Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252024v3711818rc

Scientific Article

Continuous and pulse fertigation on the accumulation and export of nutrients by cowpea

Fertirrigação contínua e pulsada sobre o acúmulo e exportação de nutrientes pelo feijão-caupi

Carolayne S. de Souza[1]*, Gerônimo F. da Silva[1], Maria V. G. da Costa[1], Manassés M. da Silva[1], João V. B. da Silva[1], Sirleide M. de Menezes[1], Antônio F. da Costa[2], Adriana A. Diniz[3]

[1]Department of Agricultural Engineering, Universidade Federal Rural de Pernambuco, Recife, PE, Brazil. [2]Instituto Agronômico de Pernambuco, Recife, PE, Brazil. [3]Universidade Estadual do Maranhão, Maranhão, MA, Brazil.

ABSTRACT - The objective was to evaluate the effects of pulse and continuous fertigation on the accumulation and export of nutrients by cowpea. The experimental design adopted was randomized blocks with 12 treatments distributed in a 5 x 2 + 2 factorial scheme, with four replicates, with five ETc replacement depths (40, 60, 80, 100 and 120%), combined with two types of fertigation application (pulse and continuous), plus two additional treatments under pulse (control 1) and continuous (control 2) irrigation with 100% ETc depth and conventional fertilization. The analyzed nutrients were N, P, K, Ca, Mg, S, Fe, Cu, Mn and Zn. Highest accumulations and exports of nutrients were obtained with pulse fertigation depths lower than 100% ETc. Conventional fertilization and pulse irrigation with 100% ETc depth promoted greater accumulation and export of nutrients compared to continuous irrigation. The descending order of nutrient accumulation for both types of fertigation application (pulse and continuous) was: N > K > Ca > P > Mg > S > Fe > Mn > Zn > Cu. The descending order of nutrient export by cowpea pods and grains was N > P > Ca > K > Mg > S > Fe > Zn > Mn > Cu for pulse fertigation and N > P > Ca > Mg > S > K > Fe > Zn > Mn > Cu for continuous fertigation.

Keywords: *Vigna unguiculata*. Plant nutrition. Fertilization via irrigation. Conventional fertilization. Pulse irrigation. Plant nutrition.

RESUMO - Objetivou-se avaliar o efeito da fertirrigação pulsada e contínua sobre o acúmulo e a exportação de nutrientes pelo feijão-caupi. O delineamento experimental adotado foi em blocos ao acaso com 12 tratamentos distribuídos em esquema fatorial 5 x 2+ 2, com quatro repetições, sendo cinco lâminas de reposição da ETc equivalentes (40, 60, 80, 100 e 120%), combinadas com dois tipos de aplicação de fertirrigação (pulsada e contínua), mais dois tratamentos adicionais os quais foram irrigados com lâmina de 100% da ETc de forma pulsada e contínua e adubado convencionalmente. Os nutrientes analisados foram N, P, K, Ca, Mg, S, Fe, Cu, Mn e Zn. Os maiores acúmulos e exportações de nutrientes foram obtidos com lâminas de fertirrigação pulsada menores que 100% da ETc. O tratamento que recebeu adubação convencional e irrigação pulsada com lâmina de 100% da ETc promoveu maiores acúmulos e exportação de nutrientes em detrimento da irrigação contínua. A ordem decrescente de acúmulo de nutrientes para ambos os tipos de aplicação da fertirrigação (pulsada e contínua) foi: N > K > Ca > P > Mg > S > Fe > Mn > Zn > Cu. A ordem decrescente de exportação de nutrientes pelas vagens e grãos do feijão-caupi, para aplicação da fertirrigação pulsada foi: N > P > Ca > K > Mg > S > Fe > Zn > Mn > Cu. Já a aplicação da fertirrigação contínua foi: N > P > Ca > Mg > S> K> Fe > Zn > Mn > Cu.

Palavras-chave: *Vigna unguiculata.* Adubação via irrigação. Adubação convencional. Irrigação por pulso. Nutrição de plantas.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: March 13, 2023.
Accepted in: September, 21, 2023.

***Corresponding author:**
<carol.silva452@gmail.com>

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is a grain legume, which belongs to the Fabaceae family and is considered of great socioeconomic relevance for the Northeast region of Brazil, with its grains being an important source of protein for communities in the semi-arid region (RIVAS et al., 2016; GUIMARÃES et al., 2020). However, cultivation in these locations still has low production levels, due to water limitations and low investment in technologies that contribute to improving production (COFFIGNIEZ et al., 2018).

Among the crops grown in large quantities, beans are the most sensitive to water deficit. This characteristic may be related to their short cycle and metabolism. Irrigation is considered the main mechanism for optimizing production in agriculture, but, if managed inappropriately, can cause losses related to the waste of water, energy and leaching of nutrients in the soil (VIÇOSI et al., 2017).

Periods of high temperatures, low rainfall and water deficit affect the yield of crops at different phenological stages, directly influencing the number of pods per plant, number of grains per pod and grain mass (CONCEIÇÃO et al., 2018).

In this context, drip irrigation is, among the existing irrigation methods, the one that stands out for promoting greater efficiency in relation to system sustainability. Associated with drip irrigation, the pulse irrigation technique, according to Almeida et al. (2018), is a technology developed to assist in the performance of irrigation systems and consists of a short period of irrigation followed by a pause and another short period of irrigation; this cycle is repeated until the entire necessary water depth is applied. This technique promotes energy savings, better use of water by crops and higher yields.

With regard to irrigated agriculture, the practice of fertigation is considered the most efficient means of plant nutrition, as the method consists in applying fertilizers via irrigation water, promoting greater nutrient and water efficiency for crops (MARTINS et al., 2017; PEREIRA et al., 2019).

Studies on nutrient accumulation and export allow identifying the nutritional requirements of plants and contribute to preventing nutritional deficiencies that may occur during the crop cycle. Knowledge on these accumulations and exports promotes improvements in fertilizer use efficiency and has been considered a tool in crop fertilization management (PURQUERIO et al., 2019).

Thus, maintenance and increase of cowpea production depend on biotic and abiotic factors, and inadequate supply of nutrients to the crop is one of the factors that affect its development (SOUSA et al., 2018).

In view of the economic importance of cowpea and considering the limiting factors of production, such as low investment in technological resources and low water availability in the main producing regions of this legume in the country, studies capable of defining an adequate management of conventional fertilization and fertigation for the production of green cowpea grains are of fundamental importance. Given the low number of studies on the subject, the objective here was to evaluate the effects of pulse and continuous fertigation on the accumulation and export of nutrients by the cowpea crop.

MATERIAL AND METHODS

The study was conducted at the Carpina Sugarcane Experimental Station (EECAC), belonging to the Federal Rural University of Pernambuco, located in the city of Carpina, PE, Brazil, at the geographic coordinates 07º 51' 13" South latitude and 35º 14' 10" West longitude and average altitude of 180 m. The experiment was carried out in a greenhouse, in a 13.20 m long by 4.5 m wide area, composed of 48 pots with capacity of 85 L each and seated at 0.20 m height from the soil surface.

The pots were filled by initially adding a layer of crushed stone with grain size of 25 mm, totaling a volume of 0.48 m³ for the 48 pots, in order to facilitate drainage. Then, a geotextile was placed so as to cover the entire upper face of the crushed stone layer, in order to retain particles from the upper layer, where the soil is contained, to the lower layer and drainage system.

Before setting up the experiment, chemical and physical analyses of the soil were performed, as well as chemical analysis of the water used for irrigation in the experiment (Table 1).

Table 1. Chemical and physical characteristics of the soil used to fill the pots and chemical characterization of the public-supply water used for irrigation in the experiment.

