Agricultural Water Management 116 (2013) 151–159

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Treated sewage effluent: Agronomical and economical aspects on bermudagrass production

S.F. Nogueira[a], B.F.F. Pereira[b,*], T.M. Gomes[c], A.M. de Paula[d], J.A. dos Santos[e], C.R. Montes[f]

[a] Embrapa Satellite Monitoring, Avenida Soldado Passarinho, 303, 13070-115 Campinas, SP, Brazil
[b] Universidade Federal do Amazonas (UFAM), Av. Gen. Octávio Jordão Ramos, 3000, 69077-000, Minicampus – Coroado, Setor Sul – Faculdade de Ciências Agrárias, Bloco J, sala 7, Manaus, AM, Brazil
[c] Universidade de São Paulo (USP), Faculdade de Zootecnia e Engenharia de Alimentos, Av. Duque de Caxias Norte, 225, 13635-900 Pirassununga, SP, Brazil
[d] Universidade Federal do Paraná (UFPR), Campus Palotina, Rua Pioneiro 2153, Jd. Dallas, Palotina, Paranã 85950-000, Brazil
[e] Universdade de São Paulo (USP), Departamento de Economia, Administração e Sociologia, Avenida Centenário, 303, 13416-903 Piracicaba, SP, Brazil
[f] Universidade de São Paulo (USP), Centro de Energia Nuclear na Agricultura, Avenida Centenário, 303, 13416-903 Piracicaba, SP, Brazil

ARTICLE INFO

Article history:
Received 16 December 2011
Accepted 12 July 2012
Available online 11 August 2012

Keywords:
Sewage effluent
Reclaimed wastewater
Water reuse
Plant nutrition
Bermudagrass
Nitrogen

ABSTRACT

This study investigated the effects of irrigation using treated sewage effluent (TSE) combined with nitrogen (N) fertilization on the productivity and quality of bermudagrass, and on its economic feasibility under tropical conditions. The treatments employed were SI – no irrigation and no fertilization; A100 (control) – irrigation with potable water plus 520 kg N ha^{-1} year^{-1} provided as NH_4NO_3; E0, E33, E66, and E100: irrigation with treated sewage effluent plus 0, 172, 343 and 520 kg N ha^{-1} year^{-1} as NH_4NO_3, respectively. Chemical properties of TSE, shoot dry matter production, N concentration in bermudagrass were determined, and benefit–cost and economic viability analyses were carried out. Tree years of irrigation with TSE had agronomical benefits to bermudagrass such as: (i) saving 33% in N fertilizer by adding of 275 kg N ha^{-1} year^{-1}, increasing N accumulation in the soil; (ii) providing 70% of the N as $NH_4{}^+$, which is the form most quickly assimilated by the plants; (iii) building up dry matter production with 7 Mg ha^{-1} year^{-1} and (iv) increasing leaf N concentration in leaf tissue. The main benefit of TSE irrigation occurs in drought seasons with the increase in N concentration in bermudagrass shoots. Higher N concentration in leaf tissue elevates the quality and the sales price for the grass harvested, thus optimizing the benefit–cost ratio for the producer. Therefore, TSE irrigation is a viable cost-effective alternative if the N concentration in the leaf tissue is considered in the sales price.

1. Introduction

Previous studies reported the economical, agronomical and environmental benefits of treated sewage effluent (TSE) irrigation (Pereira et al., 2011). Among the nutrients provided by irrigation using TSE the nitrogen (N) is emphasized (Vazquez-Montiel et al., 1996; Oron, 1996; Meli et al., 2002). According to Lemaire and Gastal (1997), N is the most limiting factor for biomass production in agro-ecosystems after water. The N economy generated by irrigation with TSE is important due to the growing costs of N fertilization. Between 1960 and 2010 the average U.S. farm price of a ton of urea fertilizer (44–46% of N) increased from US$ 82 to US$ 448 (USDA, 2010). Menzel and Broomhall (2006) concluded that TSE costs 50% of the costs of potable water (PW), thus enabling savings of AU$ 8000 ha^{-1} year^{-1}.

