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Banana fertigation with treated sanitary wastewater: postharvest and microbiological quality

Fertirrigação da bananeira com água residuária sanitária tratada: qualidade pós-colheita e microbiológica

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Abstract

Sewage may serve as a source of water and nutrients for plants. In this study, the effects of fertigation with treated sanitary wastewater from Janaúba Sewage Treatment Plant were evaluated on the postharvest and microbiological quality of 'Prata-Anã' banana. A randomized block experimental design was used. Four concentrations of wastewater were tested (70, 130, 170, and 200% of 150 kg ha^{-1} sodium). A wastewater-free control treatment was used for comparison. Two crop cycles were assessed for postharvest and microbiological quality. The parameters measured included total soluble solids, titratable acidity, total soluble solids/titratable acidity ratio, pH, total coliforms, and fecal coliforms on both the peel and the pulp. In the first crop cycle, both soluble solids and fruit pulp pH decreased as wastewater level increased up to a maximum of 141.5%. These correlations were not observed in the second cycle. Wastewater management did not affect the titratable acidity of the soluble solids. The agricultural application of treated sanitary wastewater provided banana fruits with a microbiological profile similar to that obtained with the control (pure water) and with mineral fertilizers. A microbial balance is necessary to maintain the nutritional status of the banana crop.
Key words: *Musa* spp. Agricultural wastewater reuse. Environmental sanitation.

Resumo

A utilização de água residuária proveniente do tratamento de esgoto, como fonte hídrica e nutricional para as plantas, é uma alternativa para racionalizar o aproveitamento do recurso natural na agricultura. O objetivo desse trabalho foi avaliar os efeitos da aplicação da água residuária sanitária de tratamento secundário da Estação de Tratamento de Esgoto de Janaúba – MG sobre a qualidade pós-colheita e microbiológica da bananeira 'Prata-Anã'. O experimento foi conduzido no delineamento de blocos casualizados. As doses de água residuária testadas foram equivalentes a 70, 130, 170 e 200% do limite máximo de 150 kg ha^{-1} sódio que pode ser aportado ao solo. Para efeito de comparação foi conduzido também um tratamento testemunha, irrigado com água limpa. Durante dois ciclos produtivos da cultura determinaram-se os seguintes atributos pós-colheita da banana: sólidos solúveis totais, acidez total

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titulável, relação sólidos solúveis totais/acidez titulável e o pH. Para a análise microbiológica foram coletados frutos em cada ciclo produtivo da cultura, quando se quantificou a presença de coliformes totais e coliformes termotolerantes na casca e na polpa das bananas. No primeiro ciclo de produção da bananeira, o teor de sólidos solúveis dos frutos decresce com o aumento no aporte de água residuária sanitária tratada até o limite de 141,5%, havendo também redução do pH dos frutos, porém, tal fenômeno não é verificado no segundo ciclo. A relação sólidos solúveis:acidez titulável e a acidez titulável não são influenciadas pelo manejo com água residuária sanitária tratada. Considerando o grupo de microrganismos avaliados e tendo em vista a manutenção do equilíbrio do estado nutricional da cultura, o reúso agrícola da água residuária sanitária tratada permite a obtenção de frutos de banana com qualidade microbiológica semelhante àqueles obtidos pelo manejo com água limpa e fertilizantes minerais.
Palavras-chave: *Musa* spp. Reúso agrícola de efluentes. Saneamento ambiental.

Introduction

One of the determining factors for success in fruit growing is fruit quality, the criteria for which are largely determined by consumer demands.

According to Chitarra and Chitarra (2005), the main physiological characteristics correlated to fruit quality that influence fruit preferences are pH, titratable acidity, soluble solids, ratio between soluble solids and acidity, reducing sugars, non-reducing sugars, total sugars, pectic substances, and starch content.

According to Maia et al. (2003), the relationship between fertilization and banana production has been extensively studied but the relationship between fertilization and fruit quality has received far less attention. Nevertheless, Silva et al. (1999) reported that fertilizer application rate is a pre-harvest factor directly correlated with banana quality. Therefore, the effects of crop fertilization using unconventional sources like sewage effluents (in the form of treated wastewater) must be closely monitored to ensure that they do not compromise product quality or consumer acceptance.

