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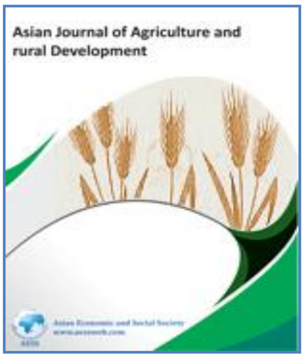

Effects of Irrigation Water Quality on the Recovery of 15N-Fertilizer by Sorghum in Field Study

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Abstract

15N-labeled fertilizer was applied to Sorghum at different rates (0, 100 kg $N.ha^{-1}$) to 1m² microplots and with two kind of water (well water "WW" and treated wastewater "TWW") to Sorghum grown in field during 1997 and 1999. Increases in DM production, N uptake and ^{15}NRF were observed with TWW. About 17% and 36% of the 15N-fertilizer were recovered in the crop with TWW in 1997 and 1999, respectively. Residual effect was higher in TWW (3% vs 5%). Water irrigation quality had no effect on the 15N-labeled fertilizer remaining in the 0-60 cm layer at final harvest. For both water qualities, the major fraction of the residual 15N-fertilizer (about 60%) was recorded in the surface layer. Losses of 15N-labaled fertilizer was unaffected by water irrigation quality being approximately 35% of the applied 15N-fertilizer. TWW irrigation can efficiently substitute WW for irrigation of Sorghum and, simultaneously save nitrogen fertilizer.

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Keywords: 15N fertilizer, sorghum, irrigation

Introduction

The use of ^{15}N labeled fertilizer has become increasingly important in field studies for drawing up the balance sheet of fertilizer N. In addition, nitrogen-15 allows to distinguish between fertilizer N and indigenous N, providing the possibility to measure both total amount of N deriving from fertilizer and taken up by crops or left in soil, and fertilizer N loss during crop growth. However, the high cost of ^{15}N labeled fertilizer limits its employment to a micro plot within a larger plot (Reddy and Reddy, 1993., Destain *et al.,* 1996). In Tunisia, Application of treated waste water to agricultural land continuing to gain public acceptance (Bahri and Brissaud, 1995; Angelakis *et al., 1999*). However, because of the short period of the reuse, only 24% of the available treated waste water is used, the reuse of that water could be considered as fertiirrigation. As a result of its nitrogen content, irrigation with treated waste water can help to reduce the requirements for commercial fertilizer (Vasquez-Montiell *et al*., 1995 and 1996; Hussain *et al*., 1996; Geber, 2000). Otherwise, to warrant a good yield farmers conceive bad to avoid application of nitrogen fertilizer. However, with the advantages of increased water supply and nitrogen fertilizer there are some hazards involving soil and ground-water pollution. Moreover, the reuse of treated waste water may increase this potential either if the total amount on nitrogen application is higher than that needed by crop, or if the treated waste water still used late in the growing season when crop doesn't need nitrogen. Due to this, obtaining optimum crop yields and good nitrogen use efficiency requires careful management of N application. Olsen *et al*. (1982) suggested that since about 60% of N used by the crop came from soil, total N uptake is not a good measure of waste water N removal. Although fertilizer recovery by the crop can be determined by the use of both unlabeled and labeled N fertilizer (Westerman and Kurtz, 1974; Harmsen and Morghan, 1988; Schindler and Knighton, 1999), the measurement of the recovery of fertilizer in the soil, and the subsequent calculation of the N that is lost from the crop/soil system can only be made using ^{15}N-labelled fertilizer (Limaux *et al*., 1998). Bole *et al*. (1985), in their study concerning the fate of in the system irrigated with waste water, including the use of ^{15}N-labelled supplementary fertilizer, note that Reed canarygrass recovered nearly 50% of applied fertilizer ^{15}N over 2 years with about 80% of total uptake in the first cutting after application. Alfalfa only recovered 24% of applied ^{15}N at low irrigation rate and 14% at higher rate. About 25% of the fertilizer N was left in

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soil after two irrigation seasons with 60% of that N remained in the surface 15 cm independent of forage species or irrigation rate.

