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Agricultural reuse of cheese whey wastewater treated by NaOH precipitation for tomato production under several saline conditions and sludge management

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ABSTRACT

NaOH precipitation applied to cheese whey wastewater (CWW) has been investigated in the pH range of 8.5–12.5. Optimum conditions were found at pH 11.0. High reductions of chemical oxygen demand—COD (40%), turbidity—T (91%), total suspended solids—TSS (69%), sulphates (93%), phosphorus (53%), total hardness (40%), calcium (50%), magnesium (27%), chlorides (12%), Kjeldahl nitrogen (23%), etc. were achieved. Treated CWW by the aforementioned process has been used for agricultural irrigation of two tomato cultivars (Roma and Rio Grande) after dilution with fresh water, which was used as control experiment (1.44 dS m^{-1}). Five different irrigation treatments, with salinity level in the range of 1.75–10.02 dS m^{-1}, were implemented with treated wastewater. Treatment did not show a significant effect on the total and marketable yield, production losses and tomato yield with physiological disorder of blossom-end rot. Nevertheless, the cultivar Rio Grande presented an increase up to 21% in the marketable yield, for salinity levels of 1.75–3.22 dS m^{-1}, owing to an increment of the fruit fresh weight. Furthermore, treatment significantly influenced the tomato yield with epidermis deformations by solar exposure, unit fruit fresh weight and tomato number per kilogram. Fruit epidermis deformations due to solar exposition were minimized in about 27–93% when using treated wastewater. Raw sludge generated in the NaOH precipitation presented an average content of organic matter, phosphorus and nitrogen of (g kg^{-1} on a dry basis) 512, 5.8 and 11.2, respectively. Additionally, this sludge was treated by means of several processes. Centrifugation was quite efficient in the sludge volume reduction. The integrated sequence: aerobic digestion + sedimentation + centrifugation constituted a suitable treatment line, achieving a sludge volume reduction of 80% and simultaneously producing an effluent with organic matter depletion around 40%. Infiltrated water from sand filters was more contaminated organic and inorganically than the effluent obtained in the sequence: aerobic digestion + sedimentation + centrifugation.

1. Introduction

The majority of the Mediterranean countries, including Portugal, Spain, Italy and Greece, has severe and frequent problems in the water availability for the diverse consuming sectors, with common and extensive periods of drought (Aiello et al., 2007), low rainfalls and hot summers (Prazeres et al., 2014). Agriculture is the largest water-consuming sector in the world, requiring about 70% of the total water consumption, compared with 20% and 10% for the industrial and domestic sectors, respectively (http://www.worldometers.info/water/ (23.07.15)). Concerning Portugal, the water consumption is estimated at 7500 millions of m^3 $year^{-1}$, where 87% is sought for the agriculture sector (http://portaldaagua.inag.pt/PT/InfoUtilizador/

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UsoEficiente/Pages/ConsumoPortugal.aspx (26.01.11)). As a consequence, the search for new water sources to agriculture has been increasing in several regions like North and South Africa, Southern Europe, Mexico and South America (Boyden and Rababah, 1996). The industrial wastewater reuse is one of the most important challenges in agricultural irrigation (Angelakis et al., 1999). Meanwhile, the reuse of reclaimed wastewater by farmers presents several advantages, such as the use of low-cost water resources, nutrient supplementation, minimizing of the application rate of commercial fertilizers, improvement of the soil and crop productivity (Angelakis et al., 1999; Jiménez-Cisneros, 1995; Paranychianakis et al., 2006). Additionally, a decrease of the wastewater treatment costs can be achieved when using reclaimed wastewater in agricultural irrigation.

The growing attractiveness of fruits and vegetables is mainly due to the nutritional and health benefits linked to their consumption (Klaiber et al., 2005). At present, the demand and preference of consumers for fruits and vegetables are becoming more diverse, for example, consumers are looking for sweet tomatoes on the market (Sato et al., 2006). In this sense, the improvement of this property can be achieved when salinity conditions are applied in the tomato production. Numerous studies have often described increments in the tomato sweetness, flavor, umami, epidermis firmness, acidity, titratable acidity, soluble solids, chloride, ascorbic acid, glucose, fructose, sucrose, organic acids, free amino acids and lycopene (Petersen et al., 1998; Sato et al., 2006; Wu and Kubota, 2008; Zushi and Matsuzoe, 1998, 2009) when salinity conditions have been used. As well, in previous works, we have studied the production of two tomato cultivars (Roma and Rio Grande), obtaining increases in the total soluble solids content (Brix grade) and epidermis firmness of fruits when using pretreated CWW as a source of water and nutrients at different salinity levels (Prazeres et al., 2013a,b, 2014).

Raw CWW is characterized as a relatively high contamination source of chemical and biochemical oxygen demand (COD and BOD), turbidity, oils and fats, suspended solids, phosphorus, nitrogen and anoxic conditions, etc. Additionally, wastewater coming from the cheese manufacture, usually, presents high salinity, monitored by electrical conductivity values in the range 11–14 dS m^{-1}. The salinity level results of the salt addition during the manufacturing process, so the concentrations of chloride and sodium are fairly elevated (2.1–3.8 g L^{-1} and 0.9–1.7 g L^{-1}, respectively).

