Environmental fate of pesticides used as seed dressing

– transport behaviour and occurrence in watercourses

Åsa Kuhlau

Treated seeds left in seed drill (Photo Å. Kuhlau)

Supervisors: Stina Adielsson & Jenny Kreuger

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Abstract

Residues of chemical substances contained in pesticides (plant protection products) have been found in streams in four agricultural areas in Sweden despite no reported direct use. This report investigated whether these residues originated from seed dressing preparations used in the areas or some other source. Nine substances, two insecticides and seven fungicides included in the Swedish Pesticide Monitoring Programme, were investigated.

Time-proportional water samples were collected from the streams in the four areas during 2002-2006. Mainly pesticides used within agriculture (plant protection products) were analysed. Data on the water samples together with information on crops, sowing dates and use of pesticides *etc.* obtained from the farmers in the four monitoring areas were analysed. Interviews with farmers about handling of treated seed and a field experiment were carried out in order to investigate potential transport pathways of seed dressing preparations into the environment. In the field experiment, a test plot in southern Sweden equipped with artificial drainage was sown with treated rape seed.

Substance concentrations reported in the database are low, and only two substances (betacyfluthrin and bitertanol) have been detected above the Swedish guideline value for surface water, on one occasion each. However, analysis of the database showed that two of the substances detected, metalaxyl and bitertanol, could be linked to sowing treated seed of a specific crop, processing peas and winter wheat respectively. The interview responses indicated that handling of treated seed was not the source of the residues detected in the four streams. However, washing of seed drills could be an exception and is a potential source worth further investigation. None of the farmers interviewed had considered seed dressing preparations as a potential source of environmental contamination. In the field experiment, two of the substances present in the rape seed dressing preparation were detected in water samples about two weeks after sowing, confirming that seed dressing preparations can leach from the soil.

The conclusion is that some of the chemical residues detected in streams can be linked to seed dressing preparations. For other substances, point sources from some other use are the most likely cause, while for yet others, both are possible sources.

Key words: Seed dressing, seed dressing preparation, dissemination, environment, pesticide, plant protection products, monitoring, fungicide, insecticide, metalaxyl, bitertanol, processing peas, seed drill.

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Sammanfattning

De första formerna av betningsmedel användes redan under antiken. Vin, urin och saltvatten nyttjades för att tvätta utsäde. I Sverige användes från början släckt kalk, varmt vatten och kopparsulfat för att förhindra angrepp av svampsjukdomar. Upptäckten att kvicksilver kunde användas i kampen mot växtsjukdomar i början på 1900-talet och utveckling av flytande preparat ledde till att nästan allt utsäde i Sverige i början på 1960-talet betades med kvicksilver. När de skadliga verkningarna av kvicksilver blev kända minskade användningen i Sverige snabbt och man försökte i stället hitta andra alternativ.

Idag används årligen ca 1700 ton pesticider inom jordbruket i Sverige. Användningen har dock minskat sedan 1980-talet och även mängden betningsmedel har minskat. Mellan 1981 och 2006 har användningen av betningsmedel minskat från 160 till 44 ton.

Sedan 2002 övervakar SLU på uppdrag av Naturvårdsverket koncentrationer av växtskyddsmedel i bäckar i fyra områden. Utöver fynd av substanser som ingår i besprutningsmedel och som är dokumenterat använda inom områdena har substanser som inte ingår i några av de använda preparaten hittats. Substanserna ingår dock i betningsmedel. De oväntade fynd av substanser som gjorts är orsaken till den här rapporten.

I rapporten har fyra mindre avrinningsområden studerats. De fyra områdena ingår i Pesticidövervakningsprogrammet och är utvalda för att representera ett större geografiskt område i några av Sveriges jordbruksdominerade områden. Områdena är belägna i Skåne (M 42), Västergötland (O 18), Halland (N 34) och Östergötland (E 21). De skiljer sig från varandra vad gäller jordar, klimat och nederbörd. Gemensamt för områdena är att växtskyddsmedel används frekvent. Det finns heller inga industrier i dessa avrinningsområden.

Sedan övervakningen startade 2002 har tidsintergrerade vattenprover samlats in veckovis med automatiska vattenprovtagare i respektive område. Provtagningen har pågått från maj till november varje år med ett avbrott i augusti månad. Vattenproverna analyseras sedan för närmare 100 olika substanser och nedbrytningsprodukter från växtskyddsmedel. Data från analyserna lagras en databas vid avdelningen för vattenvårdslära, SLU. I databasen finns också uppgifter om grödor, sådatum, datum för besprutning etc. som samlats in från lantbrukarna i de fyra områdena. Uppgifter från databasen för två insekticider och sju fungicider, som används både i betningsmedel och vid besprutning i fält har tillsammans med intervjuer med lantbrukare och ett fältexperiment utgjort materialet till den här rapporten.

Intervjuerna gjordes för att undersöka om hantering av betat utsäde kan vara en möjlig källa till de oväntade fynd som gjorts i bäckarna. Fältexperimentet, där betat rapsutsäde såddes på ett fält från vilket prover från dräneringsvattnet kan samlas in, skulle ge svar på frågan om något händer med de betade fröna i marken efter sådd.

En sökning av substanserna som används eller har använts i betningspreparat har gjorts i den Regionala databasen (som är öppen för allmänheten och kan nås via avdelningen för vattenvårds hemsida (http://vv.mv.slu.se/). Sökningen i den regionala databasen gjordes för att få en uppfattning om hur vanligt förekommande dessa substanser är i olika vattenmiljöer.

Sammanställningen av fynden från de fyra avrinningsområdena under perioden 2002 till 2006 visade att några av substanserna härrör från betningsmedel. I område M 42 kan fynden av metalaxyl kopplas till odlingen av konservärtor som startade i området 2003. Även fynden av bitertanol i område M 42 ser ut att komma från betningsmedel som använts på höstveteutsäde. I område O 18 kan fynden av metalaxyl ett år kopplas till odling av konservärtor. Det verkar också vara så att en del metalaxyl finns kvar i marken och läcker ut i samband med nederbörd. Detta är också en trolig förklaring till varför metalaxyl har hittats både före och efter appliceringsperioden i område N 34. Fynd av imidakloprid i område N 34 kan möjligen vara kopplade till betning av potatis i fält medan punktkällor är de troligaste förklaringarna till fynden av iprodion. Fynden av imazalil i tre av fyra områden (M 42, N 34 och O 18) kan bero både på betningsmedel eller någon form av punktkälla. Två substanser, fuberidazol och tolklofosmetyl, har inte hittats i något av områdena. Sökningen i den Regionala databasen från 1985-2007 visade att fynd av substanser generellt sett inte är särskilt många. Det finns fler prov utan fynd än med.

Av intervjuerna framgick att utsäde är något som behandlas med försiktighet eftersom det är dyrt att köpa. Hanteringen förefaller därför inte vara den troligaste förklaringen till de koncentrationer som hittats i bäckarna. En fråga som kvarstår är dock ifall rengöring av såmaskiner med vatten på gårdsplaner kan vara en möjlig källa till de rester av betningsmedel som hittats. Detta är ett område som skulle kunna undersökas närmare. Ett stort problem är dock att många av de substanser som ingår i betningspreparat t.ex. guazatin inte kan analyseras. Ett intressant resultat i intervjuerna var också att ingen av lantbrukarna hade funderat på möjligheten att betningsmedel kan komma ut i den omgivande miljön.

Resultatet från fältförsöket visade att betningsmedel kan läcka från fält. I proverna från fältförsöket hittades två (tiametoxam och metalaxyl) av de tre substanserna som ingick i det preparat rapsutsädet var betat med. Den tredje substansen (fluidoxonil) analyserades inte. Fynden gjordes omkring två veckor efter sådden. Det fanns inga spår av dessa ämnen i nollprovet som togs innan sådd. Även substanser från de besprutningsmedel som använts på fältet efter sådd hittades. Fynden gjordes nio dagar efter appliceringen.

Den här sammanställningen visar att betningsmedel faktiskt läcker. Hur det går till är inte helt klart men det beror antagligen mycket på varje enskild substans egenskaper. För att få klarhet i detta måste fler experiment göras. Vatten som perkolerar genom marken verkar dock vara det huvudsakliga transportmediet. Dessa uppgifter till trots finns inte någon direkt anledning att upphöra med betning av utsäde. Betning har många fördelar gentemot besprutning i fält. De mängder av den aktiva substansen som används är mindre i betningspreparaten och risken för spridning är mycket mindre jämfört med vid besprutning. För fynden av metalaxyl har inte gränsvärdet för ytvatten överstigits någon gång under perioden 2002-2006. Bitertanol har hittats över riktvärdet endast vid ett tillfälle. Så länge vi använder kemiska medel kommer de att hittas, att förvänta sig något annat är inte rimligt. En positiv utveckling inom betningsmedelsanvändningen är dock utvecklingen av biologiska preparat och en ökad användning av dessa. Inom några år kan biologiska preparat kanske komma att utgöra en betydande del av markanden för betningsmedel.

1 Introduction

Residues of chemical substances contained in pesticides (plant protection products) have been found in surface waters in Swedish areas dominated by agriculture. This might not come as a surprise. Application of pesticides constitutes a risk of spread to the environment. The analytical methods used today are very sensitive which means that substances can be detected at very low concentrations. However, there are findings of substances that are surprising. These substances have not been used in field applications, but they are used in seed dressing preparations. The question is whether these substances originate from the seed dressing preparations. The unexpected findings and their origin is the reason behind this report.

In the Swedish Pesticide Monitoring Programme, which started in 2002, samples from surface water have been collected from four areas in regions dominated by agriculture. The pesticide programme forms part of the National Environmental Monitoring Programme. Monitoring of pesticides is performed by the Division of Water Quality Management at the Swedish University of Agricultural Sciences (SLU) and is funded by the Swedish Environmental Protection Agency.

Almost 100 chemical substances from pesticides, including some degradation products, are analysed within the programme. Priorities are given to substances that are used in large amounts, have low guideline values and are susceptible to leaching. Information about crops, sowing date, use of pesticides, water flow and precipitation *etc*. are also collected from the four monitoring areas. Of all the substances used in seed dressing preparations, only nine are included in this report. The reason is that these are included in the Pesticide Monitoring Programme. The nine substances, two insecticides and seven fungicides, are approved both for seed dressing and field application.

How can substances originating from seed dressing end up in surface waters? Seed dressing preparations are expected to adhere to the seed surface and are not exposed to the environment before planting. Does something happen with the seed in the soil once it is planted or does some of the seed dressing preparation come off during handling, *e.g*. during sowing? Can the handling of seed from the store out into the field be a potential source of dissemination into the environment?

1.1 Report structure

This report is divided into six main chapters. Chapter 2 contains a literature review on earlier studies on seed dressing preparations. Some background information is provided about seed dressing use in Sweden and legislation connected to such use.

Chapters 3-5 have separate methods, results and discussion parts. A description of the four monitoring catchments and the measured concentrations of substances found in the streams can be found in Chapter 3. Chapter 4 contains interviews with farmers on routines for handling of treated seed. Chapter 5 describes the field experiment performed in the study in an attempt to answer some of the questions formulated in the introduction. All chapters are finally linked together in Chapter 6, in a common discussion with conclusions.

2 Background

2.1 Earlier studies on seed dressing substances

A number of studies have been carried out on pesticides and on the behaviour in soil and water of some of the most common substances. The behaviour in soil and water of the insecticide imidacloprid (Flores-Céspedes *et al*., 2002; Felsot *et al*., 2002; Papiernik *et al*., 2006) and its effect on bee communities when used as a seed dressing (Maus *et al*., 2003) have been studied. The fungicide metalaxyl has also been the subject of studies (Kookana *et al*., 1995; Fernandes *et al*., 2003). However, studies on the potential risks for leaching of seed dressing preparations from agricultural fields or contamination caused by various point sources are scarce.

The leaching behaviour of imidacloprid was studied in soil columns by Gupta *et al*. (2002). Imidacloprid was added to an alluvial soil as different formulations. The potential for leaching was reported to be quite high, especially for the formulation used for seed dressing. The product used in the experiment was Gaucho 70 WS. However, this behaviour of imidacloprid was not observed in a field experiment in Belgium (Rouchaud *et al*., 1994), which examined soil degradation and leaf transfer of imidacloprid applied as seed dressing (Gaucho) on sugar beet seeds (pelleted). In this experiment no imidacloprid was detected within a 10-20 cm range of soil around the sugar beet.

In two Italian studies by Greatti *et al*. (2003, 2006), the risk of contamination by imidacloprid used in seed dressing (Gaucho) for maize seed sown with a pneumatic seed drill was investigated. In the first study the aim was to investigate the possible loss of imidacloprid through the fan of the pneumatic seed drill (Greatti *et al*., 2003). The results showed that imidacloprid could be found both in filter papers placed at the fan air output and in the grass and flowers surrounding the field. The filter papers showed higher concentrations after longer exposure times. Small scales from the seeds could also be found on the filters. Verifying the amount of contamination and the persistence of imidacloprid on vegetation was the aim of the second study (Greatti *et al*., 2006). Findings of imidacloprid in both grass and flower samples confirmed spreading. Imidacloprid was found in the area surrounding the fields sown with Gaucho-dressed seeds already on the first day of sowing. One interesting result in that experiment was that the control plots also contained low levels of imidacloprid although the seed drill was washed carefully after each sowing operation. It was also shown that climate affected the persistence of imidacloprid on the vegetation. Heavy rainfall had a washing effect on the vegetation.

In an experiment by Fogg *et al*. (1994) in the English Midlands, leaching from field plots and lysimeters was investigated. A seed dressing fungicide was applied on winter wheat and leaching was monitored over nine months. The results showed that leaching was 20-60 times greater from the lysimeters than from the field plots. The result was thought to be due to differences in soil texture and soil organic carbon content. At 220 days after sowing, 36.6% of the fungicide applied was detected in the field plot soil profile.

A small-scale study on point sources related to seed dressing preparations has been performed in Sweden. In this study by Nilsson (2005), residues of seed dressing substances in empty seed packaging was investigated. The concentrations of the substances (imazalil, bitertanol, carbosulfan and carboxin) left inside the packaging, both plastic and paper, were very low or below the detection limit (0.2-0.6 μg dm^{-2}).

2.2 Seed dressing

2.2.1 Brief overview of the history of seed dressing in Sweden

Methods to avoid fungal infections on seed were used already in ancient times, when seed was treated with wine, urine or even salt water to prevent infection by smut (*Ustilago* spp.). Recommendations for seed treatment with slaked lime, water, heat and copper sulphate can be found in old Swedish literature. However, the practice of seed dressing did not become common until the end of the 19th century, when the use of copper sulphate started and treatment with hot water was introduced (Olvång, 2002). The hot water treatment was used for the control of smut fungi until the beginning of the 1960s, but the disadvantage was the problem of getting the right temperature. When the water was too cold the effect on the disease was small, while when it was too hot the seeds were damaged.

In the beginning of the 20th century, inorganic mercury compounds came into use after the discovery that mercury was effective against fungi. Seed dressing with organic mercury (methyl mercury) compounds began in Sweden during the 1920s but it was not until the end of the 1930s that such seed dressing became widespread. The reason was the introduction of mercury compounds in liquid form. In the beginning of the 1960s most seed was treated with mercury. When the book *Silent Spring* by Rachel Carson was released in 1962, it resulted in an intensive debate in Sweden about mercury seed dressing and environmental risks. The result was a large decrease in the use of mercury seed dressing. When the use was at its highest almost 4 000 kg of mercury were used annually but this quickly decreased to around 2 000 kg (Olvång, 2002). Research on alternatives to mercury also started, and in 1978 Sweden became one of the first countries in the world to ban mercury seed dressing of winter crops. For spring-sown crops imazalil, approved in 1977 (Kemikalieinspektionen, 2007d), became the substitute for mercury. The use of mercury strongly decreased after the emergence of mercury resistance in spot blotch fungi (*Dreschlera teres*) on barley in the 1980s, and mercury-free substances became dominant. Mercury seed dressing was totally banned in 1988 (KIFS 1998:8).

Efforts have been made to find seed dressing products that can decrease the environmental risks even more, with the focus on different microorganisms. The fungal genus *Trichoderma* and the bacterial genera *Streptomyces, Pseudomonas* and *Bacillus* have shown promising results. Research at SLU on the bacteria *Pseudomonas chlororaphis* led to development of the seed dressing Cedomon, which was brought into commercial use in 1998 (Olvång, 2002). Research on physical methods such as heat and hot water treatment continues.

2.2.2 Extent of seed dressing in Sweden

The annual use of pesticides (plant protection products) in Sweden is about 1 700 metric tonnes (Kemikalieinspektionen, 2006). Pesticide use within agriculture in Sweden has decreased quite rapidly since the 1980s, when about 3 000 metric tonnes were used annually. The preparations used today are more specific and adapted. Therefore smaller amounts of the substances are required to obtain the same effect as with earlier preparations (Kreuger & Adielsson, 2006). Table 1 shows a list of the nine substances included in this report. These substances are used in seed dressing preparations as well as in field applications, and are monitored in the pesticide programme.

Table 1. The nine substances analysed. I= insecticide, F= fungicide

Substance	Type	Seed dressing on	Example of seed dressing prep.	Sold amount 2006 Ψ (metric tonnes)
betacyfluthrin	I	oilseed	Chinook FS 200	1.8
bitertanol	F	cereals	Sibutol FS199 Sibutol LS	8.3
fuberidazole	F	cereals	Sibutol FS 199 Sibutol LS	0.5
imazalil	F	cereals	Cevex 300 Panoctine Plus Fungazil 100	1.7
imidacloprid	I	oilseed and sugar beet	Chinook FS 200 Montur FS 190	4.9
iprodione	F	oilseed, cabbage, bean, peas, sugar beet and onion	Rovral 500 A Rovral 75 WG	8.2
metalaxyl	F	pea, spinach and sugar beet	Apron XL	3.9
prochloraz	F	flax	Prelude 20 LF	4.0
tolclofos-methyl	F	potatoes and winter cereals	Rizolex 50 FW	0.1

Ψ Total amount, *i.e.* including also possible sale for use as field application

Most seed dressings are applied in enclosed systems at seed dressing stations. Farmers and other individuals who have taken basic courses and regular refresher courses and who have the proper equipment can perform seed dressing on their own. Today there are between 500-600 people in Sweden who have these qualifications (Hedström, pers. comm. 2007). However, there are no exact Figures on how many of these people actually perform seed dressing and therefore it is impossible to say to what extent seed dressing application take place on farms.

Most of the winter cereals grown in Sweden are treated with seed dressing preparations. Celest (with fludioxonil as the active substance), Dividend (diphenoconazole) and the biological preparation Cerall (*Pseudomonas chlororaphis*) were the most sold seed dressings for winter cereals in central Sweden in 2007 (Hellstedt, pers. comm. 2007). Celest and Dividend have been used for seed dressing in winter cereals in this part of Sweden since 2002, when approval for the substance Beret (fenpiclonil) expired at the end of 2001.

