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WATER TABLE EFFECTS ON BEAN YIELD AND NITRATE DISTRIBUTION IN THE SOIL PROFILE

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1 ABSTRACT

In order to evaluate the bean yield under different water table levels as well as the moisture and nitrate distribution in the soil profile, a field experiment was carried out in the experimental area of the College of Agricultural Sciences – UNESP, Botucatu, SP, Brazil. Beans were grown in field lysimeters under five water table depths: 30; 40; 50; 60 and 70 cm. The moisture in the soil profile was determined gravimetrically using samples collected at 10; 20; 30; 40; 50; 60 and 70 cm deep. The water table depths of 30cm and 40cm showed the highest productivities (3,228.4kg.ha^{-1} and 3,422.1kg.ha^{-1}, respectively), with no statistical differences between them. The highest productivity was related to the two highest water table levels (30 and 40cm), which provided the highest moisture average values on the basis of volume in the soil profile (33.3 e 31%) as well as the consumptive use of water (416 and 396mm). The nitrate content during the bean cycle at the extraction depth of 60cm was below the safe drinking limit of 10mg.l^{-1} for water table depths of 30; 40; 50 and 60cm, which shows the denitrification efficiency as a way of controlling nitrate pollution in water tables. The management of water table can lead to high levels of bean yield and to a better control of nitrate pollution in underground water.

KEY WORDS: lysimeters, soil moisture, denitrification.

SAAD, J. C. C.; CALEGARO, J. C. EFEITOS NO NÍVEL FREÁTICO NA PRODUTIVIDADE DO FEIJOEIRO E NA DISTRIBUIÇÃO DE NITRATO NO PERFIL DE SOLO

2 RESUMO

Para avaliar a produtividade do feijoeiro submetido a diferentes níveis de lençol freático, a distribuição de umidade e a concentração de nitrato no perfil do solo, um experimento de campo foi conduzido na área experimental do Departamento de Engenharia Rural da FCA-Câmpus de Botucatu-UNESP. O feijão foi semeado em lisímetros de campo e submetido a cinco níveis de lençol freático, 0,30; 0,40; 0,50; 0,60 e 0,70m de profundidade a partir da superfície do solo. A umidade no perfil do solo foi determinada pelo método gravimétrico, com amostras obtidas à 0,10; 0,20; 0,30; 0,40; 0,50; 0,60 e 0,70m de profundidade. As profundidades de nível freático 0,30m e 0,40m apresentaram as maiores produtividades (3.228,4kg.ha^{-1} e 3.422,1kg.ha^{-1}, respectivamente), não diferindo estatisticamente entre si. As maiores produtividades estiveram associadas aos dois níveis freáticos mais elevados (0,30 e 0,40m), que propiciaram os maiores valores médios de umidade à base de volume no perfil do solo (33,3 e 31%), as maiores lâminas totais (416 e 396 mm) e as maiores taxas de denitrificação (99,6 e 99,7%). O teor de nitrato durante o ciclo

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do feijoeiro, na profundidade de extração de 0,60m, esteve abaixo do limite tolerável de $10mg.l^{-1}$ para as profundidades de lençol freático de 0,30; 0,40; 0,50 e 0,60m, mostrando a eficiência da denitrificação como forma de controle da poluição do lençol freático por NO_3-N. O manejo do lençol freático permite tanto a obtenção de elevados níveis de produtividade do feijoeiro como o controle da poluição das águas subterrâneas por nitrato.

UNITERMOS: lisímetro, umidade do solo, denitrificação.

3 INTRODUCTION

The lowland areas in Brazil cover a total of fifteen million hectares (Christofidis, 2006). Generally, these areas have drainage problems and agricultural production requires the installation of drainage systems to remove the water excess from the plants' radicular zone. Besides, due to uneven rainfall distribution, these areas are deficient in water at some periods of the year, and supplemental irrigation is required.

