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Factors Affecting Performance of Soil Termiticides

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1. Introduction

Although baits have increased in popularity in recent years, the application of liquid termiticide to soil remains the most widely used method for protecting structures against subterranean termites (Anonymous, 2008). In addition to fast acting, repellent toxicants such as bifenthrin and other pyrethroids that act as barriers to termite movement, non-repellent, slower acting compounds including fipronil, imidacloprid and thiamethoxam are now among the preferred soil treatments. Delayed toxicity can provide opportunity for horizontal transfer of the active ingredient, potentially reducing termite activity (Remmen & Su, 2005; Shelton & Grace, 2003). While there is some evidence of colony suppression or elimination following perimeter treatments with imidacloprid (Parman & Vargo, 2010), other studies have shown that a reduction in activity occurs over only a small portion of a colony's foraging range, making it unlikely that soil treatments affect the overall termite population (Osbrink et al., 2005; Rust & Saran, 2006; Saran & Rust, 2007; Su, 2005). This limited potential for transfer emphasizes the importance of bioavailability of termiticides in soil over an extended period of time.

Failure of soil termiticide treatments is often related to factors other than the active ingredient (Su & Scheffrahn, 1990b). Efficacy and longevity of soil treatments varies greatly with application rate, soil properties (Gold et al., 1996; Su & Scheffrahn, 1990b), termite pressure (Jones, 1990), and application technique (Forschler, 1994; Su et al., 1995). Factors influencing the performance of soil termiticides can be grouped into those that determine toxicity, bioavailability, or persistence. Each of these factors is affected by properties of the termiticide and soil (Gold et al., 1996; Spomer et al., 2009; Wiltz, 2010). Although some generalizations can be made about relative toxicity of different termiticides, susceptibility differences occur among species and colonies (Beal & Smith, 1971; Osbrink & Lax, 2002). Termiticide rate and application technique influence both bioavailability and long-term persistence (Peterson, 2010). Termite population pressure and satellite nests can reduce availability of the toxicant. Finally, other environmental factors such as moisture, temperature, and microbial communities affect termiticide degradation (Baskaran et al. 1999, Saran & Kamble 2008).

2. Soil termiticides

Long-term studies evaluating chemicals as potential termiticides were initiated in the 1920's and 1930's (Randall & Doody, 1934), but it was not until after World War II that the

cyclodienes, a class of chemical compounds identified as highly effective termiticides, became commercially available (Ware, 2000). Pre-construction soil treatments with cyclodienes became the standard method of subterranean termite prevention from the late 1940s until 1988 (Lewis, 1980; Su & Scheffrahn, 1990b). The cyclodienes, particularly chlordane, were extremely efficacious and stable in soil, often protecting structures from subterranean termite infestation for several decades (Grace et al., 1993; Lenz et al., 1990; Su & Scheffrahn, 1990b).

Because of their residual longevity, questions were raised about the environmental impact of these chemicals (Lewis, 1980; Su & Scheffrahn, 1990a; Wood & Pierce, 1991). Chlordane and related chemicals were banned in most of the world in the 1970's and 1980's (Ware, 2000). However, they constitute a major environmental problem because of their high toxicity, persistence in the environment, and ability to bioaccumulate in the food chain and because they are still being used in certain countries for agricultural and public health purposes (Itawa et al., 1993; Ntow, 2005; Xue et al., 2006).

Following the loss of chlordane as a soil termiticide, the only termiticides available for use as soil barrier treatments were chlorpyrifos (an organophosphate) and several pyrethroids. The residual activity of chlorpyrifos was significantly shorter than that of the cyclodienes (Grace et al., 1993; Lenz et al., 1990). As a result of the Food Quality Protection Act of 1996, the U. S. Environmental Protection Agency (EPA) revised its risk assessment of chlorpyrifos and, in 2000, the use of chlorpyrifos as a soil termiticide was canceled (EPA, 2000).

With the loss of chlorpyrifos, pyrethroids were the primary weapon available for subterranean termite prevention. The pyrethroids are more persistent than chlorpyrifos, but less stable in the soil than the cyclodienes (Lenz et al., 1990; Pawson & Gold, 1996; Su & Scheffrahn, 1990b). Soil barriers composed of pyrethroids are more likely to fail than barriers composed of cyclodienes or chlorpyrifos (Forschler, 1994; Kard, 1999; Lenz et al., 1990; Su & Scheffrahn, 1990b; Su et al., 1993) because pyrethroids are repellant to subterranean termites (Rust & Smith, 1993; Su & Scheffrahn, 1990b; Su et al., 1

Beginning in 2000, several new nonrepellant soil termiticides appeared on the market: fipronil, a phenyl pyrazole (Aventis Corp., 2001), imidacloprid, a chloronicotinyl (Bayer Corp., 2000), and chlorfenapyr, a pyrrole (BASF Corp., 2001). Nonrepellant termiticides are an improvement over the pyrethroids because subterranean termites cannot detect gaps in the treatment and use them to gain access to structures (Potter & Hillery, 2001). Subterranean termites are unable to detect the termiticide and do not avoid soil that has been treated with them (Kuriachan & Gold, 1998). Chlorantraniliprole is a new termiticide belonging to the anthranilic diamide class of insecticides. It targets a unique receptor site, the ryanodine receptor, causing the release of stored calcium, resulting in loss of muscle control, cessation of feeding, and eventually death of the termite (Cordova et al., 2006). Unlike other soil termiticides, chlorantraniliprole has no known health effects to humans and no personal protective equipment is required for application (Dupont, 2010). Also being developed for subterranean termite control is indoxacarb, an oxadiazine proinsecticide that is metabolically activated after entering the insect (Spomer et al. 2009; Wing et al., 2000).

A large amount of the variability in effectiveness of different soil treatments can be attributed to the termiticide itself. In a study evaluating *Coptotermes formosanus* mortality on treated soils, bifenthrin performed better than fipronil or chlorfenapyr (Wiltz 2010). Bifenthrin was also found to have the highest activity against *Reticulitermes hesperus* when compared with other pyrethroids (Smith & Rust, 1990).

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Saran and Rust (2007) found that *R. hesperus* tunneled through untreated sand and stopped near the interface of fipronil treated sand. There was little tunneling in the treated sand, but termites tunneled close enough to obtain a lethal dose of fipronil. To some extent, *C. formosanus* and *Reticulitermes flavipes* penetrated sand treated with 0 - 64ppm fipronil, indicating non-repellency, but complete penetration of the treated sand was prevented by high mortality (\geq 88% for *C. formosanus* and \geq 89% for *R. flavipes* after 7 d) (Remmen & Su, 2005). While several studies conducted in small laboratory arenas have found high mortality in fipronil treatments, extended foraging arena assays demonstrated that fipronil barriers can split termite populations, with high mortality occurring close to the treatment site, but little mortality at distances >5 m (Su, 2005).

Although imidacloprid is slow to induce mortality, mobility impairment occurs within hours of exposure (Thorne & Breisch, 2001). Imidacloprid is non-repellent (Remmen & Su, 2005), but this combination of delayed mortality and rapid mobility impairment results in limited movement of termites into treated barriers and limited mortality after 7d in close proximity to imidacloprid-treated sand.