In the south of Sweden, where Scandinavian Seed AB has a large share of the market, Sibutol FS 199 (bitertanol) used to be the most common seed dressing substance for winter cereals. Sibutol FS 199 was approved on 16 December 2002 (Kemikalieinspektionen, 2007). However, over the past three years it has been increasingly replaced by Panoctine (containing guazatine and sometimes also imazalil), which is cheaper. Cerall is also rather widely used on wheat, but not if there is a risk for dwarf bunt (*Tilletia contraversa*) (Hellstedt, pers. comm. 2007). Cerall has effect on stinking smut (*Tilletia caries*), glume blotch (*Septoria nodorum)* and *Fusarium* spp., but not on *Tilletia Controversa* (Lantmännen Bio Agri, 2007).

Seed dressing in spring cereals depends on the need for treatment. About 50% of spring seed is treated (Olvång, 2002). Wide variations in weather mean that the degree of infection, and hence the need for seed dressing, varies between years. The need is usually greatest in barley and spring wheat. In most cases it is not necessary to treat oats.

Around 75-80% of spring-sown oilseed is treated (Olvång, 2002). Among peas and beans normally only processing peas are treated. The preparation Apron, containing metalaxyl, is used on processing peas to protect against fungi. Almost all sugar beet seed is treated with the preparations Marshal (carbosulfan), Montur (imidacloprid and tefluthrin) and Gaucho (imidacloprid) against insects, while Euparen (tolylfluanid) and Tachigaren (hymexazol) are sometimes used against fungi according to Hilleshög (2007). Danisco Seed (2008) use Euparen, Tachigaren, Montur and Gacho on their sugar beet seed. SESVANDERHAVE (2008) have Tachigaren and Gaucho listed as the seed dressing substances used on sugar beet.

A large amount of certified potato seed is treated against black scurf (*Rhizoctonia solani),* whereas seed dressing against rot caused by *Phoma* and *Fusarium* spp. varies from year to year (Olvång, 2002). Some seed dressing of potatoes takes place in the field. Only a very small proportion of the vegetable crops in Sweden are treated (Olvång, 2002).

The quantities of seed dressing substances sold in Sweden have decreased since 1981 (Figure 1). Nevertheless it should be kept in mind that the quantities sold do not necessarily reflect the direct use. In some years distributors buy more pesticides than they can sell. The reasons can be tax increases, environmental fees or withdrawal of pesticides. This was the case in 2003 when a 50% increase in pesticide taxes was announced and thus the amounts purchased went down during 2004. In 2006, the amount purchased (44 metric tonnes) was considered to be balanced by the use (Kemikalieinspektionen, 2006).

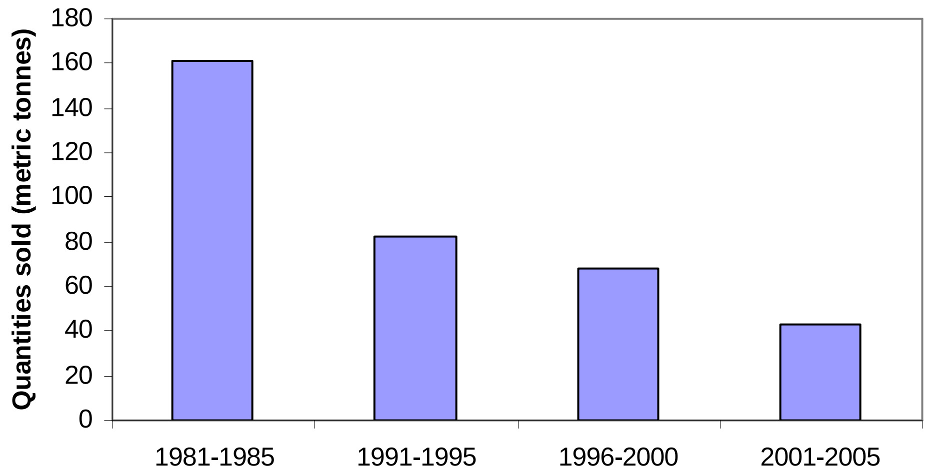

Figure 1. Mean quantities of seed dressing substances (metric tonnes) sold in Sweden during various periods between 1981 and 2005 (source: Kemikalieinspektionen, 2006).

The relative amounts of the different substances approved for use in seed dressing preparations sold in Sweden in 2002 and 2006 are shown in Figure 2 and Figure 3 respectively. A great disadvantage in this regard is that the statistics on sold quantities of single substance include the amount of the substance used in both agriculture and industry. Some substances are only used within agriculture, but for example guazatine is also used as a biocide within wood industry. It is therefore impossible to say how much of the change in sold quantities between 2002 and 2006 that can be linked to use of seed dressings. For some substances there were clear differences between the two years, whereas for others the quantity sold remained more or less the same. However, the amount of bitertanol clearly decreased between 2002 and 2006. It is likely that this change can be linked to the decreased use of the seed dressing preparation Sibutol (bitertanol).

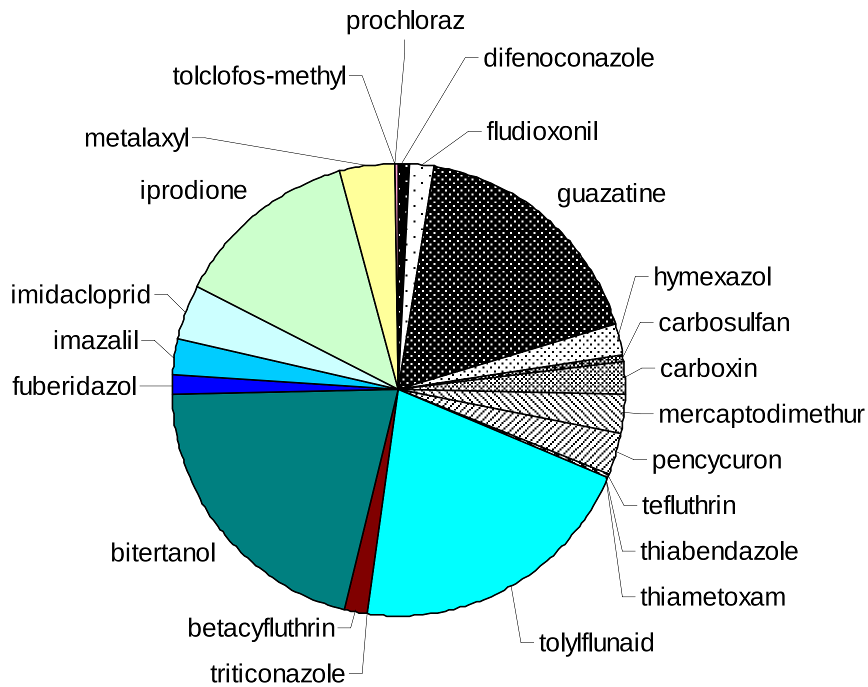

Figure 2. Relative quantities (%) of chemical substances used in seed dressings (including also possible sale for other uses) sold in Sweden in 2002 (source: Kemikalieinspektionen, 2006).

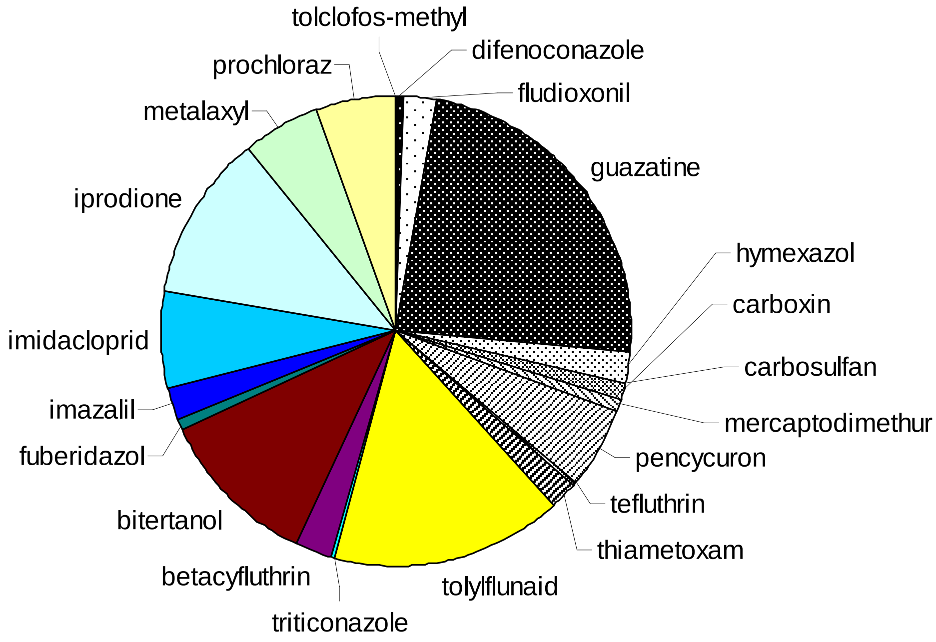

Figure 3. Relative quantities (%) of chemical substances used in seed dressings (including also possible sale for other uses) sold in Sweden in 2006 (source: Kemikalieinspektionen, 2006).

2.2.3 Other areas of use

Apart from preparations used for seed dressing and field application, substances are also used in other kinds of preparations (Kemikalieinspektionen, 2008). There are for example two registered products used against insects in houses, stores and in garden terraces that contain betacyfluthrin. These are Responsar 125 SC (re-registered in 2000) and Responsar 2.5 SC (approved in 2001). Bitertanol is the active substance used in preparations against fungi in ornamental plants (Baymat Rosenspray) and it is also used in forest nurseries (Baycor 25 WP). Iprodione is used in preparations against fungi in ornamental plants, lawns and nurseries. Imidacloprid is used in a lot of different insecticide preparations. These include preparations that can be used at home both inside and outside the house. Merit Forest WG is an insecticide that can be use in coniferous plants after planting. Imidacloprid preparations are also used in greenhouses.

2.2.4 Effective mechanisms of seed dressing preparations

Seed dressing preparations against fungi work in two different ways, either systemically or through direct contact. Direct contact substances must cover the seed surface completely to prevent germination of fungal spores. Systemic substances penetrate the seed and are taken up and transported throughout the plant when it starts to grow. Systemic substances can cure the seed if it is infected, as well as providing the young growing plant with protection against soil-borne infections during the first critical weeks.

Seed dressing substances affect one or more components of fungal cells. According to Olvång (2002) there are two main mechanisms, distinguishing substances into multi-site fungicides and single-site fungicides. Multi-site fungicides affect many processes. They can destroy the proteins inside the cells and cause malfunction of the enzymatic system. Single-site fungicides are specific; they target only one mechanism in the fungi such as the metabolism, energy production or cell division. Examples of single-site fungicides are phenylamides, *e.g.* metalaxyl, which disrupt RNA synthesis. Others are dicarboximides (iprodione) and benzimidazoles (fuberidazole), which disrupt cell division.

Seed are usually exposed to many different fungi. The main attempt in seed dressing has been to find substances that are effective against many fungi. If one particular substance is inefficient against some fungi, a mixture of that substance with another substance can be effective. Panoctine Plus, consisting of the two substances guazatine and imazalil, is such an example. Guazatine lacks efficiency against *Dreschlera* species, but when imazalil is added the combined mixture becomes effective against *Dreschlera* (Olvång, 2002).

Insecticides used in seed dressing preparations can be systemic, *i.e.* transported within the plant when it starts to grow. Imidacloprid is a systemic insecticide and it affects the central nervous system of insects. Betacyfluthrin is a non-systemic insecticide that has an effect through contact and also affects the nervous system of the insect.

2.2.5 Methods for applying seed dressing

In the early days of seed dressing it was common to mix the seed with the preparation directly on the barn floor. Techniques have improved since then and today there are a number of different machines available for applying seed dressing. These machines can be divided into four main groups based on the principle used. According to Sundgren *et al*. (2005) these main groups are:

- Auger mixer
- Rotating drum
- Curtain seed dressing
- Rotostat

In the auger mixing method, seeds are mixed with the seed dressing preparation during transport through the auger. In this method the supply of seed is continuous, in contrast to a rotating drum where a certain batch of seed is put into the machine. The preparation used in auger mixer is added at the beginning of the auger and is then distributed. Most often the preparation is a powder but liquid preparations can also be used. The simple construction generates low costs and makes the machine user-friendly. However, disadvantages such as relatively low capacity, inferior hygiene and lower precision outweigh the advantages and the auger method is not used in modern seed dressing application in Sweden. Sometimes augers are used as extra steps in other seed dressing methods, *e.g.* curtain dressing, in order to improve the mixing of seeds.

In the rotating drum method, liquid seed dressing preparations are generally used. A certain amount of the preparation is added through nozzles into the rotating drum. Two disadvantages with this type of machine are limited capacity and uneven distribution on the seeds. Rotary drum machines used to be quite common in Sweden but have nowadays been replaced by curtain seed dressing machines.

Curtain seed dressing is the dominant seed dressing method in Sweden today. It is a continuous process. During the process the seeds fall through a mist of liquid seed dressing preparation. The mist gives an equal dose of preparation on each seed. It is possible to add many different preparations at the same time. The capacity is high and the result is a more even distribution of the seed dressing preparation compared with the other methods. One critical factor is the thickness of the curtain, since if it is too thick the seeds do not receive equal amounts of the preparation.

A rotostat machine consists of a rotor placed in a cylinder. The seeds are kept in motion by the rotor and are effectively mixed with the seed dressing preparation. This method can be used with both powder and liquid substances. The preparation is applied through nozzles, a rotating plate or directly as powder on the seeds. The method gives a good distribution on the seeds, but the capacity is low.

Seed dressing application at seed dressing stations always takes place in a closed system. The preparation is pumped directly from the container into the closed machine. After application, closed transport to an automatic packing machine takes place. The seed dressing preparation is thus not exposed to the environment before opening of the seed packing on-farm.

Seed dressing of potatoes can take place when the tubers are collected from the storage house (on a mobile Table) or in the field during planting. In the field the tubers are sprayed with the substance either inside the planter (most common) or outside and under the machine (hardi-technique).

2.3 Rules and regulations

There are a number of laws regarding the use of pesticides within Swedish legislation, but these are quite general and therefore they are supplemented with statutes and directives from different authorities such as the Swedish Chemicals Agency, the Swedish Environmental Protection Agency, the Swedish Board of Agriculture, the Swedish National Food Administration, the Swedish Work Environment Authority and the Swedish National Rescue Services Agency.

Information on rules and regulations is summarised in Sundgren (2005). A pesticide can only be approved for use if it is accepTable from both a health and environmental perspective. Approval of a pesticide is granted for an initial period of five years but can be extended to a maximum of 10 years if there are special reasons. The rules are the same for seed dressing preparations. When a pesticide or seed dressing preparation is approved it is placed in one of the following classes:

Class 1: Preparations allowed only for professional use and by people with special permission.
Class 2: Preparations allowed only for professional use.
Class 3: Preparations allowed for use by the general public.

Class 1 and 2 preparations are mainly used within agriculture, forestry and horticulture. People handling Class 1 and 2 pesticide preparations must be older than 18 years and take a basic course followed by refresher courses every fifth year. The demands for seed dressing preparations in Class 1 and 2 are the same, but the basic course is shorter. There are no demands on education for the use of biological preparations.

Pesticide substances have to be jointly assessed within the European Union (EU). Preparations that contain substances approved by the EU then have to be approved in each country. The Swedish Chemical Agency (Kemikalieinspektionen) is the authority in Sweden that determines whether a substance is allowed for use or not, or whether there should be restrictions on use.

Private import of pesticide preparations by farmers is only allowed from other EU countries. However, a pesticide preparation is allowed for use only if the same preparation is approved in Sweden. The use must be performed according to Swedish rules for the particular preparation. The rules for seed dressing preparations are somewhat different than those for pesticide preparations used in field application. Import of seed dressing substances that are not approved in Sweden is banned. However seed that are already treated before being imported, with a seed dressing preparation not approved in Sweden, can still be used. If the farmer buys treated seed from *e.g.* Germany and the seed dressing preparation is not approved in Sweden, he can still sow it. The only demand is that the seed packaging has a label declaring the substances used for seed dressing. The label must also contain information about the country in which the seed dressing has been applied on the seed. Labels with information on seed dressing should be in yellow with a black frame. The common name of the preparation and registration number are sufficient information for seed treated in Sweden. Seed treated with seed dressing preparations is not permitted for use as food for humans or animals.

All seed treated with a substance classified as very poisonous, poisonous, carcinogenic, mutagenic, genitotoxic or corrosive must be kept in disposable packaging. This rule also applies for treated seed bought from abroad.

2.4 Guideline values

According to Norberg (2004), the guideline value is defined as the concentration of a substance where no effects on the aquatic environment are to be expected. Toxicity tests on different groups of aquatic organisms are used to obtain the guideline value. The tests are performed on species from three different levels of the food chain, algae, invertebrates and fish. The guideline value is designed to protect aquatic organisms in both freshwater and marine systems. Acute and chronic effects of a toxic substance are both considered in the guideline value, with values calculated separately for acute and chronic effects. The lower of these two values is then used as the final guideline value. Uncertainty factors varying between 10 and 1000 are used to compensate for uncertainties in the background material. If there are a lot of available data the correction factor is low, while if data are lacking the factor is higher.

Swedish guideline values for surface waters have been determined for 100 substances and metabolites that form part of the National Environmental Monitoring Programme or that are on the EU positive list (Kemikalieinspektionen, 2008). Based on statistics on the most sold substances in Sweden, some additional substances have also been included (Norberg, 2004).

Table 2 shows Swedish guideline values and Dutch MTR values in surface waters for those substances included in the Pesticide Monitoring Programme that are also used as seed dressings. MTR stands for Maximum Tolerable Risk and is calculated with a method comparable with the Swedish method used for guideline values. For most of the substances the two values are quite similar. The exceptions are metalaxyl and imazalil for which the Swedish guideline value is higher than the Dutch MTR value. The two insecticides, betacyfluthrin and imidacloprid, are potentially the most toxic compounds for the aquatic environment (Table 2).

Table 2. The nine substances analysed in this study. I= insecticide, F= fungicide. Dutch MTR values are used for comparison and when Swedish guideline values are missing (Otte & Evers, 2005; Schrap *et al.,* 2006; Kemikalieinspektionen, 2008)

Substance	Type	Guideline value for surface water (µg L^{-1})	MTR for surface water (µg L^{-1})
betacyfluthrin	I	0.0001	0.0002
bitertanol	F	0.3	0.31
fuberidazole	F	-	-
imazalil	F	5.0	0.87
imidacloprid	I	-	0.013
iprodione	F	0.2	0.1
metalaxyl	F	60	46
prochloraz	F	-	1.3
tolclofos-methyl	F	1.0	0.8

2.5 Transport pathways into the environment

Leaching through the soil profile, surface runoff, wind drift and volatilisation are the main transport pathways for pesticides into the environment. Physical properties, *e.g.* water solubility, molecular size and volatility, determine the behaviour of a substance in soil and water (Gevao & Jones, 2002). Leaching is the most likely dissemination pathway for substances originating from seed dressing preparations. Surface runoff, volatilisation and wind drift as for pesticides applied through spraying are less likely pathways, because seeds are planted a few centimetres down in the soil and the preparation is added to the seed before planting. Although, drift of seed dressing preparations during sowing as described by Greatti *et al*. (2003) could be considered as a possible transport route.