Despite advances in sewage treatment processes, most wastewater sources still contain large amounts of microbes that are potentially harmful to consumers and rural workers (SHUVAL et al., 1997; SCANDOLERA et al., 2001; METCALF; EDDY, 2003; BARKER et al., 2014). Al-Lahham et al. (2003) studied the quality and contamination levels of tomato fruit produced with wastewater.

Paganini (2003) argues that applying sewage waste to the soil for irrigation or any other use involving the soil-plant system creates an immediate and direct risk of microbial contamination. This risk is further increased by sprinkler irrigation, which puts the vegetation to be consumed in direct contact with the sewage waste. The author points out that microorganisms (including pathogens) generally survive for a shorter period of time on crop surfaces than in soil and water. Nevertheless, the microbes could be deposited on crowns, cracks, stems, and stalks where they would be protected from adverse environmental conditions such as solar irradiation, high temperatures, and desiccation until harvest. In this way, the crop could be rendered unfit for human consumption.

In general, field crops may be contaminated by pathogens like *Salmonella* spp., *Shigella* spp., *Campylobacter* spp., *Escherichia coli, Staphylococcus aureus, Clostridium botulinum, Bacillus cereus, Vibrio spp.*, Hepatitis A virus, and Norovirus. They could also be infested with pathogenic fungi and the parasites *Cryptosporidium* and *Cyclospora*, as well as the eggs of other intestinal parasites like *Taenia solium* (VUGIA et al., 2002).

The objective of this work was to evaluate the post-harvest and microbiological quality of the fruit of 'Prata-Anã' banana plants irrigated with treated sanitary wastewater.

Materials and Methods

This work was carried out in the experimental area of the Sewage Treatment Station (STS) of the Minas Gerais Sanitation Company, COPASA – MG in Janaúba-MG, located at 15º 49' 53'' S and 43º 16' 20'' W at an altitude of 540 m. According to Köppen, the climate is Aw (tropical, with dry winter).

The soil in the experimental area is classified as a eutrophic Red Latosol (EMBRAPA, 2013). The soil physical and chemical properties before banana orchard planting and fertigation experiment are shown in Table 1.

Table 1. Mean soil physical and chemical properties for a eutrophic Red Latosol, before fertigation experiment.

Depth	**BD**	**PD**	**TP**	**VCS**	**CS**	**MS**	**FS**	**VFS**	**Total sand**	**Silt**	**Clay**
m	g cm^{-3}		m^3 m^{-3}	g kg^{-1}							
0.0-0.2	1.77	2.58	0.31	20	85	150	180	86	521	185	294
0.2-0.4	1.66	2.54	0.34	20	75	143	177	79	494	172	334
0.4-0.6	1.57	2.53	0.37	19	67	126	153	75	441	157	403
0.6-0.8	1.52	2.62	0.42	19	62	109	144	78	411	210	379
Depth	**pH**	**[1]OM**	**[2]P**	**[2]K**	**[2]Na**	**[3]Ca**	**[3]Mg**	**[3]Al**	**[4]H+Al**	**[5]SB**	**[6]CEC_7**
m	(H_2O)	dag kg^{-1}	mg dm^{-3}						cmol$_c$ dm^{-3}		
0.0-0.2	6.2	1.3	2.3	260	0.1	2.8	0.9		0	2.2	4.5	6.7
0.2-0.4	5.5	0.7	2.0	140	0.1	2.2	0.7		0	2.2	3.4	5.6
Depth	**[7]BS**	**[8]ASI**	**[9]B**	**[2]Cu**	**[2]Fe**	**[2]Mn**	**[2]Zn**		**[10]Rem-P**	**[11]EC**		
m	%		mg dm^{-3}						mg L^{-1}	dS m^{-1}		
0.0-0.2	67	0	0.3	1.0	23.7	10.8	0.8		35.2	0.3		
0.2-0.4	61	0	0.4	0.9	24.8	3.9	0.4		30.6	0.2		

BD: soil bulk density; PD: particle soil density; TP: total porosity; VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; [1]Organic matter, colorimetric method; [2]Mehlich-1 extractor; [3]KCl 1 mol L^{-1} extractor; [4]pH SMP method; [5]SB: sum of bases; [6]CEC_7: cation exchange capacity at pH 7; [7]BS: base saturation; [8]ASI: aluminium saturation index; [9]$BaCl_2$ extractor; [10]remaining phosphorus in the equilibrium solution; [11]EC: electrical conductivity of the saturated paste extract, 1:0.5 soil/water ratio.

