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OCCURRENCE, FATE AND TRANSPORT OF 17 β -ESTRADIOL AND TESTOSTERONE IN THE ENVIRONMENT

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ABSTRACT: Being the most potent endocrine disrupters, 17beta-estradiol and Testosterone have a growing environmental and public health concern. Despite significant quantity of these hormones released into the environment through animal manure and wastewater effluent, their elimination through sorption and rapid degradation was suggested. Nonetheless, these compounds are consistently detected in surface and ground waters, and the recorded concentrations in the environment significantly exceed the reported low observable effect concentration 1 ng/l. It appears that these hormones as well as their metabolites may persist in soil or sediments for several months, and their mobility and behavior in the environment is not well understood. Thus, this study reviews the current knowledge of the occurrence, fate and transport of 17 β -estradiol and testosterone in the environment including their metabolites estrone and androstenedione, respectively. An overview of the current knowledge related to the source and behavior of these compounds in the environment is given. This study suggests that considerable quantities of these compounds may reach ground water as well as surface waters, and therefore a better understanding of the factors and processes that affect the fate and transport of these compounds is of paramount importance.

KEYTERMS: Animal manure; Androstenedione; Endocrine disrupters; Estrone; Hormone; Sorption

INTRODUCTION

The widespread occurrence of steroid hormones in the natural water resources has been reported in both ground water and surface water including streams, rivers, ponds, estuaries, seas and oceans. 17 β -estradiol (E2) and testosterone are naturally produced steroid estrogen and androgen, respectively. These compounds and their metabolites are relatively the most potent endocrine disrupters that may interfere with the normal functioning of the endocrine system at a very low concentration. For example, E2 was reported to reduce sperm fertility very drastically and induce vitellogenin in male trout at concentrations as low as 1 ng L⁻¹ (Lahnsteiner *et al.*, 2006). In general, exposure to E2 and its metabolite estrone (E1) in the environment was linked to feminization of male fish, decreased sperm counts, increased testicular, prostate and breast cancer and male reproductive disorder (Dickson *et al.*, 1986; Harrison *et al.*, 1997), whereas the presence of testosterone and its metabolite androstenedione in the aquatic ecosystem was linked to the masculinization of female mosquito fish (Thomas *et al.*, 2002).

Despite those environmental and public health concerns, the processes and factors that affect the fate and transport of these compounds is not well understood. In laboratory studies, E2 and testosterone were shown to have a strong tendency to be sorbed into the soil or sediment organic matter, and degrade rapidly in soil and water. Subsequently the possibility of leaching into the ground water was indicated to be limited (Lee *et al.*, 2003). Moreover, the persistence of these compounds in soils, ground water and surface water for several months is not consistent with the high sorption and degradation rate constants reported by the laboratory studies. Thus, for better characterization of their potential risk to the environment as well as human health, a better understanding of the factors and processes that affect the fate and transport of these compounds in the environment is imperative.

In this study, the available primary and secondary publications were reviewed and the current knowledge about the fate and transport of E1, E2, testosterone and androstenedione in the environment is summarized. Also, an overview of the potential sources and the recorded environmental concentrations in the environment is given.

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PHYSICOCHEMICAL PROPERTIES

The selected physicochemical properties of E2 and Testosterone together with their selected metabolites are indicated in Table 1, which shows that E1 and E2 are less water-soluble than testosterone and androstenedione. That is consistent with their hydrophobic property except for the androstenedione whose $\log K_{ow}$ is higher than the $\log K_{ow}$ of E1. Testosterone is relatively the least in hydrophobic property. Vapor pressure of androgens is not available, but E2 and E1 have low volatility with very low vapor pressure (2.3×10^{-13} mm Hg) indicating that loss of these compounds through volatilization process is not likely.

