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Nitrate and potassium leaching and the response of the common bean to different irrigation blades

Walter da Costa Mendes[1]*, José Alves Junior[2], Paulo César Ribeiro da Cunha[1], Anderson Rodrigo da Silva[1], Adão Wagner Pêgo Evangelista[2] and Derblai Casaroli[2]

[1]Instituto Federal Goiano – Campus Urutaí, Rodovia Geraldo Silva Nascimento, Km 2,5, 75790-000, Urutaí, Goiás, Brasil.
[2]Escola de Agronomia, Universidade Federal de Goiás – Campus Samambaia, Rodovia Goiânia-Nova Veneza, Km 0, 74001-970, Goiânia, Goiás, Brasil.

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The aim of this study was to determine the effects of increasing irrigation levels on the movement of nitrate and potassium in clay soil and on crop yields for the common bean irrigated by central pivot under Brazilian Cerrado conditions. The experiment was conducted in Urutaí, Goiás, Brazil, in Dystrophic Oxisol clayey soil in 2014. Four irrigation regimes were tested, which were equivalent to 50, 100, 150 and 200% of crop evapotranspiration (ETc), estimated using the Class A tank method. The plots were arranged in a randomized complete block design with four replications; the soil solution was evaluated seven times during the cycle. Potassium chloride with 58% K_2O was used as the potassium source, and calcium nitrate with 15.5% total nitrogen (N) as the nitrogen source. To collect the soil solutions, extractors were installed at depths of 0.20, 0.40, 0.60, 0.80 and 1.00 m. The concentrations of nitrate (NO_3^-) and potassium (K^+) were determined without filtering or digestion. At harvesting, the production components and yield were evaluated. The NO_3^- and K^+ levels within the soil profile varied between treatments, showing nutrient leaching below the root system for the higher irrigation treatments. Therefore, the application of appropriate irrigation techniques should reduce the leaching of NO_3^- and K^+ and lead to higher yields for the common bean.

Key words: Bean, aspersion, water management, loss of NO_3^- and K^+.

INTRODUCTION

The Brazilian Cerrado has been intensively explored since the early 1970s and is currently one of the most important areas of the country in terms of production of grains and meat. The soils are originally acidic and present low availability of essential nutrients for plants (Vendrame et al., 2010). Thus, they require the use of fertilizers to enable

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*Corresponding author. E-mail: mendeswalter2@gmail.com.

the production of crops.

One of the problems that occur, due to the intensive use of fertilizers in farming systems is the leaching phenomenon involving complex interaction between soil hydrology, water and nutrient uptake by plants and management practices (Van et al. 2006). Soluble ions from correctives, fertilizers and the decomposition of organic matter are potentially available to plants. However, during periods of high rainfall, intensity or excessive irrigation, there can be significant water drainage, facilitating the downward movement of these ions. For this reason, leaching is a constant concern that requires regular monitoring to prevent the loss of nutrients and environmental pollution (Santos et al., 2002).

Beans are historically one of the main food consumed in Brazil and in the world (Barbosa and Gonzaga, 2012), with important nutritional role to humans as a source of vitamins, fiber, iron, isoflavones, phosphorus, magnesium, calcium, zinc and mainly protein for the population of low income (Broughton et al., 2003).

The common bean (*Phaseolus vulgaris* L.) is a plant that requires high levels of nutrients due to its short lifecycle (70-110 days) and reduced, shallow root system, in which approximately 76 to 90% of its roots are found in the first 0.30 m of soil (Stone, 2002). Among the nutritional deficiencies found in bean crops, nitrogen (N) deficiency is the most common. Approximately, 50% of the total N absorbed is exported to the grain, making it necessary to determine the correct dose and time of application to provide adequate nutrition to the plant until the beginning of flowering to increase the number of pods per plant (Carvalho et al., 2001). The application of excessive N doses, in addition to increasing economic costs, can have serious environmental risks, whereas insufficient doses can limit productivity (Santos et al., 2002).

Nitrate (NO_3^-) is the mineral form of N in the soil that results from the application of nitrogen fertilizer or organic matter mineralization. When NO_3^- in the soil solution is not absorbed by plants or immobilized by soil microbiota, it can be easily leached, as it has a negative charge and is not adsorbed well by soil particles, which exhibit predominantly negative charges (Primavesi et al., 2006).

