EFSA Journal 2010; 8(6):1625

SCIENTIFIC OPINION

Scientific Opinion on the importance of the soil litter layer in agricultural areas[1]

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

European Food Safety Authority (EFSA), Parma, Italy

ABSTRACT

In the soil litter layer specific exposure to plant protection products takes place, including direct exposure, uptake via food, and food web transfer (biomagnification). Furthermore it is an important energy resource in soil and thus of vital importance for maintaining organism communities and their large biodiversity. Not protecting the natural processes and organisms in litter will fail the objectives of the EU regarding biodiversity, soil erosion, organic matter decline, etc. As a consequence, the litter layer should be considered in the environmental risk assessment of plant protection products. The opinion gives an overview of the composition of litter in an agricultural context, on the underlying processes which play a role in the decomposition of litter and an outline of how to consider the litter layer in the environmental risk assessment of plant protection products. Furthermore the Panel addresses the need of considering particular issues for this purpose.

KEY WORDS

litter layer, plant protection products, soil organisms, environmental risk assessment, exposure

---

1 On request of EFSA, Question No EFSA-Q-2010-00823, scientific opinion adopted on 20 May 2010.

2 Panel members: Jos Boesten, Claudia Bolognesi, Theo Brock, Ettore Capri, Anthony Hardy, Andrew Hart, Karen Hirsch-Ernst, Susanne Hougaard Bennekou, Robert Luttik, Angelo Moretto, Bernadette Ossendorp, Annette Petersen, Yolanda Pico, Andreas Schäffer, Paulo Sousa, Walter Steurbaut, Anita Stromberg, Maria Tasheva, Ton Van der Linden, Christiane Vleminckx. Correspondence: ppr@efsa.europa.eu

3 Acknowledgement: The Panel wishes to thank the members of the Working Group on Ecoregions for the preparation of this opinion: Ettore Capri, Juliane Filser, Robert Luttik, Jörg Römbke, Andreas Schäffer, and Paulo Sousa as well as EFSA’s staff member Karin Nienstedt for the support provided to this EFSA scientific output.

Suggested citation: EFSA Panel on Plant Protection Products and their Residues (PPR); Scientific Opinion on the importance of the soil litter layer in agricultural areas on the importance of the soil litter layer in agricultural areas. EFSA Journal 2010; 8(6):1625. [21 pp.]. doi:10.2903/j.efsa.2010.1625. Available online: www.efsa.europa.eu

SUMMARY

The European Food Safety Authority (EFSA) asked the Panel on Plant Protection Products and their Residues to issue a scientific opinion on the relevance of the litter layer on soil for the ecological risk assessment of plant protection products in the context of the ecoregions concept being currently developed by the PPR Panel.

In the soil litter layer specific exposure to plant protection products takes place, including direct exposure, uptake via food, and food web transfer (biomagnification). Furthermore it is an important energy resource in soil and thus of vital importance for maintaining organism communities and their large biodiversity. Not protecting the natural processes and organisms in litter will fail the objectives of the EU regarding the protection of biodiversity and the prevention of soil erosion, organic matter decline, etc. As a consequence, the litter layer should be considered in the environmental risk assessment of plant protection products.

This opinion gives an overview of the composition of litter in an agricultural context, on the underlying processes which play a role in the decomposition of litter and an outline of how to consider the litter layer in the environmental risk assessment of plant protection products.

The Panel concludes that:

- Soil litter is an ecologically relevant part of the terrestrial compartment.
- Soil litter is physically (texture, density, aggregation and water regime) and chemically (e.g. organic matter, C/N ratio) different from mineral soil.
- The soil litter layer intercepts a significant proportion of the sprayed plant protection products before they reach the mineral soil layers below.
- The environmental fate of plant protection products in litter-covered soil is expected to be different from that in bare soil.
- Uptake of plant protection products via food by soil organisms is more likely in the soil litter layer than in mineral soil.
- Not protecting the natural processes and organisms in the soil litter layer will fail the objectives of the EU regarding the protection of biodiversity and the prevention of soil erosion, organic matter decline, etc.

The Panel identified the need of considering the following issues in particular:

- Definition of clear protection goals by risk managers regarding the protection of the ecological role of the litter layer in an agricultural context.
- Selection of key species and their attributes as being explained in the upcoming scientific opinion on protection goals.
- Development of realistic worst case scenarios with respect to exposure and effects on key species and ecological processes while considering the interdependency of exposure routes via different soil layers (mineral soil and litter).
- Data should be collected to underpin the parameterisation of the litter layer (e.g. decay rate, surface to mass ratio, and other parameters as for mineral soil).
- The litter mass per area is an important parameter to be assessed because its plant protection product concentration will change.
- The proper dissipation processes from the litter layer must be considered.
- Data should be collected on the temporal and spatial distribution of the composition of the litter layer (considering distribution in different crops, regions, and over different seasons) in agricultural land.

TABLE OF CONTENTS

BACKGROUND AS PROVIDED BY EFSA

In the EFSA PPR Opinion "*The usefulness of total concentrations and pore water concentrations of pesticides in soil as metrics for the assessment of ecotoxicological effects*" (EFSA, 2009), the Panel stated that exposure assessments in soil could be refined based on a novel underlying concept using soil ecoregion maps to define ecologically relevant exposure scenarios. It would be possible to construct soil ecoregion maps based on the composition of soil organism communities (incorporating ecological and biogeographical aspects) and information on climate and soil properties. The Panel also defined three hypothetical regions (Finland, Germany, Portugal), which represent one of the highest North-South gradients in Europe, reflecting thus the most diverse climate conditions, and which could as a consequence be used for developing the concept. Additionally, a first outline of soil ecoregions was presented and welcomed in the stakeholder workshop IRIS (*Improved Realism in Soil Risk Assessment (IRIS) - How will pesticide risk assessment in soil be tackled tomorrow?*), organized by PPR and held in Ispra in May 2009. The resulting EFSA report was published in July 2009.

Additionally, in the context of EFSA's mandate which was received in early 2009 to revise the Guidance Document (GD) on Terrestrial Ecotoxicology SANCO/10329/2002[4] (EFSA-Q-2009-0002), the PPR-Panel is currently working on the development of adequate and worst case exposure assessments in soil and the development of the soil ecoregions concept is important for defining these exposure assessments.

Therefore, in order to give continuity to the work the PPR-Panel has done so far, and considering the scheduled work on its agenda for the next few years, the development of the soil ecoregions concept represents a milestone which needs early definition.

As part of this mandate, the Panel issues this opinion on the importance of the soil litter layer in agricultural areas in the context of the ecoregions concept.

TERMS OF REFERENCE AS PROVIDED BY EFSA

The Scientific Panel on Plant Protection Products and their Residues (PPR Panel) of EFSA is asked to further develop the concept of soil ecoregions in the context of the revision of the Guidance Document on Terrestrial Risk Assessment (EFSA Q-2009-00002).

1. Introduction

According to the Scientific Opinion "The usefulness of total concentrations and pore water concentrations of pesticides in soil as metrics for the assessment of ecotoxicological effects" (EFSA 2009), in the context of the risk assessment of plant protection products for the terrestrial environment, the litter layer should be considered in the definition of exposure scenarios for soil organisms in some crop types, in particular permanent crops and crops under conservative agricultural management (low tillage crops).

