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SCIENTIFIC OPINION

Scientific Opinion on emissions of plant protection products from greenhouses and crops grown under cover: outline for a new guidance[1]

EFSA Panel on Plant Protection Products and their Residues (PPR)[2, 3]

European Food Safety Authority (EFSA), Parma, Italy

ABSTRACT

The European Food Safety Authority (EFSA) asked the Panel on Plant Protection Products and their Residues (PPR) to develop an inventory of protected crop systems (e.g. greenhouses and cultivations grown under cover) and emissions from these systems to relevant environmental compartments, and to provide guidance on the importance of emission routes including the circumstances under which they are relevant. Based on literature research, the Panel concludes that such systems generally do not prevent emissions and that development of an environmental risk assessment is warranted for some cases. A system for classifying the variety of protected crop systems is proposed. Water and air may carry plant protection products across the boundaries of the systems. As the systems need ventilation and in general water is supplied in excess, it is to be expected that emissions are not necessarily different from emissions in the open field. The Panel proposes as a starting point that emissions are not different. A decision scheme was then developed in order to identify for which systems emissions might be different from field crops. However, in order to complete the decision scheme, further investigation, including scenario analyses, is necessary. These analyses will be addressed in a future opinion. The Panel concludes that it is not necessary to develop new methods for soil exposure in protected crop systems as this will be sufficiently covered by current methods.

KEY WORDS

risk assessment, protected crops, covered crop, environmental fate, pesticides, glasshouse, environmental receptor

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SUMMARY

The European Food Safety Authority (EFSA) asked the Panel on Plant Protection Products and their Residues (PPR) to develop an inventory of protected crop systems (e.g. greenhouses and cultivations grown under cover) and emissions from these systems to relevant environmental compartments, and to provide guidance on the importance of emission routes including the circumstances under which they are relevant. These are important prerequisites for the process of developing risk assessment procedures which can be used in the framework of authorisation of plant protection products (PPP) for the European market. The market share of protected crop systems compared to the open field is becoming increasingly important, both in areas devoted to these systems and in the turnover of the sector. The PPR Panel found ample evidence that emissions from protected crop systems, including greenhouses, do occur, contrary to the definition of Regulation (EC) 1107/2009, so that further investigation on the necessity for additional risk assessment methodology is warranted.

Several kinds of structures are used to protect crops, from soil mulching and direct crop cover to high-tech glass/greenhouses, so the Panel started to develop a classification system. Mulching and direct crop cover are considered to have little impact on emissions of PPP to environmental receptors, so that environmental risk assessment (ERA) for open fields can be applied. For the other protected crop systems, six classes seem appropriate to adequately describe their variety: low plastic tunnels, plastic shelter, net shelter, shade house, walk-in tunnels and greenhouses. Soil-bound cultivation is predominant in protected crop culturing. Soilless growing systems are becoming more important and are already predominant in a few countries. Closed-loop irrigation is still not generally common in soilless growing systems.

An emission from a protected crop system is defined as the net transfer of a PPP over a boundary of the system. For the development of appropriate environmental risk assessment methodologies, water and air were identified as the two main carriers to be considered. The protected crop systems need ventilation to control temperature and other growing conditions in the system. In general ventilation rates will be such that PPPs will be carried to the outside once they are present in the air in the system. Water is usually applied in excess and also closed-loop irrigation systems need to discharge water in order to control salinity and other growing conditions. The excess water and any PPP dissolved in it may end up in groundwater and / or surface water.

Recognising that emissions may occur and that conditions may not necessarily differ from open fields, the Panel proposes to use risk assessment for open fields unless it is demonstrated that the emission profiles will be different. The Panel drafted a decision scheme, but recognises that further research, including scenario studies, are necessary to complete the scheme and be able to fully answer the questions. The questions should be addressed separately for each of the receptors, air, groundwater and surface water, for each of the three regulatory zones. Appropriate risk assessment methods can then be developed afterwards for protected crop systems whose emissions are predicted to be different from emissions of field crops. The Panel concludes that it is not necessary to develop new methods for soil exposure in protected crop systems as this will be sufficiently covered by current methodology.

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BACKGROUND AS PROVIDED BY EFSA

Protected crops (e.g. greenhouses and cultivations grown under cover) are specified in the Directive 91/414/EEC[4] as amended, for fields of use of both chemical and microbial products. During the review process of the substances of the second and third list, concerns were raised by Member States regarding the lack of guidance for the environmental exposure assessment for protected crops.

There is no definition that demarcates the emission of a protected crop application from the emission of a field application. Neither is there agreement on the definitions of individual protected/covered crop systems like a specific type of greenhouse. Nevertheless, several active ingredients have been listed in Annex I with reference to use in greenhouses, in one case specifying a closed hydroponic system.

A number of Member States have expressed interest in the development of a guidance document in this area in response to a consultation on Guidance Documents by the Director of Sciences from EFSA in his letter of 3 July 2006 sent *via* the Standing Committee on the Food Chain and Animal Health.

The foreseen guidance will allow a future working group to develop emission and exposure scenarios. EFSA intends to consult Member States and stakeholders to collect comments during the development of the Guidance Document.

TERMS OF REFERENCE AS PROVIDED BY EFSA

The Scientific Panel on Plant Protection Products and their Residues (PPR Panel) of EFSA has been asked to develop an inventory of protected crop systems (e.g. greenhouses and cultivations grown under cover) and emissions from these systems to relevant environmental compartments, and to provide guidance on the importance of emission routes including the circumstances under which they are relevant.

[4] Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market. OJ L 230, 19.8.1991, p. 1-32.

1. Introduction

1.1. Background to the development of the guidance

Representatives from several European Member States have expressed concern regarding the lack of guidance for the environmental exposure assessment of Plant Protection Products (PPP) used on protected crops[5] (e.g. greenhouses and cultivations grown under cover). In response to a consultation on Guidance Documents by the Director of Sciences from EFSA in a letter 3 July 2006 sent via the Standing Committee on the Food Chain and Animal Health, they indicated that they would be grateful if new guidance were developed.

Data requirements are detailed in the new Regulation (EC) 1107/2009[6] concerning the placing of PPPs on the market. 'FOCUS' (FOrum for the Co-ordination of pesticide fate models and their USe) developed guidance at the EU level for exposure assessment of plant protection products in soil, surface water and groundwater (FOCUS 1995, 1997, 1997, 2000, 2001, 2006, 2008), including approaches for estimating Predicted Environmental Concentrations (PECs) in scenarios for numerical models. However, these data and scenarios (and sometimes also the models) were primarily developed to apply to open field conditions. In view of ongoing discussions in PRAPeR expert groups for the authorisation of new active substances and the revision of existing substances, there is a need at the EU level to know if FOCUS and other guidance can also be applied to protected crop conditions, i.e. to know whether the available data, scenarios and models sufficiently cover conditions occurring under protected crop conditions. If not, it would be helpful to generate risk assessment schemes to allow consistent assessment whether the PPP is applied in the open field or in a protected situation.

Therefore the PPR Panel has started to review existing knowledge on the fate of PPPs in protected crops in order to allow a future working group to develop emission and exposure scenarios for such systems. This preliminary activity will be addressed in a series of EFSA documents and will provide an overview/inventory of covered cropping systems, in order to:

1. Identify and describe system characteristics that are required to classify protected crop systems.

2. Identify potential emission routes and the relevance of these for the classes of covered production systems (and under which conditions they occur).

3. Provide the relevant information so as to enable the ranking of emissions, which can serve for the development of exposure scenarios and risk assessment schemes for protected cropping systems in a subsequent Working Group (WG).

4. Identify environmentally relevant data on land use intensity for the given types of protected cropping.

5. Enable competent authorities to decide what classifications have practical use with respect to inclusion of pesticides in Annex I (Directive 91/414/EEC) and national authorisations.

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[5] The word 'protection' is often used to refer to physical barriers (i.e. plastic, glass or netting) or to refer to chemical / biological products that are applied to the crop (e.g. pesticides or plant growth regulators). Since this term could be ambiguous, we have chosen to use the term 'PPP' to refer to products (Plant Protection Products) throughout this Opinion. When the word 'protection' or 'protected' appears, it refers to the physical barriers.

[6] Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing council directives 79/117/EEC and 91/414/EEC. OJ L 309, 24.11.2009, p. 1–50.

The Panel developed an initial Project Plan, which was finalised after a public consultation with experts and stakeholders (EFSA 2009a; EFSA 2010a). The Panel decided to produce several opinions and technical reports on data collection[7] (EFSA 2010b; Sas-Paszt 2010; Sigrimis 2010). The aim of this Opinion is to cover point 1, and to some extent points 2 and 3 as listed above.

1.2. The rationale for an Environmental Risk Assessment scheme in the regulatory process

Protected crops were specified in the Directive 91/414/EEC, as amended, for fields of use of both chemical and microbial products. There was no definition that demarcated the emission of a protected crop application from the emission of a field application, neither was there agreement on the definitions of individual protected/covered crop systems such as a specific type of greenhouse. However, the Directive has been replaced by Regulation (EC) 1107/2009. In this Regulation, products can be authorised for use in a greenhouse and Article 3 defines a greenhouse as follows:

> " 'greenhouse' means a walk-in, static, closed place of crop production with a usually translucent outer shell, which allows controlled exchange of material and energy with the surroundings and prevents release of plant protection products into the environment.
>
> For the purpose of this Regulation, closed places of plant production where the outer shell is not translucent (for example, for production of mushrooms or witloof) are also considered as greenhouses;"

It is the opinion of the Panel that this definition of greenhouse clearly contains a misconception in the sense that such structures may <u>not prevent release</u> of PPPs into the environment.

During the peer review process of the substances on the second and third lists, several active substances (a.s.) have been evaluated with reference to use on protected crops: considering the 136 EFSA conclusions published on the EFSA website (update 6th of August 2009), the representative uses of 45 a.s. (33 %) included a greenhouse application or indoor application, and for 11 substances (8 %) the greenhouse application or indoor use was the only use applied for by the applicant. The general pattern for exposure assessments provided by applicants was as follows:

- Air: There was a data requirement under Directive 91/414/EEC to provide Predicted Environmental Concentrations (PECs) in air. However, no guidance on calculation was available until October 2008, when the final report of the FOCUS Working Group on Pesticides in Air was noted (FOCUS, 2008). In the absence of guidance, *expert judgment* was used in the exposure assessment for the air compartment, based on the vapour pressure of the a.s., volatilization studies and estimated atmospheric half-life.