Soil chemical characterization

pH	P	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Al^{+3}	$H^{+}+Al^{+3}$	SB	CEC	t	Cu	Fe	Mn	Zn	V	OM
H_2O	Mg dm^{-3}	---- $cmol_c$ dm^{-3} ----									---- mg dm^{-3} ----				%	g kg^{-1}
4.5	8.0	1.60	1.0	0.66	0.18	0.55	4.33	3.44	7.77	3.99	0.10	33.0	9.27	1.08	44.27	2.64

Soil physical characterization

Sand	Silt	Clay	Textural Classification	BD	PD	Total porosity
---- g kg^{-1} ----			-	---- g cm^{-3} ----		---- % ----
730	90	180	Sandy loam	1.37	2.52	45.60

Chemical characterization of public-supply water

pH	EC	K^{+}	Ca^{+2}	Mg^{+2}	Na^{+}	Ammonia	Sulfate	Alkalinity	Chlorides
-	dS m^{-1}	---- mg L^{-1} ----							
6.8	0.2275	4.0	11.22	2.92	32.10	0.00	9.32	54.0	38.04

P: Phosphorus; Ca^{2+} = Calcium; Mg^{2+} = Magnesium; Na^{+} = Sodium; K^{+} = Potassium; Al^{3+} = Aluminum; BD: Bulk density; PD: Particle density; EC: Electrical conductivity.

In order to correct soil acidity, as the pH was 4.5, liming was carried out with calcitic limestone, applying the equivalent to 0.12 ton ha^{-} to each pot, according to methodological procedures recommended by Cavalcanti et al. (2008).

The recommendation for conventional fertilization was followed by applying 20 kg ha^{-1} of N as basal, using urea as a source, 40 kg ha^{-1} of K using potassium chloride as a source and 40 kg of P using single superphosphate as source. Topdressing fertilization was carried out 20 days after germination, by applying 30 kg ha^{-1} of N and 60 kg ha^{-1} of K.

Each of the experimental plots was fertilized according to the suggestions recommended by Novais, Neves and Barros (1991). The fertilizers used in fertigation were monoammonium phosphate - MAP (12% N and 61% P_2O_5), Haifa® Multi-NPK (13% N, 2% P_2O_5 and 44% K_2O), MS-multimicro (7% B, 1% Cu, 9.5% S, 7% Mn, 0.1% Mo and 12% Zn) and Fe–EDTA-6% Fe. The total amounts of fertilizers used in the eight fertigation events were 16.02 g, 23.11 g, 1.56 g, 1.2 g of Haifa® Multi-NPK, monoammonium phosphate/MAP, MS-multimicro and Fe-EDTA-6% Fe, respectively.

The experimental design was randomized blocks, with four replicates, in a 5 x 2 + 2 factorial scheme, with five irrigation depths equivalent to 40, 60, 80, 100 and 120% of crop evapotranspiration (ETc), combined with two types of fertigation application (pulse and continuous), plus two additional treatments, which were under conventional fertilization and pulse (Control 1) and continuous (Control 2) irrigation with 100% ETc depth.

Irrigation was applied by a drip system, with pressure-compensating emitters with nominal flow rate of 2 L h^{-1}, positioned in each 85 L pot, disc filter and a 0.5 CV horizontal axis centrifugal electric pump, which was responsible for collecting and pumping the fertilizer solution. The irrigation subunits consisted of lateral pipes connected to low-density polyethylene (LDPE) hoses with nominal pressure of 30 mwc and nominal diameter of 16 mm, which interconnected the drip tape and the water distribution line.

Irrigation was carried out every two days, and ETc was obtained directly based on the average water balance of three drainage lysimeters with capacity of 85 L, cultivated with the same crop evaluated in the experiment (cowpea) and installed inside the greenhouse.

The water balance was calculated every 24 hours, and the ETc was obtained by the difference between the irrigation depth (Li) applied and the drainage depth (Ld) collected, according to Equation 1.

$$\mathrm{Li} - \mathrm{Ld} = \mathrm{ETc} \tag{1}$$

For the pulse irrigation condition, five irrigation pulses were defined with a 60-minute interval between irrigations. The crop analyzed in a single cycle was cowpea, cultivar BRS Tumucumaque. Three seeds were sown in each pot, at 5 cm depth, and thinning was performed after germination and establishment of seedlings, maintaining one plant per pot. Green beans were harvested when the grains had 70% moisture, according to Freire Filho, Lima and Ribeiro (2005).

At the time of harvest, the aerial parts and fruits (pod + grains) were collected and separated in each of the treatments evaluated to quantify the accumulations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn), as well as the export of these nutrients by the fruits.

Total N was quantified by the Kjeldahl steam dragging method; K and Na by flame photometry; P by the molybdovanadate colorimetric method; S by the barium sulfate turbidimetric method; and Ca, Mg, Fe, Cu, Mn and Zn by atomic absorption spectrophotometry (BEZERRA NETO; BARRETO, 2011). Accumulation of nutrients in each of the plant parts (shoots and fruits) was obtained by multiplying the contents of the nutrients obtained in each of the parts by the amount of dry matter accumulated in these respective parts.

The data obtained were subjected to analysis of variance by the F test and, when significant effects were found, they were subjected to regression analysis (irrigation depths) and to comparison of means (continuous and pulse replacement of depths) by the Scott-Knott test at 5% probability level. The controls were compared with each other using the Scott-Knott test at 5% probability level.

The choice of the model that best fitted the data was based on four criteria: non-significant effect of the regression deviation, significance of the parameters of the fitting equation ($P < 0.05$), highest value of coefficient of determination (R^2) and biological explanation of each variable as a function of the treatments evaluated.

RESULTS AND DISCUSSION

The summary of the analysis of variance presented in Table 2 shows significant effects of the ETc replacement depths and the types of fertigation application on P, Mg and S.

For Ca, significant effect was caused only by the ETc replacement depths. For the accumulations of Fe and Zn, in turn, only the type of fertigation caused significant effect. Accumulations of N, K and Cu were significantly influenced by the interaction between ETc replacement depths and types of fertigation application.

The control treatments, conventionally fertilized and irrigated with a 100% ETc depth, showed significant effects of irrigation management (pulse and continuous) on N, K, S, Fe, Mn and Cu.

Table 2. Summary of the analysis of variance for the accumulations of macronutrients (N, P, K, Ca, Mg and S) and micronutrients (Fe, Mn, Cu and Zn) in cowpea, cv. BRS Tumucumaque, as a function of fertigation management and conventional fertilization.

SV	DF	Mean Square					
		Macronutrients					
		N	P	K	Ca	Mg	S
Depths (L)	4	186.696**	4.991**	34.000^{ns}	22.33**	0.699*	0.753*
Management (M)	1	145.542**	19.289**	412.068**	3.417^{ns}	1.122*	1.745**
L X M	4	85.517**	0.0706^{ns}	46.807*	4.709^{ns}	0.103^{ns}	0.167^{ns}
Blocks	3	2.877^{ns}	0.543^{ns}	23.392^{ns}	1.648^{ns}	0.179^{ns}	0.507^{ns}
Residual	26	24.391	0.446	14.064	2.439	0.241	0.241
CV	%	8.06	7.77	22.48	13.54	11.42	18.39
Control	1	136.951*	1.240^{ns}	33.208**	0.236^{ns}	0.000^{ns}	1.319**
Block	3	3.667^{ns}	1.391^{ns}	5.125^{ns}	0.085^{ns}	0.306^{ns}	0.145^{ns}
Residual	3	5.888	1.714	0.580	0.105	0.572	0.061
CV	%	4.01	15.19	5.29	2.74	10.10	8.19

SV	DF	Micronutrients			
		Fe	Mn	Cu	Zn
Depths (L)	4	2235.911^{ns}	785.968^{ns}	2.282^{ns}	55.301^{ns}
Management (M)	1	23047.477**	525.1663^{ns}	0.473^{ns}	1193.564**
L X M	4	793.104^{ns}	567.896^{ns}	10.436*	6.989^{ns}
Blocks	1	2276.056^{ns}	95.0200^{ns}	2.636^{ns}	126.144^{ns}
Residual	3	2665.903	346.941	3.064	87.514
CV	%	15.99	11.89	16.26	9.02
Control	1	1806.205*	1892.047*	3.259**	2.606^{ns}
Block	3	128.362^{ns}	124.082^{ns}	0.237^{ns}	5.239^{ns}
Residual	3	126.260	133.620	0.130	13.806
CV	%	3.43	7.85	2.99	3.80

^{ns} Not significant; * and **: Significant at 5% and 1% probability levels, respectively. N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; Fe= iron; Mn= Manganese; Cu= copper; Zn = zinc.

