Emerging Contaminants xxx (2018) 1–6

Contents lists available at ScienceDirect

Emerging Contaminants

journal homepage: http://www.keaipublishing.com/en/journals/emerging-contaminants/

Translocation of pharmaceuticals and personal care products (PPCPs) into plant tissues: A review

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ARTICLE INFO

Article history:
Received 25 September 2017
Received in revised form
6 February 2018
Accepted 8 February 2018
Available online xxx

Keywords:
PPCPs
Root uptake
Translocation
Human exposure
Analytical methods

ABSTRACT

Occurrence and fate of pharmaceuticals and personal care products (PPCPs) in the environment and the potential consequences for human health is of serious concern. In the current review, we have tried to provide a summary on recent research and an overview of PPCPs in the soil-plant systems, in the environment and analytical methods used for determination of PPCPs in plant tissues. Further review also include highlights on the fate of PPCPs in agricultural soils receiving treated wastewater irrigation or biosolids amendment, and plant uptake of PPCPs under laboratory and field conditions. PPCPs have shown to be released to the environment and may cause significant impacts on different environmental aspects. Plant roots showed their abilities to uptake and transfer of PPCPs into plant tissues. The uptake of PPCPs varies depending on crop type and physiochemical properties of the chemical compound that were exposed. Consumption of contaminated crops with PPCPs residues may cause serious health problems. Liquid chromatography in combination with mass chromatography was found to be the most popular analytical instrument used for PPCPs determination in different samples. Finally, the information gaps and few suggestions for future research have been proposed in this review.

1. Introduction

Using treated wastewater (TWW) to irrigate crops is already widespread in different regions particularly where freshwater is limited and this practice contributed to reduce the stress on freshwater resources. However, concerns remain about the safety of irrigation with TWW. Treated wastewater may contain concentrations of different contaminates such as salts, pathogens, heavy metals and emerging pollutants [1]. Conventional wastewater treatment systems are only moderately effective at removing many organic contaminants, including pharmaceuticals and personal care product ingredients (PPCPs) [2,3]. Pharmaceuticals are chemical compounds commonly used in disease's treatment, cure, prevention or diagnosis. Many of them are designed to be non-bioaccumulative and eliminated from humans and animals bodies in the short time after consumption. Several hundred tons of pharmaceuticals are produced and consumed annually around the world. The production and consumption of pharmaceutical is increasing continuously due to the increase in population, manufacturing and discovery of new drugs as well as chemicals [4]. Up to 200,000 tons of antibiotics are consumed yearly, about 90% of that antibiotics are excreted from the bodies as active substances [5]. Several hundred types of pharmaceuticals are used in human and animal medications as well as for aquaculture creatures and in agriculture [5].

As highlighted by many studies in the literature, pharmaceuticals and personal care products (PPCPs) are commonly found in biosolids and effluents from wastewater treatment plants. Land application of these biosolids and the reclamation of treated wastewater can transfer those PPCPs into the terrestrial and aquatic environments, giving rise to potential accumulation in plants. Therefore, this review will provide a summary of recent research and an overview of PPCPs in the soil-plant systems, including analytical methods for determination of PPCPs in plant tissues and plant uptake of PPCPs under laboratory and field conditions.

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Peer review under responsibility of KeAi Communications Co., Ltd.

https://doi.org/10.1016/j.emcon.2018.02.001

1.1. Sources and occurrence of pharmaceuticals in the environment

There are several sources of pharmaceuticals in the environment such as human, animals, agriculture, aquaculture and pharmaceutical manufacturing. Human and animals are the main producers of pharmaceutical residues in the environment because they are the most consumers. Poultry and meat processing can also increase the concentration of pharmaceuticals in wastewater and surface water. Moreover, pharmaceuticals are used to control the bacterial diseases of plants through injection or soil drenching. Soil amendments and fertilizers of contaminated animal manure and biosolids also contributed to transfer the pharmaceuticals to the water cycle through drifting, surface runoff after raining and irrigation and leaching of residues deep into the soil layers [4,6]. Pharmaceuticals are used in fish farming and for ornamental fish which may release the pharmaceuticals in the environment [7].

The different sources of pharmaceuticals are contributing through different routes to pharmaceuticals occurrence in the environment. There are different points where human release these compounds including hospital effluent, wastewater treatment plants, septic tanks and landfills [8]. Moreover, they dispose the expired and unused pharmaceuticals directly and improperly in to the toilets or in the landfills [7]. There are other practices including leakage from treatment plants and accident spill of the pharmaceutical residues during manufacturing [7,8] contribute to their occurrence in the environment. The occurrence of certain compounds in the environment and treated wastewater is related to their chemical properties [7] and their behaviour during water treatment process [6]. Furthermore, the dosage and frequency of exposure, the metabolism and environmental stability and the removal efficiency during treatment process of pharmaceuticals are other factors of the occurrence [5].

