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

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)

USE OF TREATED SEWAGE AS WATER AND A NUTRITIONAL SOURCE FOR BEAN CROPS[1]

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ABSTRACT - Considering the relevance of the reduction or replacement of fresh water supplies for irrigation, to mitigate the use of agricultural fertilizers and to improve sustainability, this study aimed to evaluate water and nutritional efficiency of treated sewage in cowpea plots. The experiment was conducted in the city of Tianguá-CE, on land belonging to the Water and Sewage Treatment Company of Ceará. It used a randomized block design for the arrangement of split plots. The plots contained two water sources (treated sewage and well water). The subplots contained four irrigation levels based on potential evapotranspiration (50%, 75%, 100%, and 125% of ETc) and the sub-subplots contained four nitrogen, phosphorous, and potassium (NPK) levels (0%, 33%, 66%, and 99% of the nutritional recommendations for cowpea cultivation). The yield variables, number of pods per plant, bean numbers per pod, and bean production, were improved with increased irrigation, regardless of the water source. Examining NPK levels in particular, yields differed depending on the water source. The use of treated domestic wastewater for bean irrigation can replace up to 100% of commercial fertilizers.

Keywords: *Vigna unguiculata*. Trickle. Recycle. Fertilizing.

USO DO ESGOTO DOMÉSTICO TRATADO COMO FONTE HÍDRICA E NUTRICIONAL PARA A CULTURA DO FEIJOEIRO

RESUMO - Objetivou-se com o presente trabalho quantificar os componentes de produtividade da cultura do feijão submetida a diferentes lâminas de irrigação com água de poço e esgoto doméstico tratado em solo com diferentes níveis de adubação NPK. O experimento foi conduzido em Tianguá - CE, na área da Estação de Tratamento de Esgoto da Companhia de Água e Esgoto do Ceará. Foi utilizado o delineamento em blocos casualizados, em parcelas subsubdivididas 2 x 4 x 4, referente à duas fontes hídricas (efluente de esgoto doméstico tratado e água de poço amazonas) nas parcelas, quatro lâminas de irrigação baseadas na evapotranspiração potencial (50, 75, 100 e 125% da ETc) nas subparcelas e nas subsubparcelas quatro níveis de NPK (0, 33, 66 e 99%) da recomendação nutricional para a cultura. As variáveis analisadas, número de vagens por planta, números de grãos por vagem e produtividade de grãos aumentaram em função do incremento da lâmina de irrigação, independente da fonte hídrica. Quanto ao tratamento níveis de NPK, os resultados produtivos divergiram em função da fonte hídrica. O uso do efluente esgoto doméstico tratado na irrigação do feijoeiro pode substituir até 100% dos fertilizantes comerciais.

Palavras-chave: *Vigna unguiculata*. Irrigação. Reúso de água. Adubação.

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[1]Received for publication in 12/09/2016; accepted in 05/30/2017.
Paper extracted from the Master dissertation of the fourth author.
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INTRODUCTION

Cowpea is a crop of economic importance in the northeast region of Brazil. However, when compared to the national average (914 kg ha^{-1}), the low average productivity of the region (330 kg ha^{-1}) compromises both the agricultural and economic viability of this crop. This is mainly due to the water and nutrient shortage that is characteristic of the soil and climate of the region (PELEGRIN et al., 2009; LOCATELLI et al., 2014).

Irrigation can complement, or even completely replace, rainfall during drought periods, ensuring agricultural production. Andrade Júnior, Rodrigues and Frizzone (2002) evaluated the productivity of irrigated beans, registering values up to 2,809 kg ha^{-1}, at an irrigation depth of 449.1 mm. This result is similar to the value of 2,946.52 kg ha^{-1} measured by Mantovani et al. (2012) at 418.16 mm of depth, with irrigation irregularly distributed throughout the crop cycle.