The analysis of the ETc replacement depths factor considering each type of fertigation for the total accumulation of N, K and Cu in the aerial part of cowpea is presented in Figures 1A, 1B and 1C, respectively. The pulse fertigation depth that promoted maximum N accumulation (4.77 g plant^{-1}) was 80.30% ETc, representing percentage increments of 79.76% over the 40% ETc depth and 11.93% over the 100% ETc depth.

Regarding the continuous fertigation application (Figure 1A), the highest N accumulation (3.77 g plant^{-1}) was obtained with the 86.7% ETc depth, which led to percentage increments of 227.83% over the 40% ETc depth and 5.94% over the 100% ETc depth. It was also observed that the 40% ETc depth was the one that resulted in the lowest N accumulation (1.15 g plant^{-1}).

Analysis of the types of fertigation application considering each of the ETc replacement depths evaluated (Figure 1A) showed a significant difference between pulse and continuous fertigation at the 40, 60 and 80% ETc depths, resulting in percentage increments of 130.2, 45.11 and 28.22 in N accumulation by the plants compared to the N accumulation obtained with continuous fertigation.

Figure 1B shows that for the ETc replacement depths analyzed considering the continuous fertigation application, maximum K accumulation (0.77 g plant^{-1}) was obtained at the 89.5% ETc depth, with an increase of 170.75% over the 40% ETc depth.

Also in Figure 1B, it can be seen that the maximum K accumulation obtained with the application of pulse fertigation was 1.15 g plant^{-1}, and this highest accumulation was observed when the 69.4% ETc depth was applied, corresponding to an increase of 58.88% compared to the accumulation found with the 40% ETc depth.

For the types of fertigation application analyzed considering each ETc replacement depth (Figure 1B), a significant difference was observed between pulse and continuous fertigation. Increments of 154.15, 85.17 and 45.39% in the total accumulation of K were observed for the 40, 60 and 80% ETc depths, respectively, compared to continuous fertigation.

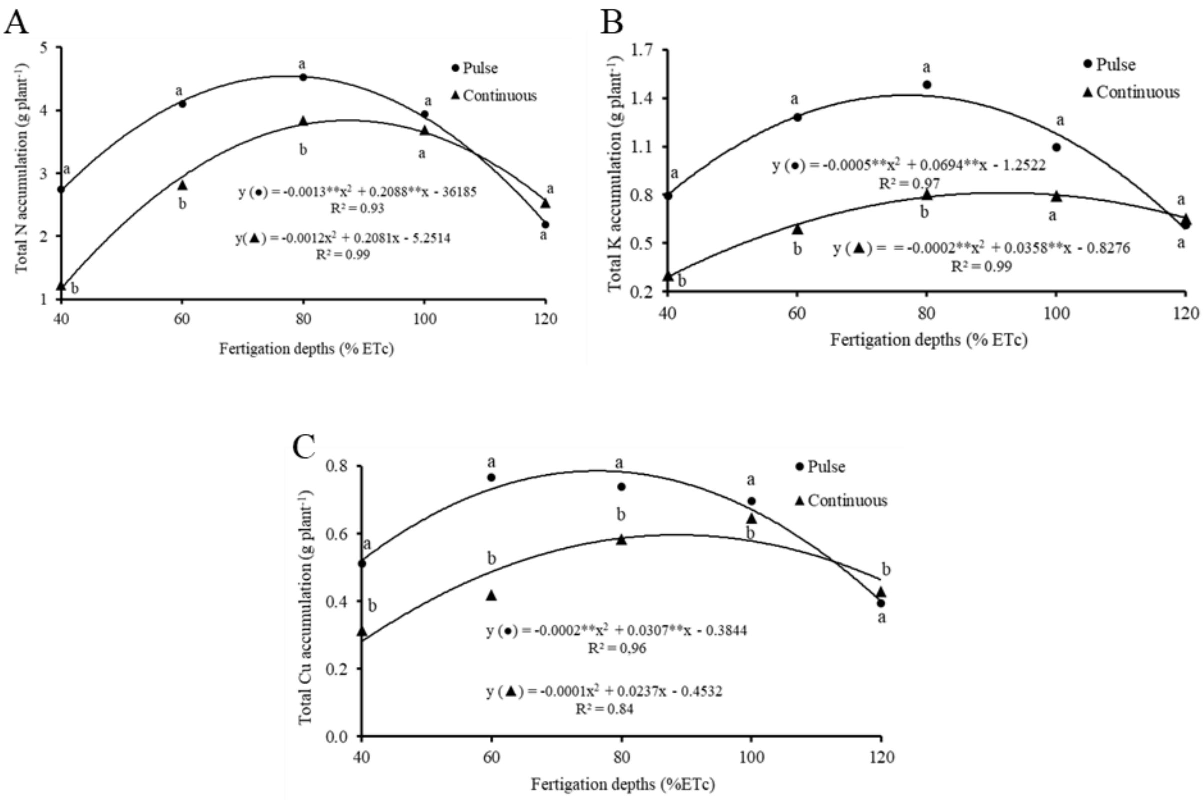

Figure 1. Total accumulation of nitrogen (N) (A), potassium (K) (B) and copper (Cu) (C) in cowpea as a function of the interaction between fertigation depths and types of fertigation application. Different letters indicate significant differences between the types of fertigation (pulse and continuous) according to the Scott-Knott test ($p < 0.05$).

For the total accumulation of Cu (Figure 1C), when analyzing the ETc replacement depths considering each type of application, maximum accumulation of the nutrient (0.79 mg plant^{-1}) was obtained under the pulse fertigation depth of 76.75%, with an increase of 50.87% compared to the 40% ETc depth. For the continuous fertigation application, maximum Cu accumulation (0.59 mg plant^{-1}) was obtained with the 95% ETc depth, corresponding to an increase of 105.72% compared to the 40% ETc depth.

Analysis of the type of fertigation application considering each ETc replacement depth (Figure 1C) showed a significant difference between pulse and continuous fertigation at the 40, 60 and 80% ETc depths, with increments of 82.56, 58.01 and 39.66%, respectively, compared to continuous fertigation. On the other hand, at the 120% ETc depth, continuous fertigation promoted higher Cu accumulation (0.52 mg plant^{-1}), causing an increase of 25.55% compared to pulse fertigation.

These results obtained for N, K and Cu are due to the split application of the water depth in the pulse fertigation method, as this type of management keeps the soil moist for longer, consequently leading to greater absorption of water and nutrients by plants (ALMEIDA et al., 2018).