The experimental design was a randomized block with four replications. The treatments consisted of different doses of treated wastewater (TWW) from the STS. The maximum annual application limit (AML) for the soil was 150 kg ha^{-1} sodium (Na) (LARCHER, 2005). The treatments were: T1 – control (clean water + mineral fertilization); T2 –70% TWW; T3 – 130% TWW; T4 – 170% TWW, and T5 – 200% TWW (relative to the reference AML).

The sewage treatment system of the Janaúba STS consists of a preliminary treatment (grille and desander), a Parshall gauge with an ultrasonic flow meter, an anaerobic upflow reactor (UASB), a facultative lagoon, and two maturation ponds in series, with a continuous flow rate capacity of up to 48.4 L s^{-1}.

The banana plant cultivar 'Prata-anã' was planted on 05/05/2012 as micropropagated seedlings on a 3 x 2 m plot. There were four rows of six plants per line for a total of twenty-four plants per plot.

Fifteen days prior to planting, the foundation was fertilized in the aforementioned planting rows by mixing soil with a 4-30-10 NPK formulation, single superphosphate, and FTE BR12. The target nutrient concentrations were 22.8 kg ha^{-1} N, 200.0 kg ha^{-1} P_2O_5, 50.0 kg ha^{-1} K_2O, 48.6 kg ha^{-1} S, 103.9 kg ha^{-1} Ca, 1.5 kg ha^{-1} B, 0.7 kg ha^{-1} Cu, 1.7 kg ha^{-1} Mn, 0.1 kg ha^{-1} Mo, and 7.5 kg ha^{-1} Zn.

TWW applications were done weekly through the irrigation system (micro-sprinkling) starting 41 days after planting (DAP). After each TWW application, water was added to meet crop requirements. By the third month of planting, chemical fertilization was started in the form of nitrogen and potassium surface fertigation in the control and complementation of all treatments with the application of effluents. Similar doses were applied to all plots in the attempt to balance the nutrient supply.

Irrigation rates were determined on the basis of the evapotranspiration rate of the crop and were calculated from the daily reference evapotranspiration (ET_0 – Penman-Monteith method) (ALLEN et al., 2006), the crop coefficient (OLIVEIRA et al., 2005), the location coefficient, and the sensitivity to soil water deficit coefficient (MANTOVANI et al., 2009). The soil moisture was monitored every two weeks at the effective root system depth (0.6 m). Adjustments in application depth were made accordingly. All other parameters followed the recommendations for the crop.

On a monthly basis, TWW samples were collected during applications for the analysis of biological and physicochemical parameters (APHA et al., 2012). TWW application depth was calculated in the respective treatments on the basis of the results of this analysis from the previous month. Table 2 shows the average chemical composition of the major wastewater constituents during the experimental period.

Tables 3 and 4 show the major wastewater constituents and nutrients added to the soil via fertigation during the first two years of the experiment. The tables also indicate the application depths.

Table 2. Mean values of treated sanitary wastewater characteristics from Janaúba Sewage Treatment Plant, between June 2012 and June 2014, during fertigation experiment.