In order to minimize nutrient seepage into the ground water, the fertilizer requirement of the crop should be precisely known. There is little data on the effect on treated waste water irrigation and fertilization management on the fertilizer nitrogen use efficiency and its effect on yields and on the balance sheet of the nitrogen fertilizer supplemented. A one year ^{15}N balance after three year of irrigation indicated uptake, soil NO_3-N, and unaccounted for N was for about 10, 19 and 71% for ^{15}N-labelled waste water and 15, 33 and 52% 15N-labeled fertilizer (Bole and Gould, 1985). The greater losses of waste water N compared with fertilizer N were attributed to enhanced denitrification due oxidizable C in the waste water.

Hence, the aims of this study were therefore to discuss the effect of water irrigation quality (WW vs TWW) on (i) dry matter production (DM) and nitrogen uptake, (ii) the recovery of nitrogen fertilizer by the crop (^{15}NRF) and on (iii) the ^{15}N-labeled fertilizer left in the soil at harvest on the basis of a field experiment with Sorghum irrigated with two kinds of water, TWW and WW.

Materials and methods

This field study was conducted in summer during 1997 and 1999, as part of a larger study, on a well-drained sandy soil of the experimental field of the Rural, Water and Forest Research Institute "INRGREF" of Tunisia. The field had been for Sudangrass production for at least 2 years prior to the experiment. Some physical and chemical properties of the experimental soil are presented in Table 1.

Table 1: Some physical and chemical properties and water contents of the experimental soil

Soil deep (cm)	Sand 20-2000µ %	Loam 2-20 %	EC mmhos.cm^{-1}	pH	CaCo3 %	OM (%)	Total N (%)	C/N	WHC (mm)	WWP (mm)	AW (mm)
0-20	83	5	0.7	7.8	0.2	0.3	0.059	3.4	1.79	6.67	14.64
20-40	92	5	0.7	7.3	0.1	0.2	0.047	2	1.28	4.45	9.5
40-60	94	5	0.9	7.3	00	00	0.036	00	1.12	3.28	6.48

WHC: water holding capacity for 10 cm. **WWP:** water at wilting point. **AW:** available water calculated for 20 cm of soil (**AW** = 2[da (WHC – WWP)] with **da**: apparent density of soil = 1.5)

The treatments comprised (i) two irrigation water qualities, treated wastewater (TWW) and well water (WW) and, (ii) different rates of nitrogen fertilizer, two nitrogen levels (0 and 100 kg N.ha^{-1}) where applied with both water quality (Table 2).

The experiment was organized in a randomized complete block design (16 blocks) with four replications (Figure 1). Each treatment block was 15 by 4 m. In 1997, three harvesting time were prospected, but only two were done. For that reason, only two of the three fractions planned were applied, with a total rate of 0 and 66 kg N.ha^{-1} in WW and TWW. In 1999, in order to apply the entire rate, two harvesting time were planned and done, with a total amount applied of 0 and 100 kg N.ha^{-1} in WW and TWW. Being given the high price of ^{15}N-labeled fertilizer, the labeled N was applied in microplots of land of 1 m² arranged within the blocks. On the way to determine the effect of application time, only one fraction was labeled. Under these circumstances, for each N rate, eight microplots were established to receive labeled N. four microplots among them received labeled N at emergence and unlabeled N after the first harvest, whereas, the remaining four microplots received unlabeled N at emergence and labeled N after the first harvest.

Table 2: Experimental protocol in the field for 1997 and 1999 [N water = volume of water brought (mm.m²) x average content on total N in water (mg N.l^{-1})

Year	1997				1999		
	N $_{(water)}$	†N $_{(fertilizer)}$	Total	(kg N. ha^{-1})	N $_{(water)}$	‡N $_{(fertilizer)}$	Total
WW0	155	00	155	WW0	148	00	148
WW100				WW100			
microplot1	155	$33^a + 33^b$	221	microplot1	148	$50^a + 50^b$	248
microplot2	155	$33^b + 33^a$	221	microplot2	148	$50^b + 50^a$	248
TWW0	320	00	320	TWW0	303		303
TWW100				TWW100			
microplot1	320	$33^a + 33^b$	386	microplot1	303	$50^a + 50^b$	403
microplot2	320	$33^b + 33^a$	386	microplot2	303	$50^b + 50^a$	403

