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Pesticide Use in South Africa: One of the Largest Importers of Pesticides in Africa

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1. Introduction

South Africa is a diverse country, with a diverse environment that is home to more than 49 000 000 people. Pesticide usage is very often necessary to maintain both agricultural productivity as well as human health. The climatic conditions range from semi-tropic to semi-arid regions. Although the majority of the country has summer rainfall, the south western coastal region is predominantly a winter rainfall area. These variations in climate allows for a wide variety of crops, from tropical fruit to maize and tree plantations. Each individual crop is susceptible to a unique host of pests that in-turn require a unique mixture of pesticides to ensure the best resulting turnover. Currently, South Africa has more than 500 registered pesticides (Pesticide Action Network (PAN), 2010) and is one of the four largest importers of pesticides in sub-Saharan Africa (Osbanjo et al., 2002). In 2006 the import of insecticides, fungicides and herbicides that were packaged for retail totalled $ 170 056 000 the main import partners being Australia, China, Germany and the United States of America (USA) (International Trade Centre, 2011). These pesticides are used in almost every facet of our everyday lives; ensuring the quantity and quality of food we eat to managing the number of rodents and insects in our homes. Although it is evident that there is a vast amount of pesticides present in the South African environment, there is very limited data on the production of pesticides. The last published data indicates that in 2002 around 10 000 kℓ of liquid insecticides was produced exclusively for crop protection of which 43% consisted of organophosphates. During the same year 2 800-tonnes of solid insecticides were

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produced (Statistics South Africa, 2003). Although the usefulness of pesticides cannot be denied, the negative environmental and human health effects cannot be ignored. In South Africa, a number of environmental and anthropogenic factors have to be considered before the impact of large-scale pesticide use can be assessed.

South Africa is a water poor country, with water resources being utilised to their maximum capacity. As discussed by Dabrowski et al. (2009), the trade-off between the economic benefits of exporting agricultural products has to be measured against the loss of water, not only through crop irrigation but also through water quality degradation. The article highlighted this aspect through the calculation of virtual water volumes. These calculated volumes indicated that to ensure sufficient dilution of all agrochemicals, to an acceptable water quality level (used in a typical farming situation applying current-use pesticides), was greater than the amount of water needed for irrigation. The seriousness of these scenarios is highlighted in literature where a diverse array of agricultural chemicals has been measured during run-off events, by once-off sampling and by water monitoring during the growing seasons. Detectable levels of atrazine, terbuthylazine, simazine, acetochlor (Du Preez et al., 2005), DDT and its metabolites, endosulfan, hexachlorocyclohexane (HCH), heptachlor, aldrin, dieldrin, endrin, chlordane (Fatoki et al., 2003), azinophos-methyl, chloropyriphos (Schultz et al., 2001; Dabrowski et al., 2002) prothiofos (Schultz, 2001), malathion, zendoxsulfan (Thiere & Schultz, 2004), cypermethrin and fenvalerate (Bollmohr et al., 2007), to name a few, have all been measured in South African waters. Pesticides in the aquatic environment have the potential to affect all end-users, including both humans and wildlife.

South Africa has the distinction of being one of the countries with the most species richness in the world. To date more than 900 bird species as well as over 200 mammals, call South Africa home. Of these mammals, seven species are endangered and 30 are vulnerable according to the 2004 IUCN red data list (IUCN, 2010). These endangered species include bats, moles, shrews and mice that are often insectivorous, thus increasing their risk of unintentional exposure to pesticides. Within avian populations, 11 species are listed as critically endangered and 43 species as vulnerable. The sensitivity of avian species to pollutants has been widely reported. With this unique diversity of species, South Africans have a responsibility towards maintaining the viability of ecosystems and natural habitats to ensure the continued existence of these creatures. This objective is not only morally relevant but also economically relevant especially in a country where tourism creates over 400 000 jobs and contributes approximately 8% to the GDP. Few studies have reported the levels of insecticides in wildlife species. However, pesticides have been detected in wild bird species (Van Wyk et al., 2001; Bouwman et al., 2008), as well as in indigenous fish species (Barnhoorn et al., 2009), indicating pesticide contamination within various habitats. This is of particular concern due to the health risks associated with many pesticides.

2. Health effects associated with pesticide usage

2.1 Biomagnification

Depending on the chemical structure of the pesticides, they have a variety of detrimental effects that were not intended when first developed and used as an insecticides or herbicide. Two of the most common ecotoxicological effects almost all pesticides exhibit (to a greater or lesser extent), are their ability to be bioconcentrated by organisms and/or bio-magnified in food webs. Bio-concentration occurs when a compound has a higher concentration in the tissues of an organism, than in its surrounding environment. This often occurs in aquatic organisms, since they are surrounded by the medium in which the insecticide/herbicide is distributed and the compound enters the aquatic organisms through their food and osmosis via the skin and gills. Bio-concentration is not limited to aquatic environments, but may occur in terrestrial environments as well. On the other hand, a compound is biomagnified if its concentration rises through the consecutive levels of a food web. This leads to the highest levels occurring in predators and these levels are much higher, than levels initially applied to land, crops or a water body. The one characteristic that probably contributes most to the extent to which a compound bio-concentrates or bio-accumulates, is its persistence. Pesticides are regarded as persistent if they are resistant to degradation through metabolic activity, ultraviolet radiation and extreme temperatures. Typical examples of pesticides with these characteristics are the organochlorine insecticides: DDT and its metabolites, as well as the cyclodiene insecticides (dieldrin, aldrin, heptachlor, endrin, telodrin and chlordane). Not only are they highly toxic, but they all share very low water solubility (log K_{ow}: 3.78 – 6.36), are highly lipophilic and have low vapour pressures ($4 \times 10^{-4} – 2 \times 10^{-7}$ mm Hg) (Walker, 2009). Due to their persistence in the environment, there is prolonged exposure to these pesticides. Therefore, they enter biota within the affected environment through all relevant routes of exposure.

As an example, when evaluating DDT, the most abundant and widespread residues found in the environment have been *p,p′*-DDE, *p,p′*-DDT and *p,p′*-DDD. All these compounds are highly persistent in soils, with half-lives of years once they have adsorbed onto the carbon content of soil. The longest half-lives have been recorded in temperate soils with a high abbundance of organic matter (Cooke & Stringer, 1982). *p,p′*-DDE has the longest half-life in terrestrial animals and might explain its presence in terrestrial food webs years after bans on DDT were promulgated (Newton, 1986). Unchanged *p,p′*-DDT tends to decrease very slowly when absorbed/ingested by land vertebrates. In female mammals a certain amount is excreted into milk or across the placenta into the developing embryo or into eggs in the case of birds and reptiles (Walker, 2009), thus leading to detrimental teratogenic or reproductive effects. The same tendency is seen for the cyclodiene pesticides. In one example, dosing small female tortoiseshell butterflies (*Aglais urticae*) with dieldrin led to an increased number of deformed adults emerging from the pupae (Moriarty, 1968). Dieldrin, aldrin and heptachlor have half-lives in soil varying between 0.3 and 2.5 years (Edwards, 1973) and in vertebrates the half-lives vary between 12 and 369 days (Environmental Health Criteria 91). Biomagnification of highly lipophilic compounds, such as DDT metabolites and the cyclodienes, in the aquatic food web is due to bioaccumulation in the trophic levels, and through bio-concentration of the chemicals present in the ambient water. In a Pacific Ocean food web, zooplankton bioconcentrated total DDT residues 10 000 times to that found in the ambient water. The levels found in the striped dolphin (*Stenella coerolea alba*) were 100 times higher than that found in the zooplankton (Tanabe & Tatsukawa, 1992). *p,p′*-DDE can also undergo bioaccumulation in terrestrial food webs. Studies with earthworms and slugs showed the bioconcentration of total DDT residues, and dead blackbirds and song thrushes contained DDT residue levels 20 times higher than that found in the earthworms (Bailey et al., 1974). The bioaccumulation factor (BAF) of dieldrin was shown to be 63 in shag (*Phalocrocorax aristotelis*) as compared with its main prey, sand eel (Robinson et al., 1967).

Although not all organometallic compounds are persistent, some free forms of methyl mercury (CH_3HgCl / MeHg) are highly lipophilic and undergo bioaccumulation and bioconcentration in the food web. According to a report from the US EPA (1980), fish bioconcentrated MeHg between 10 000 and 100 000 times its level in ambient water.

Additionally higher levels of MeHg were reported in predator compared to non-predator fish species (Environmental Health Criteria 101). Bio-accumulation of MeHg in birds was illustrated by the bioaccumulation factor of 2 in chickens that were fed dressed grain (a common application of MeHg) and a subsequent bioaccumulation factor of 4 in the goshawks that fed on the chickens (Borg et al., 1970). This provided further evidence that MeHg is slowly eliminated by vertebrates and, that predatory birds have weaker detoxifying capacity toward lipophilic xenobiotics as compared to non-predatory birds (Walker, 2009). Other forms of organometallic compounds containing mercury that have shown biomagnification, are the phenyl, alkoxy-alkyl or higher alkyl mercury compounds used as fungicides, although these mercury compounds biodegrade more easily and bioaccumulate less strongly than MeHg.

The second-generation anticoagulant rodenticides such as brodifacoum, difenacoum, flocoumafen and bromodiolone are also persistent and have very high cumulative toxicity that influences specifically the predators and scavengers of exposed rodents. They bind to proteins of the hepatic endoplasmic reticulum and therefore have long half-lives in vertebrates, often exceeding 100 days. The confounding factors that contribute to higher levels of rodenticides in predators and scavengers are:

- Rodents that consumed lethal doses of rodenticide may survive for 5 days or more before they die of haemorrhaging. In that time, they continue to feed, building up residues that finally exceed the levels needed to kill them;
- In addition, some resistant strains of rodents can tolerate relatively high levels of rodenticide and so act as more efficient vectors of the pesticide than susceptible strains;
- Poisoned rodents are likely to be more vulnerable and prone to be selected by the predator, increasing the possible dose to the predator (Walker, 2009).

Another example of a pesticide class which is not nearly as persistent as the organochlorine pesticides, but can undergo bioconcentration in the aquatic environment, is the organophosphorus pesticides (OPs). Chlorpyrifos bioconcentrated 225 fold in the eastern oyster (*Crassostrea virginica*) in comparison to its levels in ambient water (Woodburn et al., 2003). This bioconcentration was due to the very limited metabolic capacity of molluscs. OPs are easily metabolised by soil microorganisms and rapidly removed by soil animals so that these pesticides do not bioconcentrate in the soil (Walker, 2009). Although OPs do not biomagnify in the higher trophic levels, they have been implicated in the poisoning of predatory birds in the USA, UK and Canada (Mineau et al., 1999) as well as decreased earthworm numbers in South African orchards. The latter was due to chronic chlorpyrifos and intermittent azinphos methyl exposure (Reinecke & Reinecke, 2007). Pyrethroids are also lipophilic and can undergo bioconcentration in the lower trophic levels of the aquatic environment, but they are readily biodegradable by most organisms of higher trophic levels and do not biomagnify in either aquatic or terrestrial food webs. However, they strongly adsorb in soils and sediments where they become persistent.

2.2 Population decline of non-target organisms

Many pesticides can cause population declines of non-target organisms because of their persistence and modes of action. In this section examples of population declines are presented. Population decline of birds on the higher levels of the food web (such as the bald eagles, peregrines and double-breasted cormorant in North America) were explained by the two-fold effect of biomagnification and eggshell thinning (Peakall, 1993;

Wiemeyer et al., 1993; Walker et al., 2006). Eggshell thinning is possibly due to the inhibition of the Ca^{2+}ATPase in the avian shell gland (Lundholm, 1987). A second possible mechanism for eggshell thinning is the evidence that *p,p′*-DDE can affect prostaglandin levels in the eggshell gland and thus contribute to eggshell thinning (Lundholm, 1997).

Population declines of bird species from England, Scotland, Canada and Norway have been reported because of DDT contamination of the environment (Walker, 2009). Another example of population decline of predatory birds such as the sparrowhawk (*Accipiter nisus*) and the peregrine falcon (*Falco pergrinus*), in Britain, coincided with the introduction of aldrin, dieldrin, and heptachlor in 1956 (Ratcliffe, 1993). Both these predatory birds preyed on seed-eating birds that fed on grain treated with these compounds. At the time when cyclodienes were widely used in Western Europe and North America, mammalian predators such as the fox (*Vulpes vulpes*) and badger (*Meles meles*) died due to lethal doses from their prey (Walker, 2009). Furthermore, terrestrial invertebrates such as honeybees are extremely susceptible to OPs.

Herbicides can be indirectly responsible for the population declines of animals by destroying their plant food source. An example of this is the decline of the grey partridge (*Perdix perdix*) in England. The chicks died due to lack of their insect food (sawflies) which in turn were limited because their food source, a weed, was destroyed by herbicides (Potts, 2000). However, a few are also toxic to animals. Dinitro-ortho-cresol and dinoseb act as uncouplers of oxidative phosphorylation in mitochondria, dissipating the energy that would otherwise have driven ATP synthesis. Paraquat and other bipyridyl herbicides have been implicated in the deaths of hares (Sheffield et al., 2001). Their toxicity to both plants and animals is believed to be due to cellular damage caused by oxyradicals (Hassall, 1990; Timbrell, 1999). Carbamate herbicides (chlorpropham) and sulphonylurea herbicides such as chlorsulfuron and sulfometuron have effects on cell division. In the next section two particular modes-of-action that contribute to population decline are presented. Both endocrine disruption and neurotoxic effects have specific methods through which they contribute to population decline.

2.3 Endocrine disrupting effects

Many pesticides (and herbicides) mimic hormones endogenous to animal bodies. In doing so, they can activate or inhibit the natural responses to the hormone causing disruption of the healthy process. This is described as endocrine disrupting (ED) effects. *o,p′*-DDT has been shown to have oestrogenic activity in birds (Bitman et al., 1978; Holm et al., 2006) and it is considered to be a more potent oestrogen than *p,p′*-DDE (Fry & Toone, 1981). The estrogenic effects seen in fish due to *p,p′*-DDE and dieldrin are attributed to three pathways:

- direct interactions with sex steroid receptors;
- changes in sex steroid biosynthesis;
- and changes in sex steroid metabolism (Garcia-Reyero et al., 2006).

