Evaluating Brazil's Tiered Approach for Estimating Pesticide Exposure to Soil-dwelling Organisms

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The source of information to perform the modelling is described either in the main manuscript and in the Supplemental Material section (see Supplemental Material _Tables). The sources of information are already mentioned in the References section.

Disclaimer

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Abstract

Brazil's 2023 implementation of mandated ERA frameworks for pesticide registration requires the development of exposure assessment methodologies for soil organisms relevant to local conditions. This Brief Communication evaluates exposure assessment approaches within Brazil's ERA framework, comparing an ESCAPE Climate specific standard local worst-case scenario with locally developed crop-specific scenarios for high-tier exposure tools. Local scenarios were developed by the Brazilian authority for pesticide registration agency (i.e., IBAMA). We analyzed ten pesticides using a tiered approach, beginning with ESCAPE Climate screening and progressing to the USEPA PWC model for higher-tier refinement. Soil exposure was assessed at different depths (i.e., 5 and 10 cm) for earthworms, collembola, and soil microorganisms, incorporating both constant and variable temperature conditions. Initial screening using IBAMA's tier 1A standard scenario showed that temperature variability significantly influenced PEC_{SOIL} values, with differences up to 17% between constant and variable conditions.Most of the pesticides failed the risk assessment at this stage. Local scenario development using crop-specific parameters in both ESCAPE Climate and PWC demonstrated refined exposure estimates, with PWC generally producing lower PEC_{SOIL} values due to more comprehensive environmental fate mechanisms being considered.. This study highlights the importance of incorporating local scenarios and appropriate refinement tools in regulatory risk assessment schemes for soil organisms, particularly for tropical agricultural conditions. The findings support a tiered exposure assessment framework that balances conservative screening with realistic refinement options for Brazilian agricultural conditions.

Keywords: Soil organisms, Pesticide Soil Concentration, Soil Exposure Tools, Pesticide Environmental Risk Assessment, Tiered ERA approach

Introduction

The publication of a new regulation for pesticide registration in Brazil in 2023 rendered it mandatory to perform an Environmental Risk Assessment (ERA) as a component of the dossier evaluation (Brasil, 2023). This regulatory amendment highlighted the need to identify knowledge gaps and develop comprehensive ERA processes for non-target organisms (Brasil, 2023; Cione et al., 2024a). The Brazilian Institute of Environment and Renewable Natural Resources (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, IBAMA), as the responsible environmental agency, has been developing these ERA schemes, with significant progress made through recent research initiatives aimed at establishing frameworks for non-target organism assessment. Regarding soil organisms, the Brazilian environmental agency (henceforth referred to as the agency) started discussing the knowledge gaps in a workshop in 2023 (IBAMA, 2023), a prerequisite step before issuing guidelines on ERA schemes for soil organisms. One of the discussions was centered on the most appropriate soil exposure tool to estimate Predicted Environmental Concentrations in the soil (PEC_{SOIL}). During international conferences in Portugal and Germany (see supplemental material), the agency announced its decision to adopt ESCAPE, developed by Klein (2008), as the initial screening tool. ESCAPE is a soil exposure tool, which estimates pesticide concentrations in the soil and in the pore water. The agency subsequently released a worst-case scenario (IBAMA, n.d.) for initial screening, indicating that crop-specific scenarios would be necessary for advancing the ERA scheme for in-soil organisms. For cases where ERA requirements are not met, the agency recommended adopting numerical models for exposure refinement, though this high-tier exposure tool remains undefined.

Mackay et al. (2023) analyzed the advantages and limitations of available soil exposure tools and their applicability in Brazil. While agreeing with the agency's recommendation of ESCAPE as a low-tier exposure tool, the authors expressed their concerns about high-tier exposure tools like the Persistence in Soil Analytical Model (PERSAM) - currently used in the European Union's ERA framework (VITO NOV, 2021). They pointed out that such tools are unsuitable for Brazilian conditions due to their rigid parameterization specific to European conditions. These models rely on European-specific databases and fixed scenarios based on European Union soil maps and climate data (Tiktak et.al, 2013, VITO, 2019 and European Food Safety Authority [EFSA], 2015). Unlike the Pesticide Root Zone Model (PRZM) and ESCAPE, which allow for more flexible scenario creation, adapting PERSAM to Brazilian conditions would require extensive soil mapping and parameter adjustments, making it impractical for Brazilian regulatory purposes.

In this Brief Communication, we evaluate the benefits of using local scenarios in soil exposure tools (ESCAPE) and demonstrate the applicability of Pesticide in Water Calculator (PWC) tool as a higher-tier exposure tool in Brazilian soil organism ERA. .