Chemical and physical properties of a substance are very important for its leaching behaviour. A substance that is strongly bound to soil particles and degraded very fast is less susceptible to leaching. However, where a substance is located in the soil is also important. According to Bergström (2002) diffusion of a substance into smaller pores (< 0.1 µm) makes it less available in the soil solution for degradation by microorganisms. This can result in longer persistence in soil and leaching during a longer period compared with when the substance is located in larger pores.

The transport of a substance through the soil profile takes place either through diffusion or mass transfer. The diffusion rate depends on the concentration and the adsorption properties of the substance. Temperature, water content and porosity in the soil also affect the diffusion rate (Torstensson, 1987). Mass transfer occurs through forces such as water movement in the soil or movement of soil particles. Water movement through the soil profile is the most common transport pathway for chemical substances (Torstensson, 1987). The water solubility and adsorption properties of the substance together with the amount of moving water affect how fast the substance is transported through the soil.

The amount and intensity of precipitation have a great impact on the leaching of chemical substances. Intensive rainfall soon after application of a pesticide can make the substance leach rapidly down through the soil profile (Bergström, 2002). Preferential flow is the movement of substances through macropores. In the macropores the substances can move fast through the unsaturated zone, without being bound and degraded, down to the groundwater or drainage pipes. Preferential flow is common in fine-textured soils with a high clay content (Bergström, 2002).

Facilitated transport is another way for substances to reach the groundwater (Bergström, 2002). It is the transport of substances adsorbed on various mobile colloids. Organic solutes, *e.g.* nonpolar pesticides, can form complexes with dissolved organic carbon and clay particles (Bergström, 2002). The substance can then move down through the soil attached to the particles.

2.5.1 Properties affecting the behaviour of substances in soil and water

Non-polar liquids, *e.g*. octanol, hexane and oil, cannot mix with water. Table 3 shows log K_{ow}, K_{oc}, water solubility and DT_{50} (half-life) values for the nine substances examined in this report. Log K_{ow} is the octanol-water partition coefficient (concentration in octanol/concentration in water) at equilibrium. K_{ow} values are used to predict environmental distribution and bioconcentration of substances (Walker, 2001). A high K_{ow} value indicates that most of the substance is in the octanol phase and a low value that most is in the water phase.

The K_{oc} value (the soil sorption coefficient normalised to the soil organic carbon content) is a measure of sorption strength of a substance. According to Torstensson (1987), a low K_{oc} value indicates that the active substance can be expected to have a high mobility in soil, whereas a high value means that the substance is more or less immobile. Betacyfluthrin, bitertanol and fuberidazole (Table 3) should therefore be immobile in soil, whereas metalaxyl can be expected to have a high mobility.

Table 3. K_{oc} and log K_{ow} values, water solubility and half-life for the nine substances studied in this report (Tomlin, 2006)

Substance	Chemical group	K_{oc}	Log K_{ow}	Water solubility ($mg\ L^{-1}$) (20 ºC)	DT_{50} in soil (days)
betacyfluthrin	pyrethroid	>5000	5.9	0.002-0.003	< 60[b] (18-22 ºC)
bitertanol	triazole	500-2000	4.1	2.7	365
fuberidazole	benzimidazole	500-2000	2.67	220 (pH 4) 71 (pH 7)	5.8-14.7
imazalil	imidazole	1212-6000[a]	3.82	950 (pH 5) 220 (pH 7) 177 (pH 9)	> 270[a] (15ºC)
imidacloprid	neonicotinoid	150-500	0.57	610	40-110[d]
iprodione	dicarboximide	202-543	3.0	13	919
metalaxyl	phenylamide: acylalanine	70	1.75	8400[1]	29
prochloraz	imidazole	1463	4.12	34.4[2]	5-37
tolclofos-methyl	aromatic hyd-rocarbon; chlorophenyl/ nitroaniline	500-2000	4.56	0.001[2]	53-72[c] (15 ºC)

K_{oc} (0-50) very high, (50-150) high, (150-500) medium, (500-2000) low, (2000-5000) somewhat mobile, (>5000) immobile (Torstensson, 1987)

[a] Kemikalieinspektionen, 1997a
[b] Kemikalieinspektionen, 1997b
[c] Kemikalieinspektionen, 1997c
[d] Rouchad *et .al*., 1994

[1] 22ºC
[2] 25ºC

2.5.2 Factors affecting substance concentrations in water

It is not only the chemical and physical properties of a substance that determine the amount that can be found in aquatic environments. Time of pesticide application, extent of use, waterflow volumes, annual variation in drainage, size of the catchment area, type of land use and soil properties all have a large effect on substance concentrations in water.

Application of pesticides usually takes place on one or a few occasions each season. Detected concentrations are therefore highest during or shortly after application. The extent of pesticide use in the catchment is one of the most important factors affecting the concentrations detected in water. More widespread use means that the risk of finding measureable concentrations in the water environment increases (Asp *et al*., 2004).

Waterflow volumes and annual variations in drainage affect concentrations in water courses. The flow can vary from day to day during the season and between different years. Peak flows during the application season can give higher concentrations of pesticide substances in water (Asp *et al*., 2004). High water flow also affects substance concentrations by dilution.

Land use and soil properties affect the concentrations in lakes and water courses. According to Asp *et al.* (2004), high concentrations are more commonly found in areas with much agriculture and in areas where the soils contain a lot of clay. One of the reasons is that a large proportion of such land is tile-drained. Drains are not common in areas with coarser soil texture.

3 Monitoring catchments

3.1 Method

3.1.1 Short description of the four pesticide monitoring areas

Four streams in four small catchments (8-17 km^2) are included in the Pesticide Monitoring Programme. The areas are located in Skåne (M 42), Halland (N 34), Västergötland (O 18) and Östergötland (E 21) (see Figure 4). These areas were selected in order to represent a large geographical area in some of Sweden's agricultural regions.

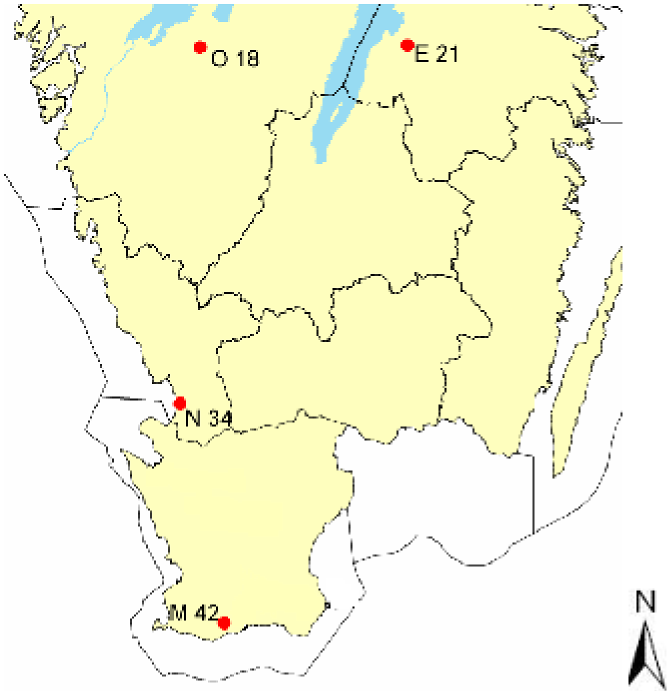

Figure 4. Location of the four areas (source: Adielsson *et al.*, 2006).

Table 4 shows that the catchments differ from each other regarding soils, climate and size. There are no industries, golf courses or plant nurseries within these areas. The areas have a frequent use of pesticides. There is some forest in area E 21 and N 34 and in E 21 there is a Christmas tree planting (1.5 ha) established in 1998.

Table 4. Information about the four pesticide monitoring areas (source: Adielsson *et al.*, 2006)

Area	**County**	**Acreage (ha)**	**Soil**	**Field[a] (%)**	**Temp.[b] (°C)**	**Precip.[b] (mm year^{-1})**	**Drainage[c] (mm year^{-1})**
42	M	828	Sandy loam, loam	94	7.7	662	213
34	N	1460	Sandy loam	92	7.2	773	343
18	O	776	Clay loam	91	6.2	571	348
21	E	1681	Sandy loam	89	6.0	477	160

[a] Total percentage of the land area that is used for agriculture
[b] Temperature and precipitation given as a mean value for 30 years at the closest weather station (SMHI).
[c] Mean value of drainage per year since measurements started (9-17 years ago).

The stream running through area M 42 is covered (*i.e.* culverted) and only a short part of it is exposed to the open environment. The open ditches were replaced with a tile-drainage system in the 1950s. Around 40% of the field area has drains at 1 m depth and 16 m apart. In the rest of the area the drains follow the natural topography. The measuring station is located at the point where the tile drain/stream comes to the surface. Water from the drains but also from surface runoff inlets, located in low-lying parts and also in some farmyards and along roads, reaches the drains (Kreuger, 1998).

In area O 18 most of the main stream is covered. The stream in E 21 on the other hand runs in the open to a large extent. In area N 34 the main stream is open but the smaller feeder streams are covered.

Analyses and collection of data on pesticide use, crops grown *etc*. started in area M 42 in 1990. For the other three areas information is only available from 2002 onwards. Figure 5 shows the number of hectares in area M 42 in which peas have been grown during the period 1993 to 2006. Processing peas, which is the only type of pea treated with seed dressing preparations, were not grown in the area before 2003.

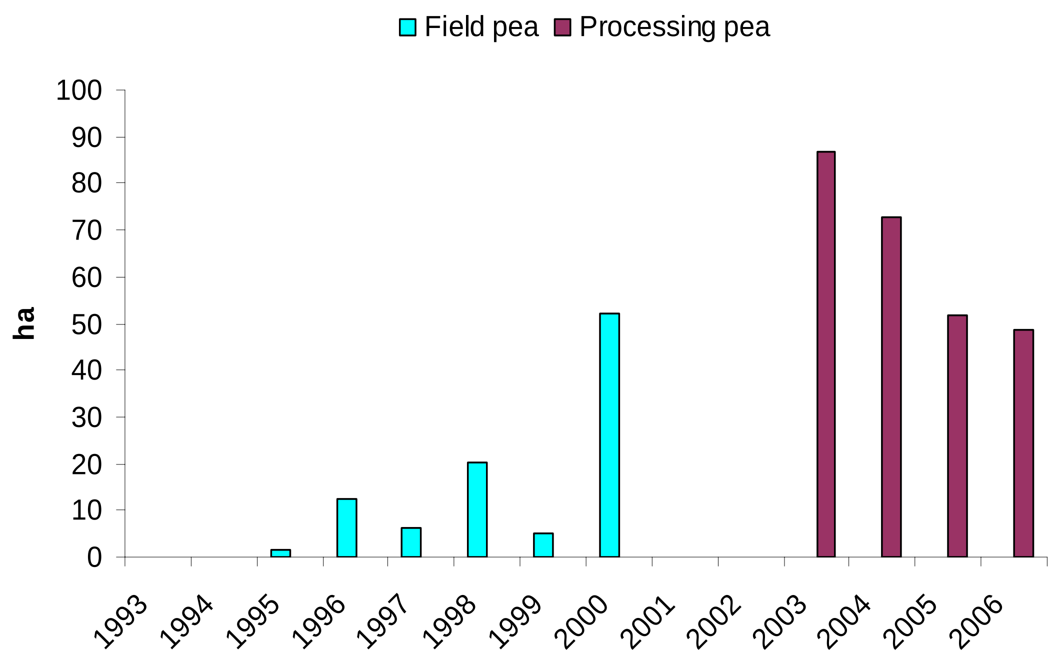

Figure 5. The numbers of hectares on which field and processing peas have been grown in area M 42 during the period 1993-2006.

According to data from the pea processing company in Sweden (Karlsson, pers. comm. 2007), which contracts pea growing out to farmers, the seed dressing preparation used until 2006 was Apron XL 350 ES, containing 350 g L^{-1} of metalaxyl-M. The preparation was re-registered in 2007 under the name Apron XL and with a slightly lower concentration of metalaxyl-M. The seed is treated with 0.21 g metalaxyl-M kg^{-1} seed. The normal seed rate is 200 kg ha^{-1} and thus 42 g metalaxyl-M is applied per hectare.

3.2 Sampling method

Water samples taken in the Pesticide Monitoring Programme were collected with automatic water samplers with built-in refrigeration, ISCO model 3700FR and 6712FR in area M 42 and ISCO model 3700R in the other three areas. Time-proportional samples with a sub-sample every 80 minutes were collected and analysed on a weekly basis. One sample thus represents the mean concentration during one week and the date of sampling given is the last day of the week. A break in the collection of samples was usually made in August each year. The reason was that the streams had very low flow or dried out during this part of the year. The samples were analysed using different methods in order to include as many substances as possible (for closer descriptions see Adielsson *et al*., 2006). Main focus of the analyses was directed towards including as many as possible of those pesticides applied within the catchments. All analyses were performed on unfiltered water.

The quantity of a substance is reported here as a concentration when the LOQ (Limit of Quantification) is exceeded. Trace values are given when the concentration exceeded the LOD (Limit of Determination) but not the LOQ. Trace values are given the mean value of the LOD and LOQ. In Figures 6-14, no distinction has been made between concentration and trace values.

Calculations on the total transport of the substance metalaxyl were performed for area M 42. The calculation was based on water flow measurements performed in the same stream as the water samples were collected.

3.3 Databases

Information collected within the National Pesticide Monitoring Programme is stored in an Access database at SLU. The different Tables in the database can be combined to answer questions. The Access database was used in this report to obtain relevant information from the four areas M 42, O 18, N 34 and E 21.

There is another database at SLU (Regional database) that collects data on pesticide findings in surface waters and groundwater from many different measurements performed outside the National Monitoring Programme. Swedish municipalities, county administrative boards and the National Food Administration are examples of authorities that report to the Regional database. This database is open to the public and a link can be found on the website of the Division of Water Quality Management at SLU (http://vv.mv.slu.se/) For the purposes of the present report, a search for the number of samples and findings of substances used in seed dressing preparations (including those substances for which the approval expired after 1993) was made in the Regional database. The reason was to get an impression of how often substances are detected in the samples collected.

3.4 Results and discussion

3.4.1 Results from the Regional database

Table 5 shows the results of the search made within the Regional Database. Most of the substances have been analysed many times. Among the listed substances there are seven substances which have been used only in seed dressing preparations (Kemikalieinspektionen, 2008). Of these, only fenfuram has been searched for. There are 768 samples that have been analysed for fenfuram but no findings have been reported. The substances used both in field and seed dressing preparations have been frequently analysed for. Exceptions are imidacloprid, betacyfluthrin, fuberidazole and mancozeb, for which the number of samples is below 100. Mancozeb is difficult to analyse, so normally the degradation product ETU was analysed instead, but the number of samples was only 245.

Table 5. Results of the search from 1985 until 2007 in the Regional database for substances used in seed dressing preparations (including substances with approval that expired after 1993)

Substance	Number of samples	Number of findings
ampropylfos *	0	-
betacyfluthrin [1]	98	0
bitertanol [1]	4809	3
carbosulfan *	933	0
carboxin	997	0
difenoconazole [2]	0	-
fenfuram *[2]	768	0
fenpiclonil *[2]	0	-
fludioxonil	0	-
fuberidazole [1]	81	0
furathiocarb [2]	0	-
guazatine	0	-
hymexazol [2]	0	-
imazalil [1]	1381	1
imidacloprid [1]	59	0
iprodione [1]	3999	19
isofenfos *	2466	0
mancozeb *	2	0
- ETU	245	1
mercaptodimethur (methiocarb)	14	0
metalaxyl [1]	2755	17
pencycuron	0	-
prochloraz [1]	2021	0
silthiofam [2]	0	-
tefluthrin	0	-
thiabendazole *	1171	0
thiametoxam	0	-
tolclofos-methyl [1]	802	1
tolylfluanid *	1334	0
triticonazole [2]	0	-

[1] Substances included in the Pesticide Monitoring Programme
[2] Substance is only used as a seed dressing preparation component.
* Substance approval as seed dressing preparation expired

The reason why some substances have been analysed more frequently than others can be that they are used in large amounts or are very toxic and therefore have priority. The five substances carbosulfan, fenfuram, thiabendazole and tolylfluanid are no longer approved in any kind of preparations. These substances are still analysed for, but the number of samples has decreased after their approval expired.

Despite the large number of samples, only six of the substances in Table 5 have been detected and the numbers of findings are low. A closer look at the data on the findings (not available on the website but can be retrieved from SLU) show that for bitertanol most of the findings have been made in surface waters. Iprodione has been detected in surface waters and in wells in areas with shallow groundwater levels. Iprodione is the only substance detected above the guideline value. It has exceeded the value in 10 of the 19 findings. Metalaxyl has only been detected in surface water. Some samples are random samples but there are also findings from time-integrated sampling series.

Most of the samples in the Regional database are random samples. This is a disadvantage because it only provides a momentary view of the situation. For some of the samples there are no data on the type of water sampled, while the number of samples of each substance varies. This makes it difficult to see the whole picture of how often a substance is present in water environments. The advantage with the Regional database is that it has a large amount of data, with many samples collected in many different places. The fact that the numbers of findings are low indicates that it is not very common to find these substances in water. Because the substances in Table 5 (with a few exceptions) are used both in seed dressing and field application, it is impossible to say anything about the spread of seed dressing preparations based on the data from the Regional database.

3.4.2 Area M 42 (Skåne)

Bitertanol, imazalil and metalaxyl have been detected in the stream in area M 42 (Table 6), although no use has been reported.

Table 6. Number of substance findings in area M 42 during the period 2002-2006

Substance	2002	2003	2004	2005	2006	Total number
betacyfluthrin	0	0	0	1	0	1
bitertanol	6	1	4	3	0	14
imazalil	0	0	1	0	1	2
metalaxyl	0	8	7	9	6	30

Betacyfluthrin was detected in 2005, but usage has only been reported for 2006. The concentration in 2005 was above the guideline value of 0.0001 µg L^{-1}. It is possible that betacyfluthrin was used in 2005 but the use was not documented. Private use in garden terraces could be another possible explanation of the single finding.

Imazalil has been detected twice, one finding from July 2004 and one from October 2006. During the weeks in which the samples were collected, there were 27 and 38 mm of precipitation respectively. On both occasions most of the precipitation fell during two days of the sampling week, but with two and three days in between. The sample from October 2006 might be explained by treated winter wheat sown in September-October. The finding from July is more difficult to explain. It is not likely that the imazalil originated from seed dressing preparations because spring cereals were sown in April. Washing of equipment such as seed drills in a farmyard before the start of the autumn sowing season might be a possible point source.

The most interesting findings in area M 42 are those on metalaxyl and bitertanol (Table 6). The first findings of metalaxyl in the area are from 2003. Growing of processing peas in the area started in 2003 (Figure 5) and processing peas are usually the only type of peas that are treated with seed dressing preparations. Field peas, which are not treated, were grown before the introduction of processing peas (Figure 5). Metalaxyl is also used in fungicide preparations for potatoes. However, potatoes are not grown in area M 42. In contrast seed dressing preparations containing metalaxyl are used on sugar beet, but sugar beet has ‘always’ been grown in the area and the findings in 2003 are thus not likely to be associated with this crop. This and the fact that the first findings of metalaxyl are from the same time as the introduction of processing peas makes it likely that the metalaxyl detected originated from the processing pea seed dressing preparation. There was no change in LOD from 2002 to 2003 explaining the sudden detections.

