USES OF OILS IN INSECT CONTROL

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USE OF AGRICHEMICALS

Development of sophisticated organic chemicals as insecticides and acaricides has revolutionized agriculture. The importance of these chemicals cannot be overemphasized. For instance, Borlaug (1972) estimates that if pesticides were completely banned, crop losses would rise to 50% and food prices would increase four- or five-fold.

Though agriculture relies on a large number of insecticides, it requires an even greater number of insecticide adjuvants. For example, by 1960 thousands of surfactants had been discovered compared to hundreds of pesticides (Grondin 1985). With so many adjuvants and insecticides in existence, a plethora of insecticide-adjuvant combinations is possible. Agricultural researchers have experimented with a number of potential adjuvants such as cedar oil, molasses, refined and unrefined vegetable oils, petroleum (mineral) oils, chlorinated terpenes, and ethylene glycol in combinations with different insecticides in various crop situations. After screening these combinations for effectiveness, numerous practical insecticide-adjuvant combinations have been developed.

One effective combination used in cotton pest control was that of methyl parathion and toxaphene. Though toxaphene itself had insecticidal properties, it was primarily used as an additive to improve the application and performance of methyl parathion. For example, Nemec et al. (1968) found that methyl parathion-toxaphene combinations were effective in controlling *Heliothis* pests of cotton. Ware et al. (1975, 1980) and Bigley et al. (1981) found that toxaphene increased the initial deposit and residue life of methyl and ethyl parathion sprays applied to cotton. Toxaphene apparently enhances parathion efficacy on cotton by altering those physical properties (e.g. high volatility) which shorten residue life of the insecticide on cotton leaves.

Similarly, Brown et al. (1982) found that fenvalerate residues on cotton were increased in the presence of toxaphene, whereas permethrin residues were reduced. However, both pyrethroids were synergized by toxaphene against various lepidopteran pests.

However, toxaphene was banned following a report by Hooper et al. (1979) that it is mutagenic. Since this ban agricultural researchers have been testing various chemicals as toxaphene substitutes. In a prescient statement, Nettles and Betz (1975) suggeted that oils and waxes might be effective toxaphene substitutes. They based this suggestion on the fact that many oils and waxes have a consistency similar to chlorinated terpenes like toxaphene, but cause less environmental damage. Indeed, recent work has shown that mineral oils and paraffins may be efficacious insecticide additives (Ochou 1985, Tsuda and Okuno 1985, Hesler 1986). *n*-Paraffins from dodecane to hexadecane and *iso*-

paraffinic oils generally appear to be most effective in synergizing pyrethroid and organophosphate insecticides against various insects.

USE OF OILS AS PESTICIDE CARRIERS

Interest in oils has been renewed due to their potential as toxaphene substitutes and their suitability in ultra-low-volume (ULV) and controlled droplet application (CDA) systems for pesticide application. Oils are also advantageous when used with insecticides in aerosol sprays (Tsuda and Okuno 1985). Where the toxicity of a pesticide depends on good coverage, as with contact insecticides, the spreading of an oil-based formulation over a surface (such as an insect's integument or a leaf surface) may increase its biological effectiveness (Boize et al. 1976).

Oils have been used as insecticide additives for many years. Herbert (1933) reported that brown apricot scale was controlled by aerial sprays of nicotine-dormant oil combinations. When pyrethrins (Barber 1939) or dichloroethyl ether (Pepper and Barber 1940, Wilcox 1943) were combined with mineral oil, optimal control of corn earworms on corn was achieved. Similarly, Wigglesworth (1942) showed that pyrethrins produced toxic symptoms sooner in Rhodnius prolixus Stal when applied in light oils.

Wickham et al. (1974) demonstrated that knockdown symptoms produced by either pyrethroids or dichlorvos in Blatella germanica (L.) occurred earlier when these insecticides were applied in kerosene than when applied in water. Elmer et al. (1983) showed that scale insects, mealy bugs and mites can be eliminated from citrus budwood when petroleum oils are combined with organophosphates. Ochou (1985) found that the toxicity of two pyrethroids, fenvalerate and permethrin, to house flies and tobacco budworms was enhanced in the presence of mineral oils. Treacy et al. (1986) found that both ULV and conventional soybean oil sprays, compared to aqueous sprays, enhanced the initial toxicity of oxamyl, a carbamate, and cyfluthrin, a pyrethroid, to boll weevils, Anthonomus grandis Boheman, on cotton. Also, they found that ULV/oil sprays increased the 24 and 48 h residual toxicity of cyfluthrin and of azinphosmethyl, an organophosphate.

However, oils do not always improve insecticide and acaricide efficacy. For example, Childers and Selhime (1983) found that lower rates of miticide in combination with a light or medium petroleum oil resulted in significant reduction in residual control of rust mite on citrus compared to standard rates of miticide alone. Ochou (1985) demonstrated that ethyl parathion, methyl parathion and methomyl did not have their immediate toxicities enhanced by oil. Also, Brattsten and Wilkinson (1977) found that the toxicity of carbaryl to southern armyworms Spodoptera eridania Cramer was reduced when combined with any of several solvents.