In addition to irrigation, a factor that contributes significantly to increasing bean yield is an adequate supply of nutrients, especially nitrogen (N), phosphorus (P), and potassium (K). Pelegrin et al. (2009) used different levels of N, and obtained a productivity of 3,762 kg ha^{-1} from 160 kg ha^{-1} of fertilizer. When considering P in particular, Silva et al. (2010) observed maximum yield values of 1,177 kg ha^{-1} from an application of 90 kg ha^{-1} of P_2O_5. Oliveira et al. (2007) assessed the yield potential of the beans as a function of potassium fertilization and found a greater yield, 25,300 kg ha^{-1}, with an application of 171 kg ha^{-1} of K_2O. In addition to water, treated domestic sewage can be used as an alternative source of nutrients for bean cultivation.

In this context, the study aimed to quantify bean productivity and productivity components, at various irrigation depth levels, using both water and treated domestic sewage in soil with differing amounts of NPK fertilizers.

MATERIAL AND METHODS

The experiment was conducted from October to December 2014 on land belonging to the Companhia de Água e Esgoto do Estado do Ceará (CAGECE), in the municipality of Tianguá, Ceará (CE) (located at latitude: 3°44′16″S; longitude: 40°59′30″W; medium altitude: approximately 740 m). According to the Köppen classification, the climate in the region can be classified as Aw (tropical dry climate), with average temperatures of 26 °C and average annual rainfall of 1,350 mm.

When preparing for the experiment, soil samples from the experimental area were collected in layers of up to 0.20 m. These samples were later sent to the Laboratório de Solos at the Federal University of Ceará, and the results from the chemical analysis have been displayed in Table 1.

Table 1. Soil chemical attributes of the experimental area, Tianguá, CE.

Chemical characteristics	Soil layer Up to 0.20 cm	Description
Organic matter g kg^{-1}	16.96	-
P (mg dm^{-3})	200	Low
K^+ ($mmol_c$ dm^{-3})	0.21	Low
Ca^{+2} ($mmol_c$ dm^{-3})	17.00	Average
Mg^{+2} ($mmol_c$ dm^{-3})	9.00	Average
Al^{+3} ($mmol_c$ dm^{-3})	0.50	-
pH	5.50	-
CE (dS m^{-1})	0.33	-

Extractors: P, Na, and K; Mehlich: Ca, Mg, and Al; KCl: pH water (1:2.5).

Soils were prepared by slicing and cross-grading. Additionally, 3 kg m^{-2} of tanned bovine manure was used, to increase organic matter concentration and therefore, to structurally improve the soil in the experimental area, following the recommendation given by Amaro et al. (2007). Cowpea (*Vigna unguiculata*) BRS Marataoã was planted in the experimental area with a spacing of 0.30 × 0.50 m, to evaluate the treatments.

The experiment followed a random block with split-plot designs, with four replications, in a 2 × 4 × 4 factorial, with two sources of water (well water and treated domestic sewage), four irrigation depth levels (50%, 75%, 100%, and 125% of the crop evapotranspiration (ETc)), and four combined levels of NPK (0%, 33%, 66%, and 100%). The plots parameters comprised water type, subplots of four irrigation depth levels, and the sub-subplots of the NPK levels.

Irrigation depth levels were established based on the potential ET of the plants with aid of a Class "A" tank. Following the advice of Santana et al. (2008), four crop coefficients (Kc) of 0.53, 0.81, 1.07, and 0.78 were used for the initial, intermediate, growth, and final stages, respectively. The levels of each nutrient were obtained by factoring the recommended upper limits of 150 kg ha^{-1} of N, 120 kg ha^{-1} of P and 90 kg ha^{-1} of K (BRASIL, 2013).

Each sub-subplot had five rows of plants. Central rows were treated as useful lines, whereas side rows served as the borders. Every row took up an area of 2.5 m^2 (0.5 × 5.0 m), with 34 plants.

