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Comparative Assessment of the Effect of Wastewater Sludge Biochar on Growth, Yield and Metal Bioaccumulation of Cherry Tomato

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ABSTRACT

To investigate the potential effects of wastewater sludge and sludge biochar on growth, yield and metal bioaccumulation of cherry tomato (*Lycopersicon esculentum* L.), a pot experiment was carried out under greenhouse environment with three different treatments, control soil (CP), soil with wastewater sludge (SS) and soil with sludge biochar (SB), to reveal the comparative effect between the amendments of wastewater sludge and sludge biochar. The soil used for pot experiment was Chromosol. Wastewater sludge and sludge biochar produced through pyrolysis process at 550 °C were applied at 10 t ha^{-1}. No significant difference was found in growth and production of cherry tomatoes between wastewater sludge and sludge biochar applications to the soil. The accumulation rates of metals in the fruits were lower in the treatment with sludge biochar than in the treatment with wastewater sludge. The study highlights the benefits of risk mitigation from toxic metal accumulation in fruits using wastewater sludge and sludge biochar as soil conditioners.

Key Words: fruit yield, heavy metals, plant height, risk mitigation, soil conditioner

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INTRODUCTION

The increasing volume of wastewater (sewage) sludge, the by-product of the wastewater processing facilities, generated by the developed and developing countries is one of the prime environmental concerns of the urban society. The safe beneficial use of wastewater sludge is a global target for all nations as the production of total wastewater sludge is expected to substantially increase with projected population growth and increased demand for water use (Pathak *et al.*, 2009).

Approximately 190 000 t of biosolids are produced each year in the Sydney basin alone (Bamforth *et al.*, 2004). Nearly 1 million m^3 year^{-1} of wastewater sludge are produced in UK, 4.2 millions m^3 year^{-1} in Switzerland and 170 000 m^3 year^{-1} in Singapore (Midilli *et al.*, 2001). More than 4 millions t (dry weight) of municipal wastewater sludge are produced annually in China (Dai *et al.*, 2007).

Disposal of wastewater sludge through soil application in agricultural, forest land, disturbed land and dedicated disposal sites is common and thought to be the most competent and cost effective method for managing this waste (Murphy *et al.*, 2000; Ščančar *et al.*, 2000; Walker *et al.*, 2003; Lagae *et al.*, 2009). However, this management method poses potential environmental implications, as the wastewater sludge contains high contents of mineral matter and metals, which might generate potential to impact human health from the bioaccumulation into food chain when distributed in agricultural soils (Kim and Owens, 2009; Li *et al.*, 2012). Previous studies have reported that heavy metals can accumulate in crops cultivated in soil amended with wastewater sludge (Wei and Liu, 2005), which is considered to be the main constraint for the use of wastewater sludge in agricultural land (Castro *et al.*, 2009). Furthermore, the repeated application of wastewater sludge in agricultural soils and subsequent bioaccumulation of heavy metals in food chain may cause metabolic disorders and chronic diseases in humans (Pathak *et al.*, 2009). Reduction of the metal content and the decontamination of wastewater sludge prior to its application in agricultural land is an important step for its sustainable management and reuse. To achieve this, applications of various chemicals have been recommended, *e.g.*, $Fe_2(SO_4)$, $FeCl_3$ (Strasser *et al.*, 1995; Ito *et al.*, 2000) and some chelating agents to extract or lock the metals in the wastewater sludge. But due to the necessity for large volumes of chemicals, high operating costs and operational difficulties, the chemi-

