Living With Pesticides: A Vegetable Case Study

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Acknowledgments

This study was a collaborative effort involving the SP-IPM, University of Bonn, Germany, IITA, and national plant protection and regulatory services, farmers and NGOs in Benin, Ghana, Mali, Niger, Nigeria and Togo in West Africa. The SP-IPM is grateful to the Governments of Switzerland through the Swiss Development Corporation and Italy through the Ministry of Foreign Affairs for sustainable funding of the SP-IPM that made this study possible; and to the German development agency GTZ for co-funding the pesticide residue studies through the University of Bonn. Contributions of the various national programs, NGOs and farmers in West Africa and of all other collaborating groups are equally appreciated.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

The pest management philosophy promoted by the CGIAR Systemwide Program on Integrated Pest Management (SP-IPM) in the developing world emphasises the need for pesticide use management in favour of biological alternatives. In pursuit of this aim, comprehensive information on pesticide use patterns and research on pesticide fates in target agroecosystems are required to advise farmers, governments, the plant protection industry and the public on existing inappropriate pesticide regimes which undermine health, environment and trade. Studies on pesticide fates in the agroecosystems are few and far in between in the developing countries. The findings reported here are from a study conducted in 2007 to assess background challenges posed by pesticides in IPM field programs and to investigate pesticide dissipation in soils and on plant surfaces, with vegetables production in West Africa as a case study.

PESTICIDE USE PATTERNS

- The findings on pesticide type, volume and application frequency in vegetables indicate that pesticide use patterns in the agroecosystem pose a grave concern in West Africa. Inter-institutional research collaboration is required to assess similar baseline situations in agroecosystems targeted for development (e.g. the emerging CGIAR Challenge Program on High Value Crops).

- The list of pesticides used in vegetables in West Africa includes one Organochlorine (endrin) and one Organophosphorus (pirimiphos methyl) that are declared obsolete/banned for use by the 2004 WHO classification of pesticides by Hazard, four WHO Classes 1b pesticides (methamidophos, carbofuran, cadusafos and fenamiphos, three of which are nematicides).

- In Benin bifenthrin and endosulfan were the most frequently used pesticides (ca. 30%) in vegetable agro-ecosystems followed by neem extracts. In Ghana, ?teflubenzuron, neem extract and chlorpyrifos ethyl, methamidophos was commonly used by the farmers. pirimiphos methyl and methamidophos are not on the list of chemical pesticides recommended to use on vegetables, but are used by the farmers in Ghana. In Mali, deltamethrin was most frequently used and in Niger and Nigeria, methamidophos was the dominant product.

- Intensive diagnosis of pesticide use patterns at vegetable production sites in Benin revealed that cabbage, tomato, *Solanum macrocarpon* and pepper were indicator of harmful pesticide regimes in the vegetable agroecosystems..

PESTICIDE FATE IN AGROECOSYSTEMS

- Soil dissipation half lives of pesticides recorded during field experiments ranged from 2.8 days to 73.7 days, DT_{50} values above 41 days pertained to endosulfan compounds in the Arenosol. For the Acrisol, pesticides may be arranged by ascending persistence as follows: diazinon < α-endosulfan <deltamethrin < ß-endosulfan < bifenthrin. For the Arenosol, positions of ß-endosulfan and bifenthrin are reversed.

- Dissipation in soils was accelerated in comparison with temperate climates by a factor of six to ten for most combinations of pesticides and soils. However, field half lives were only reduced by a factor of three for bifenthrin in both soil types (Acrisol and Arenosol), and diazinon in the Acrisol. Dissipation of endosulfan compounds in the Arenosol proceeded disproportionately slow, which was attributed to the heavy contamination of the soil with aged endosulfan residues. The metabolite endosulfan-sulfate exhibited remarkable stability in both soils and may therefore be regarded as a potential long-term pollutant in the investigated soils. Upon repeated applications, deltamethrin showed a tendency for mid-term accumulation in both soils. The same tendency is assumed for endosulfan. Analysis of both soils' depth profile at the end of the experiment did not show leaching of pesticides.

- Dissipation of pesticides on plant surfaces was faster in comparison to both, dissipation of pesticides on plant surfaces in temperate regions and dissipation of pesticides from soil in this trial. Half-lives of endosulfan on plant surfaces were the shortest published so far. Deltamethrin was more persistent than α- and ß-endosulfan on plant surfaces.

RECOMMENDATIONS

Whilst pesticides are integral elements of IPM implementation, inappropriate pesticide regimes need to be identified and targeted in pesticide stewardship programs, not only by the industry but also by national plant protection and regulatory services. This study lays a foundation encouraging IPM research to embrace pesticide use patterns and residue studies into field programs on specific pest and agro ecological issues, and thereby fully quantify the restraining influences faced in IPM implementation. Within the framework of SP-IPM themes on food quality/safety and on functional agrobiodiversity, focused research is required to develop and harmonize research tools to generate location-specific data of environmental fate on plant protection products in agroecosystems on common concern. The research questions would include, pesticide use patterns, residue levels in soils, underground waters, and food, impact of repeated applications on field half lives, accumulation of residues in soils, pesticide aging and pesticide leaching. By publicizing the research knowledge the SP-IPM would have contributed greatly to IPM advocacy to enhance livelihoods in the developing world

1. BACKGROUND

THE CGIAR SYSTEMWIDE PROGRAM ON INTEGRATED PEST MANAGEMENT

The Systemwide Program on Integrated Pest Management (SP-IPM) of the Consultative Group on International Agricultural Research (CGIAR) was launched in 1996 as a global partnership programme whose task is to draw together the Integrated Pest Management (IPM) research efforts of the international agricultural research centers and their partners and to focus these efforts more clearly on the needs of resource-poor farmers in the developing world. The International Institute of Tropical Agriculture (IITA) serves as SP-IPM Convening Center. SP-IPM membership is open to all CGIAR centers. Other partners engaged in IPM research-for-development are members by invitation from SP-IPM Steering Committee.

The SP-IPM has its origins in the 1992 Earth Summit which recognized that attempts to raise living standards through conventional development approaches were only having a limited impact on hunger and poverty in developing countries, and that inappropriate development strategies were destroying the planet's ecological life support systems. In the 'Agenda 21' action plan of the Summit, Integrated Pest Management (IPM) was identified as a key part of the solution to this problem, as it allows more food to be produced with minimal damage to agricultural and natural ecosystems. To the SP-IPM, IPM means

"…an approach to enhancing crop and livestock production, based on an understanding of ecological principles, that empowers farmers to promote the health of crops and animals within a well-balanced agro-ecosystem, making full use of available technologies, especially host resistance, biological control and cultural control methods. Chemical pesticides are used only when the above measures fail to keep pests below acceptable levels, and when assessment of associated risks and benefits (considering effects on human and environmental health, as well as profitability) indicates that the benefits of their use outweigh the costs. All interventions are need-based and are applied in ways that minimize undesirable side-effects"

Towards this aim, the SP-IPM pursues strategic alliances between researchers and pertinent stakeholder groups (e.g., government, NGO, private sector, agricultural development agencies and networks), for IPM research-for development to increase agricultural productivity while minimizing the use of inappropriate plant protection regimes to promote health, trade and environmental quality. In its activities, the SP-IPM tackles those areas where research promises to provide solutions to pressing problems in sustainable agricultural development but where impact has so far been limited, usually due to fragmentation of efforts among different organizations or in different regions of the world, or due to inadequate links between researchers and farmers. The SP-IPM expects to achieve rapid progress by alleviating such constraints, breaking down barriers to information exchange, filling research gaps where necessary and developing effective models of researcher-extension-farmer partnerships to promote adoption of IPM technologies.

PESTICIDE USE CHALLENGES IN IPM FIELD PROGRAMS

Agriculture is an important economic activity and an informal employment sector in the developing world. By 2000, the proportion of populations responsible for food production was ca. 52% in the developing world, compared to 7.6% in industrialized world. Population growth is also concentrated in developing countries and the growth is overwhelmingly urban. Inherent in the demographic pressure is the challenge to ensure matching food security in an environmentally sustainable manner. Part of that challenge concerns national capacity to halt and reverse losses due to pests[1]. In the developing world, pests caused an estimated \$12.8bn, \$145.2bn and \$21.72bn losses in Africa, Asia and Latin America respectively in 1988-1990 (Table 1).

Table 1: Estimated losses for eight crops during 1988-90[2]

Region	Losses due to pests (US$ billions)			
	Pathogens	Insects	Weeds	Total
Africa	4.1	4.4	4.3	12.8
Asia	43.8	57.6	43.8	145.2
Latin America	7.1	7.6	7	21.7

Crop loss data and farmers' perceptions of risks posed by pests drive investments in pest management strategies. Over the years pesticides have made significant improvements in global food security (Oerke, 1994). However, in response to increasing food demands and emerging market opportunities, farmers tend to quick acting solutions to vegetable pest problems. Intensified production systems, such as vegetable agroecosystems, tend to be typified by inappropriate pesticide regimes in developing countries.

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[1] Pest = harmful and disease-causing organisms and weeds which can ruin harvests and destroy livelihoods

[2] Source: Oerke et al, 1994

Although generally less intensive than in other regions, pesticide use in Africa may reach alarming levels in certain circumstances (Farah, 1994). In Benin, for example, Graef et al. (2000) indicates that 2.6 million litres of pesticide formulations were imported in 1998. The biggest portion of pesticides was used on cotton. Only about 15% of the area cultivated to food crops is regularly treated with pesticides (MDR, service statistique, 1997), with higher pesticide use in urban and peri-urban areas (Dinham, 2003; Akogbeto et al., 2006). In vegetable production in Benin, farmers often use unregistered products or pesticides meant for cotton production. In 2003, deltamethrin, endosulfan, malathion, chlorpyrifos, profenofos and acephate were among the commonly used pesticides in vegetable in the country (Williamson, 2003). In 2005, dimethoate, diazinon and malathion were used for vegetable pest control in urban and peri-urban areas of Cotonou, in Benin (Akogbeto et al., 2005). However, in the national pesticide list, only deltamethrin is registered for vegetable production.

The pest management philosophy promoted by the SP-IPM in the developing world emphasises the need for pesticide use management in favour of biological alternatives. In pursuit of this aim, comprehensive information on pesticide use patterns and research on pesticide fates in target agroecosystems are required to advise farmers, governments, the plant protection industry and the public on existing inappropriate pesticide regimes which undermine health, environment and trade. Studies on pesticide fates in the agroecosystems are few and far in between in the developing countries (Racke et al., 1997) The findings reported here are from a study to assess background challenges posed by pesticides in IPM field programs and to investigate pesticide dissipation in soils and on plant surfaces, using the needs and practices in vegetables production in West Africa as a case study.

2. MATERIALS AND METHODS

PESTICIDE USE PATTERNS

In 2007, 20 to 60 vegetable farmers in each of Benin, Ghana, Mali, Niger, Nigeria and Togo were interviewed at their respective field plots. The respondents comprised 22 farmers (0% of women) in Benin, 50 farmers (14% of women) in Ghana, 50 farmers (26% of women) in Mali, 50 farmers (8% of women) in Niger, 20 farmers (0% of women) in Nigeria and 60 farmers (17% of women) in Togo. The agronomic practices, crops associations, intercrops, rotation patterns and plant protection products applied were assessed. Farmers provided information on pest targeted by the plant protection products. In Benin, intensive diagnose of pesticide use patterns at 38 vegetable production sites provide information on quantity and frequency of the pesticides applied.