The PWC is a shell of two modelling tools, Pesticide Root Zone Model (PRZM) and Variable Volume Water Model (VVWM) (U.S. Environmental Protection Agency [EPA], 2023). The former estimates pesticide fate and transport in the soil and vadose zone, while VVWM simulates pesticide concentrations in surface water bodies. Through a modeling exercise with 10 plant protection products (PPP), we assess risks according to the soil organism risk scheme discussed by Ibama (IBAMA 2023 and Cione et al. 2024b), exploring exposure refinement options as conveyed by the agency in 2024 (see supplemental material). Our study aims to: (1) demonstrate how developing local scenarios enhances the performance of ESCAPE as a lower-tier tool, making initial screenings more representative of Brazilian conditions, (2) advocate for PWC as a viable higher-tier soil exposure tool for more realistic risk assessments, and (3) highlight the necessity of expanding local scenarios to additional crops for both tools. The findings are expected to contribute significantly to the ongoing development of Brazil's soil organism risk assessment scheme for both lower-tier screening and higher-tier refinement strategies.

Materials and Methods

Pesticide exposure scheme

Figure 1 shows the pesticide exposure scheme evaluated in this article. The scheme is based on previous public considerations by IBAMA in a workshop held in 2023 (IBAMA, 2023; Cione et al., 2024b) and in a presentation at the Akademie Fresenius in June 2025 (*see Supplemental Material*). The exposure side of the ERA scheme comprises 3 tiers: 1A, 1B, and 1C. The assessment performed in this Brief Communication at each tier is described below. Table 1 presents the soil exposure tools used in each tier and their key parameters. The pesticide application rates are shown in Table S1 (*see Supplemental Material*). Additional parameters including application dates, pesticide laboratory and field half-life values ($DegT_{50}$), and soil characteristics are provided in Tables S2, S3, and S4, respectively.

For Tier 1B we developed local ESCAPE Climate crop-specific scenarios for citrus, coffee, cotton and soybeans by adapting soil and weather file inputs from available Brazilian PWC scenarios (*see Exposure calculation in this section*). These scenarios were originally developed for aquatic ERA, and we adapted them to ESCAPE by using soil and weather data from the original scenarios (*see Supplemental Material*).

These local scenarios constitute an exercise in the absence of official regulatory scenarios for ESCAPE and that no vulnerability analysis was performed. For potato and tomato, we continued to use IBAMA´s worst-case scenario, but, when applicable we incorporated refinements such as crop interception and field $DegT_{50}$. Crop interception values were set based on Table S1, however because ESCAPE Climate does not allow the user to input crop interception values for each application, we resorted to using the average value. Input crop interception values and field $DegT_{50}$ are displayed in Table S5, while specific soil input parameters for each scenario are displayed in Table S6

-Soil depth:

(a) Earthworms: 10 cm (b) Collembola and Soil Microorganisms: 5 cm.

We used the soil column depth for earthworms and collembola according to the IBAMA's presentation (*see Supplemental Material*). Regarding soil microorganisms, as there was no indication of the soil depth, we considered a soil depth of 5 cm which represents the worst-case scenario..

Evaluated pesticides -agricultural use patterns

We used the same database as Tincani et al. (2023), who initially screened 45 different pesticides. After several refinements, 15 pesticides failed the risk assessment. Of these, five pesticides are registered in other Latin American countries but not in Brazil. Considering our study focuses specifically on Brazil and the development of local scenarios, we excluded these five pesticides and analyzed the remaining ten active ingredients. The list of these pesticides and their critical agricultural practices (cGAP) is provided in the Supplementary Materials. Pesticide names were anonymized.

Exposure calculation

(i) Equations

The equations that describe the estimation of the PEC_{SOIL} values in ESCAPE Climate and in the PWC tool are provided in the supplemental material.

(ii) Screening with ESCAPE Climate: scenario and input parameters

We used a standard worst-case ESCAPE Climate scenario released by IBAMA (IBAMA, n.d.), with input parameters shown in Table S4. The study area is located near the municipality of Itapeva, São Paulo, a region with crops such as soybeans, corn, and wheat

(Instituto Brasileiro de Geografia e Estatística, 2023). The GPS coordinates and soil physicochemical parameters were provided by the agency during a workshop in November 2023 and are also described in Cione et al. (2024b). The scenario files are available on the agency's website (IBAMA, n.d.). As this is the only scenario publicly released by the agency, we used it to estimate the PEC_{SOIL}.

To compare the effect of the weather file on the modeling output, we have used ESCAPE in (a) constant conditions and (b) variable conditions, which uses the weather file made available by the agency. This weather file contains only the daily average air temperature for the region of Itapeva (*see Figure S1*).

(iii) ESCAPE - Development of local scenarios

Local scenarios were developed for citrus, coffee, cotton, and soybeans, for which there are Brazilian PWC scenarios available. In this case, we used local weather and soil input parameters from PWC scenarios developed by the agency for aquatic ERA and adapted to ESCAPE Climate (*see Soil exposure tools, item a*). For potato and tomato, although local PWC scenarios are under discussion by IBAMA, they are not available yet; therefore, no exposure assessment was performed in steps 1B and 1C (Figure 1). We used as a template IBAMA´s worst case scenario, which contains only average daily temperatures for 2023. Additional details are provided in the Supplemental Material.

(iv) PWC scenarios

As indicated in the previous item, we have used local PWC scenarios already developed and released by the agency for aquatic ERA (IBAMA, n.d.). A description of how to estimate PEC_{SOIL} values in the PWC tool is provided by Casallanovo et al. (2025). Input parameters can be found in Supplemental Material.