Litter is mainly composed of non-living plant material laying on soil surface (see more details in Section 2.1). Ecologically, the litter layer is a keystone component of terrestrial ecosystems, being a source of soil organic matter and the place where major soil biological processes, like decomposition and nutrient cycling, start. It is one of the two large energy resources[5] in soil and thus of vital importance for maintaining organism communities and their large biodiversity. Due to its physical characteristics and high nutritional value it is the habitat for many soil invertebrate species and consequently is frequented by many predators of higher trophic levels such as beetles, spiders, shrews and birds. Litter is also important for vertical burrowing species (like the earthworm *Lumbricus terrestris*) that live in soil but visit the litter layer for feeding purposes.

When present in agroecosystems, the litter layer intercepts a significant proportion of the sprayed plant protection products before they reach the mineral soil layers (EFSA, 2010), thus presenting a concentration that may be different from the soil below. The presence of a litter layer may also influence the degradation of plant protection products when compared to bare soil, e.g. a reduction of the degradation rate of sulcotrione and glyphosate in litter material was observed when compared to rates measured in bare soil (Doublet et al., 2009). Moreover litter is associated with higher soil water content, which can alter the dynamics (transport, degradation) of plant protection products in soil, and at the same time increases the attractiveness of the upper soil layers for organisms, thus increasing the probability of their exposure. Furthermore, the changes operated in litter during the decomposition process by physical and biological agents (litter fragmentation by detritivores associated with bioturbation, mainly by earthworms) can alter soil surface structure and porosity and thus affect water flow in soil and the displacement of plant protection products (Cadisch and Giller, 1997; Edwards and Shipitalo, 1998). On the effects side, any impact on microorganisms and invertebrates living in or on the litter layer may delay the decomposition of the organic material, thereby influencing nutrient cycles (OECD, 2006).

In the soil litter layer important ecological processes as well as specific exposure to plant protection products take place, including direct exposure, uptake via food, and food web transfer (biomagnification). Therefore, the litter layer should be included when selecting exposure and effects scenarios for risk assessment procedures.

In addition, the structure and functions of the soil compartment should be protected according to different EU legislation, most prominently the Soil Framework Directive (EC, 2006). Several of the ecosystem services (and the underlying ecological processes) provided by soil are difficult to maintain if the litter layer is missing. Among the threats to soil quality and sustainable functioning that could arise from the absence of a litter layer are an increase in the risk of soil erosion and the loss of biodiversity. Most important, however, is the role litter is playing in relation to the state of soil organic matter content, which is constantly decreasing in many agricultural soils across Europe (Van Camp et al., 2004) but increasing when conservation practices are adopted at field level (EFSA, 2010).

Based on all these considerations the PPR Panel was asked to issue a scientific opinion about the importance of the litter layer in an agricultural context and its inclusion as an extra element when

[5] The 2nd largest source of energy in soil are roots and root exudates.

defining exposure and effects scenarios of plant protection products for soil organisms. The Scientific Opinion is structured as follows:

- Firstly, a characterization of litter in agricultural systems is given followed by a brief description of the decomposition processes and of the soil organism groups likely to be exposed to plant protection products via litter (section 2).

- Secondly, the exposure and effects scenarios where the litter layer should be considered in environmental risk assessment are presented. Additionally, some considerations on how to model Ecotoxicologically Relevant Concentrations (ERC) in litter are given (section 3).

- Finally, recommendations are given on the needs in terms of litter parameterization (regarding crop dependent, regional and temporal differences) for exposure assessment and the relation to effects assessment and ultimately to risk assessment.

2. Litter characterization

2.1. What is litter (and the litter layer) in the agricultural context?

The litter layer is defined as the layer of mainly dead plant organic material present on top of the mineral soil surface (Figure 1). It is composed of debris in different stages of decomposition. When decomposition of litter occurs in less than 1 year, there is often a sharp boundary between litter layer and mineral soil. In the case of slower decomposition (>>1 year), there is often an intermediate ("mixed") zone between litter layer and mineral soil. In any case there are clear differences between these two compartments, both in terms of physical (texture, water holding capacity), chemical (organic matter content, C/N ratio) and biological (see below) properties as well as their occurrence in space and time. Litter is changing quickly over time (decomposition process of few months to several years) and is rarely thicker than a few centimetres, while soil needs centuries to develop and can be several meters in depth.

In crop areas the litter layer is any organic substrate covering the soil surface present in different stages of decomposition and often characterised by a high C/N ratio, but also by other chemical (e.g. nutrients like N and P) and physical (e.g. dry weight or leaf area) properties (Palm and Rowland, 1997). Usually, the crop residues when incorporated into the soil are not included in this definition. Litter may be composed of:

- leaves from permanent crops (e.g., grass, orchards);

- "turf" derived for instance from permanent grass grown in between rows;

- crop residues left on the soil surface after harvesting (including stubbles);

- killed / dead weeds on the soil surface;

- residues from cover or catch crops laying on soil the surface;

- mulch, pruning, etc.

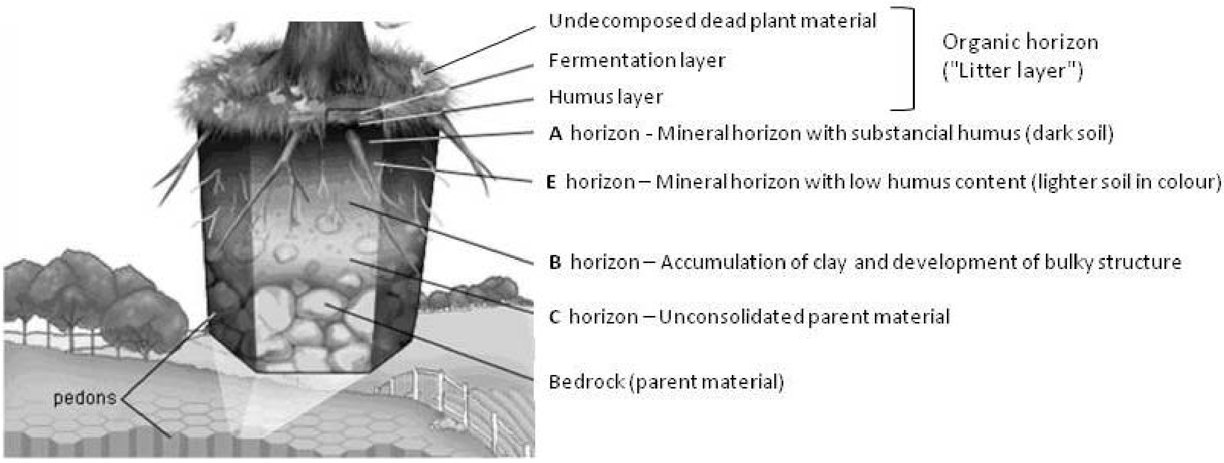

Figure 1: Soil profile including strata in the litter layer after Encyclopaedia Britannica (© 1999, Encyclopaedia Britannica, Inc)

The litter layer is not a homogeneous matrix, especially when the litter material is mostly undecomposed. As mentioned in the paragraph above, its thickness may vary according to the litter residues produced (Blume and Beyer, 1996). In forests, different strata of the litter layer can be identified and classified as follows:

Uppermost stratum: organic horizon with intact or only slightly decomposed dead plant material; fine particles represent less than 10% (in volume) of the overall amount of organic material.