Characteristic	Unit	Mean	Standard Deviation
N_{total}	mg L^{-1}	47.6000	± 8.6364
N_{ammon}	mg L^{-1}	35.7000	± 9.6572
N_{nit}	mg L^{-1}	1.0800	± 1.7207
N_{org}	mg L^{-1}	10.8200	± 8.0942
K	mg L^{-1}	33.9390	± 11.1534
Na	mg L^{-1}	84.3690	± 19.4586
P	mg L^{-1}	8.2180	± 1.6438
Zn*	mg L^{-1}	0.0880	± 0.0601
Cu	mg L^{-1}	0.0080	± 0.0011
Fe	mg L^{-1}	0.6800	± 0.2875
Mn	mg L^{-1}	0.1000	± 0.0102
B	mg L^{-1}	0.0230	± 0.0084
Cl^-	mg L^{-1}	130.6000	± 28.2479
Co	mg L^{-1}	0.0010	± 0.0086
Ca	mg L^{-1}	19.1340	± 4.9072
Mg*	mg L^{-1}	7.9630	± 3.7786
ECE	dS m^{-1}	1.1280	± 0.1619
COD	mg L^{-1}	174.8000	± 35.1715
BOD	mg L^{-1}	58.8800	± 16.8785
O&G	mg L^{-1}	11.0000	± 4.1227
pH		7.6040	± 0.2467
TSS	mg L^{-1}	70.2000	± 33.8934
TC	CFU (100 mL)$^{-1}$	5.01E+06	± 4.32E+06
E. coli	MPN (100 mL)$^{-1}$	9.60E+03	± 3.16E+05

N_{total}: total nitrogen; N_{ammo}: ammonia nitrogen; N_{nit}: nitrate nitrogen; N_{org}: organic nitrogen; K: potassium; Na: sodium; P: phosphorus; Zn: zinc; Cu: copper; Fe: iron; Mn: manganese; B: boron; Cl^-: chloride; Co: cobalt; Ca: calcium; Mg: magnesium; EC: electrical conductivity; COD: chemical oxygen demand; BOD: biochemical oxygen demand; O&G: oil and grease; TSS: total suspended solids; TC: total coliforms; *E. coli*: *Escherichia coli*; *: measured after February 2013.

Table 3. Nutrients and sodium added to soil with treatments, after two years of banana fertigation with treated sanitary wastewater.

	N_{total}			P_2O_5			K_2O			Na	
	kg ha^{-1}										
						Year 1					
	MF	TWW	Total	MF	TWW	Total	MF	TWW	Total	TWW	Total
Control	226.2	0.0	226.2	200	0.0	200	253.3	0.0	253.3	0.0	0.0
70	143.3	86.6	229.9	200	27.5	227.5	198.2	58.1	256.3	103.8	103.8
130	120.8	114.2	235.0	200	55.0	255.0	143.7	115.6	259.3	206.5	206.5
170	109.8	127.6	237.4	200	67.8	267.8	117.2	142.5	259.7	255.2	255.2
200	98.5	141.0	239.5	200	81.3	281.3	90.2	170.3	260.5	304.8	304.8
						Year 2					
Control	320.0	0.0	320.0	100.0	0.0	100.0	320.0	0.0	320.0	0.0	0.0
70	236.2	89.3	325.5	76.5	25.42	101.9	274.8	49.79	324.6	106.6	106.6
130	212.5	114.7	327.2	55.1	46.27	101.4	233.4	91.58	325.0	196.6	196.6
170	198.9	133.2	332.1	42.6	60.46	103.1	209.4	119.78	329.2	258.3	258.3
200	187.1	146.1	333.2	31.8	71.24	103.0	188.8	140.75	329.6	303.7	303.7

TWW: treated sanitary wastewater; MF: mineral fertilizer; N_{total}: total nitrogen provided to banana, P_2O_5: phosphorus; K_2O: potassium, Na: sodium; Control: potable water and mineral fertilizer top-dressing; 70: 70%; 130: 130%; 170: 170%; 200: 200% of sodium contribution limit to soil by TWW (150 kg ha^{-1} year^{-1}) (LARCHER, 2005).

Table 4. Water depth on experimental plots in two years of the banana plantation with treated sanitary wastewater fertigation.

Treatment	Year 1				Year 2			
	TWW	Rainfall	SN	Total	TWW	Rainfall	SN	Total
	mm							
Control	0	432.8	2205.2	2638	0	471.7	2010.9	2482.6
70	127.1	432.8	2078.1	2638	104.14	471.7	1906.8	2482.6
130	252.7	432.8	1952.5	2638	190.83	471.7	1820.1	2482.6
170	312.5	432.8	1892.7	2638	251.66	471.7	1759.2	2482.6
200	373.4	432.8	1831.8	2638	295.71	471.7	1715.2	2482.6

TWW: treated sanitary wastewater; Rainfall: effective rainfall; SN: supplementary net irrigation depth; Total: total irrigation depth applied to experimental plots.