- Soil: The PECsoil for which a "greenhouse application" was the unique representative use applied for, were estimated on a case by case basis, as the Directive does not give any guidance on how to proceed with the calculations. Generally, for PECsoil the same approach was followed as is used for field applications.

- Surface Water: The PECsw for the a.s. for which a "greenhouse application" was the unique representative use applied for, were estimated on a case by case basis, as the Directive does not give any guidance on how to proceed with the calculations. Generally, for PECsw the "Dutch

[7] EFSA 2010b covers the Coding Manual for designing the data collection for whole EU27. Sas-Paszt 2010 and Sigrimis 2010 cover the results of the data collection for Eastern and Southern Europe, respectively. Data collection for Northern Europe is forthcoming as EFSA report.

model" was used. The Dutch model assumes that 0.1% (areic mass%) of the application rate is deposited on surface water[8] (Linders and Jager (eds), 1997).

- Groundwater: The PECgw for the a.s. for which a "greenhouse application" was the unique representative use applied for, was not harmonized and was based on different approaches (e.g. FOCUS GW leaching models with FOCUS GW scenarios for fields, or with a scenario adapted for the protected crop system[9]).

In the context of the current regulation, it is important that risk managers know that emissions of PPP may still occur even when protective structures are in place. They will need to know when field conditions differ significantly from protected crop cultivation, and they will need to know how to evaluate the various management options available to reduce the impact of PPP. This knowledge needs to be based on realistic scenarios covering Europe as a whole.

1.3. Protected crops in Europe

The extent of protected cultivation is increasing worldwide and is presently estimated at more than three million hectares (Sonneveld and Voogt, 2009). The increase is taking place particularly in otherwise marginal agricultural land, thanks to relatively high returns coupled to high efficiency of use of resources. It is a fact that conversion of land from open field cultivation to protected cultivation enormously increases the output and earnings per unit soil surface. The example of Almeria (SE Spain; Figure 1) with approximately 27,000 hectares (Castilla and Hernàndez, 2005) of plastic greenhouses is notable. Protected crop cultivation has been responsible for the astonishing economic growth of this province over the last 20 years (Pardossi et al., 2004; Caja Rural Intermediterránea, 2005). The main driving factors may be an increasing international demand for high-quality horticultural products (including out-of-season vegetables and ornamental products) coupled to improved transportation and post-harvest storage that has allowed the production in regions far from the main markets.

Reliable statistics for the amounts of protected crop cultivation in Europe are quite difficult to find, since this agricultural sector is fairly dynamic; for instance, in the same regions the use of temporary structures such as low tunnels and walk-in tunnels may change noticeably from year to year depending on market demand.

According to EUROSTAT (http://epp.eurostat.ec.europa.eu), about 136,000 hectares were grown under cover in 2007 in Europe (excluding France). Other sources indicate that the area cultivated in France was about 11,400 ha in 2005 (Sas-Paszt 2010; Sigrimis 2010). Thus the area devoted to protected crop cultivation in European Community MS is roughly 150,000 ha. The countries with the highest areas under protected cultivation are: Spain (66,000 ha); Italy (34,600 ha); France (11,400 ha); the Netherlands (10,200 ha); Poland (6,300 ha); and Greece (4,900 ha). Protected crop cultivation is mostly based on plastic tunnels and greenhouses except in the Netherlands where glasshouse[10] production is most common.

Therefore, protected crop cultivation is a small fraction of the total cultivated land but, as a capital-, labour- and (often) energy-intensive cropping system, it may play an important role in the local economy (e.g. in the provinces of Almeria - Spain and Ragusa - Italy) or even the national economy. For instance, in the Netherlands, glasshouse cultivation covers less than 1% of agricultural land but accounts for 40% of the annual gross income from agriculture with annual crop revenue as high as

[8] If the application rate is 1 kg/ha (100 mg/m^2) then the deposition on surface water is assumed to be 0.1 mg/m^2.
[9] Personal communication EFSA PRAPeR
[10] The term glasshouse refers to a greenhouse covered with glass, see section 2.2.

600,000 €/ha (Stanghellini and Van Os, 2005). Protected crops are generally concentrated in relatively small areas (Figure 1) close to urban areas (e.g. Westland, the Netherlands; Albenga, Italy) with evident implications from the environmental point of view (Figure 2).

Figure 1: Plastic greenhouses (all white area) in the plain of Campo de Dalia, to the West of the city of Almeria (SE Spain). Images: courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov) ISS008-E-14686, inset: ISS004-E-13199.

Figure 2: Left: glasshouses fully surrounding the town of Naaldwijk, in the Dutch Westland (Photo: Wageningen UR Greenhouse Horticulture). Right, plastic greenhouses located in Carchuna, Costa tropical in Granada (Spain) mixed with residential areas. (Photo: José Antonio Jiménez, Van Pary Media)

Particularly in the Mediterranean countries, the production technology is currently undergoing a modernisation process in order to face the increasing competition arising from globalisation of both production and marketing. Moreover, the increase in the awareness of environmental pollution provoked by agriculture, the demand for healthy foods and the shortage of resources like water are pushing the growers towards the application of more sustainable growing techniques. For instance, in Almeria greenhouses, the area using biological agents for pest control has increased from 3% in 2006 to 28% in 2007 (Bielza et al., 2008).

1.4. Pesticide fate in protected crops

Greenhouse production is often perceived as an artificial process where PPP release into the environment is controlled, contrary to field conditions. Setting aside these perceptions of the two cultivation systems, for a pesticide risk assessment it is necessary to quantify the impacts on the environment. The possible environmental effects of pesticide use in protected crop systems have received very little attention so far. The lack of such assessment may be due to the peculiarity of the cultivations, none of them being a widely grown crop according to Regulation (EC) 1107/2009, and limited to specific regions of the European Union.

The goal of covering crops is to modify the agroclimatic conditions compared to the open field. These modifications may have an influence on the fate of PPPs. For instance the dissipation of PPPs is known to depend on temperature, light intensity and rain fall. In addition to the reduction of light intensity also the light energy, i.e. the wavelength spectrum of the light, within the system may be different to that in the open field. Glass is partly transparent for UV light and most plastics used for greenhouse covers are even less transparent than glass. Compared to natural sunlight in the field, photolytic degradation of volatile pesticides may be reduced in protected crop systems. The same is true for photolysis of pesticides adsorbed to soil and plant surfaces. These processes may affect the persistence of the PPP in the system and residues in crops.

Emission of a PPP from a protected crop system is defined as the net transfer of a PPP over a boundary of the system. By analogy to the field crop, the edge of the protected crop distinguishes between the in-crop and the off-crop area. Of course with different types of structures, the ratio between the in-crop and off-crop area could change but the boundaries are represented by the walls and ceiling and a hypothetical plane located at 1 m depth in the soil (Figure 3). In analogy to the distinction in the open field, for protected crops the PPR Panel defines in-crop as the protected area where a crop is grown. Off-crop is defined as the area outside the edges of the protected area where the crop is grown.

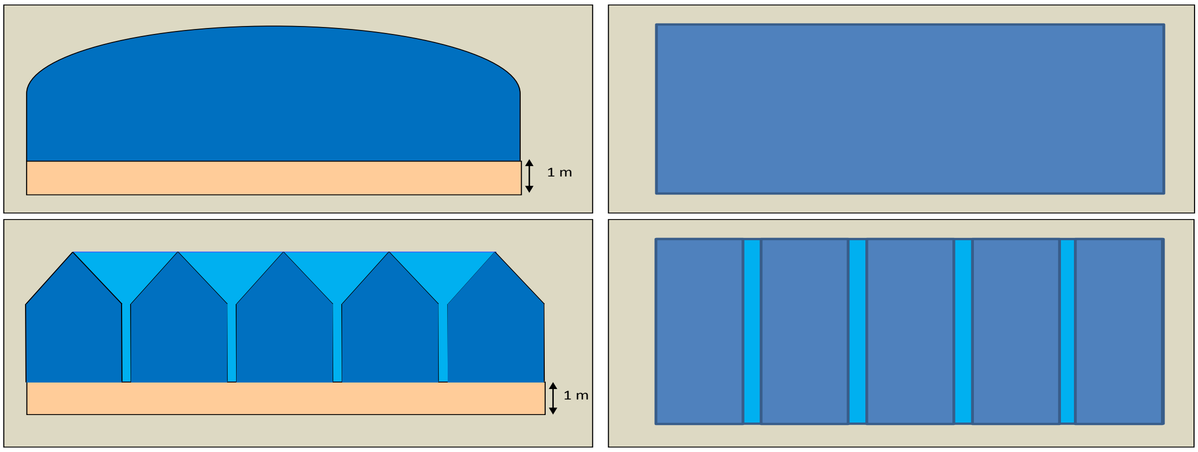

Figure 3: Off-crop (brown) is defined as the area outside the edges of the protected crop structure(s); in-crop (blue and orange) is everything inside the structure including soil down to 1 m depth. Graphs on the left show a side view; on the right a view from the top. The graph on the upper left represents glasshouse, greenhouse, shading house; on the lower left, the dark blue area represents the real structure (plastic shelter, net shelter, low tunnel and walk-in tunnel) whereas the area between the structures (light blue) is also considered in-crop. The same is illustrated in the graphs on the right as a view from the top.

The application can be made using different techniques that depend on the pest to be controlled, timing of the application and formulation type. During and after the application, a fraction of the dosage will not reach the target and will be lost from the protected crop system to the atmosphere, to surface water and / or to the groundwater, through processes common to the open-field conditions such as the spray drift, volatilization, leaching, drainage and run-off (Figure 4). These emissions may lead to undesirable effects in ecosystems. After deposition on the target area, a fraction of this applied mass may be transformed into degradation products that must also be fully considered in the risk assessment procedure (see criteria of the new Regulation (EC) 1107/2009).