Intermediate stratum (fermentation layer with the highest rate of biological activity): plant material is still identifiable as such but is clearly decomposed; the percentage volume of fine particles is between 10% and 58%.

Humus-layer ("grey" zone between litter layer and mineral soil): plant material is not obviously identifiable (except some shoot parts etc.); volume of fine particles is higher than 70%.

In grasslands and orchards, comparable stratification can be found (e.g. Ponge, 2003). In Figure 1 these strata are represented.

The percentages in the paragraph above are taken from the German Handbook for the Monitoring of Soils and may differ slightly in different sources (Ad-hoc AG Boden, 2005). No figures are given concerning the depth of these layers. In coniferous forests, and especially bogs and moors, they can reach 10 – 20 cm under temperate conditions, while in temperate deciduous forests the depth is much less (2 – 3 cm). In arable land the litter layer generally will be shallower than in forests, because (i) the plant biomass is generally lower, (ii) most of it is removed during harvest and (iii) regular incorporation of remaining litter into the soil with tillage.

Litter layers exist under the conditions outlined above in both annual and perennial crops and especially in reduced or no tillage management systems. The stratification of litter is strongly influenced by the type of crop, the soil management adopted and the geographical location. For instance, in colder areas, under a no-till management and conservative stocking rates a thick litter layer and a distinct L stratum will develop, whereas in warmer areas with no moisture limitations (where litter decomposition rate is higher), the litter layer will be thin. Moreover, the amount of litter will vary in space and in time. Usually, litter from orchard trees as well as many crop remnants will be degraded within one year, with exception of pruning residues that take longer to decompose. Thus, the depth of the litter layer is highest in winter, assuming litter fall and harvest in autumn, and lowest at the end of the summer and just before fall. Litterbag and laboratory studies (e.g., Ke et al., 2005) showed that the amount and decomposition dynamics of litter in arable land are also conditioned by litter quality (e.g. quickly degradable clover vs. cereal straw which takes several years for complete physical destruction). Generally, litter with low C/N ratio and low levels of chemical (e.g., phenols, oils) and/or physical (e.g., lignin) defences decomposes faster because it is easily conditioned by microorganisms and readily eaten and fragmented by soil fauna. Climate also has an important role in litter decomposition; warm temperatures usually favour litter decomposition, but this process is often counteracted by low moisture levels which limit the activity of microorganisms and of saprophagous soil organisms (e.g. microorganisms, mesofauna like collembolans, earthworms).

The litter contains many nutrients that are "recycled" in the soil when it is broken down. Even in a partially decomposed state, litter is an important component of the agricultural soil. The partially decayed organic material is able to store moisture, preventing water loss by evaporation and erosion due to runoff (e.g. by shielding the mineral soil and by 'disconnecting' soil and evaporative layer). The following parameters are important for defining the litter layer as dynamic system:

- Litter input: usually as dry weight input (t ha^{-1} a^{-1}), i.e. most literature data are expressed in this metric (e.g. Swift et al., 1979; Lavelle and Spain, 2001).

- Standing stock biomass (i.e. the amount of litter on the soil surface) given as g m^2. In litterbag tests performed as part of the registration of plant protection products, the amount per bag is given as mg (ash-free dry weight) (Römbke et al., 2003).

While the chemical and physical properties of different types of litter are well described (e.g. Cadisch and Giller, 1997), information on their bulk density is rare.

2.2. Litter decomposition

The litter layer of an agricultural soil is exposed to light, wind, and rain, and is broken down by saprophagous decomposers. In the following Figures 2 and 3 the theoretical background of litter decomposition is summarized, identifying the most important abiotic and biotic interacting factors and major processes (Swift et al., 1979; Heal et al., 1997).

The rate of change over time of any organic (non-living) resource from stage 1 to stage 2, representing subsequent stages of a continuous decomposition process, is influenced by a combination of three interacting groups of factors (F) (Figure 2):

- Physico-chemical environment (E)
- Quality of organic resource (Q)
- Decomposers (bacteria, fungi, invertebrates) community (O)

and is the result of three major processes (P)

- Catabolism (chemical changes including e.g. nitrogen cycling) K
- Comminution (physical changes) C
- Leaching (transport of labile resources) L

Based on the scheme explained in Figure 2, litter decomposition can be combined in a cascade model where litter weight and quality decrease over time usually following an exponential decay model. In Figure 3 four steps of this decay are represented.

In Figure 4 an example of litter decomposition is given: experimental values on the decomposition of meadow hay litter are shown, comparing some main individual components and the total mass loss of litter. The amount of water-soluble compounds (mainly sugars, but also water-soluble phenolic compounds) decreases fast, being washed out during the leaching phase. Compounds like cellulose and hemicelluloses present an intermediate rate of decomposition, whereas more resistant compounds, like lignins, lipids and some phenolics have a lower decomposition rate (see also van der Linden et al, 1987). Microbial breakdown is inhibited when the C/N ratio is higher than approximately 25 (Gisi, 1990). This means that the high initial C/N ratio in litter needs to decrease in order to become more palatable for microorganisms and invertebrates. This occurs by losing the water-soluble compounds in the early phase of the process. During the decomposition process the C/N ratio of the remaining litter decreases, however the nature of the material changes from easily degradable substances to more complex compounds with e.g. highly condensed aromatic rings.

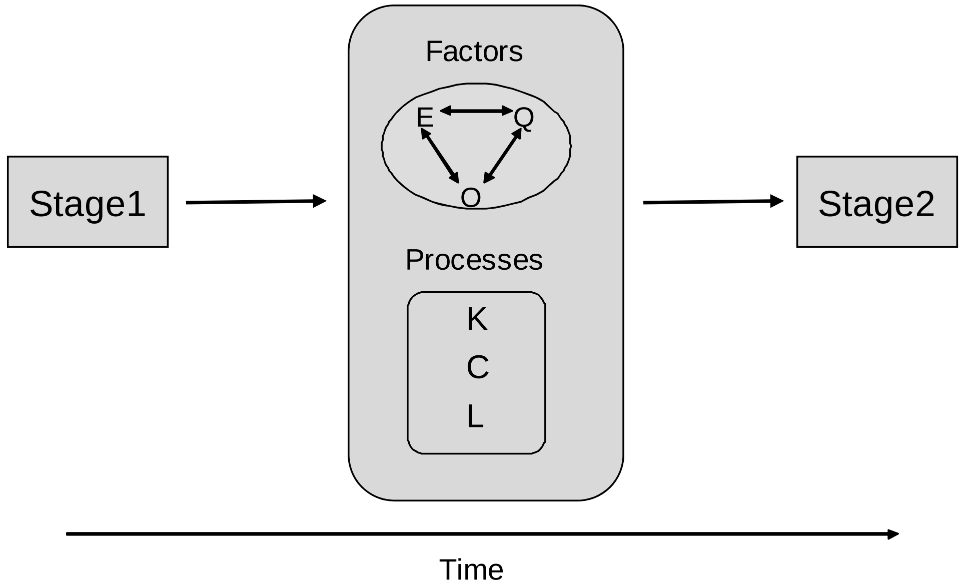

Figure 2: Scheme representing the major factors and processes involved in changes between two litter stages representing subsequent steps of the continuous decomposition process (Physico-chemical environment (E); Quality of organic resource (Q); Decomposer (Bacteria, fungi, invertebrates) community (O); Catabolism, chemical changes (K); Comminution, physical changes (C); Leaching, transport of labile resources (L))

