a Argissolo Amarelo distrófico abrupto according to Santos et al. (2013), equivalent to a hyperdystric abruptic Acrisol (IUSS Working Group WRB, 2015), with a loamy sandy texture (730 g kg^{-1} sand, 90 g kg^{-1} silt, and 180 g kg^{-1} clay), a soil and particle density of 1.37 and 2.52 g cm^{-3}, respectively, and a total porosity of 45.60%.

Before the implementation of the experiment, the soil was subjected to the chemical analysis according to Silva et al., (1998), which showed: pH 4.5; 1.60, 1.0, 0.66, 0.18, and 0.55 $cmol_c$ dm^{-3} Ca^{+2}, Mg^{+2}, Na^+, K^+, and Al^{+3}, respectively; 8.0 mg dm^{-3} P; 2.64 g kg^{-1} organic matter; and sum of bases, cation exchange capacity (CTC), and effective CTC of 3.44, 7.77, and 3.99 $cmol_c$ dm^{-3}, respectively.

The water used for irrigation in the experiment was also subjected to the chemical analysis, which showed: pH 6.8, electrical conductivity of 0.2 dS m^{-1}, 4.0 mg L^{-1} K^+, 11.22 mg L^{-1} Ca^{2+}, 2.92 mg L^{-1} Mg^{2+}, 32.10 mg L^{-1} Na^+, 0.0 mg L^{-1} ammonia, 9.32 mg L^{-1} sulfate, and 38.04 mg L^{-1} alkalinity and chlorides.

In order to correct the acidity of the soil, which presented a pH of 4.5, liming was performed by applying 60.29 g dm^{-3} calcitic limestone in each pot (Cavalcanti, 2008). For conventional fertilization, the base fertilizer was applied in granular form directly to the soil as recommended, using 4.2 g dm^{-3} N, 4.7 g dm^{-3} K, and 30.5 g dm^{-3} P, whose sources were urea, potassium chloride, and simple superphosphate, respectively. Topdressing was applied 20 days after seedling emergence, using 6.4 g dm^{-3} N and 7.05 g dm^{-3} K. Each experimental plot was fertigated (received fertilizer through irrigation water) according to Novais et al. (1991). The total amount of the fertilizers applied in eight fertigation runs were: 23.11 g monoammonium phosphate, containing 12% N and 61% P_2O_5; 16.02 g Multi-npK (Haifa Química do Brasil Ltda, São Paulo, SP, Brazil), with 13% N, 2.0% P_2O_5, and 44% K_2O; 1.56 g MS-2 Multimicros (UBY Agroquímica LTDA., Uberaba, MG, Brazil), containing 7.0% B, 1.0% Cu, 9.5% S, 7.0% Mn, 0.1% Mo, and 12% Zn; and 1.2 g Fe-EDTA 6% Fe.

The experimental design was a randomized complete block, with four replicates, in a 5x2+2 factorial arrangement, with five irrigation depths (40, 60, 80, 100, and 120% of crop evapotranspiration – ETc), combined with two types of fertigation application (pulse and continuous) plus two additional treatments, consisting of pulse (control 1) or continuous (control 2) irrigation at 100% of ETc under conventional fertilization.

The adopted irrigation system was drip irrigation, with self-compensating emitters, a nominal flow rate of 2 L h^{-1} in each pot, a disc filter, and a 0.5 HP horizontal axis centrifugal pump to collect and supply the fertilizer solution. The irrigation sub-units consisted of side pipes in which blind low-density polyethylene tubes (30 nominal pressure and 16 mm internal diameter) were inserted through connectors, interconnecting the drip tape and the water distribution line.

The irrigations were performed every two days, totaling 13 irrigations, in which the ETc was obtained directly by averaging the water balance of three drainage lysimeters with an 85 L capacity, which were used during cowpea crop growth and installed inside the greenhouse. Specifically, water balance was calculated every 24 hours, and the ETc was obtained by the difference between the applied irrigation depth and the collected drainage depth. For the application of pulse irrigation, five irrigation pulses with a 60 min rest interval between irrigations were adopted.

The evaluated crop was 'BRS Tumucumaque' cowpea in a single cycle. For this, planting was carried out in August, with three seeds sown per pot at a depth of 5.0 cm. Thinning was performed after germination and seedling establishment, maintaining one plant per pot. Harvesting took place in October, when a cycle of 53 days was completed and the green beans reached a 70% moisture content according to Freire Filho et al. (2005).