Several studies have demonstrated differences in degradation rates among insecticides. Baker and Bellamy (2006) found that of the termiticides tested, the organophosphate, chlorpyrifos, degraded the quickest, while chloronicotinyls and pyrethroids degraded at slower rates. Horwood (2007) measured termiticide residues in a weathered sand: loam mixture, finding that bifenthrin and chlorfenapyr were more persistent than chlorpyrifos, fipronil, and imidacloprid. Horwood (2007) found that after 15 months, chlorpyrifos and fipronil concentrations at lower depths were little changed from the time of treatment, but there was a major reduction in imidacloprid concentration at all depths.

3. Soil-termiticide interactions

Because soil consists of a heterogeneous mixture of mineral and organic particles, it is difficult to predict the influence of soil type on termiticides. When soil conditions fall outside an optimum range, termiticides can be immobilized or adsorbed by the soil or altered chemically to an inactive form.

Laboratory studies have found interactions between soil and termiticide properties. Effects of clay (Henderson et al. 1998; Smith & Rust 1993) and organic carbon (Felsot & Lew 1989; Forschler & Townsend, 1996; Gold et al., 1996; Spomer et al., 2009) content on bioavailability to termites differ with termiticide. Termiticide effectiveness diminishes over time, especially on soils that pose bioavailability problems (Gold et al., 1996; Su et al., 1993; Tamashiro et al., 1987).

Variation in soil properties, such as pH, clay and organic matter content, soil moisture, and electrolyte concentration, influence the adsorption and desorption characteristics of termiticides to soils. Of equal importance are the physical and chemical properties of the toxicant, including concentration, pH, and solubility.

3.1 Mobility

Mobility is one of the most important factors in determining bioavailability and efficacy of a soil treatment. If a pesticide is too mobile, it fails to protect the structure, while increasing risk of groundwater contamination. However, if the chemical is too tightly bound to soil particles, bioavailability is limited. Mobility is affected by the pesticide's sorption, water solubility, and vapor pressure and by external influences that include soil properties,

weather, topography, and vegetation. Sorption describes the attraction between a chemical and soil, vegetation, or other surfaces. However, the term most often refers to the binding of a chemical to soil particles. Sorption is defined as the attraction of an aqueous species to the surface of a solid (Alley, 1993). The sorbing species, usually an organic compound, is called the sorbate, and the solid, usually soil, to which the sorbate is attracted is known as the sorbent. This attraction results from some form of bonding between the chemical and adsorption receptor sites on the solid. Several mechanisms may operate in a particular situation, including ionic attraction, hydrophobic attraction, and hydrogen bonding. For pesticides that are weak acids or bases, sorption is influenced by soil pH.

Sorption is also influenced by soil moisture, organic matter content, and texture. Pesticides are more readily sorbed onto dry soil because water competes with pesticides for binding sites in moist soil. More sorption occurs in soils made largely of clay and organic matter. Organic matter and clay particles have small particle size, large surface area, and high surface charge. Sand particles provide less surface area for sorption, making pesticides more likely to move away from the point of application.

Several parameters are used to describe a pesticide's sorption behavior in soils. Table 1 contains sorption parameters for selected chemicals currently and previously used as soil termiticides.

Two related measures of a pesticide's sorption are the sorption coefficient (K_d) and the soil organic carbon coefficient (K_{OC}). These coefficients are ratios of adsorbed to dissolved pesticide for a specific soil (K_d) or for the organic carbon fraction of a soil (K_{OC}). These values are useful for broadly discriminating between leaching classes of pesticides, but actual adsorption depends on many factors, including soil moisture, temperature, soil pH, and type of organic matter (Wauchope et al., 2002).

Termiticide	K _{OC} (L/kg)	Log K _{ow}	H ₂ O Solubility (mg/L)	Henry's law constant (atmm ³ /mol)	Reference
Bifenthrin	1.31 x 10 ⁵ - 3.02 x 10 ⁵	6.0	0.1 (25°C)	7.2 x 10 ⁻³	Fecko (1999)
Chlordane	4.19 - 4.39	2.78	1.0 x 10-4	1.3 x 10 ⁻³	USEPA (1986)
Chlorantraniliprole	3.3 x 10 ² (average)	2.8	1.023 (20°C)	3.1 x 10 ⁻¹⁵	USEPA (2008)
Cypermethrin	6.1 x 104 (average)	6.6	4 x 10 ⁻³ (20°C)	2.5 x 10 ⁻⁷	Jones (1999)
Fipronil	3.8 x 10 ³ - 1.2 x 10 ⁴	4.01	2.4 (pH 5) 2.2 (pH 9)	3.7 x 10 ⁻⁵	Connelly (2001)
Imidacloprid	1.3 x 10 ² - 3.1 x 10 ²	0.57	514 (20°C, pH 7)	6.5 x 10 ⁻¹¹	Fossen (2006)
Indoxacarb	2.2 x 10 ³ - 9.4 x 10 ³	4.7	0.2 (25°C)	< 6.1 x 10 ⁻¹⁰	USEPA (2000)

Table 1. Soil sorption parameters of selected soil termiticides.

Because sorption coefficient values for the same pesticide vary widely with soil properties, reported values are not included in Table 1. However, K_d values are useful for comparing sorption of different chemicals to the same soil. The organic carbon sorption coefficient is a property of the pesticide and is independent of soil organic matter. The sorption coefficient and organic carbon sorption coefficient are related by the equation:

$$K_{d} = Koc (\%O.C.) \tag{1}$$

Where O.C. is the percentage organic carbon the soil contains. This relationship shows that as the organic fraction of soil increases, the distribution coefficient, K_d , increases. For this relationship to hold true, the chemical must be non-ionic because soil pH affects sorption of ionic sorbates.

As Table 1 illustrates, K_{OC} values for a pesticide are not constant. Pesticide concentration affects adsorption (Kamble & Saran, 2005), but not to an extent that prevents comparison of relative mobility of different pesticides. For polar solutes, surfaces other than organic carbon can become important sorbents particularly when soils are low in organic matter (Cheung et al., 1979; Cox et al., 1998; Means et al., 1982).

Another useful measure of potential pesticide mobility is the octanol - water partition coefficient (K_{ow}). K_{ow} is a measure of the hydrophobicity of an organic compound. The more hydrophobic a compound, the less soluble it is, therefore the more likely it will adsorb to soil particles (Bedient et al, 1994). To evaluate hydrophobicity, the organic solvent octanol is used as a surrogate for organic matter. The octanol-water partition coefficient is the ratio of the concentration of a chemical in octanol and in water at equilibrium and at a specified temperature. K_{ow} is determined by adding a known amount of the pesticide to equal volumes of octanol and water. The coefficient is determined by calculating the concentration in the octanol phase compared to the concentration in the water phase. K_{ow} values vary by several orders of magnitude and may be reported as either K_{ow} or log K_{ow} values. The octanol-water partition coefficient is correlated with water solubility; therefore, the water solubility of a substance can be used to estimate its octanol-water partition coefficient.