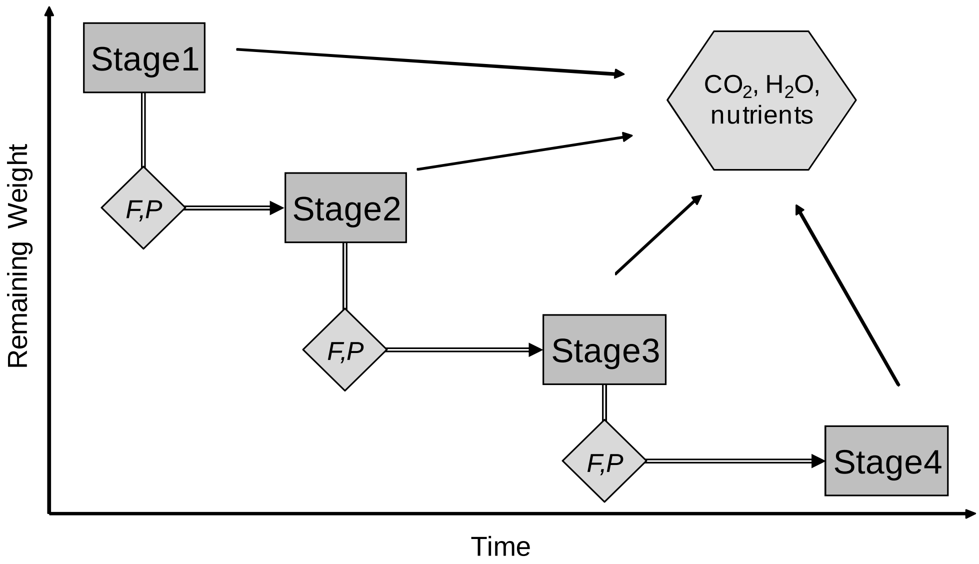

Figure 3: Theoretical scheme representing the litter decomposition process along time. Change from one stage to the next liberates H_2O, CO_2 and nutrients, and changes the C/N ratio of litter over time. At the end of the process, recalcitrant material (non decomposable organic material) remains as a major source for humus formation. Legend: F: factors. P: processes.

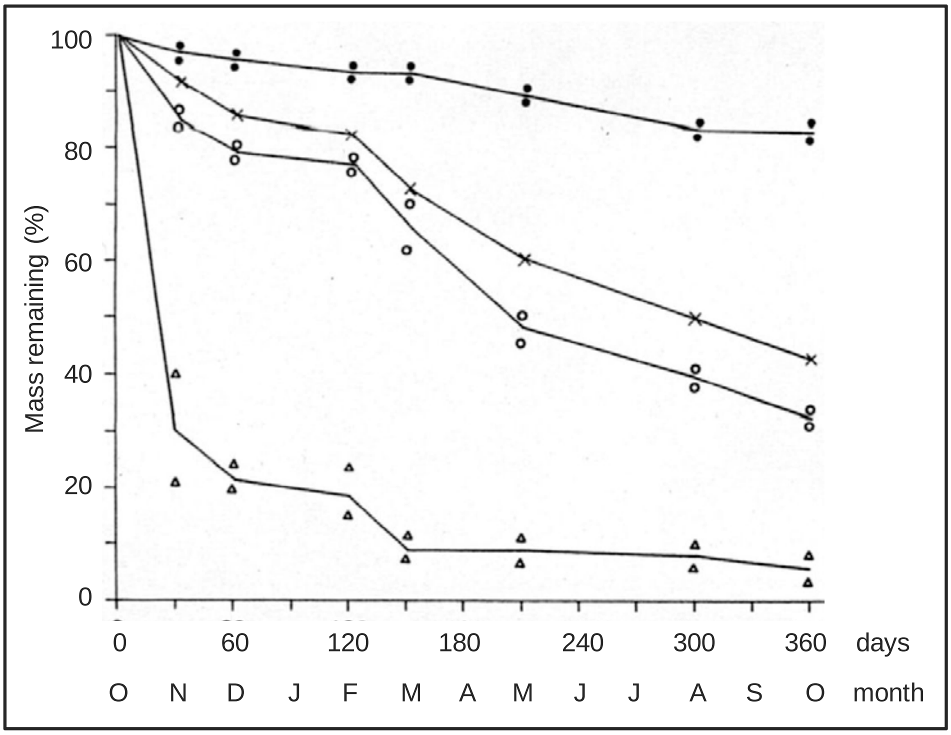

Figure 4: Breakdown of hay litter (x) and its main components (black dots: lignins; open dots: cellulose; triangles: sugars) on an acid brown soil in the field. Hay litter was exposed in litterbags which stayed on soil surface (Stöcklin and Gisi, 1989, cited in Gisi, 1990).

Environmental conditions (temperature and soil moisture) affect the persistence of litter as well, with low temperature and low soil moisture indicating higher persistence (Bottner et al., 2000). Berg et al. (1993) found a strong significant positive correlation between actual evapotranspiration and decomposition rate constants across a wide range of climatic conditions (a North – South transect across Europe).

Thus, the decomposition process is affected both by external factors (climate, chemical and physical conditions of the top layer of the mineral soil, and organisms) and intrinsic factors (the chemical composition of the litter). In general, plant leaves with a low C/N ratio and low content of phenolic compounds and lignin are decomposed faster than others, and are being considered high-quality litter. The reason is that they can be easily colonized by microorganisms, making them more palatable to detritivores and microbial grazers. However palatability of litter differs among invertebrate species. For instance, among earthworms, depending on the species and ecological group some species seem to prefer a higher litter quality with some degree of microbial conditioning (in particular anecic species coming to the soil surface to feed on litter), while others are adapted to more decomposed material of lower quality (e.g. endogeic species which live in the litter itself or in the upper soil layer).

Crop management may influence litter decomposition as well. Tutua et al. (2002) found that the decomposition and N release of understory residues in apple orchards are related not only to residue quality but also to tree line management practices. The age of the stands can also influence the degradation of plant protection products. Some studies suggest that as ecosystems mature, the rate of plant protection product degradation in litter increases (e.g. Ganapathy, 1996; Walters, 1997). A comprehensive review on these interactions has been recently published (Alletto et al., 2010).

2.3. Soil organisms, litter and chemicals

Soil fauna may be exposed to chemicals in the litter layer via the consumption of litter material and via contact with its moistened surface. The exposure depends on the specific activity patterns of the fauna including potential avoidance behaviour. The activity pattern may vary with both season and species: highly mobile organisms could be subject to more extreme time variable exposure than less mobile ones, and depending on the timing of peak activity (e.g. spring species vs. winter-active forms) the exposure situation will again be different. Soil organisms most in contact with the litter layer are epigeic micro- and macro-arthropods (e.g., epigeic collembola, mites, isopods, diplopods) and also soft-bodied organisms like enchytraeids and earthworms. In this last group both the epigeic (living in the litter itself or in the upper soil layer) and anecic (coming to the soil surface to feed on litter) species may be in contact with the litter layer. The third ecological group of earthworms, endogeics, usually occur in the mineral soil, but it is known that juvenile endogeics, at least of some species, feed in the lower litter layer (Briones and Bol, 2002). Considering that earthworm populations are often food limited (Curry, 1998), and that the demand for food in large earthworm populations is higher than litter production (e.g., Daniel, 1992, showed that in a Swiss meadow the demand for food of an exceptionally large population of *Lumbricus terrestris* was calculated as high as 93.2 g week^{-1} m^{-2}, while only 20 to 32 g week^{-1} m^{-2} were available as grass cuttings), exposure to plant protection products in litter is almost total since, in these cases, all palatable litter is consumed.

