

OVERVIEW OF THE BIOREMEDIATION AND THE DEGRADATION PATHWAYS OF DDT

Teresa J. CUTRIGHT¹ and Ziya ERDEM¹

Abstract

DDT is a persistent pesticide that was banned in most countries due to its significant environmental and human health hazards. Bioremediation has the potential for in-situ treatment of DDT contaminated sediment and soils. With the right microorganisms and conditions, DDT and its primary metabolites, DDD and DDE can be degraded into 4-chlorobenzoic acid or 4,4-dichlorobenzophenone under aerobic and anaerobic conditions, respectively. The extent of degradation and time required will depend on the initial concentration, respiration mode and microorganisms present. This review provides brief overview of bioremediation and discusses some of the key degradation pathways of DDT.

Key Words: bioremediation, DDT, 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane, degradation, metabolism

Introduction

DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane) is an organochlorine pesticide also called dichloro-diphenyl trichloroethane. It was first synthesized in 1874 by Othmer Zeidler, a German doctoral student (Proskauer, 1992). DDT usage did not become widespread until after World War II for the control of malaria and agricultural pests. Its use in many industrialized countries was banned by the early 1980's due to its recalcitrance and many environmental and health hazards (Lackmann et al., 2004). A few examples of the environmental impacts include thinning of bird eggshells, altering reproductive development in reptiles and being an endocrine disruptor (Barreto-Castro et al., 2010; Nadeau et al., 2008; Purnomo et al., 2010; Thomas et al., 2011). The human health effects from DDT span causing leukemia, being an endocrine disrupter, causing early pregnancy loss to being a suspected carcinogen (Aislabie et al., 1997; Bidlan and Mannmani 2002; Chikuni et al., 2002; Liu et al., 2008; Thomas et al., 2011; Van Zwieten et al., 2003).

Although banned more than 30 years ago, DDT contamination is still widely prevalent. This is in part due to the fact that DDT has a reported half-life of 4-35 years (Corona-Cruz et al., 1999; Muendo et al., 2012; Toan et al., 2009; Wang et al., 2007), with the specific half-life being dependent on the type of soil. Only areas of tropical climates have reported DDT half-lives less than one year (Van den Berg, 2009). In addition, three countries still produce DDT commercially. India, China and North Korea produce DDT for the control of malaria in Africa as well as a raw material in dicofol (Morisawa et al., 2002; Turgut et al., 2009; van den Berg et al., 2009). Bioremediation is being studied by numerous scientists world wide as a viable remediation method for DDT. A recent study by Sudharshan et al. (2012) provides an overview of the different bioremediation schemes of DDT and other key persistent organic pollutants. This paper will provide a brief

introduction on the requirements for bioremediation and examples of the key metabolic pathways for DDT contaminated soils.

Basic Requirements for Bioremediation

Bioremediation is the process of altering a contaminant using a living organism, such as bacteria, fungi and plants. Mineralization is the complete conversion of an organic compound such as DDT, into biomass, carbon dioxide, salts and water. Complete mineralization can occur given the correct environmental parameters, bacteria and sufficient time. Biodegradation/bioremediation is used to describe any stage of the contaminant breakdown prior to complete mineralization. The primary requirement for any successful bioremediation treatment is the presence of an adequate microbial population. Soils with a viable microbial density will have at least 10^4 colony forming units (CFU)/g of soil. It is important to note that when dealing with recalcitrant compounds such as DDT, simply verifying the total microbial count will not be sufficient. Instead, having at least 10^4 CFU/g of active degraders will be required. An active degrader refers to the ability of the microbe to use the target compound as the primary carbon source (i.e., use DDT). The extent of bioremediation that can be achieved will also depend on complexity of the target compound and the presence of key factors to key the microbe(s) alive.

If only nutrients and/or a terminal electron acceptor (TEA) are added, the process is referred to as biostimulation. Bioaugmentation refers to treatments that also add a foreign microbial source. It is important to note that when dealing with compounds such as DDT one cannot simply track the disappearance of the parent compound as intermediates may be toxic. DDD (1,1-dichloro-2,2-(4-chlorophenyl)ethane) and DDE (1,1-dichloro-2,2-(4-chlorophenyl)ethylene), the key degradation byproducts of DDT, are highly toxic and more recalcitrant than DDT (Gautam and Suresh, 2009).

¹Department of Civil Engineering The University of Akron, Akron OH 44325-3905 tcutrig@uakron.edu

Regardless of the approach, several key parameters have to be in place for bioremediation to be successful. For normal microbial functioning the appropriate TEA, pH, temperature, nutrients and moisture must be present as well as the absence of toxic material(s). Often the nutrients and/or foreign microbial source are added in a water solution thereby maintaining the proper moisture level. The toxic material may be a different contaminant, an intermediate by product or even another microbial species. The specific growth requirements can also be used to delineate the type of microorganisms. For instance, microbes that require oxygen as their TEA (i.e., respiration mode) are classified as aerobic while those that do not require oxygen as their TEA are anaerobic. Those species that can switch their respiration between aerobic and anaerobic depending on the TEA available are called facultative species. Additional, more in-depth details on the approaches to bioremediation can be found in Cookson (1995), Cutright (2005) and Eweis et al. (1998).