On the other hand, water stress, caused by the application of the lowest fertigation depths, caused reductions in the accumulation of N, K and Cu in the plants, possibly because the lack of water in the soil hindered root growth, resulting in reduced absorption of water and ions and disorder in the structure of enzymes that are responsible for transporting nutrients to the aerial part of the plants, as emphasized by Sepahvand et al. (2021).

Accumulations of P and Ca by the crop as a function of the ETc replacement depths and the type of fertigation application are represented by Figures 2A and 2B and 2C, respectively. Maximum P accumulation (0.457 g plant^{-1}) was obtained with the fertigation depth of 74.5% ETc, corresponding to an increase of 107.82% over the 40% ETc depth.

Regarding the effect of the types of fertigation (Figure 2B), significant difference was observed between pulse and continuous fertigation, with the lowest P accumulation (0.36 g plant^{-1}) obtained under continuous fertigation. On the other hand, the highest P accumulation obtained with pulse fertigation was 0.6 g plant^{-1}, representing a 66.7% increase compared to the value obtained with continuous fertigation.

In this aspect, pulse fertigation promoted greater water availability to cowpea plants, resulting in greater P absorption. According to Gurgel et al. (2020), P comes into contact with plant roots through the diffusion process and, for this process to occur, the physical-hydraulic conditions of the soil need to be adequate; otherwise, there will be a reduction in P absorption.

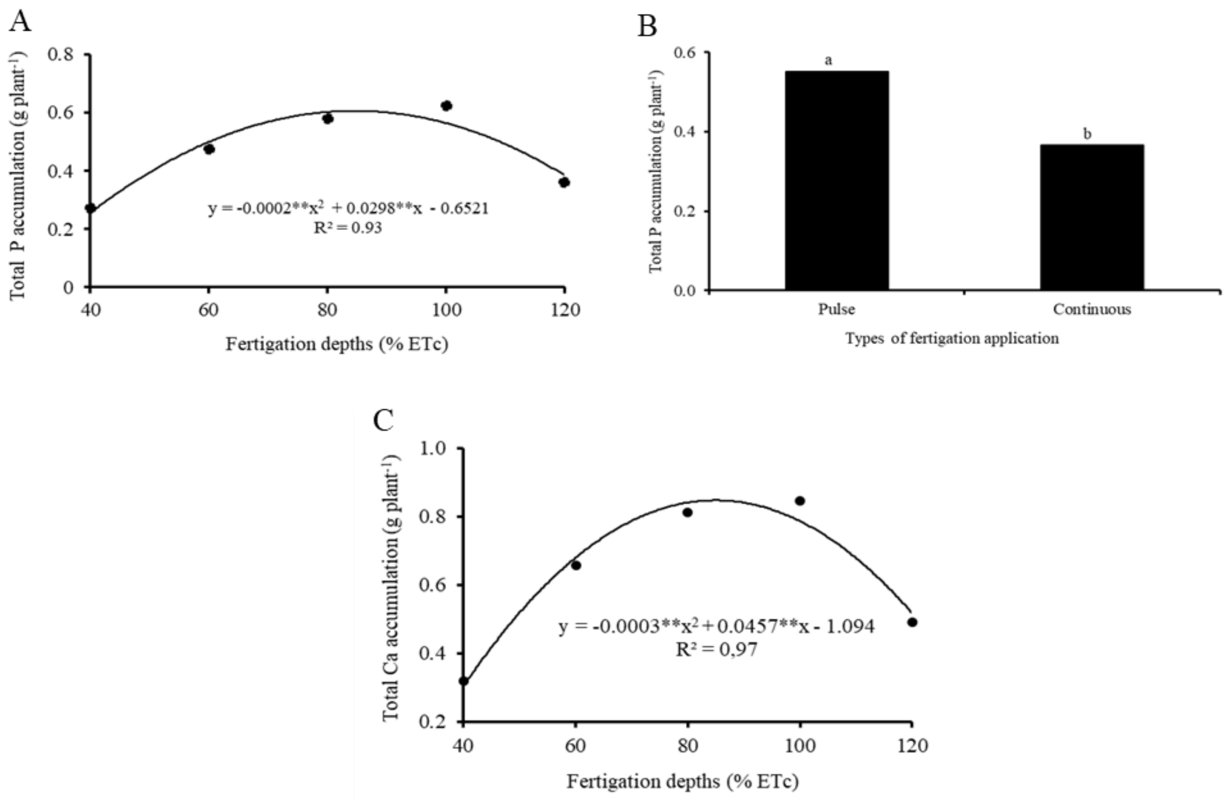

Figure 2. Total accumulation of phosphorus (P) as a function of the fertigation depths applied (A) and types of fertigation application (B), and total accumulation of calcium (Ca) as a function of the fertigation depths applied (C). Different letters indicate significant differences between the types of fertigation application (pulse and continuous) according to the Scott-Knott test ($p < 0.05$).

Regarding the accumulation of Ca as a function of the ETc replacement depths (Figure 2C), maximum accumulation (0.64 g plant^{-1}) was obtained at the fertigation depth corresponding to 76.16% ETc, representing a 152% increase compared to the 40% ETc depth. In this case, the lack of moisture in the soil, at the lowest depths applied, contributed to the lower values of Ca accumulation. Saure (2014) reports that Ca absorption by plants is affected by factors such as excess or lack of moisture in the soil, which can cause low levels of Ca in the soil, resulting in lower absorption of the nutrient by plants and, consequently, lower accumulation.

For the individual effects of the fertigation depth and types of fertigation application on the accumulation of Mg and S (Figures 3A, 3B, 3C and 3D, respectively), it was observed that the maximum accumulation of Mg was 0.27 g plant^{-1}, obtained at the 79.44% ETc depth, corresponding to an increase of 110.6% compared to the 40% ETc depth.

According to Menezes et al. (2020), the high mobility of Mg in the soil can contribute to greater leaching of this nutrient, with the application of water depths greater than 80% ETc, influencing its absorption and accumulation in the plant. For the individual effect of the types of fertigation application (Figure 3B), it was observed that pulse fertigation promoted higher Mg accumulation (0.26 g plant^{-1}) in the cowpea crop, resulting in a percentage increase of 73.3% compared to continuous fertigation.

For S accumulation (Figures 3C), a maximum value of 0.20 g plant^{-1} was observed at the 90% ETc depth, corresponding to an increase of 150.9% over the 40% ETc depth. Among the macronutrients, S was the element least accumulated by the cowpea crop. However, this nutrient is a necessary constituent for tolerance to abiotic stress and an important component in the formation of amino acids, proteins, lipids and metabolic compounds (KHAN et al., 2014).

Regarding the type of fertigation application on S accumulation, represented in Figure 3D, it was found that pulse fertigation promoted greater S accumulation (0.17 g plant^{-1}), resulting in an increase of 21.42% compared to continuous fertigation, which led to maximum accumulation of 0.14 g plant^{-1}.

In relation to the micronutrients Fe and Zn, these were significantly affected only by the types of fertigation application (pulse and continuous), and pulse fertigation promoted higher accumulation for both Fe (20.6 mg plant^{-1}) and Zn (6.4 mg plant^{-1}) compared to the accumulations obtained with continuous fertigation (Figures 4A and 4B). Increments of 49.2% for Fe and 42.2% for Zn were observed, compared to the application of continuous fertigation.