Table 1. Selected properties of estrogens and androgens

Hormone	Molecular Weight	Water Solubility at 20°C (mg L ⁻¹)	Vapor pressure (mm Hg)	$\log K_{ow}$
17 β -estradiol	272.4	13 ^a	2.3×10^{-13}	3.94 ^d
Estrone	270.4	13 ^a	2.3×10^{-13}	3.43 ^d
Testosterone	288.4	18-25 ^b	NA	3.32 ^e
Androstenedione	286.4	37-41 ^c	NA	3.69 ^e

^aLai *et al.* (2000); ^bSugaya *et al.* (1997); ^cSuzuki *et al.* (2001); ^dYing *et al.* (2002); ^eTabak *et al.* (1981); NA: Not Available

SOURCE OF CONTAMINANTION

Ground water as well as surface water contamination by steroid hormones can occur several ways, but the main potential sources and path ways are illustrated in Figure 1. The two main sources of contamination include wastewater effluents (Ternes *et al.*, 1999), and runoff from soil amended with sewage sludge or biosolids and animal manure from concentrated animal feeding operations (Finlay-Moore *et al.*, 2000). Both animals and humans excrete significant quantities of E2 and testosterone (Shemesh and Shore, 2004), which may find its way to surface waters or ground water in considerable quantity. Conventional biological wastewater treatment plants may not completely remove all steroid hormones present in the influent, and consequently wastewater effluent may contain significant concentrations of these compounds, which may directly be discharged to the receiving water or used for irrigation. Typical wastewater effluent concentration in the United States ranges from 6.2 to 54.8 ng L⁻¹ for E2, whereas E1, testosterone and androstenedione can reach up to 4 ng L⁻¹, 6.1 ng L⁻¹, and 4.5 ng L⁻¹, respectively (Kolodziej *et al.*, 2003; Jenkins *et al.*, 2001). Typical runoff concentrations of E2 and testosterone from the soil amended with poultry manure range between 20 and 2,530 ng L⁻¹, and 10 and 2,520 ng L⁻¹, respectively depending on manure application rate, the geographical and hydrological system (Lee *et al.*, 2003; Finlay-Moore *et al.*, 2000; Fisher *et al.*, 2005). Overland flow is not the only source of surface water contamination (Figure 1). In addition, steroid hormones that infiltrated into the subsurface and were transported via soil and groundwater to the stream channel may contaminate surface waters (Herman and Mills, 2003).

As abiotic processes such as granulated activated carbon and reverse osmosis can treat wastewater effluent further, manure-born steroid hormones become a growing concern for four main reasons. *First*, they are the most potent endocrine disrupting compounds other than industrial products such as alkylphenol ethoxylates (Jobling and Sumpter, 1993). *Second*, animal farms produce a significant quantity of manure together with these highly potent endocrine disrupters each year. For example, E2 ranges between 14 and 533 ng g⁻¹ with average 44 ng g⁻¹ on the dry weight basis (Shemesh and Shore 1994). *Third*, assuming the bioavailable environmental concentration would be very low due to possible biotic or abiotic transformation, these compounds are not yet regulated as they are not discharged directly into the receiving waters. *Fourth*, they are continuously present in soil and aquatic environments, including soil that is not amended with animal manures. This might be due to their possible persistence in the environment or an external input by wild animals or birds; a few studies indicated the contribution of wild turkey (Finlay-Moore *et al.*, 2000). Persistence of E2 and testosterone in the animal manure

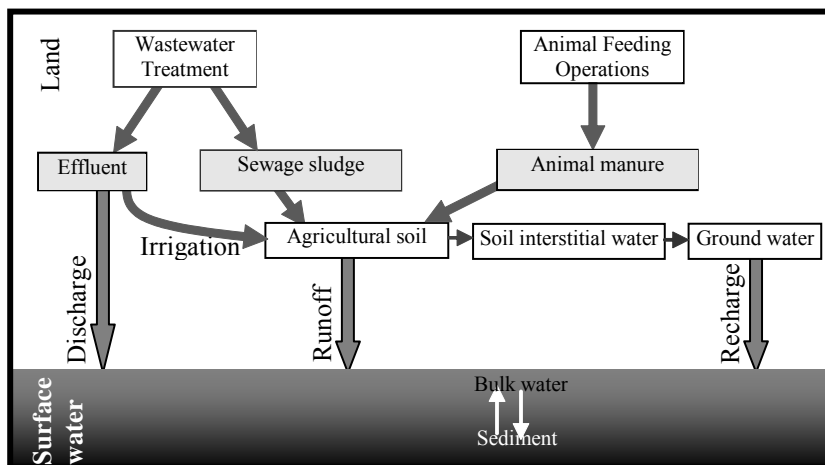


Figure 1. Schematic presentation of main sources of steroid hormones and surface and ground water contamination