The feminised effects seen in wildlife populations may result from chemicals blocking the androgen receptor (antiandrogenic) rather than as a consequence of exposure to (or in addition to) environmental oestrogens (Walker, 2009). Herbicides linuron and diuron and metabolites of the fungicide vinclozolin are antiandrogens as well (Gray et al., 1994).

Other organochlorine pesticides, methoxychlor and metabolites, and lindane and kepone can induce aberrant gonadal development, vitellogenin production, behavioural changes and disrupted ionic regulation in fish (Davy et al., 1973; Metcalfe et al., 2000). Another pesticide well known for its endocrine disruptive effects (an androgenic effect), is tributyltin (TBT). TBT compounds have been used as antifoulants on boats, as biocides for cooling systems, in paper and pulp mills, textile mills, breweries, leather plants and as molluscicides. Their toxicity is linked to two pathways:

- they act as inhibitors of oxidative phosphorylation in mitochondria (Aldridge & Street, 1964) causing disruption of the energy supply to the body;
- and they inhibit cytochrome P450 (Morcillo et al., 2004).

Cytochrome P450 enzymes are a large and diverse group of enzymes responsible for the oxidation of organic substances, including lipids, steroidal hormones, as well as drugs and toxic chemicals. It is this second toxic effect that most likely leads to TBT's hormone disrupting effect because TBT can inhibit cytochrome P450-based aromatase activity in both vertebrates and aquatic invertebrates (Morcillo et al., 2004; Oberdorster & McClellan-Green, 2002). Aromatase converts testosterone into oestrogen and when aromatase is inhibited, testosterone levels rise. The result of these inhibiting effects by TBT causes the masculinization of female gastropods (imposex) (Matthiessen & Gibbs, 1998). These females cannot reproduce, leading to decreasing population numbers. TBT also caused the masculinization of the Japanese flounder (Shimasaki et al., 2003). Of the pyrethroid pesticides, permethrin, fenvalerate, and cypermetrhin have been reported to show (anti)oestrogenic and/or (anti)androgenic activity (Sun et al., 2007). Organophosphate pesticides (OPs) have been shown to have effects on the immune system of rodents (Galloway & Handy, 2003) as well as fish reproduction (Sebire et al., 2008). Blue death, a pesticide mixture consisting of carbaryl, carbufuran and camphechlor (although campechlor has been banned in South Africa since 1970) indicated a positive correlation with birth defects of the male reproductive structures of babies born from mothers from the Eastern Cape in South Africa (Heeren, 2003). This might be due to endocrine disruption. The fungicide vinclozolin and the pyrethroid insecticides fenvalerate and permethrin have also been shown to interfere with progesterone function (Kim et al., 2005).

2.4 Neurotoxic effects

p,p'-DDT and *p,p'*-DDD are persistent neurotoxins and may very well have caused behavioural effects in the field. *p,p'*-DDT binds reversibly to a site on axonal Na^+ channels, which are voltage dependent (Eldefrawi & Eldefrawi, 1990) and delays the usual quick closure of the channel and subsequent termination of the signal generated as a result of the Na^+ current. Pyrethroids have a similar effect. *p,p'*-DDT can also act on the K^+ channel, which is important for the repolarization of the axonal membrane after passage of the action potential. DDT and pyrethroids affect nerve transmission, and therefore, disruption of the regulation of the action potential occurs and this can lead to repetitive discharge. Pyrethroid show very marked selective toxicity. They are highly toxic to terrestrial and aquatic arthropods and to fish, but only moderately toxic to rodents and still less toxic still to birds (Walker, 2009). Some combinations of pyrethroids with ergosterol-biosynthesis-inhibiting (EBI) fungicides containing the active compound, prochloraz have synergistic effects and become even more toxic to honey bees (Pilling & Jepson, 1993). This synergistic mechanism is largely attributed to prochloraz inhibiting cytochrome P450's detoxifying capacity (Pilling et al., 1995) and is of particular concern due to recent reductions in honeybee populations worldwide.

The cyclodienes, such as γ-HCH (lindane) are inhibitors of the gamma aminobutyric acid (GABA) receptor in the mammalian and insect brain as well as in insect muscles. The GABA receptors possess chloride channels that, when open, permit the flow of Cl^- with consequent repolarization of nerves and reduction of excitability. They are particularly associated with inhibitory synapses and in vertebrates exposure to cyclodienes may lead to convulsions. Other symptoms include changes in the electroencephalogram (EEG) patterns, disorientation, loss of muscular coordination and vomiting (Hays & Laws, 1991). Dieldrin showed changes in the learning ability of squirrels (Van Gelder & Cunningham, 1975) and toxaphene caused changes in the behaviour of gold fish (Warner et al., 1966).

Mercury containing compounds are also detrimental to the nervous system, particularly the organic mercury compounds. They can cross the blood-brain barrier, but the inorganic mercury salts cannot. MeHg strongly binds to the –SH groups of amino acids, preventing normal protein function (Crosby, 1998). It binds to the cysteine groups (amino acids with –SH) of acetylcholine receptors and inhibits Na^+/K^+ ATPase (Clarkson, 1987). This may cause extensive brain damage such as degeneration of small sensory neurons of the cerebral cortex leading to behavioural effects in mammals. Initially, the animals become anorexic and lethargic. As toxicity increases, muscle ataxia and blindness occur. At even higher levels, convulsions occur, which lead to death. Apart from its direct toxic effects, MeHg might have adverse interactive potentiation with other pollutants such as polychlorinated biphenyls, -dibenzo-*p*-dioxins, -dibenzofurans, *p,p'*-DDE, metals and selenium in specifically the aquatic environment specifically (Walker & Livingstone, 1992; Heinz & Hoffman, 1998).

OPs prevent the formation of the enzyme cholinesterase (ChE), which ensures that the chemical signal that causes a nerve impulse is stopped at the appropriate time and because of this, is neurotoxic to vertebrates and non-target invertebrates. They may cause behavioural effects. Symptoms of exposure include nausea, headaches, twitching, trembling, excessive salivation and tearing, inability to breath because of paralysis of the diaphragm and convulsions (Chopra et al., 2011). A few of these compounds (mipafox and leptophos) have been found to cause delayed neurotoxicity, but it was not caused by (ChE) inhibition. The target is neuropathy target esterase (NTE) (Johnson, 1992). No symptoms are seen immediately after phosphorylation of the enzyme but distal muscles become paralysed 2 to 3 weeks after the exposure and residues have disappeared from the body. Carbamates cause ChE inhibition poisoning by reversibly inactivating the enzyme acetylcholinesterase (Chopra et al., 2011). OPs and carbamates are readily biodegradable and do not bio-accumulate in the food web and are therefore regarded as "safer" than the more persistent organochlorine pesticides, but they have very high acute toxicity and some carbamates cause environmental problems because of their high vertebrate toxicity (Walker, 2009). In a study by Heeren et al. (2003) nervous system birth defects in babies born to mothers from the Eastern Cape in South Africa were positively correlated to the mother's exposure to agricultural chemicals that included OPs. Among the birth defects were nervous system defects.

The health risk posed by many pesticides was the driving force around the adoption of maximal residue levels (MRL) in agricultural products. MRLs have been initiated not only to ensure the quality of food imports, but also to ensure that the levels of pesticides that consumers are exposed to do not hold appreciable health risks. Of the 500 plus registered pesticides in South Africa, 229 have MRLs as listed in Table 1. Also listed in Table 1, are the chemical classifications of the pesticides as well the crops on which these pesticides are commonly used as related to the MRLs. The vast majority of these pesticides are carbamates, organophosphates and pyrethroid, that are additionally used on a wide variety of crops. There are also a number of alternative remedies registered for use in South African agricultural activities such as microbial, botanical and pheromone agents.

3. Agricultural activity in South Africa

In 2009, South Africa was ranked 31st on the international gross domestic product (GDP) list, making South Africa the top producing country from the African continent. The agro-industrial sector contributes approximately 12% to the GDP and employs 8% of the formal workforce. However, estimates have been as high as 30% when non-registered farm workers and subsistence farmers in rural areas were included. This entire sector is dependent on agricultural yields for their livelihood. To maintain agricultural yields a host of crop protection methods are implemented. One of the most effective and widely accepted methods is the use of pesticides. The agricultural sector is an essential part of the South African economy, and is vital for food security. According to the World Bank (2011), 70% of the world's poor rely on agriculture as their main source of income and employment. This trend is evident in South Africa as well. Smallholdings and subsistence farming are prevalent in rural areas where weather conditions permit, although current trends indicate an increased drive to develop these small-scale agricultural activities into commercial farms. However, without the necessary training and management this often leads to farming practices predominantly reliant on the use of pesticides. In the economic domain, pesticides do not only assist but also hinder sales, through export restrictions. There is a universal trend to increase pesticide legislation with more stringent adherence to MRLs in the global market.

The agricultural sector is responsible for 8% of South Africa's total exports (South African Department of Agriculture (DAFF), 2009). In the year 2008/2009, the largest agricultural export products for South Africa were wine ($922 million); maize ($904 million); citrus fruit ($814 million); apples, pears, quinces ($465 million) and grapes ($316 million) (DAFF, 2010). During this period the largest export trade partners were Zimbabwe ($698 million), the Netherlands ($695 million), the United Kingdom ($689 million), Kenya ($367 million) and Mozambique ($333 million) (DAFF, 2010). Due to favourable climatic conditions, a surplus of maize was produced in 2008/2009. Also, the recent national crisis in Zimbabwe led to increased maize export from South Africa to Zimbabwe. The trend in previous years has seen African trade increase with both Zimbabwe and Mozambique as major export destinations (DAFF, 2009; DAFF, 2010). Agricultural production and trade does vary naturally. However, wine and fruit exports consistently dominate as the major export products for South Africa.

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Propyzamide	Amide herbicide	0.02 - 0.1: Apples, apricots, cherries, grapes, peaches, pears and plums
Diphenylamine	Amine fungicide, insecticide and plant growth regulator	10: Apples and pears
Boscalid	Anilide fungicide	5: Grapes
Fenhexamid	Anilide fungicide	5: Grapes
Clodinafop-propargyl	Aryloxyphenoxy propionic acid	0.05: Wheat
Fluazifop-P-butyl	Aryloxyphenoxy propionic acid herbicide	0.01 - 0.2: Apples, apricots, beans, carrots, coffee, grapes, nuts, peaches, pears, plums, potatoes, quinces, soya beans and sugar cane
Haloxyfop-R	Aryloxyphenoxy propionic acid herbicide	0.05: Apples, apricots, citrus, grapes, peaches, pears, pineapples and plums; 0.1 - 0.5: Beans, beetroot, cotton seed, dry beans, peas, soya beans and sugar cane; 1 - 2: Groundnuts and lucerne
Propaquizafop	Aryloxyphenoxy propionic acid herbicide	0: Milk; 0.05 - 0.2: peas, cucurbits and clover
Bromuconazole	Azole fungicide	0.02 - 0.2: Apples, barley and wheat
Cyproconazole	Azole fungicide	0.02 - 0.1: Apples, barley, coffee, dry beans, grapes, pears, peas and wheat. 0.2 - 1: Cucurbits and oats
Difenoconazole	Azole fungicide	0.05 - 0.5: Apples, beans, citrus, grapes, groundnuts, pears, potatoes and tomatoes.
Fenbuconazole	Azole fungicide	0.05 - 0.1: Apples, barley, pears, plums and wheat; 1: Apricots and peaches
Flusilazole	Azole fungicide	0.01 - 0.1: Apples, barley, dry beans, grapes, groundnuts, mangoes, pears, peas and wheat
Flutriafol	Azole fungicide	0.05 - 0.1: Apples, barley, dry beans, peaches, pears, soya beans and wheat
Hexaconazole	Azole fungicide	0.01 - 0.05: Cucurbits, dry beans and mangoes; 0.1 - 1: Apples, grapes, peaches, pears, pineapples and pears
Imazalil	Azole fungicide	0.5: Cucurbits; 5: Citrus and musk melons
Myclobutanil	Azole fungicide	0.05 - 0.5 Cucurbits, dry beans, grapes and pears

Chemical	Pesticide notes	South African MRL (mg kg-1) and associated crops
Penconazole	Azole fungicide	0.02 - 0.2: Apples, cucurbits, grapes, pears and peas
Prochloraz	Azole fungicide	0.1 - 0.2: Barley, mushrooms, potatoes and wheat; 2- 10: Avocadoes, bananas, citrus, ginger and mangoes
Propiconazole	Azole fungicide	0.05 - 0.5: Bananas, barley, grapes, groundnuts, maize, peaches, nuts and wheat
Tebuconazole	Azole fungicide	0.02 - 0.1: Barley, beans, citrus, groundnuts, mangoes, oats, onions, potatoes, soya beans, tomatoes and wheat; 2 - 5: grapes
Tetraconazole	Azole fungicide	0.5: Grapes
Triadimefon	Azole fungicide	0.05 - 0.5: Apples, bananas, barley, cucurbits, mangoes, oats, peas and wheat; 2: Grapes
Triadimenol	Azole fungicide	0.05 - 0.5: cucurbits, peas, soya beans and apples; 1: Grapes
Paclobutrazol	Azole plant growth regulator	0.05: Avocadoes, litchis, nuts, mangoes, peaches and plums
Zoxamide	Benzamide fungicide	0.05: Potatoes and 2: grapes
Benomyl	Benzimidazole fungicide	0.05 - 0.1: Maize, groundnuts, pears, sugar cane and wheat. 1 - 3: Apples, apricots, avocados, bananas, grapes, peaches, pears, peppers, plums and tomatoes. 5: Citrus and mangoes.
Carbendazim	Benzimidazole fungicide	0.01 - 0.1: Avocadoes, chicory, dry beans, groundnuts, mangoes, maize, oats and potatoes. 0.2 - 1: Grapes, peas and tomatoes. 3 - 5: Apples, citrus and pears
Thiabendazole	Benzimidazole fungicide	1 - 10: Apples, avocadoes, bananas, citrus, mushroom, musk melons, pears, pineapples and potatoes
Novaluron	Benzolurea herbicide	0.01 - 0.05: Apples, cotton seed, canned peaches, pears and tomatoes
Lufenuron	Benzolurea insecticides	0.02 - 0.1: Tomatoes and cabbage
Acibenzolar-S-methyl	Benzothiadiazole plant activator and fungicide	0.2 - 0.5: Tomatoes and mangoes
Diflubenzuron	Benzoyl urea	0.01: Potatoes, 0.1: mushrooms, 1: apples and pears.
Flufenoxuron	Benzoyl urea insecticide	0.05: Apples and pears
Teflubenzuron	Benzoyl urea insecticide	0.02 - 0.5: Citrus and litchis