(v) PEC_{SOIL} values used in the risk assessment

To estimate the risks for soil organisms, we have considered the following conditions:

(a) Earthworms and Collembola: time-weighted average (TWA) PEC_{SOIL} values at 28 days as indicated by the agency (*see IBAMA's Coimbra presentation 2024 in Supplemental Material*)

(b) Soil microorganisms: as there was no indication by the agency, we considered the PEC_{SOIL} on the day of the last application (day 0), which represents the worst-case scenario.

Regarding ESCAPE Climate, we used the feature “Accumulated PEC”, which estimated the PEC_{SOIL} values after a 10-year period of multiple applications. As for the PWC, as the weather file spans a period of 35 years (1980 to 2015), we used the PEC_{SOIL} values in the last year of application (2015), which typically represents the highest value. For all exposure tools, we used estimated time-weighted average (TWA) PEC_{SOIL} values, as indicated by the agency. (see Supplemental Material).

Pesticide endpoint values

Endpoints for all evaluated soil organisms were retrieved from the Pesticide Properties DataBase (PPDB) (Lewis et al., 2016 and Pesticide Properties DataBase, 2025). They are the same as those used by Tincani et al. (2023).

Risk quotient calculation

(i) Earthworms and collembola

Based on IBAMA´s recommendation (see IBAMA´s Coimbra presentation in Supplemental Material), we have used the Toxicity Exposure Ratio approach (TER), adopted by the European Union (EFSA, 2017), and calculated as follows:

$$(1)\ TER = \frac{Effect}{Exposure};$$

This approach considers a level of concern (LOC) of 5.0 for chronic risks. Therefore, TER values above the LOC (TER >5) indicatean acceptable risk for both earthworms and collembola. The only difference regarding IBAMA’s proposition and the exercise performed in this Communication is that we did not divide TER by a factor of 2 when the log K_{OW} is higher than 2 – a procedure adopted for lipophilic PPPs by other regulatory agencies in Europe (Santé et Consommateurs, 2002), Australia (Australian Pesticides and Veterinary Medicines Authority [APVMA], 2019) and the Andean Countries (Comunidad Andina, 2019). According to van Hall et al. (2024), this correction may not be appropriate and is therefore questionable.

As for soil microorganisms, the estimated PEC_{SOIL} values were compared directly with the endpoint. If the exposure is below the effect level, the risk is considered acceptable.

Results and Discussion

Tier 1 A - Screening exposure calculation with ESCAPE Climate and risk calculation

Table 2 displays the TWA PEC_{SOIL} values for both constant (20ºC, no weather file) and variable conditions (Tier I IBAMA scenario) for different soil depths and at 0 and 28 days. PEC_{SOIL} values were estimated according to the cGAP displayed in Tables S1 (*see Supplemental Material*). Soil input data (soil density, field capacity, wilting point and organic carbon content) were the same for both conditions and are based on IBAMA's worst-case scenario; at this stage (Tier 1A), no crop interception values were considered.

For half of the pesticides, estimating the exposure under variable temperature conditions resulted in a decrease in the PEC_{SOIL} values when compared to a constant, fixed temperature; in some cases, the decrease was around -17% (Table 2). However, this result was not uniform; for the other half of the pesticides, the modeling output yielded higher PEC_{SOIL} values. The highest increase at 28 days (11 to 17 %) (Table 2) was observed for three potato crop scenarios where the date of the 1st application occurred between July 1st and July 28th (Table S1), corresponding respectively to the cGAP of Fungicide 4 and Insecticides 4 and 11. Conversely, the highest decrease in the PEC_{SOIL} was observed for the cotton scenario (Fungicide 10), for which the date of the first application occurs in December (Table S1). The difference between constant and variable scenarios is higher at 28 days than at 0-day (day of the last application).The only climatic parameter in the Itapeva weather file is the daily average air temperature. To understand its effect on the PEC_{SOIL}, we plotted the air temperature variation throughout the year and compared it with the application date (Figure S1). The month of July corresponds to the winter season in the Itapeva region, while December is already within the summer. Therefore, in July, the average air temperature is below the standard 20ºC used in ESCAPE under constant conditions, while the opposite behavior is observed in December – temperatures are above 20ºC. Because air temperature directly influences soil temperature, soil temperature is expected to follow similar seasonal patterns. According to the ESCAPE manual (Klein, 2008), the equation that is used to estimate the PEC_{SOIL} is influenced by the soil temperature, where the estimated residues are corrected/normalized against daily soil temperatures. Consequently, this normalization process can explain the different trends according to time of application.

The PEC_{SOIL} values estimated with the agency´s standard scenario was then used to estimate risks to soil organisms for each PPP (Table 3). As indicated, only Fungicide 4 passed the risk assessment. This result was expected because Fungicide 4 is not persistent in soil and only moderately toxic to soil organisms (Tincani et al., 2023). For the remaining 9 pesticides, the assessment then escalated to Tier 1B.