The bioavailability of the contaminant will also impact the extent of bioremediation (Baczynski et al., 2012). Bioavailability is dependent on the contaminant characteristics (solubility, K_{ow} , hydrophobicity, etc.) and soil type (extent and type of

organic matter and clay), which may tightly bind DDT. For instance, clays with a higher organic content were found to sorb more DDT than clays with a lower organic fraction (Dai et al., 2008).

A majority of the available literature simply report non-identified microbial or fungal species isolated from DDT contaminated soil. Often the identification of fungi is limited to classification of either white rot or brown rot fungi. Each of these fungi classifications have over three hundred different species. A partial listing of known DDT degraders by bacteria and fungi are shown in Table 1 and 2, respectively. Recent research has found that certain plants can assist with the degradation of DDT (Huang et al., 2007; Mo et al., 2008; Whitefield-Aslund et al., 2010). Even though phytoremediation (i.e., use of plants to facilitate treatment) is a subset of bioremediation, only the pathways associated with microbial (bacteria or fungi) degradation will be presented.

Degradation Pathways of DDT

The most frequently proposed reactions during DDT degradation are: reductive dechlorination, dehydrohalogenation, dioxygenation, hydroxylation,

Table 1. Partial list of bacteria that involved in at least one step of DDT degradation

Species	Respiration Mode	Reference
<i>Alcaligenes sp.</i> DG5	Aerobic	Gao et al., 2011
<i>Alcaligenes sp.</i>	Anaerobic	Beunink and Rehm 1988
	Aerobic	Xie et al., 2011
<i>Alcaligenes denitrificans</i> ITRC-4	Facultative	Ahuja and Kumar, 2003
<i>Bacillus cereus</i>	Aerobic	Mwangi et al., 2010
<i>Clostridium sp.</i>	Anaerobic	Bao et al. 2012
<i>Eubacterium limosum</i>	Anaerobic	Sudharshan et al., 2012
<i>Flavimonas oryzihabitans</i>	Aerobic	Barragan-Huerta et al., 2007
Methanogenic granular sludge	Anaerobic	Baczynski et al., 2010
Mixed sediment consortium	Anaerobic	Chiu et al., 2004
<i>Pseudomonas putida</i>	Aerobic	Barragan-Huerta et al., 2007; Gautam and Suresh, 2009
<i>Pseudoxanthomonas sp</i> wax DT-1P	Aerobic	Wang et al., 2010
<i>Pseudoxanthomonas jiangsuensis</i>	Aerobic	Wang et al., 2011
<i>Serratia mercascens</i> DT-1P	Aerobic	Bidlan et al., 2002
<i>Shewanella decolorationis</i> S12	Anaerobic	Li et al., 2010
<i>Sphingobacterium sp</i> D6	Aerobic	Fang et al., 2010

Table 2. Partial list of fungi that involved in at least one step of DDT degradation

Species	Respiration Mode	Reference
Anaerobic sludge	Anaerobic	You et al., 1996
Brown rot fungi	Aerobic	Purnomo et al., 2011
<i>Daedalea dickinsii</i>	Aerobic	Purnomo et al., 2010
<i>Fomitopsis pinicola</i>	Aerobic	Purnomo et al., 2010
<i>Fusarium solani</i>	Aerobic	Mitra et al., 2001
<i>Phanerochaete chrysosporium</i>	Facultative	Corona-Cruz et al., 1999
<i>Phanerochaete chrysosporium</i>	Aerobic	Bumpas et al., 1993; Kaplan 1992; Thomas and Gohil, 2011
<i>Phlebia brevispora</i> TMIC34596	Aerobic	Xiao et al., 2011
<i>Phlebia lindtneri</i> GB-1027	Aerobic	Xiao et al., 2011
<i>Pleurotus ostreatus</i>	Aerobic	Purnomo et al., 2010
<i>Trametes versicolor</i>	Aerobic	Sari et al., 2012
White rot fungi	Aerobic	Zhao et al., 2010
Wood rot fungi	Aerobic	Thomas and Gohil, 2011

hydrogenation and meta-ring cleavage (attack between the 2,3 carbons on the ring structure). The first primary intermediate of DDT from the aforementioned reactions is either DDD or DDE; the occurrence will depend on the respiration mode and microbe being used. Most studies cite that DDD is the most common anaerobic metabolite while DDE is associated with aerobic conditions (Hay and Focht, 2000; Liu et al., 2008). However, as will be shown below the metabolic pathway and degradation mechanism is bacteria/fungi specific.