for prolonged durations (more than 2 years) was also reported; up to 904 ng g⁻¹ and 670 ng g⁻¹ on the dry weight basis, respectively (Fisher *et al.* 2005). Moreover, the current generally accepted livestock waste management practices are not adequately or effectively protecting our water resources (Burkholder *et al.*, 2006). Consequently, both poultry compost and cattle manure remain the potential sources of steroid hormones, including synthetic estrogens, unless proper alternative actions are taken. This suggests that it requires further studies that focus on the methods used to reduce the concentrations of these hormones in the poultry compost or cattle manures most efficiently.

RECORDED CONCENTRATIONS IN THE ENVIRONMENT

Surface Water

Significant concentration of steroid hormones has been recorded in surface water including streams, rivers, ponds, estuaries and oceans. In the bulk water, typical concentrations of E2 in streams can reach up to 120 ng L⁻¹ in the USA (Herman and Mills, 2003), 27 ng L⁻¹ in Japan (Vermierssen *et al.*, 2005), and 19 ng L⁻¹ in Germany (Vermierssen *et al.*, 2005). Testosterone was also found to reach up to 200 ng L⁻¹ in the US streams (Kolpin *et al.*, 2002), whereas the androstenedione concentration ranged between 20 and 60 ng L⁻¹ in the Feholloway River, which receives paper mill effluent (Jenkins *et al.*, 2001). In addition, E2 concentration in the various surface water in the Chesapeake Bay watershed on the Eastern Shore of Maryland was shown to vary between 1.9 and 6 ng L⁻¹ for rivers, and 2.3 and 3.2 ng L⁻¹ in the costal bay (Dorabawila and Gupta, 2005). Also, Hashimoto *et al.* (2007) reported 9.2 ng L⁻¹ E2 in seawater influenced by wastewater effluent. This indicates that the occurrence of these compounds is known not only in fresh water but also in seawater that is influenced by wastewater effluent (Noppe *et al.*, 2007). It was also shown that a significant quantity of this compound could be transported a considerable distance from the source of pollution (Barel-Cohen *et al.*, 2006).

As these compounds have a strong affinity for the sediment, significant concentration of steroid hormones was also reported in the sediment. The concentration of E1 in the river sediment ranges from below detection limit to 22.8 ng g⁻¹ (Schlenk *et al.*, 2005). The sewage-impacted sediment in urban estuaries and the ocean were also tested for the contamination of estrogens. In the estuary, the concentration of E2 was indicated to range between 0.05 and 2.52 ng g⁻¹ in Jamaica Bay, New York (Schlenk *et al.*, 2005). In the ocean, in sediment 7 km away from a deep ocean sewage outfall, the concentrations of E1 and E2 were indicated to range between 0.16 and 1.17 ng g⁻¹, and 0.22 and 2.48 ng g⁻¹, respectively (Braga *et al.*, 2005). Androstenedione concentration up to 900 ng L⁻¹ was also reported in Jenkins *et al.* (2003). It was found that 17 times more androstenedione was present in the sediment than in the bulk water (Jenkins *et al.*, 2003), which indicates that this hormone has a strong affinity for the sediment.

Ground Waters

Case studies and monitoring results on ground water pertaining to steroid hormones are very limited. According to Peterson *et al.* (2000), up to 66 ng L⁻¹ of E2 was recorded in the ground water aquifer near the land where soil was amended with poultry manure in NW Arkansas, USA. Other available studies showed that the ground water concentration was lower than 1 ng L⁻¹ (Fine *et al.*, 2003). Other potential sources of ground water contamination-including leaching from soil

amended with sewage sludge or animal manures, poorly constructed lagoons, landfill, and composting facilities-should be taken into consideration.