The domestic sewage effluent that was used came from households in the municipality of Tianguá (CE), and was serially treated by a waste stabilization pond system. In the first pond, which had a small water surface and was considerably deep, anaerobic bacteria aided in the process of flocculation and separation of solid particles. The second (facultative) pond was shallow and characterized by a large surface area, water treatment was performed by aerobic bacteria, algae, and solar radiation. The third and fourth pounds were called maturation ponds, and were similar in design to the facultative pond. The sewage effluent used for irrigation was taken from the maturation ponds. Samples of the treated sewage effluent used for the experiment were analyzed, and the results are displayed in Table 2.

Table 2. Chemical analysis of the sewage effluent samples.

Item	Parameters	Results
1	pH	7.7
2	EC (μs cm^{-1})	1040.0
3	Total Solids (mg L^{-1})	742.0
4	Total Suspended Solids (mg L^{-1})	68.0
5	Total Dissolved Solids (mg L^{-1})	674.0
6	Total Alkalinity (mg $CaCO_3$ L^{-1})	224.1
7	Calcium (mg L^{-1})	11.9
8	Magnesium (mg L^{-1})	15.8
9	Chloride (mg L^{-1})	217.4
10	Sodium (mg L^{-1})	164.6
11	Potassium (mg L^{-1})	36.4
12	Total Ammonia (mg N L^{-1})	7.5
13	COD (mg L^{-1})	324.3
14	Total Phosphorus (mg L^{-1})	7.4

EC, Electrical conductivity; COD, Chemical oxygen demand.

Table 3 shows the NPK concentrations of the treated sewage effluent as a function of irrigation depth level.

The evaluated yield variables were: number of pods per plant (NPP), number of beans per pod (NBP), mass of 100 beans (M100B), and bean productivity (BP).

The data were subjected to analysis of variance, carried out using the F-test with 1% and 5% cutoffs of probability. The programs ASSISTAT® (beta version 7.6) and SAEGD® (version 9.0) were used to perform the statistical analyses.

Table 3. NPK concentration in treated sewage effluent as a function of irrigation depth level.

	Depth	Nutrients (kg ha^{-1})		
		N	P	K
D1	174 mm	13.05	12.80	63.30
D2	275 mm	20.60	20.30	100.10
D3	348 mm	26.10	26.10	126.60
D4	435 mm	32.60	32.60	158.30

RESULTS AND DISCUSSION

According to the analyses of variance, the two water sources significantly influenced the NBP and BP. In addition, all analyzed variables were noticeably influenced by irrigation depth levels (D), NPK fertilizer levels (F), and the plot dimensions W × D × N (Table 4).

Table 5 shows the highest average of NBP (12.39) was obtained using treated sewage effluent. When compared to the average (12.03) obtained using well water, the difference is significant (Table 5). The corresponding average values of NBP observed in this study were higher than the value (5.3) observed by Ramos Junior, Lemos and Silva (2005). Teixeira et al. (2010) evaluated the yield performance of BRS Marataoã and found similar values to those reported in this study, with an average of 12 beans per pod.

Table 4. Summary of the analysis of variance of the data given for number of beans per pod (NBP), mass of 100 beans (M100B), and bean productivity (BP) using two water sources (W), four irrigation depth levels (D), and four NPK levels (F).

Variation source	G.L	Middle squares		
		NBP	M100B	BP
Block	3	5.011*	8.123ns	278108.59*
Trat. (W)	1	4.124**	0.438ns	279038.49*
Res. W	3	0.058	2.435	14,796.30
Trat. (D)	3	4.203**	4.650*	1744471.97**
Int. W × D	3	1.131*	1.545ns	59255.38 ns
Res. D	18	0.231	1.177	36,036.50
Trat. (N)	3	5.543**	11.556**	434321.58**
Int. W × F	3	15.235**	11.429**	979570.37**
Int. D × F	9	3.142**	6.317**	96602.37*
Int. W × D × F	9	2.469**	4.340*	225632.53**
Res. F	72	0.814	1.832	63,605.00

**Significant at 1% probability; *Significant at 5% probability; ns, not significant.

Table 5. Average of number of beans per pod (NBP) as a function of two water sources (W), four irrigation depth levels (D), and four NPK levels (F).