Chemical	**Pesticide notes**	**South African MRL (mg kg-1) and associated crops**
Triflumuron	Benzoyl urea insecticide	0.1 - 0.5: Chicken fat, citrus, litchis, mangoes and peaches; 2: Apples and pears
Thiophanate-methyl	Bezimidazole precursor fungicide	0.1: Barley, groundnuts and wheat; 3 - 5: Apples, citrus and pears
Dicamba	Benzoic acid herbicide	0.1 - 0.2: Maize, sorghum, sugar cane and wheat.
Diquat dibromide	Bipyridylium desiccant and herbicide	0.05: Potatoes and 0.5: sunflower seed
Paraquat dichloride	Bipyridylium herbicide	0.02 - 0.5: Cotton seed, maize, sugar cane
Emamectin, benzoate	Botanical insecticide	0.01: Tomatoes
Pyrethrins	Botanical insecticide	1 - 2: Apples, apricots, beans, broccoli, Brussels sprouts, cabbage, cauliflower, cereal grains, citrus, cotton seed, cucurbits, dried fruit, dried nuts, dried vegetables, grapes, groundnuts, guavas, lettuce, oil seeds, peaches, plums, sunflower seed and tomatoes
Gibberellins	Botanical plant growth regulator	0.05- 0.2Apples, citrus and grapes
Iprovalicarb	Carbamate fungicide	0.05 - 0.5: Grapes, potatoes and tomatoes
Maneb	Carbamate fungicide	0.01: all foodstuffs except cereal grains and grapes. 0.1: cereal grains. 180: grapes
Oxycarboxin	Carbamate fungicide	0.5: Beans
Propamocarb hydrochloride	Carbamate fungicide	0.5: Potatoes and 2: cucumbers
Thiram	Carbamate fungicide	3 - 5: Apples, apricots, grapes, peaches, pears and plums
Carbosulfan	Carbamate insecticide	0.05 - 0.2: Grapes and maize
Formetanate	Carbamate insecticide	0.02 - 0.5: Apples, citrus, grapes and peaches
Methiocarb	Carbamate insecticide	0.1 - 0.2: Apples, apricots, citrus, grapes, pears and plums
Methomyl	Carbamate insecticide	0.02 - 0.2: Beans, broccoli, Brussels sprouts, cabbage, cauliflower, citrus, maize, peaches, potatoes, sorghum, sunflower seed, tomatoes and wheat

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Pirimicarb	Carbamate insecticide	0.05 - 0.5: Apples, broccoli, Brussels sprouts, cabbage, cauliflower, citrus, cotton seed, groundnuts, oats, peaches, nuts, potatoes, sorghum and wheat
Propoxur	Carbamate insecticide	0.05: grapes
Thiodicarb	Carbamate insecticide	0.1 - 0.5 Cotton seed and maize
Carbofuran	Carbamate insecticide and nematicide	0.05 - 0.5: Broccoli, Brussels sprouts, cabbage, cauliflower, cotton seed, maize, potatoes, sorghum, sugar cane, sunflower seed and wheat.
Carbaryl	Carbamate insecticide, nematicide and plant growth regulator	0.1 - 0.5: Cactus pears, castor oil seed, cottonseed, maize, meat, eggs, milk and poultry. 2.5: Apples, apricots, beans, grapes, pears, sorghum and wheat
Aldicarb	Carbamate pesticide	0.05: cottonseed, nuts, maize and pineapples. 0.2-0.5: Bananas, citrus, coffee, grapes, groundnuts, sweet potatoes and tomatoes. 1 -2: Fodder (hay), potatoes and hops (dry).
Bendiocarb	Carbamate pesticide	0.1 - 0.2: Maize and sorghum
EPTC	Carbamate pesticide	Beans, maize, potatoes, sugar cane, sunflower seed, sweet corn and sweet potatoes
Dichlorophene	Chlorinated phenol fungicide, herbicide, microbiocide	Pineapples, potatoes and tomatoes.
Alachlor	Chloroacetanilide	0.05 - 0.1: Broccoli, Brussels sprouts, cabbage, groundnuts, maize, pineapples, potatoes, soya beans, sugar cane and sunflower seed
Acetochlor	Chloroacetanilide herbicide	0.02- 0.05: Cotton seed, groundnuts, maize, sorghum and sugar cane
Metazachlor	Chloroacetanilide herbicide	0.05 - 0.1: Cabbage, dry beans, groundnuts, maize, potatoes, sugar cane, sunflower seed and sweet corn
Metolachlor	Chloroacetanilide herbicide	0.05: Beans, cotton seed, dry beans, groundnuts, maize, potatoes, sorghum, soya beans, sugar cane and sunflower seed
Propachlor	Chloroacetanilide herbicide	0.1 - 0.2: Maize, onions and sorghum

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Diclofop-methyl	Chlorophenoxy acid or ester herbicide	0.05: Wheat
MCPA and its salts	Chlorophenoxy acid or ester herbicide	0.1: Barley, maize, potatoes, rye, sorghum, sugar cane and wheat
Triclopyr	Chloropyridinyl herbicide	0.1: Citrus
Cycloxydim	Cyclohexenone derivative herbicide	0.5: Beans, cottonseed, cucurbits, dry beans, grapes, groundnuts, onions, soya beans and tomatoes.
Tralkoxydim	Cyclohexenone derivative herbicide	0.05: Barley and wheat
Dimethipin	Defoliant and plant growth regulator	0.1: Cotton seed
Tebufenozide	Diacylhydrazine insecticide	1: Apples and pears
Iprodione	Dicarboximide fungicide	0.05 - 0.5: ginger, onions and canned peaches; 1 - 5: Apricots, apples, citrus, grapes, kiwifruit, peaches, pears, plums, raspberries, strawberries and tomatoes
Vinclozolin	Dicarboximide non-systemic general use pesticide and fungicide	1 - 3: Strawberries and grapes
Pendimethalin	Dinitroaniline herbicide	0.05: Potatoes
Trifluralin	Dinitroaniline herbicide	0.05: Cabbage, chillies, cowpeas, dry beans, groundnuts, kidney beans, soya beans, sunflower seeds and tomatoes; 1: Carrots
Dinocap	Dinitrophenol derivative fungicide and insecticide	1: Apples, broccoli, Brussels sprouts, cabbage, cauliflowers, cucurbits, grapes, peaches, pears and peas
Fomesafen	Diphenyl ether herbicide	0.05: Dry beans, groundnuts and soya beans
Oxyfluorfen	Diphenyl ether herbicide	0.05: Citrus and garlic
Zineb	Dithiocarbamate fungicide	0.05 - 0.5: Groundnuts, onions and potatoes; 3: Apples, apricots, bananas, beans, boysenberries, broccoli, Brussels sprouts, cabbage, cauliflower, citrus, cucurbits, grapes, guavas, mangoes, olives, papayas, peaches, pears, peppers, plums, quinces, tomatoes and youngberries
Furfural	Fumigant	Carrots, lettuce, onions, potatoes and sugar cane

Chemical	**Pesticide notes**	**South African MRL (mg kg^{-1}) and associated crops**
Cymoxanil	Fungicide	0.01 - 0.2: Grapes, potatoes and tomatoes
Dithianon	Fungicide	2: Apples, apricots, peaches, pears and plums
Epoxiconazole	Fungicide	0.01 - < 0.05: Maize and barley
Famoxadone	Fungicide	0.01 - 0.02: Potatoes, 0.2: tomatoes, 1: grapes
Fludioxonil	Fungicide	0.5: Grapes
Fosetyl-Al	Fungicide	5 - 50: Avocadoes, boysenberries, citrus, cucumber, grapes, pineapples, potatoes and youngberries
Guazatine	Fungicide	2.5: Tomatoes and 5: Citrus
Spiroxamine	Fungicide	0.05: Barley and wheat; 0.1: peas and 1: grapes
Dodine	Guanidine fungicide and microbiocide	1: Apples, pears and quinces
Methyl bromide	Halogenated organic fumigant, herbicide, insecticide and nematicide	10- 100: Cereal grains, dried fruit, dried legumes, processed grain products and groundnuts
Cyhexatin	Heavy metal, organotin insecticide	2: Apples, citrus, peaches, pears, plums and tomatoes. 150: Hops (dry).
Fenbutatin-oxide	Heavy metal, organotin insecticide	0.2 - 2: Apples, beans, citrus, peaches, pears, peppers and tomatoes
2,4-D	Herbicide	0.5 - 2: Barley, citrus, maize, potatoes, rye, sorghum, sugar cane and wheat
Fluorochloridone	Herbicide	0.02 - 0.05: Apples, carrots, grapes, nectarines, pears, plums, potatoes and sunflower seed
Mesotrione	Herbicide	0.01: Maize
Sulcotrione	Herbicide	0.05: Maize and sugar cane
Ioxynil	Hydroxybenzonitrile herbicide	0.05: Sugar cane
Bromoxynil phenol	Hydroxybenzonitrile insecticide	0.1: Barley, maize, oats, sorghum, sugar cane and wheat
Imazapyr	Imidazolinone herbicide	0.05: Dry beans, groundnuts and soya beans
Magnesium phosphide	Inorganic fumigant and rodenticide	0.01: all foodstuffs except cereal grains and grapes. 0.1: cereal grains. 180: grapes

Chemical	Pesticide notes	South African MRL (mg kg-1) and associated crops
Phosphoric acid	Inorganic fungicide, herbicide, antimicrobial and pH adjuster	25 - 50: Grapes and citrus
Calcium arsenate	Inorganic heavy metal herbicide, insecticide and rodenticide	0.2: Citrus
Sulphur	Inorganic herbicide and insecticide	50 - 55: Apples, apricots, avocadoes, bananas, beans, boysenberries, citrus, cucurbits, grapes, litchis (pulp), mangoes, papaya, peaches, pears, peas, peppers, plums, tomatoes and youngberries; 1 000: litchis peel
Aluminum phosphide	Inorganic phosphide fumigant	0.01: all foodstuffs except cereal grains and grapes. 0.1: cereal grains. 180: grapes
Propineb	Inorganic -zink carbamate antimicrobial and fungicide	0.5: Groundnuts and potatoes; 3: Boysenberries, grapes, tomatoes and youngberries
Mancozeb	Inorganic-zinc carbamate fungicide	0.01: all foodstuffs except cereal grains and grapes. 0.1: cereal grains. 180: grapes
Metiram	Inorganic-zinc carbamate fungicide	0.5: Potatoes; 3: Apples, apricots, beans, grapes, peaches, pears, plums and tomatoes
Buprofezin	Insect growth regulator	0.05: Avocadoes and peaches
Bromopropylate	Insecticide	0.2 - 3: Bananas, citrus, cotton seed and grapes
Etoxazole	Insecticide	0.1 - 0.2: Apples, pears and tomatoes
Fenazaquin	Insecticide	0.05 - 0.5: Apples, citrus, pears and tomatoes
Indoxacarb, S-isomer	Insecticide	0.01 - 0.05: Potatoes, cauliflower; 0.02 -0.2: Tomatoes, beans, peaches and peas; 1: Apples, cabbage, broccoli, Brussels sprouts and pears
Propargite	Insecticide	0.05 - 0.5: Cotton seed and pears; 2 - 3: Apples, citrus, peaches, strawberries and tomatoes
Tetradifon	Insecticide	0.05: Cotton seed; 5 - 8: Apples, apricots, citrus, cotton seed, peaches, pears, plums and dry tea
Triforine	Insecticide and fungicide	0.1 - 0.5: Cucurbits and peas; 1 - 2: Apples, beans, peaches and plums
Spirodiclofen	Keto-enol insecticide	0.01: Peaches

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Ametryne	Methylthiotriazine herbicide	0.05 - 0.2: Bananas, maize, pineapples and sugar cane
Milbemectin	Microbial insecticide	0.01: Apples and tomatoes
Spinosad	Microbial insecticide	0.01 - 0.5: Apples, apricots, beans, citrus, cabbage, cucurbits, grapes, guavas, mangoes, olives, peaches, pears, peas, plums, potatoes and tomatoes
Dimethomorph	Morpholine fungicide	0.01: Potatoes, 0.1: tomatoes and 5: grapes
Tridemorph	Morpholine fungicide	0.1 - 0.2: Cucurbits and peas
Copper and its salts	Multiple forms and uses	1: Potatoes and nuts. 20: Apples, apricots, avocados, beans, boysenberries, broccoli, Brussels sprouts, cabbage, cauliflower, celery, cherries, citrus, coffee, cucurbits, granadillas, grapes, guavas, lettuce, mangoes, olives, peaches, pears, peppers, plums, strawberries, tomatoes and youngberries.
Acetamiprid	Neonicotinoid insecticide	0.2 - 0.50: Barley, canola, citrus, oats, cotton seed, tomatoes and wheat
Imidacloprid	Neonicotinoid insecticide	0.05 - 0.5: Apples, citrus, cotton seed, cucurbits, grapes, maize, sorghum, sunflower seed, tomatoes and wheat
Thiacloprid	Neonicotinoid insecticide	0.1: Peaches and 1: apples
Thiamethoxam	Neonicotinoid insecticide and fungicide	0.02 - 0.05: Apples and cotton seed
Cartap monohydrochloride	Nereistoxin insecticide	5: Onions, 10: tomatoes and 150: cabbage
MSMA	Organoarsenic defoliant and herbicide	0.05: Sugar cane
Dicofol	Organochlorine insecticide	Apples, apricots, bananas, beans, broccoli, Brussels sprouts, cabbage, cauliflower, cherries, citrus, cotton seed, cucurbits, granadillas, peaches, pears, peas, peppers, plums, quinces and tomatoes.