Persistence of steroid hormone in the soil amended with animal manure and poultry compost may determine the contamination of ground waters. If these chemicals are persistent in soil or water in some conditions, any surface land activities may influence the leaching potential of steroids into the ground water. For example, tillage and grass strips may increase percolation (Finlay-Moore *et al.*, 2000); Herman and Mills (2003) reported 86-160 ng L⁻¹ E2 in the interstitial water. When a chemical is able to percolate deep into the subsoil, it may reach the ground water. Thus, understanding of the processes and factors that affect the fate and transport of these hormones in soil, as well as in the receiving water, is of paramount importance.

FATE

Sorption

Sorption of E2 and testosterone to the sediment or soil determines the fate and transport of these compounds in the environment. Sorption to the soil organic matter reduces the soluble form and thereby probably limits the leaching of these compounds to the ground water. Several sorption studies have been done for E1 and E2, but little was done for testosterone and androstenedione. Selected results of sorption studies available in literature are indicated in Table 2. On the basis of the $\log K_{oc}$ values indicated in Table 2, testosterone is more mobile than E2, which is consistent with most batch equilibrium and

Table 2. Typical $\log K_{oc}$

References	$\log K_{oc}$			
	E1	E2	Testosterone	Androstenedione
Hildebrand <i>et al.</i> (2006)	4.64	3.69	NA	NA
Ying and Kookana (2005)	3.34-3.57	3.49-3.71	NA	NA
Yu <i>et al.</i> (2004)	3.3-5.25	3.14-5.38	NA	NA
Lee <i>et al.</i> (2003)	3.18-3.22	3.16-3.52	3.24-3.44	3.67-3.77
Stumpe and Marschner (2006)	NA	3.22-3.75	2.59-2.88	NA
Lai <i>et al.</i> (2000)	3.69	3.5	NA	NA

soil column studies (Stumpe and Marschner, 2006; Lee *et al.*, 2003). Androstenedione is the least mobile among four steroid hormones, including its parent compound. This is consistent with the $\log K_{ow}$, but inconsistent with its water solubility (see Table 1).

While studying the sorption of steroid hormones, six important factors need to be taken into consideration: content of soil organic carbon, type and content of clay mineral, salinity, method of sorption test, initial concentration of the test compound, and understanding of mechanism of interaction. Several studies indicated that sorption of the four hormones under consideration is correlated with the presence of organic carbon and clay content (Casey *et al.*, 2005; Lee *et al.*, 2003; Mansell *et al.*, 2004). The more organic carbon and clay that is present in the soil or sediment, the higher the quantity of these steroid hormones that would be sorbed to the soil or sediment. It should also be noted that the presence of organic carbon is not a prerequisite for sorption of the steroid hormones. For example, iron oxide alone is shown to account for 40% of sorption to organic carbon (Lai *et al.*, 2000), which indicates that the presence of iron oxide and salinity may increase sorption of these compounds.

Application of different methods may result in significantly different results in $\log K_{oc}$. In an undisturbed soil column study, sorption estimates were indicated to be lower than the batch equilibrium as the result of rate-limiting sorption due to the advective transport (Casey *et al.*, 2004). In the batch equilibrium test, which involves an aqueous phase, the sorbed phase is estimated on the basis of mass balance instead of measuring directly (Case *et al.* 2005). Such easy approach may not be reliable in some conditions when one deals with a chemical that can be biotransformed easily. In addition, the method of sterilization of the soil sample for sorption study can also affect the results of the sorption test, e.g., using sodium azide (Mansell *et al.* 2004) instead of autoclaving. According to Hildebrand *et al.* (2006), autoclaving was indicated to be the most effective sterilizer. Consequently, while most studies indicated that testosterone was more mobile than E2, Mansell *et al.* (2004) suggested that testosterone was less mobile than E2. As testosterone is relatively easily degraded, the estimated sorbed phase in Mansell *et al.* might be overestimated, and it might have included biotransformation. Therefore, for an appropriate sorption test, autoclaving and determination of the sorbed phase is essential in order to ensure the mass balance.