The evaluated variables were: number of pods per plant, number of grains per pod, fresh and dry mass of the pods without the grains, fresh and dry mass of the grains, total fresh and dry mass of the shoot, and percentage of hatched pods.

First, total shoot fresh mass (leaves, branches, and stem), the fresh mass of the pods without grains, and the fresh mass of the grains were quantified on an analytical balance with a precision of 0.01 g. Afterwards, the samples were placed in kraft paper bags, duly identified, and taken to an oven with forced-air ventilation, at 65ºC, until reaching a constant weight. Then, the dry mass of the materials was quantified in the same analytical balance in order to obtain the values of total dry mass of the shoot, dry mass of the pods without the grains, and dry mass of the grains.

The number of pods per plant and number of grains per pod were determined by counting the pods per plant and grains per pod, respectively. The percentage of hatched pods was calculated based on the number of hatched pods in each experimental plot in relation to the total number of pods.

The obtained data were subjected to the analysis of variance by the F-test, and, when significant, the observed effects (irrigation depths) were subjected to the regression analysis, and means (replacement of irrigation depth by continuous and pulse application) were compared by the Scott-Knott test, at 5% probability. Controls 1 and 2 were compared with each other, also by the Scott-Knott test, at 5% probability.

The selection of the model that best fitted the data was based on the four following criteria: non-significant effect of the regression deviation, significance of the fitting equation parameters at 5% probability, the highest value of the coefficient of determination, and the biological explanation of each variable as a function of the evaluated treatments.

Results and Discussion

According to the summary of the analysis of variance (Table 1), there was a significant effect of the ETc replacement irrigation depths and of the types of fertigation application (pulse and continuous) on the following variables: number of pods per plant, number of grains per pod, fresh mass of the pods without grains, fresh mass of the grains, dry mass of the pods, dry mass of the grains, and total dry mass of the shoot. For total fresh mass of the shoot, there was a significant effect only of type of fertigation, whereas the percentage of hatched pods was not significantly affected by any of the studied factors.

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In the treatments under conventional fertilization and irrigation with 100% of ETc, the irrigation factor (pulse and continuous) caused significant differences in number of pods, number of grains, fresh mass of the grains, fresh mass of the pods, dry mass of the grains, and total dry and fresh mass of the shoot.

Table 1. Summary of the analysis of variance for the yield variables of the BRS Tumucumaque cowpea (*Vigna unguiculata*) cultivar evaluated as a function of crop evapotranspiration (ETc) replacement depths and types of fertigation application, as well as of treatments with conventional fertilization and an irrigation depth of 100% of ETc, in 2022, in the municipality of Carpina, in the state of Pernambuco, Brazil(1).

Source of variation	DF	Mean square –Yield			Mean square – Fresh mass			Mean square – Dry mass		
		NOP	NOG	PHP	TFM	FMP	FMG	TDM	DMP	DMG
Depths (L)	4	146.400**	1,527.087**	4.912^{ns}	18,259.245^{ns}	391.760*	846.529**	1,287.177**	12.313*	63.312*
Management (M)	1	378.225**	1,716.100*	4.900^{ns}	33,266.360*	2,881.166**	853.868*	1,722.525*	26.479**	103.748*
L x M	4	11.3500^{ns}	30.5375^{ns}	7.837^{ns}	985.580^{ns}	39.796^{ns}	48.511^{ns}	48.124^{ns}	4.539^{ns}	1.933^{ns}
Blocks	3	4.158^{ns}	372.000^{ns}	0.066^{ns}	1,287.956^{ns}	180.190^{ns}	37.476^{ns}	244.201^{ns}	1.839^{ns}	1.929^{ns}
Residual	27	11.047	372.333	7.788	7,155.535	137.566	190.532	305.629	3.761	19.644
CV (%)		24.22	21.26	103.17	29.34	35.48	34.10	33.08	41.01	34.91
Control	1	72.000*	242.000**	45,125^{ns}	1,1238.752*	59.296*	244.925*	1,515.801*	2.668^{ns}	22.512**
Blocks	3	3.166^{ns}	28.33^{ns}	38.458^{ns}	233.186^{ns}	2.547^{ns}	13.840^{ns}	186.554^{ns}	0.120^{ns}	1.252^{ns}
Residual	3	4.00	8.33	45.125	633.501	4.853	28.004	89.571	1.863	0.864
CV (%)		11.59	2.99	119.42	9.71	6.46	14.59	20.73	24.63	7.18

(1)DF, degrees of freedom; NOP and NOG, number of pods and grains, respectively; PHP, percentage of hatched pods; TFM and TDM, total shoot fresh and dry mass, respectively; FMP and DMP, pod fresh and dry mass, respectively; and FMG and DMG, grain fresh and dry mass, respectively. * and **Significant at 5 and 1% probability, respectively. ^{ns}Nonsignificant.