The direct use of cheese effluents on the soil is a common and long-lasting practice (Jones et al., 1993; Lehrsch et al., 2008; Prazeres et al., 2012; Robbins and Lehrsch, 1998), but a previous treatment is typically required so as to prevent several emerging public health risk and environmental damages. Nowadays, the treatment of CWW is carried out by the application of physicochemical and biological processes, the latter being extensively used, under anaerobic (Gavala et al., 1999; Gutiérrez et al., 1991; Kalyuzhnyi et al., 1997) and aerobic (Fang, 1991; Martins and Quinta-Ferreira, 2010; Rivas et al., 2010, 2011) conditions. Bioprocess efficiencies can attain values above 80%; nonetheless, high hydraulic retention times are normally mandatory. What is more, biotreated wastewater does not ordinarily comply with the European Environmental Legislation, exceeding the COD and BOD limits allowed for the direct discharge. The levels of phosphorus and nitrogen can also lead to the eutrophication phenomena.

Physicochemical treatments partially eliminate the organic matter and nitrogen compounds (Rivas et al., 2010, 2011). Moreover, these processes are also very efficient in the removal of total coliforms, TSS, fats and phosphorus. Although treated wastewater exceeds the limits imposed by legislation, this effluent is a rich source of biodegradable organic matter and nutrients, for example, nitrogen, potassium, phosphorus, calcium, magnesium, chloride, etc., which can be recycled as growth factors in agriculture. In this context, physicochemical processes as coagulation–flocculation and basic precipitation are sustainable options to reuse the obtained effluent or apply a biological post-treatment. However, these physicochemical technologies are influenced by some variables as the reagent dose, temperature, operation pH, etc. Accordingly, the present work aimed at studying the NaOH precipitation applied to CWW under different operating conditions (pH 8.5–12.5), characterizing the supernatant and sludge obtained. The supernatant obtained from the NaOH precipitation, under optimal conditions, was reused for the production of two tomato cultivars, determining the effect of the treated CWW on the total and marketable yield, production losses, tomato yield with physiological disorders (blossom-end rot and deformations by solar exposure), unit fruit fresh weight and number of tomatoes per kilogram. Additionally, wet sludge generated in the NaOH precipitation was treated by centrifugation, compaction, filtration through sand beds, aerobic digestion + sedimentation, and aerobic digestion + sedimentation + centrifugation.

2. Materials and methods

2.1. Raw cheese whey wastewater

CWW was taken from a cheese factory located in the "*Serpa* Cheese" region of *Alentejo* (Portugal). Table 1 shows the physicochemical characterization of this raw effluent. As inferred from COD and BOD_5 maximum values (18.5 and 12.9 g L^{-1}, respectively), CWW presents a high organic matter content. The elevated biodegradability (BOD_5/COD ≈ 0.7) indicates that the effluent can be treated by biological processes. However, when this effluent was treated by aerobic digestion, a hydraulic retention time of approximately 8 days was required to reduce the COD content from 9525 mg L^{-1} to 258 mg L^{-1} (Rivas et al., 2010). Thus, slow biodegradation and bulking process formation, especially for high microorganisms concentration (6.5 g L^{-1}), constitute the principal limiting factors of the biological processes.

The low pH and high electrical conductivity values of raw CWW are the result of the manufactured whey type, anaerobic conditions of the storage lagoons and NaCl incorporation in the cheese production. The effluent presents a greenish-whitish color with high values of sodium (0.9–1.7 g L^{-1}), chloride (2.1–3.8 g L^{-1}), total solids (5.7–15.1 g L^{-1}) and turbidity (405–1386 NTU). CWW also presents a disagreeable odor of butyric acid that causes discomfort and attracts insects. The hardness of CWW is mainly due to calcium, which can be found with a concentration about 2 times higher than the magnesium concentration.

2.2. Analytical procedures for wastewater and sludge characterization

pH and redox potential measurements were performed in a WTW InoLab apparatus (sludge/water ratio = 1:2.5). Electrical conductivity (sludge/water ratio = 1:2.5) and turbidity were evaluated in a Jenway 4510 meter and WTW Turb550 turbidimeter, respectively. COD, solids, ammonium and Kjeldahl nitrogen were quantified by spectrophotometric, gravimetric and Kjeldahl standard methods (APHA, 1998). BOD and chloride were determined by respirometric and Mohr methods, respectively. Phosphorus was assessed by absorbance measurement after calcination (600 °C), dry digestion and reaction of orthophosphates with vanadate-molybdate solution (APHA, 1998). Oil and fats were measured gravimetrically after Soxhlet extraction (Sawyer et al., 1994). Sodium and potassium were evaluated in a CORNING 410 flame photometer. Sulphates determination was made by ionic chromatography using a Metrohm 761 Compact Ion Chromatography Analyzer equipped with a Metrosep A Supp 5—150/4.0 column. For