Special attention should also be paid to the use of potassium (K) fertilizer, as K is the second most important mineral nutrient required by vegetable species after N (Marschner, 1995). In particular, the bean has two periods of high K demand. The first occurs during flower bud differentiation, when crops absorb on average of 1.7 kg K ha^{-1} day^{-1}, and the second period occurs at the end of flowering and the onset pod formation, when crops absorb 2.2 to 3.3 kg K ha^{-1} day^{-1} (Rodrigues et al., 2013).

K present in the soil solution moves vertically, mainly through drainage water, and can be transported through leaching to depths inaccessible to the root system (Oliveira and Boas, 2008). This movement of potassium in the soil profile primarily depends on soil texture type (Neves et al., 2009), cation exchange capacity (CEC) and water regime, as well as fertilizer dosage and solubility (Rosolem et al., 2006).

Even though modern technologies have led to higher bean crop yields, irrigation efficiency remains a problem because irrigation management is still lacking and the producer fearing the crop to suffer from water stress, usually uses excessive application of water. Out of all water used in the world, 70% is for irrigation (Evett and Tolk, 2009). According to a study conducted by Company Energy of Minas Gerais (CEMIG), if irrigation were to be implemented rationally, approximately 20% water and 30% of the consumed energy could be saved (Lima et al., 1999).

As energy costs represent approximately 7% of the total cost of bean production (FAEG, 2015), optimal irrigation management practices would yield savings of only 2.1% of the total production cost, which producers generally consider negligible, leading them to prioritize other expenses such as manuring, which represents approximately 28% of the total production cost. However, correct irrigation practices have other benefits besides saving electricity, such as reducing nutrient loss by leaching due to the high mobility of N and K in the soil.

Therefore, the aim of this study was to determine the effects of increasing irrigation levels on the movement of nitrate and potassium in clay soil and its influence on the productivity of bean crops irrigated by center pivot in Cerrado conditions.

MATERIALS AND METHODS

Site description

The experiment was conducted between July and November of 2014 in an area irrigated by central pivot at the Federal Institute Goiano (IF Goiano), Campus Urutaí, Goiás, Brazil, in dystrophic Oxisol clayey (Embrapa, 2006), 17° 28' 41" South latitude and 48° 11' 35" West longitude, at an altitude of 823 m. The climate, according to Köppen, was classified as Cwa (tropical altitude), with dry winters and hot and rainy summers.

Before installing the experiment, the authors calculated the water distribution uniformity at the pivot (irrigated area = 19.63 ha, relief inclined = 5% of slope, blade applied to 100% = 2.32 mm and CUC = 82%), performed water infiltration tests in the soil (TIB = 159 mm h^{-1}), constructed a water retention curve for the soil for the 0 to 0.30 m layer (θ FC at 10 kPa = 0.2335 m^3 m^{-3}, θ criticism at 35 kPa = 0.1697 m^3 m^{-3} and θ PWP at 1500 kPa = 0.1149 m^3 m^{-3}) and analyzed the chemical and physical properties of the soil (Table 1). The percentage of macropores and micropores in the soil were approximately 26.80 and 23.35%, respectively.

Experiment conduction

After the desiccation of spontaneous vegetation was performed

Table 1. Chemical and physical soil characteristics.

Layer (m)	pH	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	K	N	O.M.	CEC effective	CEC pH 7,0	Clay	Silt	Sand	Ds
		(cmol$_c$ dm^{-3})				(mg dm^{-3})		(g kg^{-1})	(cmol$_c$ dm^{-3})		(%)			(g cm^{-3})
0.0-0.2	5.8	4.6	1.7	0.0	4.3	63	600	29	6.46	10.76	45.1	12.1	42.8	1.34
0.2-0.4	5.7	3.6	1.4	0.1	3.8	20	600	21	5.15	8.85	45.2	12.7	42.1	1.26
0.4-0.6	5.7	2.1	1.0	0.2	3.1	13	400	17	3.33	6.23	46.3	12.5	41.2	1.13
0.6-0.8	5.7	1.4	0.8	0.1	2.4	10	400	12	2.33	4.63	45.1	13.1	41.8	1.10
0.8-1.0	5.4	0.9	0.7	0.1	2.2	7	400	11	1.72	3.82	43.0	14.0	43.0	1.11

Ds: soil density.

mechanically on 10 July 2014, dry beans (cultivar Pearl) were sown at a spacing of 0.50 m between rows and 15 seeds per m. At the time of sowing, 450 kg ha^{-1} formulated fertilizer was applied with the following composition: 4% nitrogen, 30% phosphorus, 16% potassium, 2% calcium, 0.6% manganese, 0.54% boron and 0.27% zinc.