It is critical to keep in mind that not all laboratory studies will be able to be duplicated in the field. For instance, several researchers have found DDT will degrade more rapidly to DDD anaerobically. In a laboratory setting it will be easier to control the environment to facilitate the required respiration mode. It will be difficult, if not impossible, to maintain an anaerobic environment in the field. If the desired bacteria/fungi requires a strict anaerobic environment, in situ applications will most likely occur only after DDT has migrated to lower soil horizons or sediments (Muendo et al., 2012) or in the occurrence of high contaminant levels. Natural aerobic environments are associated with the vadose (~top three feet), as well as low levels of contamination.

Aerobic Degradation

In a historically contaminated soil, in-situ aerobic treatment would occur in the vadose zone. Nadeau et al. (1998) reported the first aerobic degradation of DDT, a modified version is shown in Figure 2. Here DDT metabolism was initiated by directly attacking the ring structure, via oxygenation to form 2,3-dihydrodiol DDT. After forming 2,3-dihydroxy DDT, meta-cleavage occurred with successive steps leading to the formation of 4-chlorobenzoic acid (4-CBA). The incorporation of two oxygen molecules requires the presence of dioxygenase enzymes. Thus the bacteria that can initiate DDT degradation by attacking the ring structure are hypothesized to produce dioxygenases. In some instances the production of specific enzymes can be influenced by a secondary carbon source. Aerobic degradation with bacteria strain KK, later identified as *Alcaligenes sp.*, was effective at degrading 65% DDT present. The degradation rate was greatly influenced by presence of 0.5% glucose (Xie et al., 2011). Although glucose inhibited DDT degradation by *Serratia marcescens* DT-1P, degradation was significantly enhanced when a mixture of yeast, peptone and tryptic soy broth was present (Bidlan and Manonmani, 2002).

If dechlorination had been the first step of attack,

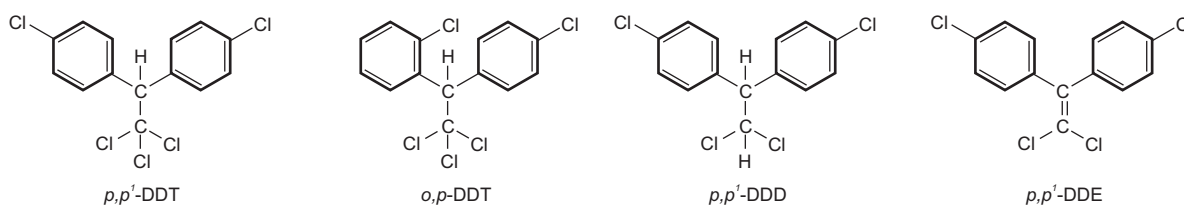


Figure .1 Structure of DDT and its metabolites. (Aislabic et al., 1997; Thomas and Gohil, 2011).

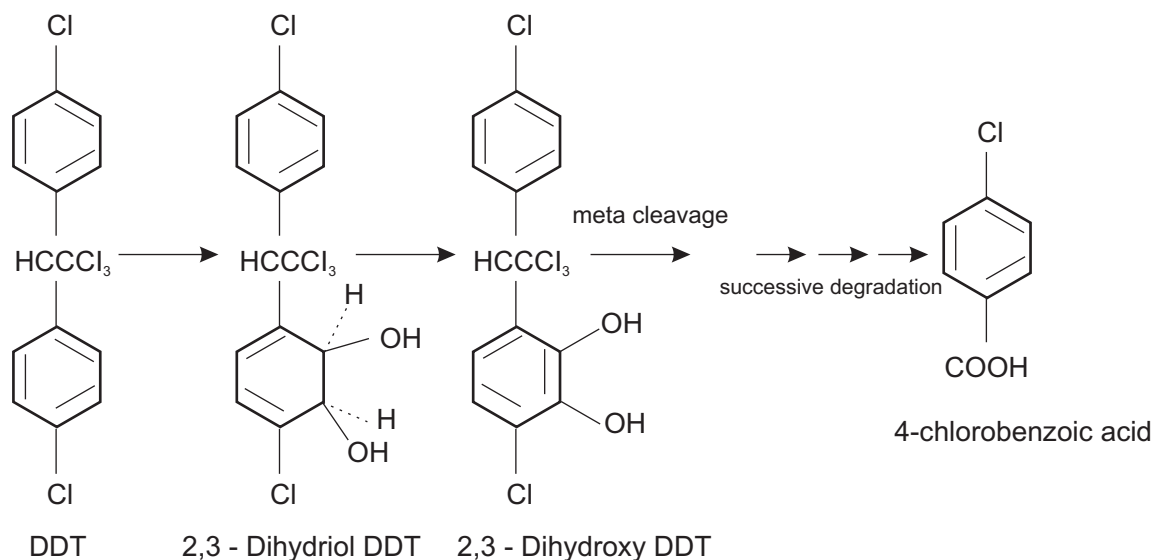


Figure 2. Modified aerobic degradation pathway of DDT as described by Nadeau et al. (1998)