Water source	Irrigation depth level (mm)		NPK level				AVERAGES
			F1	F2	F3	F4	
			Number of beans per pod (NBP)				
Well water	D1	174	13.22	11.54	11.86	12.06	12.17a
	D2	275	10.72	11.93	13.27	12.69	12.15b
	D3	348	10.63	12.23	12.00	10.31	11.29b
	D4	435	11.51	12.00	13.06	13.48	12.51a
		Averages	11.52B	11.93B	12.55A	12.14A	12.03b
Sewage	D1	174	13.03	12.76	11.79	11.16	12.19a
	D2	275	13.65	13.51	12.06	10.93	12.54a
	D3	348	13.66	13.38	11.02	10.62	12.17a
	D4	435	13.57	12.13	13.47	11.53	12.68a
		Averages	13.48A	12.95A	12.09A	11.06B	12.39a

Averages followed by different letters differ from each other by the Tukey's test at 5% probability. Lowercase letters correspond to columns, whereas uppercase letters correspond to rows.

Regression analysis was employed to estimate NBP variability as a function of NPK levels, using well water and fixed irrigation depth (D). However, it was not possible to determine a mathematical model that fitted the data for the value of D, and was consistent with 50% of ETc. In addition, the mathematical model that best fitted the irrigation depth levels with 75%, 100%, and 125% of ETc was a quadratic function for the first two, and a linear function for the last one. NBP tended to increase as function of increasing fertilizer, peaking at 13.56 beans per pod for the treatments with 125% ETc and 99% of NPK (Figure 1A).

For plants irrigated using treated sewage (Figure 1B), with fixed irrigation depth levels and different NPK levels, the statistical model that best fitted the data was a linear function. The exception to this was the treatment corresponding to 125% of ETc, for which no equation seemed to fit adequately, where an increase in NPK levels caused a reduction in NBP. The highest estimated NBP observed using sewage effluent was 13.98 and 13.89 with 75% and 100% ETc, respectively; commercial fertilizer N1 was not used in either case. It is possible that the excessive NPK levels were the result of an excess of these nutrients in the soil, because treated domestic sewage has a high concentration of these elements. This excess might also have resulted in antagonistic effects on other nutrients.

In agreement with the results obtained in this study, Sousa Neto et al. (2012) concluded that the effluent of treated domestic sewage can completely replace conventional fertilization for cotton cultivation. This was corroborated by Freitas et al. (2012), in a study using sunflower crop. The use of domestic sewage provided up to 50 kg ha^{-1} of N.

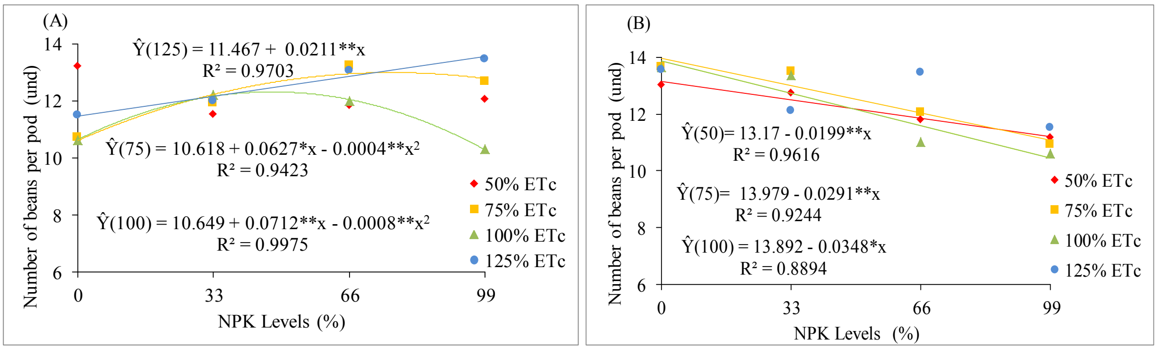

Figure 1. Number of beans per pod (NBP) as a function of NPK and irrigation depth levels for the beans irrigated with (A) well water and (B) treated domestic sewage.

