



**HAL**  
open science

# An R package to calculate potential environmental and human health risks from pesticide applications using the ‘Pesticide Load’ indicator applied in Denmark

Niklas Möhring, Per Kudsk, Lise Nistrup Jørgensen, Jens Erik Ørum, Robert Finger

## ► To cite this version:

Niklas Möhring, Per Kudsk, Lise Nistrup Jørgensen, Jens Erik Ørum, Robert Finger. An R package to calculate potential environmental and human health risks from pesticide applications using the ‘Pesticide Load’ indicator applied in Denmark. *Computers and Electronics in Agriculture*, 2021, 191, pp.106498. 10.1016/j.compag.2021.106498 . hal-03577036

**HAL Id: hal-03577036**

**<https://hal.science/hal-03577036>**

Submitted on 5 Jan 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

## **An R package to calculate potential environmental and human health risks from pesticide applications using the ‘Pesticide Load’ indicator applied in Denmark**

### **Authors:**

Niklas Möhring (Agricultural Economics and Policy Group, ETH Zürich, Switzerland and CEBC-CNRS, France) (corresponding author: [nmoehring@ethz.ch](mailto:nmoehring@ethz.ch))

Per Kudsk (Aarhus University, Denmark)

Lise Nistrup Jørgensen (Aarhus University, Denmark)

Jens Erik Ørum (Copenhagen University, Denmark)

Robert Finger (Agricultural Economics and Policy Group, ETH Zürich, Switzerland)

### **Highlights**

- New R-package for the computation of the Danish ‘Pesticide Load’ indicator.
- Computes potential environmental and health risks for all pesticide applications.
- Simple implementation to easily compute and compare data on potential pesticide risks.
- Can integrate properties automatically from the Pesticide Properties Database.
- Flexibility to adjust indicator reference values.

### **Abstract**

This paper presents and discusses the “PesticideLoadIndicator” package, a new R-package to compute potential environmental and health effects of pesticide applications using the Danish ‘Pesticide Load’ indicator. The implementation in the R *Statistical Language* makes it easy for researchers, practitioners and institutions to compare potential pesticide risks for a wide range of applications and compute risk indicators at field-, crop-, farm-, regional- or national level. The tool is publicly available. It provides a possibility for the direct integration of pesticide properties needed for indicator computation (ecotoxicity, environmental fate and human health), from the Pesticide Properties Database or other sources and allows users to change default reference values and weights.

## 1 **Introduction**

2 The reduction of environmental and health risks from agricultural pesticide use is at the top of the  
3 agenda of food-value chain actors and policymakers worldwide (Möhring et al., 2020). For example,  
4 the EU's sustainable use directive (EU Directive 128/2009EC) prescribes the use of Integrated Pest  
5 Management and all EU Member States have published National Action Plans for pesticide risk  
6 reduction that should be updated regularly. The European Commission has further emphasized these  
7 goals in its recent "Farm to Fork" strategy by demanding a 50% pesticide risk reduction by 2030  
8 (Schebesta and Candel, 2020).

9 However, the extreme heterogeneity of pesticides and their active ingredients complicate the  
10 evaluation of pesticide use, the implementation of risk reduction goals but also the development of  
11 suitable tools and policies to achieve such risk reductions (Möhring et al., 2019). Thus, tangible and  
12 transparent pesticide indicators are needed, which can be aggregated on a field and crop-, farm- or  
13 regional level and which account for the heterogeneity of active substances with regard to their  
14 potential effects on the environment and human health. However, such indicators have not been  
15 developed in most European countries so far (European Court of Auditors, 2020).

16 As a possible role model, the 'Pesticide Load' indicator, which accounts for potential environmental  
17 and health effects of pesticides on a product level, has been developed in Denmark (Kudsk et al.,  
18 2018). Other prominent examples for pesticide risk indicators include the EIQ and SYNOPSIS models  
19 (Kovach et al., 1992, Strassemeyer et al., 2017). Further, studies have assessed pesticide risks globally  
20 or their development over time (Schulz et al., 2021, Tang et al., 2021). The advantage of the here used  
21 Pesticide Load' indicator is that it can jointly account for potential fate, ecotoxicity and human health  
22 effects, has comparably low data requirements and is therefore easily scalable. The 'Pesticide Load'  
23 indicator is further broadly implemented and tested in practice: i) it is used as an indicator for the  
24 spatio-temporal assessment of pesticide risk reduction goals under the Danish National Action Plan  
25 and ii) as a basis for the Danish pesticide tax (Kudsk et al 2018). Due to its broad scope in line with  
26 current EU policy goals and its scalability, the indicator has a wide range of potential applications in  
27 institutions, industry and research (Möhring et al., 2019, Jørgensen et al., 2019, Ehlers et al., 2021). So  
28 far, however, no tangible and transparent public tool for indicator computation was available. To make  
29 the 'Pesticide Load' indicator easily accessible to a large range of stakeholders, e.g. for research,  
30 education and policy evaluation, we here present and discuss a package in the R *Statistical Language*  
31 (R Core Team, 2020) for indicator computation (Möhring et al., 2021).