Figure 6 shows the concentrations detected and the total precipitation (mm) during some of the sampling weeks from the summer of 2003. The first finding of metalaxyl is from the week after sowing of 86.7 ha of processing peas. The concentration first climbs toward a peak value and then it decreases.

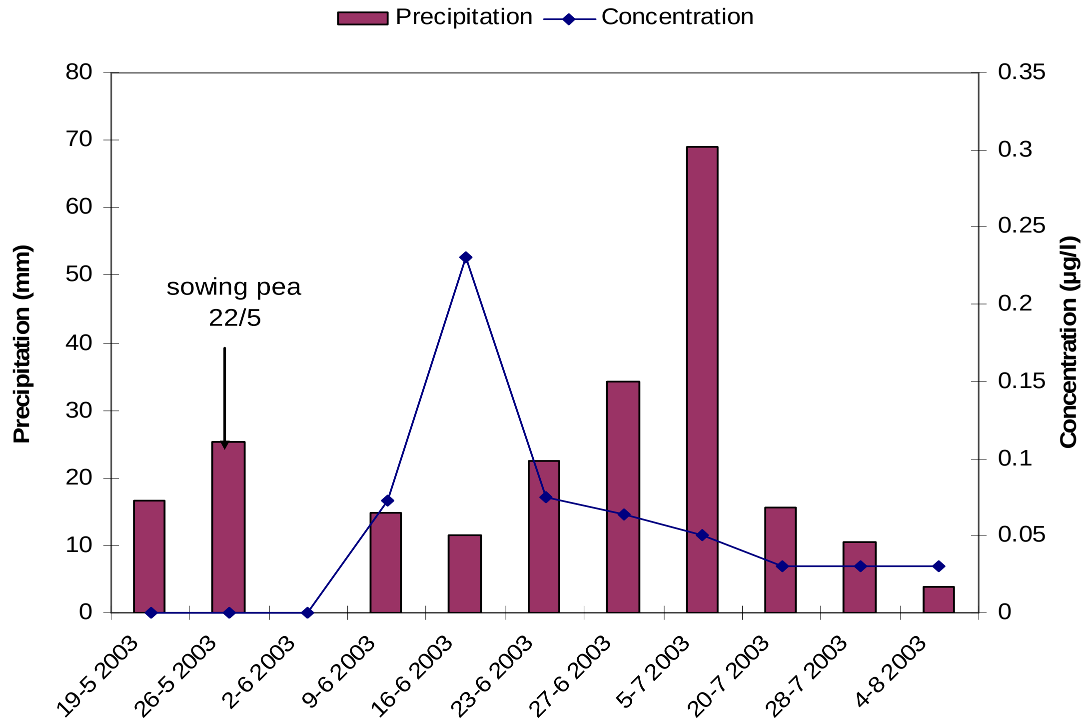

Figure 6. Measured concentrations of metalaxyl and total precipitation during some sampling weeks from the summer period 2003 in area M 42.

Processing peas were sown on 72.6 ha in 2004. The first finding of metalaxyl was detected in the week after sowing (Figure 7). This was also the case in 2005 (Figure 8). However the peak in 2005 was later than in the other two years. In 2005, processing peas were sown on two different days, 26 ha on the first day and 25 ha nine days later.

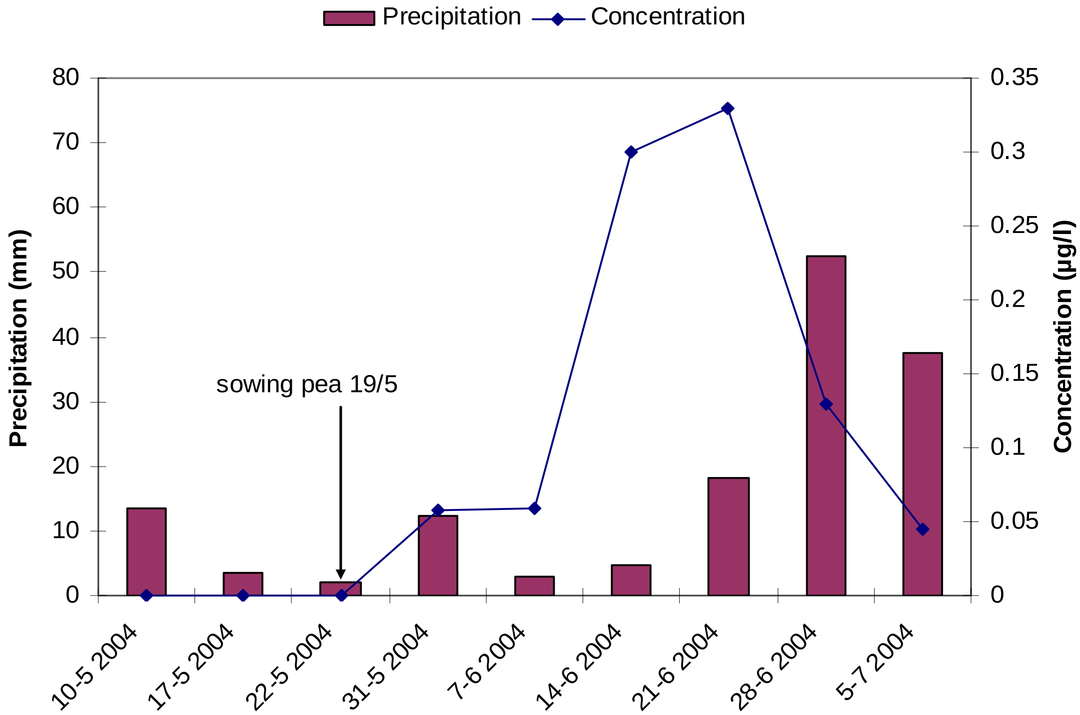

Figure 7. Measured concentrations of metalaxyl and total precipitation during some of the sampling weeks from the summer of 2004 in area M 42. A finding from 11-10-2004 is not included in the diagram.

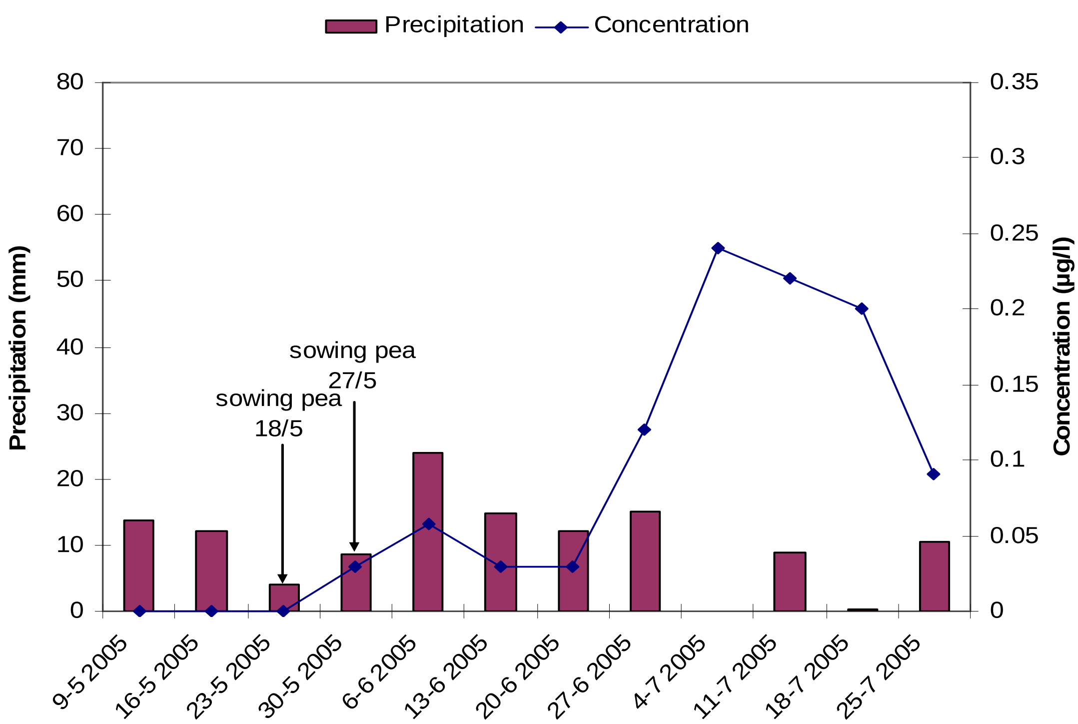

Figure 8. Measured concentrations of metalaxyl and total precipitation during some of the sampling weeks from the summer of 2005 in area M 42

The peak values seem to occur during periods with lower precipitation. One possible explanation is local thunderstorm with heavy rains, which are common during the summer. Being very local they might not have been registered at the official weather stations. However, data on precipitation from the closest official SMHI (Swedish Meteorological and Hydrological Institute) weather station and from two locations within area M 42 have no records of local thunderstorms during the periods when the peak values were detected.

There were six findings of metalaxyl in 2006. Three were from the summer period, whereas the two last findings were from the beginning of October. In 2004 there was also a finding in October. Peas are sown only in the spring, so the cause can be some kind of point source. Metalaxyl may have been bound in the soil profile during the growing season and leaching of bound metalaxyl due to autumn rain may be the reason behind the concentrations detected.

Bitertanol is used in seed dressing preparations for cereals. All findings of bitertanol, except two, in area M 42 are from October and November. The sample from July 2003 (the only finding that year) was collected during a week with a lot of precipitation (69 mm). Because there was only one sample containing bitertanol it is likely that it originated from some kind of point source. In 2005 findings of bitertanol were detected on three occasions, one in July and two in October. The samples from October may have originated from the winter cereal sowing season, whereas the one from July might be linked to washing of equipment or some other point source.

Figures 9 and 10 show the concentrations of bitertanol, the precipitation and the sowing period of winter wheat in 2003 and 2004 respectively. Winter wheat is the most grown winter cereal (about 98%) in the area each year. The other winter cereal is rye (about 2%) and in some years winter barley. The growing of winter cereals covered 37% of the area in 2003 and 41% in 2004. The findings were made shortly after or within the winter wheat sowing period. In Figure 9 the concentration of bitertanol starts at a peak and is above the guideline value of 0.3 $\mu g\ L^{-1}$. No samples were taken during September because of high flow in the stream. If there had been samples from September, the concentration curve would probably have started from a lower level. In Figure 10 it can be seen that the concentrations were lower in 2004 than 2002, but the first findings were within the sowing period for winter wheat.

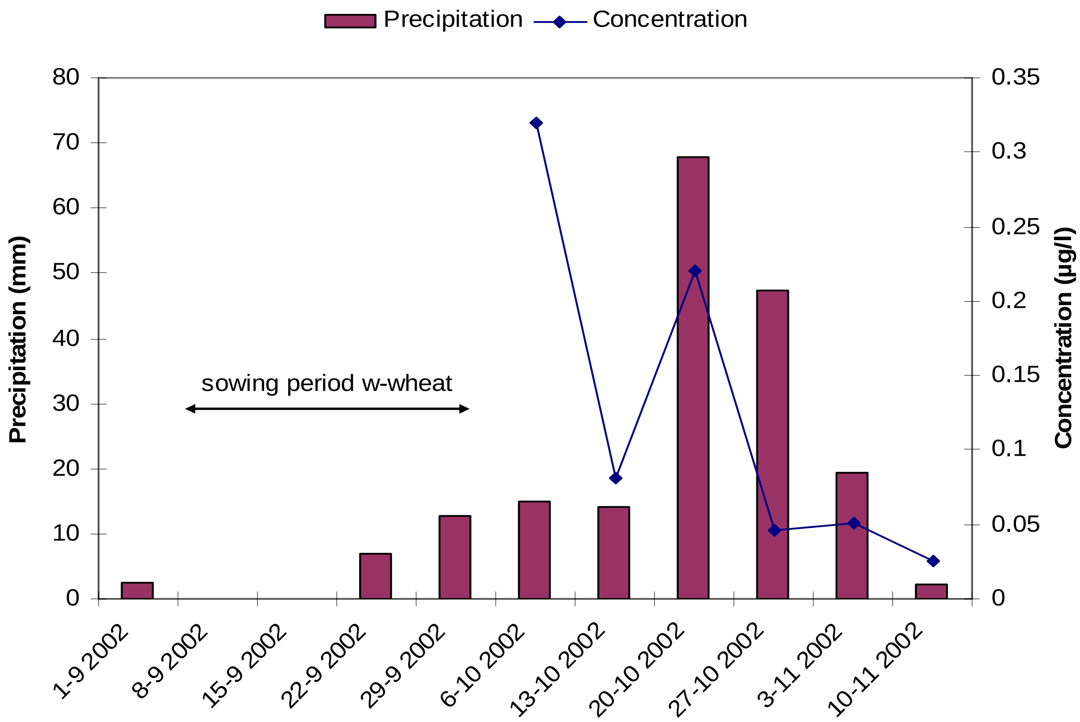

Figure 9. Measured concentrations of bitertanol and total precipitation during autumn sampling weeks in area M 42 in 2002.

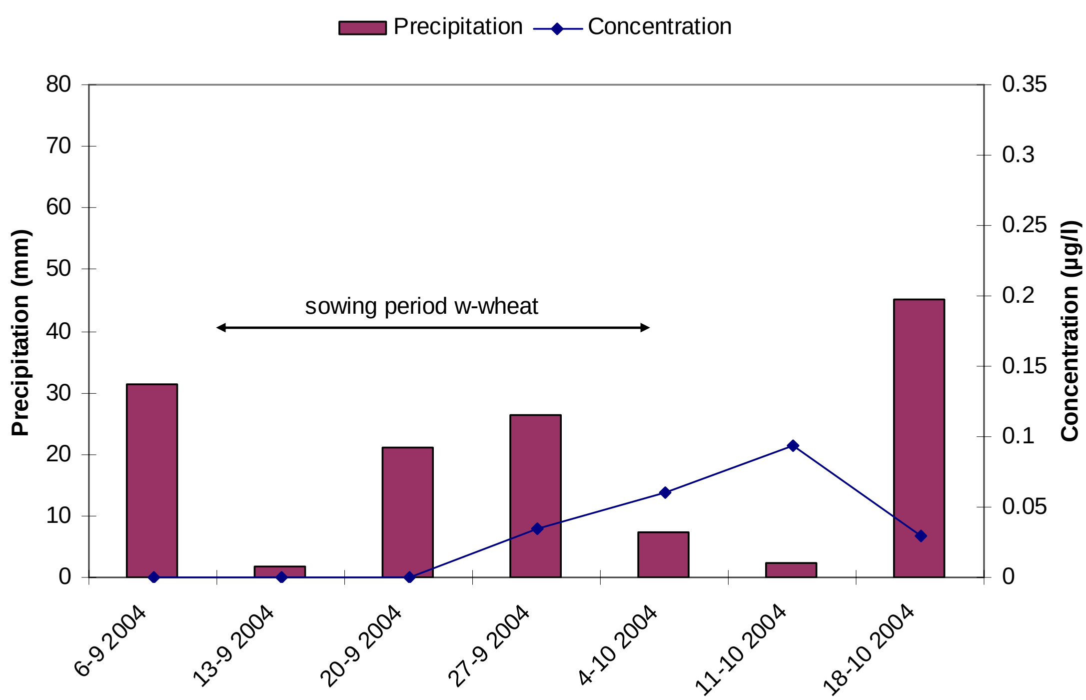

Figure 10. Measured concentrations of bitertanol and total precipitation during sampling weeks in September and October in 2004 in area M 42.

The highest concentrations of bitertanol were detected in 2002 (Figure 9). The number of hectares sown with winter wheat could have an impact on the concentrations if the seed had been treated with a preparation containing bitertanol. However, as can be seen in Table 7, the area sown with winter wheat was larger in both 2003 and 2004 than in 2002.

Table 7. Sowing period of winter wheat and number of ha in area M 42

Year	Crop	Total number of ha	Sowing period
2002	Winter wheat	212	020905 until 021004
2003	Winter wheat	310	030907 until 031016
2004	Winter wheat	356	040910 until 041008

It is more likely that the findings are connected to the amount of seed treated with bitertanol and the preparation used. The most commonly used preparation containing bitertanol at present is Sibutol FS 199, which was approved on 16 December 2002 and is thus unlikely to be the cause of the findings from autumn 2002. There was previously a preparation called Sibutol LS containing bitertanol and fuberidazole, but in different amounts. Sibutol LS was re-registered on 1 January 2002 and if it was used in winter wheat in 2002 it might explain the detected concentrations. The decreased use of Sibutol FS 199 in favour of Panoctine preparations might be the reason why the number of findings decreased from six in 2004 to no findings in 2006.

There is a preparation called Baycor 25 WP which contains bitertanol and it was reregistered in 2002 (Kemikalieinspektionen, 2008). It is used in autumn sown cereals (mostly barley). The findings can be due to application of this preparation in the field. However there is no registered use in the area.

3.4.3 Area O 18 (Västergötland)

Bitertanol, imazalil and metalaxyl were detected in the stream in area O 18 despite no reported use (Tables 8 and 9).

Table 8. Annual amount (kg) of substances included in the analyses used in area O 18 during the period 2002-2006

Substance	2002	2003	2004	2005	2006	Total amount (kg)
betacyfluthrin	0.08	0	0.19	0	0.02	0.29
bitertanol	0	0	0	0	0	0
fuberidazole	0	0	0	0	0	0
imazalil	0	0	0	0	0	0
imidacloprid	0	0	0	0	0	0
iprodione	0	0	0	0	0	0
metalaxyl	0	0	0	0	0	0
prochloraz	0	0	2.93	0	0	2.93
tolclofos-methyl	0	0	0	0	0	0

Table 9. Number of substance findings in area O 18 during the period 2002-2006

Substance	2002	2003	2004	2005	2006	Total number
bitertanol	3	0	1	0	0	4
imazalil	1	0	1	0	0	2
metalaxyl	1	1	7	5	3	16

Bitertanol was detected in the autumn in 2002 and 2004. Winter wheat was sown in the area during September in both years.

Imazalil was detected in the end of May in 2002 and in the middle of July 2004. Imazalil is used in seed dressings for cereals and it is possible that the concentration detected in 2002 originated from spring barley sown at the end of April.

The findings of metalaxyl in area O 18 varies between years. In 2004 (Figure 11), it is possible to connect the concentrations detected to the sowing of processing peas, as the first findings were detected within two weeks after sowing.