Water solubility describes the amount of pesticide that will dissolve in a known amount of water. Highly soluble pesticides are more likely to be moved by runoff or leaching. As with sorption parameters, solubility values are useful as a means of comparison, but actual values will vary with field conditions. Solubility is affected by temperature, water pH, and the presence of other chemicals. The solubility of a compound tends to be inversely proportional to the amount of sorption that it can undergo.

In addition to being adsorbed to soil or transported by water, pesticides can be volatilized. Pesticide volatilization from moist soil is described by the Henry's law constant (K_h). K_h is defined as the concentration of pesticide in air divided by the concentration in water. K_h can be measured experimentally or estimated by dividing the saturation vapor pressure of the compound by its solubility (Suntio et al., 1988). Like other sorption parameters, K_h is temperature dependent, but values are useful for comparing volatility of different compounds. Pesticides with higher K_h are more likely to volatilize from moist soil. Because sorption affects the amount of pesticide in the soil water, the tendency to volatilize from moist soil depends on both the Henry's law constant and sorption coefficients.

3.2 Clay

Soil texture has a strong impact on termiticide performance, but effects differ with insecticide. In assays conducted with bifenthrin, chlorfenapyr, and fipronil, C. formosanus mortality was generally highest when clay content was low (Wiltz, 2010). Clay content of soil was significantly related to termite mortality across all termiticides, rates, and exposure times (Wiltz, 2010). Likewise, Osbrink and Lax (2002) found that C. formosanus workers experienced greater mortality in fipronil-treated sand than in treated potting soil or a mixture of soil and clay. Bobé et al. (1997) reported that for fipronil there was a significant decrease in adsorption coefficient as the soil clay content decreased, thereby increasing bioavailability. However, the opposite result occurs with some insecticides. Smith and Rust (1993) found that increased clay content increased the toxicity of certain pyrethroids, such as cypermethrin. The authors concluded that cypermethrin and clay apparently interacted creating a formulation similar to a wettable powder, which may have an increased affinity for the nonpolar termite integument. Gao et al. (1998) investigated the adsorption of seven pesticides and metabolites with different physiochemical properties, finding that adsorption was generally more effective on smaller and larger soil particles than on intermediate-sized particles.

3.3 pH

Effects of pH on adsorption and desorption vary with insecticide chemistry and interact with other soil properties. Low pH soils increase the adsorption of weakly acidic pesticides (Boivin et al., 2005; Carrizosa et al., 2000; Halfon et al., 1996,). Desorption of endosulfan was higher at both acidic and alkaline pH ranges compared to neutral pH (Kumar & Philip, 2006). The authors found that in clay soil, adsorption decreased drastically when the pH was reduced. In soil column experiments, deltamethrin was essentially immobile in three different soils. Kaufman et al. (1981) suggested that for nonacidic soils, the pH may be a primary factor affecting mobility of deltamethrin. In bioassays of treated soils against *C. formosanus*, there was an interaction between effects of soil pH and clay content on effectiveness of chlorfenapyr and fipronil (Wiltz, 2010).

3.4 Organic carbon

Partitioning of insecticides between soil organic matter and soil solution affects bioavailability (Felsot & Lew, 1989). Like clay, organic matter decreases adsorption of fipronil (Bobé et al., 1997). Mulrooney and Gerard (2007) applied fipronil to 3 soils and found that *R. flavipes* mortality decreased with increasing organic carbon. Although no soil effects were found when soils were treated at label rates, pyrethroids applied at low rates were less available in soils with high OC (Henderson et al., 1998). Soil OC has been shown to affect adsorption of several non-acidic pesticides, but have little or no effect on weakly acidic chemicals (Barriuso & Calvet, 1992; Boivin et al., 2005; Worrall et al., 2001).

4. Application technique

In addition to properties of the soil and chemicals, variations in application technique can influence availability, persistence, and impenetrability of toxins. Such variables include gaps in soil treatment, thickness of treated layer, and watering method. Within certain ranges of application rates, availability increases with rate; however, the opposite is true at other rates.

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Initial concentration of termiticides in soil varies from several hundred to over one thousand micrograms per gram. Kard and McDaniel (1993) reported initial concentrations of 858± 990mg/g after application to a Mississippi soil, and Davis and Kamble (1992) reported initial concentrations of chlorpyrifos as high as 1500mg/g in a Nebraska loamy sand soil. Application rate affects both initial availability and degradation rate. Saran and Kamble (2008) reported an inverse relationship between the initial concentrations of bifenthrin, fipronil, and imidacloprid and their LT50 and LT90 values against R. flavipes. Greater bioavailability at higher concentrations may explain similar trends reported by Smith and Rust (1992), Forschler and Townsend (1996), and Ramakrishnan et al. (2000). At low rates, fipronil has low soil affinity, but adsorption increases with concentration (Bobé et al., 1997). Kamble and Saran (2005) found that at termiticide application rates of 0.06–0.125%, there is a reversal in the fipronil adsorption process, whereby there is a decrease in adsorption coefficient with an increase in concentration, resulting in an increase in bioavailability. Chlorpyrifos exhibited a lower degradation rate when applied at $\approx 1,000 \ \mu g/g$ soil than when applied at typical agricultural levels of $0.3-32 \mu g/g$ (Racke et al., 1994). When fipronil was applied at the labeled rate for locust control (8g AI per ha), 75% degraded within 3 d (Bobé et al., 1998). However, when applied at termiticidal rates (60-125 µg AI per g), fipronil did not show much degradation, and no metabolites were detected in residue analysis after 180 d (Saran and Kamble 2008). Gahlhoff and Koehler (2001) found that concentration and treatment thickness significantly affected both mortality and penetration by R. flavipes into imidacloprid-treated soil, with mortality remaining low after 7 d exposure to low concentrations, as well as affecting bioavailability, high termiticide concentrations may indirectly affect degradation by negatively impacting bacterial and fungal populations, resulting in prolonged inhibition of soil dehydrogenase and esterase activities (Felsot & Dzantor, 1995). Racke et al. (1996) examined hydrolysis of chlorpyrifos in 37 soils at agricultural application rates (10mg/g) and observed that in some alkaline soils hydrolysis constituted the major degradation pathway. However, they also noted that in several soils, with pH values in the range of 7.1 to 8.5, the hydrolytic reaction was inhibited at higher concentrations (1000mg/g).