Tier 1B - Exposure refinement with local Brazilian scenarios in ESCAPE Climate

According to the flowchart in Figure 1, the next step at Tier 1B is to develop specific crop scenarios in ESCAPE Climate for those cases where the risk assessment fails and include refinement options such as crop interception values and field $DegT_{50}$. As discussed by Tincani et al. (2023), accounting for crop interception values will depend on the label GAP, for instance, if the label indicates a soil application, there is no crop interception. Likewise, as indicated in Tables S3 and S6, for some pesticides the field $DegT_{50}$ does not differ much from the ones estimated under laboratory conditions. Regarding local scenarios for aquatic organisms, IBAMA has already developed and released Brazilian crop-specific exposure scenarios for the PWC, including coffee, cotton, citrus and soybeans, while scenarios for crops such as potatoes and tomatoes are under discussion, but are not available yet. Therefore, in the latter case we have resorted to using the current worst-case IBAMA scenario (Itapeva) and consider, where applicable, refinements such as crop interception and/or field $DegT_{50}$, which are displayed on Table S6), while the refined TER calculation is in Table 4.

The refined TER calculation indicates that Fungicide 10 and Insecticide 15 pass the refined risk assessment. Regarding the pesticides, the exposure can be further refined with a high-tier exposure tool (Tier 1C). However, as potatoes and tomatoes do not have local crop scenarios available, we did not continue with refinements for Fungicide 2, Insecticides 4, 5, 10 and 11. This is a data gap that can be addressed either by the agency or the scientific community, but it is not within the scope of this manuscript.

Tier 1C - Exposure estimation with PWC and with local Brazilian scenarios

As a higher-tier option (1C) for the soil exposure tool, we use the USEPA PWC to estimate the PEC_{SOIL}. The feasibility of using this exposure tool has already been discussed by Casallanovo et al. (2025). As previously described in Materials and Methods, we used local crop-specific exposure scenarios for coffee and soybeans released by the agency for aquatic ERA and recalculated the TER only for the soil organism for which concerns have been observed in the previous steps, namely collembola for Fungicide 3 and earthworms for Fungicide 6. The refined risk assessment is displayed in

Table 5. The outcome indicates that Fungicide 3 passes the risk assessment for all scenarios, while Fungicide 6 fails the risk assessment for all scenarios. In the latter case, as no additional exposure refinements are available, to continue the ERA scheme, risk assessors may resort to refining the the effect endpoint by considering the geomean, SSDs, Toxicokinetic-Toxicodynamic (TKTD) approaches, or higher-tier field studies. This approach has already been discussed by the agency in previous workshops (IBAMA, 2023; Cione et al, 2024b) and might be a viable option to continue the ERA for highly toxic PPPs to soil organisms.

Conclusion

We have evaluated the exposure side of the ERA scheme for soil organisms according to Brazilian environmental authority proposition, aiming both to evaluate its feasibility and to contribute to discussions regarding the adoption of a soil organism risk assessment scheme in Brazil. The results indicated that developing local scenarios can help refine the exposure estimates further. While ESCAPE scenarios generally produce results close to worst-case estimates (Table 2), using PWC as a high-tier exposure tool (step 1C in IBAMA's proposition) showed further reductions in PEC_{SOIL} values. However, these reductions were not always sufficient to eliminate risk concerns, as demonstrated with Fungicide 6 (Table 5). Nonetheless, it still demonstrates the potential of using this tool, as it considers mechanisms that are not accounted for in ESCAPE (Casallanovo et al., 2025). To add further realism to the evaluation, an additional step that could be addressed either by the Brazilian environmental agency and/or by the academic community is to develop crop- specific exposure scenarios for an ERA scheme for soil organisms.

References

Australian Pesticides and Veterinary Medicines Authority. (2019). *APVMA risk assessment manual, Environment (Appendix E – soil organisms)*. https://www.apvma.gov.au/sites/default/files/publication/46441-appendix_e_soil_organisms.pdf

Brasil. (2023, December 27). *Lei n° 14.785 de 27 de dezembro de 2023*. Legis Senado. https://legis.senado.leg.br/norma/38039732/publicacao/38057865

Casallanovo, F., Tincani, F., Santos, G. S., Severino, M., Cione, A. P., Simone, D. M., Young, D. F., Scorza, R. P., Jr., & Chen, W. (2025). PWC tool to estimate pesticide soil concentrations for risk assessment of nontarget soil organisms. *Integrated Environmental Assessment and Management*, *21*(4), 943–951.

Cione, A., Santos, G. S., Paniago, M. G., Sales, M., & Casallanovo, F. (2024a). A new regulatory paradigm for pesticide registration in Brazil: Comments on recent legislative amendments (Law 14.785/2023). *Integrated Environmental Assessment and Management*. Advance online publication. https://doi.org/10.1002/ieam.4923

Cione, A. P., Santos, G. S., & Casallanovo, F. (2024b). Progress in the environmental risk assessment of plant protection products in Brazil: An overview of birds and mammals and soil organisms' proposals. *Integrated Environmental Assessment and Management*. Advance online publication. https://doi.org/10.1002/ieam.4975

Comunidad Andina. (2019). *Manual técnico andino para el registro y control de plaguicidas químicos de uso agrícola* (Resolución N° 2075). https://www.comunidadandina.org/DocOficialesFiles/resoluciones/RESOLUCION2075.pdf

European Food Safety Authority. (2015). *Data & PERSAM software tool* [Dataset]. European Soil Data Centre (ESDAC). https://esdac.jrc.ec.europa.eu/resource-type/soil-projects-data

European Food Safety Authority. (2017). Scientific opinion addressing the state of the science on risk assessment of plant protection products for in-soil organisms. *EFSA Journal*, *15*(2), e04690.