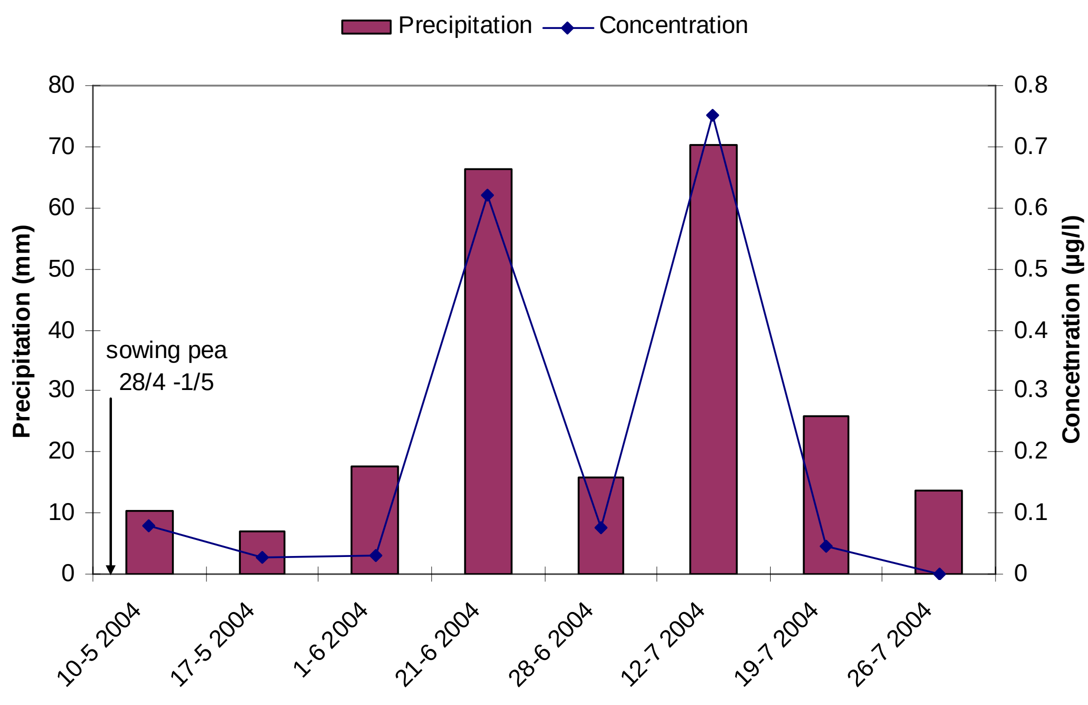

Figure 11. Measured concentrations of metalaxyl and precipitation from some of the sampling weeks in the summer period 2004 in area O 18.

In 2002, 2003 and 2005, field peas were sown in this area, but no processing peas. There was one finding of metalaxyl in 2002 (June) and one in 2003 (July), but is difficult to say where this metalaxyl came from. A direct source, *e.g.* usage on potatoes and sugar beet, is not possible because neither crop is grown in this area. However, in both 2002 and 2003 there were large amounts of precipitation (52 and 45 mm respectively) during the sampling weeks. The concentrations detected can be the result of leaching of metalaxyl bound in the soil and originating from previous crops of processing peas. In 2005 there were findings from June but also from October. The findings from June were detected during weeks with more precipitation. The findings from October are probably not connected to leaching since there was hardly any precipitation during the sampling weeks. A point source is the most likely explanation. In 2006 processing peas were sown at the end of May. There was one finding in July and two in October.

3.4.4 Area N 34 (Halland)

Imidacloprid, imazalil and iprodione were detected in the stream in area N 34 although no use was reported (Tables 10 and 11).

Table 10. The annual amount (kg) of substances used in area N 34 during the period 2002-2006

Substance	2002	2003	2004	2005	2006	Total amount (kg)
betacyfluthrin	0.51	0	0.61	0.21	0	1.33
bitertanol	0	0	0	0	0	0
fuberidazole	0	0	0	0	0	0
imazalil	0	0	0	0	0	0
imidacloprid	0	0	0	0	0	0
iprodione	0	0	0	0	0	0
metalaxyl	8.58	15.66	15.49	18.45	11.04	69.22
prochloraz	2.23	0	13.87	4.46	0	20.56
tolclofos-methyl	0	0	0	0	0	0

Table 11. Number of substance findings in area N 34 during the period 2002-2006

Substance	2002	2003	2004	2005	2006	Total number
imazalil	0	0	1	0	1	2
imidacloprid	0	0	0	1	1	2
iprodione	0	0	2	0	0	2
metalaxyl	7	6	13	18	18	62
prochloraz	1	0	0	0	0	1

Imazalil was detected on two occasions, both times in the autumn (September/October). Imazalil is used in seed dressing preparations against fungal infections in cereals. Winter cereals (wheat, rye wheat and rye) were planted during September- October in both 2002 and 2004. It is possible that the measured concentrations originated from seed dressings. However, the fact that there was only one finding in both 2004 and 2006 might suggest some kind of point source.

Imidacloprid is an insecticide used in seed dressing for oilseeds, sugar beet and potatoes. Seed dressing of potatoes can take place in the field during planting. There are two seed dressing preparations used on sugar beet that contain imidacloprid, Montur and Gaucho. Both potatoes and sugar beet are grown in the area. The finding from 2005 was detected in the middle of May. Sugar beet was sown during April and potatoes were planted from the last week in April to the middle of May. Seed dressing of potatoes in the field is a potential source of the concentration detected. In 2006 the finding was detected in the middle of June and in that year potatoes were planted during May, the last hectares about one month before the detected concentration. No rain fell during the week of sampling and not very much during the previous week. It is therefore likely that the concentration detected had a different source than seed dressing of potatoes in the field.

Iprodione was found in two samples in 2004. Both samples were from the summer season, one in the middle of May and one in June. Iprodione is a fungicide used in seed dressing preparations on oilseeds, cabbage, peas, beans, sugar beet, onion and potatoes. Sugar beet was sown in April that year, whereas potatoes were planted from the end of April to the middle of May. The concentration detected in May might have originated from planting of potatoes.

Prochloraz was detected in May 2002. Application took place during the week that the sample represents and is probably the reason it was found.

The use of metalaxyl in area N 34 is extensive and it is no surprise that it has been detected in the stream. The interesting thing about the findings is that during the period 2002-2006 (with the exception of 2003) metalaxyl was detected in samples taken before the start of the application period. In 2005, four samples with metalaxyl were collected before the starting date of the application period (Figure 12). Three findings were made before the start of application in 2006 (Figure 13). The findings from 2006 might originate from seed dressing preparations because 44 ha of processing pea were sown on four occasions during two weeks before the application period (Figure 13). There was no growing of processing peas in 2005.

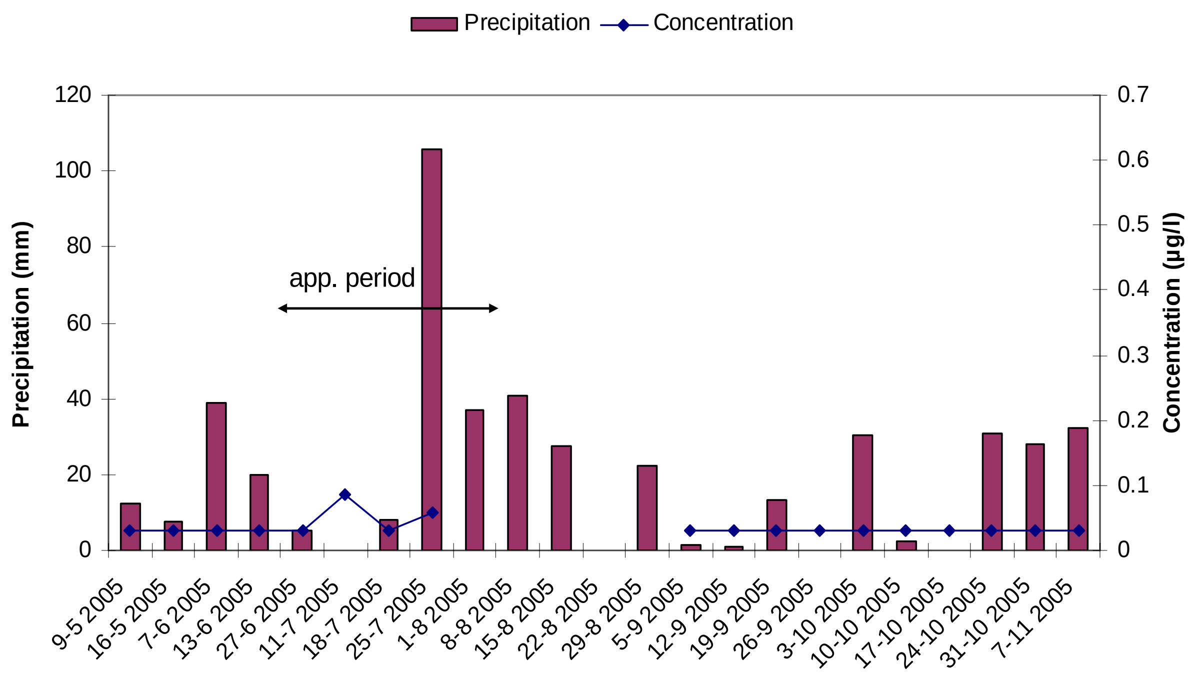

Figure 12. Measured concentrations of metalaxyl before, during and after the application period in 2005 in area N 34. No samples were collected during August.

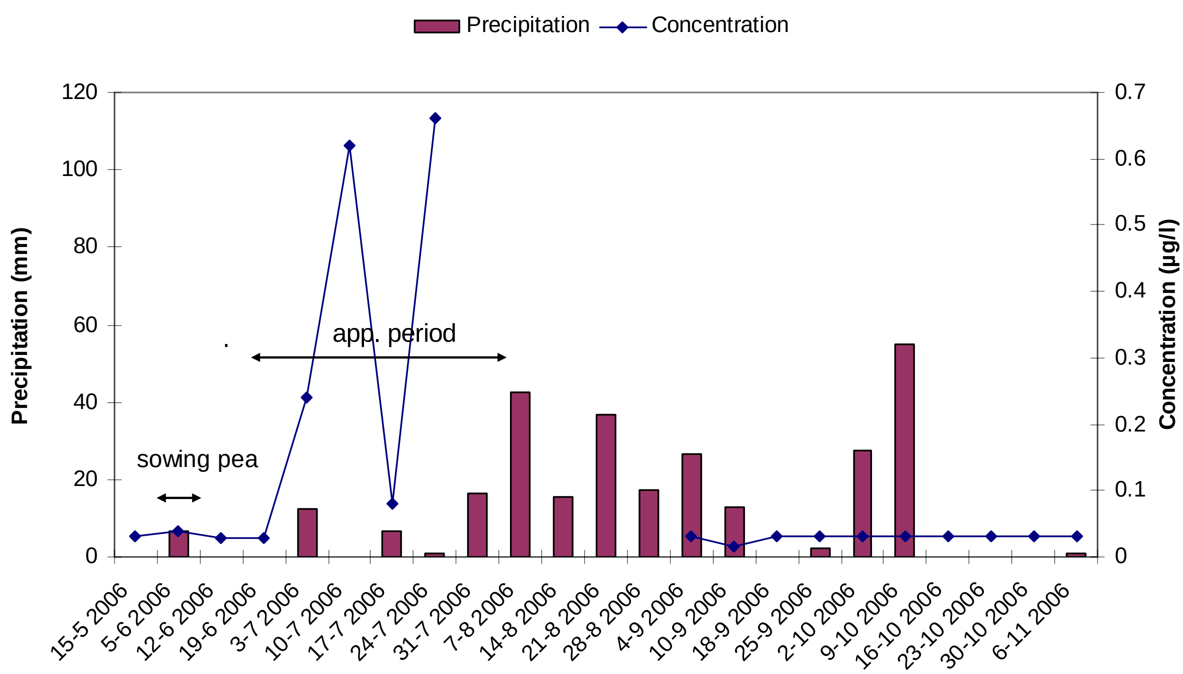

Figure 13. Measured concentrations of metalaxyl before during and after the application period in 2006 in area N 34. No samples were collected during August.

The findings of metalaxyl continued after the end of the application period during 2005 and 2006, with some findings made in September-October. This was also the case for 2002, 2003 and 2004 (see Appendix III). The concentrations after the application period seem to be quite constant at around 0.03 µg L^{-1}. The reason is probably metalaxyl (originating from regular use in field applications) that had been bound in the soil profile before it leached out.

3.4.5 Area E 21 (Östergötland)

In area E 21, two substances, imidacloprid and metalaxyl, were detected (Table 13) and they had both been used officially (Table 12).

Table 12. Total annual amount (kg) of substances used in area E 21 during the period 2002-2006

Substance	2002	2003	2004	2005	2006	Total amount (kg)
betacyfluthrin	0	0	0	0.08	0	0.08
bitertanol	0	0	0	0	0	0
fuberidazole	0	0	0	0	0	0
imazalil	0	0	0	0	0	0
imidacloprid	0	0	2.34	0	0	2.34
iprodione	2.32	0	0	0	0	2.32
metalaxyl	9.02	7.25	8.06	8.82	10.45	43.60
prochloraz	4.07	0	0	0	0	4.07
tolclofos-methyl	0	0	0	0	0	0

Table 13. Number of substance findings in area E 21 during the period 2002-2006

Substance	2002	2003	2004	2005	2006	Total number
imidacloprid	0	0	0	3	0	3
metalaxyl	7	9	6	9	9	40

Imidacloprid was found in three samples in 2005 (two at the end of May and one in July). It was reported used only in 2004, so the findings might be due to unreported usage in 2005. However, seed dressing of potatoes in the field during planting is a possible source. In 2005 potatoes were planted during May and the findings were made at the end of May. The sample from July was taken during a week with a large amount of precipitation (55 mm), which could have caused leaching. However, potatoes were grown each year during the period 2002-2006 so if the imidacloprid detected originated from a seed dressing preparation, one could expect to find it in the other years as well. The reason might be that potatoes are not always treated with seed dressing preparations. The need for treatment can vary from year to year or a preparation containing some other substance than imidacloprid might have been used. Washing of sowing/planting equipment is another possible explanation.

The use of metalaxyl is large in area E 21 (but lower than in area N 34) and the substance was detected in the stream in all years studied. During this period (2002-2006) no findings were made before the start date of the application period, as in area N 34 (Halland). Field peas were grown in the area each year but no processing peas. In both E 21 and N 34 findings have been made in September-October. Figure 14 shows that the findings in area E 21 were made as late as in November in 2003. Findings of metalaxyl were made during October in 2005 and 2006. Leaching of metalaxyl originating from field application was probably the cause.

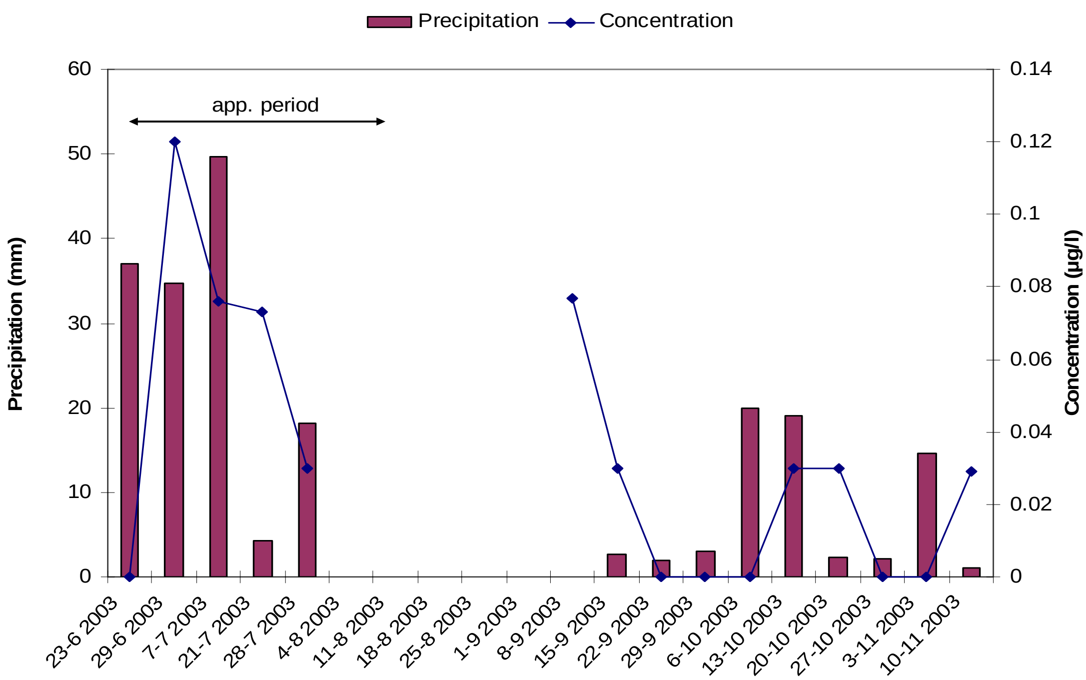

Figure 14. The measured concentrations of metalaxyl from the end of June to October in area E 21 in 2003. There are no measurements from August.

3.4.6 Total annual transport of metalaxyl from area M 42

Table 14 shows the calculated amounts of metalaxyl (g) transported annually (2002-2006) out of area M 42. The transported amounts were lower than the amount supplied through seed dressing (about 42 g ha^{-1}). In 2002, the year before the first growing of processing peas, no metalaxyl transport occurred. These facts support the theory that the findings of metalaxyl originate from seed dressing preparations.

Table 14. Calculated total transport (g) of metalaxyl in area M 42 2002-2006

Year	M 42
2002	0
2003	1.8
2004	1.2
2005	1.3
2006	3.4

3.5 Discussion of substances

The following arguments are used in this discussion in an attempt to explain the sources behind the substances detected in the four areas.

Arguments for point sources:

- Single findings with relatively high concentrations.
- Findings of substances between sowing seasons, *e.g.* in the middle of the summer.
- Findings from periods when the substances were not used. If the findings had originated from leaching through the soil profile the substance would have been detected in more samples. The findings were made a long time after usage.
- There are runoff inlets in some farmyards in area M 42 in which equipment rinsing water can be transported directly to the drainage system.
- It is known that seed drills and other equipment are often cleaned in the farmyard, where the risk of leaching is quite high.
- Some of the single findings with high concentrations have been made during sampling weeks with no or very little precipitation and it is thus not likely that they were caused by leaching.

Arguments for leaching of seed dressing preparations from the field:

- Detection of substances not reportedly used at all.
- Detections within or shortly after the sowing period.
- Many findings after each other.
- The detected substance can be linked to the seed dressing preparation used on a crop grown in the area.
- Findings are from a long period and often associated with large amounts of precipitation, resulting in leaching from the soil profile.

3.5.1 Betacyfluthrin

Only one finding of betacyfluthrin has been made, in area M 42. In areas N 34, O 18 and E 21 betacyfluthrin has been reported as used in at least one year during the period 2002-2006, but in very low amounts. One possible explanation for the finding in area M 42 can be that it is due to a point source. The finding, which was detected at trace level, exceeded the guideline value of 0.0001 µg L^{-1}. Although the finding was made at the end of November it does not seem likely that it would originate from seed dressing (betacyfluthrin is used against fungal infections in oilseed) because rape was sown in the end of August. Mobility of betacyfluthrin in soil is low and degradation is rapid (Tomlin, 2006). The precipitation was only 7.5 mm during the sampling week. All these things together seem to exclude seed dressing as a possible source. The likely explanation behind the finding of betacyfluthrin in area M 42 is thus some kind of point source. It could originate from private use such as in a garden terrace. However the guideline value of betacyfluthrin is 20 times larger than the LOD. This can also be an explanation why betacyfluthrin has not been detected more than once.