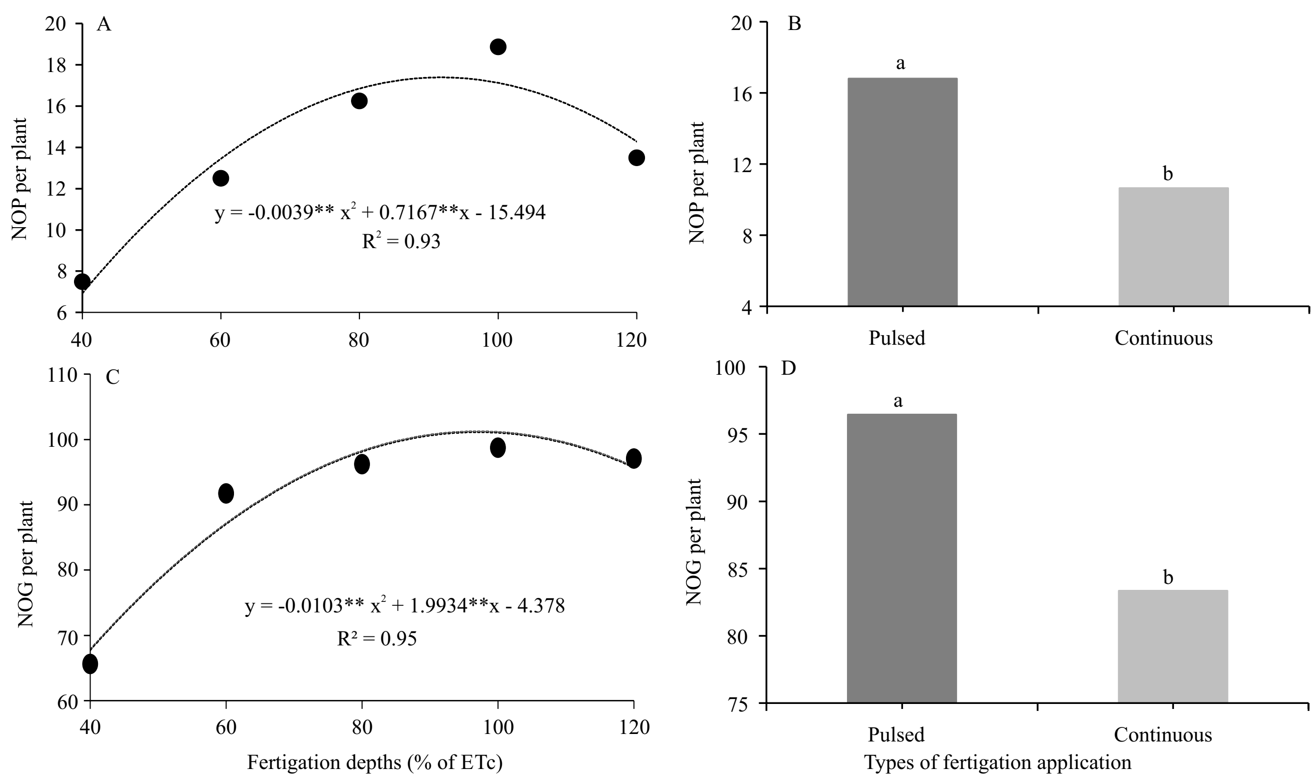

Figure 1. Number of pods (NOP) and grains (NOG) of the BRS Tumucumaque cowpea (*Vigna unguiculata*) cultivar as a function of the applied fertigation depths (A and C) and types of fertigation application (B and D), in 2022, in the municipality of Carpina, in the state of Pernambuco, Brazil. Different letters indicate significant differences between the types of fertigation application (pulse and continuous) by the Scott-Knott test, at 5% probability.