PESTICIDE DISSIPATION ANALYSES

Pesticide dissipation studies were established with *Solanum macrocarpon* (variety "Abidjan") planted at Houéyiho, the main urban vegetable production site in Cotonou and at IITA Benin experimental farm (n = 3). Recommended agronomic practices for fertilization and irrigation were adhered to. Houéyiho site has a history of pesticides use, but the experimental plots were on 4-weeks fallow land and chemical residues were expected to be low. Table 2 lists the insecticides used in the trials. To minimize application heterogeneities, insecticide spraying was done twice in tracks overlapping each other for half of the track width. The beds used to study insecticide dissipation from plant surfaces were treated once. All other beds were treated three times at 10 days intervals as per farmers' practice.

Table 2: application rate and frequency of studied pesticides

active ingredient	soil dissipation study						plant surface dissipation study	manufacturer recommendation[b]	local practice[c]
	Arenosol			Acrisol					
	1st appl.[a]	2nd appl.	3rd appl.	1st appl.[a]	2nd appl.	3rd appl			
Application rate (g a.i. ha^{-1})									
bifenthrin	-[d]	-	52	-	-	48	-	27 - 49	45 - 100
deltamethrin	20	21	21	18	21	20	20	7.5 - 13	18 - 57
diazinon	-	-	1028	-	-	966	-	230 – 460	-[e]
endosulfan	783	721	-	696	841	-	711	500 - 700	350 -875

a: application, b: product information according to the manufacture, c: according to James et al. (2005), d: pesticide not applied, e: not specified

Soil samples were taken 0, 1, 2, 4, 7 and 10 days after the first and second insecticide application and 0, 1, 2, 4, 7, 10, 13, 16, 24 and 45 days after the third application. At 0 day, sampling was done immediately after spraying. Soil samples consisted of five sub-samples taken at random. Samples were collected with a cylindrical soil auger (8 cm height and 5.5 cm inner diameter) and sub-samples were mixed thoroughly before an aliquot was wrapped into aluminium sheet and stored in plastic bags on ice until being frozen (<-16°C). On the last sampling day, a soil profile was dug and samples taken from various depths (8-15 cm; 15-25 cm; 25-35 cm; 35-45 cm; 45-55 cm) and treated as per the other samples. Samples serving for general soil analyses were taken before transplanting and on day 45 from the topsoil and the underlying horizons, respectively. Plant sampling was done immediately before pesticide application (blank matrix) and at 0, 2, 4, 8, 20, 32 and 72 h afterwards. One sample consisted of six plants each cut into 5cm pieces. The pieces were mixed and an aliquot of approximately 100g extracted and wrapped into aluminium sheet. The extract was put into a plastic bag and frozen (< -16°C) in deep freezer prior to processing and analysis.

Pesticide residues in soil or plant were extracted and results were converted to concentrations per soil dry weight or plant fresh matter. The mean concentration of the three replications and its standard error were routinely calculated. The fitting of model curves to the dissipation data was performed by using nonlinear regression (Sigma Plot 9.0, Systat Software GmbH, Erkrath, Germany), which uses the Marquardt-Levenberg algorithm. The quality of the fit is described by the correlation coefficient R^2 and by the probability value p of the parameter estimation. First-order functions (equation 1) fitted the data in most cases, but sometimes, adding a third constant parameter to the equation (equation 2) yielded a better fit.

Equation 1: $C(t) = C_0 \exp(-kt)$

Equation 2: $C(t) = C_1 \exp(-kt) + C_2$, with $C_1+C_2 = C_0$

Where:

$C(t) =$ concentration of pesticides still present in the soil at time t
$C_0 =$ concentration of pesticides at time $t = 0$
C_1 and C_2 = fractions of C0 subjected to the respective dissipation processes
k = dissipation rate constant.

Field half lives (DT_{50}) and other dissipation times (DT_{75}, DT_{90}), i.e. the time periods elapsed when 50%, 75% and 90% of the initial pesticide residues have disappeared from soil was calculated for equation 1 from: $DT_{50} = \ln(2) *k-1$; $DT_{75} = \ln(4) *k-1$ and $DT_{90} = \ln(10) *k-1$.

For equation 2, the calculation of dissipation times was done iteratively.

In the case of the endosulfan metabolite endosulfan-sulfate, whose concentration increased during the experiment, a different model was used (equation 3). It may be regarded as an empirical rather than a mechanistic function.

Equation 3: $C(t) = C_{max} * (1 - e(-kt))$

Where

$C(t)$ = concentration of pesticides present in the soil at time t

C_{max} = maximum concentration reached

k = the growth rate constant, which in fact is rather a net rate constant including metabolite formation and dissipation.

RESULTS

PESTICIDE REGIMES ON VEGETABLES

At each site, farmers cultivated a wide variety of vegetable species, frequently on small raised plots known as “beds”. Intercropping and crop rotation were common practices in each of the six West African countries: Benin, Ghana, Mali, Niger, Nigeria and Togo. Across all sites sampled in the countries, the frequency of occurrence of different species on the same bed (intercrop) was recorded as 10%, 57%, 32% and 53% for two, three, four and five species respectively. In crop rotation, the frequency of occurrence for the same crop being planted on the same bed as the 2nd, 3rd, 4th and 5th crop was 27%, 49%, 53% and 83% respectively. With such plant diversity, farmers noticed and were alarmed by a diverse range of arthropods and diseases on the various crops. Farmers were generally uninformed about the identity and roles of many of the arthropods, and believed that in the absence of chemical control interventions, the “pests” will significantly reduce the market value of their harvests. Annex 1 details chemical pesticides applied in vegetables in response to control the in the countries. The inventory includes one Organochlorine (endrin) and and Organophosporus (pirimiphos methyl) that are declared obsolete/banned for use by the 2004 WHO classification of pesticides by Hazard, four WHO Classes 1b pesticides (methamidophos, carbofuran, cadusafos, and fenamiphos, three of which are nematicides).

Figure 1 and Table 3 show the most frequently used pesticides in vegetable agroecosystems. In Benin bifenthrin and endosulfan were the most frequently used pesticides (ca. 30%) in vegetable agro-ecosystems followed by neem extracts. In Ghana,?teflubenzuron), neem extract and chlorpyrifos ethyl, methamidophos was commonly used by the farmers. Pirimiphos methyl and methamidophos are not on the list of chemical pesticides recommended to use on vegetables, but are used by the farmers in Ghana[3]. In Mali, deltamethrin was most frequently used and in Niger and Nigeria, methamidophos was the dominant product.

Intensive diagnosis of pesticide use patterns at vegetable production sites in Benin (Annex 3) revealed that cabbage, tomato, *Solanum macrocarpon* and pepper were indicator of harmful pesticide regimes in the vegetable agroecosystems. Cabbage producers applied approximately 46.8 litres pesticide concentrate per ha on the crop in 19 applications. Bifenthrin was applied 12 times and deltamethrin 7 times on each cabbage bed within 3 months prior to harvest in attempts

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[3] Source: Pesticides for horticulture production, Reference guide. 2006 Government of Ghana Environmental Protection Agency, Horticultural Export Industry Initiative (HEII) www.epaghana.gov

to control *Plutella xylostella* (Diamond Back Moth). Similarly, pepper received 18 applications of pesticide concentrates amounting to 39.6 litres of endosulfan, glyphosate and thiophanate-methyl per ha within 10 weeks of crop growth for the control of aphids, whiteflies and broad mite. In *Solanum macrocarpon* production, farmers applied 14 litres of pesticide concentrates bifenthrin and deltamethrin, and 27.8g of carbofuran and Maneb (which includes the related active ingredients mancozeb and metiram) per ha of the crop in 12 applications within 10 weeks of crop growth to control the broad mite and root knot nematodes.