Post-harvest analysis

Fruit at maturity stage 2 on the Von Loesecke scale (PBMH; PIF, 2006) were harvested to conduct post-harvest analyses. Samples were labeled and taken to the laboratory where they were left on the bench at room temperature until they reached maturation stage 5 on the Von Loesecke scale (PBMH; PIF, 2006).

The following physicochemical parameters were evaluated: (a) total soluble solids (TSS), using an ATAGO model N-1α field refractometer with a 0-95° Brix scale; (b) titratable total acidity (TA), determined by titrating 10 g crushed pulp, homogenizing it in 90 mL distilled water, and titrating it with 0.1 N NaOH solution to which three drops 1% w/v phenolphthalein was added as an indicator. Results were expressed in eq. mg. malic acid per 100 g pulp according to the standards of the Association of Official Analytical Chemists – AOAC (2012); (c) ratio of total soluble solids/ titratable acidity determined from the percentage of total soluble solids divided by the titratable acidity; (d) pH.

Data were subjected to ANOVA and, when significant, to regression analysis. Treatments were compared to the control using Dunnett's test at 5% level of significance. Data for the two production cycles were analyzed separately.

Microbiological analyses

In the first crop cycle, the fruit was harvested 30 d and 45 d after fertigation with the effluent was terminated (DAF). The fruit was collected from the basal, median and apex positions of the bunch at maturity stage 2 on the Von Loesecke scale (PBMH; PIF, 2006). In order to avoid unintentional fruit contamination during the sampling process, the worker would wear clean disposable gloves and make transverse and partial cuts in the pseudostem so the plant would drop slowly. In this way, it could be shored and contact of the fruit with the soil could be prevented.

Since there was no contamination of the fruit from the first cycle, in the second cycle they were collected for microbiological analysis in two lots (06/04/2014 and 06/11/2014), 24 h after the cessation of wastewater fertigation following the same methodology described previously.

After harvesting, the fruits were placed in sterile plastic bags, labeled, packed in expanded polystyrene boxes, and transported to the laboratory for analysis. For the pulp and peel samples, coliforms (or thermotolerant microorganism) were counted at 35°C and 45°C using the most probable number (MPN) method (SILVA et al., 2010). Dilutions were performed by aseptically removing 25-g aliquots from the samples and transferring them to sterile bags containing 225 mL peptone water; 10^{-2} and 10^{-3} dilutions were then prepared.

Coliform MPN at 35°C was determined by inoculating 1 mL of 10^{-1} sample dilution into test tubes containing inverted Durham tubes immersed in lauryl sulfate tryptose broth. Samples were incubated at 35°C for 48 h. To confirm the presence of total coliforms, the positive tubes were immersed in bright green broth.

The presence of coliforms at 45°C was confirmed by inoculating broth containing *E. coli* from positive tubes taken from the total coliform analysis and incubating them at 45°C for 48 h. Results were expressed as MPN of total coliforms per gram. Data were subjected to descriptive statistical analysis.

Results and Discussion

Among the attributes evaluated in the post-harvest analyses, only total soluble solids (TSS) and pH were significantly affected by the tested treatments (Table 5).

Table 5. Postharvest characteristics of 'Prata-Anã' banana fruits fertigated with treated sanitary wastewater in two production cycles.

Treatment	TSS ºbrix	TA[1]	TSS:TA	pH
		First cycle		
70	26.49*	0.52	51.23	4.61
130	25.60	0.50	51.77	4.57*
170	25.23	0.55	46.19	4.53*
200	26.00	0.55	48.35	4.51*
Control	**25.45**	**0.51**	**50.35**	**4.67**
		Second cycle		
70	26.70	0.68	39.52	4.10
130	25.80	0.59	43.87	4.12
170	25.65	0.69	37.41	4.03
200	26.05	0.68	39.18	4.05
Control	**25.83**	**0.66**	**39.42**	**4.05**