Termites can circumvent soil treatments by using untreated gaps, building materials, or debris as bridges between the surrounding soil and structure (Forschler, 1994; Smith & Zungoli, 1995; Su & Scheffrahn, 1998). Subterranean termite foragers are able to detect and avoid repellant termiticides so areas treated with pyrethroids are rarely contacted. The subterranean termites' ability to detect chemical barriers allows termite foragers to follow the edge of the pyrethroid treated area until they find a gap in the treatment (Forschler, 1994; Rust & Smith, 1993; Su & Scheffrahn, 1990b; Su et al., 1982). Thus, gaps in pyrethroid applications may actually funnel foragers toward the structures they are intended to protect (Forschler, 1994; Kuriachan & Gold, 1998). The inevitability of gaps in soil termiticide barriers is a major limitation to the efficacy of repellant liquid termiticides (Forschler, 1994; Kuriachan & Gold, 1998). Gaps may exist in a soil termiticide treatment for a number of reasons. Pre-construction treatments often contain gaps due to imperfect initial application or physical disturbance of the soil after application (Koehler et al., 2000; Su & Scheffrahn, 1990a, 1998). When an existing structure becomes infested and requires a remedial termiticide application, it is difficult to create a continuous horizontal barrier of liquid termiticide beneath the structure (Su & Scheffrahn, 1990a, 1998; Koehler et al., 2000). Finally, all termiticides degrade over time. An ageing soil treatment, applied below the foundation

before a structure was built, is inaccessible after construction and cannot be reapplied (Su & Scheffrahn, 1990a; Su, 1997; Koehler et al., 2000).

The total volume of pesticide suspension applied to soil affects penetration depth and concentration in the soil. In tests using imidacloprid and fipronil in five different soils, when equal amounts of pesticide were diluted in different volumes of water, the higher volume treatments penetrated further into the soil, but the more concentrated treatments deposited more pesticide in the top 1cm of soil (Peterson 2010). It is likely that the thicker barrier of lower active ingredient concentration would provide better protection, at least in the short term because it might be better able to withstand disturbances to the top 1 cm of soil. Additionally, termites are less able to tunnel through thicker barriers of lower active ingredient concentrations than through thinner barriers of higher concentration (Smith et al. 2008). However, pesticide treatments with low initial concentrations degrade faster than those with higher initial concentrations (Bobé et al., 1998; Felsot & Dzantor, 1995; Saran & Kamble, 2008). In addition to total volume of liquid applied, initial thickness of the treated zone depends on soil and termiticide properties. Smith and Rust (1992) found that termiticidal amounts of chlordane and cypermethrin moved to soil depths of at least 7 cm, while chlorpyrifos moved to a depth of at least 30 cm.

5. Environmental factors

Both biotic and abiotic pathways have been found to be important for insecticide degradation and transformation in soils (Racke et al., 1996).

5.1 Moisture

Water can compete with pesticides for sorption sites on soil particles. Dry soils become more sorptive for both polar and non-polar chemicals (Chen et al., 2000). However, chemicals with low polarity are released when soil becomes wet (Harper et al., 1976). Repeated cycles of wetting and drying affect pesticide availability and degradation, but depend on properties of the chemical, soil, number of wetting and drying cycles, time since pesticide application, and time since wetting (Garcia-Valcarcel & Tadeo, 1999; Xia & Brandenburg 2000; Ying & Kookana, 2006; Peterson, 2007).

5.2 Temperature

Soil temperature affects termiticide bioavailability through its influence on solubility and adsorption. In addition to its effect on the physical and chemical properties of the pesticide, extreme temperatures affect the rate of microbial degradation, as described in the following section. Several studies have demonstrated that temperature affects adsorption of pesticides to soil, but that the nature of this effect varies among pesticides. Although most of the work on pesticide availability and degradation has been conducted in the temperate climates of North America and Europe, soil temperature is likely to play an important role in termiticide degradation in tropical regions. Khan et al. (1996) found that lindane adsorption to silty loam and silty clay loam soils increased with temperature. Likewise, Valverde-Garcia et al. (1988) found that higher temperatures increased the adsorption of the fungicide thiram and the organophosphate insecticide dimethoate to organic soils. Temperature may interact with pH, particularly in saturated soils. In aqueous solutions, fenamiphos, fipronil, and trifluralin degradation increased with temperature and pH (Ramesh & Balasubramanian, 1999). Other studies have demonstrated a reduction in pesticide

adsorption at higher temperatures. Dios-Cancela et al. (1990) found that sorption of the herbicide cyanazine to peats decreased with increasing temperature.

5.3 Micromial degradation

Microbial degradation occurs when fungi, bacteria, and other soil microorganisms use pesticides as food or consume pesticides along with other substances. Activity of microbes is affected by soil organic matter and texture and is usually highest in warm, moist, well-aerated soils with a neutral pH. Because microbial degradation is mediated by enzymes, temperature is important in determining the rate degradation: the rate of most reactions catalyzed by enzymes tends to double for each 10°C increase in temperature between 10° and 45°C and is greatly reduced above and below these temperatures.

Naturally-occurring pesticide-degrading microorganisms may be relatively rare in pristine environments and non-exposed agricultural soils (Bartha, 1990). Some of the pesticide-degrading microbes that have been identified include *Arthrobacter, Brevibacterium, Clavibacter, Corynebacterium, Micromonospora, Mycobacterium, Nocardia, Nocardioides, Rhodococcus* and *Streptomyces* genera (De Schrijver and De Mot, 1999).

A review of earlier work on organophosphate and carbamate insecticide degradation was prepared by Laveglia and Dahm (1977). Although organophosphates are no longer used in many parts of the world, there have been several recent studies on their degradation by microbes. Li et al. (2007) reported the isolation of a bacterium, *Sphingomonas* sp., that degrades chlorpyrifos, parathion, parathion-methyl, fenitrothion and profenofos. However, several other studies have found little microbial degradation of chlorpyrifos. Goda et al. (2010) showed that the intact cells of *Pseudomonas putida* IS168 were able to degrade fenitrothion, diazinon and profenofos when present as sole carbon sources, but failed to grow on chlorpyrifos. Trichloropyridinol (TCP), one of the main chlorpyrifos metabolites, has antimicrobial properties (Cáceres et al., 2007; Feng et al., 1997; Racke et al., 1990), possibly accounting for the scarcity of chlorpyrifos-degrading microorganisms. Degradation of pyrethroids in soil has also been extensively studied (Gan et al., 2005; Jorhan & Kaufman, 1986; Kaufman et al., 1981; Lee et al., 2004; Lord et al., 1982). Most of these studies show that microorganisms play an important role in the degradation of pyrethroid compounds in soils and sediments.

6. Termite pressure and susceptibility

In studies evaluating termite tunneling through chlordane, chlorpyrifos, or permethrin treated soil, large groups of termites were able to tunnel farther than small groups (Beal & Smith, 1971; Jones, 1990). At low population density, different colonies of *C. formosanus* either totally avoided permethrin-treated soil or tunneled slightly (Jones, 1989, 1990). Jones (1990) found that while large groups of termites tunneled more than small groups in soils treated with chlordane, chlorpyrifos, or permethrin, group size had different effects on mortality in different soil treatments. Several experiments have demonstrated correlations between termite survival rates and population density (Lenz et al., 1984; Lenz, 2009; Santos et al., 2004). At population densities below 0.1 g termites / ml, Lenz et al. (1984) found that, in the absence of termiticide treatment, survival of *Coptotermes lacteus* (Froggatt) and *Nasutitermes exitiosus* (Hill) increased with population density.