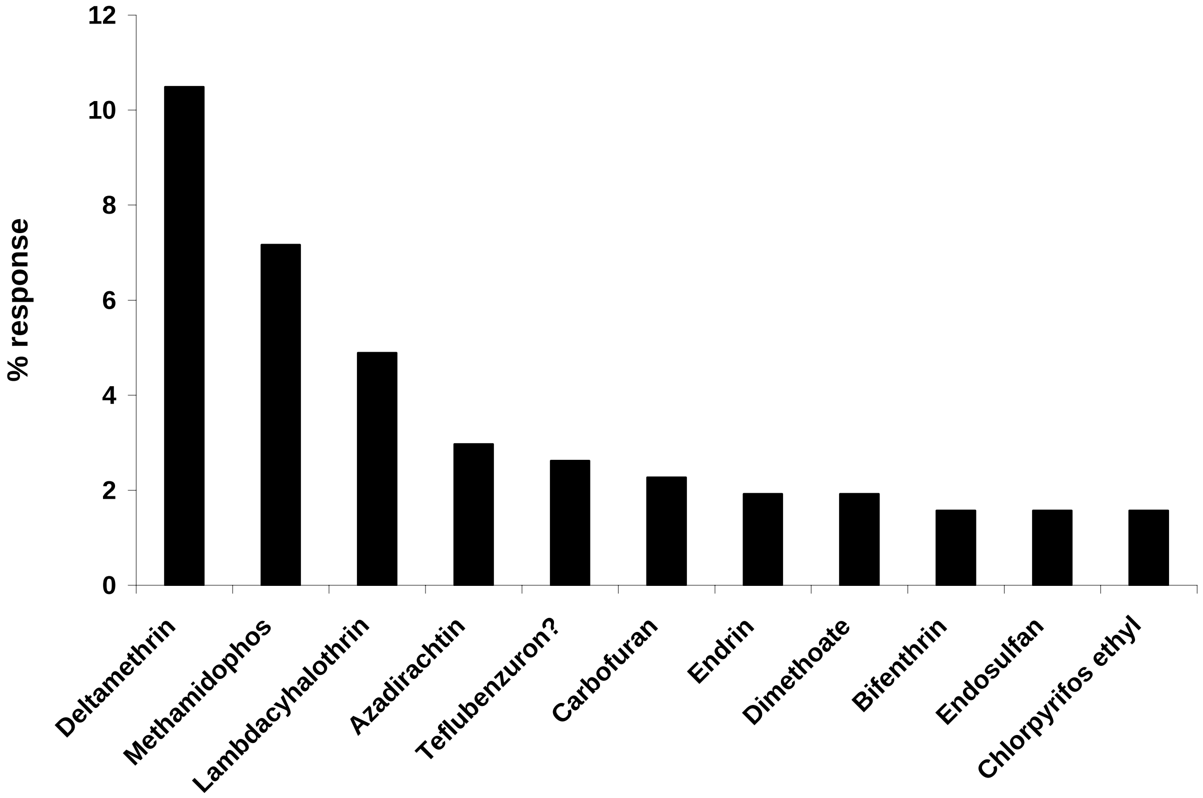

Figure 1: Frequently used pesticides on vegetables, West Africa

Table 3: Pesticides most frequently applied on vegetables in West Africa

Active ingredient	Trade name	Type of chemical	WHO Class[4]	Crop treated	Target pests
Methamidophos	Cypercal	Organophosphate	Ib	*Solanum marcrocarpon,* Pepper/sweet pepper, Igbo, amaranth, beetroot	Broad mite and aphids, whiteflies, unspecified insect pests
Deltamethrin	Decis K-Othrine	Pyrethroid	II	Cabbage; *Solanum marcrocarpon*; pepper/sweet pepper; onion; amaranth; cucumber; lettuce; beetroot; celery; minthis; courgette; carrot	Caterpillars, aphids; broad mite/mites, termites, whiteflies; unspecified insect pests
Endosulfan	Cotonfan; Thionex; endosulfan	Organochlorine	II	Tomato; pepper/sweet pepper; onion	mites, caterpillars; nematodes, whiteflies
Lambda-cyhalothrin	Karate	Pyrethroid	II	Tomato; *Solanum marcrocarpon*	*Helicoverpa amigera;* unspecified insect pests
Endrin	Endrin	Organochlorine	O	?	?
Bifenthrin	Talstar	Pyrethroid	II	Cabbage; *Solanum marcrocarpon*; lettuce; cucumber; amaranth	Caterpillars, aphids; broad mite; unspecified insect pests
Chlorpyrifos ethyl	Dursban	Organophosphate	II	Cucumber; okra	?Flea beetles; red ants
Carbofuran	Furadan	Carbamate	Ib	*S. marcrocarpon;* carrot; amaranth; okra	Nematodes; caterpillars and ants
Dimethoate	Dimethoate	Organophosphorus	II	Pepper/sweet pepper; onion; *Solanum marcrocarpon*; cucumber	Aphids; diseases;broad mite; unsspecified insects
?Teflubenzuron	Cydim Super	Benzoylurea	III	Aubergine; pepper/sweet pepper; French beans; cucumber	An insecticide
Azadirachtin	Neem extract	-	?	Cucumber	

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[4] 2004 WHO classification of pesticides by Hazard: O – obsolete/banned; Ia =extremely hazardous; Ib = highly hazardous; II = moderately hazardous; III = slightly hazardous; U = unlikely to present acute hazard in normal use

DISSIPATION OF PESTICIDES IN SOILS

The dissipation of different pesticide from the two types of soils (Acrisol and Arenosol) is summarized in Figures 2 to 8. Tables 4 summarises the curve fitting results and the calculated disappearance times for the dissipation in soil and on plants. Dissipation of bifenthrin (Fig. 2) was relatively slow, half lives ranging among the longest registered in this trial (DT_{50} 36.1 to 41 days). Deltamethrin DT_{50} varied from 5.8 days (Acrisol (AC), 1st application) to 14.5 days (Arenosol (AR), 3rd application), whereas dissipation from the Arenosol was always slower than from the Acrisol. Generally, half lives of deltamethrin tended to increase towards the 3rd application (Figure 3). Loss of diazinon was rapid in both soils (Figure 4) and dissipation was faster in the Arenosol with a DT_{50} of 2.7 days as compared with 5.5 days in the Acrisol. Due to the quick exponential decrease, good fit of the first-order functions was observed ($R^2 > 0.95$). Dissipation of α-endosulfan (Figure 5) followed a first-order function for both applications in the Arenosol and for the first one in the Acrisol. In contrast, a first-order function + constant best described loss in the Acrisol at the second application (Table 4). Disappearance times were always higher for the Arenosol as compared to the ones for the Acrisol. Moreover, DT_{50} values were increased for the second application as compared with the first. Dissipation of ß-endosulfan and endosulfan-sulfate in the Arenosol is not shown here since the background concentrations of the two substances in this soil were quite high and unevenly distributed within the beds, leading to large variations of the measured concentrations among the replicates and with time. However, dissipation of ß-endosulfan from the Acrisol (Figure 6) could be described by a first order function and by a first-order function + constant for the first and second application respectively (Table 4). DT_{50} values ranged from 10.5 days to 22 days, which is substantially higher than for the α-isomer.

The build-up of endosulfan-sulfate in the Acrisol (Figure 7) was described with an empirical model with reasonable fit quality ($R^2 > 0.76$). Yet, the model for the first application did not describe the decreasing concentrations since the fourth day after application. Surprisingly, after the second application, no phase of decreasing concentrations was observed but concentrations continued to rise until the end of the trial. Fitting curves to the sum of α- and ß-endosulfan in the Acrisol (Figure 8) resulted in good fits and field half lives were calculated at 6.5 d (1st application, first-order function) and 9.2 d (2nd application, first-order function + constant). Compared to the corresponding values for the individual isomers, these DT_{50} values were intermediate. Half lives of total endosulfan (α- + ß- + endosulfan-sulfate) in the Acrisol were longer, i.e. 8.5 and 17 d for the first and second application, respectively.

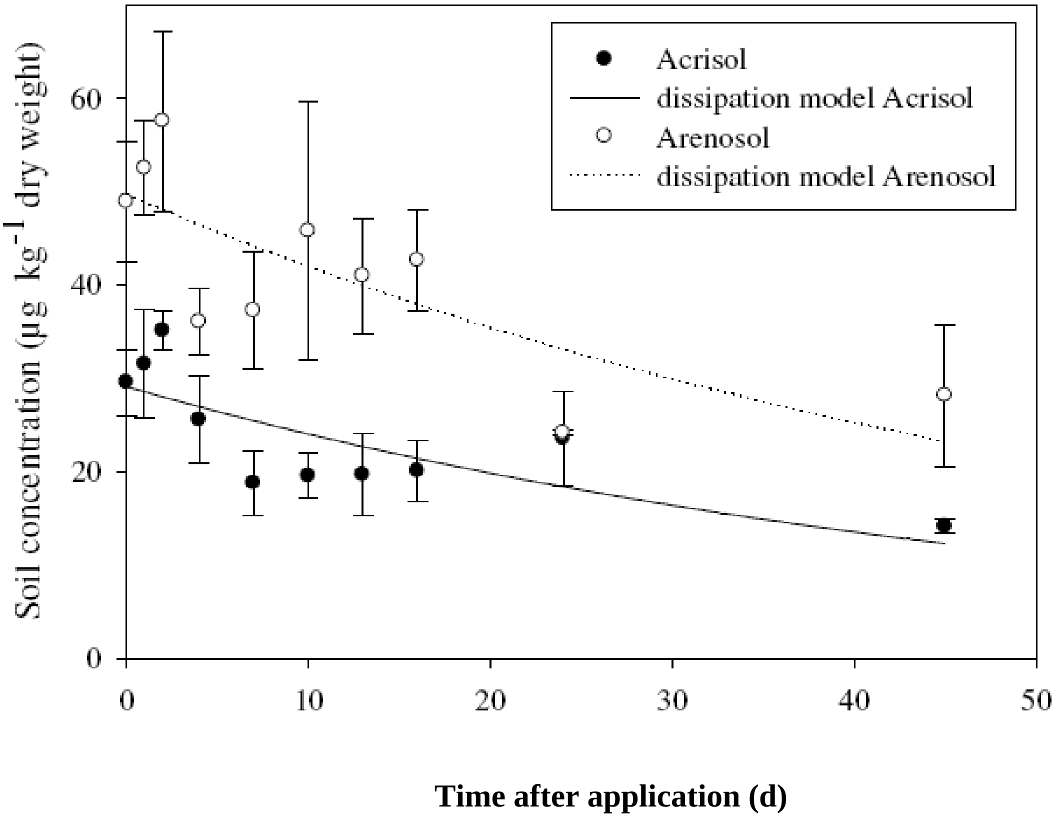

Figure 2: Dissipation of bifenthrin (n=3, error bars denote standard errors, R^2= 0.57 (AC) and 0.59 (AR)

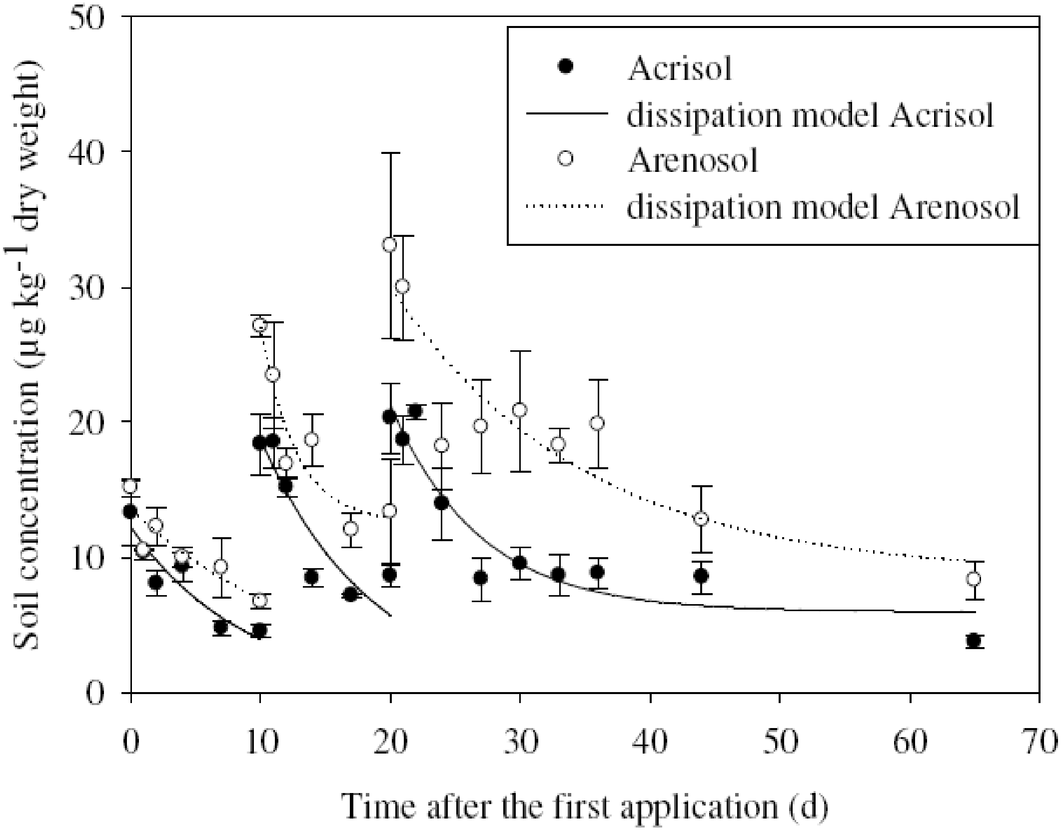

Figure 3: Deltamethrin dissipation (applications on days 0, 10, and 20, n = 3, error bars = SE, R^2 of curve fit = 0.86 (AC, 1st appl), 0.83 (AC, 2nd appl), 0.89 (AC, 3rd appl), 0.89 (AR, 2nd appl) and 0.82 (AR, 3rd application)