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Endosulfan	Organochlorine insecticide	0.05: Granadillas, nuts, pineapples and potatoes; 0.1 - 1: Apples, apricots, Boysenberries, broccoli, Brussels sprouts, cabbage, cauliflower, cherries, citrus, coffee, cotton seed, cucurbits, grapes, groundnuts, maize, onions, paprika, peaches, pears, peas, plums, quinces, sorghum, sugar cane, sunflower, tomatoes, wheat and youngberries; 20: Hops (dry)
Lindane	Organochlorine insecticide and rodenticide	0.01 - 0.02: Milk, cottonseed, onions, potatoes and sweet potatoes; 1: Apples, apricots, beans, broccoli, Brussels sprouts, cabbage, cauliflower, peaches, pears, plums.
Fenthion	Organophosphate acvicide and insecticide	0.1 - 1: Apples, apricots, coffee, cucurbits, grapes, guavas, kiwifruit, mangoes, peaches, pears, plums and quinces.
Acephate	Organophosphate insecticide	1 - 3: Apples, broccoli, Brussels sprouts, cabbage, cauliflower, grapes, peaches, pears, plums, potatoes and tomatoes
Azinphos-methyl	Organophosphate insecticide	0.05: Cottonseed, olives and potatoes. 0.04: Apples and pears. 0.1 - 0.2: Apricots, citrus, peaches and plums.
Cadusafos	Organophosphate insecticide	0.02 - 0.05: Bananas, citrus and potatoes
Chlorpyrifos-methyl	Organophosphate insecticide	8: Cereal grains
Malathion / Mercaptothion	Organophosphate insecticide	0.05: maize, peas, onions, sorghum and sugar cane; 1 - 8: Apples apricots, avocadoes, bananas, beans, broccoli, Brussels sprouts, cabbage, cauliflower, cereal grains, citrus clover, cotton seed, cucurbits, dried fruits, dried nuts, granadillas, grapes, groundnuts, guavas, litchis, mangoes, mushrooms, oil seeds, papayas, peaches, pears, peppers, pineapples, plums, quinces, sunflower seed and tomatoes

Chemical	**Pesticide notes**	**South African MRL (mg kg^{-1}) and associated crops**
Oxydemeton-methyl	Organophosphate insecticide	0.1 - 0.4: Apples, apricots, beans, broccoli, Brussels sprouts, cabbage, cauliflower, citrus, cotton seed, cucurbits, aubergine, groundnuts, maize, onions, peaches, pears, peas, peppers, plums, potatoes, Rooibos, sorghum, tomatoes and wheat.
Parathion	Organophosphate insecticide	0.05 - 0.5: Barley, beans, beetroot, broccoli, Brussels sprouts, cabbage, cactus pears, carrots, castor-oil seed, cauliflower, citrus, coffee, cotton seed, cucurbits, aubergine, groundnuts, mangoes, onions, peas, peppers, quinces, sorghum, spinach, sweet potatoes, tomatoes, turnips and wheat
Phenthoate	Organophosphate insecticide	0.1 - 0.2: Mangoes, onions and potatoes; 1: Broccoli, Brussels sprouts, cabbage, cauliflower and citrus
Phoxim	Organophosphate insecticide	0.2: Cereal grains and groundnuts
Pirimiphos-methyl	Organophosphate insecticide	3 - 10: Groundnuts, maize, sorghum, soya beans, stored wheat and sunflower seed
Procymidone	Organophosphate insecticide	0.05 - 0.5: Citrus, groundnuts, pears and potatoes; 1 - 10: Beans, grapes, peaches, plums and tomatoes
Prothiofos	Organophosphate insecticide	0.05: Apples, apricots, citrus, mangoes, pears and plums; 1: Grapes and guavas
Temephos	Organophosphate insecticide	1: Citrus
Trichlorfon	Organophosphate insecticide	0.05 - 0.2: Apples, apricots, broccoli, Brussels sprouts, cabbage, cauliflower, citrus, coffee, cucurbits, granadillas, grapes, guavas, litchis, maize, peaches, plums, quinces and sweet potatoes; 1: Beans and tomatoes

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Demeton-S-methyl (mixture)†	Organophosphate insecticide	0.1 - 0.5: Apples, apricots, barley, beans, broccoli, Brussels sprouts, cabbage, cauliflower, citrus, cotton seed, eggplant, groundnuts, maize, olives, onions, peaches, pears, peas, peppers, plums, potatoes, Rooibos, sorghum ,tomatoes and wheat
Diazinon	Organophosphate insecticide	0.02: Milk, 0.2 - 0.7: apples, apricots, beans, broccoli, brussels sprouts, cabbage, meat, cauliflower, mushrooms, peaches, pears, pineapples, plums and tomatoes
Dimethoate	Organophosphate insecticide	Apples, barley, beans, broccoli, brussels sprouts, cabbage, cauliflower, citrus, cotton seed, cucurbits, grapes, groundnuts, peaches, pears, pineapples, plums, potatoes, sorghum, strawberries and wheat
Methamidophos	Organophosphate insecticide	0.05 - 0.5: Canola, citrus, potatoes and tomatoes; 1: Apples, apricots, broccoli, brussels sprouts, cabbage, mangoes, peaches, pears and plums
Methidathion	Organophosphate insecticide	0.02 - 0.3: Apples, apricots, cactus pears, cherries, grapes, peaches, pears, plums and potatoes; 2: Citrus
Mevinphos	Organophosphate insecticide	0.05: Potatoes; 0.1 - 0.2: Beans, broccoli, brussels sprouts, cabbage, cauliflower, citrus, cucurbits, grapes, lettuce, peas, peppers, spinach, tomatoes and wheat
Omethoate	Organophosphate insecticide	0.05 - 0.5: Barley, cotton seed, oats and onions; 1 - 1.5: Apples, grapes, pears, peas and wheat
Phosmet	Organophosphate insecticide	2 - 5: Apples and pears
Profenofos	Organophosphate insecticide	0.05: Onions and potatoes; 0.5 - 1: Brussels sprouts, cabbage, cauliflower, citrus and tomatoes

Chemical	Pesticide notes	South African MRL (mg kg-1) and associated crops
Chlorpyrifos	Organophosphate insecticide and nematicide	0.05 - 1: Apples, apricots, bananas, broccoli, Brussels sprouts, cabbage, carrots, cauliflower, citrus, grapes, lettuce, mangoes, maize, wheat, peaches, pears, plums, potatoes and tomatoes.
Disulfoton	Organophosphate insecticide and nematicide	0.05 - 0.5: Cabbage, cauliflower, coffee, cotton seed, onions, potatoes, tomatoes and wheat
Ethoprop	Organophosphate insecticide and nematicide	0.01: Potatoes and 0.05: citrus
Fenamiphos	Organophosphate insecticide and nematicide	0.01 - 0.2: Bananas, citrus, cotton seed, ginger, grapes, groundnuts, guavas, litchis, onions, papaya, peaches, peas, nuts, pineapples, potatoes and tomatoes
Methyl parathion	Organophosphate insecticide and nematicide	0.05: Coffee and 1: citrus
Phorate	Organophosphate insecticide and nematicide	0.05: Apples, broccoli, Brussels sprouts, cabbage, cauliflower, cotton seed, maize, onions, potatoes and wheat
Terbufos	Organophosphate insecticide and nematicide	0.05 - 0.1: Citrus, dry beans, groundnuts, maize, potatoes, sorghum and sunflower seed
Fosthiazate	Organophosphate nematicide	0.05- 0.1: Bananas, citrus and potatoes
Ethephon	Organophosphate plant growth regulator	0.05: Maize and sugar cane. 1 - 5: Apples, cherries, citrus, cotton seed, grapes, peaches, pineapples, plums and wheat
Ortho-phenylphenol	Phenol antimicrobial	10: Citrus
Glyphosate and its salts	Phosphonoglycine herbicide	0.5: Sugar cane and 2: Maize
1-Naphthaleneacetic acid, methyl ester	Plant growth regulator	1: Apples and pears
Chlorfenapyr	Pyrazole insecticide	0.01 - 0.5: Apples, citrus, grapes, nectarines, pears, plums, potatoes and tomatoes.
Fipronil	Pyrazole insecticide	0.01 - 0.05Broccoli, cabbage, cauliflower, citrus and mangoes
Pyraflufen-ethyl	Pyrazolylphenyl herbicide	0.01: Barley and wheat

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Bioresmethrin	Pyrethroid insecticide	0.05: Groundnuts. 0.1 - 1: Apples, apricots, beans, peaches, pears and plums.
Cyfluthrin	Pyrethroid insecticide	0.05: Cottonseed. 0.1 - 0.2: Apples, beans, broccoli, Brussels sprouts, cabbage, cauliflower, grapes, maize, pears, peas, sorghum and tomatoes. 1: Wheat
Cyfluthrin, beta	Pyrethroid insecticide	0.05 - 0.2: Apples, beans, broccoli, Brussels sprouts, cabbage, canola, cauliflower, cotton seed, grapes, nuts, maize, peaches, pears, peas, potatoes, sorghum, tomatoes and wheat.
Cyhalothrin, gamma	Pyrethroid insecticide	0.01 - 0.5: Apples, apricots, grapes, beans, cotton seed, cruciferae, groundnuts, nuts, maize, onions, peaches, pears, peas, plums, potatoes, sorghum, tomatoes and wheat.
Cyhalothrin, lamba	Pyrethroid insecticide	0.01 - 0.5: Apples, apricots, beans, broccoli, Brussels sprouts, cabbage, cauliflower, grapes, groundnuts, maize, onions, peaches, pears, peas, plums, potatoes, sorghum, tomatoes, wheat and nuts
Cypermethrin	Pyrethroid insecticide	0.05 - 0.1: Beans, broccoli, Brussels sprouts, cabbage, cauliflower, cottonseed, grapes, groundnuts, nuts, peas and plums. 0.2 - 1: Apples, citrus, maize, peaches, pears, green Rooibos tea, tomatoes and wheat. 2: Dried rooibos tea
Cypermethrin, alpha	Pyrethroid insecticide	0.02-0.05: groundnuts, cotton seed, grapes, nuts, potatoes, sugar cane and wheat. 0.1 - 0.5: Beans, broccoli, Brussels sprout, cabbage, cauliflower, maize, peaches, pears, peas and tomatoes
Cypermethrin, beta	Pyrethroid insecticide	0.05 - 0.5: Apples, beans, citrus, cruciferae, grapes, groundnuts, nuts, maize, peaches, pears, peas, plums, sorghum, tomatoes and wheat.

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Cypermethrin, zeta	Pyrethroid insecticide	0.05 - 0.5: Apples, beans, broccoli, Brussels sprouts, cabbage, cauliflower, cotton seed, grapes, nuts, maize, peaches, pears, peas, sorghum, tomatoes and wheat.
Deltamethrin	Pyrethroid insecticide	0.05: Cactus pears, groundnuts, mangoes, onions, potatoes, sweet potatoes and tomatoes. 0.1 - 0.2: Apples, beans, broccoli, Brussels sprouts, cabbage, cauliflower, cotton seed, grapes, lettuce, maize, paprika, peaches, pears, plums, sorghum. 1 - 5: Hops (dry), oats, rye, stored grain and wheat.
Esfenvalerate	Pyrethroid insecticide	0.05 - 0.5: Apples, beans, cotton seed, grapes, mangoes, maize, pears, peas, potatoes, sorghum, sunflower seed, tomatoes and wheat, 15: hops (dry).
Fenvalerate	Pyrethroid insecticide	0.05 - 0.1: Grapes, mangoes, wheat, peas, potatoes, tomatoes; 0.5 -1: apples, beans, cotton seed, maize, pears, sorghum, sunflower seed; 15: hops (dry)
Permethrin	Pyrethroid insecticide	0.05 - 0.5: Apples, beans, cotton seed, grapes, groundnuts, maize, pears, peas, potatoes, sorghum, soya beans and tomatoes; 2: Cereal grains
Tau-fluvalinate	Pyrethroid insecticide	0.05 - 0.2: Apples, canola, cotton seed, peaches, pears, tomatoes and wheat
Bifenthrin	Pyrethroid insecticide	0.05 - 0.2: Apples, cottonseed, maize, pears, potatoes and tomatoes.
Acrinathrin	Pyrethroid insecticide and acaricide	0.1: Apples, pears, tomatoes and hops with MRL of 10
Fluroxypyr	Pyridinecarboxylic acid	0.1 - 0.5: Fat, meat, milk and kidney
Bupirimate	Pyrimidine fungicide	0.05 - 0.5: Apples, cucurbits, mangoes and peaches
Cyprodinil	Pyrimidine fungicide	0.05 - 0.1: Apples, barley and grapes
Fenarimol	Pyrimidine fungicide	0.2: Apples and grapes
Mepiquat chloride	Quatenary ammonium plant growth regulator	1: Cotton seed
Quinoxyfen	Quinoline fungicide	0.5 - 1: Cucurbits and grapes