Susceptibility differences occur among termite species and colonies. Most soil termiticide evaluations have included only one target species. However, in studies comparing

responses of two or more species, there are frequently differences in susceptibility. *C. formosanus* penetrated soil treated with aldrin, chlordane, dieldrin, or heptachlor, while *R. virginicus* and *R. flavipes* failed to penetrate lower rates of the same chemicals and were killed more quickly than *C. formosanus* (Beal & Smith 1971). In a laboratory assay, chlorpyrifos, permethrin, cypermethrin, bifenthrin, isofenphos, lambda-cyhalothirn, and fenitrothion all provided equal barrier protection against *R. flavipes* (Su et al. 1993). However, in the same assay, *C. formosanus* generally tunneled deeper into sand treated with organophosphates than with pyrethroids. Penetration of sand treated with thiamethoxam or fipronil was similar for *C. formosanus* and *R. flavipes*, but thiamethoxam was more toxic to *C. formosanus* than to *R. flavipes* (Remmen & Su 2005). Osbrink and Lax (2002) evaluated seven insecticides against termites from colonies that had been previously been identified as either insecticide susceptible or tolerant, finding differences in substrate penetration and mortality among colonies and insecticides.

Termite traits other than population size or susceptibility to toxicants can increase the likelihood that soil treatments will fail to protect a structure. Aerial infestations account for a large percentage of structural infestations by *C. formosanus* (Su & Scheffrahn, 1990), making soil treatments ineffective. Additionally, *C. formosanus* colonies may seal off or avoid treated areas (Su et al. 1982) when repellent toxicants are used, but use gaps in the soil barrier to access the structure (Forschler, 1994).

7. Conclusion

Several long-term studies of termiticide persistence have been conducted. In USDA Forest Service trials, which have been conducted for the past 40 years, tests consist of treated soil plots covered by concrete slabs. Treatments are considered failures when termites penetrate >50% of field replicates to reach a wood block placed in a pipe running through the slab (Kard, 2003; Wagner, 2003). In these tests, longevity differed with geographic location and termiticide class (Mulrooney et al., 2007). Such studies have the advantage of being performed under natural soil weathering conditions for an extended period of time and provide a standard method of comparing termiticides. However, products are evaluated on a limited number of soils and it is impossible to tell if a lack of penetration into plots should be attributed to effectiveness of the termiticide or to the absence of termite pressure. To overcome this problem, other studies have included laboratory bioassays coupled with field termiticide persistence studies (Gold et al., 1996; Grace, 1991; Su et al., 1993). Unfortunately, most of these studies have evaluated relatively few soil types. Because performance is so dependent on a combination of temiticide and soil properties and weathering, more research is needed to evaluate new and existing products under a larger range of conditions. Soil termiticides have been extensively evaluated for toxicity, bioavailability, and degradation. However, reasons for termiticide failure are complex and often local in nature, indicating the need for more research and localized treatment recommendations regarding choice of toxicant, application technique, and treatment frequency.

8. References

Alley, W., (1993). Regional Groundwater Quality, Van Nostrand Reinhold, New York, New York, 1994.

- Anonymous. (2008). State of the industry. Termites: Kicked to the "B" list? PCT October 10, 2008. http://www.pctonline.com/Article.aspx?article_id=37550.
- Aventis Environmental Science. (2001). Termidor SC termiticide label. Montvale, NJ.

BASF Corporation. (2001). Phantom termiticide label. Triangle Park, NC.

- Baker, P. B., and D. E. Bellamy. (2006). Field and laboratory evaluation of persistence and bioavailability of soil termiticides to desert subterranean termite *Heterotermes aureus* (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 99: 1345-1353.
- Barriuso, E. & Calvet, R. (1992). Soil type and herbicide adsorption. *International Journal of Environmental Analytical Chemistry*, 46: 117–128.
- Bartha, R., (1990). Isolation of microorganisms that metabolize xenobiotic compounds. In: Isolation of Biotechnological Organisms from Nature, Labeda, D. P. (Ed.), pp. 283-307, McGraw-Hill Publishing Company, New York, USA.
- Baskaran, S., Kookana, R. S. & Naidu, R. (1999). Degradation of bifenthrin, chlopyrifos, and imidacloprid in soil and bedding materials at termiticidal application rates. *Pesticide Science*, 55:1222–1228.

Bayer Corporation. (2000). Premise 75 WSP termiticide label. Kansas City, MO.

- Beal, R. H., & Smith, V. K. (1971). Relative susceptibilities of Coptotermes formosanus, Reticulitermes flavipes, and R. virginicus to soil insecticides. Journal of Economic Entomology, 64: 472-475.
- Bedient, P.H., Rifai, H. S. & Newell C. J. (1994). Ground Water Contamination: Transport and Remediation, Prentice Hall, Englewood Cliffs, NJ, 1994.
- Bobé, A., Coste, C. M. & Copper, J –F. (1997). Factors influencing the adsorption of fipronil on soils. *Journal of Agricultural and Food Chemistry*, 45: 4861–4865.
- Bobé, A., Cooper, J. -F., Coste, C. M. & Muller, M. -A. (1998). Behaviour of fipronil in soil under Sahelian plain field conditions. *Pesticide Science*, 52: 275–281.
- Boivin, A., Cherrier, R. & Schiavon, M. (2005). A comparison of five pesticides adsorption and desorption processes in thirteen contrasting field soils. *Chemosphere*, 61: 668-676.
- Cáceres T, He, W., Naidu, R. & Megharaj, M. (2007). Toxicity of chlorpyrifos and TCP alone and in combination to *Daphnia carinata*: the influence of microbial degradation in natural water. *Water Research*, 41: 4497–4503
- Carrizosa, M. J., Calderon, M. J., Hermosin, M. C. & Cornejo, J. (2000). Organosmectites as sorbent and carrier of the herbicide bentazone. *Science of the Total Environment*, 247: 285–293.
- Chen D., Rolston, D. E., and Yumaguchi, T. (2000). Calculating partition coefficients of organic vapors in unsaturated soils and clays. *Soil Science*, 165: 217-225.
- Cheung, M. W., Mingelgrin, V. & Biggar, J. W. (1979). Equilibrium and kinetics of desorption of picloram and parathion in soils. *Journal of Agricultural and Food Chemistry*, 27: 1201-1206.
- Connelly, P. (2001). Environmental fate of fipronil. Environmental Monitoring Branch. Department of Pesticide Regulation. California Environmental Protection Agency.
- Cox, L. Koskinen W. C., Celis, R., Yeen, P. Y., Hermosin, M. C. & Cornejo, J. (1998). Sorption of imidacloprid on soil clay mineral and organic components. *Soil Science of America Journal*, 69: 911-915.

- Davis, R. W. & Kamble, S. T. (1992). Distribution of sub-slab injected Dursban TC (chlorpyrifos) in a loamy sand soil when used for subterranean termite control, *Bulletin of Environmental Contamination and Toxicology*, 48: 585-591.
- De Schrijver, A. & De Mot, R., (1999). Degradation of pesticides by actinomycetes. *Critical Reviews in Microbiology*, 25: 85-119.
- Dios-Cancela, G., Romero, T. E. & Sanchez-Rasero, F. (1990). Adsorption of cyanazine on peat and montmorillonite clay surfaces. *Soil Science*, 150: 836-843
- Dupont. (2010). Dupont Altriset MSDS.
- Environmental Protection Agency. (2000). Chlorpyrifos revised risk assessment and agreement with registrants. -

http://www.epa.gov/pesticides/op/chlorpyrifos/agreement.pdf.