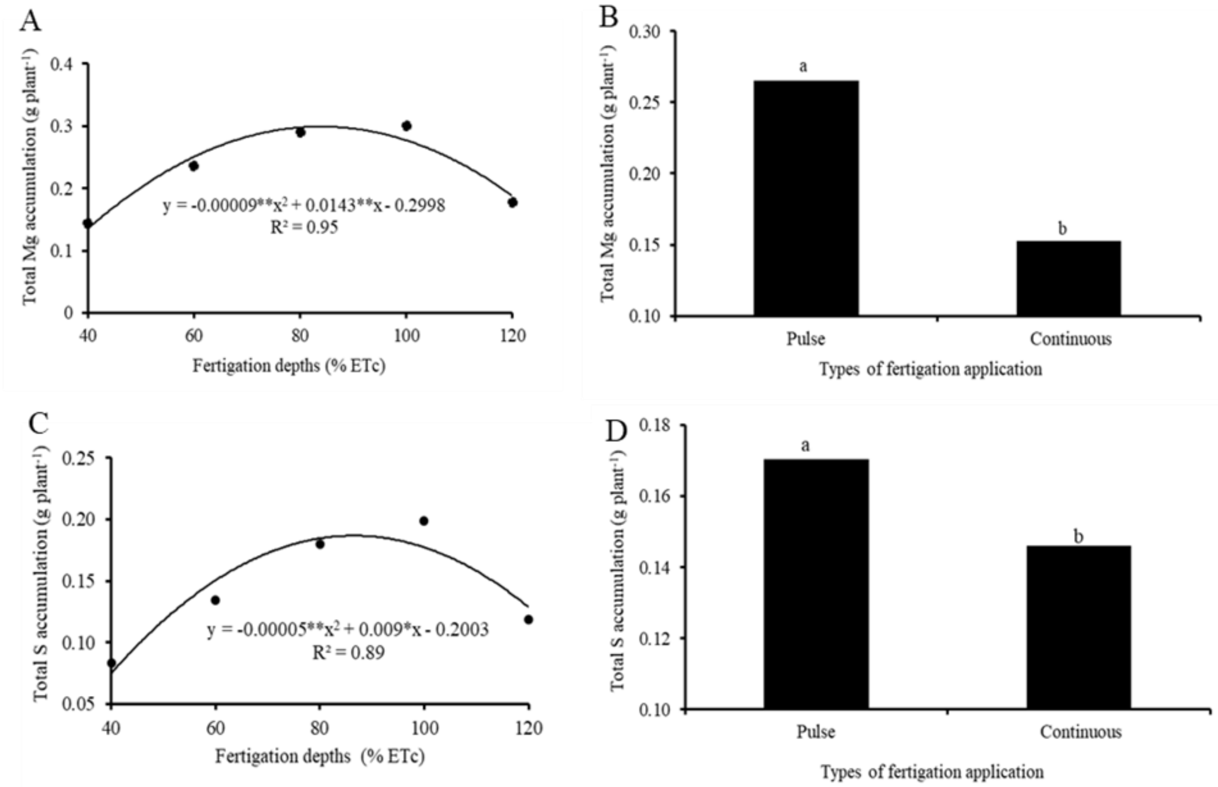

Figure 3. Total accumulation of magnesium (Mg) and sulfur (S) as a function of the fertigation depths applied (A) (C) and total accumulation of magnesium (Mg) and sulfur (S) as a function of the types of fertigation application (B) (D). Different letters indicate significant differences between the types of fertigation application (pulse and continuous) according to the Scott-Knott test ($p < 0.05$).

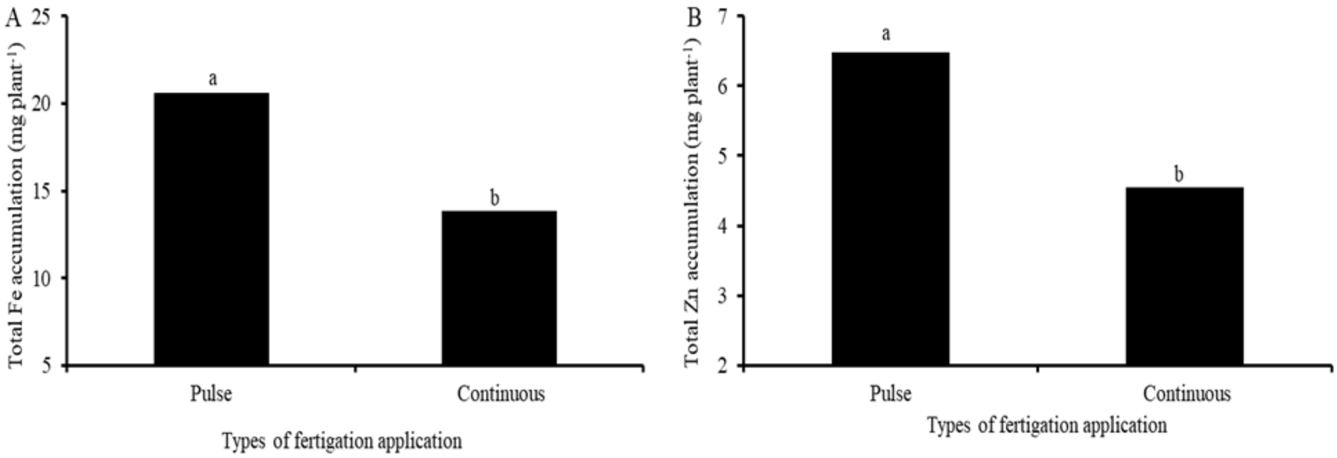

Figure 4. Total accumulation of iron (Fe) (A) and zinc (Zn) (B), as a function of the types of fertigation application (pulse and continuous). Different letters indicate significant differences between the types of fertigation application (pulse and continuous) according to the Scott-Knott test ($p < 0.05$).

Madane, Kdam and Tokhal (2018) explain that pulse irrigation is a viable alternative for irrigation management as it reduces water and nutrient losses by percolation, promoting higher yields to crops throughout their production cycle.

For the control treatments, which were under conventional fertilization and pulse (control 1) and continuous (control 2) irrigation with 100% ETc depth, there were significant differences for N, K, S, Fe, Cu and Mn. The highest values for the analyzed variables were obtained under application of pulse irrigation, with increments of 114.52% for N, 148.72% for K, 150% for S, 104.32% for Fe, 108.33% for Cu and 130% for Mn.

The summary of the analysis of variance for the export of macro and micronutrients by cowpea (Table 3) shows significant effects of the types of fertigation and ETc replacement depths on P and Mn.

Table 3. Summary of the analysis of variance for the export of macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Fe, Mn, Cu and Zn) in cowpea, cv. BRS Tumucumaque, as a function of fertigation management and conventional fertilization.

SV	DF	Mean Square					
		Macronutrients					
		N	P	K	Ca	Mg	S
Depths (L)	4	17.053^{ns}	3.108**	1.648**	0.066^{ns}	0.137^{ns}	3.525**
Management (M)	1	87.468^{ns}	2.623*	0.539^{ns}	0.335^{ns}	1.346**	0.323^{ns}
L X M	4	0.566^{ns}	0.411^{ns}	0.065^{ns}	0.013^{ns}	0.024^{ns}	1.759**
Blocks	3	9.543^{ns}	1.315^{ns}	0.944*	0.1675^{ns}	0.040^{ns}	1.627**
Residual	26	21.439	0.519	0.250	0.166^{ns}	0.124	0.375
CV	%	13.50	16.43	17.40	11.24	13.67	21.96
Control	1	52.02*	2.123**	0.480**	1.19^{ns}	0.000^{ns}	0.383**
Block	3	1.863^{ns}	0.137^{ns}	0.0183^{ns}	0.992^{ns}	0.003^{ns}	0.021^{ns}
Residual	3	3925	0.005	0.015	0.498	0.004	0.007
CV	%	5.45	1.58	3.68	16.15	2.50	6.55

FV	GL	Micronutrients			
		Fe	Mn	Cu	Zn
Depths (L)	4	101.823^{ns}	123.220**	0.824^{ns}	211.018**
Management (M)	1	358.088*	142.525*	2.093^{ns}	10.027^{ns}
L X M	4	32.637^{ns}	58.618^{ns}	1.371^{ns}	83.909^{ns}
Blocks	1	213.968*	97.435*	1.263^{ns}	66.213^{ns}
Residual	3	70.305	26.517	1.464	50.886
CV	%	10.65	14.77	22.99	13.81
Control	1	62.347**	117.78^{ns}	0.864**	9.665^{ns}
Block	3	1.926^{ns}	58.707^{ns}	0.048^{ns}	74.320^{ns}
Residual	3	5.161	40.500	0.029	52.929
CV	%	3.01	18.82	3.46	7.99

^{ns} not significant; * and **: Significant at 5% and 1% probability levels, respectively. N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; Fe= iron; Mn= Manganese; Cu= copper; Zn = zinc.