Typical species important for litter decomposition at agricultural sites in temperate regions of Europe include both macrofauna (e.g. earthworms) and mesofauna (e.g. collembolans). As a general rule, the importance of earthworms and enchytraeids is higher in wet regions (Central and Northern Europe) while in dry Mediterranean regions arthropods dominate. Some typical species occurring in crop areas of Northern and central Europe are:

- <u>Oligochaetes (earthworms, enchytraeids):</u> *Lumbricus terrestris*, *Lumbricus rubellus*, *Aporrectodea longa*, *Aporrectodea caliginosa*, *Aporrectodea rosea*, *Octolasion cyaneum*, *Octolasion lacteum*, *Buchholzia appendiculata*, *Fridericia sp.*, *Henlea sp.*

- Arthropods (Collembolans): *Protaphorura fimata, Mesaphorura macrochaeta, Brachystomella parvula, Hypogastrura assimilis, Parisotoma notabilis, Isotomurus palustris, Cryptopygus thermophilus, Folsomides parvulus, Folsomia litsteri, Folsomia fimetaria, Folsomia quadrioculata, Folsomia candida, Desoria olivacea, Isotoma viridis, Lepidocyrtus cynaneus, Sminthurinus aureus.*

In Table 1 (four mesofauna taxa) and Table 2 (earthworms), some typical groups of soil organisms at non-Mediterranean crop sites are described (Schaeffer et al., 2010).

Table 1: Abundance, biomass and species number, given as range of mean numbers of selected micro- and mesofauna groups in agricultural soils of Central Europe, based on literature reviews after Schaeffer et al. (2010).

Organism group	Number of organisms per surface area (m^{-2})	Dry biomass ($g\ m^{-2}$)	Number of species per surface area (m^{-2})
Nematoda	3000 – 13000 [a]	≈ 0.440	17 – 20 [b]
Acari (mites)	<1000 – 5000	≈ 0.120	3 – 10
Collembola	1500 – 33000	≈ 0.120	17 – 38
Enchytraeidae	2000 – 30000	0.110 – 0.640	3 – 22

[a] per kg soil DW
[b] families, not species
≈ numbers deduced from grassland sites

Table 2: Compilation of data describing the "average" earthworm community of agricultural sites in Central Europe. Where possible ranges are also given (after Schaeffer et al., 2010[a] and Merli et al., 2009[b]).

Area and habitat	Number of organisms per surface area (m^{-2})	Dry biomass ($g\ m^{-2}$)	Number of species per surface area (m^{-2})
Central European crop sites [a]	6 – 453	0.5 – 15.2	0 – 11
Central European crop sites (excluding UK) [a]	74.7 (0.9 – 187)	4.8 (0.1 – 12.1)	3.6 (1 – 7)
Swiss crop sites [a]	-	11.0 [c] 0.6 – 28.6	7.0 5 – 9
Bavarian crop sites [a]	9 (0 – 280)	0.6 (0 - ?)	3.0 (0 - ?)
German vineyards [a]	36.7 (0 – 83)	6.8 (0 – 20.7)	1.9 (0 – 4)
Italian vineyards [b]	0 – 15	0 – 29	0 – 2

[c] re-calculated from fresh weight
\- no literature data available

3. How to consider litter layer in risk assessment of plant protection products

3.1. Litter in the context of the current risk assessment of plant protection products

Under the current risk assessment of plant protection products, litter is considered on the effects side via the performance of the litter bag test. According to the data required under Annex III, point 10.6.2 of EC Directive 91/414/EEC, the litter bag is required if the DT_{90f} of the compound is higher than 365 days. However it can also be triggered when this value lies between 100 and 365 days (EC, 2002).

This litter bag test is currently performed with the litter being buried into soil (5 cm depth), thus becoming an in-soil test reflecting common agricultural practice. However, the burying has a consequence that any relationship between actual exposure of the litter-degrading in-soil fauna and response within the litterbags cannot be verified. Due to this reason the relation between exposure of soil organisms and effect in-soil is unclear. For this reason the PPR Panel (EFSA, 2007) proposed to remove this test from the current risk assessment and change it accordingly.

In many cases, the current methodological approach gives non-significant or transient significant results for different PPPs tested (Dinter et al, 2008). However, evidence exists that if the litter is left on the soil surface significant effects can be found (Knacker et al, 2003). Nevertheless, according to the litter definition given in this opinion, the litter layer is not considered in the current risk assessment. However, not protecting the natural processes in litter will fail the objectives of the EU regarding the protection of biodiversity and the prevention of soil erosion, organic matter decline, etc.

3.2. Possibilities for future risk assessment of plant protection products considering the litter layer

3.2.1. Crop scenarios for considering the litter layer in environmental risk assessment

According to the Scientific Opinion “The usefulness of total concentrations and pore water concentrations of pesticides in soil as metrics for the assessment of ecotoxicological effects” (EFSA, 2009), the litter layer should be considered in some of the defined exposure scenarios for permanent crops (Figure 5). Most prominently, this consideration for risk assessment purposes is always necessary for various types of pastures and meadows (covering the entire area) as well as for those crops which are planted in rows (e.g., orchards, olive groves, hops and vineyards). Here litter can accumulate in the rows as well as in between the rows (especially the cases of auxiliary vegetation).

Additionally, in no-tillage or reduced tillage management of various annual crops (e.g. corn, wheat, sugar beet and potato) considerable amounts of organic material may occur on top of the soil (mainly in Northern Europe). However, an important distinction should be made between the plant litter that is present during the vegetation period of the crop (either residues from the previous crop or killed weeds) and the litter that might be present only between crops, especially during winter. While the first is potentially exposed to spraying of plant protection products, the latter is not expected to be sprayed with plant protection products (e.g. cover crops) and therefore it may not be of relevance for the risk assessment of plant protection products.

For protecting the ecological role of the litter layer in an agricultural context, the PPR Panel concludes that the situations shown in Figure 5 should be considered as a minimum (see also EFSA, 2009).

