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Review

Fate of antibiotics in soil and their uptake by edible crops

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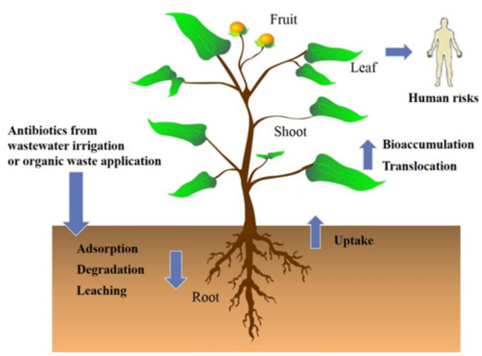
HIGHLIGHT

- We provide an in-depth and up-to-date overview of the fate of antibiotics in soil and their uptake by edible crops.
- We review the occurrence, usage, persistence processes, uptake mechanisms and potential human exposure of different antibiotics.
- Knowledge gaps and future research perspectives are proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

Antibiotics are bioactive substances, and their use as human and animal medicines for illness prevention, disease treatment and growth promotion has increased in recent decades. They are excreted, either unchanged or metabolized, and are discharged to the environment through animal manure, municipal wastewater or biosolids. Consequently, these chemicals reach cropland, which is advocated as a means of recycling. As these drugs are used in escalating quantities, there is growing concern over their presence, toxicity and fate in the soil, which may pose adverse effects on plant growth and productivity, as well as result in their uptake and accumulation in crops. These will contaminate the food chain and eventually affect human health. In this review, we summarize recent research and provide a detailed overview of antibiotics in soil–plant systems, including 1) the occurrence and determination of antibiotics around the world and their routes of entry to the environment, 2) the impact of wastewater irrigation and animal manure or biosolids amendment on agricultural soils, 3) the transport and persistence of antibiotics in the terrestrial environment, and 4) the bioaccumulation and translocation of antibiotics in different tissues of edible crops under laboratory and field conditions. Their impacts on the environment and potential human exposure are elucidated. Knowledge gaps and future research perspectives are discussed.

Contents

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1. Introduction

Environmental research on the bioaccumulation and environmental risks of pharmaceutical residues, such as antibiotics and personal care products (PPCPs), in soil-plant systems has been given special attention in recent years (Hurtado et al., 2016; Prosser and Sibley, 2015; Wu et al., 2015). Antibiotics are widely used in human medicine as well as in animal and fish farming for illness prevention, disease treatment and growth promotion (USEPA, 2012). They are considered to be pseudopersistent given their continuous input into the environment (Sarmah et al., 2006; Van Boeckel et al., 2015). Routes for antibiotics to enter agroecosystems include wastewater irrigation and soil application with animal manures or biosolids (Daghrir and Drogui, 2013). Wastewater is commonly used to irrigate agricultural land in arid and semi-arid regions because of water shortages resulting from climate change, urbanization, regional drought, and pollution (IPCC, 2009; WWAP, 2012). Animal manures and biosolids are also frequently used as fertilizers in arable land. The use of wastewater, animal manures and biosolids presents multiple economic and environmental benefits. However, their broad agricultural application faces a new challenge, because conventional wastewater treatment processes are unable to remove most of the wastewater-derived organic contaminants (e.g., antibiotics) effectively. Studies over the last two decades have shown that many antibiotics are present in wastewater, animal manure and biosolids, which are mostly biologically active and hence create potential risks to the environment (Chen et al., 2011; Papadopoulos et al., 2009; Yan et al., 2013).