it would have occurred at the alkyl chain. In this pathway, the removal of the chlorine leaves the alkyl chain unstable leading to the double bond in p,p'-DDE (Xie et al., 2011). In some instances, the double bond is more stable and thereby more difficult to degrade leaving p,p'-DDE an end product (Nguyen et al., 2011). The subsequent degradation of DDE (as with other intermediates) will require a consortium of bacteria (Mwangi et al., 2010; Wang et al., 2010). For instance, Hay and Focht (2000) reported that DDE could only be degraded when *Pseudomonas acidovorans* M3GY was added after another microbe had initiated DDT degradation. Research by Megharaj et al. (1998) also found that DDE could be degraded aerobically, but at a much slower rate.

As shown in Table 2, certain fungal strains can also degrade DDT under aerobic conditions. A modified pathway by Xiao et al (2011) via a combined culture of *P. lindtneri* and *P. brevispora* that could degrade 15.5 μmol/L DDT in 21 days is shown in Figure 3. This is a novel pathway in that the first metabolite under aerobic conditions is DDD. This is followed by several non-identified intermediates prior to the occurrence of DDA (2,2-bis(4-chlorophenyl)acetic acid) shown in Figure 3. After several successive steps, DBP (4,4-dichlorobenzophenone) would be the next key intermediate. At this point, DBP can be further degraded via two different routes, both of which lead to 4-dichlorobenzoic acid (4-DCB). Most of the other fungal pathways reported are based on the initial work by Bumpus et al. (1993) where both DDD and DDE can be formed. In that pathway DDD undergoes hydroxylation to form dicofol before being further metabolized to 4-DCB. As such, 4-DCB is often viewed as the 'end-product' of DDT. Although studies have documented the successful degradation of DBP, they were initiated with DBP and not DDT (McCullar et al., 2002).

Anaerobic Degradation

Rapid DDT degradation is typically associated anaerobic conditions via reductive dechlorination (Xiao et al., 2011). This mode of attack is usually restricted to the alkyl chain. For instance, 74% of 5.8 mM DDT underwent reductive dechlorination to DDD under anaerobic conditions by *Clostridium sp.* BXM (Bao et al., 2012). An unidentified anaerobic sediment culture was able to degrade 10 μg/L DDT into DDD within 15 days (Chiu et al., 2004). Baczynski et al. (2010) reported that 19 mg/kg DDT was converted into DDD within the first two weeks. Although both DDD and DDE can be formed under anaerobic conditions (depending on the microbe used), DDE is not desirable as it can be more resistant to subsequent treatment (Barragn-Huerta et al., 2007; Van Zwieten et al., 2003).

A representative anaerobic pathway with DDD as the primary initial metabolite is shown in Figure 4 (You et al., 1996). This pathway is one of the most complete in that it identifies seven key intermediates before the formation of DBP (4,4-dichlorobenzophenone). DBP is often considered the 'end product' under anaerobic conditions (Baczynski et al., 2010). Fang et al. (2010) reported a similar pathway for their study with *Sphingobacterium sp.*, which could degrade 12.9% of the DDT present in 90 days. A recent study by Yu et al. (2011) documented the formation of these metabolites in-situ for contaminated sediments under anaerobic conditions via both dehydrochlorination and reductive dechlorination of the alkyl chain. They also found that if DDE was formed, it would degrade into p,p'-DDMU (1-chloro-2,2-bis-(p-? chlorophenyl)ethylene) followed by successive degradation into p,p'-DDNU (2,2-bis(p-chlorophenyl)ethylene) (Yu et al., 2011).