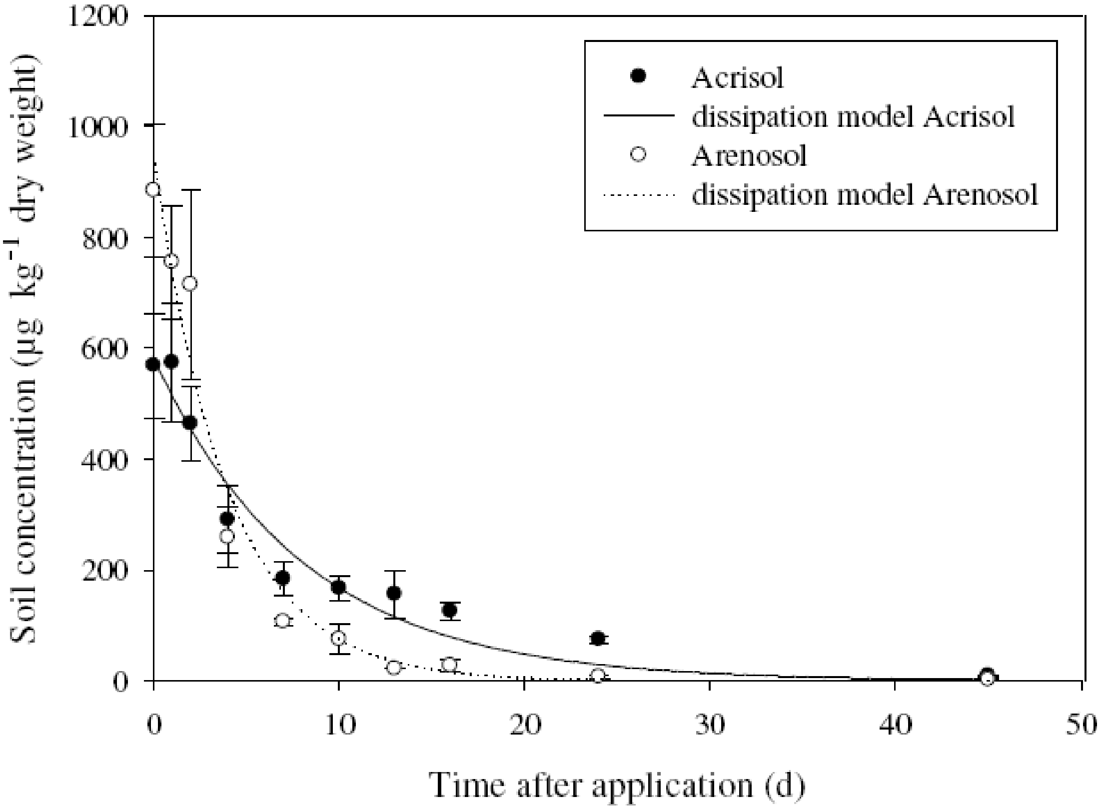

Figure 4: Dissipation of diazinon (n=3, error bars denote standard errors, R^2 = 0.95 (AC) and 0.97 (AR))

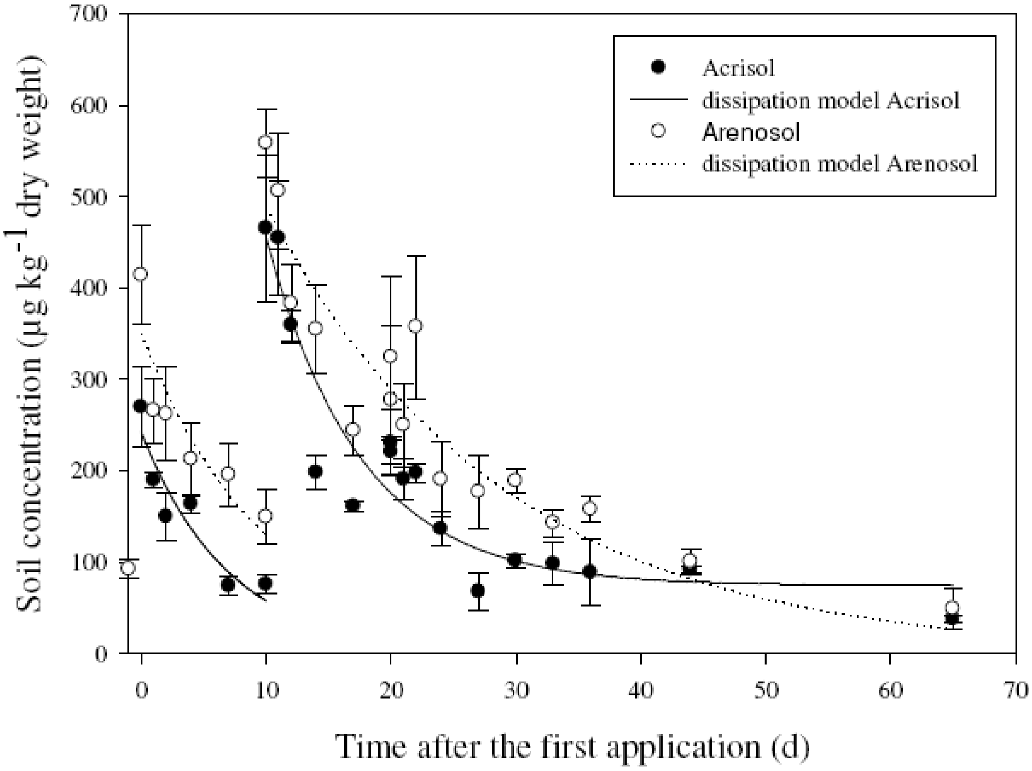

Figure 5: Dissipation of α-endosulfan (pesticide applications on days 0 and 10, n = 3, error bars denote standard errors, R^2 of the curve fit = 0.87 (AC, 1st application), 0.85 (AC, 2nd application), 0.79 (AR, 1st application) and 0.88 (AR, 2nd application))

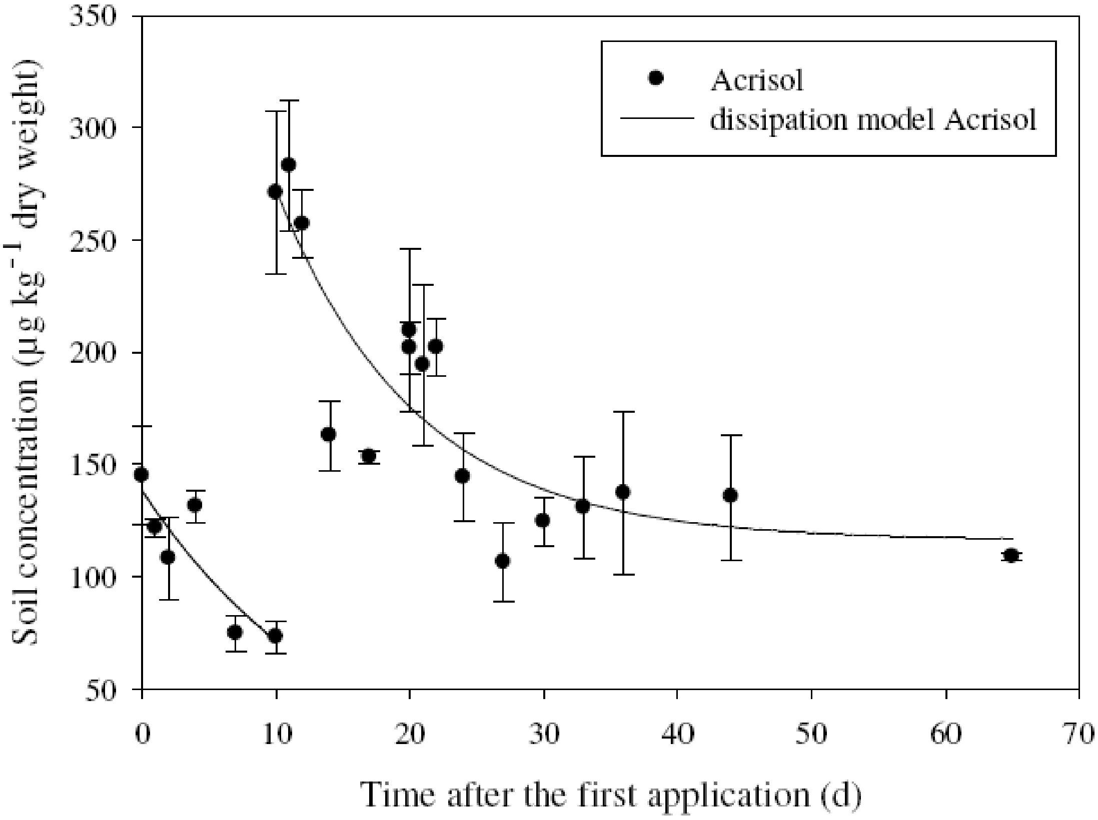

Figure 6: Dissipation of β-endosulfan (pesticide application on days 0 and 10, n = 3, error bars denote standard errors, R^2 of the curve fit = 0.76 (AC, 1st application), 0.75 (AC, 2nd application) data for the Arenosol not shown)

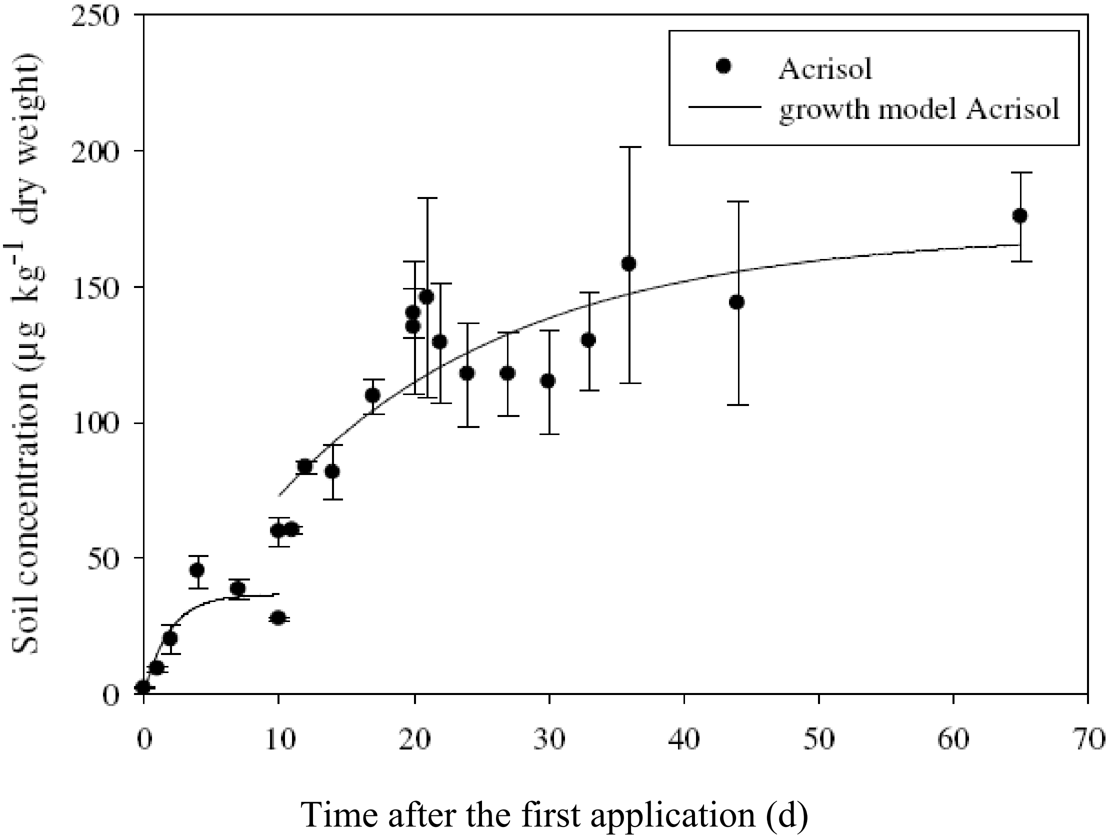

Figure 7: Build-up of endosulfan-sulfate (pesticide application on days 0 and 10, n = 3, error bars denote standard errors, R^2 of the curve fit = 0.78(AC, 1st application) and 0.76 (AC, 2nd application) data Arenosol not shown)