For K and Zn, there were significant effects only of the ETc replacement depths, as well as for Fe and Mg, which were significantly affected only by the type of fertigation. Regarding S, there was a significant effect of interaction between ETc replacement depths and types of fertigation application.

The controls, under conventional fertilization and irrigated with 100% ETc depth, showed significant effect of the irrigation management factor (pulse and continuous) on N, P, K, S, Fe and Cu.

Figure 5 shows the effects of fertigation depths (Figures 5A and 5C) and types of fertigation application (Figures 5B and 5D) on the export of P and Mn, respectively, for the cowpea crop.

For P export as a function of the fertigation depths (Figure 5A), it was observed that the maximum value (0.08 g pod^{-1}) was obtained at the 87.5% ETc depth, with an increase of 129.8% over the 40% ETc depth.

These results demonstrate that the water deficit caused by the lowest water depths applied contributed to reducing P export. On this aspect, Machado et al. (2011) emphasize that water deficit affects P availability to plants, interfering in its absorption and export, which was confirmed in the present study.

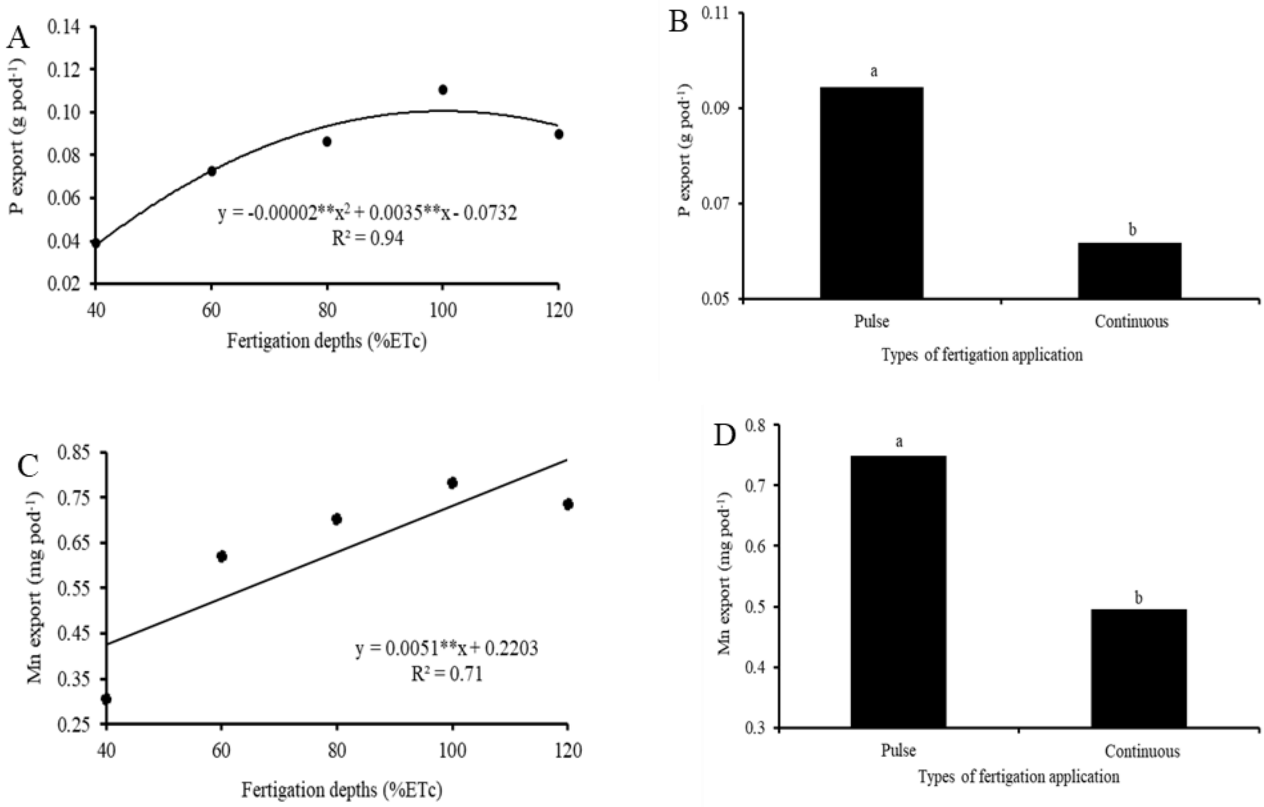

Figure 5. Export of phosphorus (P) and manganese (Mn) as a function of the applied fertigation depths (A) (C) and export of phosphorus (P) and manganese (Mn) as a function of the types of fertigation application (B) (D). Different letters indicate significant differences between the types of fertigation application (pulse and continuous) according to the Scott-Knott test ($p < 0.05$).

For the type of fertigation (Figure 5B), it was observed that pulse fertigation was more efficient than continuous fertigation, as it promoted a higher P export (0.09 g pod^{-1}), corresponding to an increase of 50% compared to continuous fertigation, which led to P export of 0.06 g pod^{-1}.

This occurred because pulse fertigation promotes greater water availability in the soil, contributing to the solubilization of P, since this nutrient is poorly soluble and has low mobility in the soil. Assouline et al. (2006) explain that high frequency of irrigation positively influences the absorption and availability of P, promoting greater export of the nutrient in the plant.

For Mn, an increasing linear model was fitted, and the highest depth applied (120% ETc) promoted maximum export (0.83 mg pod^{-1}) by the crop (Figure 5C), with an increase of 0.0051% per unit increase in the ETc replacement depths.

Regarding the types of fertigation, pulse fertigation promoted a higher Mn export (0.75 mg pod^{-1}) by the plants compared to continuous fertigation (0.49 g pod^{-1}), causing an increase of 53.06% compared to continuous fertigation (Figure 5D). Hartz et al. (2008) explain that soil water deficit inhibits the translocation of nutrients to fruits, causing significant damage to their production and quality.

The exports of K, S and Zn as a function of fertigation depths are shown in Figures 6A, 6B and 6C, respectively. It can be seen that for K, the model that best fit the data was the increasing linear (Figure 6A), and the maximum export of 0.074 g pod^{-1} was obtained at the 120% ETc depth, with an increase of 0.0005% per unit increase in the ETc replacement depths.

Regarding this aspect, Wietholter (2007) argues that the decrease in soil water content reduces K absorption, as it hinders the diffusion process and K is not replaced in the root absorption zone.

Analysis of S exports by cowpea revealed a significant effect of interaction between the ETc replacement depths and the types of fertigation application (Figure 6B). The data related to S export were described by the increasing linear model, according to which the maximum export, for the two conditions of fertigation application, was obtained at the 120% ETc depth.