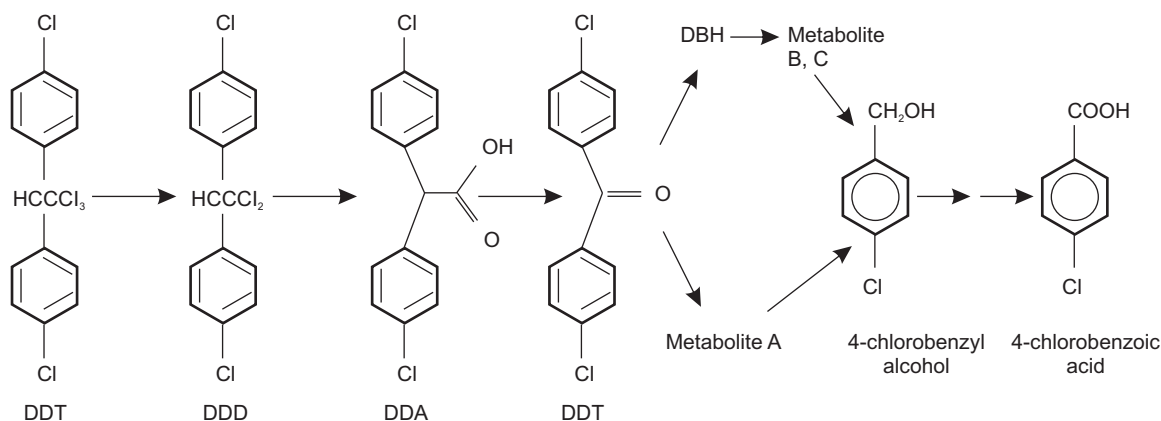


Figure 3. Novel aerobic pathway for DDT by fungi as proposed by Xiao et al. (2011)

Conclusions

These findings outlined above indicate that bioremediation can be a viable method to treat DDT contaminated sites. Degradation of DDT has been demonstrated under both aerobic and anaerobic conditions by a variety of different organisms. The primary 'end product' reported for most pathways has been 4-chlorobenzoic acid (4-CBA). Under anaerobic conditions, the end product is often dichlorobenzophenone (DBP). Although complete mineralization may be possible for DDT and its metabolites, it has not been reported to date. This is in part due to the fact that most studies often focused on the efficiency of one or two microbes. Complete mineralization, especially in efficient time frames, will require a consortium of different microbes.

Additional research with aerobic consortiums is recommended in order to facilitate future in-situ treatments of the vadose soils.

References

- Aislabie JM, Richards NK, Boul HL (1997) Microbial degradation of DDT and its residues – a review. *New Zealand Journal Agricultural Research* 40: 269-282.
- Ahuja R, Awasthi N, Manickam N, Kumar A (2001) Metabolism of 1,1-dichloro-2,2-bis(4-chlorophenyl)ethylene by *Alcaligenes Dentrificans*. *Biotechnology Letters* 23: 423:426.
- Ahuja R, Kumar A (2003) Metabolism of DDT [1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane] by *Alcaligenes denitrificans* ITRC-4 Under Aerobic and Anaerobic Conditions. *Current Microbiology* 46: 65-69.