Systems that are able to provide both irrigation and drainage within a single structure, removing excess water and providing water when necessary, are known as subirrigation systems. The use of the same structure for drainage and subirrigation requires small modifications on the drains spacing, and have the advantage of being low cost with low energy consumption. The water table handling and management in turn, require specific and accurate knowledge on the response of several crops to water table levels. Such information, which is variable and site-specific due to lowlands peculiarities, is not available in the literature.

The increase on the agricultural activities on drained and subirrigated lowlands allied with high yields, has led to the employment of high dosage of organic matter and fertilizers. This may cause environmental damage initially through soil contamination, where nitrate is leached through the subsurface drainage system, by the removal of water from the profile, causing the surface water and water table contamination. Beside polluting the environment, this contamination also exposes human beings to the risk of diseases such as cancer. The natural and safe mechanism to reduce environmental nitrate pollution is denitrification, which involves facultative anaerobic and/or anaerobic microbial activity, where nitrogenated oxides are reduced into nitrogen gas, which are lower oxidation state and less harmful and more useful compounds.

Beans are sources of protein and energy on the Brazilians nutrition, which are mostly grown at small and medium size properties. It is one of the most important crops but it is low yielding. However, the use of irrigation allied to adequate cropping practices may improve productivity and production stabilization of this legume.

Southwick et al. (1995) studied the losses by nitrates and atrazines leaching, applied to rain-fed sugar cane, with drains spaced at 5.5 and 10.9m. Nitrogen (122kg/ha) was applied during the month of June. The losses were measured at one hundred days interval over two cropping seasons. Five days after the application, NO_3-N had its highest concentration, of 5 up to 11mg/l, in the drainage water; after this first event, the concentration remained below 10 mg/l in the summer season, with the total losses for this season ranging from 3 to 8% from the applied NO_3. Almost 50% from the NO_3 leached for the subsuperficial drains occurred after the sixty-sixth day.

Madramootoo (1990) used the Drainmod model and climatic data from a 24 years period in order to simulate the corn crop productivity on heavy loam soil and the advantages of the water table management for four drains spacing (5, 10, 15 and 20m). The lateral drains spacing of 15m showed adequate drainage with no reduction in yield during the wettest years. However, for years with average rainfall during the growing seasons, the dry stress reduced the yield approximately 12% for all studied drains spacing.

Madramootoo et al. (1992) developed a study that analyses soy crop in field lysimeters during two growing seasons under four water tables levels 40, 60, 80, and 100cm from the soil surface. The bean yields was evaluated and the high water table significantly increased the crop yield.

Dukes et al. (2003) conducted a 2 years study to determine the effectiveness of controlled drainage, riparian buffers and a combination of both in the middle coastal plain of North Carolina, USA. It was hypothesized that raising the water table near the ditch would enhance nitrate-nitrogen reduction through denitrification. Nitrate removal effectiveness was attributed to local soil and landscape properties, such as denitrification in deeper reduced zones of the soil profile.

Jaynes et al. (2004) comparing the efficacy of several tile and cropping modifications for reducing nitrate concentrations in tile drainage versus the nitrate concentration in drainage from a control treatment consisting of a free-flowing tile installed at 1.2m below the surface. Average NO_3^- concentration in tile drainage from the control was about 25 mg-N L^{-1} compared with less than 10 mg N L^{-1} for the denitrification walls treatment. This represented an annual reduction in NO_3^- mass loss of 50kg N ha^{-1} for the denitrification walls treatment.

This research had as targets the effects of different water table levels on bean productivity as well as on the moisture distribution and on the nitrate content in the soil profile.

4 METHODOLOGY

The experiment was conducted in lysimeters installed on the experimental area at the Rural Engineering Department from the School of Agronomic Sciences – UNESP, Botucatu, SP, Brazil.

According to a survey performed by Carvalho et al. (1983), the local soil was classified as structured rich soil “intergrade”, for Dark Red Latosoil, dystrophic. The soil granulometry values are found on Table 1.