In the most of the sorption studies conducted for steroid hormones, higher initial concentrations were applied in order to ensure a concentration range of above the detection limit of the analytical technique under consideration. In application of such a high concentration rather than an environment related concentration, sorption equilibrium was reached within a day.

However, when 20 times lower than their solubility limit (0.1 mg/l) is applied, equilibrium is reached within two weeks (Yu *et al.*, 2004). When 0.4% of their water solubility limit was applied for testosterone and androstenedione, sorption equilibrium was reached within three weeks (Kim *et al.*, 2007). Moreover, Kim *et al.* indicated that under such a low concentration, $\log K_{oc}$ could vary from 6.30 to 6.80 and 6.16 to 6.92 for testosterone and androstenedione, respectively. This is significantly different from the data presented in Table 2, and thus further investigation on the basis of environment relevant concentrations is essential.

In-addition of hydrophobic interaction, considering other possible ways of interaction of steroids and soil particles includes hydrogen bonds, covalent bonds and intercalation (sorption between the kaolinite structure). The polar groups of E2 and testosterone may react with humic acids and mineral surfaces by hydrogen or covalent bonds (Yamamoto *et al.*, 2003). The author indicated that the measured $\log K_{oc}$ was independent of $\log K_{ow}$ for sorption of E2 to humic acids. In the case of intercalation, soils or sediments rich in swelling clay or montmorillonite are effective in sorbing E2 (van Emmerik *et al.*, 2003), minimizing the likelihood of ground water contamination. It indicates that sorption can lead to significant retardation during leaching in soils; however, strong sorption into soil can increase the potential for surface runoff losses and surface water contamination during storm events.

Desorption

Limited studies are available for the desorption study of estrogens, but no data is available for the androgens. On the basis of limited data available in literature, two important factors can be considered as the determining factors for the desorption of these hormones. Firstly is the initial concentration of the compound of concern applied for desorption study. In sandy soil, rapid desorption of E1 and E2 was reported, and the greatest degree of desorption occurred within the lowest initial concentration of $10 \mu\text{g L}^{-1}$ (Hildebrand *et al.*, 2006). At initial concentration of 10 ng L^{-1} , there was > 85 % desorption reported for both E1 and E2. The author also showed that desorption of estrogens was being increased with decreasing initial concentration. This suggests that at environmentally relevant concentration, desorption may be the determining factor for the fate and transport of estrogen in soil or sediments.

Secondly is the type of dominating clay minerals in soil or sediment may play a great roll in determining desorption of steroid hormones in soil. According to van Emmerik *et al.* (2003), E2 was indicated to desorp rapidly (within a few seconds) in the kaolinite and illite. On the other hand, in the swelling clay dominating soil or sediment, lack of desorption from montmorillonite due to intercalation into interlayer regions was reported (van Emmerik *et al.*, 2003). It appears that in soil containing significant quantity of montmorillonite, sorption may limit leaching of E2 into the ground water. Note that at an environmentally relevant concentration and in soil that has no swelling clay, estrogens exhibit rapid sorption and desorption (Hildebrand *et al.*, 2006), and therefore leaching to the ground water is most likely. For a better understanding of the kinetics and mechanisms of desorption for all of the four steroid hormones under consideration, further investigation is required.

Biodegradation

Although natural steroid hormones can be degraded by abiotic processes such as photolysis, the biodegradation process is mainly responsible for the elimination of E2 and testosterone including their metabolites in soils as well as in the receiving water. Laboratory studies have shown that these compounds would degrade rapidly at various conditions of moisture content and temperature (Culucci *et al.*, 2001). Nevertheless, their continuous presence in agricultural soil for several months indicates the potential persistence of these compounds in the environment.