The choice of an additive can affect activity of a particular insecticide. Ochou (1985) stated that differential effects of oils on insecticides could be explained by differences in the solubility or miscibility of the insecticide with which they are combined. He found that the relatively more oil-soluble pyrethroids had improved toxicity when combined with oils; whereas relatively less oil-soluble organophosphates and a carbamate did not.

Additionally, Brattsten and Wilkinson (1977) stated that most adjuvants are usually considered toxicologically inert and do not directly interfere with a pesticide's metabolic fate. Rather, they alter a pesticide's performance by affecting only physical properties (e.g. solubility, viscosity, surface tension). Sun and Johnson (1972) termed this effect quasi-synergism. However, Brattsten and Wilkinson (1977) contend that additives are not always inert ingredients of pesticide-additive mixtures, but sometimes have metabolic activity. Toxaphene, for instance, has been shown to have significant toxicological activity (Hooper et al. 1979), probably greater than that of most other pesticide additives.

OILS AS INSECTICIDES

Oils have not only been used as pesticide additives or synergists, but also they have been used directly as insecticides and acaricides. Use of oils as insecticides has at least three advantages (Chapman 1967). First, oils pose little human health hazard. Second, insects and mites are apparently less likely to develop resistance to oils. Finally, oils are usually cheaper than competitive pest control products.

Mineral and plant oils are the two major types of oils applied in pest management situations. Uses of mineral oils often differ from those of plant oils. Therefore, the applications and characteristics of both mineral and plant oils will be discussed separately below.

Control of insects with mineral oils or formulations which include mineral oils is an ancient and effective practice (de Licastro et al. 1983). About 1880, kerosene became the first oil regularly used in insect control (Chapman 1967). In orchards, mineral oils have been used as dormant sprays to control scale insects, mites, insect eggs and some hibernating caterpillars, and as summer sprays to control aphids, mealybugs, mites, thrips, psyllids, whiteflies and scale insects (Metcalf et al. 1962, Chapman 1967). Messina and Renwick (1983) found that mineral oils were effective in controlling cowpea weevils Callosobruchus maculatus (F.). However, control of pests of field crops such as cotton may be impractical. Laboratory tests (Ochou 1985, Hesler 1986) showed that mineral oils produced significant mortality of eggs and first instar tobacco budworm larvae, Heliothis virescens (F), only at high dosages of 300 ug/vial or more.

Pearce et al. (1942) discussed the characteristics of mineral oils which provide for their use as insecticides. The major types of oils are hydrocarbons having saturated and unsaturated carbon bonds occurring as either open chain or ring structures. The paraffin series of hydrocarbons exemplifies the saturated, open chain structures. Alternatively, aromatic oils are characterized by carbon chains with substituents such as benzene and naphthalene.

Chapman et al. (1943) cited a study which claimed that mineral oils composed largely of aromatic rings were effective against psyllid and aphid eggs by some unspecified chemical action. Comparatively, their study indicated paraffinic oils kill eggs by enveloping and "stifling" them, i.e. by some kind of physical action. Nevertheless, Pearce et al. (1942) used dormant oils and Chapman et al. (1943) used summer oils to show that the efficiency of ovicidal activity was correlated with paraffinicity, or the absence of aromatic constituents. Thus, oils appeared to act primarily as physical poisons.

Smith and Pearce (1948) elucidated the mode of ovicidal action of mineral oils. Their evidence showed that mineral oil exerts its lethal effect through a mechanical interference with normal gaseous exchange in the egg. However, this interference does not cause oxygen impoverishment nor carbon dioxide accumulation. Rather, mortality seems to occur by accumulation of an unknown gaseous metabolite which oils prevent from passing out through the chorion.

Plant oils, too, have commonly been used as insecticides. These oils are effective in controlling stored food pests (Schoonhoven 1978, Hill and Schoonhoven 1981, Qi and Burkholder 1981, Messina and Renwick 1983). Additionally, cockroaches and grasshoppers showed more susceptibility to dinettia oil, the extract of an African fruit, than to three synthetic insecticides (Iwuala et al. 1981).

Like mineral oils, plant oils are considered physical poisons which interfere with respiration in insects (Chapman 1967). However, some plant oils possess compounds that cause chemical poisoning as well. For instance, Hill and Schoonhoven (1981) showed that triglycerides and oleic acid extracts alone were toxic to bruchids.

EFFECTS OF OILS ON INSECTICIDE RESIDUES ON LEAVES

The fate of insecticide residues on leaves is important in regard to the time in which an insecticide is available and active as a contact poison to insects. Also, an understanding of the fate of insecticides on leaves is critical in regard to field worker reentry standards (Ware et al. 1980) and to concerns about environmental contamination.

Once an insecticide is applied to a leaf surface, it can be lost in several ways: volatilization, photodegradation, translocation into leaf compartments and other plant organs, washing off by rain, etc. (Metcalf 1982, Southwick et al. 1983). The degree of loss by any of these means depends on the chemical composition of the insecticide, the particular kind of plant to which the insecticide is applied, environmental conditions, and the nature of any adjuvant used in application. Insecticide remaining on and in the leaf is available for soil incorporation following leaf fall.