Table 1. Soil physical characteristics.

Texture (%)			Soil	Density	Porosity	Macropore	Micropore
Sand	Clay	Silt	Texture	(g/cm^3)	(%)	(%)	(%)
47	41	12	Sandy Clay	1.50	42.83	6.49	36.44

Twenty reinforced concrete waterproof lysimeters, with 15 mm thickness walls, 1.84m^2 (1.60m x 1.15m) of exposure area and 0.75m depth were used on the experiment (Figure 1). The lysimeters were filled up with soil, maintaining the layers’ original sequence and the same level between the edge and the inner part of the boxes, which tops were situated 0.05m above the soil level in order for the water originated from the runoff outflow would not run into the lysimeter. Each lysimeter contained, at the lower part, a net of parallel drains composed by three pipes with 1.20m length, 19mm diameter and spaced 0.30m from each other. Each pipe showed four rows of 60 holes of 3mm diameter along its length, covered with filtering material blanket geotextil, (BIDIM-OP 30) type, which was responsible for the water filtering, this way avoiding the dragging of thin particles from soil into the pipes. The drainage network – lysimeters subirrigation was connected to the water table control chamber through a 19mm diameter x 10m length PVC pipeline (Figure 2). A layer of crushed rock was placed underneath the drains in order to level them.

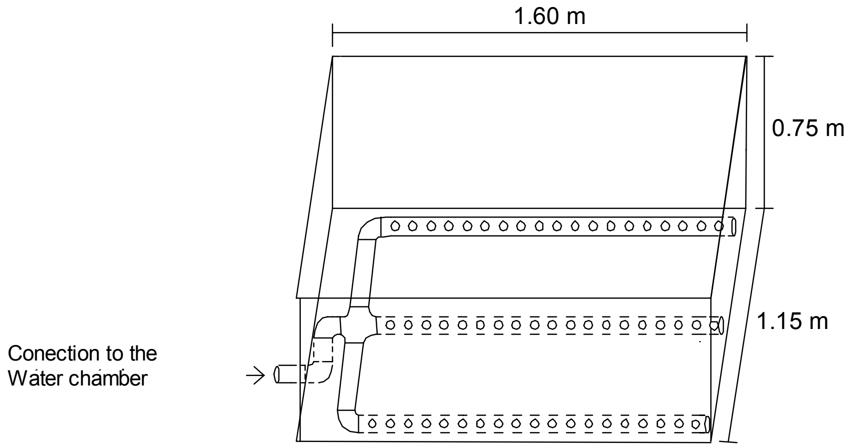

Figure 1. Lysimiter dimensions and the drainage system.