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cal decontamination of the wastewater sludge from metals prior to its use has limitations (Blais *et al.*, 2005). Conversion of wastewater sludge into biochar and then application of the biochar in the soils could prove to be a viable option to manage the sludge and reduce the accumulation of metals in the crop. The beneficial impact of biosolids on growth and productivity of horticultural crop have been studied extensively (Maynard, 1995; Chang *et al.*, 1997; Brown *et al.*, 1998; Perez-Espinoza *et al.*, 1999; Bradford and Peterson 2000). When applied to soils, biochars can improve soil water holding capacity and soil aeration, increase microbial activity, stimulate nutrient dynamics, supress nutrient leaching, decreases plant parasites and sequester carbon in the soils (Lehmann *et al.*, 2003; Lehmann *et al.*, 2006; Zhang *et al.*, 2013). Our research group has also performed extensive research on production of biochar from wastewater sludge (Hossain *et al.*, 2011) and demonstrated the benefits from the use of wastewater sludge biochar for cultivation of cherry tomato (*Lycopersicon esculentum* L.) (Hossain *et al.*, 2010) and biomass crop (Hossain et al., 2015). However, the previous studies have not revealed if conversion of the wastewater sludge to biochar offers any major environmental or production benefits comparing to the direct use of the sludge in cultivation of the same crop. The objectives of this study were to extend the previous findings and compare the environmental and production benefits of cherry tomato when cultivated in soils amended with wastewater sludge and wastewater sludge biochar. The study provides comparative analyses of growth, yield and bioaccumulation of the key heavy metals and trace elements in cherry tomato.

MATEIRIALS AND METHODS

Soil

A composite soil sample was collected down to 10 cm from the flat paddock south of Sydney near Camden, New South Wales (NSW), Australia. The soil used for this study was Chromosol according to the Australian Soil Classification (Isbell, 1996). The agronomic properties of the soil used in this experiment are shown in Table I. The soil was low in total nitrogen, ammonium nitrogen and phosphorus and acidic in nature, thus having poor agricultural potential.

Wastewater sludge

The digested wastewater sludge sample was collected from an urban wastewater treatment plant which processes wastewater from primarily industrial surrounding activities. The agronomic properties of the wastewater sludge used in this study are shown in Table I. The wastewater sludge sample was found to be high in NH_4^+-N, low in NO_3^--N and acidic in nature.

TABLE I

General agronomic properties of soil, wastewater sludge and its biochar used in pot experiment

Parameter	Soil	Wastewater sludge	Sludge biochar
Electrical conductivity (dS m^{-1})	0.1	11.9	1.9
pH ($CaCl_2$)	4.6	4.4	8.2
Total N (g kg^{-1})	1	33	23
P (Colwell) (mg kg^{-1})	15	748	1 100
NH_4^+-N (KCl extract) (mg kg^{-1})	4	7 275	11
NO_3^--N (KCl extract) (mg kg^{-1})	4.9	35.0	0.5

Biochar preparation

The biochar for this study was produced from the wastewater sludge through the process of pyrolysis. The wastewater sludge sample was first air dried and then pyrolysed using a fixed bed reactor set at a heating rate of 10 °C min^{-1} and heated up to the maximum temperature of 550 °C. Nitrogen gas was flown through the sample at a rate of 100 mL min^{-1} to ensure inert heating conditions. The agronomic properties of the pyrolysed wastewater sludge biochar used in this experiment are shown in Table I. The biochar was found to be alkaline, high in phosphorus, but low in nitrogen.

Pot experiment

A pot experiment was carried out using cherry tomato as a test plant species to compare the growth and bioaccumulation of metals from soil amended with wastewater sludge and sludge biochar. The pot experiment was conducted in temperature-controlled (20–26 °C) glasshouse environment. Cylindrical plastic pots, 19 cm in height, 15 cm in diameter at the bottom and 20 cm in diameter at the top were used for the pot trial. The experimental design was a factorial randomised block design with 3 treatments: i) control soil (CP), ii) soil with sludge biochar (SB), and iii) soil with wastewater sludge (SS). Each treatment was carried out with six replicates. In each pot, 6 kg of air-dried soil were packed and the rates of applied wastewater sludge and sludge biochar were equivalent to 10 t ha^{-1}. The pots were wetted up to the field capacity using de-ionised water. Five seeds of tomato were sown in each pot and after 12 d the germinated seedlings were thinned and the healthiest plant from each pot were retained. Plants were irrigated with de-