- Fecko, A. (1999). Environmental fate of bifenthrin. Environmental Monitoring and Pest Management Branch. California Department of Pesticide Regulation.
- Felsot, A. S., & Lew, A. (1989). Factors affecting bioactivity of soil insecticides: relationships among uptake, desorption, and toxicity of carbofuran and terbufos. *Journal of Economic Entomology*, 82: 389-395.
- Felsot, A. S., & Dzantor, E. K. (1995). Effect of alachlor concentration and an organic amendment on soil dehydrogenase activity and pesticide degradation rate. *Environmental Toxicology and Chemistry*, 14: 23-28.
- Feng Y, Racke, K. D. & Bollag, J. M. (1997). Isolation and characterization of a chlorinatedpyridinol-degrading bacterium. *Applied Environmental Microbiology*, 63: 4096–4409
- Forschler, B. T. (1994). Survivorship and tunneling activity of *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae) in response to termiticide soil barriers with and without gaps of untreated soil. *Journal of Entomological Science*, 29: 43–54.
- Forschler, B. T. & Townsend, M. L. (1996). Mortality of Eastern subterranean termites (Isoptera: Rhinotermitidae) exposed to four soils treated with termiticides. *Journal of Economic Entomology*, 89: 678-681.
- Gahlhoff, J. E. & Koehler, P. G. (2001). Penetration of the eastern subterranean termite into soil treated at various thicknesses and concentrations of Dursban TC and Premise 75. *Journal of Economic Entomology*, 94: 486-491.
- Gan, J., Lee, S. J., Liu, W. P., Haver, D. L., Kabashima, J. N. (2005). Distribution and persistence of pyrethroids in runoff sediment. *Journal of Environmental Quality*, 36: 834-841.
- Gao, J. P., Maguhn, J., Spitzauer, P. & Kettrup, A. (1998). Sorption of pesticides in the sediment of the Teufelsweiher pond (Southern Germany). I: Equilibrium assessments, effect of organic carbon content and pH. *Water Research*, 32: 1662-1672.
- Garcia-Valcarcel, A. I. & Tadeo, J. L. (1999). Influence of soil moisture on sorption and degradation of hexazinone and simazine in soil. *Journal of Agricultural and Food Chemistry*, 47: 3895–3900.
- Goda, S. K., Elsayed, I. E., Khodair, T. A., El-Sayed, W. & Mohamed, M. E. (2010). Screening for and isolation and identification of malathion-degrading bacteria: cloning and sequencing a gene that potentially encodes the malathion-degrading enzyme, carboxylestrase in soil bacteria. *Biodegradation*, 21: 903–913.

- Gold, R. E., Howell, H. N., Pawson, B. M., Wright, M. S. & J. C. Lutz. (1996). Persistence and bioavailability of termiticides to subterranean termites (Isoptera: Rhinotermitidae) from five soil types in Texas. *Sociobiology*, 28: 337-363.
- Grace, J. K. (1991). Response of eastern and Formosan subterranean termites (Isoptera, Rhinotermitidae) to borate dust and soil treatments. *Journal of Economic Entomology*, 84: 1753–1757.
- Grace, J. K., Yates, J. R., Tamishiro, M. & Yamamoto, R. T. (1993). Persistence of organochlorine insecticides for Formosan subterranean termite (Isoptera: Rhinotermitidae) control in Hawaii. *Journal of Economic Entomology*, 86: 761-766.
- Halfon, E., Galassi, S., Bruggemann, R. &. Provini, A. (1996). Selection of priority properties to assess environmental hazard of pesticides, *Chemosphere*, 33: 1543–1562.
- Harper, L. A., White, A. W. Jr., Bruce, R. R., Thomas, A. W., and Leonard, R, A. (1976) Soil and microclimate effects on trifluralin volatilization. *Journal of Environmental Quality*, 5: 236-242.
- Henderson, G., Walthall, P. M., Wiltz, B. A. Rivera-Monroy, V. H., Ganaway, D. R. & H. M. Selim. (1998). Analysis of soil properties in relation to termiticide performance in Louisiana. In Proceedings of the National Conference on Urban Entomology, San Diego, CA, April 26-28, 1998.
- Horwood, M. A. (2007). Rapid degradation of termiticides under field conditions. *Australian Journal of Entomology*, 46: 75-78.
- Itawa, H., Tanabe, S., Sakai, N., Tatsukawa, R., (1993). Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of ocean on their global transport and fate. *Environmental Science & Technology*, 27: 1080-1098.
- Jones, D. (1999). Environmental fate of cypermethrin. Environmental Monitoring and Pest Management Branch. California Department of Pesticide Regulation.
- Jones S. C. (1989). Field evaluation of fenoxycarb as a bait toxicant for subterranean termite control. *Sociobiology*, 15: 33-41.
- Jones, S. C. (1990). Effects of population density on tunneling by Formosan subterranean termite (Isoptera: Rhinotermitidae) through treated soil. *Journal of Economic Entomology*, 83: 875-878.
- Jorhan, E. G. & Kaufman, D. D. (1986). Degradation of cis- and transpermethrin in flooded soil. *Journal of Agricultural and Food Chemistry*, 34: 880-884.
- Kamble, S. T. & Saran, R. K. (2005). Effect of concentration on the adsorption of three termiticides in soil. *Bulletin of Environmental Contamination and Toxicology*, 75: 1077-1085.
- Kard, B. (1999). Termiticides: the Gulfport report. Pest Control, 67: 42-46.
- Kard, B. M. (2003). Integrated pest management of subterranean termites (Isoptera). *Journal* of Entomological Science, 38: 200–224.
- Kard B. M. & McDaniel, C. A. (1993). Field evaluation of the persistence and efficacy of pesticides used for termite control, in Pesticides in Urban Environments - Fate and Significance, ed by Racke KD and Leslie AR, ACS Symposium Series 522, American Chemical Society: Washington DC. pp 42-62.