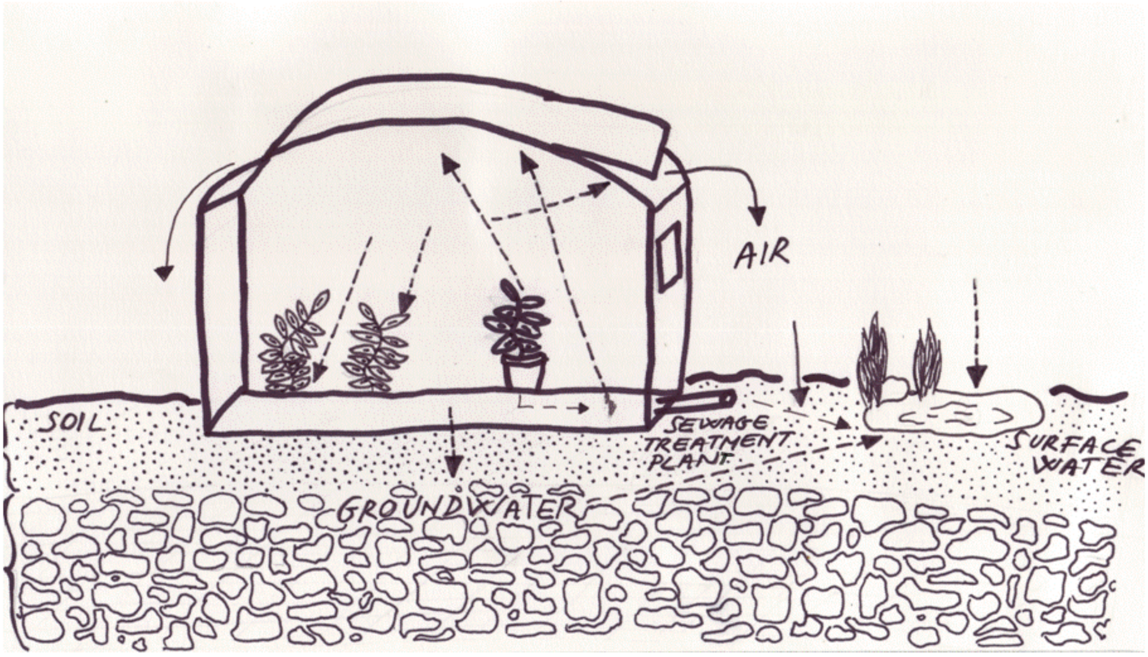

Figure 4: Pesticide point and non-point source terms and receptors with an indication of main routes (arrows) such as the drift, atmospheric deposition, drainage, crop wash-off, volatilization, run-off and discharge.

1.5. Literature review on environmental impact of protected crops

An extensive literature research was performed in order to get a systematic overview of available literature regarding fate of pesticides in protected crop growing systems. The literature search was performed in the database “Web of Knowledge” (including sub-databases Web of Science, Current Contents Connect, CAB Abstracts, Food Science and Technology Abstracts). Articles available in English were selected and included in the database without any restriction on the year of publication.

The search was performed on 20/01/2009 using the following profile of search terms:

Topic=(greenhouse or protected crops or glasshouse or covered crops)
AND
Topic=(pesticide or biocide or plant protection product)
AND
Topic=(emission routes or fate or drainage or volatilization or drift or leaching or "gas emission" or "water emission" or waste or dissipation or model)
NOT
Topic=("global warming" or "greenhouse effect" or "greenhouse gases")

The search with the above-mentioned conditions yielded 314 hits, and for each the title and (where available) abstracts were scrutinized. Only those papers addressing emissions of pesticides from protected crops and related areas were considered further. Papers dealing exclusively with topics as e.g. residues in and on crops grown in protected structures, degradation of PPPs in the crop and papers on effects on humans not including data on exposure, were excluded and not considered further. The main areas covered and of relevance to this WG were dissipation in greenhouse soil, volatilization under greenhouse conditions, and deposition patterns in greenhouses. The same search was repeated on 26/01/2010 in order to cover new information published during 2009 yielding 31 hits from 2009 and 2010. In total 54 papers were selected by the WG based on the above criteria (see appendix A). The 54 articles were each summarized by two WG members following a common approach (Figure 5) and are included as background information for the activity of the WG highlighting the relationship between the agronomic management conceived as driving source, the routes of exposure and the receiving receptors.

In addition to the papers found in the literature search, grey literature was used, including e.g. reports from national authorities, research projects and conference proceedings, also in other languages than English. The grey literature was identified based on citations in scientific literature and/or was proposed in the comments received during the public consultation.

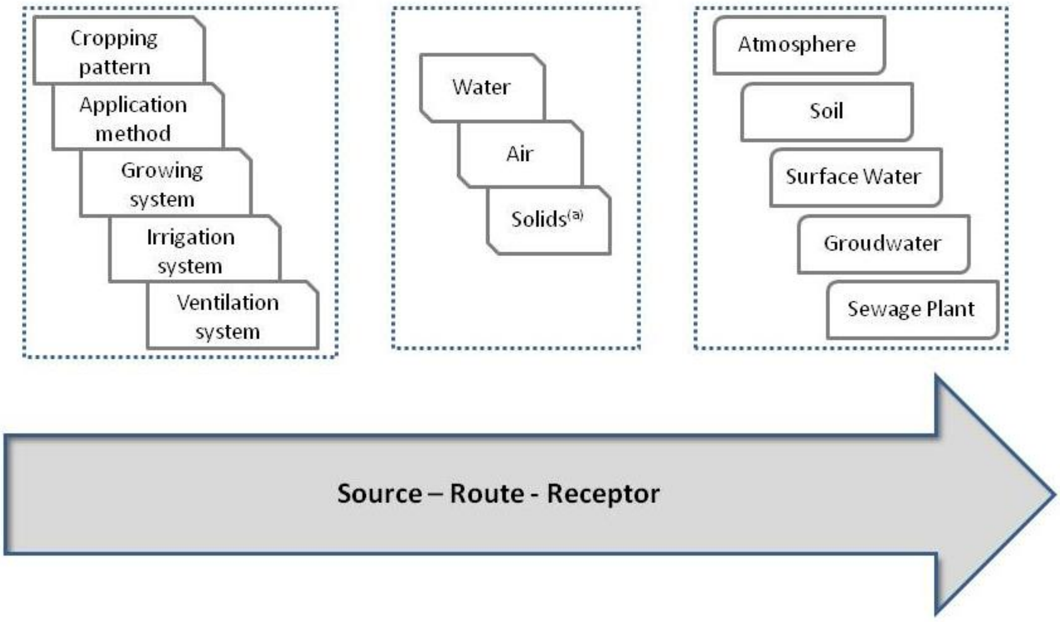

Figure 5: Diagram showing the flow of information used in the literature search.
[(a)] Solids, i.e. plant material and soil or substrate, removed from the protection structure.

Although many studies have been conducted, mainly in Northern Europe, the environmental fate of pesticides in protected cropping presents many contradictions and still remains poorly understood because there are a lot of variables that are impossible to control in a single study. Publication of papers concerning the effects of management practices on pesticide fate in soil, water and air started slowly during the 1980s but increased rapidly during the 1990s.

The papers that were useful to the WG were classified as follows: 22 papers on PPP in air; 21 papers on PPP in soil / substrate; 5 papers dealing with PPP deposition patterns; together with 6 on analytical methods. Eight papers were published in proceedings from conferences, 15 in journals of agronomic sciences and most of the rest in journals of environmental sciences.

Most of the studies were carried out to investigate the processes of indoor air contamination as a source of exposure for the operator, and for assessing dissipation in soil. Modelling has received attention and several authors have proposed different approaches based on Life Cycle Assessment, fugacity and deterministic models.

For processes such as leaching to drains, groundwater or surface water, in a broad sense the literature search showed the high relevance of the type of structure and the agronomic management in determining the pesticide fate. The application method and the application rate of the pesticide are driving factors for soil loading. Wash-off and the irrigation system do not seem to have much influence. Driving forces for transport through the soil profile are the water management (timing of irrigation, net excess of water and water recirculation), the growing media material (soil, perlite, etc.) together with the soil (sorption, hydrology) and the pesticide properties (uptake, degradation and sorption) (Van Os et al., 1994; Gonzales-Pradas et al., 2002; Börjesson et al., 2003; Fang et al., 2006).

Pesticide properties such as the vapour pressure and the degradation in air are the most important factors influencing air pollution within the structure. The driving force for transport from the indoor to outdoor conditions are the environmental parameters (temperature and irradiation), the management of the pesticide distribution (i.e. application method and rate) as well as the management of the protection structure (air exchange) (Brouwer et al., 1992; Siebers and Mattusch, 1996; Van den Berg et al., 1999).

Some papers report computer simulation of the pesticide fate in protected crop conditions. They focus mainly on model building (Garratt and Wilkins, 2004), emission throughout the drainage water (Leistra et al., 1984b), leaching (Garratt et al., 2007), and air dissipation and emissions (Guth et al., 2004).

Monitoring studies have also been carried out in order to address the question of pesticide exposure, with many findings being positive. So far pesticides have been detected in water bodies in very different hydrogeologic conditions of the protected crop regions, for example in Finland, Spain and Italy (Glass et al., 2002), Sweden (Kreuger et al., 2010), the Netherlands (e.g. Teunissen, 2005; Van der Wal et al., 2007) and in Turkey (Tuncel et al., 2008). Such studies have helped to provide information on the conditions under which pesticide transport is most likely such as in very vulnerable soils due to the presence of shallow groundwater or with a vadose zone characterised by fractured and karstic rocks or in the case of high hydraulic connectivity to surface water. Furthermore there is evidence that contamination is most severe when the area covered by protected crop structures is very high per unit of area. It is most likely that point contamination of the surface water occurs due to inappropriate management practices such as the discharge of exhausted irrigation water (Leistra et al., 1984a, 1984b).

Pesticides have been detected in the atmosphere surrounding greenhouse areas of Europe, showing a potential exposure of bystanders and resident population. The conditions under which residents and bystanders are exposed to pesticides vary widely and influence the degree of exposure (EFSA 2010c). An attempt was made to assess exposure by air of a population living in the vicinity of greenhouse areas in the Netherlands where more than 20 pesticides were used (Leistra et al., 2001).

In summary:

- The aim of this opinion is to identify and describe system characteristics useful to discriminate between the systems themselves and between open-field and protected crops.
- Protected crops cover a small fraction of total cultivated land in the EU, but they may play an important role for the regional or national economy.
- Protected crops are often concentrated in relatively small areas (sometimes near urban areas) with potential repercussion on the environment.
- Protected crops allow for an increasing use of non-chemical pest control (e.g. biological pest control).
- In the literature, examples show the relevance of protected cropping in being a source of contamination of air, water and soil, but the environmental fate of pesticides under protected cropping still remains poorly understood.