3.5.2 Bitertanol

Bitertanol is one of the most interesting substances found. Although not reported as used in any of the areas, 14 findings have been made in area M 42 and four in area O 18. It has only once been detected above the guideline value of 0.3 µg L^{-1} (in area M 42). Bitertanol is used in the seed dressing preparation Sibutol against fungal diseases in cereals. Sibutol used to be the most common seed dressing in winter cereals in the south of Sweden, but around 2004 it began to be replaced by the cheaper product Panoctine, containing guazatine. Some of the Panoctine preparations also contain imazalil. The numbers of findings in area M 42 and O 18 have decreased from 2002 to 2006 and this might be explained by the decreased use of Sibutol.

Most findings of bitertanol have been made in the autumn during or shortly after the winter cereal sowing season. Many findings in succession, no documented use and detection within or shortly after the sowing season of winter wheat make it very likely that the bitertanol detected in streams originates from seed dressing preparations. However, why bitertanol was also found in the summer is difficult to explain. According to the literature (Tomlin, 2006), degradation of bitertanol in soil is rapid and the mobility is low, and therefore bitertanol bound in the soil profile from the previous year does not seem to be the explanation. One explanation might be rinse water from washing of seed drills that has entered a ditch. Use in gardens of preparations for ornamental plants could be another explanation.

3.5.3 Imazalil

The fungicide imazalil, used for seed dressing of cereals, has been found in a total of six samples in areas M 42, N 34 and O 18, despite no reported use. The findings of imazalil were few and sporadic and occurred quite late in the season in area M 42 (except for one sample) and area N 34, whereas in area O 18 findings were earlier. The concentrations never exceeded the Swedish guideline value of 5 µg L^{-1}, but two samples exceeded the Dutch MTR value of 0.87 µg L^{-1}. The findings from the autumn could be due to seed dressing preparations used in winter cereals. The earlier findings such as the one in area O 18 in the middle of July cannot be explained by this. The reasons behind the detected concentrations of imazalil could be both seed dressings and point sources.

3.5.4 Iprodione

Iprodione is a fungicide used in seed dressings for peas, cabbage, potatoes, oilseeds, sugar beet *etc*. It has only been found in area N 34, but there is no reported use in any of the areas. The concentrations detected were low and below the guideline value. Seed dressing of potatoes was likely performed in the field during planting. Residues of iprodione in the soil from planting of potatoes in the end of April might explain the findings. However, the infrequency of findings makes a point source the most likely explanation.

3.5.5 Imidacloprid

Imidacloprid has been found in area N 34 and E 21. The reason might be potatoes treated with seed dressing preparations during planting. Imidacloprid is also used in seed dressing for sugar beet. Sugar beet is grown in area N 34 but not in area E 21. Two of the seed dressing preparations used on sugar beet contain imidacloprid. These are Gaucho and Montur (imidacloprid and tefluthrin). It is possible that these preparations are linked to the findings in area N 34. However the fact that there were only three findings and that no findings have been made in area M 42, in which a lot of sugar beet is grown, indicates that this is not the answer. Imidacloprid is used in many insecticides for private use both inside and outside houses and this might be the reason why imidacloprid has been detected in streams. However, one important aspect is that the high detection limit for imidacloprid applied in this investigation compared to the Dutch MTR value of 0.013 µg L^{-1}. Thus we can not rule out possible risks associated with imidacloprid uses without further investigation.

3.5.6 Metalaxyl

Metalaxyl has not been used in areas M 42 and O 18, yet the findings were frequent in all four areas compared with the other substances. The most surprising is the findings of metalaxyl in area M 42, which are probably associated with the growing of processing peas that started in 2003. Apron XL (metalaxyl) against downy mildew is the most common seed dressing preparation used on processing peas. No reported use, many findings in succession and from a long period, together with the fact that metalaxyl can be linked to the growing of processing peas, are strong arguments for seed dressing preparations as the source of the concentrations of metalaxyl detected in area M 42.

In area O 18, the findings of metalaxyl also seemed to be associated with the growing of processing peas in one year. There were also findings from area O 18 in years when no processing peas were grown. Some of the samples were collected during weeks with large precipitation and leaching of bound metalaxyl could be one explanation. However, according to Tomlin (2006) the mobility of metalaxyl in soil is high and the halflife is only 29 days. These facts indicate that metalaxyl does not accumulate in soil and should not be able to leach out as long as year after the growing of processing peas. In contrast Fernandes *et al.* (2003) found that the mean halflife of metalaxyl in the natural soils used in their experiment was 75 days. Metalaxyl halflife increased with increased organic matter content in the soil.

There are more findings of metalaxyl in the autumn samples from the areas where the substance had been applied on the fields (areas N 34 and E 21). The explanation can be that larger amounts of the substance were used in field application, but differences in soil properties such as structure and organic matter content can also be the reason.

4 Interviews with farmers

The aim of the interviews was to investigate whether the handling of treated seed from packaging to field was a potential source of the substances detected in the streams in the four areas. Interviews with 10 farmers were carried out during October 2007 and are intended to provide a general idea of the practices on farms in Sweden and to help consider or exclude sources. The interview questions are given in Appendix VI. Seven of the interviews were carried out in Skåne in the south of Sweden (three of them in area M 42). The other three interviews were carried out in Uppland. The farms chosen are conventional farms on which different seed dressing preparations are used. The production is dominated by cereals, sugar beet and oilseeds in Skåne and cereals, oilseeds and some field peas in Uppland.

4.1 Interview answers

4.1.1 Buying of seed and most common seed dressing preparations (Questions 1-3)

All farmers responded that they primarily buy Swedish seed. One of the farmers also used seed from his own farm as a complement. Seven out of ten farmers reported that they sometimes buy seed from Denmark and in some cases Germany. The most common reason for buying seed from abroad was lack of availability in Sweden.

Most of the cereals sown in the autumn are treated with seed dressing preparations. The spring crops can be treated or untreated depending on the need. Oat seed is usually untreated. Not all the farmers interviewed knew which preparation their seed was treated with, mostly because they buy it pre-treated from a company which performs the seed dressing. Some of the most common preparations reported were Cedomon (on barley) and Panoctine, Sibutol, Dividend and Cerall (on winter wheat). Chinook was common on sugar beet. Two of the ten farmers reported that seed dressing had been performed on the farm some 10-20 years ago.

4.1.2 Handling of seed and packaging (Questions 4-6)

Seed in its packaging is usually kept in a barn or a machine garage for one to two months before sowing in spring according to the farmers interviewed. The winter seed is usually planted directly because harvest and sowing are so close. Two farmers sometimes buy older seed from the previous year just to be sure to have enough for the autumn sowing season. In those cases the seed arrives on the farm in May or June. Any seed not used is saved until the next year. One farmer reported that if the remaining seed is treated with a preparation that will expire in the following year, it is sown in a field and allowed to grow.

Large spills of seed are taken up and re-used, while two farmers burn waste seed in a furnace. Very small spills of seed in the farmyard are usually not collected. Seven farmers responded that the seed drill is filled and refilled in or near the fields. Seed is expensive and therefore it is treated with care.

Empty seed packaging is recycled. The farmers generally leave it at a recycling station but sometimes (mostly in Skåne) companies organise special collections and pick up empty seed packaging at the farm. Paper packaging for sugar beet seed is burned when empty. One of the farmers who lives quite far from the closest recycling station sometimes burns plastic packaging.

4.1.3 Sowing and cleaning of machines (Questions 7 and 8)

It is usually the farmer himself or an employee that takes care of the sowing. The larger farms in Skåne can have several employees. Two of the farmers interviewed cooperate with neighbours. One farmer in Skåne engages a contractor for the sowing of sugar beet. Two of the farmers in Uppland use direct drilling after peas and oilseed rape. They buy this service from a company because they do not have the type of seed drill required.

Seven of the ten farmers interviewed clean the seed drill when changing crops. Five of them use compressed air to clean the machine, whereas two use an industrial vacuum cleaner. The cleaning is usually done in a machine garage or on a concrete platform (with separate collection of rain and rinse water). Three of the ten farmers sometimes clean machinery in the farmyard. Three farmers do not use air or water to clean the seed drill between crops. They empty the machine by opening the base flaps and remove remaining seed by hand. The seed drill is instead cleaned carefully after the end of the sowing season.

All farmers clean their seed drills carefully at the end of the sowing season. In five cases water is used to wash the entire machine, while one farmer only uses water on the outside. Four farmers use compressed air and no water. In the cases when contractors are engaged and the same crops are sown, no cleaning takes place between sowing on different farms.

4.1.4 Pesticide use and routines for filling and cleaning of the sprayer (Questions 9 and 10)

It is common practice to apply pesticides (usually herbicides) on autumn-sown crops in Skåne. Application of pesticides in the autumn does not take place in Uppland because of colder weather. Crops sown in the spring are usually sprayed at a certain growth stage (two-four leaves) and depending on temperature and rain this can take place within two to four weeks or more from the sowing date. On all ten farms the sprayer is filled and cleaned in the field or on a biobed.

The most common practice is to clean the sprayer in the field with clean water. Four of the seven farmers in Skåne have an on-farm biobed which is used for filling and washing of the sprayer. One of the farms in Uppland had a biobed. Four of the farms in Skåne have a concrete platform with collection of rinse water on which the sprayer can be washed (*i.e.* one farm has both concrete platform and a biobed). One of the farms lacks special collection for rinse water. The collected rinse water is then spread in the field.

4.1.5 Spreading in the environment and health risks (Question 11)

None of the farmers had considered seed dressing preparations as a potential source of water pollution. They do not handle treated seed without gloves and they feel that the colour has a repellent effect. Nevertheless they have much more respect for preparations used in field applications. The amount of seed handled is quite small and is therefore not considered dangerous. Two farmers mentioned exposure to dust during cleaning with compressed air and that it is important to have good ventilation during cleaning of the seed drill.

4.2 Discussion

The answers received in the interviews were quite similar. It seems unlikely that handling of treated seed constitutes a major risk of spread into the environment, although the cleaning of machines is perhaps an exception. One factor to be considered is that the farms included in the interview, especially in Skåne, were quite large and might not be representative of agricultural farms in Sweden in general. Large farms might have better routines than small farms because they have more employees and thus the workload is less. Farmers have no time to plan the work and consider risks if the workload is too heavy during busy parts of the year.

Most of the time empty seed packaging is recycled. However as one farmer pointed out, it is likely that many farmers living far from recycling stations and in areas where companies do not organise collections sometimes burn the packaging instead. Ash of incinerated packaging might still contain some traces of the substances. However, the study by Nilsson *et al*. (2005) showed that substances on the inside of empty packaging were present in very low or non-detectable concentrations. However, one serious problem is that not all substances present in seed dressing preparations can be analysed.

Cleaning of seed drills seems to have the largest potential of being a point source. It is possible that many farmers clean the machine in the yard and rinse water can then reach a drain or a well. If there is a concrete platform it might be used, but it is not certain that the rinse water is collected and spread in a field later on. Washing of seed drills is a source worth more investigation. Also here the problem remains that many seed dressing products contain substances that cannot currently be analysed.

A question was asked about ownership of the sprayer and time of the first pesticide application after sowing to determine whether substances detected in streams might originate from spraying. The responses showed that if spraying take place some weeks after sowing it is often against weeds. Using a preparation containing the same active substance as the seed dressing preparation would increase the risk of resistance against that substance.

5 Field experiment

A field experiment was performed in order to investigate potential dissemination pathways for substances from seed dressing preparations. A test field plot in southern Sweden was used to investigate whether seed dressing can be lost from the seed after sowing. The field is equipped with artificial drainage and equipment to collect water samples.

5.1 Method

A field in area M 42 in southern Sweden was sown with oilseed rape (*Brassica napus*) on 28 August 2007. The rape seed was treated with the preparation Cruiser OSR, containing the substances thiamethoxam (280 g L^{-1}), metalaxyl (32.3 g L^{-1}) and fludioxonil (7 g L^{-1}). The soil is classified as sandy loam, loam (Table 4). The field is about 33.8 ha and is equipped with artificial drainage conducting the water to an underground measuring station. Flow-proportional water samples were collected using an ISCO 6712 sampler for 50 days after sowing. The end of the sampling period was 15 October 2007. Due to some technical problems with the measuring equipment some samples were initially taken manually. Collection of flow proportional samples started on 10 September. A total of 27 flow-proportional samples and 10 manual samples were collected during the 50-day period. Nine of the samples were selected, based on flow data (Figure 15), and analysed. A reference water sample was taken manually on the day before sowing and analysed with the other nine samples. The flow proportional samples analysed were selected based on water flow *i.e.* water level in the underground station. They were collected during periods with high water level (Figure 15). The collection time intervals for each analysed sample are listed in Table 20 in Appendix VII.

During the investigation period field application of the herbicide Butisan Top took place on 11 September. It includes the active substances quinmerac (125 g L^{-1}) and metazachlor (375 g L^{-1}) which were also included in analyses of the water samples.

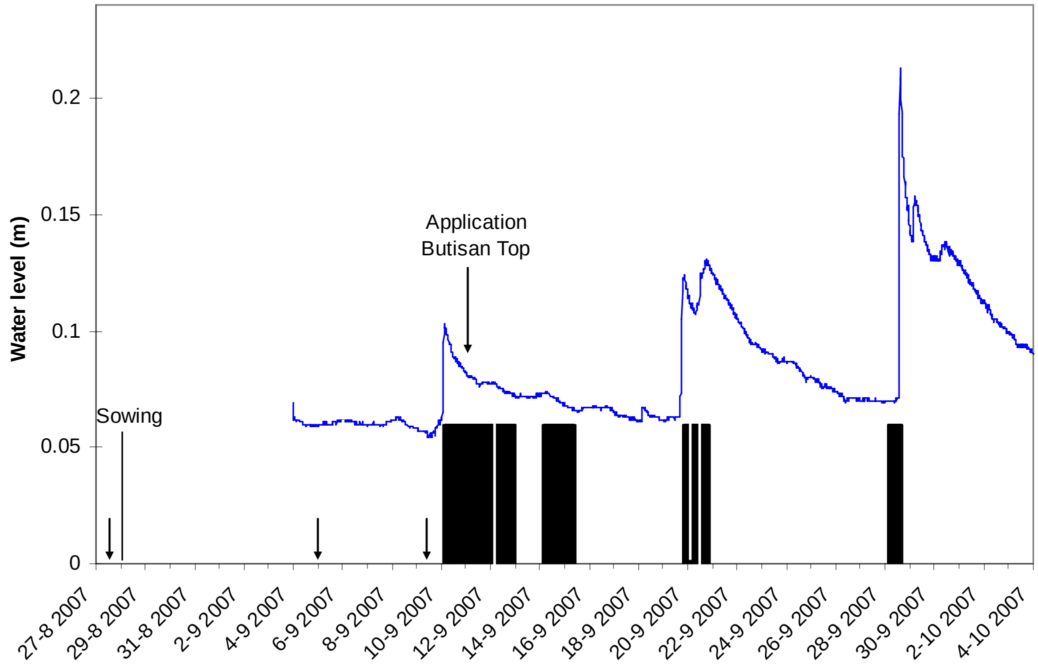

Figure 15. Water level plotted against sampling period (time). The flow-proportional samples are represented by the black marked intervals (7 samples) and the momentary samples by the short arrows. Flow levels are not available before 4-9 2007.

5.2 Result and discussion

Metalaxyl and thiamethoxam were first detected in the sample collected about two weeks after the sowing date (Figure 16). The concentration of thiamethoxam was larger than for metalaxyl in most of the samples (Figure 16). The seed dressing preparation Cruiser contains more thiamethoxam than metalaxyl (9:1) and this is probably why the detected concentrations of thiamethoxam were higher. Metazachlor and quinmerac from the applied herbicide were first detected nine days after application and concentrations were quite elevated during the remaining period (Figure 17).

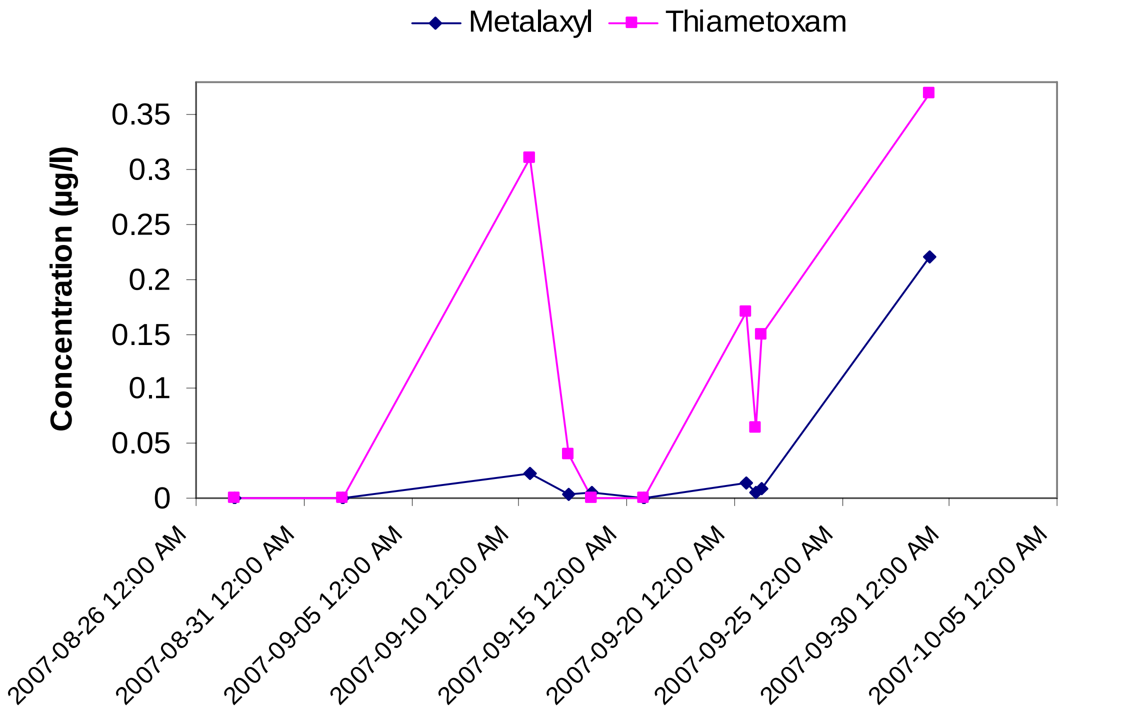

Figure 16 . Thiamethoxam and metalaxyl concentrations in samples collected from the experimental field. The first three samples are the momentary samples.