In addition, there was an isolated effect of fertigation depths and types of fertigation application on the number of pods and grains (Figure 1). As a function of fertigation depths, the highest number of pods (17.4 per plant) was obtained at a depth of 91.88% of ETc, showing an increase of 151.08% over the depth of 40% of ETc (Figure 1 A). Regarding the type of fertigation application, the number of pods per plant were 16.8 and 10.5, respectively, for pulse and continuous fertigation, with the former increasing the number of pods in 60% compared with the latter (Figure 1 B).

The estimated number of grains per plant was 100.8 with the application of a depth of 96.76% of ETc, a value 49.05% higher than that of 67.63 obtained with the application of a depth of 40% of ETc (Figure 1 C). Fertigation type, however, had an isolated effect on the number of grains per plant, which was 96.45 with the application of pulse fertigation, showing an increase of 16.20% in comparison with that of 83 grains per plant obtained with continuous fertigation (Figure 1 D).

These results are an indicative that the water deficit at a depth of 40% of ETc reduced plant growth and, consequently, the amount of grains and pods per plant. This occurred because, under water deficit conditions in the vegetative stage of cowpea, the photosynthetic rate of the plants is reduced due to stomatal closure, a mechanism associated with transpiration control when there is a low water supply, directly affecting grain and pod yield per plant (Melo et al., 2022).

The higher grain and pod yield obtained with pulse fertigation can be attributed to the fact that this management keeps soil moist for a longer time due to the fractioning of the applied irrigation depth, allowing of a greater absorption of water and nutrients, necessary elements for the formation of the grains and pods of the cowpea crop (Almeida et al., 2018).