† ^{15}N labeled fertilizer at 9.861 At% abundance. ‡ ^{15}N labeled fertilizer at 4.792 At% abundance. (a): labeled fertilizer. (b): unlabelled fertilizer. WW: well water. TWW: treated waste water

Sudangrass (*sorghum sudanense*, Piper) was planted on monthly statement of May in 0.3 m row spacing at a population of 333000 plants ha^{-1} in both years. In the microplots population was double the density shortly after emergence. The ^{15}N-microplots were arranged to include four rows of sorghum with ten plants per row.

Water irrigation levels were designed to approximate the seasonal evapotranspiration (ET) minus precipitation deficit. The crop ET requirement is 630 mm per season from 15 Mai to mid-September under local conditions. According to Rebour and Deloye (1971), water use efficiency was estimated at 70% in field experiment, so that an additional of 30% (equal to 190 mm) excess water was applied to meet 100% water use efficiency. Irrigation was made from May through September, consisted of a total of 30 and 32 irrigations during 1997 and 1999 respectively. Overall, the crop received a total of 870 and 820 mm of water in 1997 and 1999 respectively. WW from a mixture of wells was stored in a big pond, then water from a pond was pumped and conducted via plastic tube (Ǿ 63) until the experimental plot. In the edge of each treatment block, water was applied by a siphon connected to 4m tubes that contain seven perforations (Figure 1).