1.2. Environmental effects of pharmaceuticals

Pharmaceuticals have several significant ecological effects on different environmental aspects including aquacultural creatures, developing of antibiotics emergence resistance and they may transfer to human through food chain. They can influence organism's behaviour [9]. They alter the hormones function and disrupted the endocrine system [10]. Survival or reproduction system of fish can be affected if the exposure to the pharmaceuticals for long time [8]. The growth of some algae was inhibited even at low concentrations (less than 0.1 mg/L) of antibiotics which lead to decrease in the algae population and affected the aquatic system balance as algae are an important component of food chain [11]. Any accumulation of pharmaceuticals from biosolids or treated wastewater in the soil may promote plants to uptake those compounds [12]. Significant health problems may effect human if they are exposed for high dosage of pharmaceuticals that are accumulated in vegetables and fruits.

PPCPs have been detected in wastewater effluents, biosolids, biosolids-amended soils, runoff from effluent-irrigated fields, and surface and groundwater systems that are receive treated wastewater [3,13–18]. Moreover, plants have the potentiality of uptake and accumulation of PPCPs in their tissues as was shown by several studies [4,12,19–22]. Unfortunately, lack of knowledge and misunderstanding of pharmaceuticals usage and disposal ways are of a serious environmental concern.

Recently, pharmaceutical pollutants are of environmental concerns and they are increasing with regard to the occurrences and fate. The acceptable daily intake values of pharmaceuticals considered as the important route of exposure and their effects. It is very important to avoid exposure to pharmaceuticals through number of routes at once in values higher than the acceptable daily intake [23]. The continuous disposal of pharmaceuticals into the environment through different pathways can cause serious health problems and affect plants and aquatic organisms even at lower concentrations. Therefore, it is important to increase the knowledge about pharmaceuticals and their related issues in the environment. Reviewing the sources of pharmaceuticals in the environment, occurrence, effects on organisms and their transformation in plants is very important. Through plants some of pharmaceuticals can enter in to food chain.

2. Transformation of PPCPs from planting media in to plant tissues

In a soil-plant system, the fate, behaviour and accumulation of PPCPs in plants may be affected due to the chemical physical and biological processes in the growing system. It must be noted that the plant accumulation of these PPCPs is greater in use of hydroponic cultivation in relation to soil cultivation, due to the absence of chemical process and sorption to soil organic matter and minerals [24]. Moreover, the physicochemical properties (e.g., ionization, water solubility, hydrophobicity, octanol–water partition coefficient) of PPCPs may also have significant effects on the uptake and translocation of PPCPs in plants [25–29]. Analyses of biosolids and soil samples amended with contaminated animal manures or biosoilds in different studies indicated that, for the selected compounds, measurable residues of these compounds were occurred for at least some months following the application of the contaminated manure containing [11,30]. There are different processes resulted in elimination of organic compounds in the environment. Different factors or processes limiting the uptake of PPCPs by plant, PPCPs may be adsorbed to soil or degraded microbial in the root zone depending on the soil and chemical properties [31].

Elimination of organic compounds in soil is affected by plant uptake of PPCPs through root. These processes can be biotic, i.e. photodegradation (Photolysis) and biodegradation by bacteria and fungi or non-biotic, i.e. sorption, hydrolysis, photolysis, oxidation and reduction. Some of these processes occur in soil or surface water and some of them in treatment plants. Sorption, photodegradation and biodegradation are the most important processes occur in soil matrix. Sorption is the reversible sorptive exchange of compounds between the water phase and a solid-phase sorbent which can be soil or sediment [32]. This process can occur in soil or treatment plants where sediments particles are present. In soil, organic compounds are bound to particles or formed synthesis which may cause a lack in antibiotics activity and then lack in their detection [11].

Humus materials in soil may alter the surface properties and availability of sites for sorption. Higher organic content resulted in increased nonlinearity of sorption behaviour [33]. Studies reported that the presence of humus substances in dissolved forms or mineral-bound surfaces is increased the environmental mobility of tetracycline compounds. They can either inhibit or promote sorption of organic compounds to soil [11]. For some organic compounds it was found their elimination by sorption to soil particles is a significant process, for example sulfadiazine and other sulphonamides compounds [11,32,34–36]. Photodegradation is a significant process in elimination of PPCPs if the compound is light sensitive. Photo-decomposition takes place mainly in clear surface water but not in soil. Biodegradation process depend on conditions such as temperature, composition of matrix, latitude etc. [11,37]. Several investigations showed that chemical compounds are extensively applied in fish farming had long half-lives in soil and sediment. While, some substances were degraded partly, i.e., ampicillin, doxycycline, oxytetracycline, and thiamphenicol were significantly degraded, josamycin remained at initial levels and

Please cite this article in press as: R.S. Al-Farsi, et al., Translocation of pharmaceuticals and personal care products (PPCPs) into plant tissues: A review, Emerging Contaminants (2018), https://doi.org/10.1016/j.emcon.2018.02.001