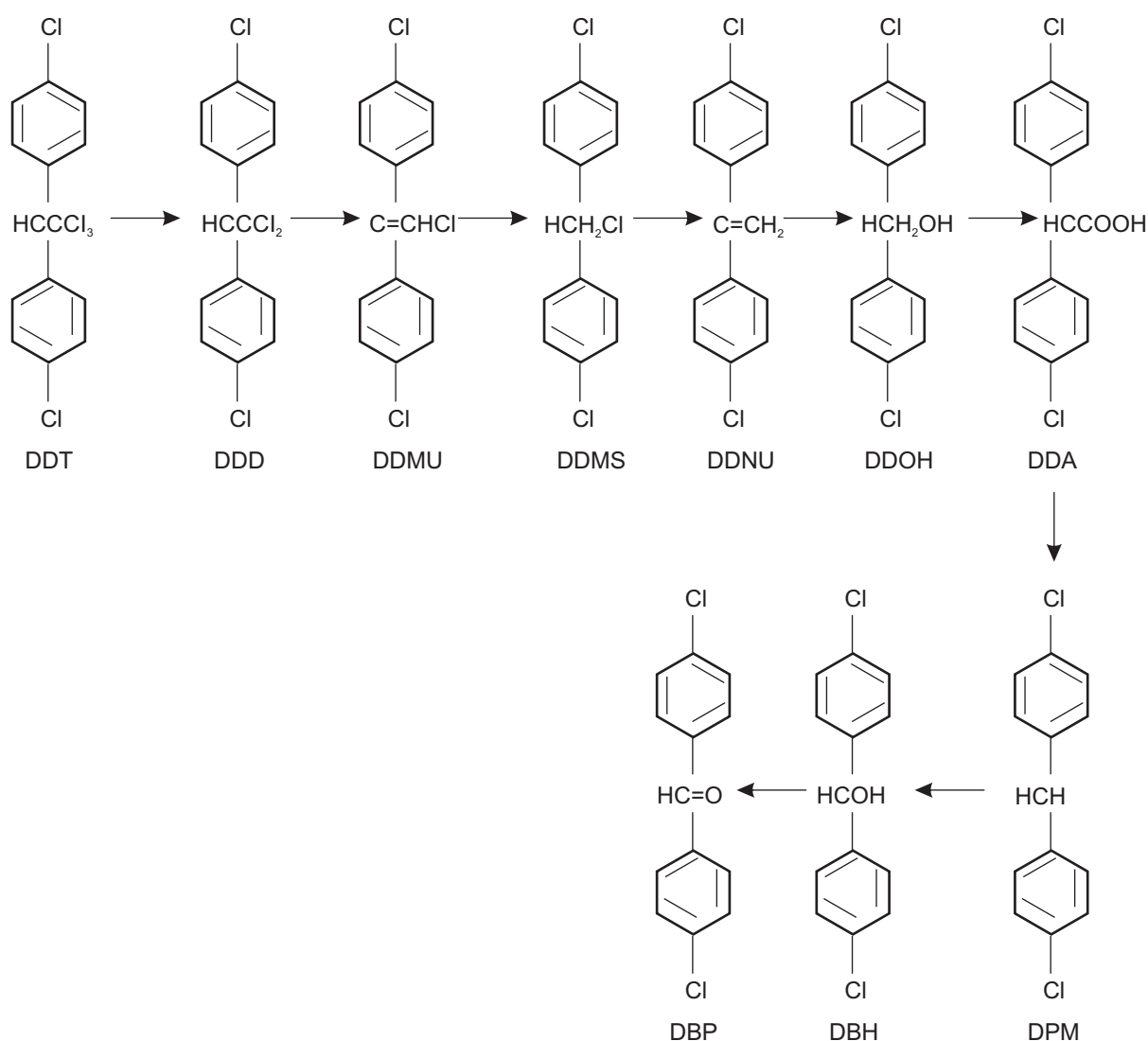


Figure 4. Metabolic pathway of DDT under anaerobic conditions as modified by research of You et al. (1996). DDMU is 1-chloro-2,2-bis(p-chlorophenyl)ethylene; DDMS is 1-chloro-2,2-bis(p-chlorophenyl)ethane; DDNU unsym-bis(p-chlorophenyl)ethylene; DDOH is 2,2-bis(p-chlorophenyl)ethanol; DDA is dichlorodiphenylacetate; DPM is dichlorophenylmethane; DBH is dichlorobenzylhydrol and DBP is dichlorobenzophenone.