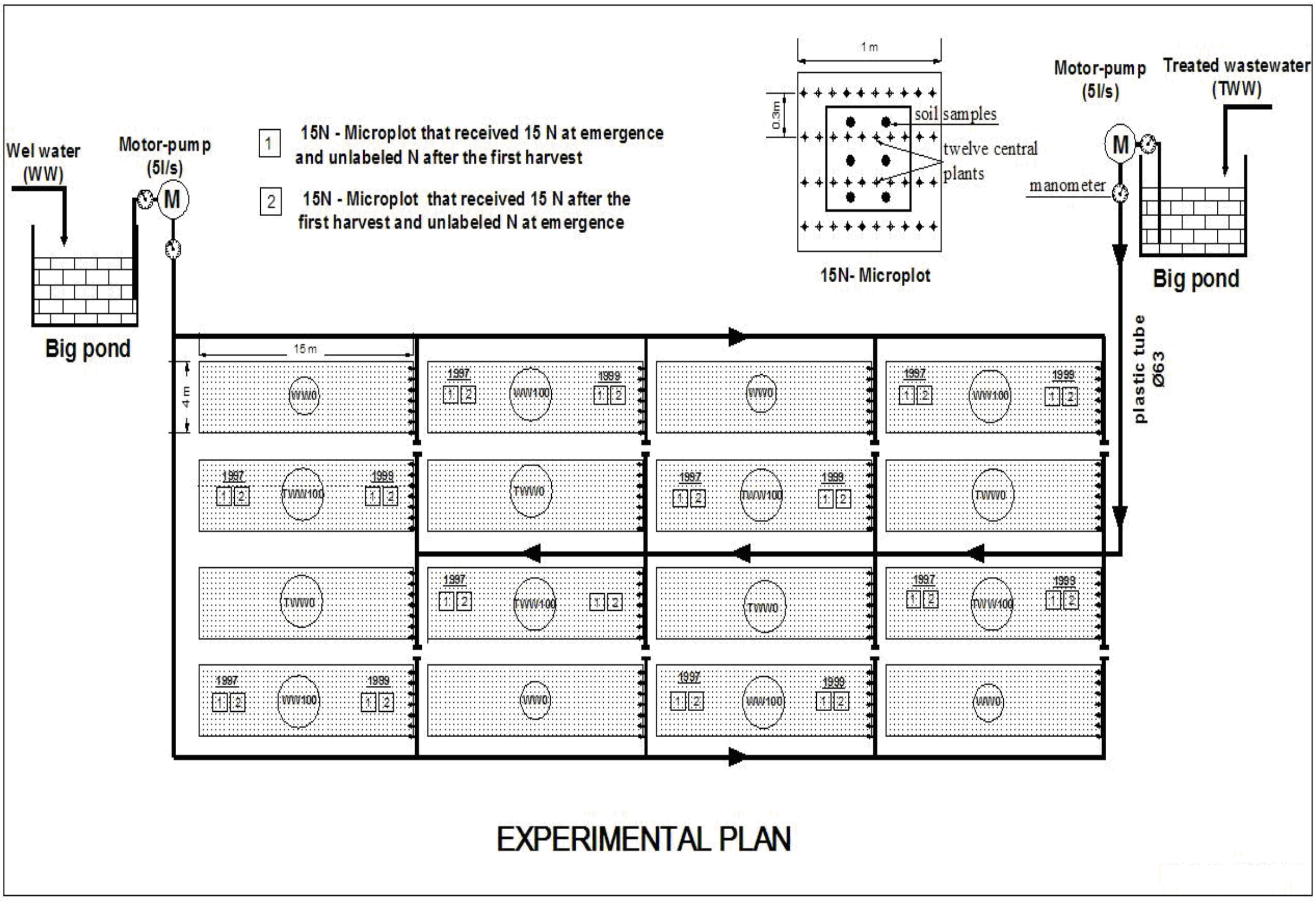

Figure 1: Experimental plan

TWW was produced by a treatment plant situated at 7 km from the experimental field and conducted via pipe line and stored in a big pond. TWW was then pumped and conducted via a plastic tube until the experimental plot. To control the distributed volume of water, we installed for each kind of water a manometer. Overall, the crop received a total of 870 and 820 mm of water in 1997 and 1999, respectively. ^{15}N-microplots were irrigated at the same time as the main plots with a watering-can with a sprinkler head.

The N composition of TWW ranged from 19.2 to 40.3 mg.L^{-1} of total N, with an average of 37 mg N.L^{-1} in the main part as NH_4^+ (about 35 mg N-NH_4.L^{-1}) and accounted less than 5 mg.L^{-1} of NO_3^--N. Well water used was a mixture from five wells situated on the experimental field and accounted about 18 mg.L^{-1} of NO_3-N. for both years, N were added as ammonium nitrate (NH_4NO_3) applied in two fractions, at emergence and after the first harvest, with a corresponding ^{15}N excess of 9.495 and 4.426 atom % in 1997 and 1999, respectively.
The isotope treatments were applied during irrigation. The soil surface were moistened with 15 liters irrigation water, after that ^{15}N-labeled fertilizer was uniformly applied with an watering-can with a sprinkler head in 2 liters of distilled water, then watering-can was rinsed immediately with 1 liter of distilled water and the rinse was also applied, followed by an additional 2 liters of distilled water to wash Sudangrass foliage from deposit ^{15}N. Plants of the surrounding plot received unlabelled-N fertilizer, applied by hand at the corresponding N rate within the same day with care to prevent any unlabeled N fertilizer from being applied to the ^{15}N-microplots. The sampling concerned only the microplot, no data was determined outside of the microplot. Two harvests were made in each experiment. At each harvest, the plant material was harvested when the Sudangrass was at the beginning of the flowering stage for yield measurement. Twelve central sorghum plants were harvested to determine Fertilizer N recovered as ^{15}N in the plant (^{15}NRF) according to the equation below:

$$^{15}\text{NRF} = \frac{\text{NP x Yp}}{\text{NF x Yf}}$$

Where NP and NF are the nitrogen taken up by the plants in the N-fertilized plot and the amount of fertilizer N applied, respectively. And where Yp and Yf are the atom percent excess 15N in the plant and the applied fertilizer, respectively.

