Industrial Crops and Products 68 (2015) 17–23

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Wastewater reuse for fiber crops cultivation as a strategy to mitigate desertification

Bruno Barbosa[a], Jorge Costa[a], Ana Luisa Fernando[a,*], Eleni G. Papazoglou[b]

[a] UBIA, Departamento de Ciências e Tecnologia da Biomassa, Faculdade de Ciências e Tecnologia, FCT, Universidade Nova de Lisboa, Campus de Caparica, 2829-516 Caparica, Portugal
[b] Agricultural University of Athens, Laboratory of Systematic Botany, Department of Crop Science, 75 Iera Odos, 11855, Athens, Greece

ARTICLE INFO

Article history:
Received 3 April 2014
Received in revised form 29 June 2014
Accepted 2 July 2014
Available online 19 July 2014

Keywords:
Fiber crops
Wastewater reuse
Water resources
Desertification
Biodiversity loss
Soil conservation
Sustainable management
Sustainable irrigation

ABSTRACT

Combating desertification, a marked problem in arid, semi-arid and other desertification-affected areas of the world, encompasses the management of water resources and the conservation of soil properties. Establishing vegetation on land and reuse of wastewaters in irrigation may be advantageous as a strategy to mitigate desertification and biodiversity loss. In this context, fiber crop production under wastewater irrigation is reviewed, with the aim of identifying prospects and limitations. Reports of laboratory, pilot and field research indicate that bast and grass fiber crops show potential simultaneously to deliver high yields, restore soil properties and promote water quality improvement. Their production in water-scarce regions could provide environmental benefits and social and economic opportunities, safeguarding freshwater resources. Nevertheless, this practice has environmental and social concerns due to the presence of harmful substances in wastewater. Several technical and economic barriers should also be considered when designing and managing a system, such as wastewater quality, and the quantity and quality of biomass produced. In order to promote the sustainable reuse of wastewater for irrigation of fiber crops, further research is needed, factoring in issues such as yields, inputs and costs, as well as potential environmental and socio-economic impacts. It is recommended that site-specific factors should be accurately assessed to evaluate the adequacy among crop, location and wastewater irrigation, in order to overcome negative impacts and public rejection.

1. Introduction

Desertification is the process that leads to the loss of ecosystem services in arid, semi-arid and dry sub humid areas caused by climatic variation and by anthropogenic activities, affecting one-quarter of the world's land surface, containing one-fifth of the world's population (UNCCD, 1994). This process involves the loss of biological or economic productivity and biodiversity, and has political and socio-economic implications (Barbero-Sierra et al., 2013; Yang et al., 2005). The rapid spread of desertification is mainly due to non-sustainable anthropogenic activities, such as overcultivation and overgrazing, fuel gathering, deforestation and ineffective irrigation and land management practices. In areas suffering from desertification, the main environmental consequences are a permanent imbalance in water availability, damage to soil, increased flash flooding, loss of riparian ecosystems, changes in vegetation pattern and structure, and deterioration of the ecosystem's carrying capacity (Millennium Ecosystem Assessment, 2005; Pereira et al., 2002; Li et al., 2006).

More specifically, regions disturbed by desertification are characterized by an imbalance between water needs and water reserves, resulting in the frequent reuse of non-conventional waters. Wastewater is any water that has been adversely affected in quality by anthropogenic influence, and it has been used as a source of irrigation water for centuries. Irrigation with treated wastewater in agriculture combines several advantages, such as: offering a low cost water source, eliminating part of the demand for synthetic fertilizers by its fertilizing properties (fertirrigation), increasing the available agricultural water resources and eliminating the need for expensive tertiary treatment (Angelakis et al., 1999). Nevertheless, its utilization may involve many risks and in some cases public acceptance is difficult. Wastewater quality should satisfy agronomic and public health protection requisites and should not be a vehicle for harmful substances, especially if these substances exacerbate desertification. According to Monte and Albuquerque (2010), salinity and dissolved inorganic salts, suspended solids, biodegradable organic matter, refractory organic

* Corresponding author. Tel.: +351 212948543; fax: +351 212948543.
E-mail addresses: ala@fct.unl.pt (A.L. Fernando), elpapazo@aua.gr (E.G. Papazoglou).

http://dx.doi.org/10.1016/j.indcrop.2014.07.007
0926-6690/

compounds, heavy metals, nutrients, pH, residual chlorine and pathogenic microorganisms, are the most important characteristics of wastewaters to be controlled since they are associated with most of the water quality problems derived from its reuse in agriculture.

One of the options to mitigate desertification is the introduction of alternative livelihoods that may have less negative impacts on dryland resources, or the creation of economic opportunities in these lands by introducing a vegetative cover that might restore soil properties and increase biodiversity (Chiaramonti et al., 2000; Cortina et al., 2011; Hooke and Sandercock, 2012; Millennium Ecosystem Assessment, 2005; Mohammad and Adam, 2010; Qadir et al., 2007).

The demand for natural fibers has increased sharply due to their diverse uses and industrial applications, such as textiles, papers, woven clothes, mats, hats, ropes and cordage material, as well as in composite applications for the automotive and construction industries (Akil et al., 2011; Ardente et al., 2008; Faruk et al., 2012; Pandey and Gupta, 2003). Even though production of fiber crops sustains employment and income in many regions, the intensive use of land may lead to soil nutrient and water depletion, as well as to degradation and pollution. These impacts are very important, especially in water-scarce regions, where the competition for land and water among agriculture, industry and urbanization are leading to environmental desertification (Barbero-Sierra et al., 2013; Portnov and Safriel, 2004). Therefore, fiber crop production in desertified areas should be established in a sustainable multiple-crop rotation system.