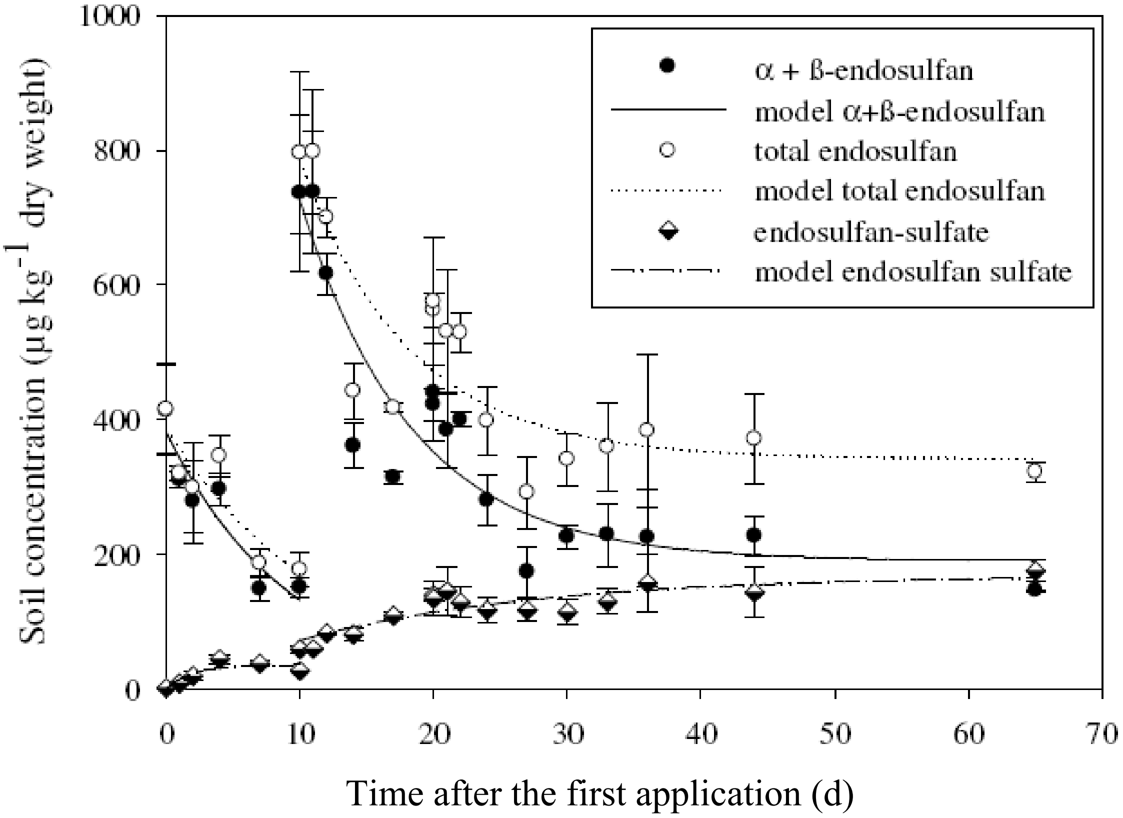

Figure 8: Dissipation of α + β-endosulfan, total endosulfan and endosulfan-sulfate at the Acrisol (pesticide application days 0 and 10, n = 3, error bars denote standard errors, R^2 of the curve fit = 0.87 (α + β, 1st application), 0.85 (α + β, 2nd application), 0.8 (total endosulfan, 1st application), 0.76 (total endosulfan, 2nd application), for endosulfan-sulfate, see figure 6)

Table 4: Estimated model parameters and statistical model parameters

Substance	Soil	No. of Appl.	Model type	Model parameters			p	R^2
				$C_0/C_1/C_{max}$ μg*kg^{-1}	C2	k day^{-1} (S.E. of estimate)		
bifenthrin	AC		1st –order	29.2	-	0.0192 (0.0067)	> 0.05	0.57
	AR		1st -order	49.7	-	0.0169 (0.0057)	-do-	0.59
deltamethrin	AC	1	1st –order	12.2	-	0.1133 (0.0266)	-do-	0.86
		2	1st –order	18.8	-	0.1189 (0.0314)	-do-	0.83
		3	1st –order + C2	15.3	5.0	0.1462 (0.0529)	-do-	0.89
	AR	1	1st –order	13.6	-	0.0679 (0.0186)	-do-	0.80
		2	1st –order + C2	14.4	12.6	0.3731 (0.1555)	-do-	0.89
		3	1st –order + C2	21.3	8.7	0.0685 (0.0374)	-do-	0.82
	Plant		1st –order	1.1	-	0.0080 (0.0027)	-do-	0.69
diazinon	AC		1st –order	582.4	-	0.1247 (0.0158)	-do-	0.95
	AR		1st –order	947.2	-	0.2538 (0.0338)	-do-	0.97
α -endosulfan	AC	1	1st –order	242.1	-	0.1435 (0.0342)	-do-	0.87
		2	1st –order + C2	380.5	74.2	0.1324 (0.0327)	-do-	0.85
	AR	1	1st –order	350	-	0.0997 (0.0287)	-do-	0.79
		2	1st –order	488.6	-	0.0526 (0.0067)	-do-	0.88
	Plant		1st –order	23.7	-	0.4444 (0.0409)	-do-	0.99

Table 4 (contd.): Estimated model parameters and statistical model parameters

Substance	Soil	No. of Appl.	Model type	Model parameters			p	R^2
				$C_0/C_1/C_{max}$ µg*kg^{-1}	C2	k day^{-1} (S.E. of estimate)		
β -endosulfan	AC	1	1st –order	138.5	-	0.0659 (0.0206)	> 0.05	0.76
		2	1st –order + C2	156.2	116	0.0968 (0.0399)	-do-	0.75
	AR	1	not feasible	n.m.	n.m.	n.m.	n.m.	n.m.
		2	1st –order	436.7		0.0108 (0.0046)	> 0.05	0.34
	Plant		1st –order + C2	8.6	4.5	0.2172 (0.0078)	-do-	0.92
endosulfan-sulfate	AC	1	Rise to max.	36.6	-	0.5301 (0.3212)	≤ 0.17	0.78
		2	Rise to max.	169.8	-	0.0562 (0.0110)	> 0.05	0.76
	AR	1	not feasible	n.m.	n.m.	n.m.	n.m.	n.m.
		2	not feasible	n.m.	n.m.	n.m.	n.m.	n.m.
	Plant		Rise to max.	5.1		0.1886 (0.0606)	> 0.05	0.88
α+β-endosulfan	AC	1	1st –order	381.9	-	0.1061 (0.0238)	-do-	O.87
		2	1st –order + C2	534.9	190	0.1198 (0.0238)	-do-	0.85
	AR	1	not feasible	n.m.	n.m.	n.m.	n.m.	n.m.
		2	1st –order	884.8		0.0256 (0.0061)	> 0.05	0.64
	Plant		1st –order + C2	32.3	5.4	0.3848 (0.0528)	-do-	0.99
total endosulfan	AC	1	1st –order	387.6	-	0.0831 (0.0229)	-do-	0.80
		2	1st –order + C2	441.7	342	0.1223 (0.0473)	-do-	0.76
	AR	1	not feasible	n.m.	n.m.	n.m.	n.m.	n.m.
		2	1st –order	12542		0.0094 (0.0045)	> 0.05	0.28
	Plant		1st –order + C2	26.7	10.4	0.4404 (0.0761	-do-	0.98

n.m. = not modelled since curve fitting was not feasible

DISSIPATION OF PESTICIDES ON PLANT SURFACES

The dissipation rate of deltamethrin (Figure 9) was the lowest of all pesticides in this trial, with a calculated half life of 86.6 h, which is a little beyond the temporal span of this trial (72 h) and therefore needs to be interpreted with caution. Also, the fit quality of the first order function used was the poorest of all investigated pesticides ($R^2 = 0.69$). To characterize the dissipation of endosulfan on plant surfaces (Figures 10 and 11), the following models were chosen: a first-order model for α-endosulfan and a first-order model + constant for ß-endosulfan, α-+ß-endosulfan and total endosulfan, respectively. All of them yielded good fit qualities ($R^2 > 0.92$, Table 5). Concentration of α-endosulfan dropped fast to almost zero at 20 h after application, while a seemingly constant fraction of ß-endosulfan remained on the leaves until the end of the trial. The increase of endosulfan-sulfate on plant surfaces was described by an empirical function (exponential growth to the maximum, $R^2 = 0.88$), and no further decrease in concentration could be observed during the experimental period. Measured half lives were rather short for all endosulfan compounds, from 1.6 h for the α-isomer, 2.3 h for the sum of α and ß to 6.7 h for the ß-isomer.

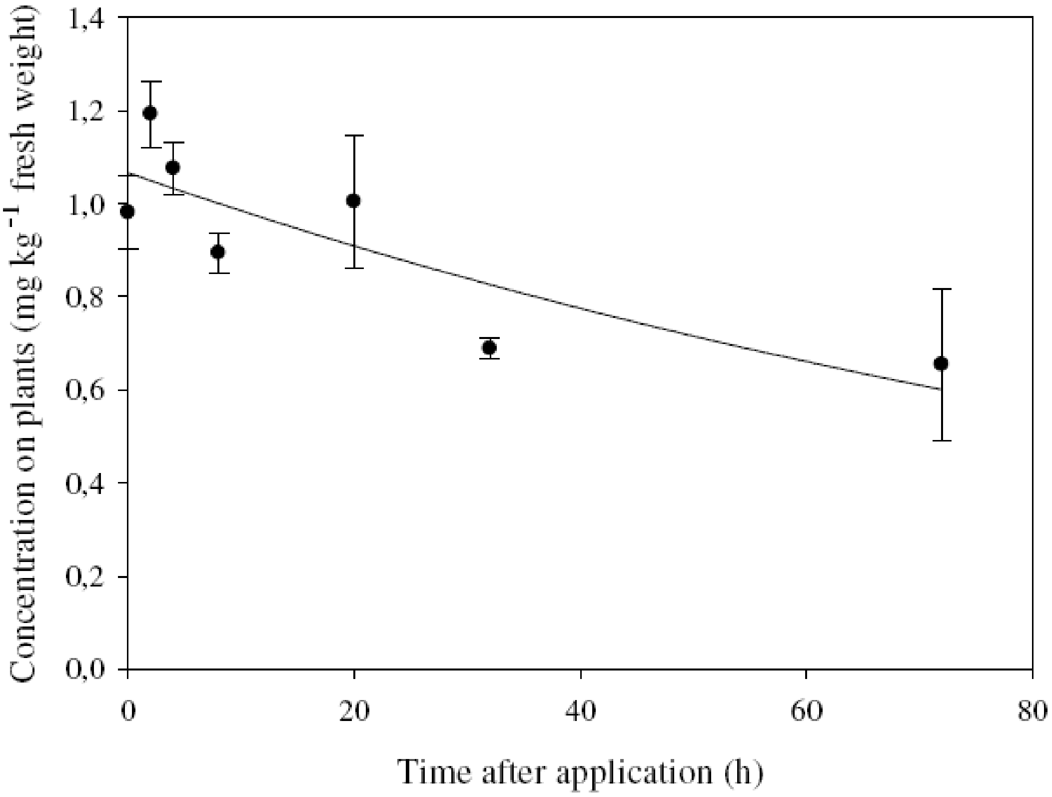

Figure 9: Dissipation of deltamethrin on plant surfaces (n = 3, error bars denote standard errors, $R^2 = 0.69$)