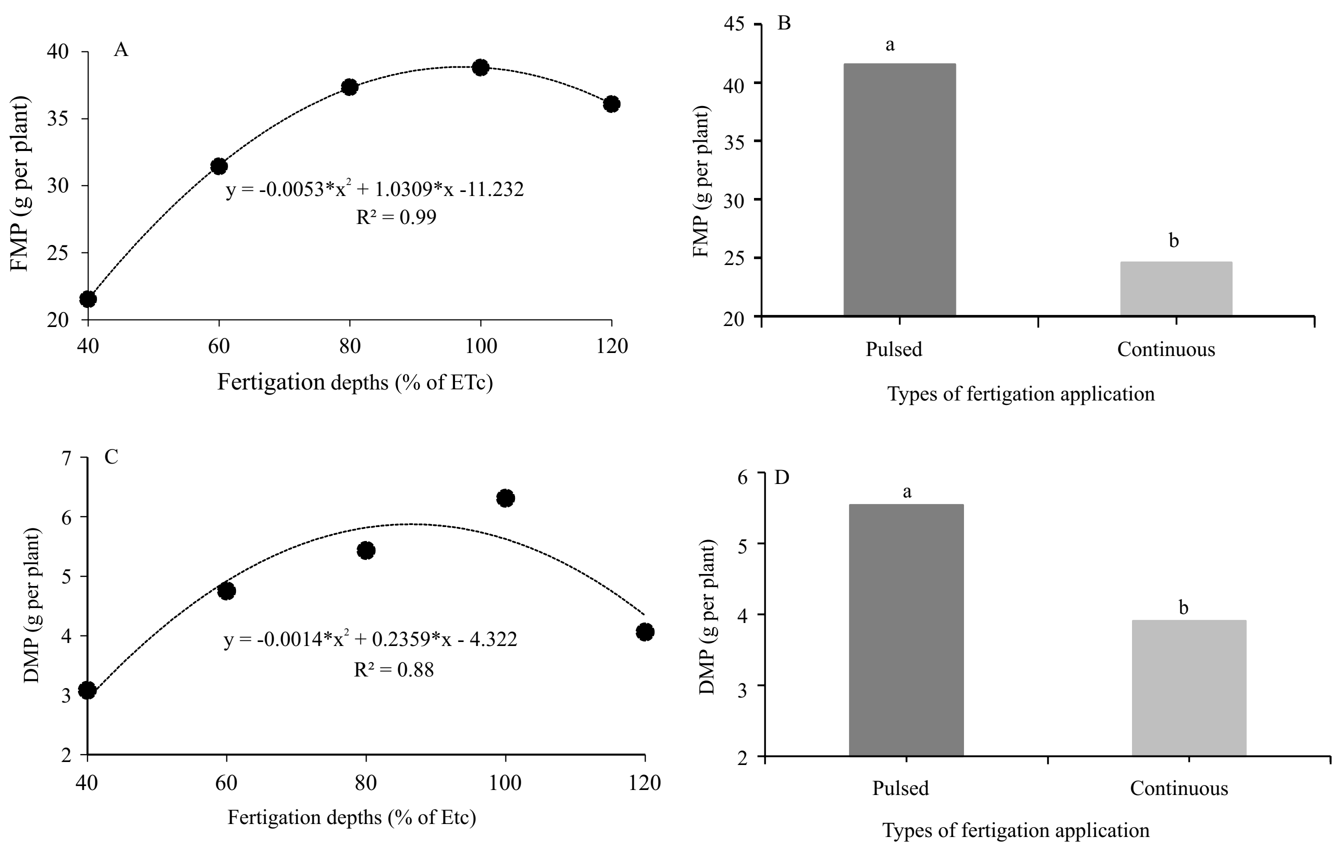

Figure 2. Fresh (FMP) and dry pod (DMP) mass of the BRS Tumucumaque cowpea (*Vigna unguiculata*) cultivar as a function of the applied fertigation depths (A and C) and types of fertigation application (B and D), in 2022, in the municipality of Carpina, in the state of Pernambuco, Brazil. Different letters indicate significant differences between the types of fertigation application (pulse and continuous) by the Scott-Knott test, at 5% probability.

The production of the fresh and dry mass of the pods suffered an isolated effect of the depths and types of fertigation (Figure 2). As a function of fertigation depths, the highest estimated value for fresh pod mass was 38.90 g per plant, obtained at a depth of 97.25% of ETc, showing an increase of 80.9% in comparison with the 21.5 g per plant observed at a depth of 40% of ETc (Figure 2 A).

Considering the type of fertigation application, the highest fresh pod mass yield was 41.54 g per plant under pulse fertigation, a value 69.13% higher than that obtained with continuous fertigation (Figure 2 B). Regarding fertigation depths, pod dry mass presented the highest estimated value of 5.6 g per plant at a depth of 84.25% of ETc, showing an increase of 95.12% in comparison with the 2.87 g per plant obtained with the application of a depth of 40% of ETc (Figure 2 C). The average for pod dry mass was 5.54 g per plant with pulse fertigation, a value higher than the average of 3.91 g per plant with continuous fertigation (Figure 2 D).

Irrigation depths below 80% of ETc resulted in losses in plant yield (Figure 2). This behavior, according to Carrega et al. (2019), can be justified by the fact that water stress, either by water deficit or excess, causes physiological changes that compromise the development and growth of the plants, leading to losses of up to 43% in their number of pods, which reflects directly on their yield.

The highest value for fresh mass of the grains was 48.56 g per plant, obtained with the application of 98.16% of ETc, corresponding to an increase of 103.4% over the depth of 40% of ETc (Figure 3 A). Regarding fertigation application, grain fresh mass showed an increase of 25.77% under pulse fertigation (Figure 3 B).

The highest grain dry mass of 14.93 g per plant was obtained with 99.45% of ETc, showing an 81.76%