During cultivation, the culture was irrigated using 34 water blades with the Class A tank method, and the tank was located approximately 500 m from the experimental area. To estimate the crop evapotranspiration (ETc), the coefficient of the tank (Kp) was fixed at 0.7 (Cunha et al., 2013) and an adapted version of the bean crop coefficient (Kc) proposed by Silva and Stone (1999) was used: 00-14 days after emergence (DAE) Kc = 0.49; 15-24 DAE Kc = 0.69; 25-34 DAE Kc = 0.77; 35-44 DAE Kc = 0.90; 45-54 DAE Kc = 1.06; 55-64 DAE Kc = 0.89; 65-74 DAE Kc = 0.74; 75-84 DAE Kc = 0.48; and 85-95 DAE Kc = 0.27.

The first irrigation was performed one day after sowing (DAS), to raise the surface layer of 0.15 m to field capacity (FC) for all treatments. Another four irrigations were performed every two days to replace water lost to evaporation and ensure seed germination, which occurred at eight DAS. The sixth and last common irrigation for all treatments was performed with the aim of restoring ETc and raised the FC of the soil profile from 0 to 0.30 m. Afterward, irrigations were performed every three days, and the bean was subjected to four different water regimes (treatments) characterized by water slides of 50, 100, 150 and 200% ETc. The plots were arranged in a randomized complete block design with four replications located 200 m from the center of the pivot with 15 m between them. Each plot cultivation consisted of six bean lines 5-m in length.

As top dressing, 522 kg ha^{-1} calcium nitrate fertilizer with 15.5% total Nitrogen (14.4% N-Nitric and 1.1% N-Ammonium) was applied, which was made available in two applications at the beginning of the V3 and V4 stages of the bean crop. During bean development, all relevant cultural and phytosanitary treatments recommended by Barbosa and Gonzaga (2012) were performed.

To collect the soil solution, solution extractors were installed in the bean planting row at the center of the plots, one per depth at 0.20, 0.40, 0.60, 0.80 and 1.00 m, which were used for seven extractions. With the aid of a hand pump, the extractors were used to apply a vacuum pressure of approximately 70 kPa 24 h after an irrigation, and the solutions were collected six hours after the application of vacuum. The first six extractions were performed at 12, 33, 48, 63, 78 and 92 DAS, with the crops in the field, and the seventh and final extraction was performed 124 DAS, fifteen days after the bean harvest. In the four days preceding the last extraction, daily irrigation levels equivalent to 23 mm were applied to moisten the soil and ensure solution extraction at all depths of treatment. The extracted soil solutions were assayed directly without filtering or digestion of nitrate (NO_3^-) or potassium (K^+). The NO_3^- concentration was determined using a HORIBA LAQUAtwin nutrient meter, model B-343 and the K^+ concentration using a HORIBA LAQUAtwin nutrient meter, model B-731 (TRACOM EQUIPAMENTOS LTDA, São Paulo - SP, Brazil).

The bean harvest was performed at 109 DAS. At harvest, the plants located two-m from one of the central lines of each plot were counted to determine the final plant population, and then ten consecutive plants were collected from the useful area of each plot to evaluate the following production components: number of pods per plant, number of grains per pod and mass of 100 grains. At the time of determination of grain moisture, which was performed using a Gehaka Agri G800 moisture meter, the mass per hectoliter for each sample was also determined. The grain yield was obtained using the manual pull-off method on two four-m lines in the floor area of each parcel, disregarding 0.5 m from each end. Plants were air-dried and subjected to manual threshing, and the grains obtained were weighed; the data were processed in kg ha^{-1} with humidity adjusted to 13%.

After the harvest of bean crop, a final set of soil samples were collected for chemical analysis to compare soil metrics before and after the experiment.