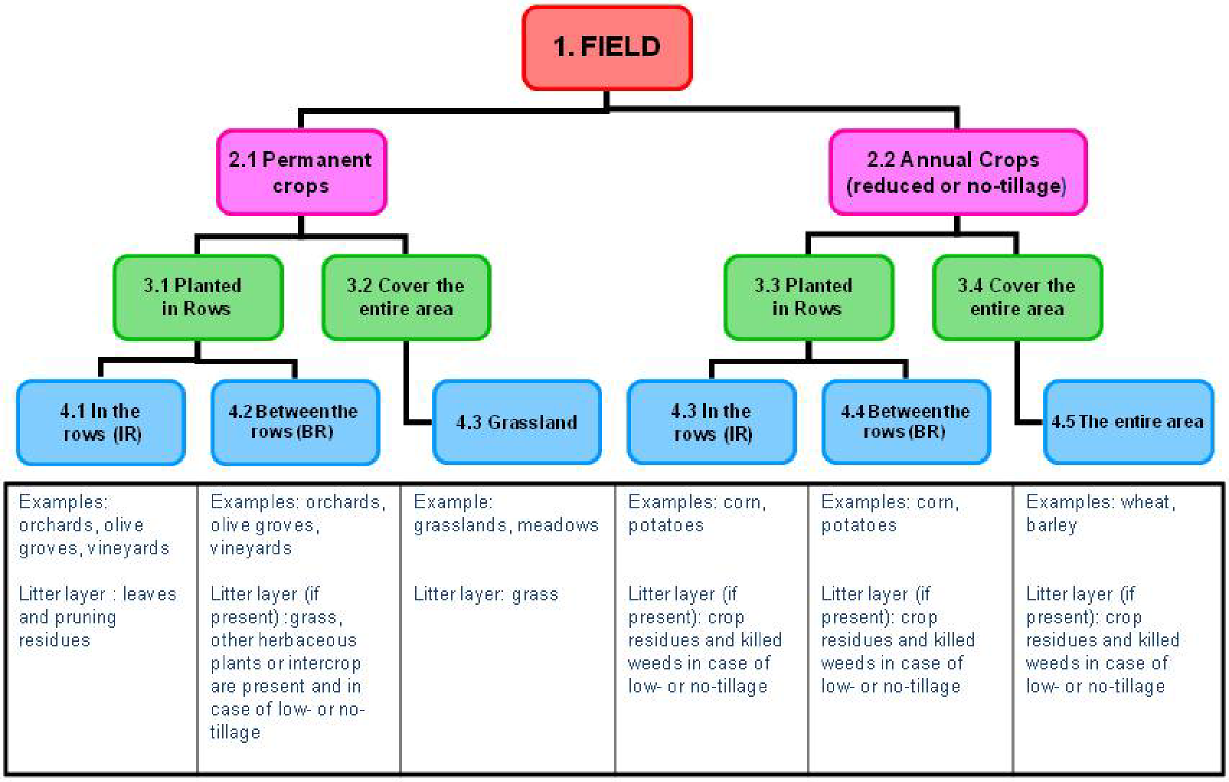

Figure 5: Situations for considering the litter layer in environmental risk assessment (adapted from EFSA, 2009).

3.2.2. Measures to address effects on litter inhabiting organisms in the risk assessment of plant protection products

Due to its ecological relevance for the terrestrial systems as an important exposure route for soil organisms, the exposure of soil organisms via litter should be assessed in the environmental risk assessment. Note that the key species identified for the litter layer may also be exposed via the mineral top soil and that an interdependency may exist between exposure in the litter layer and exposure in the mineral soil. This should be taken into account when defining the Ecotoxicologically Relevant Concentrations (ERC) for the different key species.

The main exposure routes for organisms in the litter layer are by contact and via food uptake. Regarding contact exposure, the Panel concluded already that it is via pore water (EFSA, 2009), but also uptake of volatile substances may take place via the gas phase. Exposure via food could be parameterised by a simple approximation. For instance, considering earthworms it can be assumed that (i) earthworm populations are often food limited (Curry, 1998), (ii) earthworms eat, on average, between 10-30% of their body weight per day (Edwards and Bohlen, 1996), and (iii) assuming the average litter consumption rate of a well-developed earthworm population in grassland as 100%, litter demand is higher than litter supply (Daniel, 1992). For example: if the earthworm fresh biomass is 80 g m^{-2} (assuming a well-developed population of 200 individuals per m^2 with a fresh biomass of 400 mg individual^{-1}), the consumption will be 100% in all cases where litter fresh mass is below 24 g m^2 of that value and will linearly decrease with increasing litter mass.

As an outline for developing the risk assessment schemes considering the litter layer, the PPR Panel proposes the following:

- Selection of vulnerable key species as being explained in the upcoming scientific opinion on protection goals (EFSA-Q-2009-00861)
- Development of realistic worst case scenarios with respect to exposure of and effects on key species, including ecological processes. The upcoming scientific opinion on protection goals should be considered (EFSA-Q-2009-00861)

For developing the details of this risk assessment scheme, a tiered approach is envisaged. For the development as a 1st step a reference tier should be developed and lower tiers should be calibrated with this reference tier (EFSA, 2010).

3.2.2.1. Approaches for experimentally assessing effects on litter organisms and litter break-down

When selecting potential tests for assessing effects on litter dwelling organisms at higher tier level, the following criteria should be considered:

1. Standardized laboratory test protocols already exist for the soil compartment (earthworm/enchytraeid tests[6], collembolan test[7], microbial test[8], predatory mite test[9]). In a tier 1 assessment it should be investigated if the results of these tests could be used to extrapolate the effects in the litter layer. For subsequent tiers, these protocols may need to be adapted including for instance the usage of a more relevant test medium. This should be further investigated.

2. Potentially, new protocols could also be used for the effects assessment:

    a. isopod feeding inhibition test (e.g., Ribeiro et al., 2001) covering another litter detritivore group and being more relevant for non-central European conditions.

    b. bioaccumulation with soil invertebrates should be considered in risk assessment due to the high proportion of predators in the litter food web.

    c. litterbag test[10], but placing litter on the soil surface and mimicking field relevant exposure scenarios.

3.2.2.2. Approaches for modelling litter layer according to exposure pathways

The exposure assessment of plant protection products in the litter layer assists effect assessment. Therefore the first step in exposure assessment is the definition of the types of concentrations that are needed for the effect assessment, the so-called Ecotoxicologically Relevant Concentrations (ERC) and the time aspect of these concentrations (e.g. EFSA, 2010). The Panel proposes to develop exposure assessment methodologies for the following ERCs:

---

[6] OECD 207, OECD 222, OECD 220, ISO 17512-1
[7] ISO 11267
[8] OECD 216, OECD 217
[9] OECD 226
[10] OECD Doc. 56 (2006)

1. peak, time profile, and time weighted average concentrations in the total litter layer (in terms of mass of substance per mass of dry litter).

2. peak, time profile, and time weighted average concentrations in the pore water in the total litter layer (in terms of mass of substance per volume of liquid in the litter layer).

The Panel proposes to develop a litter exposure assessment in a tiered approach. A simple conservative 1st tier could for instance be based on no crop interception and the peak concentration after applications over the years, depending on the litter break-down rates. The Panel notes again the interdependency between different soil layers (mineral soil and litter), which needs to be considered.

When developing exposure scenarios for the litter layer, the following aspects should be considered:

1. The litter layer needs to be parameterised in terms of bulk density, depth, pH, quality of organic matter, moisture content and litter mass per area. Variation in these parameters over the season should be accounted for.

2. One may expect that the properties and the thickness of the litter layer of e.g. olive orchards in southern Europe differ from that of e.g. apple orchards in Denmark, since differences in both climate and litter quality will not only affect the breakdown process itself but also the sorption behaviour of plant protection product substances. Therefore the assessment needs to be crop and climate specific.

3. Different exposure assessment methodologies may be needed for different application methods.

4. Developing an exposure assessment for the pore water in the soil litter layer. It is *a priori* unknown whether the K_{oc} concept is also valid for the litter layer. A literature search is needed to explore this.