Several factors may affect biodegradation of steroid hormones in environment including temperature, aeration, soil moisture and organic matter content. In well-aerated soil, rapid degradation of E2 and testosterone was reported at temperatures higher than 12°C (Culucci *et al.*, 2001). Under aerobic conditions, the typical available biodegradation rate constants in soil are indicated in Table 3, which shows that testosterone degrades relatively faster than E1 and E2. Soil microcosm study showed that, at soil temperature between 20 and 30, aerobic biodegradation of E2, E1 and testosterone increases with soil moisture; higher at 15% than air dried or moistened to the field capacity (Culucci *et al.*, 2001; Lorenzen *et al.*, 2005). The authors showed that temperature below 12°C , dried soil, and moisten soil to the field capacity could reduce the biodegradation of steroid hormones. Note that soil moistened to field capacity limits oxygen supply to aerobic biodegradation. This suggests that the persistence of steroid hormones is more likely in dried sandy soil, moistened soil at field capacity or saturated soils.

Under anaerobic conditions, biotransformation of both E2 and testosterone is indicated to be limited. In anoxic or anaerobic conditions, E2 was shown to degrade slowly and E1 accumulates (Fan *et al.*, 2007; Jürgens *et al.*, 1999); complete degradation is not likely. This is consistent with the tests conducted under strict anaerobic conditions including sulphate, nitrate and iron reducing, and methanogenic conditions in which E2 degradation was limited (Czajka and Londry, 2006). The author found even slower degradation of E2 under nitrate reducing conditions. Occurrence of a high concentration of

androstenedione in anoxic sediment of the Fenholloway River (Jenkins *et al.*, 2003) could also suggest that this compound can persist in anaerobic or anoxic conditions. If steroid hormones are persistent in anoxic sediment, which is mostly the case for E1 and androstenedione, the sorbed phase may desorb and get released into the overlying water where it can pose a risk to the pelagic fish. This shows that anoxic or anaerobic sediment can be a potential source for steroid hormones.

Moreover, the presence of viable microbial biomass and associated inhibiting factors, including antibiotics in the manure or biosolids, and agricultural practices may affect the biotransformation rate of steroid hormones in the amended soil. According to Shi *et al.* (2004), ammonia-oxidizing bacteria degrade E2 without E1 accumulation, whereas degradation of E2 to E1 is conducted by other heterotrophic bacteria. It indicates that any inhibiting factors that affect the activities of ammonia oxidizers may determine the accumulation of E1. The presence of antibiotics (chlortetracycline) and biosolids application can affect the degradation of testosterone (Chun *et al.*, 2005).

Agricultural practices including tillage, grass strips and soil aeration may affect the degradation of steroids in soils. Tillage, grass strips and soil aeration increase soil permeability, enhance incorporation of manures into the soil, reduce surface runoff, and increase the biotransformation of these compounds (Fisher *et al.*, 2005; Herman and Mills, 2003). In the

Table 3. Aerobic biodegradation of steroid hormones in soil

Soil type	Organic Mater (%)	pH	Moisture (%)	Temperature (°C)	Degradation rate constant (d ⁻¹)		
					E1 ¹	E2 ¹	T ²
Loam	3.2	7.4	15	30	0.75	0.52	6.4
Silty loam	2.9	6.7	35	30	0.41	0.45	1.17
Sandy loam	0.8	5.8	15	30	0.47	0.47	NA

¹Culucci *et al.* (2001); ²Lorenzen *et al.* (2005)

non-till and grazing lands where there is no incorporation, groundwater contamination was shown to be limited, which may play a great role in surface water contamination through runoff (Fisher *et al.*, 2005). Soil aeration would be required when there is a significant surface compaction, slow water infiltration, low earthworm activity, and low microbial activities. It is also important to investigate the effect of other agricultural practices including the application of crop-residue-derived ash on the soil bed, which may reduce biodegradation of these hormones by reducing bioavailability (Zhang *et al.*, 2004).