Additionally, water and land resources must be included in an integrated management strategy in order to ensure food and water security, as well as biological and landscape diversity. In this context, the use of non-conventional water, such as domestic and agro-industry wastewaters, in the irrigation of fiber crops could reduce the cost of their cultivation, meet their growing water demands, preserve freshwater supplies and reduce the contamination of water bodies (Cirelli et al., 2012; Norton-Brandão et al., 2013; Qadir et al., 2007; Zema et al., 2012). In order to be sustainable and to conserve, mitigate or reverse desertification, the established species should display low water and nutrient demands, present commercial value for a specific region, have few environmental constraints, no competition with food crops, and be integrated with waste management (Laraus, 2004; Kassam et al., 2012; Norton-Brandão et al., 2013).

This article reviews the potential of fiber crops to mitigate, control and reverse the desertification process in susceptible areas through re-utilization of non-conventional sources of water. In the discussion, benefits and constraints of wastewater reuse in the irrigation of fiber crops are highlighted and prospects and recommendations are presented.

2. Production of fiber crops irrigated with wastewaters: case studies

There has been a growing interest in crops from which natural fibers are taken, resulting in a growing market for biodegradable and recyclable materials. In order for their cultivation to be sustainable and economically viable, suitable fiber crops with low input requirements should be selected.

Crops such as jute, hemp, kenaf and sisal are cultivated mainly for their fiber content, while from other plants, such as pineapple, palm and coir, fibers are produced as by-products (Faruk et al., 2012). There are different types of natural fibers: (a) bast fibers made from the phloem of plants such as jute, flax, hemp, ramie and kenaf; (b) leaf fibers such as from abaca, sisal and pineapple; (c) fibers from seeds of plants, such as coir, cotton and kapok; (d) core fibers such as from kenaf, hemp and jute; (e) grass and reed fibers, such as from wheat, corn and rice, and (f) all other wood and roots crops (Faruk et al., 2012).

In this work, the production of bast and grass fiber crops when irrigated with wastewater is reviewed.

2.1. Wastewater reuse on bast fiber crops

Bast fiber crops are generally annual crops and when cultivated in marginal, desertified and degraded lands can enhance soil fertility and structure, increase soil organic matter content, help in controlling erosion and increase biological and landscape diversity (Fazio and Monti, 2011; Fernando et al., 2010; Finnan and Styles, 2013; Zegada-Lizarazu and Monti, 2011). Generally, they have low establishment cost and can be cultivated under rotation systems with other food or economically valuable non-food crops. Their insertion into a crop rotation can improve yield and profitability over time, control diseases and weeds, limit insect and other pest infestations, provide an alternative source of nitrogen and increase soil organic matter, reduce soil erosion and runoff of nutrients and chemicals, and the potential for contamination of surface water. An additional benefit is gained if the selected crop is simultaneously a source of biomass for both fiber and bioenergy.

The effects of wastewater reuse on kenaf (*Hibiscus cannabinus* L.), hemp (*Cannabis sativa* L.) and nettle (*Urtica dioica* L.) have been reported (*e.g.*, Adler et al., 2008; Fernando et al., 2011; Sinha et al., 2006). These works focus mainly on the capacity of these crops to remove contaminants from wastewaters, with information on growth and yield responses. Especially in water-scarce regions, the potential to reuse wastewaters in the irrigation of bast fiber crops seems promising and will contribute to preserving freshwater supplies.

The growth responses and the biomass quality and productivity of kenaf irrigated with wastewater with different ammonium, nitrate and phosphate concentrations were studied (Fernando et al., 2011, 2012, 2013). The results showed that irrigation with wastewater enriched with nitrates (up to 100 mg dm^{-3} NO_3) or phosphates (up to 2.4 mg dm^{-3} P) did not affect the growth and productivity of kenaf (with an average yield of *ca.* 700 g m^{-2} (dry weight) for the aerial tissues). Wastewater with increased levels of ammonium up to 30 mg dm^{-3} NH_4^+, did not affect the biomass productivity either. In contrast, application of a higher amount of ammonium ion, 60 mg dm^{-3} NH_4^+, negatively affected plant biomass productivity. The bulk supply of ammonium ion and its concomitant absorption by the plants may lead to acidification of the rhizosphere, affecting the availability of other nutrients, and the enzymes of the cytosol. Concerning the biomass quality, irrigation with wastewater correlated with an increased uptake of minerals, nitrogen and phosphorus by the crop, a fact that may penalize its use for combustion purposes but not for biomaterials, since the total fiber content is not affected. These studies also suggested that excess nitrates, phosphates and ammonium ion in wastewater are easily trapped and accumulated by the kenaf root system, avoiding contamination of groundwater resources. These findings are consistent with those of Abe and Ozaki (1998, 2007) and Davison et al. (2006), who also indicated that kenaf is a good candidate plant for nutrient removal from wastewater in constructed wetland systems. However, Abe and Ozaki (2007) stated that low dissolved oxygen affects the rate of nutrient removal by kenaf. Moreover, kenaf is described as opportunistic in relation to water availability, with a high rate of stomatal conductance and transpiration rate when water is not limited, and a markedly reduced stomatal conductance and transpiration rate when water availability is restricted (Fernando, 2013; Patanè and Sortino, 2010; Scordia et al., 2013). This is a relevant trait of this crop to be explored in water-scarce regions when wastewater availability (in terms of volume) is low.