- Baczynski TP, Pleissner D, Grotenhuis T (2010) Anaerobic biodegradation of organochlorine pesticides in soil – significance of temperature and availability. *Chemosphere* 78: 22-28.
- Baczynski TP, Pleissner D, Krylow M (2012) Bioremediation of chlorinated pesticides in field contaminated soils and suitability of Tenax solid phase extraction as a predictor of its effectiveness. *Clean Soil Air Water* 40: 864-869.
- Bao P, Hu ZY, Wnag XJ, Chen J, Ba YX, Hua J, Zhu CY, Zhong M, Wu CY (2012) Dechlorination of p,p'-DDTs coupled with sulfate reduction by novel sulfate-reducing bacterium *Clostridium* sp. *BXM*. *Environmental Pollution* 162: 303-310.
- Barragan-Huerta BE, Costa-Perez C, Peralta-Cruz J, Barrera-Cortes J, Esparza-Garcia F, Rodriguez-Vazquez R (2007) Biodegradation of organochlorine pesticides by bacteria grown in microniches of the porous structure of green bean coffee. *International Biodeterioration Biodegradation* 59: 239-244.
- Barreto-Castro M, Gomez-Matrinez LE, Gold-Bouchot G (2010) Tamoxifen affects the Toxicokinetics of o,p'-DDT in male Nile tilapia (*Oreochromis niloticus*). *Bulletin Environmental Contaminant Toxicology* 85: 545-549.
- Beunink J, Rehm HJ (1988) Synchronous anaerobic and aerobic degradation of DDT by an immobilized mixed culture system. *Applied Microbiology Biotechnology* 29: 72-80.
- Bidlan R, Mannmani HK (2002). Aerobic degradation of dichlorodiphenyltrichloroethane (DDT) by *Serratia marcescens* DT-1P. *Process Biochemistry* 38: 49-56.
- Bumpus JA, Powers RH, Sun T. (1993) Biodegradation of DDE (1,1-dichloro-2,2-bis(4-chlorophenyl)ethane by *Phynerochaete chryso sporium*. *Mycology Research* 97: 95-98.
- Chikuni O, Nhachi CFB, Polder A, Bergan S, Nafstud I, Skaare JU (2002) Effects of DDT on paracetamol half-life in highly exposed mothers in Zimbabwe. *Toxicology Letters* 134: 147-153.
- Chiu TC, Yen JH, Liu JT, Wang YS (2004) Anaerobic degradation of the organochlorine pesticides DDT and heptachlor in river sediment of Taiwan. *Bulletin Environmental Contaminant Toxicology* 72: 821-828.
- Cookson JT Jr. (1995) *Bioremediation Engineering: Design and Application*. McGraw-Hill, New York.
- Corona-Cruz A, Gold-Bouchot G, Gutierrez-Rojas M, Monroy-Hermosillo O, Favela A (1999) Anaerobic-Aerobic Biodegradation of DDT (Dichlorodiphenyl Trichloroethane) in Soils. *Bulletin Environmental Contamination Toxicology* 63: 219-225.
- Cutright TJ (2005) *Bioremediation*, in Lee S (ed) *Encyclopedia of Chemical Processing*, Marcel Dekker. doi: 0.1081/E-ECHP-120007679.
- Dai RL, Zhang GY, Gu XZ, Wang MK (2008) Sorption of 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane (DDT) by clays and organoclays. *Environmental Geochemistry Health* 30: 479-488.
- Eweis, JG, Ergas, SJ, Chang, DPY (1998) *Bioremediation Principles*. McGraw-Hill, New York.
- Fang H, Dong B, Yan H, Tang F, Yu Y (2010) Characterization of a bacterial strain capable of degrading DDT congeners and its use in bioremediation of contaminated soil. *Journal Hazardous Materials* 184: 281-289.
- Gao B, Leu W, Jia WB, Jia, LJ, Xu L, Xie J (2011) Isolation and characterization of an *Alcaligenes* sp. Strain DG-5 capable of degrading DDTs under aerobic conditions. *Journal Environmental Science Health Part B* 46: 257-263.
- Gautam SK, Suresh S (2009) Biodegradation of 1,1-diphenylethylene and 1,1-diphenylethane by *Pseudomonas putida* PaW 736. *Current Science* 96: 10.
- Hay AG, Focht DD (2000) Transformation of 1,1-dichloro-2,2-(4-chlorophenyl)ethane (DDD) by *Ralstonia eutropha*. *FEMS Microbiology Ecology* 31: 249-253.
- Huang Y, Zhao X, Luan s (2007) Uptake and biodegradation of DDT by 4 ectomycorrhizal fungi. *Science Total Environment* 385: 235-241.
- Kaplan DL (1992) Biological degradation of explosives and chemical agents. *Current Opinion Biotechnology* 3: 253-260.
- Lackmann GM, Schaller KH, Angerer J (2004) Organochlorine compounds in breast-fed vs. bottle-fed infants: preliminary results at six weeks of age. *Science Total Environment* 329: 289-293.
- Li FB, Li XM, Zhou SG, Zhuang L, Cao F, Huang DY, Xu W, Liu TX, Feng CH (2010) Enhanced reductive dechlorination of DDT in an anaerobic system of dissimilatory iron-reducing bacteria and iron oxide. *Environmental Pollution* 158: 1733-1740.
- Liu W, Li C, Zheng M, Wang L, Li S, Ba T, Su G, Gao L, Zhang L (2008) Distribution of DDT in a typical DDT waste contaminated site. *Bulletin Environmental Contaminant Toxicology* 80: 280-282.
- McCullar MV, Koh SC, Focht DD (2002). The use of mutants to discern the degradation pathway of 3,4'-dichlorobiphenyl in *Pseudomonas acidovorans* M3GY. *FEMS Microbiology Ecology* 42: 81-87.
- Megharaj M, Hartmans S, Engesser KH, Thiele JH (1998) Recalcitrance of 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene to degradation by pure cultures of 1,1-diphenylethylene degrading aerobic bacteria. *Applied Microbiology Biotechnology* 49: 337-342.
- Mitra J, Mukherjee PK, Kale SP, Murthy NBK (2001) Bioremediation of DDT in soil by genetically improved fungus *Fusarium solani*. *Biodegradation* 12: 235-245.
- Mo CH, Cai QY, Li HQ, Zeng QY, Tans SR, Zhao YC (2008) Potential of different species for use in the removal of DDT from the contaminated soils. *Chemosphere* 73: 120-125.
- Morisawa S, Kato A, Yoneda M, Shimada Y (2002) The dynamic performances of DDTs in the environment and Japanese exposure to them: a historical perspective after the ban. *Risk Analysis* 22: 245-263.
- Muendo BM, Lalah JO, Getenga ZM (2012) Behavior of pesticide residues in agricultural soil and adjacent river Kuywa sediment and water samples from Nzoia sugarcane belt in Kenya. *Environmentalist* 32: 433-444.
- Mwangi K, Boga HI, Muigai A, Kiiyukia C, Tsanuo MK (2010) Degradation of dichlorodiphenyltrichloroethane (DDT) by bacterial isolate form cultivated and uncultivated soil. *African J Microbiology Research* 4: 185-196.
- Nadeau LJ, Saylor GS, Spain JC (1998) Oxidation of 1,1,1-trichloro-2,2-bis(4-chlorophenyl)Ethane (DDT) by *Alcaligenes eutrophus* A5. *Archives Microbiology* 171: 44-49.
- Nguyen ATP, Sato Y, Iwasaki T, Miyauchi K, Tokuda M,