Instituto Brasileiro de Geografia e Estatística. (2023). *PAM - Produção agrícola municipal: Tabela 3.25 São Paulo* [PAM - Municipal agricultural production: Table 3.25 São Paulo]. https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9117-producao-agricola-municipal-culturas-temporarias-e-permanentes.html?=&t=resultados

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. (2023). *Workshop sobre bases técnico-científicas da avaliação de risco ambiental de agrotóxicos* [Workshop on the technical-scientific bases of the environmental risk assessment of pesticides]. https://www.gov.br/ibama/pt-br/assuntos/eventos/2023/ibama-promove-o-2o-workshop-sobre-bases-tecnico-cientificas-da-avaliacao-de-risco-ambiental-de-agrotoxicos

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. (n.d.). *Projeto Ibama/FDD: Implementação da avaliação de risco ambiental, item 5. 1º Workshop sobre bases técnico-científicas da avaliação de risco ambiental de agrotóxicos, cenários de exposição brasileiros - organismos aquáticos* [Ibama/FDD Project: Implementation of environmental risk assessment, item 5. 1st Workshop on technical-scientific bases of the environmental risk assessment of pesticides, Brazilian exposure scenarios - aquatic organisms]. Retrieved September 9, 2025, from https://www.gov.br/ibama/pt-br/assuntos/quimicos-e-biologicos/agrotoxicos/projeto-ibama-fdd/arquivos/202580207_OrgAqu1WS1.zip

Klein, M. (2008). *Calculation of PECsoil including plateau concentrations for pesticides dependent on FOCUS degradation kinetics: User manual ESCAPE version 2*. Fraunhofer-Institut für Umweltchemie und Ökotoxikologie. https://www.ime.fraunhofer.de/en/Research_Divisions/Division_AE/Software_E/ESCAPE.html

Lewis, K. A., Tzilivakis, J., Warner, D. J., & Green, A. (2016). An international database for pesticide risk assessments and management. *Human and Ecological Risk Assessment: An International Journal*, *22*(4), 1050–1064. https://doi.org/10.1080/10807039.2015.1133242

Mackay, N., Cione, A., Hammel, K., Jene, B., Tincani, F., & Spickermann, G. (2023). Development of a soil exposure assessment for plant protection products in Brazil: Requirements, options, and recommendations. *Integrated Environmental Assessment and Management*, *19*(4), 862–869.

Microsoft. (n.d.). Copilot [AI assistant]. Retrieved July 11, 2025, from https://copilot.microsoft.com

Pesticide Properties Database. (2025). *Ecotoxicology*. University of Hertfordshire. https://sitem.herts.ac.uk/aeru/ppdb/en/docs/5_2.pdf

Santé et Consommateurs (Directorate General Health and Consumers). (2002). *SANCO/10329/2002 Rev 2 final guidance document on terrestrial ecotoxicology under Council Directive 91/414/EEC*. European Commission.

Tincani, F., Cione, A. P., Casallanovo, F., Bottoms, M., Alvarez, T., Loutseti, S., & Thompson, H. (2023). Applying a tiered environmental risk assessment framework to estimate the risk of pesticides to soil organisms in Latin America. *Integrated Environmental Assessment and Management*, *19*(2), 446–460.

van Hall, B. G., Sweeney, C. J., Bottoms, M., & van Gestel, C. A. (2024). The influence of soil organic matter content and substance lipophilicity on the toxicity of pesticides to the earthworm *Eisenia andrei*. *Science of The Total Environment*, *917*, 170206.

VITO NV. (2019). *Update of PERSAM software models for predicting environmental concentrations in soil in permanent crops and annual crops: Software architecture* (EFSA Supporting Publication 2019:EN-1762). EFSA. https://doi.org/10.2903/sp.efsa.2019.EN-1762

VITO NV. (2021). Update of PERSAM software models for predicting environmental concentrations in soil in permanent crops and annual crops. *EFSA Supporting Publications*, *18*(1), 1756. https://doi.org/10.2903/sp.efsa.2021.EN-1756

Tiktak, A., Boesten, J., Egsmose, M., Gardi, C., Klein, M., & Vanderborght, J. (2013). European scenarios for exposure of soil organisms to pesticides. *Journal of Environmental Science and Health, Part B*, *48*, 703–716. https://doi.org/10.1080/03601234.2013.780525.

Table Caption

Table 1. Soil exposure assessment tools and parameters by tier level

Table 2. PEC_{SOIL} values for pesticides at different soil depths under constant (20ºC) and variable temperature conditions and their percent difference (%).