2. Protection structures and growing systems

2.1. Introduction

The broad term 'crop protection' refers to any activity to protect crop plants against biotic and/or abiotic stress using physical, chemical or biological means. This Opinion has its focus on the physical means of climatic control aimed at: i) eliminating the effects of meteorological events such as rain, hail and snow; ii) alleviating the severity of environmental stress, such as low temperature (e.g. freezing, chilling or just sub-optimal temperature), heat, excessive or poor irradiance, in particular regions and/or seasons; iii) modifying one or more environmental parameters (e.g. temperature, carbon dioxide concentration, light intensity etc. – see Figure 6) to enhance crop growth and yield or to manipulate crop development (for instance, to induce the flowering of photoperiodic plants by means of day-length extension or reduction). **Hereafter, protected crops are defined as cultivations carried out under any kind of permanent or temporary shelter covering the entire crop with the aim of enhancing its productivity.** This definition is substantially different from the one reported for *greenhouse* by Regulation (EC) 1107/2009 as previously quoted (see section 1.2).

Figure 6: Cultivation of roses in artificial substrate in a heated greenhouse (glasshouse) with artificial lighting in the Netherlands. A clear example of how the growing conditions can be modified and controlled in greenhouses (Photo: Fernando Malorgio).

Typically, the protected crop industry grows horticultural species, both herbaceous and woody, most of which are warm-season crops: leaf and fruit vegetables, cut flowers, pot ornamentals and a few fruit crops, such as strawberry, table grape, banana, peach (nectarine) etc. This is the reason why, very often, 'protected horticulture' is a synonym of greenhouse/protected crops.

2.2. Protection structures

Various kinds of structures are currently used for protected crops, including soil mulching with plastic or organic (e.g. straw) material or direct crop cover with non-woven fabric.

A technical classification is proposed for protected crop systems by taking into consideration the nature of the emission routes for PPPs (EFSA 2010b). The classification considers the structure (frame and covering) as well as the growing system, in particular the possibility to grow plants in media other than soil (soilless culture) and to recycle drainage water (from both soil-bound and soilless culture) in what are named "closed-loop systems". Protection structures may be categorized also considering the accessibility for the workers (i.e. low, inaccessible tunnels or accessible structures such as large tunnels and greenhouses) and whether they are permanent or temporary. The permeability of the covering material is another relevant criterion in regard to PPP emissions.

Based on these criteria, many kinds of protection structures can be identified (Figure 7); however, the main categories considered in this Opinion are low plastic tunnels, (high) plastic shelters or shade houses, walk-in tunnels and greenhouses (Table 1).

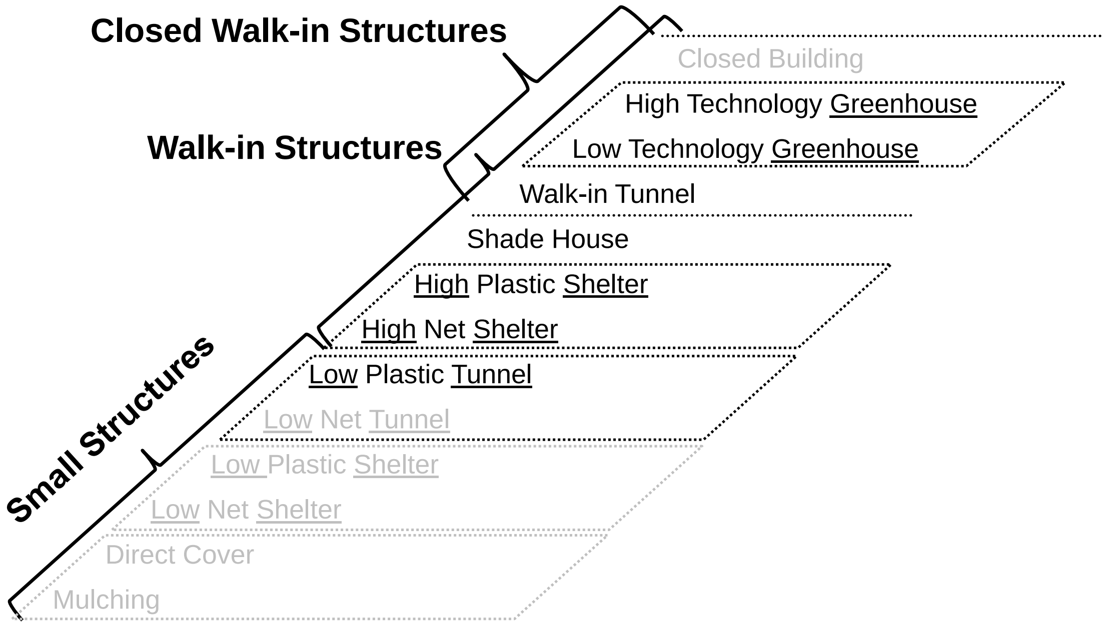

Figure 7: Main categories of protection structures (from EFSA 2010b). Small structures are not accessible to the workers, and are generally temporary. Walk-in structures are large enough to work in the structure and may be closed at all sides with water-proof screens. Small structures and closed buildings with a non-translucent outer shell which are not explicitly addressed in this Opinion are shown in grey. The main structures focused on in this Opinion are shown in black.

Table 1: Classification criteria and main categories of protection structures.

	Accessibility [a]	Temporary structure	Permeable cover [b]
Low plastic tunnel	No	Yes	No
(High) Plastic shelter	Yes	Yes	No
(High) Net shelter	Yes	Yes/No	Yes (net)
Shade house	Yes	Yes/No	Yes (net)
Walk-in tunnel	Yes	Yes	No
Greenhouse	Yes	No	No

(a): accessibility for operators
(b): permeable to water

The cultivations under tunnels and greenhouses are included in the current definition of 'indoor' PPP use (FOCUS, 2008) along with closed buildings, such as storehouses and the growth cabinets employed for growing witloof and mushrooms or for *in vitro* culture. In the latter cases, the system consists of a non-translucent outer shell and a concrete floor, thus matching the definition of greenhouses reported by Regulation (EC) 1107/2009.

Soil mulching and direct cover, if not used for cultivations under tunnel and greenhouse, have not been considered as protected structures in the sense of this Opinion. Non-translucent growth cabinets were also left out since the in-out flow of air and water is much more controlled compared to the typical tunnels and greenhouses.

2.2.1. Low (mini) tunnel

This is a simple plastic cover generally associated with mulching (Figure 8). It is a temporary cover, in that it is removed some weeks well before the harvest.

Figure 8: Examples of low tunnels (photo: Alberto Pardossi).

2.2.2. Plastic shelter

A plastic shelter is generally used for fruit crops, such as table grape and strawberry (Figure 9), in order to protect them against cold or rain and to extend the harvest period. In some cases, the cover is discontinuous, that is the shelter is placed only above the crop row (Figure 9, right).

Figure 9: Plastic shelters used for table grape in Italy (left) or soilless-grown strawberry in Poland (right, photo: Lidia Sas-Paszt).

2.2.3. Net shelter and shade house

A net shelter is used to protect vegetable (Figure 10, left) or ornamental crops from excessive heat and/or light, wind, insects and birds; it may have the shape of a tunnel or small greenhouse, the only difference consisting of a permeable cover fabric. A shade house is a shading net in the shape of a tunnel or small greenhouse; it is generally used for ornamental crops (Figure 10, right).

Figure 10: Net shelter (left, photo: Franco Tognoni, UNIPI) for vegetable cultivation in the Canary Islands (Spain) and shade house for pot ornamentals in Italy (right, photo: Alberto Pardossi)

2.2.4. Walk-in tunnel

A Walk-in tunnel is an unheated structure used for growing plants (Figure 11). It usually consists of a single layer of plastic supported by plastic or metal arches or hoops. These structures are large enough to walk and work inside, and generally they are temporary, in that they or their coverings are generally removed at the end of cultivation.


Figure 11: Walk-in tunnels for soil (left) or soilless (right) cultivation of strawberry (photos: Alberto Pardossi).

2.2.5. Greenhouse

A greenhouse is defined as a walk-in, static, closed place for crop production with a transparent outer shell. Greenhouses can be classified according to the geometry (e.g. single span or multi-span) and the material used for the frame (wood, aluminium, steel, or a combination of them) and the shell (plastic, both rigid pans and films; glass). These structures range in size from small sheds to very large buildings. For example, newly built glasshouses in the Netherlands may have a cultivation area of up to 10 ha, with an average height of 8 m.

Following Pardossi et al. (2004), both low- and high technology greenhouses can be identified (Figure 12, Figure 13); they are briefly described in the Text-Box 1.


Figure 12: Examples of low-tech plastic greenhouse: the traditional low-cost ‘parral’ (left) and the more innovative pre-fabricated arch-shaped multi-tunnel (right) (photos: Alberto Pardossi).

Figure 13: Examples of high-tech greenhouses in Italy (left, photo: Alberto Pardossi) and in the Netherlands (right, photo: Wageningen UR Greenhouse Horticulture).

Text-Box 1: Classification of greenhouses according to the technological level.

- **Low-technology greenhouses** *(Figure 12). They have a very simple structure, with plastic covering and poor climate control; very often, they lack a heating system. Vegetables and low-value cut flowers are grown under this kind of shelter.*

- **High technology greenhouses** *(Figure 6 and 13). They have a metal structure, are covered by plastic (also rigid pans) or glass (obviously, the term 'glasshouse' refers to this kind of structure) and have an automatic climate control, which may include root zone heating, forced ventilation, evaporative cooling, light conditioning (shading and/or artificial lighting) and carbon dioxide enrichment. Soilless growing systems are often installed to maximise space-use efficiency and minimise hand labour. They are generally employed for high-value crops, such as out-of-season vegetables, cut flowers (e.g. roses), pot ornamentals and propagation materials (seedlings, cuttings, ex vitro plantlets, etc.).*

2.3. Growing systems

2.3.1. Growing media

Soil-bound cultivation is predominant, in terms of hectarage, in protected crop cultivation in the EU. On the other hand, the use of soilless growing systems in the protected crops sector is increasing (Pardossi et al., 2006), especially in Southern countries (e.g. in Spain; Castilla and Hernàndez, 2005; Gallardo et al., 2009). Soilless growing system (synonyms are hydroponics and hydroculture) is a wide term that includes all techniques for cultivating plants without soil in artificial substrates (aggregate culture) or with bare roots in aerated nutrient solution (liquid or water culture) (Pardossi et al., 2006).