Data analysis

The final population results for plant number, yield components and bean yield were subjected to analysis of variance and the variables that showed significant differences at 5% probability of error were analyzed via regression for the quantitative factor (irrigation blades) to determine the model that best predicted the relationships between variables.

RESULTS AND DISCUSSION

The treatments received the following water slides (mm) based on percentage of ETc: treatment 50% (rain = 112, irrigation = 215, total = 327), treatment 100% (rain = 112, irrigation = 377, total = 489), treatment 150% (rain = 112, irrigation = 539, total = 651) and treatment 200% (rain = 112, irrigation = 701, total = 813).

The dynamic water balance during the bean development

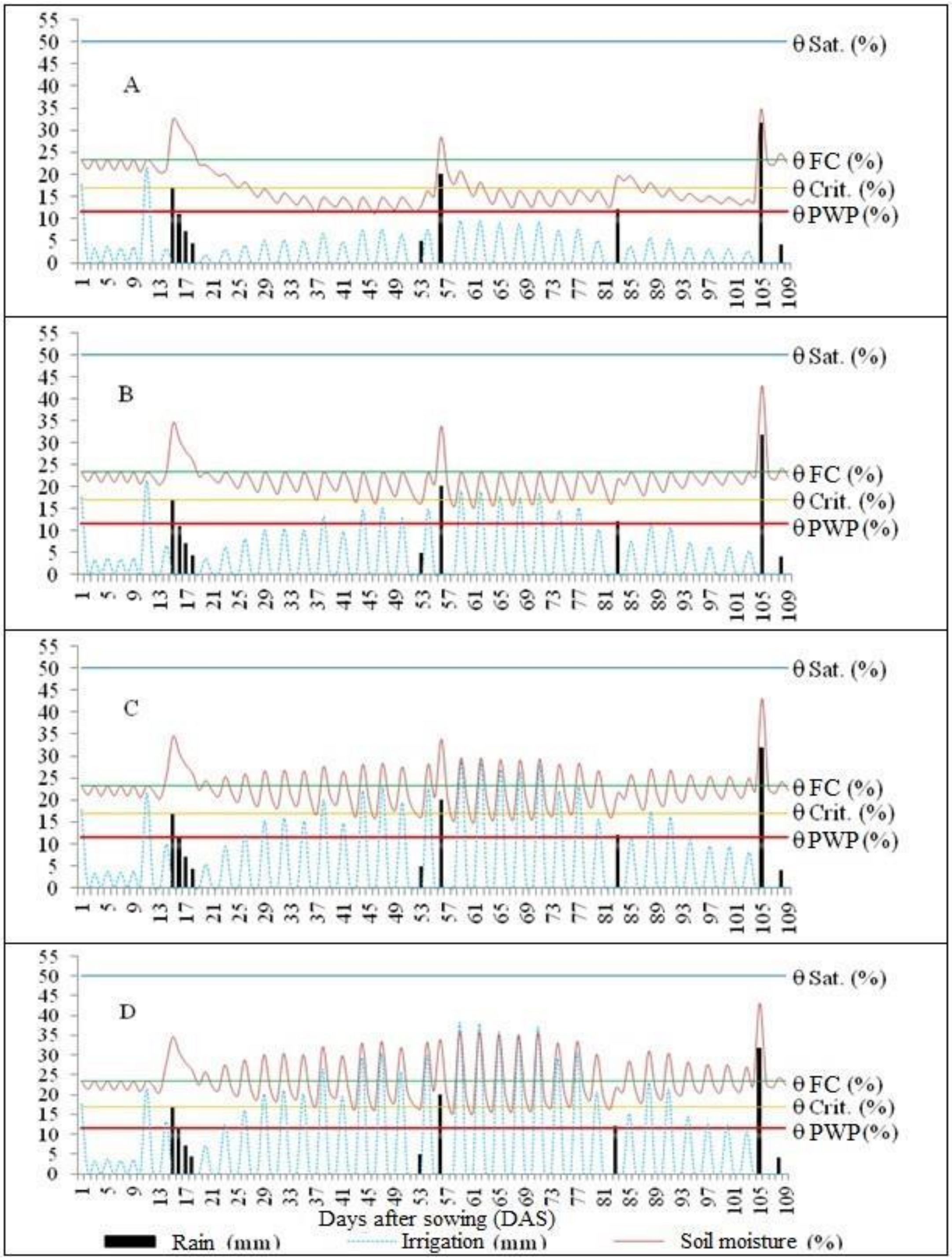

Figure 1. Dynamic water balance in the soil. Treatment with 50% (A), 100% (B), 150% (C) and 200% (D) ETc for the bean crop. For 1 to 10 DAS, the root system was considered to reach a depth of 0.15 m, and afterward to a depth of 0.30 m.