For pulse fertigation, maximum S export by the crop was 0.085 g pod^{-1}, corresponding to an increase of 0.0006% per unit increase in the ETc replacement depths. In relation to continuous fertigation, the maximum amount of S exported was 0.071 g pod^{-1}, corresponding to an increase of 0.0007% per unit increase in the ETc replacement depths (Figure 6B).

Results similar to those obtained here were found by Carvalho et al. (2014), who evaluated the export of nutrients in grains of common bean under different irrigation depths and observed that the highest averages of S export were also obtained with the application of the highest irrigation depths.

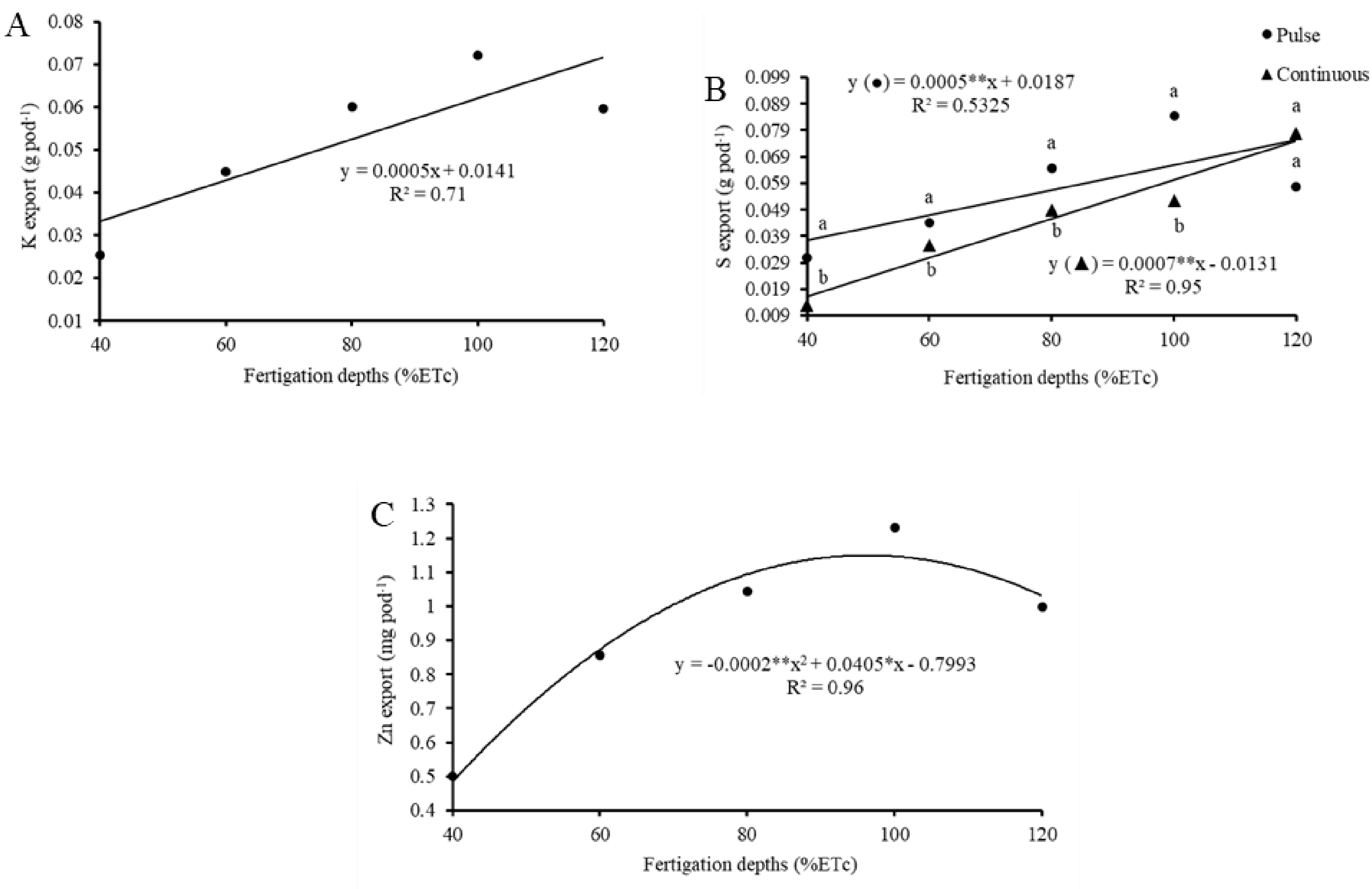

Figure 6. Export of potassium (K) (A), sulphur (S) (B) and zinc (Zn) (C) as a function of the fertigation depths applied.

In the analysis of the type of fertigation application considering each replacement depth (Figure 6B), significant difference was observed between pulse and continuous irrigation at the 40, 60, 80 and 100% ETc depths, with increments of 148.99, 69.89, 42.42 and 28.47% in S exports compared to continuous fertigation.

When analyzing the Zn export as a function of the fertigation depths applied, it was observed that the means of Zn export (Figure 6C) were described by the quadratic model, and the highest estimated value for this variable was 1.25 mg pod^{-1} at the 101.25% ETc depth, corresponding to an increase of 149.65% over the 40% ETc depth.

According to Aragão et al. (2012), water availability in the soil in adequate quantities promotes greater absorption of nutrients by plants, which may result from the increase of nutrients available in the soil solution, which are absorbed and transported to the fruits and shoots with less difficulty compared to plants subjected to water deficit.

In relation to Mg, the individual effect of the type of fertigation (Figure 7A) revealed that pulse fertigation promoted greater export, with a maximum value of 0.05 g pod^{-1}, representing a percentage increase of 66.6% compared to the application of continuous fertigation (0.03 g pod^{-1}).

For Fe (Figure 7B), pulse fertigation promoted the greatest export (1.66 mg pod^{-1}), with a percentage increase of 46.9% compared to continuous fertigation (1.13 mg pod^{-1}). On this aspect, Karmeli and Peri (1974) suggested the application of irrigation water by pulses, as this technique reduces the leaching of nutrients from the soil and promotes greater absorption and, consequently, greater translocation of these nutrients to the fruits.

The control treatments, under conventional fertilization and pulse (control 1) and continuous (control 2) irrigation with 100% ETc depth, caused significant differences on N, P, K, S, Fe and Cu. The highest values for the analyzed variables were obtained with the application of pulse irrigation, with increments in the exported values of 48.15% for N, 83.33% for P, 40% for K, 200% for S, 37.28% for Fe and 42.86% for Cu.

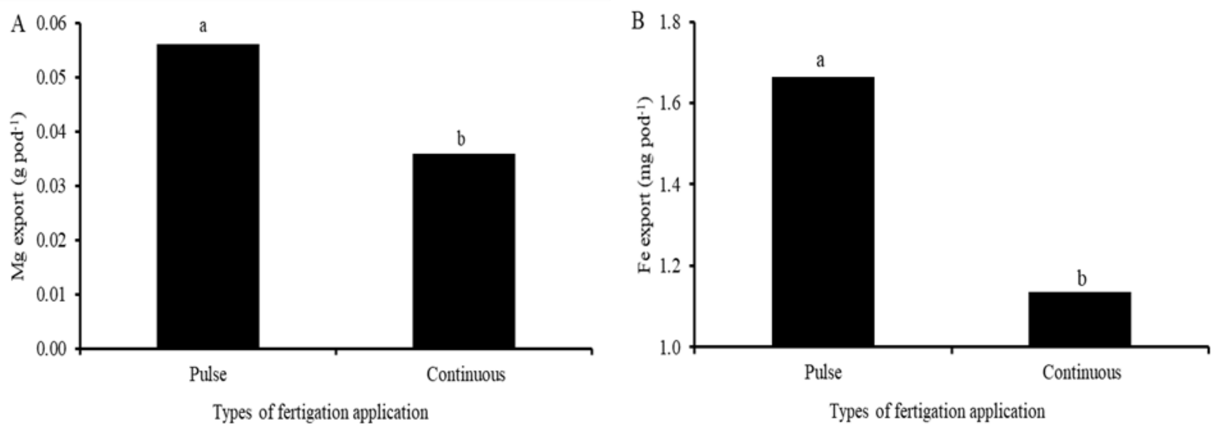

Figure 7. Export of magnesium (Mg) (A) and iron (Fe) (B) as a function of the types of fertigation application. Different letters indicate significant differences between the types of fertigation application (pulse and continuous) according to the Scott-Knott test ($p < 0.05$).