Aggregate (substrate) culture is the most widely used method for growing fruit vegetables (e.g. tomato, pepper, eggplant, cucumber, melon and zucchini), strawberry and cut flowers (e.g. rose, gerbera, chrysanthemum, anthurium and bulbs). In aggregate culture, the plants are grown in containers of different shapes and dimensions (banquette, pots, bags, slabs) filled with substrate and fed with a nutrient solution by means of drip irrigation or subirrigation (Figure 14). Both open- and closed-loop systems may be set up for aggregate culture.

Figure 14: Aggregate growing systems in a plastic greenhouse (Spain) and in a glasshouse (the Netherlands) (photos: Alberto Pardossi).

The most used water culture techniques for commercial production are the nutrient film technique (NFT), floating raft system and aeroponics, which all are closed-loop systems. The application of NFT and aeroponics is limited compared to floating systems.

In floating systems, the plants are grown in styrofoam trays ("rafts") placed in a pool filled with nutrient solution to a depth of 10-30 cm. The nutrient solution is stagnant or fairly static, with slow recirculation through a nutrient reservoir where it is aerated, checked and adjusted for pH and electrical conductivity, and possibly disinfected. The system is mostly used for leafy vegetables, herbs, bulb flowers like tulips and tobacco transplants (Figure 15).

Figure 15: Floating growing systems for the production of tulip (left) or basil (right) (photos: Alberto Pardossi).

In NFT, a thin film of nutrient solution flows continuously or intermittently through light-insulated plastic gullies that gently slope and contain the plant roots. There are many variations of NFT, depending on the type and the size of growing gullies (Figure 16, left). Aeroponics is another type of water culture where the plants are cultivated in holed plastic panels with the roots suspended in air beneath the panel and frequently sprayed with a fine mist of nutrient solution (Figure 16, right).

Figure 16: Examples of NFT (tomato, on the left, photo: Fernando Malorgio) and aeroponics (lettuce, on the right, photo: Alberto Pardossi).

2.3.2. Irrigation systems

In this Opinion, two main schemes for irrigation system have been distinguished:

1) open-loop systems: the water leaching from the soil or draining from the substrate (in soilless culture) is not recovered and re-used. The drainage fraction (i.e., the ratio between supply and drainage water) in a well-managed system will be around 0.20 to 0.30 (Pardossi et al., 2006; Gallardo et al., 2009).

2) closed-loop systems: the drainage water is captured and reused after nutrient replenishment and, possibly, disinfection (by heat, UV light, slow sand filtration, etc.) in order to minimize the risks of root borne diseases. Closed-loop irrigation is generally applied to soilless growing systems, although this is not a common practice in many countries apart from the Netherlands, where closed systems are compulsory, with a few exceptions. At intervals, the recycling water is discharged at least partially to surface water, sewage treatment plants, and, rarely, to surrounding fields, and replaced by newly-prepared nutrient solution. So the term 'semi-closed loop' would perhaps be more appropriate. The frequency of nutrient solution discharge generally depends on the salinity of the irrigation water and the crop tolerance to salt stress. In some cases, the nutrient solution is discharged every 5-10 days and the drainage fraction might be the same as in a well-managed open system (Carmassi et al., 2007).

2.3.3. Interactions between growing media and irrigation systems

The possible interrelationships between the main types of constructions and the growing systems are illustrated in Table 2.

Table 2: Interrelationships between protection structures and growing systems.

Protection structure	Main crops[(a)]	Growing system[(b)]			
		Soil with water drainage recycling	Soilless with water drainage recycling	Soil without water drainage recycling	Soilless without water drainage recycling
Low plastic tunnel	C-LVG, C-FVG, C-FR			X	
(High) plastic shelter	C-LVG, C-FVG, C-FR			X	X
(High) net shelter	C-LVG, C-FVG, C-FR			X	
Shade house	C-PO			X	
Walk-in tunnel	C-LVG, C-FVG, C-FR			X	X
Greenhouse	C-LVG, C-FVG, C-CF, C-PO, C-PM	X	X	X	X

(a): C-LVG, leafy vegetables; C-FVG, fruit vegetables; C-CF, cut flowers; C-FR, fruit crops (e.g. strawberry, table grape, peach); C-PO, pot ornamentals; C-PM, propagation materials (e.g. seedlings, cuttings, ex vitro plantlets)
(b): Colour code: dark grey = frequent; light grey = not frequent; white = rare or absent.

In summary:

- Many kinds of structures are used to protect crop plants, from soil mulching and direct crop cover to high-tech glass/greenhouse; however only low plastic tunnels, walk-in tunnels and shelters and greenhouses have been considered in this Opinion.
- Soil-bound cultivation is predominant in protected horticulture; although soilless growing systems are predominant in a few countries.
- Closed-loop irrigation is not generally applied to soilless growing systems, apart from The Netherlands where this irrigation scheme is compulsory.
- Closed-loop irrigation systems generally are not emission-free since, more or less frequently, the recycling water has to be discharged.

3. Emission routes

3.1. Introduction

In the previous sections the variety of protective structures across Europe as well as the connected growing systems were presented. As it would not be feasible to quantify the potential risk of any possible emission route for this vast number of systems identified, a higher level of abstraction is needed. The purpose of this section is to describe the general processes that may determine or affect emissions from protected crops, whatever their shape and whatever the application method of the product (see Text-Box 2).

All plant protection products, before ending up in any of the environmental receptors (soil, water, air), must cross the boundaries of the protected cultivation, see Figure 3 for the definition of the boundaries. To do so, they may be carried either by air that is exchanged or by water that percolates below the 1 m deep boundary plane or is drained into surface water or a sewage system. There is a third potential "carrier" which is the solids that are removed from the greenhouse. The non-organic solids (e.g. plastic covers and substrates) are disposed or recycled in waste treatment plants (Directive 2006/12/EC[11]). There is no fundamental difference between protected crops and field crops with respect to the fate of the biomass, therefore this emission route is not addressed in this opinion. However, contaminated biomass used for composting, fermentation, or as organic fertilisers, may end up on the soil and this route should be addressed separately in relation to residues shortly after the application.

In the following we describe the factors that determine the size of the "carrier" flow out of the protective system, and attempt an initial analysis of the conditions which would ensure the emission to be either certainly equal to or certainly different from the emission that could be expected for a field crop under similar conditions.

Text-Box 2: *Application techniques.*

Irrigation system: *PPP are applied through irrigation water drippers in open growing systems or into the recirculating water in closed-loop soilless systems.*

Fogging: *high pressure nozzles or high air speed are used to atomize the PPP solution in fine droplets (less than 10 microns) producing a mist.*

[11] Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste. OJ L 114, 27.4.2006, p. 921.

Fumigation: *this method refers to canned chemicals that have a vaporizing agent (or heat may be used) and are opened in closed walk-in structures for pest control.*

Soil injection: *PPP (usually disinfectant) is applied into the soil with special equipment before sowing or planting at a certain depth (mixing may occur afterwards).*

Soil treatment: *PPP is sprayed onto the soil and mixed through the soil immediately after application.*

Spraying: *it is an application of PPP solution at low or high pressure through atomizing nozzles onto the foliage of plants. The size of the spray droplets is such that most of the droplets will settle fairly quickly (by gravity).*

3.2. Air exchange

Light is the "fuel" of photosynthesis, which is the basis of vegetable growth. For this reason the outer shell of protected cultivations needs to be translucent. Typically it transmits some 60% of sunlight. Sunlight carries a lot of energy: at midday in summer it can reach 800-1000 W m^{-2} even at Northern European latitudes, whereas midday radiation on a very dark day is typically around 100 W m^{-2}. This energy heats up the greenhouse air. Obviously the cover is never perfectly insulating, so some energy is dissipated as soon as there is a temperature difference between in- and outside (Figure 17). Covers that insulate poorly (e.g. single glass) dissipate less than 10 W m^{-2} for each ºC difference in temperature, and most covers are made to be more insulating than that (that is to dissipate less).

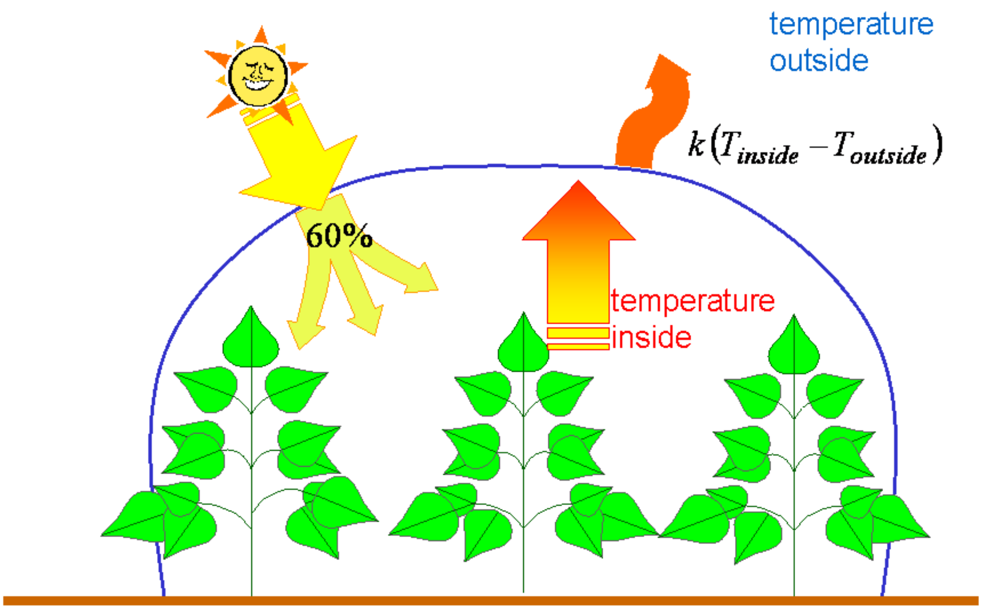

Figure 17 Energy balance of a protected cultivation enclosure. A typical cover lets some 60% of the sun energy in, and dissipates energy in proportion (factor k) to the temperature difference between inside and outside. The factor k is typically less than 10 W m^{-2} for each degree of temperature difference.

A simple calculation shows that sunshine would cause the air within a glasshouse to be about 6 ºC warmer than outside even during a very cloudy day, up to some 50ºC warmer than outside in midsummer. Within a polyethylene tunnel it would be even warmer. It is easy to realize then, that more often than not, it would be so warm within a closed shelter that no crop would grow. Indeed, [natural] ventilation is the means by which temperature inside is managed. Even when there would be no need for ventilation to reduce temperature, there is often the need to ventilate in order to get rid of the vapour produced by the crop, so as to prevent the relative humidity inside reaching values conducive to the development of fungal pathologies. A third important reason for ventilation is the need to let in carbon dioxide (the other input to photosynthesis), except in the high-tech greenhouses where carbon dioxide is artificially supplied.