5. The proper dissipation processes from the litter layer must be assigned. Litter as an organic substrate is highly exposed to rainfall influencing the leaching of the plant protection product as already demonstrated in artificial biomix spiked with plant protection products (De Wilde et al, 2009a; De Wilde et al, 2009b). A high flow rate will probably decrease retention time of the pesticide, which decreases the exposure time; a low flow may increase retention time and therefore also increase degradation allowing a higher microbial activity; a no-flow typical of the dry season may allow a higher residence time. The water content of the litter layer influences its lipophilicity (high in dry and low in wet litter, respectively) and strongly affects sorption and transport dynamics of plant protection products (see e.g. Goss and Madliger, 2007).

6. The litter mass per area is an important parameter to be assessed: the lower it is, the higher the probability to be consumed by organisms and thus their exposure increases.

7. The spatial unit to be considered is an agricultural field where the crop considered is grown with surface area at the scale where the plant protection products are applied (e.g. olive orchards of a few hectares). The statistical population of these spatial units is defined as all such spatial units in the area of concern for the assessment (e.g. all olive orchards in Italy or all olive orchards in the southern regulatory zone).

CONCLUSIONS AND RECOMMENDATIONS

The Panel concludes that:

- Soil litter is an ecologically relevant part of the terrestrial compartment.
- Soil litter is physically (texture, density, aggregation and water regime) and chemically (e.g. organic matter, C/N ratio) different from mineral soil.
- The soil litter layer intercepts a significant proportion of the sprayed plant protection products before they reach the mineral soil layers below.
- The environmental fate of plant protection products in litter-covered soil is expected to be different from that in bare soil.
- Uptake of plant protection products via food by soil organisms is more likely in the soil litter layer than in mineral soil.
- Not protecting the natural processes and organisms in the soil litter layer will fail the objectives of the EU regarding the protection of biodiversity and the prevention of soil erosion, organic matter decline, etc.

The Panel recommends addressing the following issues in particular:

- Definition of clear protection goals by risk managers regarding the protection of the ecological role of the litter layer in an agricultural context.
- Selection of key species and their attributes as being explained in the upcoming scientific opinion on protection goals.
- Development of realistic worst case scenarios with respect to exposure and effects on key species and ecological processes while considering the interdependency of exposure routes via different soil layers (mineral soil and litter).
- Data should be collected to underpin the parameterisation of the litter layer (e.g. decay rate, surface to mass ratio, and other parameters as for mineral soil).
- The litter mass per area is an important parameter to be assessed because its plant protection product concentration will change.
- The proper dissipation processes from the litter layer must be considered.
- Data should be collected on the temporal and spatial distribution of the composition of the litter layer (considering distribution in different crops, regions, and over different seasons) in agricultural land.

REFERENCES

Ad-Hoc-Arbeitsgruppe Boden: Wolf Eckelmann. Red.:; Sponagel H, Grottenthaler W, et al, 2005. Bodenkundliche Kartieranleitung. 5. verbesserte und erweiterte Auflage. Herausgegeben von der Bundesanstalt für Geowissenschaften und Rohstoffe in Zusammenarbeit mit den Staatlichen Geologischen Diensten der Bundesrepublik Deutschland. Hannover, 438 pp, ISBN 978-3-510-95920-4.

Alletto L, Coquet Y, Benoit P, Heddadj D and Barriuso E, 2010. Tillage management effects on pesticide fate in soils: a review. Agronomy for Sustainable Development, 30 (2), 367 – 400.

BBCH, 1994. Compendium of growth stage keys for mono- and dicotyledonous plants - extended BBCH scale. BBA, BSA, IGZ, IVA, AgrEvo, BASF, Baer & Ciba-Geigy AG, Switzerland.

Berg B, Bottner P, Box E, Breymeyer A, Ca de Anta R, Couteaux M, Escudero A, Gallardo A, Kratz W, Madeira M, Mälkönen E, McClaugherty C, Meentemeyer V, Muñoz F, Piussi P, Remacle J and Virzo de Santo A, 1993. Litter mass loss rates in pine forests of Europe and Eastern United States: some relationships with climate and litter quality. Biogeochemistry, 20, 127 - 159.

Blume H-P, and Beyer L, 1996. The definition of humus forms from soils under cultivation. I. Diagnostic properties. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft 80, 183 – 185.

Bottner P, Couteaux MM, Anderson JM, Berg B, Billes G, Bolger T, Casabianca H, Romanya J and Rovira P, 2000. Decomposition of ^{13}C-labelled plant material in a European 65-40 degrees latitudinal transect of coniferous forest soils: simulation of climate change by translocation of soils. Soil Biology and Biochemistry, 32(4), 527 - 543.

Briones MJI and Bol R, 2002. Earthworm isotopic values under different cropping treatments. The 7th International Symposium on Earthworm Ecology, 1st - 6th September 2002, Cardiff (Wales), Book of Abstracts, 115 - 116.

Cadisch G and Giller KE, 1997. Driven by Nature, Plant Litter Quality and Decomposition. CAB International, Wallingford, UK, 409 pp.

Curry JP, Byrne D and Boyle KE, 1995. The earthworm population of a winter cereal field and its effects on soil and nitrogen turnover. Biology and Fertility of Soils, 19, 166 - 172.

Curry JP, 1998. Factors affecting earthworm abundance in soils. In: Earthworm ecology, Edwards C.A. (ed), CRC Press, Boca Raton, FL USA, 37 - 64.

Daniel O, 1992. Population dynamics of *Lumbricus terrestris L.* (Oligochaeta: Lumbricidae) in a meadow. Soil Biology and Biochemistry, 24(12), 1425 - 1432.

De Wilde T, Mertens J, Simunek J, Sniegowski K, Ryckeboer J, Jaeken P, Springael D and Spanoghe P, 2009a. Characterizing pesticide sorption and degradation in micro scale biopurification systems using column displacement experiments. Environmental Pollution, 157, 463 - 473.

De Wilde T, Spanoghe P, Sniegowski K, Ryckeboer J, Jaeken P and Springael D, 2009b. Characterizing pesticide sorption and degradation in macro scale biopurification systems using column displacement experiments. Environmental Pollution, 157, 1373 - 1381.

Dinter A,Coulson M, Heimbach F, Keppler J, Krieg W and Kölzer U, 2008. Technical experiences made with the litter bag test as required for the risk assessment of plant protection products in soil. Journal of Soils and Sediments 8: 333-339.

Doherty J, 2000. PEST – model-independent parameter estimation. Watermark Computing, Corinda, Australia.

Doublet J, Mamy L and Barriuso E, 2009. Delayed degradation in soil of foliar herbicides glyphosate and sulcotrione previously absorbed by plants: consequences on herbicide fate and risk assessment. Chemosphere, 77(4), 582 – 589.

EC (European Commission), 2002. Guidance Document on Terrestrial Ecotoxicology under Council Directive 91/414/EEC (SANCO/10329/2002) rev.2 final, 17.10.2002, 1 - 39.

EC (European Commission), 2006. Proposal for a Directive of the European Parliament and of the council establishing a framework for the protection of soil and amending Directive 2004/35/EC. COM/2006/0232 final – COD 2006/0086.

Edwards CA and Bohlen P, 1996. Biology and ecology of earthworms, Chapmann & Hall, 426 pp.

Edwards WM and Shipitalo MJ, 1998. Consequences of earthworms in agricultural soils: Aggregation and porosity. In: Earthworm ecology, Edwards, CA. (ed.), CRC Press, Boca Raton, FL USA, 147 - 161.