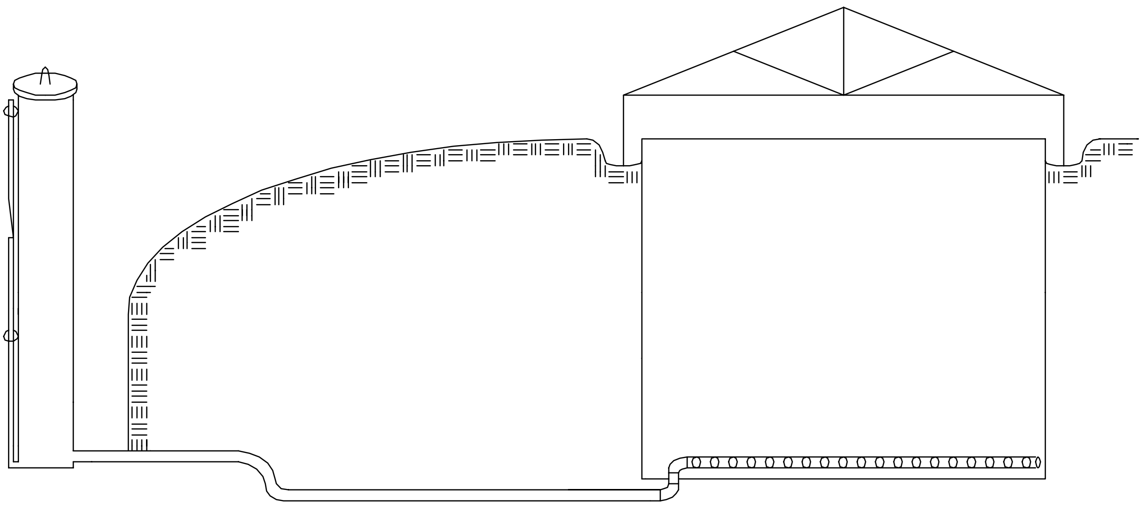

Figure 2. Lysimeter schematic and the water control chamber.

The water table level control chamber was constructed of sealed zinc plane plates, with 0.20m diameter and 1.00m height, closed at the bottom and endowed with lid in order to allow replenishment and to avoid water loss by evaporation (Figure 3). The water consumptive use was daily measured at 5pm, through a transparent crystal-type hose with 9mm diameter, which height was the desired water table level, responsible for water excess outflow in cases of higher rainfall intensities. The water consumptive use daily readings were performed through a millimeters-graduated scale, which initial point was coincidental to the water table maximum allotment.

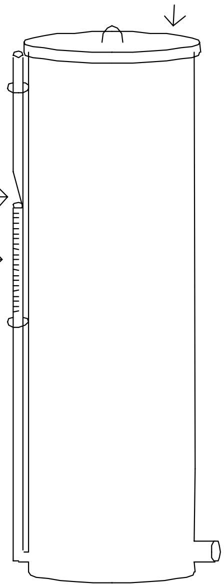

Figure 3. Schematic of the water control chamber.

The used culture was the bean crop (Phaseolus vulgaris L.), cultivar IAC – carioca, which is the recommended one for the state of São Paulo. This cultivar is Type III, showing an indeterminate growth behavior, trending to weaken or to climb up on plant supports, which was cultivated on twenty lysimeters and on the edge area, accomplishing a total of 600m^2 of cultivated area.

The effect of five water table levels (Table 2), from the soil surface, on the bean crop productivity and the moisture in the soil profile were evaluated. The plants from the edge area were cultivated in order that the island and edge effects would be denied.

Table 2. Treatments and water table depths.

Treatments	Water table depth (cm)
T_1	30
T_2	40
T_3	50
T_4	60
T_5	70

The cropping was manually performed on pre-fertilized furrows spaced 50cm between rows using 20 seeds per linear meter. Ten days after emergence, plant thinning was performed in order to obtain a final population of 200.000 plants per hectare, corresponding to 33 plants on each lysimeter, kept until the end of the cycle.

The edge irrigation was performed by conventional sprinkle-irrigation. The irrigation frequency on the edge was variable, performed whenever hydric balance required. The advection effect, which may influence significantly, when the purpose of the assay requires accuracy on the water consumption measurements, was thus reduced. The lysimeters and the edge were sprinkle-irrigated at the fourth and the tenth days after cropping, aiming at germination and good crop establishment in the field. For plants on the lysimeters, water was supplied by capillary ascension for the rest of the period, characterizing the type of irrigation called subirrigation and by natural rainfall.

After crop seeding, the water table was established at different levels on the lysimeters, and the measurements began, until the end of the crop cycle. The water losses on the level lysimeters occur through the soil and plants surface, then the drop on the established water table shortly occurs on response to the evapotranspiration process. The management of the water content, which was daily supplied by the water table level control chamber allowed the total evapotranspiration measurement.

The harvest was manually performed at the 97th day after cropping. All plants from the lysimeters' central line were harvested in order to allow the productivity comparison at the different water table levels.

The harvest of plants placed on the lysimeters' central row was performed, with the pods being manually threshed and the grains weighted separately for each lysimeter. Then, the moisture was determined through the standard oven method.