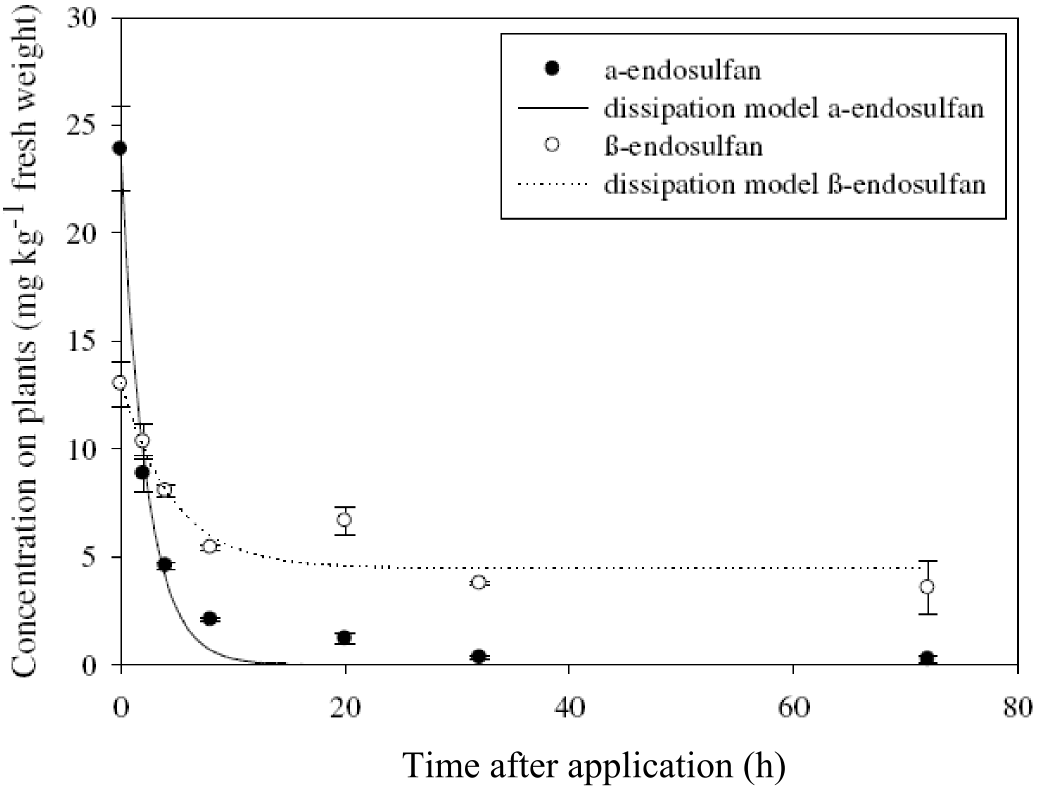

Figure 10: Dissipation of α- and β-endosulfan on plant surfaces (n = 3 error bars denote standard errors, $R^2 = 0.99$ (α- endosulfan) and 0.92 (β-endosulfan))

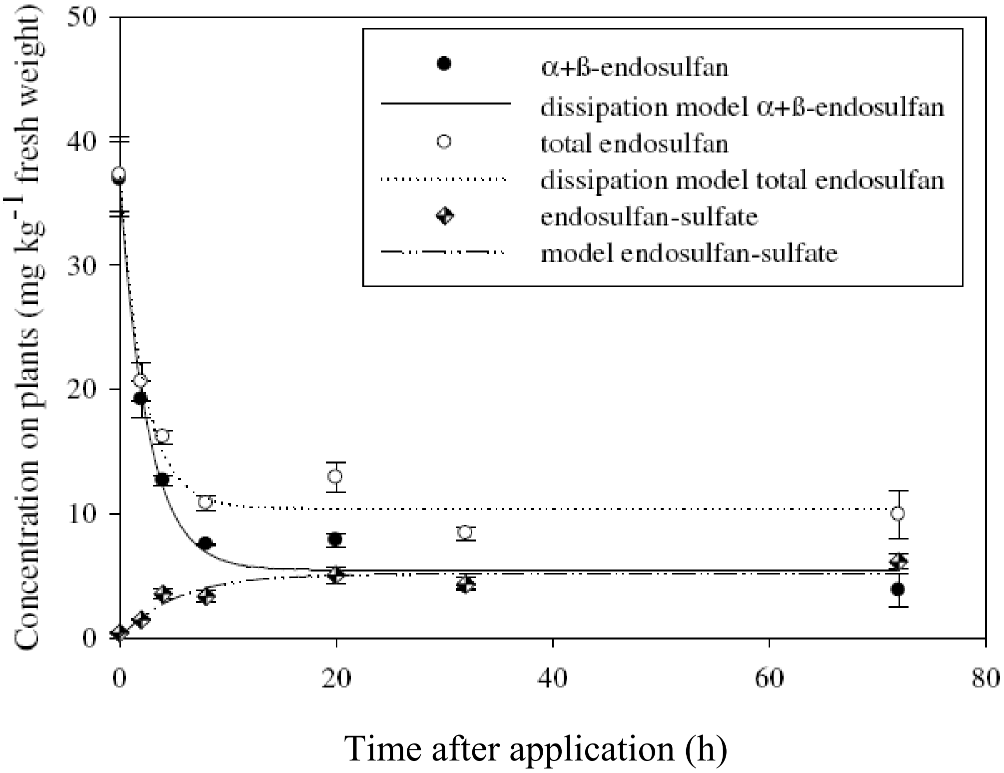

Figure 11: Dissipation of α + β-endosulfan and total endosulfan and build-up of endosulfan-sulfate on plant surfaces (n = 3, error bars denote standard errors $R^2 = 0.99$ (α + β), 0.98 (total endosulfan) and 0.88 (endosulfan-sulfate))

Table 5: Dissipation times for the pesticides used in the different trials

substance	soil/plant	Application no1	Application no2	Application no3
		DT50 (days unless otherwise stated)		
bifenthrin	AC	36.1	-[a]	-
	AR	41.0	-	-
	Plant	-	-	-
deltamethrin	AC	6.1	5.8	8.9
	AR	10.2[§]	7.3	14.5
	Plant	86.6 h[§]	-	-
diazinon	AC	5.5	-	-
	AR	2.8	-	-
	Plant	-	-	-
α -endosulfan	AC	4.8	6.6	-
	AR	7.0	13.1	-
	Plant	16.6 h	-	-
β -endosulfan	AC	10.5[§]	22.0	-
	AR	n.m.	64.2	-
	Plant	6.7 h	-	-
α+β-endosulfan	AC	6.5	9.2	-
	AR	n.m.	27.0	-
	Plant	23 h	-	-
tot al endosulfan	AC	8.5	17.0	-
	AR	n.m.	73.7[§]	
	Plant	2.7 h	-	-

Key for pesticide applications

a = pesticide not applied

§ = beyond the temporal span of the trial

n.m = not modelled since curve fit not possible

LEACHING OF PESTICIDES IN THE SOIL PROFILE

Figure 12 shows the depth profile of pesticides on the last day of trial (day 65) at the Arenosol site. Bifenthrin, diazinon and α-endosulfan were not detectable in samples. Endosulfan-sulfate and, to a lesser extent, ß-endosulfan were found throughout the whole tillage depth (0 -30 cm) at decreasing concentrations with increasing depth. Deltamethrin was only found once, at a depth of 35-45 cm. The high standard errors of many of the calculated means are due to large differences between the two replicates, i.e. large spatial variability. Total pesticide amount found below the soil surface (i.e. below 8 cm depth) accounted for approximately 10% (ß-endosulfan) and 25% (deltamethrin) of the amount applied during one application and for 30% (endosulfan-sulfate) of the amount found in the surface horizon at day 65.

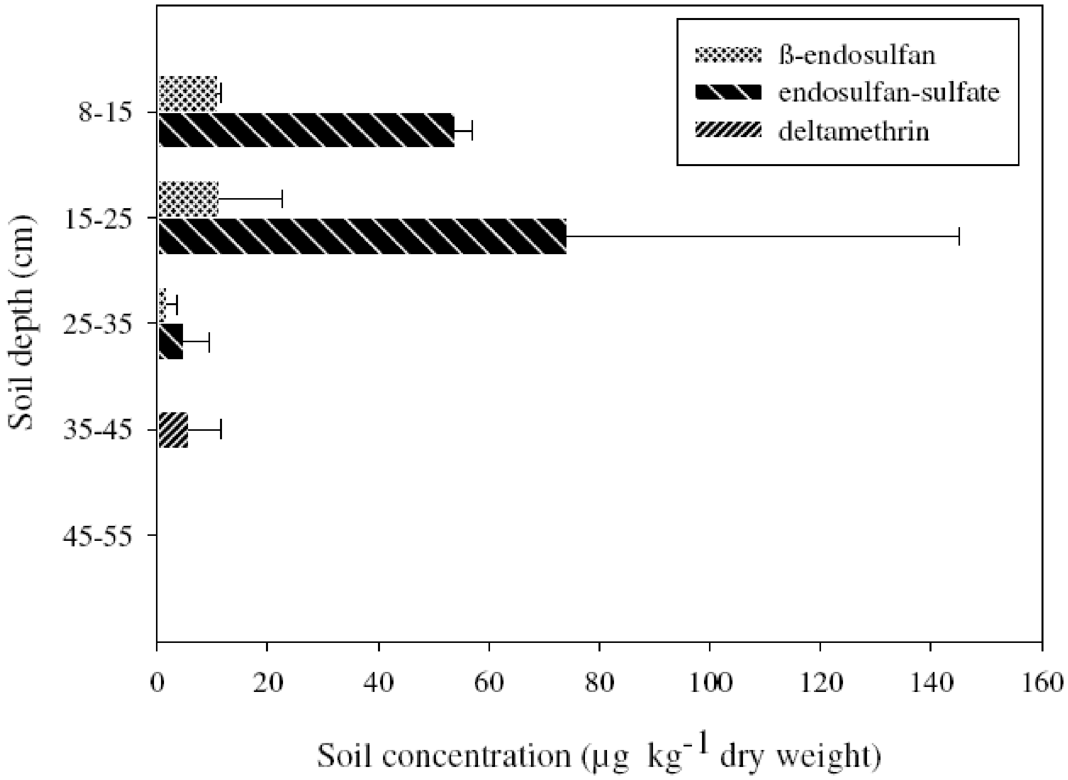

Figure 12: Dissipation of pesticides in depth on the last day of the trial at the Arenosol (n = 2, error bars denote standard errors)

4. DISCUSSION

The SP-IPM emphasises the need for pesticide use management in favour of biological alternatives. Studies on pesticide fates in the agroecosystems are however few and far in between in the developing countries. In line with the SP-IPM position on use of synthetic chemical pesticides, this study provides comprehensive information on pesticide use patterns and on pesticide fates in vegetable agroecosystems to advise on existing inappropriate pesticide regimes which undermine health, environment and trade. The findings on pesticide type, volume and application frequency in vegetables indicates that pesticide use patterns in the agroecosystem pose a grave concern in West Africa. Inter-institutional research collaboration is required to assess similar baseline situations in agroecosystems targeted for development (e.g. the emerging CGIAR Challenge Program on High Value Crops)

In the studies on pesticide dissipation in soils, the pyrethroid bifenthrin showed the longest field half life and also the smallest reduction in half life as compared to temperate climates (maximum factor of three). The difference in dissipation dynamics between the two soils (Arenosol and Acrisol) is not substantial. Bifenthrin's relative persistence in the environment might be due to its high photostability on soil surfaces (photolysis DT50: 96.9 days, reviewed by Laskowski, 2002), its strong adsorption to soils (K_{oc}: 120000 – 300000 ml g_{oc}^{-1}) and a low potential for volatilization. The highest bifenthrin soil concentrations were measured on the third day after application for both soils. Ciglasch et al. (2006) reported on a similar behaviour for some pesticides they had applied on a terrain covered with grass in Northern Thailand. Possibly, pesticides were washed-off from plants by irrigation during the first day after application and therefore, soil concentrations increased accordingly.