EFSA (European Food Safety Authority), 2007. Opinion of the Scientific Panel on Plant protection products and their residues (PPR) related to the revision of Annexes II and III to Council Directive 91/414/EEC concerning the placing of plant protection products on the market - Ecotoxicological studies. The EFSA Journal, 461, 1 - 44.

EFSA (European Food Safety Authority), 2009. Scientific Opinion of the Panel on Plant Protection Products and their Residues (PPR) on the usefulness of total concentrations and pore water concentrations as metrics for the assessment of ecotoxicological effects in soil. The EFSA Journal, 922, 1-90.

EFSA (European Food Safety Authority), 2009. Scientific Report of EFSA: Report on the PPR Stakeholder Workshop Improved Realism in Soil Risk Assessment (IRIS) – How will pesticide risk assessment in soil be tackled tomorrow? The EFSA Journal 338, 1-32

EFSA (European Food Safety Authority), 2010. Scientific Opinion of the Panel on Plant Protection Products and their Residues (PPR), on outline proposals for assessment of exposure of organisms to substances in soil. The EFSA Journal, 8(1), 1442.

Encyclopaedia Brittanica, Inc. 1999. http://www.britannica.com/EBchecked/topic-art/552611/19380/The-soil-profile-showing-the-major-layers-from-the-O

Ganapathy C, 1996. Environmental fate of hexazinone. Environmental Monitoring and Pest Management Branch. Department of Pesticide Regulation, Sacramento, CA 95814 - 5624.

Gisi U, Schenker R, Schulin R, Stadelmann FX and Sticher H, 1990. Bodenökologie. Thieme, Stuttgart. 304 pp.

Goss KU and Madliger M, 2007. Estimation of water transport based on in situ measurements of relative humidity and temperature in a dry Tanzanian soil. Water Resources Research 43(5),W05433, 10 pp.

Heal OW, Anderson JM and Swift MJ, 1997. Plant litter quality and decomposition: An historical overview. In: Cadisch G and Giller KE, 1997. Driven by Nature. Plant Litter Quality and Decomposition. CAB International, Wallingford, 3 – 32.

ISO (International Organisation for Standardisation), 1999. ISO 11267. Inhibition of reproduction of Collembola (*Folsomia candida*) by soil pollutants. Geneve, Switzerland.

ISO (International Organisation for Standardisation), 2008. ISO 17512-1. Soil Quality - Avoidance test for evaluating the quality of soils and effects of chemicals on behaviour – Part 1: Test with earthworms (*Eisenia fetida/andrei*). Geneve, Switzerland.

Ke X, Winter K and Filser J, 2005. Effects of soil mesofauna and farming management on decomposition of clover litter: a microcosm experiment. Soil Biology and Biochemistry 37: 731-738.

Knacker T, Förster B, Römbke J and Frampton G, 2003. Assessing the effects of plant protection products on organic matter breakdown in arable fields. Soil Biol. Biochem. 35: 1269-1287.

Lavelle P and Spain AV, 2001. Soil Ecology. Kluwer Academic, Dordrecht, 654 pp.

Linden AMA van der, Veen JA van, and Frissel MJ, 1987. Modelling soil organic matter level after long-term applications of crop residues, and farmyard and green manures. Plant and Soil 101: 21-28.

Merli A and E Capri, 2009. Pesticide risk assessment in Vineyards: case studies in Veneto and Apulia regions. La Goliardica edizioni, 123 pp.

OECD (Organisation for Economic Cooperation and Development), 1984. Guideline for testing of chemicals. No. 207. Earthworm acute toxicity tests. Paris, France.

OECD (Organisation for Economic Cooperation and Development), 2000. Guideline for the testing of chemicals. No. 216. Soil Microorganisms, Carbon Transformation Test. Paris, France.

OECD (Organisation for Economic Cooperation and Development), 2000. Guideline for the testing of chemicals. No. 217. Soil Microorganisms, Nitrogen Transformation Test. Paris, France.

OECD (Organisation for Economic Cooperation and Development), 2004. Guideline for Testing of Chemicals No. 222. Earthworm Reproduction Test. Paris, France.

OECD (Organisation for Economic Co-Operation and Development), 2004. Guideline for Testing of Chemicals No. 220. Enchytraeidae Reproduction Test. Paris, France.

OECD (Organisation for Economic Co-operation and Development), 2006. OECD Series on Testing and Assessment No. 56. Guidance document on the breakdown of organic matter in litterbags. OECD, Paris.

OECD (Organisation for Economic Cooperation and Development), 2008. Guideline for Testing of Chemicals No. 226. Predatory mite (Hypoaspis (Geolaelaps) aculeifer) reproduction test in soil. Paris, France.

Palm CA and Rowland AP, 1997. A minimum dataset for characterization of plant quality for decomposition. In: Cadisch G and Giller KE, 1997. Driven by Nature. Plant Litter Quality and Decomposition. CAB International, Wallingford, UK, 379 - 392.

Ponge JF, 2003. Humus forms in terrestrial ecosystems: a framework to biodiversity. Soil Biology and Biochemistry 35, 935 - 945.

Ribeiro S, Sousa JP, Nogueira AJA and Soares AMVM, 2001. Effect of Endosulfan and Parathion on Energy Reserves and Physiological Parameters of the Terrestrial Isopod Porcellio dilatatus. Ecotoxicology and Environmental Safety, 49, 131 - 138.

Römbke J, Heimbach F, Hoy S, Kula C, Scott-Fordsmand J, Sousa P, Stephenson G and Weeks J (Eds), 2003. EPFES: Effects of Plant Protection Products on Functional Endpoints in Soil (EPFES Lisboa 2002). SETAC, Pensacola, USA, 92 pp.

Schaeffer A, De Jong F, Hoy S, Roembke J, Heimbach F, Sousa JP, Ross-Nickoll M and van den Brink P, 2010. Guidance from the SETAC Europe Workshop: Semi-field Methods for the Environmental Risk Assessment of Pesticides in Soil (PERAS). SETAC, Pensacola, USA (in press).

Swift MJ, Heal OW and Anderson JM, 1979. Decomposition in Terrestrial Ecosystems. Studies in Ecology 5, Blackwell Scientific Publications, Oxford, 372 pp.

Tutua SS, Goh KM and Daly MJ, 2002. Decomposition and nitrogen release of understorey plant residues in biological and integrated apple orchards under field conditions in New Zealand. Biology and Fertility of Soils, 35(4), 277 - 287.

Van Camp L, Bujarrabal B, Gentile AR, Jones RJA, Montanarella L, Olazabal C and Selvaradjou SK, 2004. Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. Luxembourg EUR 21319 EN/3, OOP EC 872 pp.

Walters J, 1997. Environmental Fate of 2,4-Dichlorophenoxyacetic Acid. Environmental Monitoring and Pest Management, Department of Pesticide Regulation, Sacramento, CA 95814 - 3510.

GLOSSARY AND ABBREVIATIONS

EFSA	European Food Safety Authority
ERA	Environmental Risk Assessment
ERC	Ecotoxicologically Relevant Concentration
EU	European Union
GD	Guidance Document
IRIS	EFSA stakeholder workshop “Improved Realism in Soil Risk Assessment (IRIS) - How will pesticide risk assessment in soil be tackled tomorrow?”
Koc	Partitioning coefficient between (soil) organic carbon and water
PPP	Plant protection product
PPR	Panel on Plant Protection Products and their Residues