The water content in the soil profile was gravimetrically determined, with the soil samples collected at 10; 20; 30; 40; 50; 60 and 70cm depth.

The analysis of the soil solution samples based on treatments was performed with the establishment of the NO_3^- concentration, with the employment of the continuous outflow injection analytical system.

For the analysis of nitrate concentration results in the soil profile before different water table levels, the standard of 10 mg.l^{-1} was adopted as the safe drinking water limit, above which, the nitrate concentration is considered unsuitable for the occurrence of healthy reactions on the environment.

The results regarding the crop parameters were statistically studied through the analysis of variance, with the measures compared by the Tukey test at 5% probability level.

5 RESULTS AND DISCUSSION

Non-weighable field lysimeters were used in the experiment, and even with lower accuracy, provide an estimative of consumptive use of water by plants for the different water table levels (Table 3).

Table 3. Consumptive use of water in each treatment.

Treatment	Consumptive use (mm)
T_1	416
T_2	396
T_3	360
T_4	274
T_5	218

The total and daily average crop evapotranspiration values for bean crop, found by Valadão (1995), on the lysimeters, for the water table level of 55cm were 348mm and 3.75mm respectively; for the water table level of 75cm, the total evapotranspiration value was 224.8mm, which represents 64.6% from the value observed for the water table level of 55cm.

Guerra (1981) also observed proportionality between water table levels and water consumption by bean crop, on green houses. The most elevated water table level (30cm) had the highest water consumption (430mm), and the lowest water table value (90cm), the lowest water consumption (100mm). A drop on the water consumption by plants with the increase of the water table depth is observed through the results, this way reflecting differences on the water content on soil for the regarded water table levels.

Water use effectiveness

The water use effectiveness (WUE) was determined as the volume of water the plant used to produce one Kg of grain. Saad (1991) obtained WUE of 0.8Kg.m^{-3} for bean crop irrigated by center pivot in Guaira-SP, and Valadão (1995) found values of 0.78 and 0.65Kg.m^{-3} for water table levels of 55 and 75cm, respectively, at the experiment neighboring area.

The water use effectiveness values for water table depths evaluated in this study are shown in Table 4.

Table 4. Water use efficiency (WUE) for each water table depth.

Water table depth (cm)	WUE (%)
30	77
40	86
50	75
60	68
70	70

Moisture in the soil profile

The soil moisture was actually influenced by the water table management (Figure 4). The moisture in the soil profile increased with the increase on the water table level. This fact is quite important for plant development.