Most simple protected cultivation structures ensure that there is enough ventilation through openings that are either fixed or manually adjusted on a seasonal basis: for instance net houses/shelters or tunnels (Figure 18), or most greenhouses in the Mediterranean region. For instance in a survey of the greenhouses in the Southern Spanish region of Almeria, Céspedes López et al. (2009) have observed that 99.7% of the greenhouses typical of the zone have manually operated lateral openings and when a zenithal opening is present, it is manually operated in 98.8% of the cases. Perez Parra et al. (2002) had shown that the whole volume of such greenhouses is refreshed more than once per hour, even in the absence of wind, and could be 4 to 8 times per hour at a wind speed of 4 m s^{-1}, which is about the mean wind speed in the region. Typical greenhouses in less windy places have zenithal openings to take advantage of the buoyancy of warm air to ensure the necessary air exchange (Kittas et al., 1997).

Figure 18: Seasonal manipulation of ventilation in tunnels in Sicily, IT. From left to right, winter, early spring, late spring. The next step is complete removal of the cover. Photos: Cecilia Stanghellini (left) and Giuseppe Noto (centre and right).

Even relatively air-tight Dutch Venlo glasshouses were found by De Jong (1990) to have a refreshment rate around 0.5 volumes per hour, with closed ventilators. As high energy prices since then have made growers aware of the attached heating costs, the most modern Dutch glasshouses have an estimated refreshment rate of 0.1 volumes per hour, when all ventilators are closed. Even that would not be enough to prevent a significant fraction of plant protection products present in air after application to leave the enclosure, Figure 19 (after Stanghellini, 2009a).

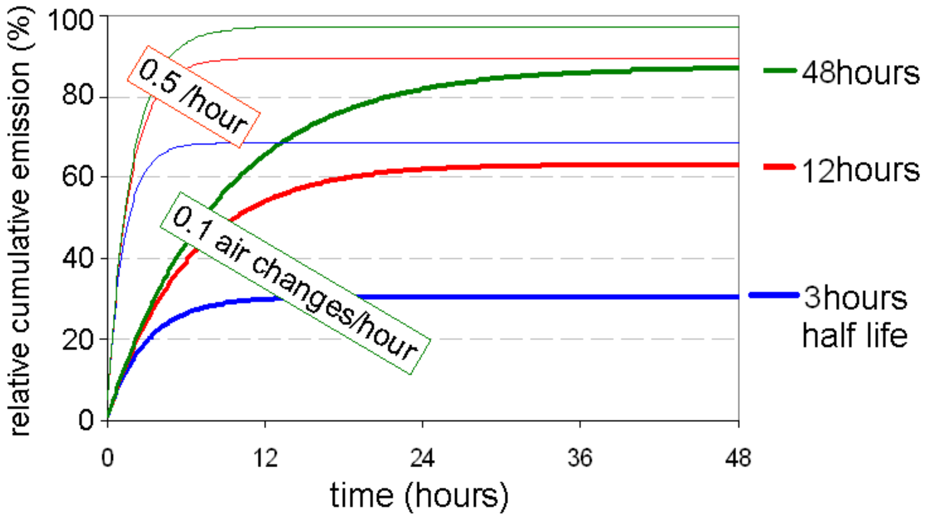

Figure 19: Cumulative emission (as a fraction of the matter present in air after application - not of the applied dose) against time, for chemicals having a half-life of 3 (blue), 12 (red) and 48 (green) hours, under refreshment rates of 0.1 (thick lines) and 0.5 (thin) volumes per hour. Mean height of the greenhouse is assumed to be 5 m. In this context the half-life is taken to be the net result of all processes (other than ventilation) that may remove (degradation or deposition) or add (volatilization of deposits) the substance from/to the air inside the greenhouse.

For instance, Schmidt et al. (2002) applied the pesticides lindane, parathion, pirimicarb, procymidone, or tebufenpyrad in two experimental greenhouses and the atmospheric concentration of these substances was measured in each house during the following 24 hours, during which the greenhouses were ventilated. Even after 24 hours there were detectable concentrations of all substances in the air in the middle of the greenhouses, the highest concentration being measured for the substance with the highest volatility.

In conclusion, the more volatile the chemical, the more will be available in the greenhouse air to be carried away by ventilation. Volatility is known to be affected by temperature, besides the nature of the substance. Therefore, an estimate of the long term emission must be based firstly on an estimate of the long term source within the greenhouse, accounting for the factors that may affect it, and then on the ventilation rate. For volatile chemicals, the worst case presumption seems to be that most of the applied dose will be eventually carried outside by ventilation.

There have been very few measurements made of airborne emissions of PPP from protected crop cultivation. Duyzer and Vonk (2002) used concentrations of plant protection products in rainfall as an indicator of airborne emissions. Indeed, in the Dutch Westland greenhouse region they measured higher concentrations of greenhouse-specific PPPs than elsewhere in the country. In the framework of research about risks to local residents, Duyzer et al. (2004) have shown that very high concentrations of the substance could be measured downwind of a greenhouse, right after a spray application. Kreuger et al. (2010) have measured the concentration of several PPPs in water courses draining greenhouse production areas in Sweden. They have consistently found detectable concentrations of more PPP’s there than in other, non-protected horticultural production areas. Of the substances that could be detected in both cases, the concentration in the greenhouse regions was the highest. Since detectable concentrations (sometimes exceeding the aquatic guideline value) were observed also regarding at least two products (azoxystrobin and hexythiazox) for foliar application, aerial emission (spray droplets and/or re-evaporation) must have played a role.

For the carrier air, the situation can be summarised as follows: emissions to air from protected crop cultivation will be similar to emissions from open fields unless two conditions can be met: (1) all openings can be maintained closed for a good number of hours; and (2) the substance has a relatively short net half-life for dissipation from the greenhouse atmosphere. Since that is the net result of degradation, deposition and re-evaporation of deposited substance, all processes that are affected by the greenhouse environment (temperature, humidity and UV radiation) need to be considered. Detailed calculations may be needed to quantify the conditions that would ensure emissions significantly different from field application.

3.3. Water as a potential carrier

3.3.1. Excess irrigation

All farmers know that there are few costs associated with over-irrigation, whereas the risk of yield loss with insufficient irrigation is always there; excess irrigation is therefore quite normal. Overabundant irrigation, which is often called "leaching" in agronomic literature, makes economic sense because the value of yield exceeds the cost of irrigation, which is certainly the case of protected crops (relatively high-value). Excess irrigation can percolate or end up in surface water or in the sewerage whenever a drainage system is present in the subsoil or whenever the soil surface has been made impermeable (concrete, plastic mulching or gutters). As the most common source of irrigation water is [unmetered] groundwater, data of real water use versus crop water uptake of commercial firms are not readily available. A survey of 53 growers in Almeria (Thompson et al., 2006) concluded that excess irrigation was within 50% of the dose locally advised (e.g. EEFC, 2009) in 68% of the cases, the rest of the growers irrigating more. The excess irrigation was not evenly distributed during the cropping season, as large volumes (30 to 60 mm) were applied in one dose to wash salts from the soil. Excess irrigation in soilless systems with open-loop irrigation may well be at levels comparable to soil-grown systems.

One should be aware that when dealing with pesticide fate in soil, irrigation cannot be treated as a uniform lamina (a flat sheet of water over the surface of the soil). Drip irrigation is the norm, even in very low-tech protected cultivation. Therefore, the distribution of concentrations cannot be assumed to be uniform, as is done in most soil-fate models. Glass et al. (2002) measured spatial concentrations of dye and two PPP's supplied through drip irrigation in a greenhouse in Almeria. Their conclusion is that for pesticides applied in the irrigation water, a significant movement away from the drip pipes can be expected within a period of a single day. Thus some of the pesticide will be available for uptake by plant roots from the day of application, and some of the pesticide will accumulate at a considerable distance from the plant.

Closed-loop irrigation systems may be seen as a solution to the problem of discharge of contaminated water. However, even in the Netherlands, where closed-loop irrigation systems are in practice mandatory, discharge of water to surface water or sewage treatment plant is allowed when a crop-specific concentration of sodium is reached in the closed loop. A recent survey of 561 growers (voluntary respondents among the 4150 receiving the questionnaire) pointed out that some 40% acknowledge discharging with some regularity or incidentally (Anonymous, 2008). The optimal volume that needs to be discharged to control salinity can be calculated (Stanghellini et al., 2005; Carmassi et al., 2007; Stanghellini et al., 2007; Stanghellini, 2009b). However, 2/3 of the respondents admitted discharging for reasons other than sodium concentration, which is the only legal reason at present. Therefore, actual discharge rates will be higher than the optimal amount.

If the ground is permeable, then excess irrigation can transport PPPs, leading to potential emissions of PPP to groundwater. If the ground is impermeable (e.g. concrete) or if there is a drainage system in place, then excess irrigation will be routed to surface water rather than vertically downwards.

If the covering on the structure is permeable or semi-permeable to rain, this will supplement any irrigation and thus the emission towards groundwater is certainly no less than the emission under open-field conditions. A truly non-permeable greenhouse cover ensures that irrigation is more controlled than in the field. Probably a risk assessment could be made through scenarios where the role of rain is taken over by irrigation. As stated above, the assessment should take into account the absence of spatial uniformity caused by drip irrigation and, as follows below, condensation dripping in particular places.

3.3.2. Condensate

Condensate dripping from the cover on the soil is even less a controlled factor than irrigation. The amount of condensation has been measured in 3 glasshouse compartments with a chrysanthemum crop in the Netherlands in several preselected periods (Van der Staaij and Douwes, 1996). Their results provide a reasonable validation of daily condensation calculated through a greenhouse climate model (De Zwart, 1996) for a representative year. The resulting estimate is that condensation amounts to some 15% to 25% of crop transpiration (depending on the crop) in the heated glasshouses of the Netherlands and the fraction might be higher in unheated greenhouses. Usually the condensate glides down hard covers with a slope of at least 22º and is collected in gutters to prevent it falling on the crop, but usually there are no rules about where the gutters discharge. In the Netherlands, collected condensate may not be discharged and is usually routed to the recirculation system or the rain collection basin (Anonymous, 2002). General experience with arched plastic film covers shows that the condensate will drip down from the height where the slope meets particular conditions that depend on the surface properties of the plastic (Gbiorczyk, 2003). Altogether this means that condensate will funnel (either by gutters or by its dripping down) into a limited number of discharge points, where relatively high concentrations of PPP may be reached.

