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The effect of long-term wastewater irrigation on accumulation and transfer of heavy metals in *Cupressus sempervirens* leaves and adjacent soils

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HIGHLIGHTS

- We studied the impacts of treated wastewater (TWW) on nutrients concentrations in green and senesced leaves of *Cupressus sempervirens* and soil in three desert plantations
- The species accumulated high amounts of Zn, Mn, Cu and Cd in senesced leaves compared to green
- Transfer factor of Zn and Cu from soil to trees was 2-15 times > that reported for forage crops
- Stoichiometric ratios were decreased under TWW irrigation
- A considerable amount of heavy metals return by senesced leaves to soil

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ABSTRACT

Wastewater reuse for agriculture is an important management strategy in areas with limited freshwater resources, yielding potential economic and environmental benefits. Here the effects of long-term irrigation with wastewater on the nutrient contents of green and senesced leaves of *Cupressus sempervirens* L. were assessed for three planted forests in Egypt. Stoichiometric ratios, transfer factors for nutrients from soil to plant and enrichment factors in contaminated soils were estimated and compared to a ground water irrigated control site. Under wastewater irrigation, *C. sempervirens* transferred most of the estimated nutrients, particularly heavy metals, from green to senesced leaves. This could be a self-protecting mechanism under continuous wastewater irrigation. The accumulation of four metals (Zn, Mn, Cu and Cd) with transfer factors > 1 for wastewater-irrigated trees, indicated the ability for metal accumulation of *C. sempervirens*. Stoichiometric ratios decreased under wastewater irrigation compared to the control site and global trends, which suggests nutrient disorders in these plants. The values of enrichment factors in the wastewater-irrigated soils showed remarkable availability and distribution of metals. Decreased resorption of metals by senesced leaves of *C. sempervirens* will add considerable amount of these metals to the soils, which will likely have adverse affects on the desert ecosystem components.

1. Introduction

In Mediterranean countries, natural water resources are limited, whereas their demand is constantly increasing. Thus, in this region, and other arid and semi-arid regions confronted with increasing water shortages, treated municipal wastewater is a valuable source for recycling and reuse of water, and commonly used in agriculture (Pedrero et al., 2012). Consequently, there is a considerable interest in the long-term effects of treated wastewater on the quality of crops intended for human consumption (Klay et al., 2010; Belaida et al., 2012; Pedrero et al., 2012). Wastewater can provide an important supplementary of some nutrients which have favorable effect on the growth of certain crops. However, it can also cause soil quality modification by structure deterioration and soil pollution by hazardous elements such as metals (Bahri, 1995; Pedrero et al., 2010; Belaida et al., 2012). The rate of metal uptake by plants remains difficult to forecast, since it depends on a great number of factors, including metal speciation in soil and plant species (Belaida et al., 2012). Despite this being a problem that may have direct impacts on consumer's health and the

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environmental quality, the extent of accumulation of nutrients and heavy metals in soils and plants due to wastewater irrigation has not been adequately studied (Pedrero et al., 2010).

The main cultivation purposes of *Cupressus sempervirens* and other woody trees in Egypt are to produce commercial wood for building uses, fire wood, purifying the air by reducing air pollution and to reduce the importation of wood from abroad (MESA, 2009). The wood of this species is valued for its resistance to decay (Farjon, 2013). Environmentally, we found that *C. sempervirens* is a shelter for some understory weed species and some birds (Farahat and Linderholm, 2012; Farahat et al., 2012). By extensive cultivation of the species in Egyptian deserts, the extraction of its essential oils for medicinal and commercial purposes will be economically important.

In Egypt, a few studies have focused on the impacts of wastewater on native understory vegetation in terms of biodiversity, size-structure, biochemical products and mineral content (Farahat and Linderholm, 2012, 2013), and the effects, including growth dynamics and ecological traits, of wastewater irrigation on several tree species (*Eucalyptus camaldulensis*, *Khaya senegalensis*, *Dalbergia sissoo*, *C. sempervirens*, *Casuarina* spp. and *Pinus eldarica*) have been described previously (Farahat, 2011; Farahat and Linderholm, 2011; Tabari et al., 2011). However, relatively little is known about the effect of continuous application of wastewater on mature trees or age series of planted forest tree species (e.g., Pereira et al., 2011), and the impact of long-term wastewater application on the nutrient and heavy metal concentration in green and senesced leaves in mature forest tress has, to our knowledge, not yet been studied. Such studies are important to fill the knowledge gaps related to the potential effects that the wastewater reuse practices might induce on human health and the environment.

The overall goal of this study was to investigate the effect of 15 years application of treated wastewater on the mineral content of green and senesced leaves of *C. sempervirens* in two desert plantations and compare that to trees irrigated by ground water at another site. In addition, the transfer of available heavy metals to the leaves and its enrichment in the soils adjacent to the trees were assessed. Estimation of nutrient contents in senesced and green leaves will enable us to determine the strategy of the species to cope with continuous water and nutrient availability and help in improving our understanding to the removal efficiency of nutrients and heavy metals from wastewater by trees.

2. Material and methods

2.1. Study sites

The present investigation was conducted in three desert forests plantations in Egypt, where two forests, Sadat Forest (30°27′56.11″ N, 30°35′12.58″ E) and Sarapium Forest (30°30′36.79″ N, 32°19′ 28.38″ E) are irrigated by treated wastewater. The third forest (Wadi El-Natrun, 30°28′11.04″ N, 30°11′5.18″ E) is irrigated by ground water and was chosen as a control site (see Fig. 1 for the location of the sites). The treatment of wastewater in Sadat forest is primary, where oxidation pools are used for precipitating the suspended solid particulates and then the lightly treated water is directly used for irrigation. In Sadat forest, wastewater is mixed with variable amounts of industrial water effluents. Treatment of wastewater in Sarapium forest is primary and secondary (MESA, 2009). Drip irrigation is applied in both forests. The understory vegetation was composed of native desert plants and agricultural weeds. Rooting depths of the trees confined to the superficial moist soil below the irrigation pipes, which could be attributed to the application of drip irrigation system (Personal observations) (see Farahat and Linderholm (2012, 2013) for detailed information about these forests and its soil physical analysis).

The study sites are characterized by mild winters and hot summers: the mean temperature of the hottest month is 28 °C (daily average), while total annual precipitation is around 30 mm year^{-1} (Ayyad and Ghabbour, 1986).

2.2. Selected species

C. sempervirens L. (Italian cypress, Family Cupressaceae) is a medium-sized coniferous evergreen tree that can reach heights of up to 35 m. It is native to North America, Africa, southeastern Europe and western Asia. It is cultivated in desert plantations in Egypt as a single overstory species (Farahat and Linderholm, 2012). The average mean density of the species in the study sites ranged from 1213 trees ha^{-1} in Sadat forest to 825 trees ha^{-1} in Sarapium forest with mean ages of 15 years (Farahat and Linderholm, 2011).

Fig. 1. Location map showing the planted forest sites of the present study.