cycle with a water replacement regime of only 50% ETc was first analyzed (Figure 1A). Note that with the exception of the initial period of crop establishment (from the 1 to 13 DAS), as well as some periods following

Table 2. Nitrate and potassium concentrations (mg dm^{-3}) in the soil solution at different depths for the irrigation treatments with 50% (A), 100% (B) 150% (C) and 200% (D) ETc.

Depth (m)	Days after sowing (DAS)													
	12		33		48		63		78		92		124	
	NO_3^-	K^+	NO_3^-	K^+	NO_3^-	K^+	NO_3^-	K^+	NO_3^-	K^+	NO_3^-	K^+	NO_3^-	K^+
(A)														
0.20	64	10	385	27	-	-	-	-	-	-	-	-	94	6
0.40	-	-	83	3	17	1	44	1	-	-	-	-	139	4
0.60	-	-	50	4	60	4	84	6	-	-	-	-	39	3
0.80	-	-	24	1	25	1	27	1	-	-	-	-	21	1
1.00	-	-	14	2	13	2	12	2	-	-	-	-	10	2
B														
0.20	109	13	445	34	730	39	434	16	76	7	-	-	22	3
0.40	-	-	35	2	42	1	74	2	22	2	-	-	27	1
0.60	-	-	14	3	13	1	11	1	9	1	10	2	21	1
0.80	-	-	15	3	13	3	9	2	7	2	7	1	8	2
1.00	-	-	14	4	11	3	9	3	9	2	8	2	7	2
C														
0.20	84	4	510	8	888	20	85	6	11	2	17	1	24	3
0.40	-	-	103	1	225	1	165	1	44	1	21	1	22	1
0.60	-	-	43	2	88	1	37	1	96	1	62	1	20	1
0.80	-	-	23	4	28	4	22	3	13	2	15	2	24	2
1.00	-	-	17	4	17	4	15	3	13	2	12	2	13	2
(D)														
0.20	57	7	398	15	443	5	53	2	9	2	13	2	15	3
0.40	-	-	174	5	410	6	99	3	9	1	12	2	24	2
0.60	-	-	46	2	93	1	56	1	65	1	40	1	25	1
0.80	-	-	146	4	64	3	61	2	54	2	52	1	39	2
1.00	-	-	11	3	11	2	12	2	54	2	47	2	42	2

rainfall (15, 16, 17, 18, 53, 56, 83, 105 and 108 DAS), moisture levels in the soil remained between the critical moisture level and the permanent wilting point (PWP), leading to water deficits during nearly every culture cycle.

For the 50% ETc water treatment, it was not possible to extract soil solutions at all given times and depths due to low humidity in the soil. When solutions were extracted, the highest concentrations of NO_3^- and K^+ during the crop cycle (from the 1st to the 6th extractions) were at a depth of 0.20 m (Table 2A). High nutrient levels, primarily for NO_3^-, were found at depths of 0.40, 0.60 and 0.80 m at 33, 48 and 63 DAS, most likely due to the influence of rainfall at these times, leading to the leaching of nutrients to these layers. The last extraction at 124 DAS, which occurred fifteen days after the bean harvest, showed high concentrations of NO_3^-, in the two soil layers in particular, which were not absorbed by the bean crop, possibly due to low soil moisture when replacing only 50% of the ETc.

Figure 1B shows the dynamic water balance during the bean development cycle with a water replacement regime of 100% ETc. With the exception of certain periods under the influence of rain, which increased soil moisture above the FC, most of the time soil moisture levels remained between the FC and the critical moisture, indicating correct irrigation management throughout the cycle.

Table 2B shows that during the growing cycle with 100% ETc replacement, higher concentrations of NO_3^- and K^+ were present in the 0.20 m layer, the region in which most of the been root system is located. Intermediate values of NO_3^- were found at a depth of 0.40 m, which may have been due to the influence of rains during the experiment. At layers of 0.60 m and deeper,

Table 3. Chemical characterization of the clay soil after the bean harvest for treatments with different irrigation blades.