The above mentioned Dutch study (Anonymous, 2008) measured aqueous PPP concentrations in 12 commercial greenhouses (10 different crops) and detected all substances applied in condensate. In the ditches or water streams in the surroundings of these greenhouses, PPPs were found, occasionally in concentrations exceeding the Dutch maximal allowed concentration for surface water. Their estimates for the total amount of four common substances that ends up wherever condensate is discharged are biased by an excessive estimate of the total amount of condensation. The values resulting after correction for that are reported in Table 3.

Table 3: Total amount in the condensate (g ha^{-1} y^{-1}) of four common substances, for three different types of crops in the Netherlands (recalculated from Anonymous, 2008); (n.a.=substance not applied).

	Pot plants	Vegetables	Cut flowers
Deltamethrin	0.1	n.a.	n.a.
Imidacloprid	0.2	0.05	0.1
Kresoxim-methyl	n.a.	n.a.	3.4
Pirimicarb	n.a.	0.5	n.a.

It can be summarised for the carrier water: (1) cultivations under covers that are partly permeable to rain may be expected to have water-carried emissions broadly similar to field crops; (2) an impermeable layer on the soil surface or the presence of a drain system ensures that water-carried emissions end up in another receptor than would be the case with field crops, but not necessarily that the emission is lower; and (3) the net effect of a truly impermeable cultivation cover above a permeable soil surface depends on many factors, among them the horizontal heterogeneity, caused by the irrigation technique and the management of condensate.

In summary:

- There is no reason to expect that incomplete cultivation covers and all nets that are permeable to air and water make an appreciable difference with respect to emissions compared to open fields be it water- or air-carried.
- Structures with openings that cannot be (or usually are not) closed have refreshment rates high enough that air-carried emissions will be similar to those in open fields.
- Since even closed greenhouses have some air leakage there is a need to quantify the combinations of leakage, substance properties and greenhouse environment that would cause emission to be significantly lower than in field applications.
- Whereas the presence of an impermeable soil surface or of a drainage system may redirect water-carried emissions towards other receptors than in the open field, it cannot be said for sure that emissions are reduced.
- Soil scenarios/models able to deal with point discharge (drip irrigation and release of condensation) may be needed to assess the risk of water-carried emissions in the remaining cases (truly impermeable crop cover above a permeable soil surface).
- Closed-loop irrigation systems fed with good-quality water may be expected to reduce water carried emissions. However, there is a need for well-defined Good Practices to minimise the risk of point discharge of water with a high concentration of PPP.

4. Future steps / Outlook

4.1. Is it necessary to perform always separate assessments for covered crops?

In the previous sections we have shown that there is no *a priori* reason to expect that protected cultivation prevents emissions, and that the scarce data available do confirm this statement. As there is a large variety in protected crop systems (see section 2), the questions now arise whether emissions from protected crops systems differ from emissions from open field systems and, if so, how these emissions can be assessed. The information currently asked from applicants (the crop and whether the intended use is greenhouse/indoor or field) is inadequate to evaluate whether the intended use is likely to lead to emissions different from field application. We have shown that additional information such as construction, growing system and application type is necessary. It seems therefore appropriate to develop decision schemes to select the combinations of covered crop systems, intended use of the PPP and possibly other conditions that might lead to emissions <u>different</u> from field application and how these emissions may be assessed. Such a decision scheme needs to be applied to each receptor separately.

As demonstrated in section 3, climatic conditions prevailing outside the protected cropping system highly influence the conditions inside and therewith management practices in the various constructions, especially with regard to ventilation rate and irrigation. The result of the decision scheme will therefore depend on the climatic conditions. Further research is necessary on how many climatic and other conditions should be taken into account to cover adequately the variety in these conditions. Tentatively, the regulatory zones North, Centre and South will require separate assessments.

In Figure 20 a general decision tree is proposed. The approach is identical for all receptors, but the result (i.e. the decision) may be different for each receptor. The starting point is that an application should not be assessed differently from an open field application unless it is demonstrated through the decision tree that a protected crop assessment is warranted. If the application is considered not different from open field, then the appropriate risk assessment method for open field applications applies.

First of all, the applicant has to decide whether the intended use of the substance is an application to a crop grown in any of the protected structures as described in section 2. If this is the case, the following questions have to be answered:

1. Does the protection structure in / under which the crop is grown significantly influence the emission to or the exposure in / of the receptor or organisms in that receptor?

2. Does the growing system on which the crop is grown significantly influence the emission to the relevant receptor or the exposure of organisms in the receptor?

3. Does the application technique by which the PPP is applied significantly influence the emission to the relevant receptor or the exposure of organisms in the receptor?

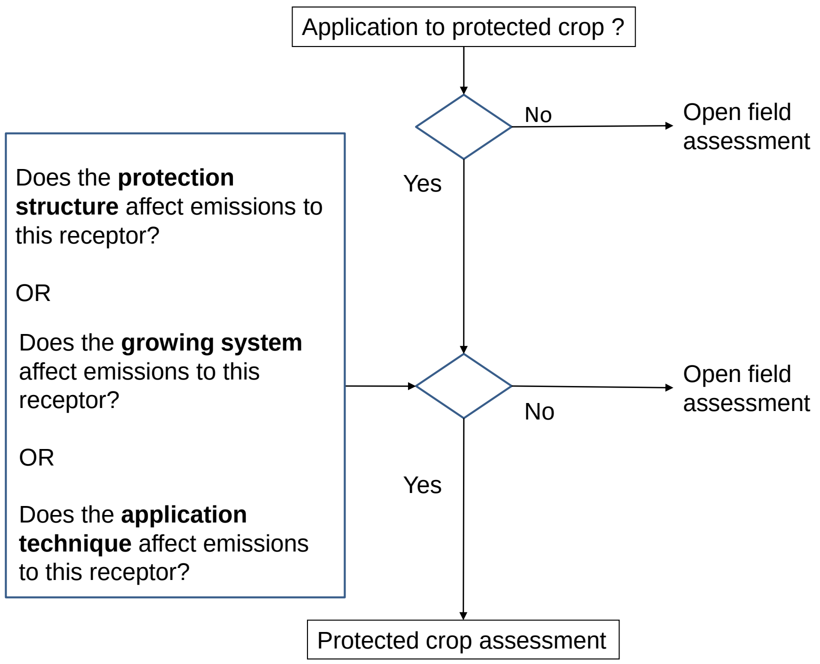

Figure 20: Decision tree for identifying whether an assessment specific to protected crops has to be performed. Decisions have to be taken **for each receptor separately**, for each of the regulatory zones (North, Centre, South).

A ‘No’-answer leads to the decision: not different from an open field application and an assessment for open field applications has to be undertaken. A ‘Yes’-answer to any of the three questions in the box leads to the decision that an assessment specific to protected crops has to be undertaken. The boundaries for the term “significantly different” cannot be defined exactly at the moment. Note that ‘different’ is not identical to ‘lower risk’. More information on protected crop systems and their management as well as results from emission estimations have to become available. 'Not different' here has to be interpreted as: the situation is sufficiently covered by an open field risk assessment and therefore no separate assessment is necessary, whereas 'different' has to be interpreted as: the situation assessed by the open field risk assessment is not representative of the situation occurring in the protected crop situation and a separate assessment has to be performed.

At the moment, insufficient information is available to complete the decision trees for the various receptors in detail, i.e. to exactly define for which situations separate assessments have to be performed. The Panel recommends completing the decision trees after performing scenario studies, relying on current knowledge about the systems and their management, for various protection structure – growing system – application technique – combinations and analysing and comparing the results with results for the open field. As an example, Figure 21 illustrates the work that has to be performed to distinguish between Yes and No as illustrated in Figure 20. For each of the receptors air, groundwater and surface water, information has to become available in order to find out whether specific combinations lead to the decision YES or NO. In Figure 21, the blue colour indicates situations which are to be considered 'not different'; the red colour indicates 'different' and the transition between the colours that, at the moment, insufficient information is available to demarcate the border between Yes and No. The location of the transition zone is different for each of the receptors air, groundwater and surface water, indicating that the Yes / No decision might be different per receptor.

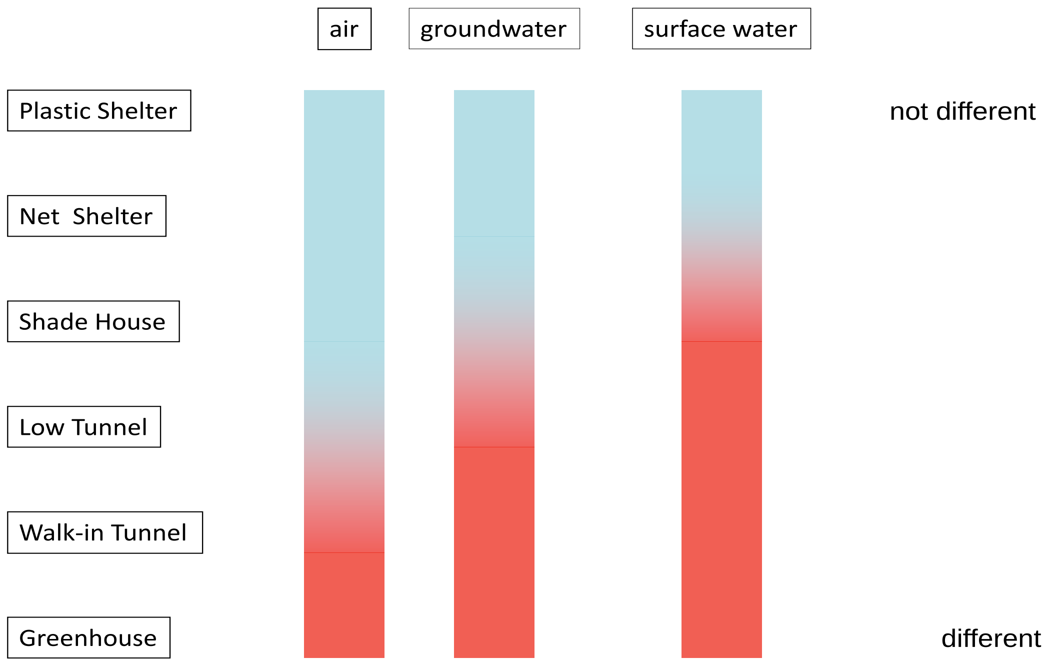

Figure 21: Example of decision rules for distinguishing between open field and covered crop assessment. The order in which the construction types are given is not necessarily correct. Only the distinction between different Yes / No is essential. The answer may be different for each receptor, as indicated by the three vertical bars. Colours: blue: not different, red: different, transition: to be decided after further investigation.