Table 3. Tier 1A risk estimation based on ESCAPE Climate and IBAMA worst-case scenario output. In bold, PPPs which failed the risk assessment

Table 4. Tier 1B risk estimation based on ESCAPE Climate, refined IBAMA worst-case scenario and local crop scenarios. In bold, PPPs which failed the risk assessment

Table 5. Tier 1C risk estimation based on PWC and local crop scenarios. In bold, PPPs which failed the risk assessment

Figure Caption

Figure 1. Overview of soil organism ERA exposure assessment. (A) IBAMA-specified soil column depths by organism type, and (B) tools for PEC_{SOIL} estimation. Panel A illustration created using Microsoft Copilot Artificial Intelligence (AI); Panel B content based on IBAMA (2023) and Supplemental material.

Note: IBAMA – Instituto Brasileiro do Meio Ambiente e Recursos Renováveis [*Brazilian Institute of Environment and Renewable Natural Resources*], PEC_{SOIL} -Predicted Environmental Concentration in the soil

Alt text: A two-part diagram illustrating a tiered environmental risk assessment (ERA) framework for soil organisms. Panel A is a cross-section of a soil profile showing the required assessment depths: 5 cm for collembola, soil mites, and microorganisms, and 10 cm for earthworms. Panel B is a flowchart detailing the three-tiered assessment process: Tier 1A involves initial screening using the ESCAPE analytical model with a worst-case scenario; Tier 1B involves refined assessment using ESCAPE with crop-specific scenarios if Tier 1A fails; and Tier 1C involves higher-tier assessment using the USEPA PWC model to consider additional environmental transformation mechanisms if Tier 1B fails

Figure 1.

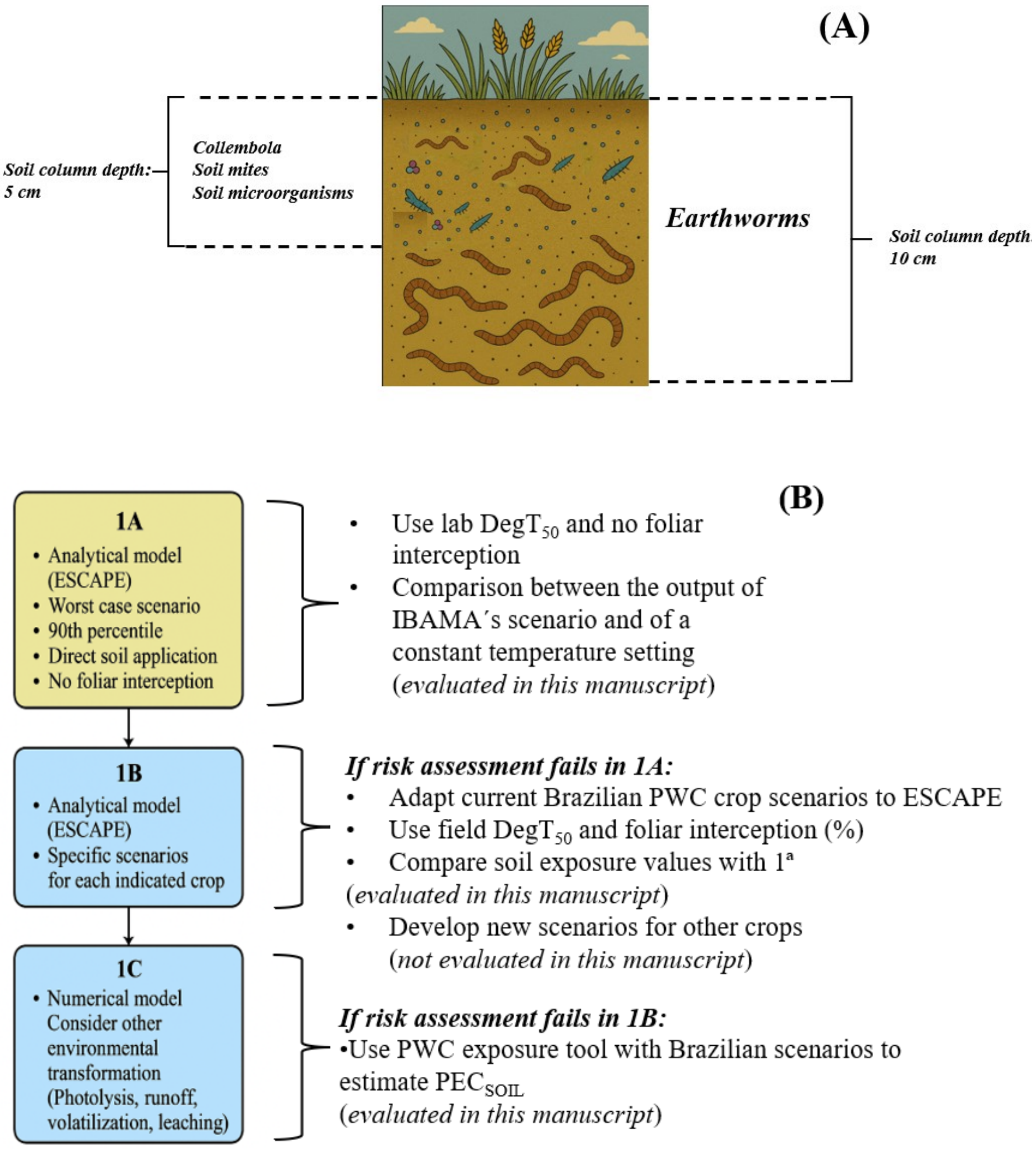
(A)
Soil column depth:
5 cm
Collembola
Soil mites
Soil microorganisms
Earthworms
Soil column depth
10 cm
(B)
1A
• Analytical model (ESCAPE)
• Worst case scenario
• 90th percentile
• Direct soil application
• No foliar interception
• Use lab $DegT_{50}$ and no foliar interception
• Comparison between the output of IBAMA´s scenario and of a constant temperature setting
(evaluated in this manuscript)
1B
• Analytical model (ESCAPE)
• Specific scenarios for each indicated crop
If risk assessment fails in 1A:
• Adapt current Brazilian PWC crop scenarios to ESCAPE
• Use field $DegT_{50}$ and foliar interception (%)
• Compare soil exposure values with 1ª
(evaluated in this manuscript)
• Develop new scenarios for other crops
(not evaluated in this manuscript)
1C
• Numerical model
Consider other environmental transformation (Photolysis, runoff, volatilization, leaching)
If risk assessment fails in 1B:
•Use PWC exposure tool with Brazilian scenarios to estimate PEC_{SOIL}
(evaluated in this manuscript)