Layer (m)	Treatment	K	N	Treatment	K	N
		(mg dm^{-3})			(mg dm^{-3})	
0.00-0.20	50% (1)	160	800	150%	112	800
0.20-0.40	50%	72	500	150%	44	800
0.40-0.60	50%	116	500	150%	32	500
0,60-0.80	50%	36	400	150%	24	400
0.80-1.00	50%	28	400	150%	20	400
0.00-0.20	100%	100	800	200%	96	800
0.20-0.40	100%	36	1000	200%	44	800
0.40-0.60	100%	32	500	200%	28	600
0.60-0.80	100%	32	400	200%	20	500
0.80-1.00	100%	28	400	200%	24	600

(1) 50, 100, 150 and 200% ETc, representing the percentage of water applied by irrigation, based on ETc.

only low concentrations of NO_3^- and K^+ were found. Failure to extract solutions at depths of 0.20 and 0.40 m at 92 DAS was likely to be due to a decrease in irrigation water, as the crop was already in the maturation stage. Extractions performed after crop harvesting in this treatment did not show high concentrations of NO_3^- and K^+ in the soil solution, indicating that most of these nutrients were absorbed by the culture or were retained in soil colloids.

The dynamic water balance during treatment with a water replacement regime of 150% ETc (Figure 1C) revealed that soil moisture levels fluctuated between the critical moisture level and points above the FC, which is indicative of excess irrigation and leading to water loss through percolation to layers below the root system.

Table 2C shows that for the irrigation regime based on 150% ETc, high K^+ concentrations were found in soil solutions collected 0.20 m from the ground surface, whereas the concentrations of NO_3^- varied at the different depths analyzed. Up to 48 DAS, the highest NO_3^- levels were found in the first 0.20 m of soil, although high levels were present up to 0.80 m below the surface. After 63 DAS, the highest NO_3^- concentrations were measured 0.40 m from the surface, and at 78 and 92 DAS, the highest concentrations of this of the nutrient were found in the 0.60 m layer. Extractions performed after harvesting for this treatment did not show high concentrations of any analyzed nutrient, suggesting they were retained in soil colloids, diluted in the soil solution or leached to lower soil layers.

Figure 1D illustrates the dynamic water balance during a water replacement regime of 200% ETc. In this treatment, soil moisture levels varied between the critical moisture level and points well above the FC, again indicating excessive irrigation. In this treatment, water seepage losses to layers below the root system were even more evident.

Table 2D shows that even with the use of irrigation levels based on 200% ETc, the highest K^+ concentrations in soil solutions are found at 0.20 and 0.40 m below the ground surface, whereas NO_3^- concentrations fluctuated greatly. Up to 33 DAS, the highest NO_3^- concentrations were within the first 0.20 m of soil, although high concentrations were found up to 0.80 m. At 48 DAS, the highest NO_3^- concentrations were found in the 0.20 and 0.40 m layers, again with high values up to 0.80 m. After 63 DAS, the highest concentration of NO_3^- were present in the 0.40 m layer, with high values up to 0.80 m. By 78 and 92 DAS, NO_3^- concentrations were already low in the 0.20 and 0.40 m layers and high in the 0.60, 0.80 and 1.00 m layers. The NO_3^- concentration measurements after harvesting showed low values for NO_3^- in the 0.20 m layer, which increased up to 1.00 m, confirming the leaching of NO_3^- to deeper soil layers in this treatment.

By comparing the chemical characteristics of the soil after bean harvest (Table 3) with those from before planting (Table 1), it can be observed that there was a substantial increase in K, which was retained in the soil at all depths in all the four treatments, with the highest values in the layer at 0.00 to 0.20 m. This is likely why we observed low K concentrations in the soil solutions. The K values found in the soil in the 50% ETc treatment were much higher than that in the other treatments, primarily in the upper soil layers. Therefore, it appears that low soil moisture levels in this treatment must have affected the rate of potassium uptake by the crop, leading to a greater amount of this nutrient being adsorbed on soil colloids.