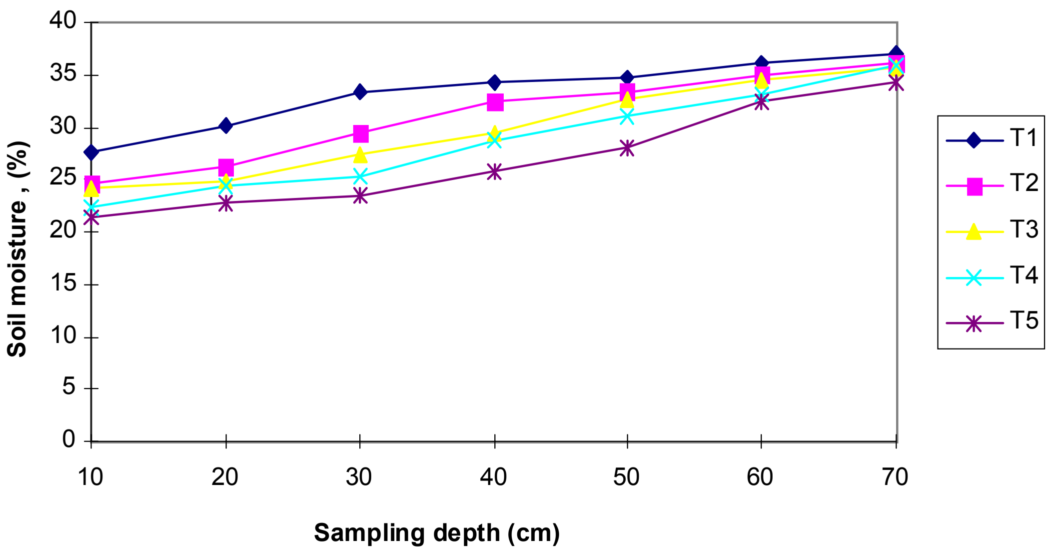

Figure 4. Soil moisture versus sampling depth, for each water table depth.

Productive parameters

The parameters used to evaluate productive potential were yield, number of pods per plant and number of grains per pod. The analysis of variance and the Tukey test of data that evaluate the productivity parameters (Table 5 and Figure 5), the number of pods per plant (Table 6) and the number of grains per pod (Table 7) show significant differences at the 5% probability level. The best results for all parameters were obtained at the higher water table levels, showing a close relation between each other and the water availability for the crop during the development cycle.

Table 5. Analysis of variance and Tukey test for productivity data on the lysimeters.

Water table depth (cm)	Yield ($kg.ha^{-1}$)*
30	3,228.4 a
40	3,422.1 a
50	2,685.9 b
60	1,869.1 c
70	1,538.8 c

**Bean with 13% of moisture content; Significant at 5% probability level Means followed by same letter are not statistically different from each other, on the mentioned probability level.*

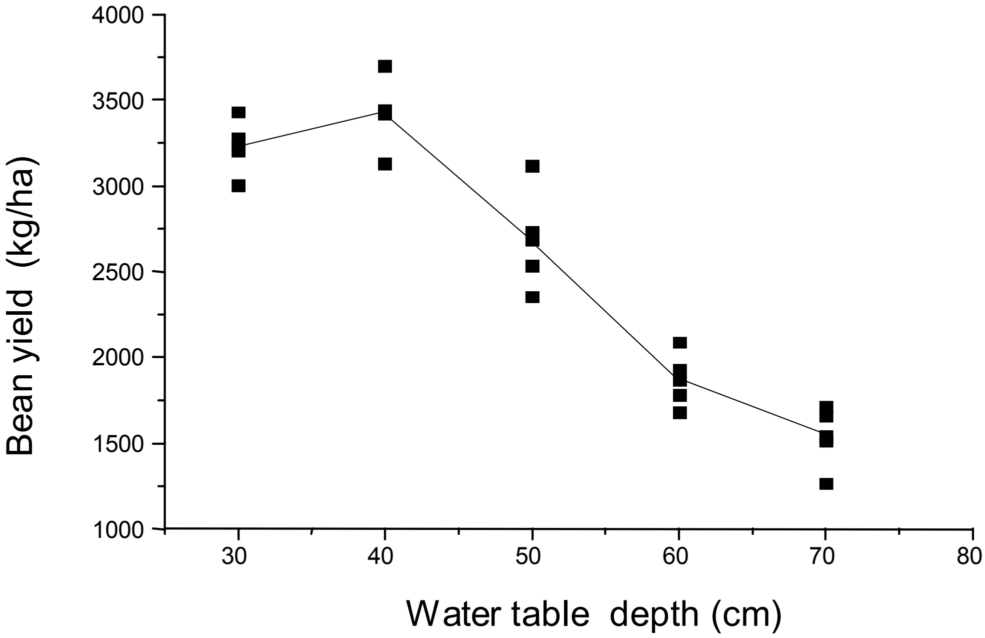

Figure 5. Bean yield versus water table depth.

Table 6. Analysis of variance and Tukey test for the number of pods per plant.

Treatment (m)	Number of pods/plant
T_1	13.36 ab
T_2	14.36 a
T_3	11.45 b
T_4	8.95 c
T_5	7.95 c

Significant at 5% probability level. Means followed by same letter are not tatistically different from each other, on the mentioned probability level.