Table 6 shows the average mass of 100 beans (M100B) was 18.98 and 19.10 g using well water and treated domestic sewage, respectively, and they did not differ statistically. Independent of the water source, these averages were higher than the 15.5 g observed for the same cultivar recorded by Freire Filho et al. (2005) and Teixeira et al. (2010).

Table 6. Average mass of 100 beans (M100B) as a function of two water sources (W), four irrigation depth levels (D), and four NPK fertilization levels (F).

Water source	Irrigation depth level (mm)		NPK level				AVERAGES
			F1	F2	F3	F4	
			Mass of 100 beans (M100B)				
Well water	D1	174	19.36	20.29	17.65	20.16	19.37a
	D2	275	17.99	18.87	21.58	17.68	19.28ab
	D3	348	16.91	20.53	17.02	18.15	18.15b
	D4	435	18.56	19.19	19.43	19.32	19.12ab
		Averages	18.20B	19.97A	18.92B	18.83B	18.98a
Sewage	D1	174	19.9	20.41	18.04	19.02	19.34a
	D2	275	20.28	19.95	18.12	17.26	18.9ab
	D3	348	19.6	19.6	19.39	16.71	18.83b
	D4	435	20.33	18.58	19.82	18.54	19.32ab
		Averages	20.03A	19.64A	18.84AB	17.88B	19.10a

Averages followed by different letters differ from each other by the Tukey's test at 5% probability. Lowercase letters correspond to columns, whereas uppercase letters correspond to rows.

Regarding the M100B data, it was not possible to find a simple mathematical model that explained the biological behavior of the data against the variation observed among the studied factors. The highest value of M100B noted in plants irrigated with well water was 21.58 g, obtained with an irrigation depth of 275 mm (75% of ETc) and 66% of recommended NPK (99 kg ha^{-1} of N, 79.2 kg ha^{-1} of P, and 59.4 kg ha^{-1} of K). In contrast, for plants grown using domestic sewage effluent the highest value was 20.33 g, obtained using a combination of an irrigation depth corresponding to 125% of ETc (435 mm) and 0% of NPK. One possible explanation for this performance without the use of commercial fertilizers may be the availability of NPK and other nutrients in treated domestic sewage, which with an irrigation depth of 435 mm produced a total of 32.6 kg of N ha^{-1}, 32.6 kg of P ha^{-1}, and 158.3 kg of K ha^{-1}. These were added in installments throughout the cropping cycle.

Table 7 shows that the highest productivity (935.8 kg ha^{-1}) was observed in plants irrigated with treated domestic sewage, differing significantly ($P < 0.05$) from the average of 842.4 kg ha^{-1} observed in plants irrigated with well water. Bezerra et al. (2014), working with sunflowers and using two water sources (treated domestic sewage effluent and well water), found a significant increase in productivity of the plants that had been irrigated with domestic sewage effluent.

Table 7. Averages of bean productivity (BP) as a function of two water sources (W), four irrigation depth levels (D), and four NPK levels (F).