With respect to N, high N-NO_3^- concentrations were

Table 4. Summary of the analysis of variance with sources of variation, degrees of freedom, mean squares, coefficient of variation (CV), calculated F and P-values for the number of plants per hectare (NP), number of pods per plant (NPP), mass of 100 grains (M100G), plant length (PL), number of grains per pod (NGP), mass per hectoliter (MH) and grain productivity (PROD).

Sources of variation	Degrees of freedom	Mean squares						
		NP	NPP	M100G (g)	PL (cm)	NGP	MH (kg)	PROD (kg ha^{-1})
Blocks	3	2946223958	16.67	2.09	44.36	0.08	1.73	20868
Blades	3	622265625	14.03	1.10	1117.79	1.21	14.04	889950
Residue	9	900130208	5.15	2.75	53.28	0.10	2.75	42578
CV (%)		13.34	19.58	6.59	7.21	6.93	2.16	9.82
Calculated F *		0.69	2.72	0.40	20.98	11.61	5.10	20.90
P-value *		0.57	0.09	0.76	0.00	0.00	0.02	0.00

*The values of calculated F and P-value refer to the blades.

observed in soil solutions for all treatments. The main difference between the treatments was that for the 50 and 100% ETc regimes, the highest concentrations of NO_3^- were found in the 0.20 m layer throughout the crop cycle, whereas for the 150 and 200% ETc treatments, the NO_3^- levels remained highest in the 0.20 m layer only until 48 DAS. After this period, the highest concentrations of NO_3^- were found in deeper soil layers. Treatment with 150% and 200% of ETc caused NO_3^- levels to be highest in the 0.60 and 0.80 m layers, respectively, demonstrating the leaching of NO_3^- to soil layers below the bean root system. Dynia (2000) found that NO3 has high mobility in tropical soils with ion accumulation between 2.20 and 4.60 m depth in loamy soil, and between 3.40 and 6.00 m depth in sandy soil, therefore, much below the exploration root zone of most crops.

In this work, only the concentrations of NO_3^- and K^+ in the soil solution were measured, so it was not possible to quantify the losses of these nutrients to soil layers below the bean root system. However, it can be concluded that nutrient loss was most relevant to NO_3^- for treatments with irrigation blades of 150 and 200% ETc, as high concentrations of this nutrient were found in the deeper soil layers, inaccessible to the culture root system. According to Sharpley and Halvorson (1994), high concentrations of N and K in surface water and groundwater have caused not only environmental problems but also affected human health. According to Goulding et al. (2008), better management of essential nutrients for the plants is needed to promote sustainable agriculture. The number of plants per hectare, number of pods per plant and mass of 100 grains did not show significant differences ($p \geq 0.05$) between treatments, whereas plant length, number of seeds per pod, weight per hectoliter and grain yield did show significant differences ($p < 0.05$) (Table 4). The number of plants per hectare was not significantly affected likely because differentiation between water slides occurred after crop establishment.

For plant length, the regression curve (Figure 2A) that best fit the data was the second-order polynomial. Based on this model, optimal plant length would be achieved with an approximately 175% ETc irrigation regime. According to Costa et al. (2008), the reduction in plant height is due to the fact that water stress reduces the turgor of cells and, consequently, their growth. A small leaf area means less perspiration, conserving a limited water supply in the soil for a longer period, thus, reduction of leaf area can be considered as the first line of defense against dryness (Taiz and Zeiger, 2009).

For the number of grains per pod, the regression curve (Figure 2B) that best fit the data was the second-order polynomial. Based on this model, the highest number of seeds per pod would be achieved with water blades of approximately 179% ETc. According to Stone and Moreira (2000), water restriction in the reproductive phase promotes reduction in the number of grains per pod, due to egg abortion.

For mass per hectoliter, the regression curve (Figure 2C) that best fit the data was the second-order inverse polynomial. Based on this model, the highest mass per hectoliter would be obtained with water blades of approximately 131% ETc.

For grain yield, the regression curve (Figure 2D) that best fit the data was the second-order inverse polynomial. Based on this model, the highest productivity would be obtained using water blades of approximately 100% ETc. It can be observed in the curve that there is a marked increase in productivity between 50 and 100% ETc, whereas the increases in productivity for 150 and 200% ETc are more modest.