Among the forage plant crops with potential for TSE irrigation is the bermudagrass. This species responds to N fertilization, is highly productive under adequate soil humidity conditions, and has high tolerance to salinity (Hill et al., 1993; Alvim et al., 1999; Maas, 1985) and high economic added value. Recent studies have pointed to the influence of: (i) N sources in different doses; (ii) fertilization seasons and (iii) irrigation with well water, and its effects on the production of bermudagrass. When N was added as a control-release fertilizer there was an increase of 10% in the green color of bermudagrass in comparison to bio-solid and to dung pellets (Barton et al., 2006). Bermudagrass responded to irrigation and application of N to the soil under different doses according to each season of the year (Xiong et al., 2007). Wherley et al. (2009) described that even during the transition months, when there is less growth, bermudagrass assimilated N efficiently. During the late season (September–October), less than 59% of the N applied to the soil was recovered (Adeli et al., 2003). Barton et al. (2006) found interaction between the N fertilizer source, the doses applied and the production of dry matter (DM). These authors state that doses of 200–300 kg N ha^{-1} per harvest were adequate for the

---

* Corresponding author. Tel.: +55 92 88276103; fax: +55 92 33054041.
E-mail address: brunoffp2000@yahoo.com.br (B.F.F. Pereira).

0378-3774/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2012.07.005

production of bermudagrass. Moreover, water-soluble or control-release fertilizers doubled the DM production in comparison to organic fertilizers.

Few studies investigated the influence of TSE irrigation as a partial source of N fertilizer on the production of bermudagrass especially in tropical conditions. In this study, we hypothesized that irrigation using TSE as a partial source of N associated with N regular-fertilizer may affect DM production and N concentration in the shoots and the economic feasibility. Menzel and Broomhall (2006) identified an increase of 4% on DM for bermudagrass irrigated with TSE in comparison to irrigation with potable water. These authors reported a 40% decrease in N leaf concentration in plants irrigated with TSE between May and August. Mancino and Pepper (1992) detected increase in total N concentration in the soil during the first year of irrigation with TSE. However, after 2.3 years the N concentration at the plots irrigated with TSE did not differ from that of the plots irrigated with PW. Irrigation with TSE added 335 kg N ha^{-1} $year^{-1}$ to the soil and represented an economy of 32–81% in N use in the production of bermudagrass (Fonseca et al., 2007). Fonseca et al. (2007) also detected an increase in protein concentration in bermudagrass irrigated with increasing doses of TSE.

Several studies identified the importance of N fertilization and irrigation with well water for bermudagrass cultivation. However, few studies investigated the effects of irrigation with TSE on: (i) N addition to the soil; (ii) dry mass production by the crop; (iii) N leaf concentration; (iv) changes to these variables at different seasons of the year and (v) benefit–cost (BC) ratio of irrigation systems. Although N economy, other costs, such as those involved in the irrigation system, superior-quality harvest and final quality of the harvested grass must be taken into consideration for the BC ratio. These items may vary with TSE irrigation associated with N mineral fertilizer. The BC analysis determines which studied investment project (agricultural system) must be selected, based on the greater investment return (Mishan, 1988).

This work aimed at evaluating: (i) the effects of different management practices using irrigation with TSE associated with N fertilization on the production of bermudagrass and the quality of the hay produced and (ii) the economical feasibility of the use of TSE on the cultivation of bermudagrass.

2. Materials and methods

2.1. Study area

The field for researches on agricultural reuse was installed at Lins, São Paulo, Brazil (21°40′43″S, 49°44′23″W, 437 m a.s.l.), in an area adjoining the municipal sewage treatment station operated by the sanitation company of the state of São Paulo, SABESP (Companhia de Saneamento Básico do Estado de São Paulo).

The soil in the area is a sandy clay loam, classified as Typic Haplustult (Soil Survey Staff, 1999) according to the physico-chemical characteristics described by Fonseca et al. (2007).