In the first harvest, only the above-ground plants were cut, while in the finale harvest the hole plant were harvest. All plant portions were dried at 70°C, and weights were recorded. The plant tissue was ground and analyzed for total N using kjeldahl digestion method (Bremner and Mulvaney, 1982). At the second harvest, soil samples were collected with an auger at three depths (0-20, 20-40 and 40-60 cm) from six locations in each microplot and composited. Analysis for total N in soil was carried out using kjeldahl method modified to include nitrate (Olsen, 1980) cited by Guiraud and Fardeau (1977). The isotopic composition of N was determined by mass spectrometry (VG SIRA12. UK). The % ^{15}N abundance obtained by mass spectrometry was transformed into atom% ^{15}N excess by subtracting the natural abundance (0.3663 atom% ^{15}N) from the % N abundance of plant and soil samples. To avoid cross-contamination during the steam-distillation process, the distillation unit was flashed with ethanol for 3 minutes between samples. The data set was statistically analyzed using SAS (1985) for significance of N application levels, and of the effect on confined and unconfined ^{15}N-microplots on ^{15}NRF. Mean comparison were made by protected LSD tests at 0.05 level of probability.

Results

Plant production and nitrogen uptake

The lowest dry matter production obtained was recorded when WW was used with no fertilizer added and was significantly higher with TWW in 1997 and 1999. The assessment of irrigation water quality proves a significant effect of TWW in increasing dry matter production and nitrogen uptake (Table 3).

Table 3: Labeled and unlabeled N used by the whole plant and retention in soil of labeled N as affected by microplot design, fertilizer application rates and water irrigation qualities

Year (treatment)	^{15}N-labeled NO_3NH_4	Total dry matter (DM)	Total plant N uptake			Labeled N remaining in soil				N unaccounted for
			Labeled N	Unlabelled N	total	0-20 cm	20-40 cm	40-60 cm	total	
			(Kg.ha^{-1})				(%)			
<u>1997</u>										
WW0	0	7793 c	-	132† a	132 a					
WW100	66	11902ab	9 b	153† a	162ab					
TWW0	0	9731 bc	-	175‡ a	175ab					
TWW100	66	12656 a	11 a	181‡ a	192a					
LSD*		2366	1.1	38	39.6					

1999										
WW0	0	3647	-	73† d	73 d	-	-	-	-	-
WW100	100	7409	23 b	101† c	124 c	22 a	9 a	7 a	38 a	39 b
TWW0	0	6730	-	159‡ b	159 b	-	-	-	-	-
TWW100	100	9141	36 a	175‡ a	210 a	21 a	7 a	6 a	33 a	31 b
LSD*		971	10.41	13.3	11	5.16	10.0	16.5	22.7	

†N originating from soil. ‡ N originating from both soil and treated waste water (^{14}N). * Least significant difference at 0.05 level of probability

Moreover, dry matter production and plant N uptake were greatly affected by nitrogen rates either in WW or TWW irrigation. The amount of unlabeled N originating from soil increased by 21 and 28 kg $N.ha^{-1}$ in fertilized plots when WW was used in 1997 and 1999 respectively (Table 3). Although unlabeled N originating from both soil and TWW increases by 6 and 16 kg $N.ha^{-1}$ in the fertilized microplot in 1997 and 1999 respectively (Table 3). The apparent increase in the uptake of soil N could be due to an increased mineralization from soil organic matter, pool substitution between 14N and 15N in the soil, or increased root development in the fertilized treatments.

Fertilizer nitrogen recovery

The differences in fertilizer N use between the different treatments and irrigation water qualities become clear when they are expressed on the percent recovery basis. Fertilizer nitrogen recovery (^{15}NRF) in Sudangrass plants was higher in TWW than in WW irrigation in 1997 and 1999. An average of 17 and 26% of ^{15}N-labelled fertilizer was recovered in the presence of WW and TWW, respectively (Table 4).

Table 4: Fertilizer N recovery (^{15}NRF) in the whole plant as estimated by isotopic method

Year	^{15}N-labeled NH_4NO_3 applied	Fertilizer N recovery (^{15}NRF)			
		First harvest	Second harvest (%)	Residual effect	total
1997					
WW100	66	15 b	10a	1 b	13 b
TWW100	66	21 a	11 a	2 a	17 a
LSD‡		2.9	3.97	0.91	3.43
1999					
WW100	100	26 a	16 a	3 b	23 b
TWW100	100	38 a	29 a	5 a	36 a
LSD‡		15.9	4.30	1.47	10.41

‡ Least significant difference at 0.05 level of probability

Comparing the residual effect, we note that fertilizer N recovery were very low in both years, with however, a more important residual effect when TWW was used for irrigation.