Chemical	Pesticide notes	South African MRL (mg kg^{-1}) and associated crops
Azoxystrobin	Strobin fungicide	0.01 - 0.05: Brussels sprouts, cabbage, maize and potatoes. 0.2 - 1: Broccoli, cauliflower, citrus, grapes, mangoes and tomatoes.
Kresoxim-methyl	Strobin Fungicide	0.01 - 0.5: Apples, citrus, cucurbits, grapes, mangoes and pears
Pyraclostrobin	Strobin Fungicide	0.1 - 0.5: Citrus and grapes
Trifloxystrobin	Strobin fungicide	0.05 - 0.5: Apples, citrus, cucurbits, grapes, maize, pears and potatoes
Chlorsulfuron	Sulfonylurea herbicide	0.05: Oats and wheat
Iodosulfuron methyl, sodium salt	Sulfonylurea herbicide	0.05: Barley and wheat
Metsulfuron-methyl	Sulfonylurea herbicide	0.05: Barley and wheat
Nicosulfuron	Sulfonylurea herbicide	0.05: Maize
Thifensulfuron-methyl	Sulfonylurea herbicide	0.05: Barley and wheat
Triasulfuron	Sulfonylurea herbicide	0.05: Barley and wheat
Tribenuron methyl	Sulfonylurea herbicide	0.05: Barley and wheat
Piperonyl butoxide	Synergist	5 - 20: Apples, apricots, beans, broccoli, Brussels sprouts, cabbage, cauliflower, cereal grains, citrus, cotton seed, cucurbits, dried fruit, dried nuts, dried vegetables, grapes, groundnuts, guavas, lettuce, oil seeds, peaches, pears, plums, sunflower seed and tomatoes
Clofentezine	Terazine insecticide	0.05- 0.2: Apples, pears and tomatoes
Captan	Thiophtalimide	15: Apples, apricots, boysenberries, celery, grapes, guavas, olives, peaches, pears, plums, quinces, spinach, strawberries, tomatoes and youngberries.
Folpet	Thiophtalimide fungicide	0.5: Tomatoes; 15: grapes
Amitraz	Triazapentadien insecticide and acaricide	0.2 - 0.5: Apples, citrus, cotton seed, tomatoes
Simazine	Triazine herbicide	0.2: Apples, grapes, maize and pears; 10: Asparagus
Atrazine	Triazine herbicide	0.05: Maize, sorghum and sugar cane
Cyanazine	Triazine herbicide	0.05: Cottonseed, maize, sugar cane and sweet corn. 0.1 -1: Peas and rooibos
Prometryn	Triazine herbicide	0.05: Cottonseed and 0.5: carrots
Terbutryn	Triazine herbicide	0.05: Groundnuts and peas

Chemical	**Pesticide notes**	**South African MRL (mg kg^{-1}) and associated crops**
Terbuthylazine	Triazine herbicide, antimicrobial and algaecide	0.05: Maize, peas and sorghum
Cyromazine	Triazine insecticides	0.05: Potatoes, 0.5: tomatoes, 2: mushrooms and 5: green beans
Pymetrozine	Triazine insecticides	0.02 - 0.05: Cabbage and cotton seed
Hexazinone	Triazinone herbicide	1: Pineapples
Metribuzin	Triazinone herbicide	0.05: Asparagus and soya beans
Sulfentrazone	Triazolone herbicide	0: Sugar cane
Florasulam	Triazolopyrimidine herbicide	0.01: Wheat
Flumetsulam	Triazolopyrimidine herbicide	0.05: Wheat
Terbacil	Uracil herbicide	1: Peaches
Thidiazuron	Urea defoliant and plant regulator	0.5: Cotton seed
Pencycuron	Urea fungicide	0.05: Potatoes
Diuron	Urea herbicide	0.05 - 0.1: Asparagus and sugar cane
Benalaxyl	Xylylalanine fungicide	0.05: Potatoes and tomatoes. 2: Grapes
Metalaxyl	Xylylalanine fungicide	0.05 - 0.5: Avocados, broccoli, Brussels sprouts, cabbage, cauliflower, pineapples, potatoes and tomatoes. 1 - 1.5: Boysenberries, citrus, grapes and youngberries

Table 1. Pesticides registered in South Africa, including information on chemical classification, application use and relevant crops as indicated by South African MRL levels (South African Department of Health (DOH), 2005; PAN, 2010).

The main agricultural exports in 2009/2010 were wine ($846 million), citrus fruit ($797 million), grapes ($495 million), apples, pears and quinces ($435 million) and cane sugar ($377 million) (DAFF, 2010). During 2009/10, the Netherlands, the United Kingdom, Zimbabwe, Mozambique and Germany were the five largest trading partners. Approximately 20.7% of South Africa's total agricultural exports for the period July 2009 to June 2010 went to the Netherlands and the United Kingdom (DAFF, 2010). These are all crops requiring the responsible use of pesticides (including fungicides and herbicides). The EU, U.S.A and Japan, have stringent food safety requirements as compared to African countries that typically adhere to FAO/WHO CODEX Alimentarius recommendations. To ensure continued trade, South African exporters must continuously ensure that their export products may meet the EU food safety standards in addition to private standards set by large food retailers, e.g., Tesco, Marks & Spencer, Sainsbury's in the U.K (Urquhart, 1999; Frohberg, 2006; String Communication, 2007).

The financial impacts of providing fresh produce that meet the requirements of the importing country are significant. For example: should South Africa be suspended from trading citrus fruit due to exceeding an EU pesticide MRL (either through incorrect pesticide use or incorrect measurements), South Africa would have lost an estimated income of $ 54 million through trade (assuming a typical minimum four month period that is required to take corrective action and have the citrus trade re-instated). To avoid such losses, South Africa is obliged to meet export requirements in primarily two ways, namely through the responsible and correct use of pesticides and through the accurate, internationally recognised measurement and monitoring of pesticide residues (Frohberg et al., 2006; DAFF, 2009, 2010). The European Commission's (EC) Rapid Alert System for Food and Feed (RASFF) identifies risks in food and feed imported into the EU (EU, 2011). Depending on the risk level, the EC will either prohibit the consignment from entering the country (border rejection) or send out an alert notification or an information notification. The former requires immediate corrective action, i.e., withdraw/recall of the product, while the latter requires precautions to be taken in future to avoid further notifications (EU, 2011, 2009). Since 2000, South Africa has received only 4 information notifications and one alert notification for pesticide residues detected on fruit. The detected pesticides were omethoate, dimethoate and ethephon in grapes; methomyl in pears and prophenophos in peppers. The majority of South African border rejections and notifications are due to MRLs being exceeded for aflatoxins in groundnuts. In general the mycotoxin hazard category tends to dominate as the main cause for border rejection in the EU across all importers (EU, 2011, 2009).

In accordance with Article 12 of EU Regulation 882/2004 (EU, 2004), laboratories designated for official control of pesticide residues within the EU must be accredited to ISO/IEC 17025. Accreditation of laboratories is seen as the most effective way of defeating non-tariff technical barriers to trade (for example, eliminating doubt on the quality of test results from exporting countries). For export purposes, measurements performed by analytical laboratories who are accredited to ISO 17025, are internationally accepted, in terms of the International Laboratory Accreditation Cooperation Mutual Recognition Arrangement (ILAC MRA) for trade, of which South Africa is a signatory since November 2000 (ILAC), 2001). Although there are several laboratories analysing pesticide residues in South Africa (National Laboratory Association (NLA), 2010), according to the South African National Accreditation System (SANAS), (SANAS, 2010), there are only nine ISO 17025 accredited analytical laboratories in South Africa capable of analysing pesticide residues in food and feed. Of these laboratories, two are able to analyse the raw and finished products of pesticide formulations (SANAS, 2010). There are two government entities responsible for pesticide residue measurements in food and plant products in South Africa, namely the Department of Agriculture, Forestry and Fisheries and the Department of Health (DoH). Fresh produce for export is well monitored by the Perishable Products Export Control Board (PPECB). The PPECB is South Africa's official certification agency for the export of perishable products. It is mandated by the Department of Agriculture to deliver cold chain services in terms of the PPECB Act, No.9 of 1983 and delivers inspection and food safety services, under the APS Act, No.119 of 1990. The PPECB is also responsible for monitoring imported consignments of fresh produce. The PPECB is ISO 17025 accredited for the analysis of mycotoxins in various plant products (PPECB, 2011). The DoH Food Control Directorate has inspectors that regularly sample food items from the local trade industry; the analysis of which is outsourced to private accredited laboratories with the capacity to conduct extensive analyses.

The DoH, currently does not have the capacity to test a large number of samples for residues. As with several non-accredited facilities in South Africa, reasons for local laboratories not being able to obtain accreditation for residue monitoring include (Apps, 2007; Dlamini, 2007; Fernandes-Whaley, 2009):

- a high turnover of analysts in the laboratory,
- lack of skilled, competent technicians,
- poor financing for analytical equipment required to meet stringent MRLs,
- and lack of appropriate reference materials and the high cost of proficiency testing (PT) scheme participation.

There has been concern that the ever-decreasing MRLs for pesticide residues on food may be considered as technical barriers to trade, especially for developing countries in Africa (Urquhart, 1999; Frohberg, 2006; String Communication, 2007). This may be true, especially for countries in the regions without the necessary technical infrastructure, analytical capability and skills. However, in South Africa, recent proactive investment by government and industry has been implemented into improving the analytical infrastructure for pesticide residues on food (Aldrich & Street, 1964; SABS, 2011), although the lack of skilled human resources still remains a limitation (Apps, 2007; Dlamini, 2007; Fernandes-Whaley, 2009). South Africa currently has nine ISO 17025 accredited laboratories for pesticide residue analysis in plant products. Most of these accredited facilities have obtained technique accreditation for pesticide residues on processed foods and plant products using state-of-the art gas chromatography mass spectrometry and liquid chromatography tandem mass spectrometry techniques, which are able to meet EU MRL requirements and thereby ensuring trade within the South African framework.

4. Alternatives to the use of pesticides in agricultural pest control

In recent years there have been fast developments in alternate pest control mechanisms to reduce environmental levels of organic and inorganic pesticides. One of these developments is genetically modified (GM) crops, such as GM maize and cotton. Sprays of the bacteria, *Bacillus thuringiensis* (Bt), have been used to control pests for decades. The crystalline (cry) protein produced by this bacteria kills certain insect species and was reported to have limited effects on most non-target species (Schnepf et al., 1998). The use of commercial Bt sprays have, however, been limited due to their relatively high cost, poor crop coverage, rapid environmental inactivation, and less than desirable level of pest control, especially when compared with less expensive conventional chemical insecticides (Benedict & Altman, 2001).

More recently, toxin-encoding genes from *B. thuringiensis* have been expressed in transgenic crop plants, providing protection from some key pests (Schnepf et al., 1998). In South Africa two of these key pests of maize are the lepidopteran stem borers, *Busseola fusca* (Lepidoptera: Noctuidae) and *Chilo partellus* (Lepidoptera: Crambidae) which are of economic importance throughout Southern and Eastern Africa. Large-scale planting of Bt crops to control these pests in South Africa commenced during 1998. Bt cotton for control of the boll worm complex, particularly the African bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae), was also introduced into South Africa during 1998. Adoption rates of Bt maize and cotton were high and in many areas of the country, more than 90% of famers plant GM maize or cotton. Based on surface area, South Africa is currently ranked 9th worldwide in planting GM crops (James, 2011). The benefits as well as possible disadvantages of planting Bt maize, from a South African famers perspective was reported by Kruger et al. (2009, 2011) and that of Bt cotton by Mellet et al. (2003).

Although many benefits may be associated with the use of GM crops for pest control, there are also a number of disadvantages. From an environmental and human-health perspective, the use of genetically modified crops has several benefits.

- While many broad-spectrum insecticides reduce the impact of biological control agents that help to control insect and mite pests, studies indicated that Bt maize is compatible with biological control and has little effect on the natural enemies of pests (Bessin, 2010);
- Control of lepidopteran pests with Bt endotoxins provides several advantages from the grower's perspective. These benefits could be particularly important in subsistence agriculture where literacy levels of farmers are low and extension support is poor or lacking. Control is no longer affected by the weather. The crop is protected even if the field conditions are not suitable for aerial or ground application of insecticides (Meeusen & Warren, 1989);
- A related advantage is the protection of plant parts that are difficult to reach with insecticide spraying or the protection of new growth that emerges after spray applications like tillers and ears of maize (Meeusen & Warren, 1989);
- The crop is also protected continuously in the field and the laborious task of scouting to timeously detect pest infestations may be reduced;
- Finally, and most importantly, is the reduction in insecticide applications.

For example, reduced insecticide use was reported from the Makathini Flats region of Kwa-Zulu Natal, South Africa, where 95% of smallholder (1-3 hectares) cotton producers grew rain-fed Bt cotton. Farmers that adopted Bt cotton reported reduced insecticide use and a reduction in labour (Ismael et al., 2001). A typical farmer, often a woman, was spared 12 days of arduous spraying, saving more than a 1 000 litres of water that would have been used in pesticide application (Conway, 2004). Similar benefits have been reported in small-scale maize farming systems in South Africa. Between 16 and 62% higher yields were reported with Bt maize above the conventional iso-line (Gouse, 2005) due to improved stem borer control. Bt maize adopting-farmers were better off than farmers who planted conventional hybrids, despite the additional technology fee in terms of seed costs (Gouse, 2005). A reduction in pesticide application also reduces the potential pesticide drift onto other crops or environmentally sensitive areas (Meeusen & Warren, 1989). Because the active Bt toxin material is produced directly in the crop tissue, concerns such as spray drift and groundwater contamination are precluded (Meeusen & Warren, 1989). Therefore, the use of transgenic crops reduces the use of insecticides, minimizes the impact of these chemicals on non-target organisms, and has positive health consequences for farm workers themselves (Barton & Dracup, 2000).

Although GM crops have become a major component of insect control strategies, a proper perspective of its potential demands a close look at limitations and uncertainties that may reduce its future impact on agriculture. Since the first deployment of Bt crops there has been concern with regard to the development of resistance of target pests and potential non-target organism effects (Tabashnik, 1994; Gould, 1998). For this reason, studies have been conducted to prioritise non-target Lepidoptera species for further research in South Africa (Van Wyk et al., 2007). Bt maize seed is more expensive than comparable non-Bt seed and is only an advantage when a specific insect pest is present. Wind-mediated gene-flow and cross-pollination of landraces (local variety of the plant species) of crops can result in "contamination" of maize fields within several hundred meters from GM crop fields. This may present a problem for organic farmers or in cases where it is important to keep the grain Bt-free. This could also be important in the development of target pest resistance since the uncontrolled presence of the Bt-gene in landraces results in reduced expression of the cry protein and subsequent increased survival of the target pest in crops.