2.2. Crop and experimental design

The grass selected for cultivation was Tifton 85 bermudagrass (*Cynodon dactylon* Pers. × *Cynodon nlemfuensis* Vanderyst), due to its tolerance to salinity (Maas, 1985) and its economic added value. The experimental design consisted of completely randomized blocks with six treatments and four replicates. The plots were 10 m wide, 10 m long and had a 10-m border. The treatments employed were: (1) SI – no irrigation and no fertilization; (2) A100 (control) – irrigation with PW plus 520 kg N ha^{-1} $year^{-1}$ provided as NH_4NO_3; (3) E0, (4) E33, (5) E66, and (5) E100: irrigation with TSE plus 0, 172, 343 and 520 kg N ha^{-1} $year^{-1}$ as NH_4NO_3 respectively. Fertilizations were divided into six applications along the year, and the 520 kg N ha^{-1} $year^{-1}$ dose was the standard mineral fertilization amount (Werner et al., 1996).

To simulate harvesting for haymaking, the bermudagrass was removed every two months at a height of 3 cm from the soil. After felling, all plots except that of the SI treatment received different doses of N and the same amounts of K (415 kg K_2O ha^{-1} $year^{-1}$) applied every two months (Alvim et al., 1999) and simple superphosphate (140 kg P_2O_5 ha^{-1} $year^{-1}$) applied every six months (Werner et al., 1996).

2.3. Irrigation system and climate data

The conventional irrigation system was employed using sprinklers (NAAN model 5024) with 3.0 bar pressure and 0.63 m^3 h^{-1} flow installed at 90 cm distance from the soil surface at the center of each plot. Porous cup tensiometers were placed in 0–20, 20–40 and 40–60 cm soil layers. The tensiometers were read every 2 days, and the irrigation system was activated if the average tensiometer readings were under the critical soil tension for the crop (−34 kPa). Rainfall data were collected using a rain gauge installed locally. Accumulated rainfall was determined for each drought (April–September) and rainfall (October–March) season for the period between 2004 and 2007. The evaluated seasons were named drought-04, rainfall-05, drought-05, rainfall-06, drought-06 and rainfall-07, which represented 338, 1000, 182, 1026, 151 and 1472 mm of accumulated rainfall respectively. Rainfall variations during these periods, as well as maximum and minimum temperatures are detailed in Fig. 1.

2.4. Characteristics of the potable water and the treated sewage

Treated sewage effluent and PW samples were collected monthly at the irrigation emitters, preserved and prepared according to international standards (Eaton et al., 1995) and the adaptations described below (Table 1).

Electrical conductivity (EC) and pH of the TSE and PW were determined using a pH/conductivity meter (Model 220, Denver Instrument Inc., Denver, USA). For other analyses, sub-samples of TSE and PW were separated and analyzed in three groups: (i) for dissolved organic carbon (DOC), an aliquot of each sample was filtered through a GF/F glass fiber filter (Whatman™ – 0.45 μm) and preserved with $HgCl_2$ at 5 °C. Dissolved organic carbon was analyzed by high-temperature catalytic combustion (Shimadzu TOC-500-A, Kyoto, Japan). The GF/F glass fiber filters containing particulate material were dried in a stove at 55–60 °C for 48 h and weighed again. Part of the particulate material was stored in tin capsules for posterior total particulate nitrogen (TPN) analysis using an element analyzer (Carlo Erba, model EA 1110). Thus, the N element composition (%) was determined as follows: (ii) for the analysis of macro-/micro-nutrients and heavy metals, an aliquot of samples was filtered through an acetate cellulose membrane filter (Millipote™ – 0.22 μm) and the filtrate was analyzed for the concentrations of Ca, Mg, Na, B, Cu, Fe, Mn, Ni, Zn, Al, Cd, Cr by inductively coupled plasma optical emission spectrometry (ICP-OES); and (iii) for the measurement of dissolved inorganic carbon (DIC), Cl^-, NO_3^- and NH_4^+, an aliquot of the samples was filtered through an acetate cellulose membrane filter (0.22 μm) and preserved with thymol (2-isopropyl-5-methylphenol) at 5 °C prior to analysis. Dissolved inorganic carbon was determined by high-temperature catalytic combustion. The concentrations of Cl^-, NO_3^- and NH_4^+ were analyzed by spectrophotometry (FIAstar model 5000 – FOSS – Höganäs, Sweden).