The dissipation of deltamethrin was considerably faster than dissipation of bifenthrin. This complies well with the known sensitivity of deltamethrin to photodegradation, which leads to photolysis half life on soil ranging from 9 days (Tomlin, 1997) to 35 days (Laskowski, 2002). As deltamethrin also shows a low potential for volatilization due to low vapour pressure and strong adsorption to soil, the initial dissipation of deltamethrin in temperate climates is attributed mainly to photolysis rather than to volatilization (Hill et al., 1985; Zhu and Selim, 2002). This conclusion supposedly remains valid in the tropics, despite of high temperatures and potential volatilization rates. Hence, the accelerated dissipation of deltamethrin observed in the present study, as compared with data from temperate climates, may be traced back to enhanced photolytic and microbial degradation.

The organophosphate diazinon was the only pesticide studied that dissipated faster from the Arenosol than from the Acrisol. DT_{50} values in the Arenosol were half as large as in the Acrisol and differences between dissipation rate constants were substantial..

For endosulfan, the α-isomer dissipated faster than the ß-isomer presumably due to its higher volatility (Kathpal et al., 1997; Kennedy et al., 2001; Ciglasch et al., 2006). DT_{50} values of the two isomers were higher for the second application, suggesting accumulation of endosulfan compounds in the Acrisol. Yet, a substantial difference between dissipation rate constants can not be observed. Endosulfan-sulfate, which is the major metabolite of α- and ß-endosulfan in soil (Martens, 1977) and plants (Chopra and Mahfouz, 1977), is generally comprised in the residue calculation of endosulfan, since is still exhibits toxicity (Goebel et al., 1982). It was obviously more persistent than the parent compounds in test soils, as its concentration accounted for 18% of the overall applied endosulfan and 54% of the endosulfan residues still present in the soil at the end of the trial. The decline of endosulfan-sulfate concentration in the soil was not observed during the entire field trial, which is in accordance with the large DT_{50} values (99 ± 47 d) reported by Kennedy et al. (2001) in a study on Australian cotton fields, as well as with a dissipation half life of 130 to 160 days calculated from laboratory data of Diaz Diaz et al. (1995) for endosulfan-sulfate.

Dissipation of endosulfan in the Arenosol is considered separately, as a high background contamination with endosulfan residues before application seemingly influenced the fate of endosulfan in this soil. Therefore, endosulfan dissipation was substantially slower than in the Acrisol, and thus, the dissipation rate of endosulfan was increased in comparison to temperate climates disproportionately less in the Arenosol (factor of 2 to 3), especially for ß-endosulfan. The background contamination of the Arenosol was less for α-endosulfan, since it is less persistent than the ß-isomer. Consequently, the higher application rate of the α-isomer resulted in a more clearly discernible dissipation of the substance in the trial. As the concentrations of α-endosulfan dropped below the initial residue level at the end of the trial, the background residues also dissipated partially. A difference in dissipation rate constants for α-endosulfan was not significant between both soils for the first application, yet was substantial for the second application.

With the more persistent ß-endosulfan, residue concentrations in soil (139.5 ± 14.5 $\mu g\ kg_{-1}$ dry soil (S.E.), n = 5) apparently were high (and irregularly distributed) enough to mask dissipation of the freshly applied pesticide which necessarily occurred although it could not be observed (first application) or was very slow (second application). Indeed, the applied amount of ß-endosulfan (164.2 µg kg^{-1} dry soil) and background residues were approximately equal, but the latter presumably were very heterogeneously distributed within beds. Given that the overall dissipation of ß-endosulfan is comprised of the dissipation of both, the residual and the freshly applied pesticide portions, dissipation of the latter is presumably somewhat faster than the overall rate suggests while it was even slower for the residual ß-endosulfan. This implies that residues of ß-endosulfan virtually did not dissipate in the field trial, suggesting a very strong binding to soil, which is termed "aging".

For α-endosulfan, a low tendency for aging has been reported (Laabs and Amelung, 2005), but properties of ß-endosulfan may be different in this respect. In any case, the solvents used for soil extraction (acetone/ethyl acetate/water, AEW) are known to exhaustively extract pesticides from soil, even the strongly adsorbed fractions (Laabs and Amelung, 2005). However, further testing would be required to endorse the hypothesis of ß-endosulfan aging in the Arenosol. For instance, a sequential extraction of the soil with water, methanol and AEW can be used to segregate pesticide fractions of different adsorption strength (Laabs and Amelung, 2005). In this way, the aged residues could be distinguished from the freshly applied pesticide fraction, whose dissipation could then be followed in the water and methanol fractions.

The background concentrations of endosulfan-sulfate in the Arenosol (157.3 µg kg^{-1} dry soil) were higher than those of α- and ß-endosulfan, which also confirms the relative persistence of this metabolite. The extreme heterogeneity of endosulfan-sulfate concentrations in the Arenosol did not allow to know if endosulfan-sulfate concentrations diminished towards the end of the trial or not. Endosulfan-sulfate concentrations in the Acrisol did not decrease towards the end of the trial, although residues had fewer time for aging at that site. Endosulfan-sulfate is a potential long-term pollutant in the investigated soils.

The effect of repeated applications could be estimated from deltamethrin, which was applied three times. For deltamethrin, differences in dissipation rates or in the 'constant' fraction C_2 could not be detected among the various applications on each type of soil on which chemical pesticides dissipation trials were carried out. Hence, the theoretical data could provide evidence neither for the increase of pesticide residues in the soil and the slowdown of dissipation nor for the acceleration of the microbial degradation, which both could be suspected as a result of repeated applications (Wada et al., 1989; de Andrea et al., 2003). Though, the calculation of accumulation factors from the measured pesticide concentrations reveals a different picture. For instance, 300% and 125% of the deltamethrin residue of the first application (10 days after application) were still present in the Arenosol 10 and 45 days after the third application. These data call for careful interpretation, as they may be biased by the application of compost, but even for the Acrisol, these values reach 210% and 80%, respectively, indicating at least a mid-term accumulation.

Hence, pesticide residues may accumulate in the investigated soils if frequent applications are practiced, as was already indicated by the initial contamination of the Arenosol with endosulfan residues. Generally, the results of this trial allow for the following statements: Pesticide dissipation observed under the tropical conditions of this study was always faster than reported from temperate climates and laboratory experiments. Pesticides half lives were shortened by a factor of six to ten for most combinations of pesticides and soils, which is in good agreement with the results of Laabs et al. (2002). However, half lives were only reduced by a factor of three for bifenthrin, endosulfan compounds in the Arenosol and diazinon in the Acrisol.

High dissipation rate of pesticides in the tropics is commonly attributed to high volatilization and high microbial degradation. However, a correlation between the observed half lives and any physicochemical property of a pesticide as a measure for its tendency to one specific dissipation process (e.g. vapour pressure and volatilization) could not be found. This may be due to the similar nature of the pesticides included in this study, i.e. to the limited range of pesticide physicochemical properties, yet, it may also indicate that various dissipation pathways are relevant under field-conditions instead of one process playing a major role.

With the exception of diazinon, pesticide dissipation was faster from the Acrisol than from the Arenosol. Although both soils had a comparable content of organic matter, which strongly determines adsorption of non-ionic pesticides (Barriuso and Calvet, 1992), it seems pesticides were less strongly adsorbed and thus more readily available for dissipation in the Acrisol. However, pesticide adsorption is not only determined by the amount of organic matter but also by its nature (Spark and Swift, 2002), which may differ considerably between soils. This was surely the case of the two soils under study. At the Arenosol, organic matter was stemming mainly from compost utilized as organic amendment, whereas at the Acrisol, organic amendments were scarce. Furthermore, one should bear in mind that a fresh layer of compost has been applied to the Arenosol before the second application. Another potential reason for the differences in dissipation rate between the two soils could be a smaller microbial activity in the Arenosol, due to e.g. toxic levels of pesticides (endosulfan residues for instance) in the soil.

Pesticide dissipation from plant surfaces was considerably faster than from soil. Dissipation of α-endosulfan was rapid, whereas initial fast decline of ß-endosulfan was followed by a second phase of much slower dissipation. This pattern was also observed by Kennedy et al. (2001) for the dissipation from cotton foliage and is similar to the one described for soil dissipation in the present study. α-endosulfan was lost almost completely during the initial phase (1.4% of the applied amount remaining after 32 h), yet ß-endosulfan dissipated to a lesser extent (28.9% of the applied amount remaining after 32 h) and thus did not reach DT_{75} or DT_{90} during the study period (72 h). Again, concentrations of endosulfan-sulfate continued to increase within the three-days trial, indicating a relative stability of the metabolite as compared to its parent compounds on plant surfaces since 32 h after application. However, half life times reported in this study are to my knowledge the shortest measured for endosulfan so far (Table 8). Contrary to that, dissipation of deltamethrin from plant surfaces was remarkably slow, i.e. half life time was distinctively longer than for endosulfan (87 h). Furthermore, dissipation time was only reduced by a factor of up to two as compared with temperate climates, while for endosulfan, a reduction of DT_{50} values by a factor of up to 14 was observed. Rüdel et al. (1992 and 1997) investigated the volatilization of both substances from plant surfaces in wind tunnel experiments at 20 to 25 °C and reported that 60% of the applied amount of endosulfan volatilized from French beans within 24 hours, compared to < 1% of deltamethrin. Volatilization being enhanced in tropical temperatures (Bedos et al., 2002a), yet playing only a very minor role for deltamethrin in general, it is obvious that the acceleration of dissipation should be greater for endosulfan than for deltamethrin. Findings of Raha et al. (1993), who investigated the dissipation of endosulfan and deltamethrin from eggplant leaves in tropical India, indicated that deltamethrin dissipated faster than endosulfan, with DT_{50} values of 40 h for the pyrethroid. Seemingly, dissipation of deltamethrin in that trial was unusually high, yet the reasons remain unclear.