- Kaufman, D. D., B. A. Russell, C. S. Helling, and A. Kayser. (1981). Movement of cypermethrin, decamethrin, permethrin and their degradation productions in soil. *Journal of Agricultural and Food Chemistry*, 29: 239-345.
- Koehler, P.G., Su, N. –Y., Scheffrahn, R. H. & Oi, F.M. (2000). Baits to control subterranean termites: the Sentricon system, ENY 2000, Florida Cooperative Extension Service, Institute of Food and Agricultural Services.
- Kumar, M., & Philip, L. (2006). Adsorption and desorption characteristics of hydrophobic pesticide endosulfan in four Indian soils. *Chemosphere*, 62: 1064-1077.
- Kuriachan, I. & Gold, R. E. (1998). Evaluation of the ability of *Reticulitermes flavipes* Kollar, a subterranean termite (Isoptera: Rhinotermitidae), to differentiate between termiticide treated and untreated soils in laboratory tests. *Sociobiology*, 32: 151-166.
- Lee, S, Gan, J. Y., Kim, J. S., Kabashima, J. N. & Crowley, D. E. (2004). Microbial transformation of pyrethroid insecticides in aqueous and sediment phases. *Environmental Toxicology & Chemistry*, 23: 1-6.
- Lenz, M. (2009). Laboratory bioassays with subterranean termites (Isoptera) the importance of termite biology. *Sociobiology*, 53: 573-595.
- Lenz, M., Barrett, R. A. & Williams, E. R.. (1984). Implications for comparability of laboratory experiments revealed in studies on the effects of population density on vigor in *Coptotermes lacteus* (Froggatt) and *Nasutitermes exitious* (Hill) (Isoptera: Rhinotermitidae & Termitidae). *Bulletin of Entomological Research*. 74: 477-485.
- Lenz, M, Watson, J.A L., Barrett, R.A. & Runko, S. (1990). The effectiveness of insecticidal soil barriers against subterranean termites in Australia. *Sociobiology*, 17: 9-35.
- Lewis, D. L. (1980). Environmental and health aspects of termite control chemicals. Sociobiology. 5: 197-203.
- Li, X., He, J., & Li, S. (2007). Isolation of a chlorpyrifos-degrading bacterium, *Sphingomonas* sp. strain Dsp-2, and cloning of the mpd gene. *Research in Microbiology* 158(2):14–143.
- Lord, K. A., Mckinley, M. & Walker, N. (1982). Degradation of permethrin in soils. *Environmental Pollution*, 29 (2): 81-90.
- Masters, G. M., (1991). Introduction to Environmental Engineering and Science, Prentice Hall, Englewood Cliffs, NJ.
- Means, J. C., Wood, S. G. Hassett, J. J., & Banwart W. L. (1982). Sorption of amino-and carboxy-substituted polynuclead aromatic hydrocarbons by sediments and soils. *Environmental Science Technology*, 16: 93-98.
- Mulrooney, J. E., & Gerard, P. D. (2007). Toxicity of fipronil in Mississippi soil types against *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). *Sociobiology* 50: 63-70.
- Mulrooney, J. E., Wagner, T. L., Shelton, T. G., Peterson, C. J. & Gerard, P. D. (2007). Historical review of termite activity at Forest Service termiticide test sites from 1971 to 2004. *Journal of Economic Entomology*, 100: 488-494.
- Ntow, W. J. (2005). Pesticide residues in Volta Lake, Ghana, Lakes Reservoirs. *Research and Management*, 10: 243-248.
- Osbrink, W. L. A., & Lax, A. R. (2002). Effect of tolerance to insecticides on substrate penetration by Formosan subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 95: 989-1000.

- Osbrink, W. L A., Cornelius, M. L. & Lax, A. R. (2005). Effect of imidacloprid soil treatments on occurrence of Formosan subterranean termites (Isoptera: Rhinotermitidae) in independent monitors. *Journal of Economic Entomology*, 98: 2160–2168.
- Parman, V. & Vargo, E. L. (2010). Colony-Level Effects of Imidacloprid in Subterranean Termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 103: 791-798.
- Pawson, B. M. & R. E. Gold. (1996). Evaluation of baits for termites (Isoptera: Rhinotermitidae) in Texas. *Sociobiology*, 28: 485-491.
- Peterson, C. J. (2007). Imidacloprid mobility and longevity in soil columns at a termiticidal application rate. *Pest Management Science*, 63: 1124-1132.
- Peterson, C. J. (2010). Varying termiticide application rate and volume affect initial soil penetration. *Journal of Economic Entomology*. 103: 433-436.
- Potter, M. H. & Hillery, A. E. (2001). Exterior-targeted liquid termiticides an alternative approach to managing subterranean termites (Isoptera: Rhinotermitidae) in buildings. *Sociobiology* 39: 373–405.
- Racke, K. D., Fontaine, D. D., Yoder, R. N. & Miller, J. R. (1994). Chlorpyrifos degradation in soil at termiticidal application rates. *Pesticide Science* 42: 43-51.
- Racke K. D., Laskowski D. A. & Schultz M. R. (1990). Resistance of chlorpyrifos to enhanced biodegradation in soil. *Journal of Agricultural and Food Chemistry*, 38: 1430–1436.
- Racke K. D., Steele, K. P., Yoder, R. N., Dick, W.A. & Avidov E. (1996). Factors affecting the hydrolytic degradation of chlorpyrifos in soil, *Journal of Agricultural and Food Chemistry*, 44: 1582-1592.
- Ramakrishnan, R., Suiter, D. R., Nakatsu C. H. & Bennett, G. W. (2000). Feeding inhibition and mortality in *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) after exposure to imidacloprid-treated soils. *Journal of Economic Entomology*, 93: 422-428.
- Randall, M. and Doody, T. C. (1934). Wood preservatives and protective treatments, pp. 463-476. In C.A. Kofoid [ed.] Termites and Termite Control. University of California Press, Berkeley, CA.
- Remmen, L. N. & Su, N.-Y. (2005). Tunneling and mortality of eastern and Formosan subterranean termites (Isoptera: Rhinotermitidae) in sand treated with thiamethoxam or fipronil. *Journal of Economic Entomology*, 98: 906–910.
- Rice, R. C., Jaynes, D. B. & Bowman, R. S. (1991). Preferential flow of solutes and herbicide under irrigated fields. *Transactions of the American Society of Agricultural Engineers*, 34: 914-918.
- Ramesh, A. & Balasubramanian, M. (1999). Kinetics and Hydrolysis of Fenamiphos, Fipronil, and Trifluralin in Aqueous Buffer Solutions. *Journal of Agricultural and Food Chemistry*, 47: 3367-3371.
- Rust, M. K. & Saran, R. K. (2006). The toxicity, repellency, and transfer of chlorfenapyr against western subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 99: 864–872.
- Rust, M. K. & Smith, J. L. (1993). Toxicity and repellency of components in formulated termiticides against western subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 86: 1131-1135.