Table 7. Analysis of variance and Tukey test for the number of grains per pod obtained on the lysimeters.

Treatment	Number of grains per pod
T_1	5.73 a
T_2	5.65 ab
T_3	5.56 b
T_4	4.95 c
T_5	4.59 d

Significant at 5% probability level. Means followed by same letter are not statistically different from each other, on the mentioned probability level.

The best treatments for parameter productivity were: T_1 and T_2, with 3,228.4 and 3,422.1Kg.ha^{-1} respectively, which were not statistically different from each other, but significantly higher than the others. Treatment T_3 with water table level at 50cm produced 2,685.9Kg.ha^{-1}, showing the second best result and higher than results found for treatments T_4 and T_5, which produced 1,869.1 and 1,538.8Kg.ha^{-1}, respectively. These results were not statistically different from each other. The productivity data, found by Valadão (1995) for bean type carioca cultivated on lysimeters, at water table levels of 55 and 75cm, at an area near the experiment, were 2,709 and 1,455Kg.ha^{-1}, with higher water table level showing better results. The statistical analysis of the number of pods per plant showed how better are treatments with elevated water table levels, T_1 and T_2, which were not significantly different; treatment T_3 was not different from treatment T_1, which were significantly higher than treatments T_4 and T_5, which were not significantly different from each other.

The best results for the number of grains per pod, according to the productivity results tendency, and for the number of pods per plant were also obtained for elevated water table levels.

Water table depth and nitrate concentration in the soil profile

The denitrification mechanism has local and global implications. The local implication relates to ineffective nitrogenous fertilization, especially affecting the farmer's economy. The global implications relate to the environment and to human health. The environmental nitrate pollution causes eutrophication of surface waters, affecting the ecological equilibrium of the region. The denitrification mechanism has been seen as a natural control of this type of pollution, in which nitrate is converted into nitrogen gas, which evaporates into the atmosphere, this way restarting the nitrogen cycle.

The analysis of nitrate concentrations on the soil's profile was divided into three parts in order to make the interpretation of the results easier. Samples of soil solution at 30cm and 60cm depth were extracted in all experiments, corresponding to the bean roots zone and the zone with no roots, respectively. The first part regards treatment T_1, where both solution extractors were at the saturated zone with the water table at 30cm from the surface. The second part regards treatments T_2 , T_3 and T_4 , where extractors at 30cm were at the unsaturated zone, and the extractors at 60cm were at the saturated zone; finally, the third part, corresponding to treatment T_5 where extractors at both depths, were at unsaturated zones. On treatment T_1, the nitrate concentration decreased with time, whereas from the first up to the fourth extraction, values of 55.4; 43.0; 5.93; 3.33mg.l^{-1} were obtained (Table 8). For extractors placed at 60cm, the nitrate concentrations were 0.05; 0.05; 0.23 and 0.07mg.l^{-1}, showing denitrification occurrence with time within extraction depth at 30cm as well as reduction on nitrate concentration when both depths are compared to each other, evidencing the occurrence of denitrification. On treatments T_2, T_3 and T_4, the extractors at 30cm were at the unsaturated zone, once the water table levels were at 40; 50 and 60cm, therefore, the nitrate levels were more susceptible to variations with rainfall, evapotranspiration, as well as with the removal by the plants, once the ions were within reach of roots. For treatment T_2, it was observed that the nitrate concentration decreased at each sampling in the following sequence: of 56.2; 42.1; 32.6 and 9.6mg.l^{-1}, for extraction depth of 30cm and of 0.07; 0.07; 0.26 and 0.07mg.l^{-1} for sampling depth of 60cm. On treatment T_3, a decrease on the nitrate concentration with time also occurred, however, with lower intensity, showing a sequence of values of 46.6; 43.0; 38.0 and 36.3mg.l^{-1}, for extraction depth of 30cm, and of 0.26; 0.07; 1.69 and 4.95mgl^{-1}, for extraction depth of 60cm; it was observed that up to this level, the NO_3-N concentrations, sampled at a depth of 60cm, were below 10mg.l^{-1} , which is the safe drinking limit. Treatment T_4 showed an inversion on such tendency, increasing the NO_3 concentration with time on extraction points at 30 and 60cm of depth, from the first up to the fourth extractions at both depths, the nitrate concentrations were 35.6; 43.3; 42.4 and 80.8 mg.l^{-1}; and of 4.4; 6.43; 10.3 and 12.1mg.l^{-1} respectively, it was observed that at a depth of 60cm, the concentration values start getting beyond the safe limit. On treatment 5, both extractors are at the unsaturated zone, where ions were free to change with the climatic and natural phenomenon, the nitrate concentrations were 29.7; 38.0; 52.7 and 125.8mg.l^{-1}, at the extraction depth of 30cm, and 19.3; 24.2; 26.2 e 34.6mg.l^{-1}, at the extraction depth of 60cm, far exceeding the safe drinking limit. When results are analyzed altogether, it was observed that the denitrification process actually occurred, which was more intense at elevated water table levels, where the nitrate concentration control was also more effective.