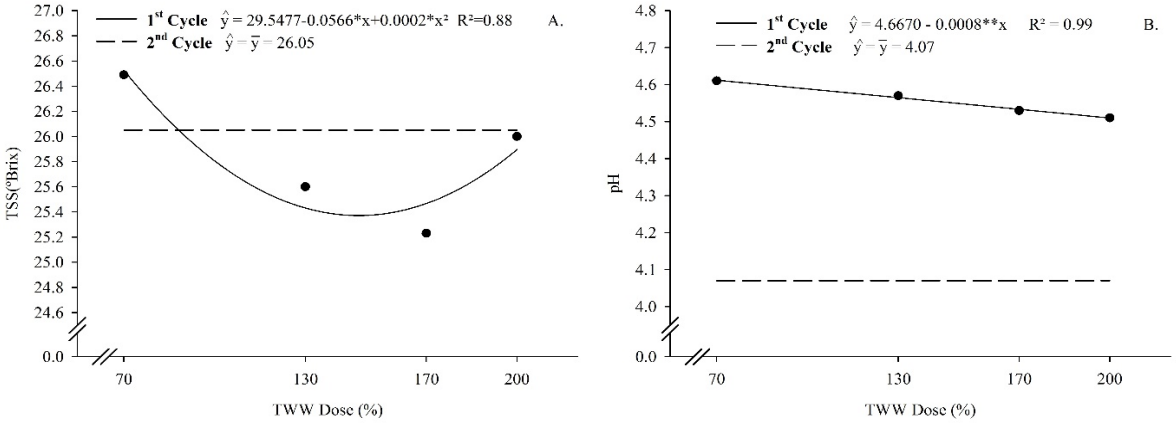
[1]Gram equivalent of malic acid (100 g pulp)$^{-1}$. *Mean differ from the control within the cycle, by Dunnett test ($p \leq 0.05$). TSS: Total soluble solids; TA: titratable acidity; TSS: TA: total soluble solids:titratable acidity ratio.

Table 5 shows that in the first cycle of banana production, the 70% TWW treatment resulted in a higher TSS content than the control (clean water and conventional fertilization). Regression analysis was performed on this parameter.

In the first crop cycle, TSS was described by a quadratic model (Figure 1 A) and decreased up to the TWW dosage equivalent to 141.5% of the maximum sodium input. From this point to the 200% TWW dosage, TSS increased slightly with TWW dose but did significantly differ from the control (Table 5).

Increasing TWW up to 141.5% of the maximum sodium input may have caused imbalances in the soil nutrients, which in turn may have reduced the TSS in the banana fruit. This condition may have been reversed beyond this TWW dose and the nutrient imbalance corrected. Since the banana tree consumes more nitrogen and potassium than any other nutrient (EMBRAPA, 2009), the imbalance caused by the very high TWW doses may have been influenced by them. Weber et al. (2006) examined the effects of nitrogen and potassium fertilization on "Pacovan" bananas and TSS decreases with increasing N dosage but increases with increasing K application. Spironello et al. (2004) obtained similar results when testing the effects of NPK fertilization on pineapple fruit production and quality.

Figure 1. A) pH and; B) Total soluble solids (TSS) in banana fruit versus treated sanitary wastewater doses in Janaúba county, Minas Gerais State.



The various TWW doses may have altered the crop cycle so that fruit harvest did not occur at the same developmental stage for all bunches. The application of different TWW doses may have changed the subjective criteria used to determine harvest time such as fruit color and the loss of fruit corners.

The immature (green) banana fruit has high starch content. As it matures (ripens), the starch is broken down into sugars used in respiration. This process increases the soluble solids content (PIMENTEL et al., 2010). Bleinroth et al. (1992), however, stated that using fruit peel color as the single criterion for the harvest time may not, in fact, indicate the correct maturation point since the peel color changes with solar radiation intensity and water availability.

In the first banana cycle, 130%, 170%, and 200% TWW produced fruit with lower pH values than those of the control (Table 6). Thus, regression analysis was performed on this parameter and

indicated that it was best described by a linear model (Figure 1 B). It was found that for each percentage unit increase in TWW, the pH decreased by 0.0008 units.