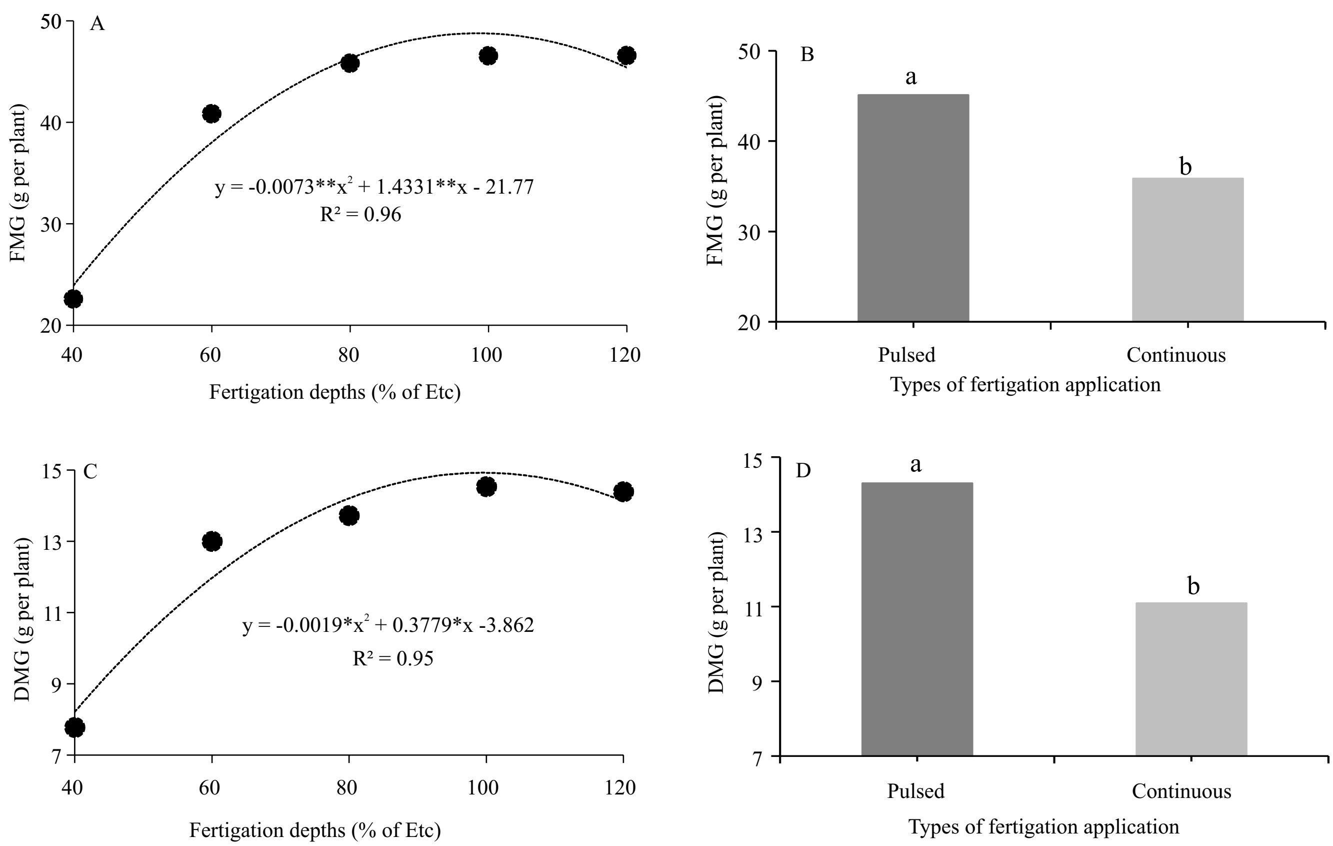

Figure 3. Fresh (FMG) and dry grain (DMG) mass of the BRS Tumucumaque cowpea (*Vigna unguiculata*) cultivar as a function of the applied fertigation depths (A and C) and the types of fertigation application (B and D), in 2022, in the municipality of Carpina, in the state of Pernambuco, Brazil. Different letters indicate significant differences between the types of fertigation application (pulse and continuous) by the Scott-Knott test, at 5% probability.

increase compared with the value observed with 40% of ETc (Figure 3 C). In addition, grain dry mass was 14.3 g per plant with pulse fertigation, showing a 30% increase in yield compared with the value of 11 g per plant obtained with continuous fertigation (Figure 3 D). Once again, the fractioning of irrigation depth keeps water and soluble nutrients close to the crop root zone, facilitating their absorption by the plant, which explains the higher yield obtained with pulse fertigation (Zamora et al., 2019).

The data for dry and fresh mass of the grains showed a similar behavior to those for fresh and dry mass of the pods, with the lowest yield being observed with the application of the lowest irrigation depth of 40% of ETc. According to Fernandes et al. (2015), environments with low soil water levels result in low crop yields due to a reduced stomatal conductance in the plants, with consequent low rates of transpiration and photosynthesis, which are mechanisms responsible for plant development.

Total shoot fresh mass was significantly affected only by the type of fertigation application (Figure 4 A). A higher average value of 317.16 g per plant was obtained with pulse fertigation, showing an increase of 22.16% compared with the 259.48 g per plant observed with continuous fertigation.

Moreover, the highest total shoot dry mass was 65.93 g per plant with an irrigation depth of 83.81% of ETc, showing an increase of 87.14% over the depth of 40% of ETc (Figure 4 B). Regarding the types of fertigation application, total shoot dry mass showed an increase of 28.35% with pulse fertigation (Figure 4 C).

Considering the results obtained in the present study, according to Dias et al. (2019), when water is applied in amounts higher than those required by the crop, the higher moisture on soil surface can lead to a lower plant development. Duarte et al. (2013) added that water stress, either by lack or excess of water, causes changes in membrane properties, inhibits photosynthesis, and increases respiration, with consequent decreases in dry matter production, premature senescence, and reductions in the yield of plant components.