Another potential disadvantage is that biotechnology is being pursued to repair the problems caused by previous agrochemical technologies. Since more than 500 species of pests have already developed resistance to conventional insecticides, pests can also evolve resistance to Bt toxin in GM crops (Altieri, 2004). Resistance of the target pest of Bt maize in South Africa, the African stem borer was reported by Van Rensburg (2007) and Kruger et al., (2009) who reported a further increase in the geographic spread of resistance. The most significant environmental threat of resistance development is the subsequent reversal to the use of broad-spectrum insecticides, which is currently the case in South Africa (Kruger et al., 2011).

The challenge for the sustained use of GM technology in South Africa and especially in developing agriculture throughout Africa is the management of these crops to delay resistance development and to prolong the usefulness of the technology. On its own, insecticidal GM crops will not be the solution to pest problems. Over reliance on this technology may be its downfall and only an integrated approach to pest management will be effective on a long-term basis.

One example of an effective alternative to Bt maize for the management of stem borers is the "push-pull" habitat management systems that has been adopted by between 20 000 – 30 000 farmers in East Africa. As part of a novel approach to control stem borers in cereal crops, the International Centre of Insect Physiology and Ecology (ICIPE) developed habitat management strategies for farmers in resource-poor regions of East Africa (Khan et al., 2000). In the push-pull system, trap and repellent plants are used to control populations of stem borers. Insects are trapped on highly susceptible trap plants (pull) and repelled from the main crop by repellent intercrops (push). Khan et al. (1997) observed that the two fodder crops, namely Napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum sudanensis*) attract significantly more oviposition than maize. These grasses were consequently used in further developing habitat management strategies for stem borers. It was reported that planting Sudan grass as a border around maize plots reduced stem borer numbers in maize by 30% while only 20% of larvae on Napier grass survived, although this species was preferred by stem borers. The volatiles of non-hosts such as Molasses grass (*Melinis minutiflora*) can have a marked impact on reducing borer infestations on maize (Khan et al., 1997). It was discovered that these volatiles repel the stem borers, but attract their natural enemies (Khan et al., 2000). A push–pull system that combines the repellent *M. minutiflora* grass with a highly attractant plant like Napier grass would fit in well with farmers practising a mixed agricultural system. These alternatives in totality, if managed correctly, can help to reduce the widespread use of agricultural pesticides in modern farming practices.

5. Pesticides used to control disease vectors

In South Africa, as in many countries with temperate climates, pesticides are crucial not only in the agricultural setting but also in the management of disease vectors. For South Africa, malaria is the only disease currently managed in this manner. Since before the 2nd World War, malaria in South Africa has been controlled by means of ecological and biological control, as well as with oil and Paris green as a larvicide. Also, a weekly indoor application of pyrethrum has been used since 1943. Since the middle 1940s, the availability of DDT and hexachlorobenzene meant that Indoor Residual Spraying (IRS) with insecticides, a technique developed in South Africa by de Meillon in the 1930s (de Meillon, 1936), became the mainstay for effective malaria control worldwide (Sharp et al., 1988; Musawenkosi et al., 2004).

The insecticides are sprayed on indoor walls and roof beams, as well as outside under the eaves. The residual insecticide then kills female mosquitoes, interrupting transmission from a person with malaria to an uninfected person. The rates of malaria dropped significantly with the use of DDT, and many lives have been saved in this manner (Bouwman et al. 2011). However, in 1996, DDT was replaced with pyrethroids as IRS in South Africa. The rates of infections and deaths climbed dramatically, forcing the reintroduction of DDT in 2000 (Hargreaves et al., 2000; Maharaj et al., 2005). Infection and mortality rates have now returned to original levels, and pyrethroids are used in some places. In 2009 in South Africa, 6 072 people contracted malaria and 45 died (WHO, 2010). During the same year, an estimated 236 million people contracted malaria globally, resulting in nearly 781 000 deaths of which more than 90% were from Africa. This indicates a dire need for expanded and improved malaria control measures.

In South Africa, the registration of DDT for all purposes except malaria control was withdrawn in 1976, with all resale and use of hexachlorobenzene (HCB) and DDT prohibited since 1983 (Bouwman, 2003). DDT continues to be used in malaria control as indicated above, but this use often leads to exposure of both the inhabitants of the sprayed houses, as well as the immediate environments. At a rate of 2 g m^{-2}, an average house receives anywhere between 80 – 200 g per year. Seen that this is applied mainly indoors, a continuously enriched DDT environment is created. Since DDT is also semi-volatile, it is present throughout the year in air in the homes, and probably redistributes itself to furniture and food inside (van Dyk et al., 2010). This continuous redistribution, adds to uptake opportunities that are reflected in the high levels of DDT found in inhabitants (Bouwman et al., 2006). The highest levels of DDT in blood were found in breast feeding infants of mothers living in sprayed houses (Bouwman et al., 1992). Van Dyk et al., (2010) suggests that a Total Homestead Environment Approach (THEA) should be followed when looking at exposure, uptake and exposure reduction opportunities.

Very little research has been conducted on the effects in people living in sprayed houses, but in 2009, Bornman et al. published convincing associations between living in DDT-sprayed villages and urogenital malformations in baby boys from the Limpopo Province. Eskenazi et al. (2009) reviewed 494 studies published between 2003 and 2008 and found that "...*DDT and its breakdown product DDE may be associated with adverse health outcomes such as breast cancer, diabetes, decreased semen quality, spontaneous abortion, and impaired neurodevelopment in children*." Subsequently, Bouwman et al. (2011), based on further assessment of information, strongly suggested that DDT (that is currently considered as safe for use in malaria control) should now be considered in terms of precaution, with an urgent recommendation that exposure reductions be implemented. DDT does not remain restricted to the homestead environment. It is transported to adjacent sites and can be found in water, sediment, birds and fish near and far away from sprayed areas (Barnhoorn et al., 2009). The findings of urogenital malformations in baby boys by Bornman et al. (2009) are a further implication of the endocrine disruptive activities of DDT, DDE and DDD all have some kind of endocrine disruptive activity (as discussed previously), as implied by the findings of urogenital malformations in baby boys by Bornman et al. (2009). Intersex in tilapia fish has also been found in the major river that flows through the same area where the malformations were found (Barnhoorn, 2010).

The alternative insecticides used in IRS should not be ignored. Most of them are pyrtheroids such as deltamethrin and permethrin, but organophosphates such as malathion and primiphos-methyl, and bendiocarb, a carbamate, are also recommended by the WHO (2006). It has been noted though, that very little risk assessment of most of these compounds has been done with relevance to an IRS exposure scenario. Hopefully they are safe, but caution should be applied (Bouwman & Kylin, 2009), as pyrethroids have been found in the same breast milk as DDT (Bouwman et al., 2006), a potentially dangerous situation as toxic interactions have been detected in laboratory animals at relevant levels (Bouwman & Kylin, 2009).

These, often low-income, families are at an increased risk to DDT exposure and consequently the associated adverse health effects. People that are poverty stricken generally are at a higher risk to contract diseases due to malnutrition and lack of resources. When combined with the constant presence of HIV, these communities are more susceptible to health risks. Pesticide levels that would be of no real concern in healthy individuals could, theoretically be detrimental to people living in these communities. IRS using insecticides will undoubtedly remain in the arsenal of malaria control measures for a considerable period. However, as science and knowledge advances, urgent attention should be directed towards safer methods, exposure reductions, and better chemicals.

6. Pesticides levels in the South African environment

Many studies have focused on both historic and current use pesticide levels in South Africa. As can be seen in table 2, these levels are highly variable depending on the activity of the area as well as the sampling media. As previously described, levels are typically higher in biotic matrices as compared to abiotic matrices due to the effect of biomagnification, specifically in OCPs. DDT is still a prevalent pesticide although use outside of the malaria regions is strictly prohibited.

Most of these studies have concentrated on areas where there were high levels of expected impacts. Therefore a pilot study was done in 2006 to assess the levels of persistent organic pollutants including OCPs in an industrial area of South Africa concurrently with areas mainly impacted by agriculture. The focus was on industrial pollutants but this study was also used to assess the occurrence and distribution of OCPs in areas with a large variety of land use.

This pilot study is presented here as a typical research approach to gather and interpret data concerning pesticides in the environment. It gives a brief overview of commonly used ratio’s to differentiate between historic and current applications as well as the use of statistical tools to determine variation within datasets.

Land use or activity	Matrix	N	Pesticide and levels	Reference
DDT used in IRS programme	Water	8	∑DDT: LOD – 7 000	Barnhoorn et al., 2009
DDT used in IRS programme	Fat of indigenous fish	28	∑DDT: 360 – 24 000	Barnhoorn et al., 2009
Mixed: large city	Air	48	Pentachlorobenzene: 3.6 HCB: 4.5 Heptachlorepoxide: 0.62 Toxaphene: 12	Batterman et al., 2007
Agriculturally impacted estuary (apple, pear and plum orchards)	Water	27	Chlorpyrifos: 0.085 Prothiofos: 0.032 Cypermethrin: LOD ∑ Endosulfan: 0.003 *p,p'*-DDE: 0.01	Bollmohr et al., 2006
Corn-production region	Water	5	Atrazine: 1.2 – 9.3 Terbuthylazine: 1.04 – 4.1	Du Preez et al, 2005
Various sampling areas across South Africa	Wild bird eggs	43	∑DDT: 1.9 - 710 ∑HCH: 0.21 - 470 ∑Chlordanes: 0.12 - 11 HCB: 0.29 – 7.8 Mirex: 0.21 – 1.8	Bouwman et al., 2008

Table 2. Pesticide levels (pg m^{-3} or µg kg^{-1} or µg ℓ-1) reported in various publication from SA

7. Case study: A baseline of organochlorine pesticide residues in soil and sediment from the Vaal Triangle, South Africa

7.1 Introduction

OCPs have been used extensively throughout the world for the protection of crops as well as the control of disease vectors (Kumar et al., 2008). Because of their detrimental effects, many of the OCPs are banned, or restricted to the control of disease vectors. However, due to their highly persistent nature and potential for long-range transport, residues of these chemicals are still found in areas where use had been banned for decades (Gong et al., 2007; Hung et al., 2007). These residues may pose chronic toxicity to animals and humans via air, water, and food intake (Darko et al., 2008). Due to the general lack of data on organochlorine pollution in soils and sediments from South Africa, the objective of this baseline study was to investigate the presence and concentration of OCPs in soil and sediment from an industrialised in addition to agriculturally impacted areas of South Africa.

7.2 Materials and methods

7.2.1 Sampling area

The Vaal Triangle is a highly industrialised area in central South Africa (Figure 1) with a population of approximately 790 000. The main industries in the area include ferrous and non-ferrous metal production and petrochemical processes. There is also limited farming activity, mainly consisting of maize and cattle. Soil was collected in the industrial (Vdb-Ind-Soil and S-Ind-Soil) and low-income residential areas (Vdb-Inf-Soil and S-Inf-Soil) close to these industries. Sediment was collected from rivers and streams including the Vaal River (VaalRivV) and its tributaries; Riet Spruit (RietSpr), Klip River (KlipRiv), Suikerbosrand River (SkbrRiv3) and the Taaibos Spruit (TbosSpr) (Figure 1). Concurrently, sediment was collected from agricultural areas upstream and downstream of the Vaal Triangle: SkbrRiv1 and SkbrRiv2, east of the Vaal Triangle and VaalRivK, in the Vaal River approximately 70 km downstream of Vanderbijlpark inside the Vredefort Dome World Heritage Site, and a site in the Orange River (OrangeRiv) just after the confluence with the Vaal River. Agriculture in the Vredefort Dome is comparable to that of the Vaal Triangle while the Orange River catchment is impacted by the cultivation of a variety of other crops (wheat, cotton, potatoes, as well as fruit). There are no malaria control activities in this area; the closest malaria control activity is 260 km away towards the Mozambican border (Figure 1).

7.2.2 Sample extraction, clean up and analysis

Extraction and analysis for DDT, dicofol, endosulfan and hexachlorocyclohexane (HCH) was done under Norwegian accreditation at NILU in Norway. Analytical details are given in Bengtson Nash et al.(2008) and Knutzen (2003). In short: samples were spiked with ^{13}C-labelled analogs of the analytes and extracted with cyclohexane. Interfering molecules were removed through size exclusion chromatography and sulphuric acid clean-up. Before quantification, the samples were spiked with a recovery control standard. Analytical quantification was using gas chromatography coupled with high resolution mass spectrometry (GC-HRMS; Agilent 6890N GC coupled to an Micromass Waters Autospec HRMS, Manchester UK). The HRMS was operated at a resolution of >10 000 using electron ionization. Two masses were monitored for each isotope cluster of both the analyte and the added ^{13}C-labelled surrogate. The recoveries of the added internal standard compounds were also established. Procedural blanks were run throughout. The limit of quantification was set to the detection limit based on at least five consecutive blank samples plus three standard deviations. All concentrations are reported on a mass basis. The following conditions had to be met for an unequivocal identification and quantification of the analytes: (1) correct retention time (2) signal-to-noise ratio greater than 3:1, (3) correct recovery of the internal standard, and (4) acceptable blank values of the complete clean-up and quantification procedures.

7.2.3 Statistical analysis

The software package used for statistical analyses was STATISTICA (version 8). Normal distribution was tested using the Shapiro-Wilk test and groups were compared using the Mann-Whitney U test. Principal component analysis (PCA), using all of the congener data, with data transformations according to Howell (2007), was performed with CANOCO (version 4.5) to investigate the pollutant patterns at the sites, as well as possible differences in the matrices sampled.