Differences in the crop cycle may have accounted for the variable TSS as well as differences in banana maturity not perceived at harvest time. Nevertheless, the average TSS values obtained in all treatments lie within the normal range for mature banana fruit (JESUS et al., 2004; VIVIANI; LEAL, 2007; PIMENTEL et al., 2010).

According to Nascimento Júnior et al. (2008), the pH of the banana tends to decrease with maturation due to the release of organic acids, mainly malic acid. Green banana pulp has a pH range of 5.0-5.6 whereas the mature fruit pulp has a pH range of 4.2-4.7 (MATSUURA; FOLEGATTI, 2001). Therefore, the variations in pH with fruit ripening corroborate the hypothesis that the fruit receiving the wastewater treatments (130%, 170%, and 200% TWW) matured unevenly compared to the control. The fact that the fruit derived from the 130%, 170%, and 200% TWW treatments had lower pH than those of the control suggests that the former were slightly more mature than the latter (Table 6). This difference may be explained by a physiological response of the banana tree to the relatively high sodium input from the TWW.

Table 6. Microbiological analysis of peel and pulp fruits of 'Prata-Anã' banana in two production cycles and different times after treated sanitary wastewater fertigation.

First Cycle								
Treatment	30 DAF				45 DAF			
	TC MPN g^{-1}		TtC MPN g^{-1}		TC MPN g^{-1}		TtC MPN g^{-1}	
	Peel	Pulp	Peel	Pulp	Peel	Pulp	Peel	Pulp
Control	< 3	< 3	< 3	< 3	23	< 3	9.2	< 3
70	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
130	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
170	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
200	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Second Cycle								
Treatment	Sampling 1				Sampling 2			
	TC MPN g^{-1}		TtC MPN g^{-1}		TC MPN g^{-1}		TtC MPN g^{-1}	
	Peel	Pulp	Peel	Pulp	Peel	Pulp	Peel	Pulp
Control	< 3	< 3	< 3	< 3	23	< 3	9.2	< 3
70	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
130	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
170	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
200	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3

MPN: most probable number; TC: Total coliforms; TtC: thermotolerant coliforms; DAF: days after fertigation.

Soares (2006) verified that the cultivar 'Prata-Anã' irrigated with water of 1.66 dS m^{-1} electrical conductivity (EC) developed precociously relative to plants irrigated with water of 0.31 dS m^{-1} EC. In the present study, the average electrical conductivity of the wastewater was 1.128 dS m^{-1} (Table 2). Soares et al. (2011) point out, however, that the banana tree may accumulate sodium in its rhizome to protect the other organs from sodium intoxication.

The titratable acidity (AT) and the soluble solid:titratable acidity ratio (SST:AT) in both crop cycles were significantly affected by all TWW treatments and corroborated the values reported by Jesus et al. (2004).

Despite the differences in post-harvest quality observed in this study, crop productivity was similar for all treatments and both crop cycles. The average yield was 26.32 t ha^{-1} in the first cycle and 33.81 t ha^{-1} in the second (ALVES, 2014).