Water source	Irrigation depth levels (mm)		NPK level				AVERAGES
			F1	F2	F3	F4	
			Productive potential				
Well water	D1	174	823.54	519.68	450.09	543.61	584.23c
	D2	275	522.94	719.96	938.25	673.96	713.78c
	D3	348	573.46	887.87	1,177.85	824.68	865.97b
	D4	435	951.22	1,372.76	1,256.98	1,241.96	1,205.73a
		Averages	717.79B	875.07B	955.79A	821.05AB	842.43b
Sewage	D1	174	1,084.45	1,056.22	572.08	482.84	798.90c
	D2	275	1,130.34	895.42	613.49	482.82	780.52c
	D3	348	1,312.84	1,225.00	609.14	637.34	946.08b
	D4	435	1,625.30	885.85	1,383.38	976.36	1,217.72a
		Averages	1,288.23A	1,015.62B	794.52BC	644.84C	935.80a

Averages followed by different letters differ from each other by the Tukey's test at 5% probability. Lowercase letters correspond to columns, whereas uppercase letters correspond to rows.

Assessing BP as a function of NPK levels for each irrigation depth yielded the quadratic function that best fitted the well water data (Figure 2A). BP tended to increase with NPK, except for the irrigation depth with 50% of ETc (174 mm) where yielded decreased as NPK increased. This could be explained by an increase in salt concentration in the soil tied to an increase in NPK, that is associated with water shortage. This effect was noted by Assis Júnior. et al. (2007), who concluded that increasing salinity decreases the bean yielded.

With respect to the plants irrigated using sewage, BP data was adjusted to fit a linear function, where a decrease in yielded levels and an increase in NPK levels were observed. This can be associated with excess nutrients, because the sewage already contains nutrients (Figure 2B). Viana et al. (2011) observed a quadratic effect on bean performance relating to nitrogen (N) and phosphorus (P) concentrations; N was tested at 0, 70, 140, and 210 kg ha^{-1} and P 0, 100, 200, and 300 kg ha^{-1} of P_2O_5. The highest productivity (1,528 kg ha^{-1}) was obtained with 98 kg ha^{-1} of N and 201 kg ha^{-1} of P, emphasizing that there is a limit to these relationships; above that value, yielded decreases.

Analyzing the effect of irrigation depth levels on BP for every level of NPK, it was observed that the polynomial model had the best fit, regardless of water source. Additionally, higher water availability also contributed to increasing BP (Figure 2C and 2D). Andrade Júnior, Rodrigues and Frizzone (2002) experimented with the cowpea BR 14 Mulato using different irrigation depth levels, and noted the same quadratic behavior for the yielded of this plant.

The highest estimated potential yield was 1,355 kg ha^{-1} for plants irrigated with well water equivalent to 125% of ETc (435 mm) and 66% of NPK. There was an increase of approximately 208% when compared to BP of 439 kg ha^{-1}, corresponding to the estimate for plants irrigated using well water, but with the lowest water availability, an irrigation depth equivalent to 50% of ETc, and 64% of NPK. These results demonstrated the importance of irrigation and efficient fertilization for increasing yield. Mantovani et al. (2012) observed a maximum yielded for the common bean of 2,946.52 kg ha^{-1} using an irrigation depth of 418.16 mm, a value that is very close to what was observed in this work.

Comparing the lowest yield observed in this work (under conditions of 50% of ETc, 64% of NPK, and well water) with the maximum BP of 1,625 kg (under conditions of 125% of ETc, without fertilizer but with treated domestic sewage) reveals an increase of 270%, suggesting that treated domestic sewage can be used as a water source that also provides an alternative source of nutrients and thereby maximizes production. In short, the nutrients available in treated domestic sewage are provided as part of the irrigation treatment, to provide the best yield. A similar effect was noted by Hussar et al. (2005), who worked with beet plants, and showed that treated domestic sewage can provide up to 100% of the necessary nutrients, thereby eliminating the need for additional fertilizers. Rebouças et al. (2010) also reported on the use of treated sewage for the provision of nutrients when they studied the effect of dilutions of well water and sewage; they concluded that the recycled water exceeded nutritional requirements for cowpea. Finally, Santos et al. (2006) demonstrated that treated domestic sewage added to okra gave yields similar to those obtained with common water and mineral fertilizers.