- Kasai D, Masai E, Fukuda M (2011) Characterization of the 1,1-dichloro-2,2-bis(4-chlorophenyl)ethylene (DDE) degradation system in *Janibacter sp.* TYM3221. *Enzyme Microbial Technology* 49: 532-539.
- Purnomo AS, Mori T, Kamei I, Nishii T, Kondo R (2010) Application of mushroom waste medium from *Pleurotus ostreatus* for bioremediation of DDT-contaminated soil. *International Biodeterioration Biodegradation*, 64: 397-402.
- Purnomo AS, Mori T, Takagi K, Kondo R (2011) Bioremediation of DDT contaminated soil using brown-rot fungi. *International Biodeterioration Biodegradation* 65: 691-695.
- Sari AA, Tachibana S, Muryanto A (2012) Correlation of ligninolytic enzymes from the newly found species *Trametes versicolor* U97 with RBBR decolorization and DDT degradation. *Water Air Soil Pollution* 223: 5781-5792.
- Sudharshan S, Naidu R, Mallavarapu M, Bolan N (2012) DDT remediation in contaminated soils: a review of recent studies. *Biodegradation* 23: 851-863,
- Thomas JE, Gohil H (2011) Microcosm studies on the degradation of o,p-DDT and p,p-DDT, DDE and DDD in a muck soil. *World Journal Microbiology Biotechnology* 27: 619-625.
- Toan VD, Thao VD, Walder J, Ha CT (2009) Residue, temporal trend, and half-life time of selected organochlorine pesticides (OCPs) in surface soils from Bac Ninh, Vietnam. *Bulletin Environmental Contaminant Toxicology* 82: 516-521.
- Turgut, C, Ates D, Gokbulut C, Cutright TJ (2009) Contents and sources DDT impurities in Dicofo formulations in Turkey. *Environmental Science Pollution Research* 16: 214-217.
- Van den Berg H. (2009) Global Status of DDT and its alternatives for use in vector control to prevent disease. *Environmental Health Perspective* 17: 1656-1663.
- Van Zwieten L, Ayres MR, Morris SG (2003) Influence of arsenic co-contamination on DDT breakdown and microbial activity. *Environmental Pollution* 124: 331-339.
- Xiao P, Mori T, Kamei I, Kondo R (2011) A novel metabolic pathway for biodegradation of DDT by the white rot fungi, *Phlebia lindtneri* and *Phlebia brevispora*. *Biodegradation* 22: 859-867.
- Xie H, Shu L, Xu Q, Wang J, Liu W, Jiang J, Meng Y (2011) Isolation and degradation ability of the DDT-degrading bacterial strain KK. *Environment Earth Science* 62: 93-99.
- Wang G, Zhang J, Wang L, Liang B, Chen K, Li S, Jiang J (2010) Co-metabolism of DDT by the newly isolated bacterium, *Pseudoxanthomonas sp.* wax. *Brazilian Journal Microbiology* 41: 431-438.
- Wang F, Jiang X, Bian Y, Yao F, Gao H, Yu G, Munch JC, Schroll R. (2007) Organopesticides in soils under different land usage in the Taihu Lake region, China. *J Environmental Science* 19: 54-590.
- Wang GL, Bi M, Liang B, Jiang JD, Li SP (2011) *Pseudoxanthomonas jiangsuensis* sp. Nov., a DDT-degrading bacterium isolated from a long term DDT-polluted site. *Current Microbiology* 62: 1760-1766.
- Whitefield-Aslund ML, Lunney AI, Rutter A, Zeeb BA (2010) Effects of amendments on the uptake and distribution of DDT in *Cucurbita pepo* plants. *Environmental Pollution* 158: 508-513.
- Yu HY, Bao LS, Liang Y, Zeng EJ (2011) Field validation of anaerobic degradation pathways for dichlorodiphenyltrichloroethylene (DDT) and 13 metabolites in marine sediment cores from China. *Environmental Science Technology* 45: 5245-5252.
- You G, Sayles GD, Kupferle MJ, Kim IS, Bishop PL (1996) Anaerobic DDT biotransformation: enhancement by application of surfactants and low oxidation reduction potential. *Chemosphere* 32: 2269-2284.
- Zhao Y, Yi X, Li M, Liu L, Ma W (2010) Biodegradation Kinetics of DDT in Soil under Different Environmental Conditions by Laccase Extract from White Rot Fungi. *Chinese Journal Chemical Engineering* 18: 486-492.

Sorumlu Yazar

Teresa J. CUTRIGHT

tcutrig@uakron.edu

Geliş Tarihi : 05.10.2012

Kabul Tarihi : 16.12.2012

Copyright of Journal of Adnan Menderes University, Agricultural Faculty is the property of Adnan Menderes University and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.