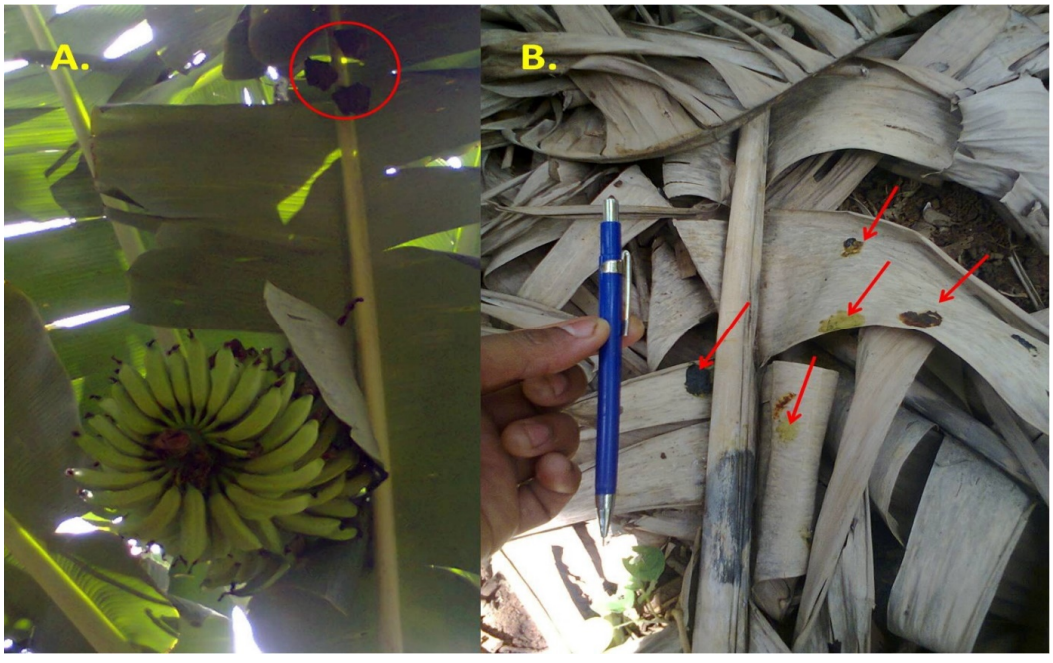
In the first crop cycle, no contamination by total coliforms and/or thermotolerant coliforms was observed in the peel or pulp for any of the evaluated treatments (Table 6). The suspension of wastewater fertigation 30 d and 45 d before harvest may explain the lack of coliforms. Even if some microbial fruit contamination did occur during wastewater fertigation under the conditions of this study, the fertigation-free time interval may have sufficed to eliminate total and thermotolerant coliforms.

According to Sousa et al. (2006), the survival of pathogens on crop surfaces depends on environmental factors such as sunlight, temperature, and relative humidity. The author also emphasizes that, in general, these conditions are unfavorable to pathogen proliferation.

In the second crop cycle, microbial analyses were performed 24 h after wastewater fertigation. The sampling performed on 06/11/2014 showed that contamination with thermotolerant coliforms and *E. coli* was detected in the banana peel from the control treatment (Table 6).

According to Sarria and Filgueiras (2006), contamination may occur at harvest and post-harvest due to improper handling, domestic animals, conveyor belts, wash water, quick-cooling water, harvest packaging, commercializing packaging, pallets, trucks, and improper handling. Based on this information, it is believed that the contaminants found in the control sample peels may be accounted for by the presence of birds and bats frequently found in the experimental area and on or near the bunches (Figure 2). Nevertheless, the contamination levels detected are in accordance with the standards established by ANVISA (2001), namely, 500 MPN/g thermotolerant coliforms in fruit samples.

Figure 2. A) Bats in banana leaves (circled) and; B) Bat droppings on fallen leaves (arrows) under the same banana plant fertigated with treated sanitary wastewater, Janaúba county, Minas Gerais State.



Rodrigues et al. (2013) found 5.4-35.1 g^{-1} total coliforms and <3-26.3 g^{-1} thermotolerant coliforms in banana peel irrigated with water from irrigation channels and tubular wells in the North-Mineira region. These contamination levels, however, were verified not at harvest but during washing of the fruits with contaminated water.

In the present work, banana fruits were harvested in such a way as to avoid any contamination other than that which would result from the wastewater treatments themselves. The fruits to be analyzed were collected on the plant to avoid soil contact, and clean gloves were worn during the sampling. The bananas were not washed and no products were applied to them in the field at the time of harvest. Additional measures were taken to avoid cross-contamination at harvest, during transport to the laboratory, and during the analyses. The micro-sprinkler fertigation system proved to be highly efficient because it avoided direct contact of the sanitary effluent with the fruit and minimized the risk of contamination.

Conclusions

Banana tree fertigation with treated sanitary wastewater from the Janaúba-MG STS produced fruit with a post-harvest quality similar to those derived from banana trees treated with mineral fertilizers and clean water. Nevertheless, very high doses of treated sanitary wastewater may impair nutritional balance and fruit quality.

Fertigation of banana trees with treated sanitary wastewater also results in fruit whose microbiological quality resembles that obtained by fertigation with clean water and mineral fertilizers.

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