Table 8. Nitrate concentrations (mg.l^{-1}) on different water table levels, sampling date and soil solution extraction depth.

Extraction date	Days after N application	Extraction depth (cm)	Treatments				
			T_1 (30cm)	T_2 (40cm)	T_3 (50cm)	T_4 (60cm)	T_5 (70cm)
10/13/97	04	30	55.4	56.2	46.6	35.6	29.7
		60	0.05	0.07	0.26	4.6	19.3
10/18/97	10	30	43	42.1	43	43.3	38
		60	0.05	0.07	0.07	6.43	24.2
11/07/97	30	30	5.93	32.6	38	42.4	52.7
		60	0.23	0.26	1.69	10.3	24.2
11/30/97	53	30	3.33	9.6	36.3	80.8	125.8
		60	0.07	0.07	4.95	12.1	34.6

Table 9 summarizes results from the field experiment. The denitrification process was effective on reducing the nitrate concentrations, and such efficiency was higher for elevated water table levels, whereas only treatment T_5 with extractions at 60cm, showed average nitrate concentrations above $10mg.l^{-1}$.

Table 9. Bean productivity, soil moisture and nitrate concentration.

Water Table Depth (cm)	Productivity ($kg.ha^{-1}$)	Soil Moisture (%)	Nitrate ($mg.kg^{-1}$)		Nitrate Reduction (%)
			Extraction (30cm)	Extraction (60cm)	
30	3,228.4	33.3	25.66	0.10	99.6
40	3,422.1	31.0	35.33	0.12	99.7
50	2,658.9	29.8	41.05	1.73	95.6
60	1,869.1	28.7	52.23	8.36	84.0
70	1,538.8	26.9	62.52	25.6	59.1

6 CONCLUSIONS

The water table depths of 30 and 40cm showed the highest productivities ($3,228.4kg.ha^{-1}$ and $3,422.1kg.ha^{-1}$, respectively), not statistically different from each other, and also showed the highest nitrate reduction rates among the extraction depths of 30 and 60cm (99.6 and 99.7, respectively).

The nitrate content during the bean cycle at a extraction depth of 60cm was below the safe drinking limit of 10 $mg.l^{-1}$ for water table depths of 30; 40; 50 and 60cm, showing the denitrification effectiveness as a control of water tables by NO_3-N pollution.

The highest productivities were related to the two most elevated water table levels (30 and 40cm), which provided the highest moisture average values on volume basis in the soil profile (33.3 and 31%), the highest use consumptive of water (416 and 396mm) and the highest denitrification rates (99.6 and 99.7%) as well.

The water tables handling allows both the attainment of high bean productivity levels as well as the nitrate pollution control of underground waters.

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