7.2.4 Results and discussion

The concentration of OCPs at all the sites was relatively low when compared with literature (Table 3) from other countries. ∑OCPs measured ranged between 0.58 - 6.9 ng g^{-1} with the highest values found in Vanderbijlpark soil (Vnd-Inf-Soil & Vnd-Ind-Soil), and sediment from the Klip River (KlipRiv) (Figure 2). Vanderbijlpark is a highly industrialised area with ferrous and non-ferrous industries, with some farming activities. The largest contributor of the OCPs in soil sites was *p,p′*-DDE measured in Vnd-Inf-Soil and Vnd-Ind-Soil (6.61 - 4.82 ng g^{-1}), followed by γ-HCH (1.7 ng g^{-1}) in S-Ind-Soil and *p,p′*-DDE (1.1 ng g^{-1}) in Vnd-Inf-Soil. The Klip River (a tributary of the Vaal River) has a large catchment area that includes the industrial and residential areas of Soweto, Lenasia, Meyerton and Vereeniging. As with Vnd-Inf-Soil, the largest contribution to sediment was from *p,p′*-DDT (3.7 ng g^{-1}) followed by α-HCH (0.58 ng g^{-1}).

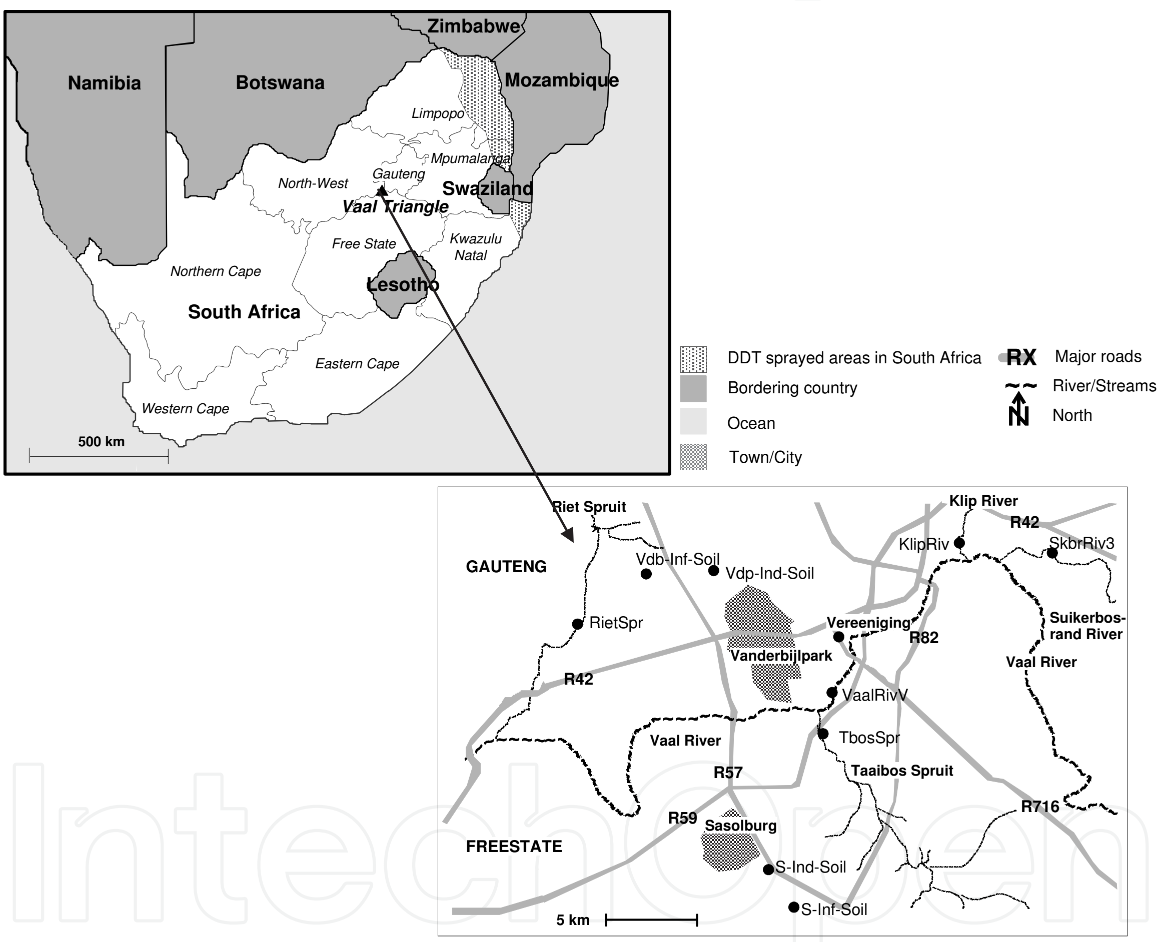

Fig. 1. Map of South Africa and its provinces; indication the location of the sampling sites in the areas assessed for OCPs.

Levels from South Africa and Brazil are in the same order of magnitude for DDT and HCH, with levels in Morocco being lower for these two compounds but higher for endosulfan (Table 3). It should be taken into account that China is currently the largest producer of DDT for vector control, as well as the pesticide dicofol (Cheung *et al*., 2007) that may contain DDT as contaminant, this would explain the higher DDT levels (Table 3). On the other hand, the high average levels reported in the Canadian study were mainly attributed to a single site.

The lowest OCP levels for the South African study were measured in the Taaibos Spruit (TbosSpr), which receives run-off impacted by low-income residential areas as well as petrochemical industries. The OCP levels for sites primarily influenced by agricultural activities ranged between 2.3 - 0.59 ng/g (Figure 2). Of the four classes of OCPs (ΣDDT, dicofol, ΣHCH and Σendosulfan), ΣDDT was the highest at all sites, except for one sediment site in an agricultural area (OrangeRiv), and one soil site in an industrial area, S-Ind-Soil (Figure 2); in both ΣHCH was the highest. In general, the concentration of OCP classes decreased as follows: ΣDDT>ΣHCH>Σendosulfan>dicofol. The levels of OCP within the classes varied between sites as described in the next section.

Country	Land use	Matrix	N samples	Σ Endosulfan	Σ HCH	Σ DDT	Reference
Canada	Mixed	Sediment	7	0.36	0.03[#]	6.8	Wong et al., 2009
Canada	Mixed	Soil	7	0.13	0.04[#]	68	Wong et al., 2009
China	Fallow	Soil			14^	25	Wang et al., 2007
Brazil	Agricultural	Soil	29	0.52	0.1	1.4*	Rissato et al., 2006
Morocco	Agricultural	Soil	5	1.5	0.02	0.03*	Bakouri et al., 2008
Uganda	Mixed	Soil	8	0.4	NM	0.3	Ssebugere et al., 2010
SA	Industrial	Soil	4	0.09	0.70	3.5	Present study
SA	Mixed	Sediment	9	0.05	0.52	1.7	Present study

* *o,p′*-DDT + *p,p′*-DDD + *p,p′*-DDT + *p,p′*-DDE, # α,γ HCH, ^ α,β,γ,δ-HCH, [a] I-Endosulfan + II-Endosulfan, NM: not measured, SA: South Africa

Table 3. Mean OCP levels ($ng\ g^{-1}$) as reported in other international studies.

7.3 HCH

γ-HCH, better known as lindane, was one of the most widely used pesticides in the world. However, on 9 May 2009 lindane was added to Annex A (chemicals cited for elimination) of the Stockholm Convention. Lindane was commonly used in the treatment of seed, livestock and as a household biocide (Osibanjo et al., 2002). Although relatively little literature has been published on the use and production of these chemicals in South Africa, it is known that HCH was produced until the early 1980s at a site in Kempton Park (Osibanjo et al., 2002). Kempton Park is situated approximately 80 km northeast of the Vaal Triangle. The main wind direction for that area is north and north-northwest, which could have contributed to dispersing lindane to the Vaal Triangle in the past. However, lindane is currently registered and used in the agricultural of cotton, maize and wheat crops, amongst others, as well as in domestic gardens (Nel et al., 2002, Table 1). It would be interesting to track possible changes in soil and sediment levels following eventual de-registration.

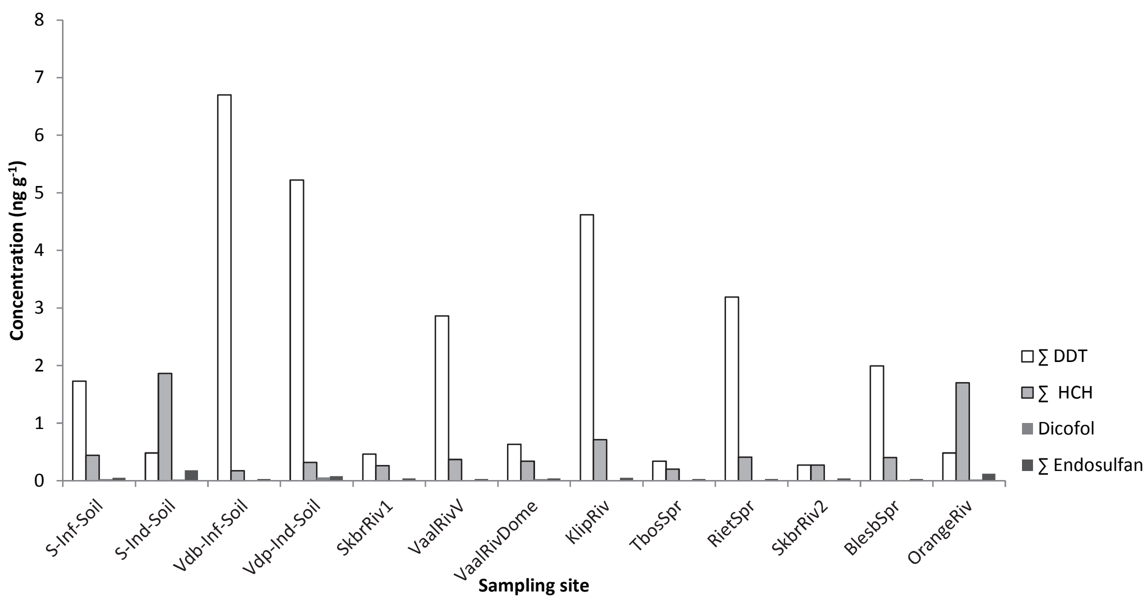

Fig. 2. Distribution patterns of different OCPs between sites

The ΣHCH concentration in soil varied between 0.17 - 1.86 ng g^{-1} with the highest concentration measured at Sasolburg (S-Ind-Soil) in soil collected close to the petrochemical plant. The lowest level was measured in the low-income residential area in Vanderbijlpark (Vdb-Inf-Soil). In sediment, the concentration varied between 0.3 - 1.7 ng g^{-1}, with the highest concentration measured in the predominantly agricultural area of the Orange River (OrangeRiv). The values for HCH are in the same order of magnitude as determined in other studies (Table 3).

Lindane consists of a mixture of all HCH isomers with approximately 90% γ-HCH (Wang et al., 2007). In technical HCH, the isomer ratio is different with α-HCH representing 55 – 80% of the total mixture (Gong et al., 2007). In both soil and sediments, γ-HCH was the most prevalent with more than 80% contribution to ΣHCH levels (Table 4), followed by β-HCH and α-HCH. This points to recent use of lindane rather than technical HCH or historic inputs, since γ-HCH is degraded more rapidly than α-HCH both under aerobic and anaerobic conditions (Wu et al., 1997).

Matrix	Nr of samples	Mean ΣHCH (ng g^{-1})	Concentration range ΣHCH (ng g^{-1})	% α-HCH	% β-HCH	% γ-HCH
Soil	4	0.70	1.9 – 0.17	4	12	85
Sediment	9	0.52	0.2 – 1.7	5	6	89

Table 4. Summary of mean HCH values and percentage contribution of each isomer for soil and sediment

7.4 DDT and dicofol

DDT, in use since the Second World War, was the first internationally used pesticide due to its highly effective insecticidal properties and ease of manufacture (Stenersen, 2004). DDT is often found in the environment even in areas where it is not currently applied due to its highly persistent nature and ability to be passively (wind and water) and actively (through biota) transported. The current study area falls outside the endemic malaria regions of South Africa (Figure 1), the closest of which is 700 km away. As expected, the ΣDDT levels measured were relatively low, varying between 0.3 - 6.7 ng g^{-1}, with the highest values measured in Vnd-Inf-Soil. The ΣDDT levels measured in soil were compared to those measured in sediment. The data was not normally distributed (p = 0.03, Shapiro-Wilk test) and the relationship was tested with the non-parametric Mann-Whitney U test. Although the levels in soil were higher than those in sediment, this difference was not statistically significant (p = 0.24).

To assess when DDT was applied, the ratio of DDT/(DDE + DDD) was calculated. Values greater than one indicate recent applications, while values lower than one indicate historic use (Chen et al., 2005; Gong et al., 2007). The mean ratios were lower than 0.5 (Table 5) with the exception of S-Ind-Soil that had a ratio of 1.1. The mean ratio was also less in sediment than in soil. The ratio of *o,p′*-DDT to *p,p′*-DDT distinguishes between pollution caused by technical DDTs and pollution from other sources such as dicofol. (Fu et al., 2009). Since *o,p′*-DDT is less stable, it is expected to be less prevalent in the environment. Dicofol would produce a higher *o,p′*-DDT to *p,p′*-DDT ratio since there is generally more *o,p′*-DDT in dicofol than *p,p′*-DDT (Qiu et al., 2005). The ratio in this study was 0.24 for soil and 0.58 for sediment (Table 5). These values indicate that the DDT pollution detected is more likely from the use of technical DDT.

Matrix	Nr of samples	Mean ΣDDT (ng g^{-1})	Concentration range ΣDDT (ng g^{-1})	Mean ratio of DDT to DDT metabolites	Mean ratio of DDE to DDD	Mean ratio of *o,p*'DDT to *p,p*'DDT
Soil	4	3.5	0.5 – 6.7	0.42	120	0.24
Sediment	9	1.7	0.3 – 4.6	0.07	16	0.58

Table 5. Summary of mean DDT values and metabolite ratio's for soil and sediment

Once applied, DDT degrades to DDD and DDE. Degradation to DDD is through reductive dechlorination, while degradation to DDE is through dehydrochlorination processes (Wang et al., 2007). The ratio of DDE/DDD at all sites was greater than one. This indicates that the majority of DDT is degraded to DDE in both matrices, with the DDD levels playing a larger role in sediment than soil due to anaerobic conditions. This may show that a larger portion of DDT is degraded through reductive dechlorination in sediment than in soil.