Table 1. Soil exposure assessment tools and parameters by tier level

Tier	Tool Used	Description	Key Parameters
1A	ESCAPE Climate	Initial screening	- IBAMA's worst-case scenario (Tier-1_IBAMA) - 0% crop interception - Laboratory $DegT_{50}$
1B	ESCAPE Climate	Refined assessment	- Local crop-specific scenarios - Crop interception (if applicable) - Field $DegT_{50}$
1C	USEPA PWC	Higher-tier assessment	- Local crop-specific scenarios - Crop interception (if applicable) - Field $DegT_{50}$ - Most refined parameters: application method, soil layers*, crop-specific parameters**

*Multiple of soil horizons and its parameters (e.g. soil horizon thick, soil horizon density)
**Emergence, maturity and removal dates, root depth, canopy details (cover, height and hold-up)

Note:

USEPA – United States Environmental Agency, PWC – Pesticide in Water Calculator, IBAMA – Instituto Brasileiro do Meio Ambiente e Recursos Renováveis [*Brazilian Institute of Environment and Renewable Natural Resources*]

$DegT_{50}$ – pesticide half-life in soil

Table 2

Molecule	Crop	Soil depth (cm)	PEC_{SOIL} (mg a.i./kg soil dw)					
			0-day			28-day, TWA		
			Constant	Variable	Difference (%)	Constant	(b)Variable	Difference (%)
Fungicide 2	Potato	5	5.57	5.41	- 2.88	5.49	5.33	- 2.94
		10	2.79	2.71		2.75	2.67	
Fungicide 3	Soybeans	5	2.10	2.19	+ 4.59	1.56	1.71	+ 10.1
		10	1.05	1.09		0.778	0.857	
Fungicide 4	Potato	5	3.35	3.71	**+ 10.8**	2.00	2.35	**+ 17.3**
		10	1.67	1.86		1.00	1.17	
Fungicide 6	Coffee	5	0.525	0.520	- 0.93	0.493	0.485	- 1.46
		10	0.263	0.260		0.246	0.243	
Fungicide 10	Cotton	5	0.265	0.231	**- 12.8**	0.198	0.164	**-17.4**
		10	0.133	0.116		0.099	0.0817	
Insecticide 4	Potato	5	10.3	11.0	+ 6.36	7.60	8.58	+ 12.9
		10	5.17	5.50		3.80	4.29	
Insecticide 5	Tomato	5	7.43	7.18	- 3.36	7.29	7.00	- 3.92
		10	3.72	3.59		3.64	3.50	
Insecticide 10	Potato	5	1.49	1.50	+ 0.66	1.39	1.42	+ 1.94
		10	0.743	0.748		0.697	0.710	
Insecticide 11	Potato	5	2.11	2.20	+ 4.73	1.17	1.31	+ 11.6
		10	1.05	1.10		0.587	0.655	
Insecticide 15	Citrus	5	0.513	0.510	- 0.58	0.470	0.456	- 2.83
		10	0.256	0.255		0.235	0.228	

Note 1: values were rounded up

Note 2: PEC_{SOIL} -Predicted Environmental Concentration in the soil, TWA – time-weight average

Table 3.