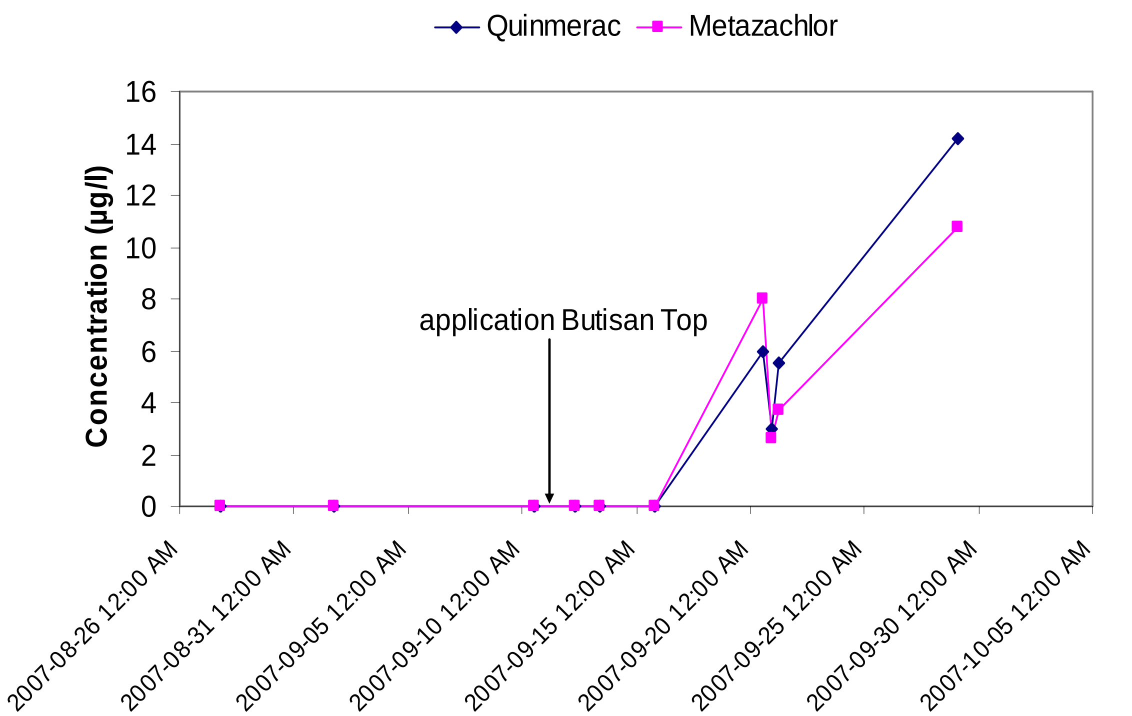

Figure 17. Quinmerac and metazochlor concentrations analysed in the same water samples as metalaxyl and thiomethoxam from the experimental field. The first three samples are the momentary samples.

The field experiment supports the theory that pesticides used as seed dressings might be susceptible to leaching, thus contributing to the diffuse losses of pesticides from agricultural fields. Metalaxyl and thiamethoxam were not detected in the blank sample and have not been applied through spraying in the field, so it is very likely that they originate from the seed dressing preparation used on the seed. It takes some time for the water to move through the soil and for the substances to reach the drainage system. The transport of metazachlor and quinmerac seem to be faster because they were detected nine days after application. It is not clear how the substances could reach the drains so fast but a possible explanation could be transport of the pesticide with rainwater from the soil surface down through macropores in the soil.

6 Discussion and conclusions

This report shows that for two particular substances, metalaxyl and bitertanol, seed dressing preparations are behind the residues detected in streams. The field experiment supported the theory that substances contained in seed dressing preparations can leach out after planting. However, the guideline value of a substance has only been exceeded on two occasions during the sampling period 2002-2006 in the four areas. There are actually more samples without findings than with findings.

Seed dressing has many advantages compared with application of pesticides in the field, e.g. it limits the need to apply pesticides through spraying. When seed dressing preparations are used the substance is applied directly to the treatment object and the risk of dissemination in the environment is much lower. Smaller amounts of the active substance are required in seed dressing compared with field application.

The presence of seed dressing residues in surface waters is of course undesirable and should be avoided, but the evidence indicates that there is no real reason to stop the use of seed dressings, because the advantages still outweigh the disadvantages. However, some of the seed dressing preparations on the market should be investigated further and ways to improve the adherence of the preparation to the seed might be helpful. This report shows that it is very important to investigate the substances that are still lacking a guideline value but that are used in seed dressing preparations. It would also be very interesting to see how much the concentration of residues varies from day to day during the sampling period. At present, only the medium concentration for the whole sampling period is retrieved.

One of the major questions formulated in the introduction to this report was how the substances from seed dressing preparations end up in streams. The results show that the actual pathway seems to depend on the particular substance. For metalaxyl and bitertanol, seed dressing products used on the planted seed are the source of the residues detected in streams. Other substances could originate from both a point source and seed dressing. For imazalil and iprodione, seed dressing of potatoes is a possible source but point sources could also be a possible explanation. In many cases, residues are detected in stream water after precipitation, and thus transport with percolating water through the soil profile seems to be the cause. However, the amount of leaching of a substance by this route is most likely dependent on soil properties such as structure and organic matter content, plus the intensity of the rain. Research on specific substances is necessary in order to obtain accurate knowledge of how the seed dressing preparation is lost from the seed surface.

The handling of treated seed was one of the aspects investigated. The interviews with farmers gave the impression that the most likely point source of chemicals was washing and cleaning of equipment, e.g. seed drills, but unfortunately this could not be confirmed. However, the theory that washing of seed drills is associated with dissemination of substances should not be dismissed. Studies by Greatti *et al.* (2003, 2006) in Italy on dispersion of imidacloprid from seed-dressed maize sown by pneumatic seed drill confirmed that imidacloprid was spread to surrounding vegetation. Filters placed at the drill fan air output contained low levels of imidacloprid. Rain was found to have a washing effect on imidacloprid deposited on the vegetation. The most important factor was that even the control samples showed low levels of imidacloprid, although the machine was carefully washed between each sowing. It thus seems likely that some residues of the chemicals used in seed preparations could be left on the seed drill and then be washed off during cleaning, so if this is done directly in the farmyard there is probably a risk of dissemination into the environment. Most of the seed drills used in Sweden employ similar sowing techniques to that in the equipment studied by Greatti et al. (2003, 2006) and dispersion during sowing could be an explanation for the residues detected. However, this is contradicted by the fact that most residues found in Swedish waters have been detected some time after sowing and not during the first day of sowing as in the Italian study.

Seed packaging was initially thought to be a potential source of dissemination of seed dressing substances, but studies by Nilsson *et al.* (2005) did not support this theory. The responses received during interviews in the present study did not identify the handling of packaging as a major risk. Paper packaging that had contained sugar beet seeds was usually burned and sometimes also plastic packaging. If the concentrations of chemical residues on the inside of empty seed packaging are very low or below the LOD, as shown in the study by Nilsson *et al.* (2005), this should not be a problem. However, an important factor to consider is that most of the substances could not be analysed and there might be differences between substances.

Leaching from the soil profile is probably one of the major pathways for seed dressing substances entering the aquatic environment. Studies by Gupta *et al.* (2002) and Fogg *et al.* (1994) showed that substances used in seed dressing preparations could leach out or remain in the soil for quite a long time. This is probably very strongly connected to properties such as K_{oc} and K_{ow} for each substance and to soil properties. Differences in soil properties such as organic matter content and structure could be one explanation for differences in the behaviour of an individual substance, e.g. metalaxyl, between the areas investigated. The field experiment points towards the fact that rain, and thus the amount of water moving through the soil, affects how fast a substance reaches drains and subsequently water courses.

The impression obtained during interviews and contact with the industry was that biological seed treatment is being used increasingly and that within a few years it might constitute the major proportion of the seed dressing preparation market. This is very positive because it will limit the use of chemical pesticides within agriculture and the risk of dissemination of chemical substances into the environment will decrease.

Conclusions

- The field experiment showed that seed dressing preparations can leach from the soil
- Leaching of a substance with percolating water through the soil profile is probably the main pathway for losses
- The differences in detection frequency between substances indicate that the physical and chemical properties of a substance are factors affecting whether a substance leaches or not
- The way in which the preparation is lost from the seed surface after planting needs further investigation
- Possibly the adhesive binding of the seed dressing preparation to the seed is not optimal. A quick dissipation of the pesticide from the seed is negative both from a plant protection perspective and from an environmental perspective.
- For metalaxyl and bitertanol, seed dressing preparations are the source behind the concentrations detected in streams
- For imazalil both seed dressings and point sources are likely causes of the concentrations detected in streams
- For iprodione the findings can be due to seed dressings or point sources such as use in gardens
- The findings of betacyfluthrin, imidacloprid and prochloraz are probably due to a point source
- Two substances, fuberidazole and tolclofos-methyl, have never been detected in the streams
- Detected concentrations of pesticides possibly resulting from seed dressing preparations were generally low
- There are more samples without findings than with findings
- Handling of treated seed is probably not a source of dissemination of seed dressings into the environment, with the possible exception of seed drill washing
- The potential of seed drill washing as a point source could be worth further investigation
- Seed packaging is not a likely source of the substances detected in streams
- Increased use of biological seed dressing preparations could decrease dissemination of chemical substances into the environment.

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References

Literature

Adielsson, S., Törnquist, M., Kreuger, J. 2007. Bekämpningsmedel (växtskyddsmedel) i vatten och sediment från typområden och åar samt i nederbörd under 2006. Ekohydrologi 99. Institutionen för markvetenskap, avdelningen för vattenvårdslära. ISRN SLU-VV-EKOHYD-99-SE. ISSN 0347-9307. Uppsala.

Asp, J., Kreuger, J., Ulén, B. 2004. Riktvärden för bekämpningsmedel i ytvatten – Hur tas riktvärden fram och hur tillämpas de internationellt? – Hur förhåller sig svenska riktvärden till uppmätta halter i ytvatten? – Förslag till hur de svenska riktvärdena ska tillämpas. Ekohydrologi 82. Institutionen för markvetenskap, avdelningen för vattenvårdslära. ISRN SLU-VV-EKOHYD-82-SE. ISSN 0347-9307. Uppsala.

Bergström, L. 2002. Leaching. In: Pimentel, D. (ed.) *Encyclopedia of Pest Management.* Marcel Dekker Inc. New York. p. 442-444.

Carson, R. 1963. Silent spring. London, Hamilton.

Felsot, A. S., Rupert, J. R. 2002. Imidacloprid residues in Willapa Bay (Washington State) water and sediment following application for control of burrowing shrimp. Journal of Agricultural and Food Chemistry, 50, 4417-4423.

Fernandes, M. C., Cox, L., Hermosín, M. C., Cornejo, J. 2003. Adsorption-desorption of metalaxyl as affecting dissipation and leaching in soils: role of mineral and organic components. Pest Management Science, 59, 545-552.

Flores-Céspedes, F., González-Pradas, E., Fernández-Pérez, M., Villafranca-Sánchez, M., Socías-Viciana, M. and Ureña-Amate, M.D. 2002. Organic Compounds in the Environment- effects of dissolved organic carbon on sorption and mobility of imidacloprid in soil. Journal of Environmental Quality, 31, 880-888.

Fogg, P., Carter Andrée, D., Brown, C.D. 1994. A comparison of the use and regulatory interpretation of a predictive model, lysimeter and field studies to determine the leaching potential of a seed dressing. Brighton crop protection conference: Pests and diseases, 1994 Vol. 1-3 :3, 1283-1288.

Gevao, B., Jones, K.C. 2002. Pesticides and organic pollutants. In: Heygarth, P.M and Jarvis, S.C (eds.) *Agriculture, Hydrology and Water Quality.* p. 83-100.

Greatti, M., Sabattini A.G., Barbattini, R., Rossi, S., Stravisi, A. 2003. Risk of environmental contamination by the active ingredient imidacloprid used for corn seed dressing. Preliminary results. Bulletin of Insectology 56 (1): 69-72. ISSN 1721-8861.

Greatti, M., Barbattini, R., Stravisi, A., Sabattini A.G., Rossi, S. 2006. Prescence of the a.i. imidacloprid on vegetation near corn fields sown with Gaucho dressed seeds. Bullentin of Insectology 59 (2): 99-103. ISSN 1721-8861.

Gupta, S., Gajbhiye, V. T., Kalpana Agnihotri N. P. 2002. Leaching behavior of imidacloprid formulations in soil. Bulletin of Environmental Contamination and Toxicology, 68, 502-508.

Kookana, R.S., Di, H. J., Aylmore, L. A. G. 1995. A field study of leaching and degradation of nine pesticides in a sandy soil. Australian Journal of Soil Research, 33, 1019-1030.

Kreuger, J. 1998. Pesticides in stream water within an agricultural catchment in southern Sweden, 1990-1996. The Science of the Total Environment, 216, 227-251

Kreuger, J., Adielsson, S. 2006. Bekämpningsmedel letar sig ut i bäcken. Miljöforskning nr 4 September 2006. p 8-9.

Maus, C., Gaëlle, C., Schmuck, R. 2003. Safety of imidacloprid seed dressings to honey bees: a comprehensive overview and compilation of the current state of knowledge. Bulletin of Insectology 56, 51-57.

Nilsson, E. 2005. Rester av kemiska betningsmedel i tömda utsädesförpackningar. Slutrapport till Jordbruksverket.

Norberg, H. 2004. Riktvärden för växtskyddsmedel i ytvatten, beskrivning av den svenska metoden. Kemikalieinspektionen, Bekämpningsmedel och biotekniska organismer. http://www.kemi.se/upload/Bekampningsmedel/Vaxtskyddsmedel/Riktvarden_for_vaxtskyddsmedel_i_ytvatten.pdf

Olvång, H (ed.) 2002. Utsädesburna sjukdomar på jordbruksväxter. Jordbruksinformation 8-2000 2:a upplagan oktober 2002. Jordbruksverket. p 77-83.

Otte, A.J., Evers, C.H.M., 2005, Bestrijdingsmiddelenrapportage 2005, Het voorkomen van bestrijdingsmiddelen in het Nederlandse oppervlaktewater in de jaren 2001 – 2003. Eindrapport 9P4561. Royal Haskoning, 's Hertogenbosch.

Papiernik, S. K., Koskinen, W. C., Cox, L., Rice, P. J., Clay, S. A., Werdin-Pfisterer, N. R., Norberg, K. A.2006. Sorption-desorption of imidacloprid and its metabolites in soil and Vadose zone materials. Journal of Agricultural and Food Chemistry, 54, 8163-8170.

Rouchaud, J., Gustin, F., Wauters, A. 1994. Soil biodegradation and leaf transfer of insecticide imidacloprid applied in seed dressing in sugar beet crops. Bulletin of Environmental Contamination and Toxicology, 53, 344-350.

Schrap SM, Tiesnitsch J, Staeb JA. 2006. Bestrijdingsmiddelenscreening in de rijkswateren. Honderden bestrijdingsmiddelen in 2005. Lelystad, RIZA, rapport 2006.020. ISBN 9036913551.

Sundgren, A. (edt) et.al. 2005. Säker bekämpning. Natur och kultur fakta. p 160-165.

Tomlin, C. D. S (ed.). 2006. The Pesticide Manual fourteenth edition. British Crop Protection Council. UK.

Torstensson, L. 1987. Kemiska bekämpningsmedel-transport, bindning och nedbrytning i marken. Aktuellt från lantbruksuniversitetet 357 Mark Växter. ISSN 0347-9293. ISBN 91-576-2964-1. p 25-35.

Walker, C. H., Hopkin, S. P., Sibly, R. M., Peakall, D. B. 2001. Principles of Ecotoxicology, second edition. Bell & Bain Ltd, Glasgow Great Britain. p 36-39.

Personal communication

Hedström Ingrid. Växtskyddsenheten Kemikalieinspektionen, Sundbyberg. Telephone 2007-09-10, 1.50 pm.

Hellstedt Bo. Seed Production Manager at Lantmännen, Norrköping. Telephone 2007-09-28, 2.50 pm.

Karlsson, B. Findus konsumentkontakt. Telephone and e-mail 2007-11-20 10.30 am.

Internet

Danisco Seed (Maribo)
http://sockerbetor.nu/cms/connect/agri/sv/beet+growing/growers+guidelines/seed_sv.htm
2008-01-23

Hilleshög Syngenta homepage
http://www.hilleshog.se/sockerbetor/froproduktion/froprodukt_pelletering_betningar.asp
2007-09-28

Kemikalieinspektionen, Swedish Chemicals Agency homepage, bekämpningsmedel
http://www.kemi.se/templates/Page2827.aspx
2007-08-14 to 2007-12-19

Kemikalieinspektionen, 2006. Försålda kvantiteter av bekämpningsmedel 2006. ISSN 1401- 4251. Kemikalieinspektionen. Available at:
http://www.kemi.se/upload/Trycksaker/Pdf/Statistik/forsalda_bkm_2006.pdf
2008-01-11

Kemikalieinspektionen, 1997a. Imazalil. Available at:
http://apps.kemi.se/bkmregoff/Bkmblad/Imazalil.pdf
2008-01-11

Kemikalieinspektionen, 1997b Betacyflutrin. Available at:
http://apps.kemi.se/bkmregoff/Bkmblad/Betacyfl.pdf
2008-01-11

Kemikalieinspektionen, 1997c. Tolklofosmetyl. Available at:
http://apps.kemi.se/bkmregoff/Bkmblad/Tolklofo.pdf
2008-01-11
Kemikalieinspektionen, 2007d. Swedish Chemicals Agency homepage. bekämpningsme-delsregistret ämnesinformation, imazalil
http://apps.kemi.se/bkmregoff/default.cfm
2007-12-12

Kemikalieinspektionen, 2008. Swedish Chemicals Agency homepage. Riktvärden för yt-vatten, http://www.kemi.se/templates/Page.aspx?id=3294
2007-01-10

Kemikalieinspektionen, 2008. preparatinformation
http://apps.kemi.se/bkmregoff/default.cfm
2008-01-26

KIFS 1998:8 Kemikalieinspektionens författningssamling. Available at
http://www.kemi.se/upload/Forfattningar/KIFS/K98_8.pdf
2008-01-11

Lantmännen Bio Agri
http://www.bioagri.se/cerall.html
2007-12-18

Markvetenskap, vattenvårdslära homepage
http://vv.mv.slu.se/
http://vv.mv.slu.se/ShowPage.cfm?OrgenhetSida_ID=6005
2007-12-10

SESVANDERHAVE (Holly Hybrids)
http://www.hollyhybrids.com/agronomy/coating.php
2008-01-26

Appendix I M 42 (Skåne)

Table 15. Data about the findings in area M 42 during the period 2002 to 2006. Bold Figures mean that the concentration exceeds the Swedish guide line value