Recovery of fertilizer N in soil

Distribution of fertilizer N in the soil profile as influenced by N rate and water qualities is presented in the Table3 and Figure 2.

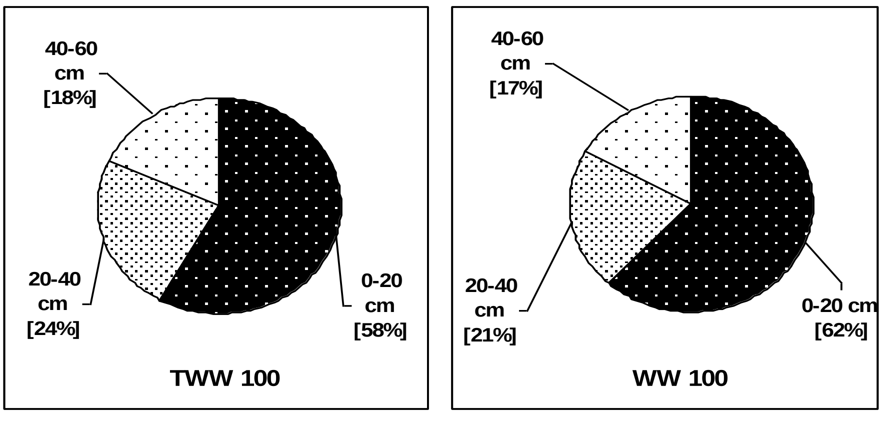

Figure 2: ^{15}N-labeled fertilizer remaining in the soil as influenced by N rate and water quality

Neither fertilizer rate nor water quality had an effect on the ^{15}N-labeled fertilizer remaining in the 0-60 cm layer at final harvest (Table 3). The ^{15}N-labeled fertilizer remained in the soil after harvest is then rather related to the characteristic and the capacity of the soil to retain N than to the rate of N applied or irrigation water quality. Residual ^{15}N-labeled fertilizer in the soil fluctuates from 33 to 49% in the 0-60 cm layer for both water qualities. Most of residual ^{15}N-labeled fertilizer remaining in the soil was located in the surface 0-20 cm layer, with an average of 22% despite N rate and water irrigation qualities (Table 3). Moreover, the proportion of total ^{15}N remaining in the top 20 cm of soil was unaffected by water qualities. About 60% of the residual 15N-fertilizer was retained in the top of the soil for WW and TWW (Figure 2). This better immobilization of nitrogen in the top layer was attributed by many authors to an important concentration of microflore biomass at the surface soil.

Discussion

Dry matter production was greatly affected by nitrogen rate, either in WW or TWW irrigation. Otherwise, as reported by others (Campbell *et al.*, 1982; Bielorai *et al.*, 1984; Papadopoulos and Stylianou, 1988), TWW without fertilizer N addition significantly increased DM yield and total N recovered by plant when compared to WW. Moreover, at the same rate of N fertilizer added, DM production was significantly higher with TWW irrigation. Hussain *et al.* (1996) suggest that this could be attributed to the presence of appreciable amount of N, P, K and some other micro-elements essential for plant growth compared to WW. Total N removed by plants increased significantly when a smallest amount of fertilizer N was supplemented with treated wastewater irrigation. Papadopolos and Stylianou (1982), concluded that cotton yield, could be higher with the effluent particularly when supplemented with lower N rates. However, with the highest N level there was a reduction in yield obtained with the treated effluent. According to Hussain *et al.* (1996) a higher wheat grain yield and N use efficiency could be achieved with low application rates if the crop is irrigated with TWW containing N in the range of 20 mg.L^{-1} and above. However, Vaisman *et al.* (1982), suggest that for good yield, Rhodes grass grown under field condition required 250 kg N.ha^{-1} in addition to the 117.7 kg N.ha^{-1} added in the irrigation water. Moreover, according to Ferriera da fonseca *et al.* (2007), secondary-treated sewage effluent irrigation can efficiently substitute potable water for irrigation of Tifton 85 bermudagrass pasture and, simultaneously, save 32,2-81% of the recommended N rate without loss of grass DM and protein content yield.