The scenario studies referred to above should consider the most important emission routes. Greenhouse climate models exist that could be a starting point for estimating emissions from protected crop systems to air (see section 3). There is a need to adapt such models in order to get estimates of emissions, also accounting for possible interactions with condensation (Van der Linden, 2009). Recently, models have been developed for calculating emissions to air and surface water for substrate growing systems in greenhouses (Vermeulen et al., 2010 in prep.). Further evaluation of these models is necessary, also to find out whether a full coverage of such systems over the entire EU is possible.

With respect to groundwater, leaching models that are currently used in risk assessment are not capable of addressing drip irrigation systems. Further investigation has to be performed in order to find out how this influences the decision scheme. Drip irrigation also occurs in the open field and is not taken into account in risk assessment at the moment.

The drift route may be non-existent for specific greenhouses and walk-in tunnels and in low tunnel spray applications may be impossible (i.e. cover needs to be (partly) removed before spraying is possible). For the other constructions additional information has to become available in order to be able to judge whether drift is different from open field applications.

With respect to soil (not shown in Figure 21), in risk assessment usually a distinction is made between the soil inside treated fields (= 'in-crop') and the soil outside treated fields (= 'off-crop'). In a soil-bound protected crop system, the in-crop soil is assumed to receive part of the applied substance directly. As this is not very different from open field, the PPR Panel considers it appropriate to perform risk assessment for in-crop soil in protected crop systems according to methodology developed for open fields. For example, the PPR Panel recommends to assess persistence of substances in soil in a protected crop system according to the methodology for open fields, for each of the Regulatory Zones separately. For substrates, such an assessment is not necessary.

Off-crop soil may be exposed via drift (for Low Tunnel, Shade House, Plastic Shelter, Net Shelter and Walk-in Tunnel with ventilation holes, see section 2) or via deposition of air-borne emissions. It is unlikely that drift emissions from protected crop systems are very different from drift emissions for open field situations, taking equivalent application techniques into account. It is also unlikely that short-range atmospheric deposition (see FOCUS (2008) for definition) is different for the same systems. So for these systems the existing open field methodologies can be applied. Drift emissions do not occur in walk-in tunnels without ventilation holes and greenhouses. Models exist for calculating emission to air and concentrations in air at short range distance from greenhouses (Linders and Jager, 1997). It is not clear whether these models can be used for off-crop soil risk assessment.

4.2. Outlook

The final goal is to develop risk assessment methodologies for applications of plant protection products in protected crop systems, including the scenarios that have to be used in the risk assessment by or on behalf of the EFSA PRAPeR unit. In first instance therefore the development is for use at the European level, but the approach is such that application at the level of Member States should be feasible as well. The development of scenarios is outside the mandate of the current working group and therefore has to be performed under a new mandate.

The current working group will analyse potential emissions from covered crop systems in more detail, following the lines depicted in section 4.1. The result will be a proposal on combinations of construction, growing system and application technique that should be considered separately from open field situations, for each receptor separately and for each of the regulation zones North, Centre and South. The working group will prepare a proposal on the number of scenarios that will be necessary for carrying out the risk assessment. The number will depend on the variability in emissions to each receptor. Results of pilot emission estimations will be used to rank emissions and cluster possible combinations as far as warranted.

For the receptor air it has to be investigated whether the current practice according to FOCUS (2008) is sufficient.

At the moment, there is no generally accepted model to calculate leaching and drainage for situations where irrigation water is not evenly distributed over the cropping area, for example when drip-irrigation is used. In soil-bound protected crop systems this is the rule rather than the exception, but it occurs also rather frequently in open field situations. Leaching and drainage assessment for these situations will only be possible when models capable of simulating non-homogeneous irrigation become available. Existing leaching models (FOCUS, 2000, 2001) cannot be used except for the rare case when irrigation water, and for some systems also rain, is distributed homogeneously over the cropping area.

Appropriate leaching and drainage scenarios for these situations can be included in the existing databases of the models. By doing so, assessment of leaching and drainage from such protected crop systems follows existing procedures and can be easily implemented.

In summary:

- With regard to risk assessment for protected crop systems, the PPR Panel is of the opinion that additional methodology should only be developed if conditions are considerably different from open field situations. A general decision scheme is proposed to distinguish between open field and protected crop risk assessment.
- Development of appropriate scenarios will be necessary for each of the regulatory zones North, Centre and South, for the receptors Air, Groundwater and Surface water.
- For risk assessment for both ‘in-crop’ and ‘off-crop’ soil, the existing risk assessment methodology for open field applications will be adequate.
- Development of appropriate scenarios and verification of models is necessary before risk assessment methodology can be completed.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Protected crops are becoming more and more important in Europe for the production of fruits and vegetables as well as flowers and ornamentals. The importance is reflected in the area devoted to protected crops as well as the financial turnover of the sector.

In contradiction to the wording in Regulation (EC) 1107/2009, where it is stated that a greenhouse prevents the release of PPP into the environment, both airborne and waterborne emissions from greenhouses have been proven, including emissions from closed-loop irrigation systems. There is no reason to assume that emissions of PPPs from other protected crop systems do not occur.

There is a huge variability in protected crop systems (structures, growing systems and application techniques). A system for categorising has been developed to cope with this variability. This system will be helpful in selecting the appropriate risk assessment procedure for applications to crops in protected crop systems.

For the purpose of further guidance development, water and air are considered the main carriers of the emissions to environmental receptors. As the processes leading to emission are also affected by climate, a zonal risk assessment may be necessary for protected crops, as it is for field crops.

As it is likely that many combinations of conditions (protection structure, growing system, application, climate) will not lead to emissions significantly different from open field application, there is a need to reduce the number of cases for which a separate risk assessment will have to be made. The reduction can be achieved via scenario calculations for several combinations of conditions as a tool to demarcate, for each receptor and regulatory zone, the boundary between combinations likely to lead to emissions significantly different from field applications and the cases that may be addressed through open field assessment scenarios.

The current methods and models used for assessments of emissions need to be modified to be applicable to protected crop cultivation. At the moment, it is not possible to define the level of detail that should be considered in the risk assessment methodology for protected crops. The level of detail will be addressed in a subsequent Opinion, which will evaluate whether the approach should also include regulatory zones as recently introduced in open field risk assessment.

The PPR Panel considers it not necessary to develop new methodologies for in-crop and off-crop risk assessment for soil in protected crop systems, as there is no reason to assume that the situation is very different from soil in open field systems. However, dissipation rates of PPPs maybe different.

The removal of solids may carry residues of PPP outside the protected crop system. The emissions by these carriers are either not different from open field or covered by other regulations (for example Directive 2006/12/EC on waste). The PPR Panel therefore considers it not necessary to develop guidance in this direction specific to protected crop systems.

RECOMMENDATIONS

The PPR Panel encourages risk managers to consider environmental risk assessment for protected crops as an integral part of the evaluation of plant protection products.

The set-up of the proposed risk assessment methodology for protected crop systems as described in this opinion is intended for use at the EU level. However, we recommend that the set-up is such that it can be adapted for use at the national and regional level. The PPR Panel recommends risk managers to consider the implementation of this methodology at those levels.

Current open field risk assessment methodology with regard to leaching to groundwater and drainage to surface water disregards the possibilities of higher and lower leaching from soil-bound systems when the irrigation water is heterogeneously distributed over the surface. In many protected crop systems heterogeneous distribution of the irrigation water is the rule rather than the exception and it is becoming more important in the open field as well. Both risk assessment and agricultural and horticultural practice may benefit from further development and implementation of simulation models capable of simulating water movement under such irrigation regimes.

Dissipation processes of PPPs in protected crops might be influenced by the cover (see section 1.4). This may affect persistence in soil, residues in crops and worker exposure. The PPR Panel recommends considering these aspects further in ongoing and future development and revision of guidance.

Documentation provided to EFSA

1. Background and Terms of Reference for the development of the Guidance Document on Emissions from Protected Crops.

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APPENDICES

A. APPENDIX - PUBLICATIONS THAT WERE SELECTED FROM LITERATURE REVIEW

In the following, the bibliographic information for the publications selected in the literature search is listed. 50 publications were selected in the first search run on 20/01/2009, four publications were selected from the second search repeated with the same search profile on 26/01/2010. For details see section 1.5.

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GLOSSARY AND ABBREVIATIONS

a.s.	active substance
closed-loop	irrigation system in which the water is, partly, recirculated
EC	European Community
EEC	European Economic Community
EFSA	European Food Safety Authority
emission	technical term signifying the transfer of a substance over a boundary
ERA	Environmental Risk Assessment
EU	European Union
FOCUS	FOrum for the Co-ordination of pesticide fate models and their USe
GW	groundwater
NFT	nutrient film technique
PEC	Predicted Environmental Concentration
PECair	PEC in air
PECsoil	PEC in soil
PECsw	PEC in surface water
PPP	plant protection product
PPR	Panel on Plant Protection Products and their Residues
PRAPeR	Pesticide Risk Assessment Peer Review
protection	The word 'protection' is often used to refer to physical barriers (i.e. plastic, glass or netting) or to refer to chemical / biological products that are applied to the crop (e.g. pesticides or plant growth regulators). Since this term could be ambiguous, we have chosen to use the term 'PPP' to refer to products (Plant Protection Products) throughout this Opinion. When the word 'protection' or 'protected' appears, it refers to the physical barriers.
receptor	For the purpose of this opinion, a receptor is an environmental compartment receiving emissions, such as surface water, air, soil and groundwater.
SE	South East
solids	For the purpose of this opinion, solids are defined as solid materials such as plastic covers, plant residues, soil and substrate that can be removed from the protected structure.

subirrigation	This irrigation method is widely used for pot plants productions. The plants are grown in an porous substrate that transports water and nutrients to the roots by capillary action from a shallow nutrient solution or from a capillary mat saturated with nutrient solution. In the former case, the pots are placed in gullies with an intermittent flow of nutrient solution or in ebb-and-flow benches flooded periodically with a thin layer of nutrient solution that is then drained back into the main reservoir.
substrate	any material, not in connection with subsoil, used for growing plants on
UV	Ultra Violet light
WG	Working Group