Since the goal of insecticide application generally is to leave a residue upon a leaf surface where it is available as a contact poison to insects, any adjuvants which increase the amount and duration of surface residues of insecticide are advantageous for insect control.

Mineral oils (Grondin 1985) and crop oils (Pigg and Board 1986) often enhance penetration of some pesticides (usually herbicides and systemic fungicides) through the waxy layer of cuticle on a leaf. However, Ware et al. (1980) reported that oils increase surface residues of insecticides, and therefore their efficacy, by countering volatility and by providing a protective screen to photodegradation and removal by rainfall. Cole (1986) showed that oils increase total residues of fenvalerate and methyl parathion on cotton leaves.

Enhanced residual insect control can be cost-effective and labor-saving for farmers. Improved residual activity can reduce the number of insecticide applications needed, prolong the intervals between spray treatments and decrease the amount of insecticide applied. However, increased residue duration could also increase the persistence of insecticides in the environment and extend worker reentry intervals.

EFFECTS OF OILS ON THE RATE OF INSECTICIDE UPTAKE BY INSECTS

The cuticle of an insect plays a critical role in the poisoning process of a contact or topically-applied insecticide. Several researchers (Forgash et al. 1962, Matsumura and Brown 1963, Vinson and Brazzel 1966, Plapp and Hoyer 1968, Benezet and Forgash 1972) have demonstrated that decreased penetration of insecticides through the cuticle is one mechanism of resistance.

The exact mechanisms of insecticide penetration through the cuticle have not been fully ascertained. However, the first step appears to be simple dissolution of the insecticide in the epicuticular wax (Ebeling 1974). After dissolution, an insecticide passes into and through the procuticle. The insecticide may traverse the procuticle via the dermal glands (Wigglesworth 1942) or microscopic pore canals (Ebeling 1974), both of which run from the epicuticle through the procuticle to the epidermal cells. However, Matsumura (1963) found that before any significant amount of insecticide passes through the procuticle and enters the hemocoel, most insecticide molecules must bind to and saturate procuticular proteins. Following cuticular penetration, insecticide enters the hemocoel and is distributed via the hemolymph to sites of toxic action.

Wigglesworth (1942) demonstrated that insects with thicker cuticles, probably endocuticles in particular, required more time to be paralyzed by pyrethrum. Since the endocuticle contains relatively more water than other cuticular components, an oil-soluble insecticide may encounter increased resistance in traversing the endocuticle.

Several additives have been shown to expedite insecticide penetration through the cuticle. For example, Nettles and Betz (1975) treated boll weevils with DDT and DDT plus Strobane® (a polychloroterpene, like toxaphene) by injection and by topical application. They observed synergism of DDT by Strobane with topical treatments, but not with injection treatments. This evidence suggested that Strobane aided penetration of topically-applied DDT through the cuticle.

Similarly, Schouest et al. (1983) found that two carbamate insecticides, biscarbofuran-N,N'-disulfide and dicarbasulf, crystallized on the thorax of flies when topically applied in acetone and showed virtually no toxicity. However, when applied in an acetone-kerosene mixture, crystal formation of the cuticle was decreased and toxicity was enhanced. This implied that use of kerosene as a synergist may increase penetration of insecticide through the cuticle by any or all of the following ways: 1) transporting the insecticide to the wax-water interface; 2) concentrating the insecticide at the interface and thus increasing the diffusion gradient; and 3) increasing the solubility of insecticide by raising its partition coefficient and further increasing its rate of diffusion through the cuticle.

Minerals oils share similar properties with Strobane and kerosene and, thus, should enhance insecticide penetration through the cuticle. De Licastro et al. (1983) demonstrated synergism of ethyl parathion by mineral oils against Triatoma infestans (Klug). They attributed the synergism to increased cuticular surface coverage and to speedier penetration of the toxin. Greater penetration was achieved with oils having lower viscosity.

Additionally, Quraishi and Poonawalla (1969) found that ^{14}C-DDT and ^{14}C-lindane applied in oil to the dorsal thorax of cockroaches spread over the entire integument, including the wings, within a few minutes. Oils, then, apparently improve distribution of insecticides to critical sites of entry on the integument, such as the intersegmental membranes.

SUMMARY

Matsumura (1975) ascribed the enhanced toxicity of insecticides applied with oils to three factors. First, oil improves the attachment of contact insecticides to the cuticle. Second, oil dissolves the epicuticular wax and facilitates passage of the insecticide through the wax. Third, oil disrupts the internal protein organization of the cuticle.

As Schouest et al. (1983) note, the interaction of insecticides with the cuticle is probably one of the least understood of the vital processes in insect toxicology. Several oils have been shown to apparently expedite penetration of insecticides through the cuticle. Nevertheless, further research is required to fully elucidate the ways in which oils modify the interaction of insecticides with the insect.

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