As to both control treatments, significant differences were observed for the variables number of pods per plant, number of grains per pod, pod fresh mass, grain fresh mass, grain dry mass, and total shoot fresh and dry mass.

For the aforementioned variables, the values obtained with pulse irrigation were higher than those observed with continuous irrigation, showing

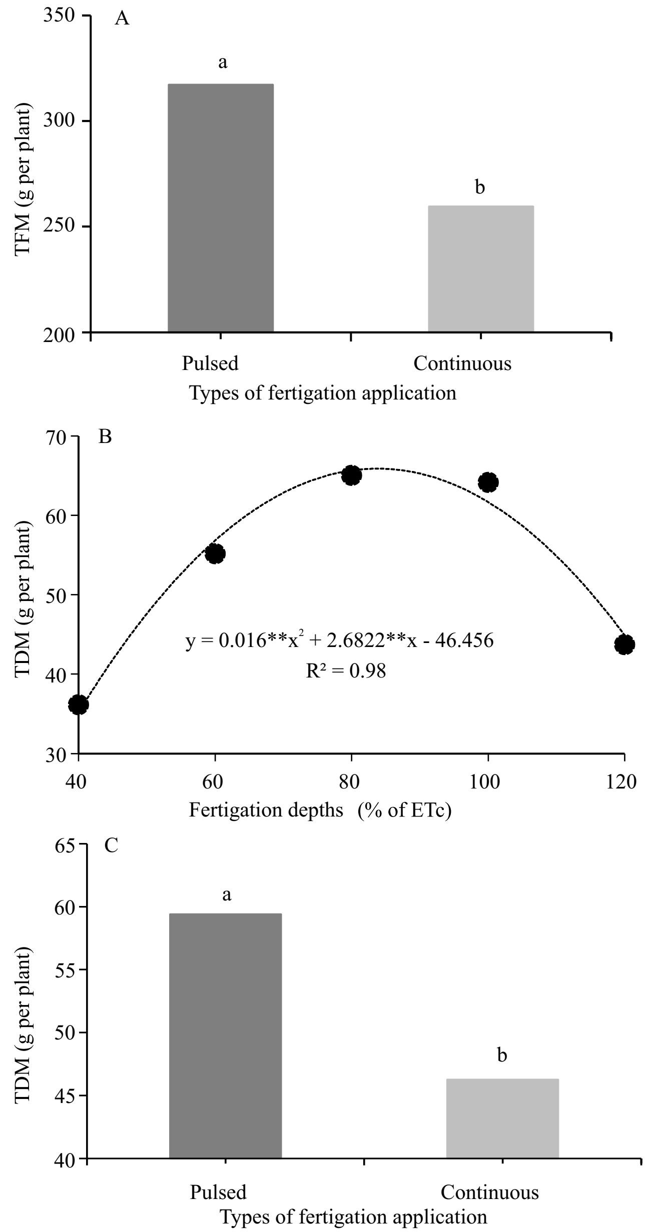

Figure 4. Total shoot fresh mass (TFM) of the BRS Tumucumaque cowpea (*Vigna unguiculata*) as a function of the types of fertigation application (A), as well as total shoot dry mass (TDM) as a function of the applied fertigation depths (B) and types of fertigation application (C), in 2022, in the municipality of Carpina, in the state of Pernambuco, Brazil. Different letters indicate significant differences between the types of fertigation application (pulse and continuous) by the Scott-Knott test, at 5% probability.

increases of: 42.10% for number of pods, 12.08% for number of grains, 44.21% for grain fresh mass, 33.09% for grain dry mass, 17.38% for pod fresh mass, 33.81% for total shoot fresh mass, and 86.36% for total shoot dry mass.

Conclusions

1. Fertigation depths from 80 to 100% of crop evapotranspiration (ETc) provide the best yield performance for green cowpea (*Vigna unguiculata*) beans, while depths of 40 and 120% of ETc cause yield losses.
2. Pulse fertigation promotes higher yields for all production variables analyzed.
3. Plants irrigated with a depth of 100% of ETc and fertilized conventionally show higher yields under pulse irrigation than under continuous irrigation.
4. Regardless of the type of application (pulse or continuous), the productive variables show better results at the fertigation depths estimated for maximum physical efficiency than in the treatments with conventional fertilization and irrigation with a depth of 100% of ETc.

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