It must also be noted that most biodegradation tests were conducted under higher initial concentrations, rather than the concentration that can be detected in the real environment. Culucci *et al.* (2001) applied 10 mg steroid hormone per kg soil. Similarly, Czajka and Londry (2006) applied 5 mg L⁻¹. It is not known if environment related concentration will show similar results. Note that environmentally relevant concentrations of steroid hormones might be too low to be utilized by heterotrophic microbial biomass as a carbon source. In that case, the availability of dissolved organic carbon may affect the degradation of organic contaminants positively as well as negatively (Deksissa and Vanrolleghem, 2005). With a limited carbon source, which is the case with low loaded water, small quantity of additional organic matter may enhance biodegradation of trace organic contaminants. According to Herman and Mills (2003), addition of 1 mg L⁻¹ dissolved organic carbon increased the biotransformation of E2. The author also showed that higher concentrations of readily available carbon sources inhibited E2 degradation. This suggests that the availability of higher concentration of readily biodegradable organic carbon in water, as well as in soil or sediment may negatively affect the degradation of E2. A similar investigation need to be done for testosterone too. Thus, further assessment on biodegradation of these hormones need to be with under environment relevant concentrations, and would have to involve a different approach such as the use of ¹⁴C-labelled estrogens and androgens.

Linking Sorption and Degradation

As sorption and biodegradation are the main governing processes for the fate and transport of E2 and testosterone in the environment, understanding the causal link of these two key processes is of paramount importance. There is little available data to conduct an appropriate study; however an attempt was made to apply the available data to illustrate the possible link (Figure 2). Subsequently, using data presented in Lee *et al.* (2003), the degradation half-life of testosterone is inversely related to the distribution coefficient K_d at R^2 of 0.99.

This might be due to the fact that sorption decreases the bioavailability of testosterone as it reduces the dissolved phases. It was also found that the addition of organic matter to the loam soil enhanced sorption and thereby reduced bioavailability (Jacobsen *et al.*, 2005). The reduction in bioavailability results in a reduction of mineralization. Such a negative impact of sorption on the biodegradation of the steroid hormone needs to be investigated for all steroid hormones under consideration.

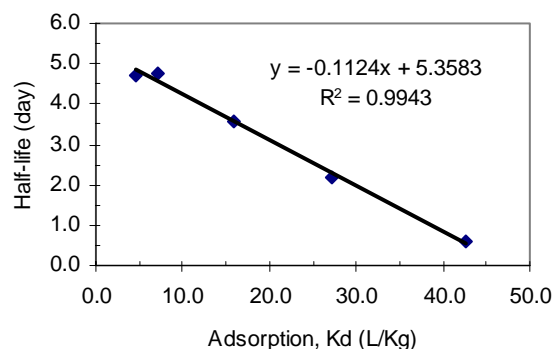


Figure 2. Sorption versus degradation of testosterone in aerobic soil (calculated from *Lee et al.*, 2003)

SUMMARY

This review study indicates that there is a widespread occurrence of E2 and testosterone in the environment, but little is known about the behavior of these endocrine disrupting hormones as well as their metabolites. Significant concentrations of these compounds were reported to reach ground water as well as surface water. Sorption, desorption and biodegradation processes are the governing processes of fate and transport of these compounds in environment. Sorption and desorption are affected by the type and quantity of the compound, soil type, and content of organic carbon and swelling clay. In the absence of swelling clay, the review study reveals that at environmentally relevant concentrations, estrogens may have a rapid desorption rate constant.

On the other hand, factors that affect the biodegradation of E1, E2, testosterone and androstenedione include types of compounds present and their initial concentration, soil type, soil organic matter content, moisture content, clay minerals, aeration, inhibiting factors including antibiotics, viable microbial biomass and temperature. All four hormones may degrade rapidly within a week in both waters and soils or persist for several months in soil and or sediment depending on those factors. Under aerobic conditions, all three steroid hormones will be degraded rapidly, provided that the carbon source, temperature and soil moisture are not the limiting factors. Low temperature (<12°C), dry soil and moisten soil to the field capacity can negatively affect biodegradation of these compounds. Under anaerobic conditions, biodegradation of all four steroid hormones under consideration is limited. E2 and testosterone tends to degrade very slowly, and their metabolites E1 and androstenedione may accumulate. Thus, persistence of E1 and androstenedione in anoxic conditions, together with their possible rapid desorption, may govern the fate and transport of these compounds in soil and surface water. In addition, the increase of sorption, due to higher clay content or organic carbon content, may reduce the biodegradation rate constant of testosterone as it reduces bioavailability. Further researches are required to investigate such an effect for E1, E2 and androstenedione too.

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