CONCLUSIONS

Pulse fertigation depths between 80 and 100% ETc were the ones that, in general, promoted the highest accumulations and exports of the nutrients evaluated. Conventional fertilization and pulse irrigation with 100% ETc depth (control 1) promoted higher accumulations and exports of nutrients by the plants compared to plants under continuous irrigation (control 2).

The descending order of total nutrient accumulation by cowpea for both types of fertigation application and for pulse irrigation management of plants under conventional fertilization was: N > K > Ca > P > Mg > S > Fe > Mn > Zn > Cu. For plants under conventional fertilization and continuous irrigation, the order was: N > Ca > K > P > Mg > S > Fe > Mn > Zn > Cu. The descending order of nutrient export by cowpea pods and grains for pulse fertigation application was: N > P > Ca > K > Mg > S > Fe > Zn > Mn > Cu. For the application of continuous fertigation, the descending order of export was: N > P > Ca > Mg > S> K> Fe > Zn > Mn > Cu.

Conventionally fertilized and pulse-irrigated plants showed the following descending order of export: N > P > Ca > K > Mg > S > Fe > Zn > Mn > Cu. For plants under continuous irrigation management and conventional fertilization, the descending order of export was: N > Ca > K > P > Mg > S > Fe > Zn > Mn > Cu.

In view of the results presented in this study, aiming at satisfactory production of green cowpea grains, pulse fertigation management, associated with crop evapotranspiration replacement depths between 80 and 100%, is recommended.

REFERENCES

ALMEIDA, W. F. et al. Yield of green beans subjected to continuous and pulse drip irrigation with saline water. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 22: 476-481, 2018.

ARAGÃO, V. F. et al. Produção e eficiência no uso da água do pimentão submetido a diferentes lâminas de irrigação e níveis de nitrogênio. **Revista Brasileira de Agricultura Irrigada**, 6: 207-216, 2012.

ASSOULINE, S. et al. Soil-plant system response to pulsed drip irrigation and salinity. **Soil Science Society of America Journal**, 70: 1556-1568, 2006.

BEZERRA NETO, E.; BARRETO, L. P. **Análises químicas e bioquímicas em plantas**. 1. ed. Recife, PE: UFRPE, Editora Universitária da UFRPE, 2011. 267 p.

CARVALHO, J. J. et al. Teor e acúmulo de nutrientes em grãos de feijão comum em semeadura direta, sob déficit hídrico. **Irriga**, 1: 104-117, 2014.

CAVALCANTI, F. L. A. et al. **Recomendações de adubação para o Estado de Pernambuco**. 3. ed. Recife, PE: Instituto Agronômico de Pernambuco – IPA, 2008. 212 p.

COFFIGNIEZ, F. et al. Bohuon, PKinetic study of enzymatic α-galactoside hydrolysis in cowpea seeds. **Food Research International**, 113: 443-451, 2018.

CONCEIÇÃO, C. G. et al. Economically optimal water depth and grain yield of common bean subjected to different irrigation depths. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 22: 482-487, 2018.

FREIRE FILHO, F. R.; LIMA, J. A. A.; RIBEIRO, V. Q. **Feijão-caupi: avanços tecnológicos**. 1. ed. Brasília, DF: Embrapa Informação Tecnológica, 2005. 519 p.

GUIMARÃES, D. G. et al. Desempenho da cultivar de feijão-caupi BRS Novaera sob níveis de irrigação e adubação em ambiente protegido. **Cultura Agronômica**, 29: 61-75, 2020.

GURGEL, A. L. C. et al. Compactação do solo: Efeitos na nutrição mineral e produtividade de plantas forrageiras. **Revista Científica Rural**, 22: 13-29, 2020.

HARTZ, T. K. et al. **Bell pepper production in California.** Oakland: University of California, 2008. 4 p.

KHAN, A. N. et al. tolerance in plants: revisiting the role of sulfur metabolites. **Journal of Plant Biochemistry & Physiology**, 2: 1-8, 2014.

KARMELI, D.; PERI, G. Basic principles of pulse irrigation. **Journal of the Irrigation and Drainage Division**, 100: 309-319, 1974.

MACHADO, V. J. et al. Curvas de Disponibilidade de Fósforo em solos com diferentes texturas após aplicação de doses crescentes de fosfato monoamônico. **Bioscience Journal**, 27: 70-76, 2011.

MADANE, D. A.; KDAM, U. S.; TOKHAL, R. Study of white onion (Allium cepa L.) on yield and economics under pulse irrigation (drip) for different irrigation levels. **International Journal Agriculture Engineering**, 11: 128-134, 2018.

MARTINS, P. H. M et al. Análise de crescimento do feijoeiro a diferentes manejos de adubação nitrogenada na região do cerrado. **Revista Agrotecnologia**, 8: 63-70, 2017.

MENEZES, S. M. et al. Continuous and pulse fertigation on dry matter production and nutrient accumulation in coriander. **Revista DYNA**, 87: 18-25, 2020.

NOVAIS, R. F.; NEVES, J. C. L.; BARROS, N. F. Ensaio em ambiente controlado. In: OLIVEIRA, A. J. et al. (Eds.). **Métodos de pesquisa em fertilidade do solo**. Brasília,DF: Embrapa Sea, 1991. v. 3, cap. 2, p.190-253.

PEREIRA, V. G. M. F. et al. Irrigação e fertirrigação na cultura do eucalipto. **Ciência Florestal MS (Aquidauana)**, 29: 22-34, 2019.

PURQUERIO, L. F. V. et al. Growth, yield, nutrient accumulation and export and thermal sum of Italian zucchini. **Horticultura Brasileira**, 37: 221-227, 2019.

RIVAS, R. et al. Drought tolerance in cowpea species is driven by less sensitivity of leaf gas exchange to water deficit and rapid recovery of photosynthesis after rehydration. **South African Journal of Botany, Pietermaritzburg**, 103: 101-107, 2016.

SAURE, M. Por que a deficiência de cálcio não é a causa da podridão foliar em tomate e pimentão: uma reavaliação. **Scientia Horticulturae**, 174: 65-89, 2014.

SEPAHVAND, T. et al. Symbiosis of AMF with growth modulation and antioxidant capacity of Caucasian Hackberry (Celtis Caucasica L.) seedlings under drought stress. **Central Asian Journal Environmental Science and Technology Innovation**, 2: 20-35, 2021.

SOUSA, et al. Resposta do feijão-caupi à inoculação de bradyrhizobium japonicum, adubação nitrogenada e nitrogênio do solo. **Revista Agroecossistemas**, 10: 298-308, 2018.

VIÇOSI, K. A. et al. Estresse hídrico simulado em genótipos de feijão, milho e soja. **Journal of Neotropical Agriculture**, 4: 36-42, 2017.

WIETHOLTER, S. Bases teóricas e experimentais de fatores relacionados com a disponibilidade de potássio do solo às plantas usando trigo como referência. **Revista Brasileira de Ciência do Solo**, 31: 1011-1021, 2007.