- Santos, C. A., DeSouza, O. & Guedes, R. N. C. (2004). Social facilitation attenuating insecticide-driven stress in termites (Isoptera: Nasutitermitinae). *Sociobiology*, 44: 539-546.
- Saran, R. K., & Kamble, S. T. (2008). Concentration-dependent degradation of three termiticides in soil under laboratory conditions and their bioavailability to eastern subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 101: 1373-1383.
- Saran, R. K. & Rust, M. K. (2007). The toxicity, uptake, and transfer efficiency of fipronil in western subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 100: 495–508.
- Shelton, T. G. & Grace, J. K. (2003). Effects of exposure duration on transfer of nonrepellent termiticides among workers of *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 96: 456–460.
- Smith, B. C. & Zungoli, P. A. (1995). Rigid board insulation in South Carolina: its impact on damage, inspection and control of termites (Isoptera: Rhinotermitidae). *Florida Entomologist*, 78: 507-515.
- Smith, J. L. & Rust, M. K. (1990). Tunneling response and mortality of the western subterranean termite (Isoptera: Rhinotermitidae) to soil treated with termiticides. *Journal of Economic Entomology*, 83: 1395–1401.
- Smith, J. L., & Rust, M. K. (1992). Activity of water-induced movement of termiticides in soil. *Journal of Economic Entomology*, 85: 430-434.
- Smith, J. L. & Rust, M. K. (1993). Cellulose and clay in sand affects termiticide treatments. *Journal of Economic Entomology*, 86: 53-60.
- Spomer, N. A., Kamble, S. T. & Siegfried, B. D. (2009). Bioavailability of chlorantraniliprole and indoxacarb to eastern subterranean termites (Isoptera: Rhinotermitidae) in various soils. *Journal of Economic Entomology*, 102: 1922-1927.
- Su, N.-Y. (1997). Protecting Historic Buildings and structures from termites. Cultural Resource Management 20(7). National Park Service. http://crm.cr.nps.gov/issueindex.cfm.
- Su, N. -Y. (2005). Response of the Formosan subterranean termites (Isoptera: Rhinotermitidae) to baits or nonrepellent termiticides in extended foraging arenas. *Journal of Economic Entomology*, 98: 2143–2152.
- Su, N.-Y. & Scheffrahn, R. H. (1990a). Economically important termites in the United States and their control. *Sociobiology*, 17: 77-92.
- Su, N.-Y. & Scheffrahn, R. H. (1990b). Comparison of eleven soil termiticides against the Formosan subterranean termite and the eastern subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 83: 1918-1924.
- Su, N.-Y. & Scheffrahn, R. H. (1998). A review of subterranean termite control practices and prospects for integrated pest management programs. *Integrated Pest Management Reviews*, 3: 1-13.
- Su, N.-Y., Scheffrahn, R. H. & Ban P. M. (1993). Barrier efficacy of pyrethroid and organophosphate formulations against subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 86: 772-776.

- Su, N. -Y., Tamashiro, M., Yates, J. R. & Haverty, M. I. (1982). Effect of behavior on the evaluation of insecticides for prevention of or remedial control of the Formosan subterranean termite. *Journal of Economic Entomology*, 75: 188-193.
- Su, N. -Y., Wheeler, G. S. & Scheffrahn, R. H. (1995). Subterranean termite (Isoptera: Rhinotermitidae) penetration into sand treated at various thicknesses with termiticides. *Journal of Economic Entomology*, 88: 1690–1694.
- Sunti, L. R., Shiu, W. Y., Mackay, D., Sieber, J. N. & Glotfelty, D. (1988). Critical review of Henry's law constants for pesticides. Reviews of Environmental Contamination & Toxicology. 103: 1–59.
- Tamashiro, M., Yates, J. R. & Ebesu, R. H. (1987). The Formosan termite in Hawaii: problems and control, pp. 15-22. In Biology and control of the Formosan subterranean termite: M. Tamashiro and N. –Y. Su, eds., 67th Meeting of the Pacific Branch of the Entomological Society of America, Research Extension Series 083, University of Hawaii, Honolulu.
- Thorne, B. L. & Breisch, N. L. (2001). Effects of sublethal exposure to imidacloprid on subsequent behavior of subterranean termite *Reticulitermes virginicus* (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 94: 492–498.
- USEPA. (1986). U.S. Environmental Protection Agency. Pesticide fact sheet: chlordane. U.S. Environmental Protection Agency. Washington, DC.
- USEPA. (2001). U.S. Environmental Protection Agency. Pesticide fact sheet: chlorfenapyr. U.S. Environmental Protection Agency. Washington, DC.
- USEPA. (2000). U.S. Environmental Protection Agency. Pesticide fact sheet. Indoxacarb. U.S. Environmental Protection Agency. Washington, DC.
- USEPA. (2008). U.S. Environmental Protection Agency. (2008). Pesticide fact sheet: chlorantraniliprole. U.S. Environmental Protection Agency. Washington, DC.
- Wagner, T. L. (2003). U.S. Forest Service termiticide tests. *Sociobiology*, 41: 131–141.
- Ware, G.W. (2000). The Pesticide Book 5th Ed. Thompson Publications. Fresno, CA. 386 pages.
- Wauchope, R. D., Yeh, S., Linders, J., Kloskowski, R., Tanaka, K., Rubin, B., Katayama, A., Kördel, W., Gerstl, Z., Lane, M. & Unsworth, J. B. (2002). Review: Pesticide soil sorption parameters: theory, measurement, uses, limitations, and reliability. *Pest Management Science*, 58: 419–445.
- Wiltz, B. A. (2010). Laboratory Evaluation of Effects of Soil Properties on Termiticide Performance against Formosan Subterranean Termites (Isoptera: Rhinotermitidae). Sociobiology, 56 (3): 755-773.
- Wing, K. D., Sacher, M., Kagaya, Y., Tsurubuchi, Y., Mulderig, L., Connair, M. & Schnee, M. (2000). Bioactivation and mode of action of the oxadiazine indoxacarb in insects. *Crop Protection*, 19: 537-545.
- Wood, T. G. & Pierce, M. J. (1991). Termites in Africa: The environmental impact of control measures and damage to crops, trees, rangeland and rural buildings. *Sociobiology*, 19: 221-234.
- Worrall, F., Fernandez-Perez, M., Johnson, A. C., Flores-Cesperedes, F. & Gonzalez-Pradas,
 E. (2001). Limitations on the role of incorporated organic matter in reducing pesticide leaching, *Journal of Contaminant Hydrology*, 49: 241–262.

- Xia, Y. & Brandenburg, R. L. (2000). Effect of irrigation on the efficacy of insecticides for controlling two species of mole crickets (Orthoptera: Gryllotalpidae) on golf courses. *Journal of Economic Entomology*, 93: 852–857.
- Xue, N., Zhang, D. & Xu, X., (2006). Organochlorinated pesticide multiresidues in surface sediments from Beijing Guanting reservoir. *Water Research*, 40: 183-194.
- Ying, G. G. & Kookana, R. S. (2006). Persistence and movement of fipronil termiticide with under slab and trenching treatments. *Environmental Toxicology and Chemistry*, 25: 2045–2050.





Insecticides - Basic and Other Applications Edited by Dr. Sonia Soloneski

ISBN 978-953-51-0007-2 Hard cover, 268 pages **Publisher** InTech **Published online** 08, February, 2012 **Published in print edition** February, 2012

It is our hope that this book will be of interest and use not only to scientists, but also to the food-producing industry, governments, politicians and consumers as well. If we are able to stimulate this interest, albeit in a small way, we have achieved our goal.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Beverly A. Wiltz (2012). Factors Affecting Performance of Soil Termiticides, Insecticides - Basic and Other Applications, Dr. Sonia Soloneski (Ed.), ISBN: 978-953-51-0007-2, InTech, Available from: http://www.intechopen.com/books/insecticides-basic-and-other-applications/factors-affecting-performance-of-soil-termiticides

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