According to Silveira and Stone (2004), the common bean is sensitive to deficiency and excess in the soil. Thus, to obtain high yields, one should avoid the deficit or

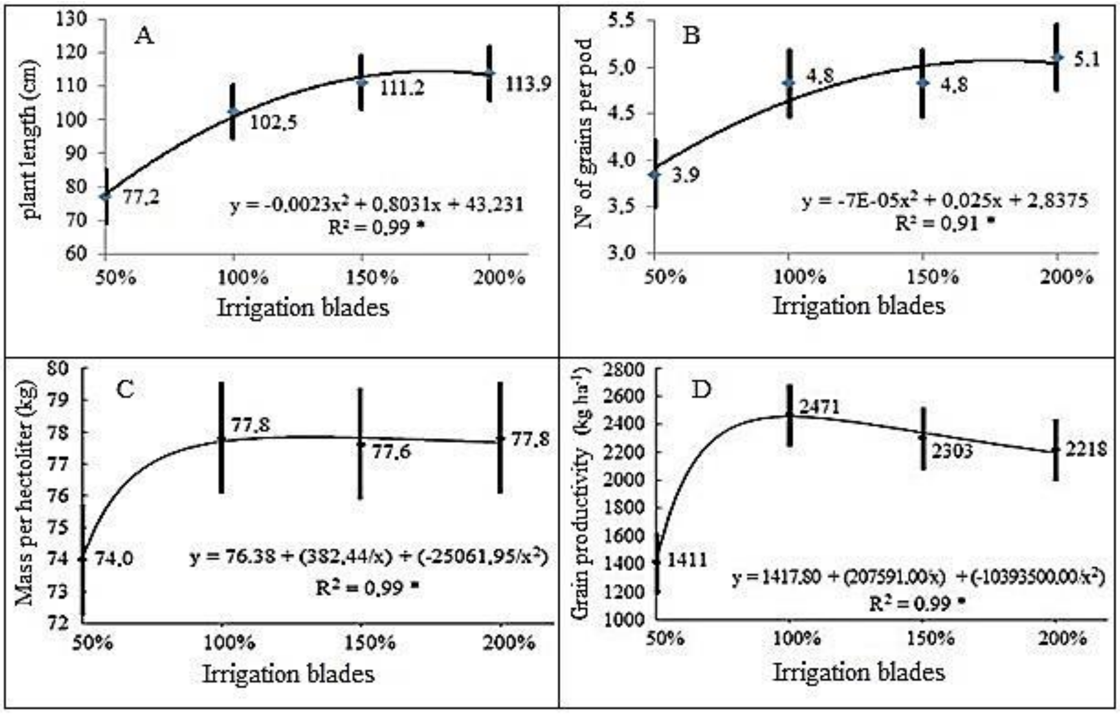

Figure 2. Adjustment of averages: plant length (A), number of grains per pod (B), mass per hectoliter (C) and grain productivity (D) depending on irrigation blade. The 50, 100, 150 and 200% represent the percentage of irrigation water applied based on ETc. Vertical lines indicate standard deviation. *Significant at 5% probability ($p < 0.05$).

excess water in the soil at any stage of the crop cycle (Posse et al., 2010).

When comparing the average yields for the 50 (1411 kg ha^{-1}), 150 (2303 kg ha^{-1}) and 200% (2218 kg ha^{-1}) ETc treatments with that of the 100% ETc treatment (2471 kg ha^{-1}), the results were as follows: treatment with 50% ETc produced a 57% yield, treatment with 150% ETc produced a 93% yield and treatment with 200% ETc produced a 90% yield.

For the conditions in this study, it was found that water deficits were more harmful to bean yield than excess water. According to Nobrega et al. (2004), the duration, intensity, frequency and time of stress can interfere with most morphological and physiological processes in plants, adversely affecting yield components. Low water availability in the soil is a crucial limiting factor in bean production, particular during the three critical stages of germination, flowering and grain filling (Soratto et al., 2003).

Conclusions

Water blades above 100% ETc in clay soil cultivated with the common bean cause nitrate and potassium leaching and reduce the efficiency of these fertilizers. Water deficits lead to lower losses of nitrate and potassium through leaching. However, water deficits also lead to significant yield reductions. Proper irrigation management in the common bean (100% ETc), combined with appropriate timing and doses of nitrogen and potassium, provides the highest yield of grains.

Conflict of Interests

The authors have not declared any conflict of interests.

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