Molecule	Earthworm, NOEC	28-day PEC_{SOIL} TWA, 10 cm	TER	Collembola, NOEC	28-day PEC_{SOIL} TWA, 5 cm	TER	C&N, effect	0-day PEC_{SOIL}, 5 cm	Risks?	Final Result
Fungicide 2	1.2	2.67	**0.45**	1000	5.33	187	8	5.41	No	**Fail**
Fungicide 3	1.0	0.857	**1.17**	0.36	1.71	**0.21**	2	**2.19**	**Yes**	**Fail**
Fungicide 4	50	1.17	42	18	2.35	7.66	4.8	3.71	No	Pass
Fungicide 6	0.75	0.243	**3.09**	55.8	0.485	115	3.33	0.520	No	**Fail**
Fungicide 10	0.315	0.082	**3.86**	5	0.164	30.6	1	0.231	No	**Fail**
Insecticide 4	0.84	4.29	**0.19**	0.21	8.58	**0.02**	4.0	**11.0**	**Yes**	**Fail**
Insecticide 5	12.7	3.50	**3.6**	0.08	7.00	**0.01**	6.4	**7.18**	**Yes**	**Fail**
Insecticide 10	500	0.710	704	0.08	1.42	**0.06**	0.893	**1.50**	**Yes**	**Fail**
Insecticide 11	1.8	0.655	**2.75**	9.26	1.31	7.07	3.33	2.20	No	**Fail**
Insecticide 15	0.29	0.228	**1.27**	3.38	0.456	7.41	8	0.51	No	**Fail**

Note 1: values were rounded up
Note 2: NOEC = No Observed Effect Concentration, values in mg a.i./kg soil
PEC_{SOIL} -Predicted Environmental Concentration in the soil, values in mg a.i./kg soil dw
TWA – time-weight average
TER = Toxicity Exposure Ratio
C&N = carbon and nitrogen studies. Units are in mg a.i./kg soil

Table 4.

Molecule	Scenario name	Earthworm, NOEC	28-day PEC_{SOIL} TWA, 10 cm	TER	Collembola, NOEC	28-day PEC_{SOIL} TWA, 5 cm	TER	C&N, effect	0-day PEC_{SOIL}, 5 cm	Risks?	Final Result
Fungicide 2	IBAMA Tier I	1.2	1.41	**0.85**	1000	2.82	355	8	2.92	No	**Fail**
Fungicide 3	Alegria	1.0	0.134	7.48	0.36	0.267	**1.35**	2	0.373	No	**Fail**
	LEM		0.105	9.51		0.210	**1.71**		0.312	No	
	Nova Candelaria		0.133	7.51		0.267	**1.35**		0.373	No	
Fungicide 6	Coqueiral	0.75	0.245	**3.06**	55.8	0.477	117	3.33	0.530	No	**Fail**
	Jaguaré		0.178	**4.21**		0.353	158		0.403	No	
	Santana da Vargem		0.245	**3.06**		0.477	117		0.530	No	
Fungicide 10	Brasnorte	0.315	0.0268	11.7	5	0.0536	93.3	1	0.0848	No	Pass
	LEM		0.0219	14.4		0.0438	114		0.0709		
	Sapezal		0.0221	14.3		0.0442	113		0.0696		
	Sorriso		0.0262	12.0		0.0525	95.2		0.0838		
Insecticide 4	IBAMA Tier I	0.84	2.74	**0.31**	0.21	5.47	**0.04**	4.0	**9.17**	**Yes**	**Fail**
Insecticide 5	IBAMA Tier I	12.7	0.527	24.1	0.08	1.05	**0.08**	6.4	1.37	No	**Fail**
Insecticide 10	IBAMA Tier I	500	0.614	814	0.08	1.22	**0.06**	0.893	**1.37**	**Yes**	**Fail**
Insecticide 11	IBAMA Tier I	1.8	0.479	**3.76**	9.26	0.958	9.66	3.33	1.69	No	**Fail**
Insecticide 15	Avai/Duartina*	0.29	0.0386	7.51	3.38	0.0772	43.8	8	0.120	No	Pass
	Ipigua		0.0367	7.90		0.0735	46.0				
	Itajobi		0.0376	7.71		0.0752	44.9				
	José Bonifacio		0.0366	7.92		0.0732	46.2				

*Local soil input data *(see Table S5*) and weather file are the same

Note 1: values were rounded up

Note 2: NOEC = No Observed Effect Concentration, values in mg a.i./kg soil

PEC_{SOIL} -Predicted Environmental Concentration in the soil, values in mg a.i./kg soil dw

TWA – time-weight average

TER = Toxicity Exposure Ratio

C&N = carbon and nitrogen studies. Units are in mg a.i./kg soil

Table 5.

Molecule	Crop	Scenario name	Collembola, NOEC	28-day TWA PEC_{SOIL} (mg a.i./kg soil dw), 5 cm	TER
Fungicide 3	Soybeans	Alegria	0.36	0.0423	8.51
		LEM		0.0496	7.25
		Nova Candelária		0.0054	66
Molecule	**Crop**	**Scenario name**	**Earthworm, NOEC**	**28-day TWA PEC_{SOIL} (mg a.i./kg soil dw), 10 cm**	**TER**
Fungicide 6	Coffee	Coqueiral	0.75	0.172	**4.36**
		Jaguaré		0.156	**4.81**
		Santana da Vargem		0.197	**3.81**

Note: LEM – Luis Eduardo Magalhães, Bahia state
NOEC = No Observed Effect Concentration, values in mg a.i./kg soil
PEC_{SOIL} -Predicted Environmental Concentration in the soil, values in mg a.i./kg soil dw
TWA – time-weight average
TER = Toxicity Exposure Ratio