In terms of leaching of pesticides, residues of ß-endosulfan and endosulfan-sulfate, which were found throughout the entire tillage depth in the Arenosol, presumably stemmed from previous applications with subsequent incorporation. Concentrations of endosulfan residues were quite high and can not be ascribed to downward movement by leaching only, as these compounds are known to be quite immobile in sandy soils (Laabs et al., 2000) and were not been found below 10 cm depth in various field studies (Kathpal et al., 1997, Kennedy et al., 2001). Differences in persistence of the individual endosulfan compounds can explain why the amount of endosulfan-sulfate, the persistent major metabolite, was detected at the highest concentrations, while α-endosulfan, the least persistent, could not be detected. Variability of endosulfan concentrations within the soil surface layer even increased with soil depth, presumably due to non-systematic tillage. At a depth of 25 to 35 cm, concentrations of endosulfan decreased sharply, because no incorporation of topsoil occurred at this depth anymore. However, from a depth of 35 cm downwards, endosulfan compounds were no longer detectable in the soil profile and thus, a build-up of significant amounts of endosulfan in the subsoil by leaching can be excluded on the conditions of this trial, despite of the heavy contamination of this horticultural soil. However, a groundwater monitoring study in Portugal by Gonçalvez et al. (2007) indicated that endosulfan compounds may be a major groundwater pollutant in vulnerable areas. Thus, also for Southern Benin, a groundwater monitoring in areas with heavy use of endosulfan should be implemented. A substantial concentration of deltamethrin was also found in one sample at 35 to 45 cm depth. Generally, that pyrethroid is characterized by a high adsorption to soil and low water solubility, leading to non-susceptibility for leaching (Selim and Zhu, 2002). In various studies, it was found only in minor quantities (< 1 % of the applied amount) if at all below the soil surface or in the leachate (Hill et al., 1985, Laabs et al., 2002b, Selim and Zhu., 2002), so that its detection at this soil depth was quite surprising. However, Ciglasch et al. (2005) reported a detection of the pyrethroid cypermethrin in soil leachate, which could not be explained by solute transport alone. They therefore suggested a pyrethroid-specific “enhancement of transport” in soil, e.g. mediated by dissolved organic matter. Yet, as deltamethrin was detected only in one sample, no further conclusions can be drawn.

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Annex 1: Pesticides on vegetables in six West African countries

Active ingredient	**Trade name**	**Type of chemical**	**WHO Class**[5]	**Crop treated**	**Target pests**	**Countries**					
						Benin	Ghana	Mali	Niger	Nigeria	Togo
Pirimiphos-Methyl	Actellic	Organophosphorus	III	Tomato			**x**				
Endrin	Endrin	Organochlorine	O	Cabbage	Aphids, Caterpillars			**x**			
				Cucumber	Insects			**x**			
				Okra	Insects			**x**			
				Tomato	caterpillars			**x**			
Methamidophos	Cypercal	Organophosphate	Ib	*Solanum marcrocarpon*	Broad mite and aphids	**x**	**x**	**x**	**x**	**x**	
				Pepper/sweet pepper	Aphids, whiteflies,mite	**x**	**x**				
				Amaranth	?					**x**	
				Amaranth	Insect pests						**x**
				Beetroot	Insect pests						**x**
Carbofuran	Furadan	Carbamate	Ib	*S. marcrocarpon*	Nematodes	**x**	**x**	**x**	**x**		
				Carrot	Nematodes	**x**					
				Amaranth	Nematodes						**x**
				Okra	Caterpillars and ants			**x**			
Cadusafos	Rugbi 10	Organophosphate	Ib	Lettuce	Nematodes						**x**
Fenamiphos	Nemacur	Organophosphate	Ia	Cucumber	Nematodes						**x**
Cypermethrin	Cypermethrin	Pyrethroid	II	Lettuce	Insect pest				**x**		**x**
Endosulfan	Cotonfan; Thionex; endosulfan	Organochlorine	II	Tomato	Whiteflies, mites, caterpillars, nematodes	**x**					
				Pepper/sweet pepper	?	**x**					
				Onion	?	**x**					
Lambda-cyhalothrin	Karate	Pyrethroid	II	Tomato	*Helicoverpa amigera*		**x**		**x**	**x**	
				Amaranth	*?*					**x**	

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[5] 2004 WHO classification of pesticides by Hazard: O – obsolete/banned; Ia =extremely hazardous; Ib = highly hazardous; II = moderately hazardous; III = slightly hazardous; U = unlikely to present acute hazard in normal use

Annex 1 (contd.): Pesticides on vegetables in six West African countries

Active ingredient	**Trade name**	**Type of chemical**	**WHO Class**[6]	**Crop treated**	**Target pests**	**Countries**					
						Benin	Ghana	Mali	Niger	Nigeria	Togo
DDT	DDT	Organochlorine	II	Cabbage	Insect pests						**x**
				Green bean	Insect pests						**x**
				Aubergine	Insect pests						**x**
				Pepper	Insect pests						**x**
				Courgette	Insect pests						**x**
				Tomato	Insect pests						**x**
				Onion	Caterpillars		**x**				
				Okro	Caterpillars		**x**				
Deltamethrin	Decis K-Othrine	Pyrethroid	II	Cabbage	Caterpillars, aphids	**x**	**x**	**x**	**x**	**x**	
				Solanum marcrocarpon	Broad mite and aphids	**x**					
				Pepper/sweet pepper	Mites, termites, caterpillars; whiteflies			**x**	**x**		
				Onion	?				**x**		
				Amaranth	Caterpillars	**x**					
				Cucumber	Insect pests			**x**			
				Lettuce	Insect pests			**x**			
				Beetroot	Insect pests			**x**			
				Celery	Insect pests			**x**			
				Mintis	Insect pests			**x**			
				Courgette (zucchini)	Caterpillars						**x**
				French beans/sweet pepper	Insect pests						**x**
				Carrot	Insects	**x**					
Chlorpyrifos	Pyrinex	Organophosphate	II	Onion	soil red ants, mites		**x**				
				Tomato	Caterpillars, leaf miners		**x**				
Diazinon	Diazol	Organophosphate	II	Cabbage	Nematodes, insects		**x**				

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Annex 1 (contd.): Pesticides on vegetables in six West African countries

Active ingredient	**Trade name**	**Type of chemical**	**WHO Class**[7]	**Crop treated**	**Target pests**	**Countries**					
						Benin	Ghana	Mali	Niger	Nigeria	Togo
Fenpropathrin	Fenpropathrin	Pyrethroid	II	Tomato	Aphids, whiteflies, broad mite, whiteflies, nematodes	**x**					
				Okra	Caterpillars and ants			**x**			
				Pepper/sweet pepper							**x**
				French beans	Insect pests						**x**
Hexachlorocyclohexane	Lindane	Organochlorine	II	Cucumber	Insect pests			**x**		**x**	
Malathion	Malathion	Organophosphorus	III	?	?						
Acephate	Orthène	Organophosphate	III	Green beans	Insects, ?Disease	**x**					**x**
				Onion	Caterpillars	**x**					**x**
Bifenthrin	Talstar	Pyrethroid	II	Cabbage	Caterpillars, aphids	**x**					
				Solanum marcrocarpon	Broad mite and aphids	**x**					
				Lettuce	Unspecified insect pests	**x**					
				Cucumber	Unspecified insect pests	**x**					
				Amaranth	Caterpillars	**x**					
Chlorpyrifos ethyl	Dursban	Organophosphate	III	Cucumber	?		**x**				
				Okra	Flea beetles; red ants		**x**				

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Annex 1 (contd.): Pesticides on vegetables in six West African countries

Active ingredient	**Trade name**	**Type of chemical**	**WHO Class**[8]	**Crop treated**	**Target pests**	**Countries**					
						Benin	Ghana	Mali	Niger	Nigeria	Togo
Bacteria/ *Bacillus popilliae* (toxin/spores)	Doom, Biobit	Biopesticide	?	Amaranth	Maggot and butterfly					**x**	
				Scent Leaf (minthis)	Stemborers; leaf hopper; other insects					**x**	
Dimethoate	Dimethoate	Organophosphorus	II	Pepper/sweet pepper	Aphids				**x**		
				Pepper/sweet pepper	Caterpillars, Aphids	**x**					
				Onion	?	**x**					
				Cucumber	?		**x**				
				Carrot	Nematodes						**x**
Glyphosate	Rambo	glycine derivative	III	Pepper/sweet pepper	Aphids, whiteflies and broad mite	**x**					
				Onion	?	**x**					
Maneb + zinc oxide	Trimangol		III	?	?		**x**				
				Solanum marcrocarpon	Mites, aphids, diseases	**x**					
				Lettuce	Fungal diseases	**x**					
Thiophanate-methyl	Topsin-M	benzimidazole	III	Aubergine	Diseases	**x**	**x**	**x**			**x**
				Solanum marcrocarpon	Diseases;broad mite	**x**					
				Cucumber	Diseases and insects						**x**
				Pepper/sweet pepper	Diseases	**x**					
?Teflubenzuron	Cydim Super	benzoylurea	III	Aubergine	Diseases	**x**	**x**				**x**
				Pepper/sweet pepper	?		**x**				
				French beans	?		**x**				
				Cucumber	?		**x**				

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Annex 1 (contd.): Pesticides on vegetables in six West African countries

Active ingredient	**Trade name**	**Type of chemical**	**WHO Class**[9]	**Crop treated**	**Target pests**	**Countries**					
						Benin	Ghana	Mali	Niger	Nigeria	Togo
Mancozeb?	Dithane; Cyperfos; Termicol	see above	III	Cucumber	?						**x**
				?	?		**x**				
				Tomato	Aphids			**x**		**x**	
				?	?						
?Oxyde of copper	Ridonyl plus	-	ÎII	Lettuce	Diseases						**x**
?Profenofos	CotolmP	Organophosphorus	II	Tomato	?				**x**		
Fipronil	Regent; Profonos	Phenylpyrazole	II	Aubergine	Diseases						**x**
				Pepper/sweet/pepper	?			**x**			
Cypermethrin	Cytoate	Pyrethroid	II	Pepper/sweet/pepper	Aphids				**x**		
Azadirachtin	Neem extract	?	?	Cucumber			**x**				

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Annex 2: Frequency of pesticide application on vegetables in Benin

Crop	Weeks to harvest	No. of pesticide application prior to harvest								Total no. application
		Carbofuran	Maneb	Bifenthrin	Deltamethrin	Endosulfan	Glyphosate[i]	Thiophanate-methyl, + methamidophos+ Profenofos	Fenpropathrin	
Cabbage	12	-	-	12	7	-	-	-	-	19
Tomato	10	-	-	-	-	2	-	4	8	14
S. macrocarpon	4 (first harvest)	3	2	2	5	-	-	-	-	12
Pepper	10	-	-	-	-	2	10	6	-	18
Lettuce	4	-	2	2	-	-	-	-	-	4
Carrot	10	2	-	-	1	-	-	-	-	3
Onion	16	-	-	-	-	3	3	-	-	6
Amaranth	3 (first harvest)	-	-	1	1	-	-	-	-	2
Cucumber	8	-	-	1	-	-	-	-	-	1

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[i] Herbicide