Antibiotics are frequently detected in different environmental matrices, with concentrations between ng/L to low mg/L in wastewater (Awad et al., 2014; Watkinson et al., 2009), ng/g to mg/g (dry weight, dw) in animal manure (Hu et al., 2010; Li et al., 2015), ng/g to low μg/g dw in soil (Li et al., 2015; Li et al., 2011; Pan et al., 2014) and ng/g dw in plant tissues (Hu et al., 2010; Pan et al., 2014; Wu et al., 2013). Antibiotic residues have different persistence and transportation modalities and values in agricultural soil, including sorption, degradation and leaching. For example, the soil adsorption coefficient (K_d) of tetracycline ranged from 400 to 1147 (1/kg) in clay loam, while chlortetracycline had the highest adsorption ability in clay loam with a K_d from 1280 to 2386 (1/kg) (Gupta et al., 2003; Pan and Chu, 2015; Wu et al., 2014). As a result, they have a longer degradation time in soil or manure, ranging from 9 to 180 days (De Liguoro et al., 2003; Kay et al., 2004; Pan and Chu, 2015). Therefore, when wastewater, animal manure or biosolids are used in the soil-plant system, antibiotics possibly accumulate in irrigated soil and can be taken up by crops. The majority of antibiotics present in soil are polar compounds with ionizable functional groups, and root uptake is expected to be an important route of exposure for plants when they are grown in antibiotic-contaminated soil. Previous studies have indicated that antibiotics and other pharmaceuticals can accumulate in different plant tissues (Prosser and Sibley, 2015; Wu et al., 2014; Wu et al., 2015), while the effects of environmental antibiotics on terrestrial ecosystems and human health are still unclear. The understanding of the mechanisms of antibiotic uptake by plants and the phytotoxicity of antibiotics remains rather limited. Some studies have reported that antibiotics have a biphasic effect on plant growth characterized by hormesis with a low-dose stimulation and a high-dose inhibition (Li, 2006; Pan and Chu, 2016). Plant uptake of antibiotics and other PPCPs has received increasing attention over the last decade, but differences in experimental design and analytical methods hinder comparisons among studies.

In this review, we provide an in-depth and up-to-date overview of the fate of antibiotics in the soil-plant system and their uptake by edible crops, including their occurrence and entry to the soil environment, processes and persistence in soil, bioaccumulation and transport of antibiotics from soil to plants in laboratory and field experiments, as well as mechanisms regulating their uptake by and translocation in plants. The potential human exposure by consuming crops grown with wastewater, animal manure or biosolids contaminated with antibiotics is also discussed, as well as their corresponding environmental risks.

2. Occurrence and usage of antibiotics

Five classes of antibiotics, including tetracycline, sulfonamides, quinolones (fluoroquinolones), macrolides and 'others' (5 antibiotics in the 'others' category: trimethoprim, thiamphenicol, chloramphenicol, lincomycin and clindamycin), were included. They are frequently used for veterinary and human therapy and in the agricultural sector as feed additive around the world, have been detected in different environmental matrices, and have different physicochemical properties (Jiang et al., 2014; Sarmah et al., 2006; Zhou et al., 2011).

Van Boeckel et al. (2014) used sales data for retail and hospital pharmacies from the IMS Health MIDAS database for seventy-one countries from 2000 to 2010 to estimate global antibiotic use in low-income and middle-income countries (Fig. 1). During this period, the total global antibiotic consumption increased from approximately 54 billion to 74 billion standard units, an increase of approximately 36%. Penicillins and cephalosporins were the most-used antibiotic classes in 2010; they accounted for nearly 60% of total consumption and increased by 41% from 2000. Among the antibiotic classes in the market, some of the oldest and most popular antibiotics are still the most popular first-line treatments for common infections around the world, e.g., penicillins, cephalosporins, macrolides, quinolones and tetracyclines (Gelband et al., 2015; Van Boeckel et al., 2014). Moreover, tetracyclines ranked second among antibiotics in production and usage worldwide in 2013, and is the most produced and frequently used class of antibiotics in China (Cheng, 2005; Xie et al., 2010). The usage of tetracyclines accounts for approximately 90% of the total antibiotics used in the UK and >50% in Korea (Kim et al., 2011). In 2013, the total amount of sulfonamides, quinolones, macrolides and 'other' antibiotics used in