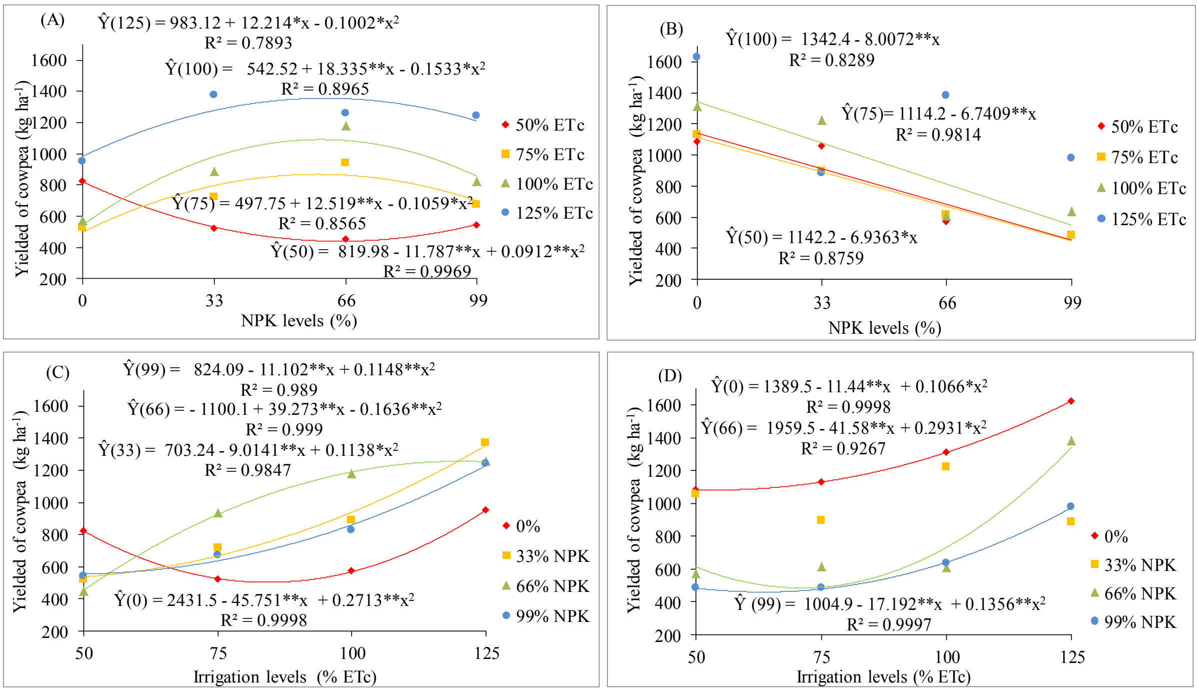

Figure 2. Yielded of cowpea irrigated with (A and C) well water and (B and D) treated domestic sewage as a function of NPK levels (A and B) and irrigation depth levels (C and D).

CONCLUSION

An increase in water availability promoted improved productivity. A reference depth of 125% of evapotranspiration (ETc) gave the best bean productivity, regardless of the water source.

For beans irrigated with well water, there was an improvement in productivity with increasing fertilizer up to the recommended NPK limit of 66%. Plants irrigated at a depth of 50% of ETc gave reduced yields with increasing levels of NPK fertilizer, which was a response to water stress.

For plants irrigated with treated domestic sewage, an increase in fertilizer levels resulted in a decrease in yielded due to the excess of nutrients, because these were already present in the sewage.

The treated domestic sewage made nutrients available in part for every irrigation treatment; this resulted in an efficient distribution of nutrients, which was reflected in the increased BP.

Treated domestic sewage can be used as a source of both water and nutrients for common bean cultivation, allowing for substitution of up to 100% of NPK fertilizer.

ACKNOWLEDGEMENTS

CAGECE–Companhia de Água e Esgoto do Ceará for making the area available and for partially supporting this research.

IFCE–Instituto de Educação Ciência e Tecnologia do Ceará for providing research funds.

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