Date, end of sampling.	Precipitation during s. period (mm)	Substance	Concentration (µg L^{-1})	Trace value (µg L^{-1})	LOD (µg L^{-1})
28-11-2005	7.5	betacyfluthrin	0	**0.026**	0.002
06-10-2002	15	bitertanol	**0.32**	0	0.02
13-10-2002	14.1	bitertanol	0.081	0	0.02
20-10-2002	67.7	bitertanol	0.22	0	0.01
27-10-2002	47.2	bitertanol	0.046	0	0.01
03-11-2002	19.4	bitertanol	0.051	0	0.01
10-11-2002	2.3	bitertanol	0	0.025	0.01
05-07-2003	69.1	bitertanol	0	0.04	0.01
27-09-2004	26.3	bitertanol	0	0.035	0.02
04-10-2004	7.4	bitertanol	0	0.06	0.02
11-10-2004	2.3	bitertanol	0.093	0	0.01
18-10-2004	45	bitertanol	0	0.03	0.01
04-07-2005	0	bitertanol	0	0.03	0.01
08-11-2005	24.4	bitertanol	0	0.06	0.02
14-11-2005	21.5	bitertanol	0	0.06	0.02
26-07-2004	27.2	imazalil	0	0.045	0.02
30-10-2006	38.8	imazalil	0	0.115	0.03
09-06-2003	14.9	metalaxyl	0.073	0	0.01
16-06-2003	11.5	metalaxyl	0.23	0	0.01
23-06-2003	22.4	metalaxyl	0	0.075	0.05
27-06-2003	34.3	metalaxyl	0.064	0	0.02
05-07-2003	69.1	metalaxyl	0	0.05	0.03
20-07-2003	15.7	metalaxyl	0	0.03	0.01
28-07-2003	10.5	metalaxyl	0	0.03	0.01
04-08-2003	3.8	metalaxyl	0	0.03	0.01
31-05-2004	12.3	metalaxyl	0.058	0	0.01
07-06-2004	2.8	metalaxyl	0.059	0	0.01
14-06-2004	4.6	metalaxyl	0.3	0	0.01
21-06-2004	18.2	metalaxyl	0.33	0	0.01
28-06-2004	52.5	metalaxyl	0.13	0	0.01
05-07-2004	37.6	metalaxyl	0	0.045	0.03
11-10-2004	2.3	metalaxyl	0	0.035	0.02

Date, end of sampling.	Precipitation during s. period (mm)	Substance	Concentration (μg L^{-1})	Trace value (μg L^{-1})	LOD (μg L^{-1})
30-05-2005	8.7	metalaxyl	0	0.03	0.01
06-06-2005	24	metalaxyl	0.058	0	0.01
13-06-2005	14.9	metalaxyl	0	0.03	0.01
20-06-2005	12	metalaxyl	0	0.03	0.01
27-06-2005	15	metalaxyl	0.12	0	0.01
04-07-2005	0	metalaxyl	0.24	0	0.01
11-07-2005	8.8	metalaxyl	0.22	0	0.01
18-07-2005	0.3	metalaxyl	0.2	0	0.01
25-07-2005	10.4	metalaxyl	0.091	0	0.01
05-06-2006	11.5	metalaxyl	0	0.045	0.02
12-06-2006	0.8	metalaxyl	0	0.0295	0.009
20-06-2006	6.2	metalaxyl	0	0.0295	0.009
17-07-2006	0.1	metalaxyl	0	0.035	0.02
02-10-2006	15.5	metalaxyl	0	0.03	0.01
09-10-2006	19.1	metalaxyl	0	0.03	0.01

Appendix II O 18 (Västergötland)

Table 16. Data about the findings in area O 18 during the period 2002 to 2006

Date, end of sampling.	Precipitation during s. period (mm)	Substance	Concentration (µg L^{-1})	Trace value (µg L^{-1})	LOD (µg L^{-1})
23-09-2002	8	bitertanol	0	0.035	0.01
30-09-2002	0	bitertanol	0	0.035	0.01
07-10-2002	13.4	bitertanol	0	0.03	0.02
11-10-2004	21.4	bitertanol	0	0.03	0.01
20-05-2002	1.9	imazalil	0	0.4	0.2
19-07-2004	25.8	imazalil	0	0.045	0.02
03-06-2002	51.9	metalaxyl	0	0.02	0.01
07-07-2003	44.6	metalaxyl	0	0.05	0.03
10-05-2004	10.4	metalaxyl	0.078	0	0.005
17-05-2004	7	metalaxyl	0	0.0285	0.007
01-06-2004	17.5	metalaxyl	0	0.03	0.01
21-06-2004	66.3	metalaxyl	0.62	0	0.01
28-06-2004	15.8	metalaxyl	0.076	0	0.01
12-07-2004	70.3	metalaxyl	0.75	0	0.03
19-07-2004	25.8	metalaxyl	0	0.045	0.02
06-06-2005	71.2	metalaxyl	0.24	0	0.01
13-06-2005	22.4	metalaxyl	0	0.03	0.01
12-09-2005	3.7	metalaxyl	0	0.03	0.01
10-10-2005	0.9	metalaxyl	0	0.03	0.01
17-10-2005	0.9	metalaxyl	0	0.03	0.01
03-07-2006	25.1	metalaxyl	0	0.03	0.01
16-10-2006	0.2	metalaxyl	0.2	0	0.01
23-10-2006	27.7	metalaxyl	0	0.03	0.01

Appendix III N 34 (Halland)

Table 17. Data about the findings in area N 34 during the period 2002 to 2006

Date, end of sampling.	Precipitation during s. period (mm)	Substance	Concentration (µg L^{-1})	Trace value (µg L^{-1})	LOD (µg L^{-1})
27-09-2004	31.4	imazalil	0	0.065	0.03
30-10-2006	0	imazalil	0	0.115	0.03
16-05-2005	7.6	imidacloprid	0	0.17	0.04
12-06-2006	0	imidacloprid	0.4	0	0.05
17-05-2004	32.2	iprodione	0	0.035	0.01
14-06-2004	13.6	iprodione	0	0.03	0.01
21-05-2002	7.6	prochloraz	0.58	0	0.05
13-05-2002	0	metalaxyl	0	0.03	0.01
03-06-2002	28	metalaxyl	0	0.02	0.01
01-07-2002	71.4	metalaxyl	0	0.03	0.01
08-07-2002	35.6	metalaxyl	0.11	0	0.01
15-07-2002	0.2	metalaxyl	0	0.03	0.02
02-09-2002	18.8	metalaxyl	0	0.03	0.01
23-09-2002	46	metalaxyl	0	0.03	0.01
28-07-2003	12	metalaxyl	0	0.03	0.01
08-09-2003	2.8	metalaxyl	0	0.045	0.02
15-09-2003	11.2	metalaxyl	0	0.03	0.01
29-09-2003	8.6	metalaxyl	0	0.03	0.01
06-10-2003	3.4	metalaxyl	0	0.03	0.01
13-10-2003	24.8	metalaxyl	0	0.03	0.01
10-05-2004	3.8	metalaxyl	0	0.0075	0.005
21-06-2004	47.2	metalaxyl	0	0.03	0.01
28-06-2004	24	metalaxyl	0	0.03	0.01
12-07-2004	51.4	metalaxyl	0	0.045	0.03
19-07-2004	26.6	metalaxyl	0	0.045	0.02
26-07-2004	44.2	metalaxyl	0	0.045	0.02
06-09-2004	29.4	metalaxyl	0	0.035	0.02
13-09-2004	4.4	metalaxyl	0	0.03	0.01
20-09-2004	30.8	metalaxyl	0	0.03	0.01
27-09-2004	31.4	metalaxyl	0	0.03	0.01
04-10-2004	9.4	metalaxyl	0	0.03	0.01

Date, end of sampling.	Precipitation during s. period (mm)	Substance	Concentration (µg L^{-1})	Trace value (µg L^{-1})	LOD (µg L^{-1})
11-10-2004	14.2	metalaxyl	0	0.035	0.02
25-10-2004	29.6	metalaxyl	0	0.03	0.01
09-05-2005	12.2	metalaxyl	0	0.03	0.01
16-05-2005	7.6	metalaxyl	0	0.03	0.01
07-06-2005	39	metalaxyl	0	0.03	0.01
13-06-2005	20	metalaxyl	0	0.03	0.01
27-06-2005	5	metalaxyl	0	0.03	0.01
11-07-2005	0.2	metalaxyl	0.085	0	0.01
18-07-2005	8.2	metalaxyl	0	0.03	0.01
25-07-2005	105.8	metalaxyl	0.057	0	0.01
05-09-2005	1.2	metalaxyl	0	0.03	0.01
12-09-2005	1	metalaxyl	0	0.03	0.01
19-09-2005	13.2	metalaxyl	0	0.03	0.01
26-09-2005	0	metalaxyl	0	0.03	0.01
03-10-2005	30.4	metalaxyl	0	0.03	0.01
10-10-2005	2.6	metalaxyl	0	0.03	0.01
17-10-2005	0	metalaxyl	0	0.03	0.01
24-10-2005	30.8	metalaxyl	0	0.03	0.01
31-10-2005	27.8	metalaxyl	0	0.03	0.01
07-11-2005	32.4	metalaxyl	0	0.03	0.01
15-05-2006	0.2	metalaxyl	0	0.03	0.01
05-06-2006	6.8	metalaxyl	0	0.04	0.01
12-06-2006	0	metalaxyl	0	0.0295	0.009
19-06-2006	0	metalaxyl	0	0.0295	0.009
03-07-2006	12.4	metalaxyl	0.24	0	0.01
10-07-2006	0	metalaxyl	0.62	0	0.02
17-07-2006	6.6	metalaxyl	0.08	0	0.02
24-07-2006	0.8	metalaxyl	0.66	0	0.02
04-09-2006	26.4	metalaxyl	0	0.03	0.01
10-09-2006	12.8	metalaxyl	0	0.015	0.01
18-09-2006	0	metalaxyl	0	0.03	0.01
25-09-2006	2.2	metalaxyl	0	0.03	0.01
02-10-2006	27.4	metalaxyl	0	0.03	0.01
09-10-2006	54.8	metalaxyl	0	0.03	0.01
16-10-2006	0	metalaxyl	0	0.03	0.01
23-10-2006	0	metalaxyl	0	0.03	0.01
30-10-2006	0	metalaxyl	0	0.03	0.01
06-11-2006	1	metalaxyl	0	0.03	0.01

Appendix IV E 21 (Östergötland)

Table 18. Data about the findings in area E 21 during the period 2002 to 2006

Date, end of sampling.	Precipitation during s. period (mm)	Substance	Concentration (µg L^{-1})	Trace value (µg L^{-1})	LOD (µg L^{-1})
22-05-2005	2.9	imidakloprid	1	0	0.04
30-05-2005	20	imidakloprid	0.9	0	0.1
25-07-2005	55.3	imidakloprid	0	0.2	0.1
08-07-2002	10.4	metalaxyl	0.24	0	0.01
22-07-2002	25.3	metalaxyl	0	0.035	0.02
29-07-2002	9.5	metalaxyl	0.064	0	0.01
05-08-2002	1.8	metalaxyl	0.1	0	0.01
23-09-2002	6.2	metalaxyl	0	0.03	0.01
30-09-2002	3.1	metalaxyl	0	0.03	0.01
14-10-2002	9.2	metalaxyl	0	0.035	0.02
29-06-2003	34.7	metalaxyl	0.12	0	0.02
07-07-2003	49.6	metalaxyl	0.076	0	0.03
21-07-2003	4.3	metalaxyl	0.073	0	0.01
28-07-2003	18.2	metalaxyl	0	0.03	0.01
08-09-2003	0	metalaxyl	0.077	0	0.02
15-09-2003	2.6	metalaxyl	0	0.03	0.01
13-10-2003	19	metalaxyl	0	0.03	0.01
20-10-2003	2.3	metalaxyl	0	0.03	0.01
10-11-2003	1.1	metalaxyl	0	0.029	0.008
28-06-2004	15.9	metalaxyl	0	0.03	0.01
05-07-2004	6	metalaxyl	0.4	0	0.03
12-07-2004	44	metalaxyl	1.3	0	0.03
19-07-2004	24.4	metalaxyl	0.076	0	0.02
26-07-2004	11.4	metalaxyl	0	0.045	0.02
02-08-2004	12.7	metalaxyl	0.06	0	0.01
06-06-2005	51.4	metalaxyl	0	0.03	0.01
25-07-2005	55.3	metalaxyl	0.56	0	0.01
05-09-2005	0	metalaxyl	0.16	0	0.01
12-09-2005	0.8	metalaxyl	0	0.03	0.01
19-09-2005	2.6	metalaxyl	0	0.03	0.01
26-09-2005	0	metalaxyl	0	0.03	0.01
03-10-2005	18.7	metalaxyl	0	0.03	0.01
10-10-2005	0.6	metalaxyl	0	0.03	0.01
17-10-2005	0	metalaxyl	0	0.03	0.01

04-09-2006	13.1	metalaxyl	0.5	0	0.01
11-09-2006	7.9	metalaxyl	0.14	0	0.01
18-09-2006	0.6	metalaxyl	0.14	0	0.01
25-09-2006	0.6	metalaxyl	0	0.03	0.01
02-10-2006	5.7	metalaxyl	0	0.03	0.01
09-10-2006	11	metalaxyl	0	0.03	0.01
16-10-2006	0.6	metalaxyl	0.16	0	0.01
23-10-2006	38.5	metalaxyl	0.071	0	0.01
30-10-2006	66.2	metalaxyl	0	0.03	0.01

Appendix V List of other substances used (or formerly used) in seed dressing preparations in Sweden

Table 19. Swedish guide line values and Dutch MTR-values for surface water are given. F= fungicide, I= insecticide and (B) = biologic seed dressing. The list includes substances whose approval expired after 1993 (source: Kemikalieinspektionen, 2008; Otte & Evers, 2005; Schrap *et al.*, 2006)

Substance	Type	Seed dressing on	Guide line value (µg L^{-1})	MTR (µg L^{-1})	Example of seed dressing prep. Ψ
ampropylfos [1] (potassium salt)	F	cereals	-	-	Fortin 10 (2001)
carbosulfan[1]	I	oilseed, sugar beet and vegetable crops	0.01	-	Marshal 40 DB (2007)
carboxin	F	cereals	3.0	12	Cevex 300 Fungazil C Vitavax 200
difenoconazole	F	cereals	0.02	0.011	Dividend Formula M
fenfuram [1]	F	cereals	-	-	Pano-ram 37 fs (1997)
fenpiclonil [1]	F	cereals	-	5.9	Beret Combi 100 FS (2001)
fludioxonil	F	cereals and sugar-beet	-	0.98	Celest 025 FS Maxim TECH
furathiocarb	I	oilseed sugar beet and brown bean	-	-	Promet 400 CS (2003)
guazatine	F	cereals	-	-	Panoctine 30 Panoctine Plus Panoctine 400 Panoctine Aqua Aako Guazatine 350 LS
hymexazol	F	sugar- beet	-	-	Tachigaren 70 WP
isofenfos [1]	I, F	cabbage, carrot, cucumber and bean	-	-	Oftanol em (1996)
mancozeb[*]	F	potatoes and onion	0.2	6.9	Dezäta granulat (1994)
mercaptodimethur (methiocarb)	I	maize and sugar beet	-	0.016	Mesurol 500 SC
Pencycuron	F, I	potatoes	-	2.7	Monceren FS 250 Prestige FS370
Pseudomonas chlororaphis	F (B)	barley, oat and wheat	-	-	Cedomon Cerall
silthiofam	F	winter cereals	-	-	Latitude
Streptomyces griseoviridis stam K61	F (B)	green house grown vegetables, spices and ornamental plants	-	-	Mycostop

Substance	Type	Seed dressing on	Guide line value (µg L^{-1})	MTR (µg L^{-1})	Example of seed dressing prep. Ψ
tefluthrin	I	sugar beet, beet and oilseed	-	-	Force 20 CS Montur FS 190
thiabendazole[1]	F	spring cereals	-	3.3	Cevex Vår (2002)
thiamethoxam	I	sugar beet	-	-	Cruiser 600 FS Cruiser 70 WS
tolylfluanid[1]	F	apple, melon, cucumber, squash, cabbage and bean	0.2	0.5	Euparen M 50 WG (2007)
Trichoderma harzianum IMI 206040	F (B)	potatoes, grass tomatoes, cucumber strawberries, trees and shrubs	-	-	BINAB TF WP
Trichoderma polysporum IMI 206039	F (B)	Fungal diseases in potatoes, grass tomatoes, cucumber strawberries, trees and shrubs	-	-	BINAB TF WP
triticonazole	F	Fungal diseases in cereals	1.0	-	Premis 25 FS Robust

[1] Substance approval in seed dressing preparation expired
Ψ Year of ban within parenthesis
* Substance still approved, though not as a seed dressing component

Appendix VI Interview questions asked on farm visits

1) Kommer utsädet från Sverige eller utlandet, eller är det egenproducerat?
Where does the seed you use come from? From Sweden, from abroad or from your own production?

2) Är utsädet betat eller obetat?
Is the seed treated with seed dressings or not?

3) Om ja, vilket betningsmedel har använts?
If yes, which seed dressing substance has been used?

4) Var och hur länge förvaras utsädet innan sådd?
Where and for how long is seed stored before sowing?

5) Hur hanteras eventuellt spill av betat utsäde vid hantering och sådd?
What is done with any seed spilled during handling and sowing?

6) Vad händer med tömda utsädesförpackningar, hur hanteras de?
How is empty seed packaging disposed of?

7) Sår du själv eller någon anställd med egen såmaskin? Med lånad eller gemensam såmaskin? Sår någon annan; granne eller maskinstation? Vet du var, hur de fyller och rengör såmaskinen?
Do you do the sowing by yourself or is it done by an employee, with your own seed drill? Is the seed drill borrowed or shared with a neighbour or from a contractor? If yes, do you know where they fill and clean the drill?

8) Görs såmaskinen ren efter varje sådd, var (betongplatta, gårdsplan etc.) och hur (med vatten, tryckluft)?
Is the seed drill cleaned after each sowing, where (concrete platform, yard etc.) and how (water, compressed air)?

9) Sker besprutning av ogräs någon gång under de närmaste tre veckorna efter sådd? Sprutar du själv eller någon anställd med egen spruta? Med lånad eller gemensam spruta? Sprutar någon granne eller maskinstation? Vet du var de fyller och gör ren sprutan?
Is the sown crop sprayed against herbicides within three weeks after sowing? Do you spray by yourself or is it done by an employee, with your own sprayer? Is the sprayer borrowed or shared with a neighbour? If yes, do you know where they fill and clean the sprayer?

10) Har det under de senaste fem åren skett några förändringar i rutinerna för t.ex. hantering av bekämpningsmedel och rengöring av sprutan innan och efter användning som t.ex. byggande av biobädd eller uppsamlingsbrunn för spillvatten?

During the past five years, have there been any changes in your routines for handling of pesticides or cleaning of the sprayer before and after use, for example by construction of biobed or tank for collection of rinse water?

11) Har du själv (brukaren) tänkt på att betat utsäde kan utgöra en risk för spridning eller hälsa?
Have you (the farmer) considered treated seed as a potential risk of pesticide pollution or as a health risk?

Appendix VII Time collection intervals from field experiment

Table 20. Collection intervals for the analysed water samples from the field experiment. The first three samples were collected manually

Sample	Mark	Collection interval
sample blank	27/8	18:00
momentary sample	1/9	19:00
momentary sample	10/9	12:00
flow proportional sample	12/9	10/9 13:00 - 12/9 06:50
flow proportional sample	13/9	12/9 08:00 – 13/9 09:20
flow proportional sample	15/9	14/9 13:30 – 15/9 19:00
flow proportional sample	20/9	20/9 06:00 – 20/9 14:00
flow proportional sample	20/9	20/9 14:10 – 20/9 23:30
flow proportional sample	21/9	20/9 23:40 – 21/9 06:20
flow proportional sample	29/9	29/9 13:30 – 29/9 02:10

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