Fertilizer N recovery as estimated by the isotopic method was higher when TWW was used. For the same amount of N applied in TWW and WW, 15NRF was about 13 and 22% in WW irrigation and 17 to 36% in TWW irrigation. Values obtained with TWW were similar to that reported in other investigations when confined microplot was used on sorghum (Westerman and Kurtz, 1974; Harmsen and Morghan, 1988) and on maize (Tobert *et al.* 1992; Reddy and Reddy, 1993; Schindler and Knighton, 1999). This better use of N in TWW irrigation could be a result of better growth of the plant and their roots in TWW irrigation. While, the weak values of 15NRF noted in WW irrigation are to be related to the nature of the soil which is sandy with low organic matter content (OM). Therefore, we suppose that applications of fertilizer on similar nature of soil (with 0,5% of OM) are, in effect, maintaining soil fertility rather than directly fertilizing the crop.

Residual effects measured at the second harvest were very low for both water qualities. From 1% to 5% of the N fertilizer previously applied at raising were taken by the crop in the second harvest. That labeled N expressed by the residual effect, couldn't be originating from ^{15}N fertilizer stocked in the soil and found probably him origin in the ^{15}N fertilizer accumulated in the roots and at the bottom of the stem at the first harvest. At the same rate of N application, residual effect was higher with TWW than WW (3 vs 5%). Neither fertilizer rate nor water quality had an effect on the ^{15}N-labeled fertilizer remaining in the soil at final harvest. About 33 to 38% of the N fertilizer applied was left in the 0-60 cm layer at final harvest for water qualities, most of them were located in the surface 0-20 cm layer, with an average of 21,5% despite N rate and water irrigation qualities. Studies reported in the literature (Olsen, 1980; Power and Legg, 1984) have also concluded that most of the N remaining in the soil was in the surface layer. Moreover, the proportion of total ^{15}N remaining in the top 20 cm of soil was comparable (58 vs 62%) for both water irrigation qualities with the same rate of ^{15}N-fertilier applied, which is in line with others studies (Destain *at al.* 1996; Khelil *et al.* 2005). This better immobilization of N in the top layer suggested that this N was in the organic forms as described by Allen *et al.* (1973) and on large scale it was attributed by Speir *at al.* (1999) to an important concentration of microflore biomass at the surface soil. According to Crosier *at al.* (1998) and Pilbeam *et al.* (1997), enrichment in the apparent immobilization of ^{15}N-labeled fertilizer would be the most likely explanation for the reduced crop recovery as the N fertilizer rate increased.

A N balance for this study shows that recovery of ^{15}N-labelled fertilizer by sorghum was enhanced by TWW. An average of 17 and 26% of 15N-labelled fertilizer was recovered in the presence of WW and TWW, respectively. Total recovery from soil and crop of 15N-fertilizer were deduced from year 1999, for the same amount of N applied (100 kgN.ha^{-1}), total recovery of 15N-fertilizer was unaffected by water irrigation quality, being 61% and 69% for

WW and TWW, respectively. Against total recovery of ^{15}N-labelled fertilizer, water irrigation had no effect on the proportion of 15N-fertilizer unaccounted for. Approximately 35% of the applied N fertilizer was lost following the application of 100 kgN.ha^{-1} to Sudangrass irrigated with either TWW or WW. Pertaining to the nature of our soil, the most likely mechanisms responsible for the loss of about one third of that applied is leaching of nitrate below the sampling depth.

Conclusion

The results obtained in this study have provided information on the likely behavior on fertilizer N in plant/soil system under irrigation with two kind of water WW and TWW in field experiment. For both years TWW provided a substantial amount of N, consequently the efficiency of the fertilizer brought in complement is relatively low (^{15}NRF = 17-36%). This experiment carried over two years should be done during longer duration, so that long-term effects can be studied. Moreover, attention should also be given to those waste water constituents behavior and particularly to N that if it is applied in amount exceeding crop needs may adversely affect crop growth and pollute groundwater

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