Dicofol is a non-systemic acaricide used in the control of mites on numerous crops including cotton citrus and other fruit (Clark et al., 1990; Qiu et al., 2005). Dicofol is registered for use in South Africa, mainly for cultivation of fruit and garden use (Nel et al., 2002; Table 1). Due to the process of dicofol synthesis, it is often contaminated with DDT. Dicofol levels were low in all samples analysed, with soil and sediment levels in the same range. The highest dicofol level (0.06 ng g^{-1}) was measured for Vnd-Ind-Soil. Considered together with the calculated DDT/(DDD + DDE) ratios (table 3), again indicates DDT rather than dicofol as source of the DDT breakdown products measured in soils and sediment.

7.5 Endosulfan

Endosulfan, a cyclodiene insecticide, is widely used in agricultural applications as both an insecticide and acaricide (Osibanjo et al., 2002). Endosulfan is a wide spectrum contact insecticide (Capkin et al., 2006) that consists of a mixture of endosulfan-I and II isomers

(Kumar et al., 2008), can moderately adsorb to soil, and is metabolised to endosulfan-sulfate, endosulfandiol and endsulfan ether, amongst other breakdown products. Endosulfan-I is the least persistent with a half-life of 35 days (Osibanjo et al., 2002) in contrast to endosulfan-II and endosulfan-sulfate, which may persist for years, depending on environmental conditions. Endosulfan is currently registered in South Africa for a wide variety of crops (Nel et al., 2002; Table 1).

Levels of endosulfan were low in all samples, ranging between 0.03 and 0.18 ng g^{-1}. The highest values measured were in S-Ind-Soil (0.18 ng g^{-1}) and in the sediment of the Orange River (OrangeRiv) (0.12 ng g^{-1}). The mean concentration of endosulfan in soil and sediment was very similar (Table 6). Percentage contributions show the predominance of endosulfan-I when compared to endosulfan-II and endosulfan-sulfate (Table 6). This would usually indicate the current use of endosulfan. However, the low levels of this pesticide detected, makes it difficult to draw any clear-cut conclusions.

Matrix	Nr of samples	Mean concentration of ΣEndosulfan	Concentration range ΣEndosulfan	%Endosulfan I	%Endosulfan II	%Endosulfan -sulfate
Soil	4	0.09	0.03 – 0.18	61	21	18
Sediment	9	0.05	0.03 – 0.12	47	26	26

Table 6. Summary of mean Σendosulfan values and compound ratio's for soil and sediment

7.6 Principle component analysis

Due to the restricted sample size, it was not possible to draw definitive conclusions from the PCA. However, the available data did shed some light on patterns in the data sets. In the PCA, factor 1 explained 40%, factor 2, 30% and factor 3, 16% of the variance in the data. The greatest contributors to factor 1 were endosulfan-I, γHCH and α-HCH on the positive side and *p,p′* DDE on the negative side (Figure 3). Factor 1 therefore contrasts OCPs still in use with DDT that is not in use in the study area. There is no clear clustering of sampled sites because of factor 1. Factor 2 is formed by a contrast between DDT isomers: *o,p′*-DDT and *p,p′*-DDT on the positive side and *p,p′*-DDD and *p,p′*-DDD on the negative side. This factor seems to have influenced the distribution of the sites on the biplot roughly into soil sites (on the positive side of factor 2) and the sediment sites on the negative side of factor 2 (Figure 3). Factor 3 consists of a contrast between DDT and its DDD metabolites on the positive side and the metabolites and isomers of endosulfan, *o,p′*-DDE and dicofol on the negative side. It is when factor 2 and 3 are plotted together that the clustering effect of the sites due to factor 2 is clearly observed (Figure 4). In a previous investigation by Nieuwoudt et al (2009) in the same sampling area, the distinction between soil and sediment concentrations was also made for dioxin-like chemicals.

In summary, the pesticide residues measured in both soil and sediment in this study were generally low, with values ranging from below the detection limit to 6.6 ng g^{-1}. The highest concentrations found did not coincide with agricultural land use, but with industry (Vnd-Ind-Soil). This site consisted of mainly industrial and residential areas in Vanderbijlpark. A PCA of the data showed a separation between sediment and soil profiles of the OCPs. Although agricultural use of DDT has been banned in South Africa since 1983, measurable levels were found in soil and sediment in areas outside the endemic malaria area where it is still sprayed.

The reasons for the differences between soils and sediment profiles and levels indicates the need for further studies, while exposure and accumulation in humans and biota needs scrutiny even at these low levels. A previous study by Bouwman et al (2008) found measurable levels of OCPs in wild bird eggs, including DDT and its metabolites as well as HCH. These levels (ΣDDT: 1.48 – 300 ng g^{-1} ww) were also higher than what can be expected from the low levels measured in sediment and soil here (ΣDDT: 0.02 – 6.7 ng g^{-1}dw). Although these interactions are influenced by other factors such as diet, bio-accumulation and collection area, they all play a crucial part. Very little is known about these aspects under African and South African conditions. This pilot study indicated that knowledge concerning background levels of pesticides is important. If background levels are not investigated, patterns of pesticide occurrence and distribution would be missed.

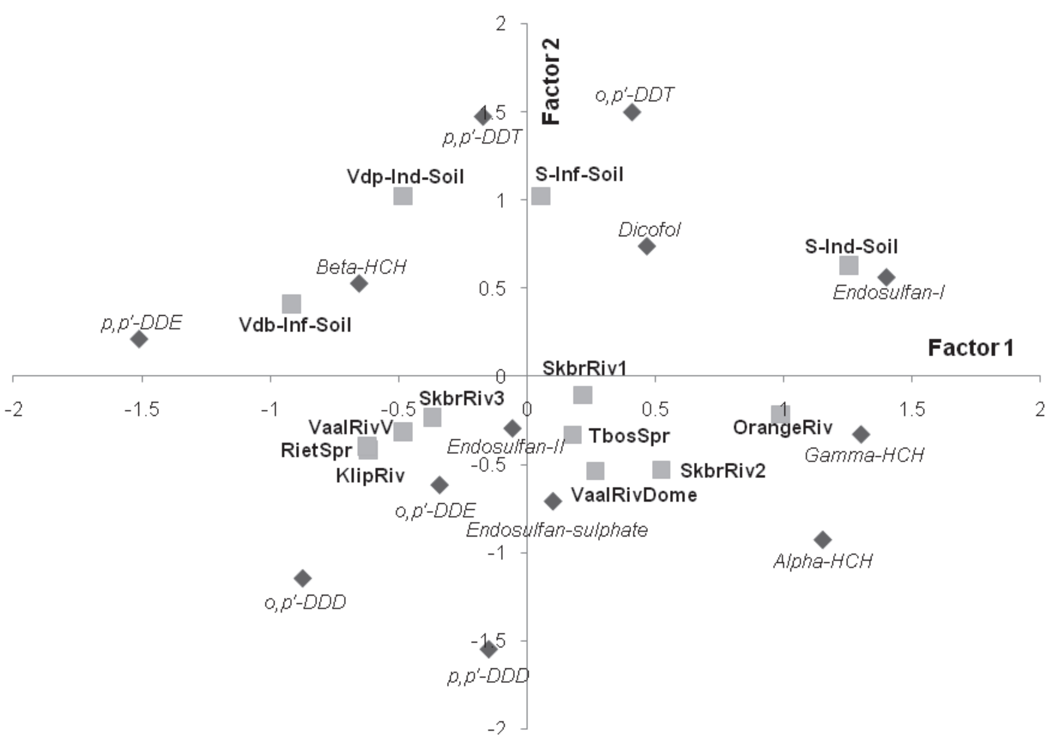

Fig. 3. A PCA bi-plot of factor 1 and factor 2, including all OCP data. Sites are indicated with a square and compounds with a triangle.

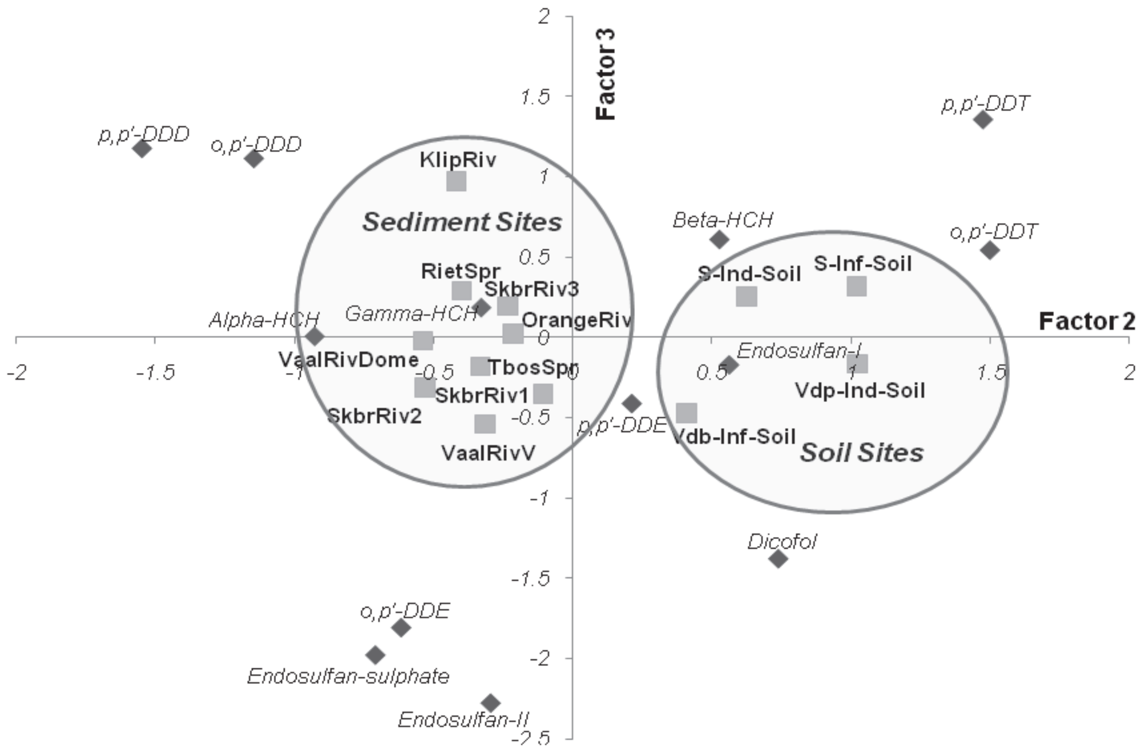

Fig. 4. A PCA bi-plot of factor 2 and factor 3, including all OCP data. Sites are indicated with a square and compounds with a triangle.

8. Conclusions and parting thoughts

Pesticide use is an integral part of every-day South African's life. It does not only impact populations at risk from malaria, but also the farmer, consumer, exporter and end-user of natural resources such as water. Therefore, the use of pesticides must be regarded as a serious management issue and not only at farm level, but, also at government level. Although pesticide research is well founded in South Africa, limitations exist within laboratory frameworks. Although pesticides have been detected in almost all conceivable media, there is still a lack of knowledge of background levels. These levels are needed to make realistic impact and health assessments when studying highly impacted areas. The serious health risks associated with certain pesticides are not only for occupational exposure, but also for end-user exposure. MRLs have been established to protect both the importer as well as the consumer. Table 1 indicates that South African MRLs are within the same range as those listed for the EU on the EU pesticide database (EU, 2010b). This ensures continued trade as well as protecting the health of the South African citizen. Aspects not specifically raised in this text that should be kept in mind within the South African context include the occurrence of accidental poisoning cases among farm workers as well as children. This occurs easily when the user did not receive proper training and does not understand how to use the pesticide. This is specifically a problem in areas with low literacy. There is also the question of obsolete pesticide stockpiles that can leach into the environment and have disastrous effects on ground water. These are challenges unique to developing economies, rarely seen in developed countries and should be considered in the international decision making process regarding the use and import of pesticides. In conclusion; although the need and usefulness of pesticides cannot be denied, the advantages of introducing these chemicals into the environment needs to be weighed against the possible negative side effects. Therefore, serious consideration should be given to expanding the correct use of less harmful alternatives.

9. References

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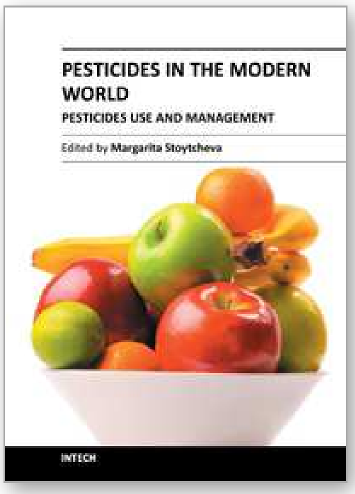

Pesticides in the Modern World - Pesticides Use and Management
Edited by Dr. Margarita Stoytcheva

ISBN 978-953-307-459-7
Hard cover, 520 pages
Publisher InTech
Published online 19, October, 2011
Published in print edition October, 2011

This book brings together issues on pesticides and biopesticides use with the related subjects of pesticides management and sustainable development. It contains 24 chapters organized in three sections. The first book section supplies an overview on the current use of pesticides, on the regulatory status, on the levels of contamination, on the pesticides management options, and on some techniques of pesticides application, reporting data collected from all over the world. Second section is devoted to the advances in the evolving field of biopesticides, providing actual information on the regulation of the plant protection products from natural origin in the European Union. It reports data associated with the application of neem pesticides, wood pyrolysis liquids and bacillus-based products. The third book section covers various aspects of pesticides management practices in concert with pesticides degradation and contaminated sites remediation technologies, supporting the environmental sustainability.