32 The package allows users to compute the Pesticide Load and its sub-indicators for potential  
33 Ecotoxicity, Environmental Fate and Human Health effects based on pesticide application data. It  
34 further provides a possibility for the direct integration of pesticide properties, needed for the  
35 computation, from the Pesticide Properties Database (Lewis et al., 2016). Finally, it is flexible to

36 integrate other data sources and/or adjust default (Danish) reference values and weights for indicator  
37 computation.

38 Following, we briefly describe the indicator, its background and limitations, provide a description of  
39 the package and its functions and give an example of its application using integrated test data.

#### 40 **Description of the Pesticide Load indicator**

41 The Pesticide Load and its sub indicators are computed for each pesticide product (eq. 1 & 2). They  
42 may then be aggregated at a field and crop-, farm, regional or national level. We further provide the  
43 Load Index in the package, given applied standard dosages are provided.

44 (1) Pesticide Load [Load units per kg/l product] = Ecotoxicity Load + Environmental Fate Load +  
45 Human Health Load

46 (2) Load Index [Load per standard dosage] = Pesticide Load \* Applied standard dosages of  
47 product (standard dosage of product defined in national pesticide databases)

48 The *Ecotoxicity Load* is calculated, based on 11 LC/LD/EC50 (median lethal dose/concentration) and  
49 NOEC (No Observed Effect Concentration) parameters. Eight of these parameters relate to acute  
50 ecotoxicity/short-term effects of active substances on birds, mammals, fish, daphnia, algae, aquatic  
51 plants, earthworms, bees, while three relate to chronic ecotoxicity/long-term effects on fish, daphnia  
52 and earthworms, respectively. Values for chronic ecotoxicity are adjusted for degradation rate of the  
53 active ingredient in case half-life values in soil and water are available.

54 The *Environmental Fate Load* is based on three parameters: the half-life in soil (DT<sub>50</sub>), the  
55 bioaccumulation factor (or the log P<sub>ow</sub> value if no BCF value is reported) and the SCI-GROW index  
56 that reflects the mobility and risk of leaching to the groundwater of the active ingredient and the major  
57 metabolites listed in the Pesticide Properties Database.

58 Whereas the calculation of the Ecotoxicity and Environmental Fate Loads are based on properties of  
59 the active ingredients in the product and are then aggregated on a product level, the *Human Health*  
60 *Load* is directly calculated based on the risk phrases and symbols on the product label and the  
61 formulation of the products. It should be noticed that the Human Health sub-indicator primarily  
62 addresses the potential exposure of operators (and to a lesser extent by-standers), but not consumers,  
63 who are mainly exposed via pesticide residues in food and drinking water. All ecotoxicology and  
64 environmental fate values are normalized by reference values (the active ingredient with the maximum  
65 or minimum value depending on the parameter in question) and weighted according to the (Danish)  
66 weighting scheme described in Kudsk et al. (2018). The weighting scheme was introduced to ensure  
67 that Ecotoxicology, Environmental Fate and Human Health each contributed with approx. 1/3 at a  
68 national level in the reference year 2007. Furthermore, it guaranteed that all Ecotoxicology and  
69 Environmental Fate parameters contributed to the overall values. For example, in 2007 aquatic

70 ecotoxicity related parameters, bees, bird, as well as mammals and earthworms (=soil organisms)  
71 contributed 41, 21, 18 and 21% to the Ecotoxicology load aggregated at national level. However, the  
72 package explicitly allows users to also change reference values and weights to adapt the indicator to  
73 other countries and circumstances and easily access respective changes in Load values. This allows  
74 testing hypothetical scenarios of changes in reference values and weighting, e.g. for the  
75 implementation in other countries with different preferences. However, note that such changes shift  
76 weights between the three main categories (Human Health, Fate, Ecotoxicity) and relative importance  
77 of pesticide properties (e.g. ecotoxicity for bees vs. aquatic organisms). For a detailed description of  
78 the Pesticide Load and the Load Index on different aggregation levels see Kudsk et al. (2018) and  
79 Möhring et al. (2019).

80 It should be stressed that the “PesticideLoadIndicator” tool made available here is not identical to the  
81 Danish Pesticide Load used by the Danish authorities and the calculated pesticide loads may therefore  
82 be different. This is because pesticide products and their formulation may differ and change over time  
83 and country and pesticide properties data from the Pesticide Properties Database may have been  
84 amended and completed. The here computed indicators should further not be confused with the so  
85 called “Pesticide Load Indicator (PBI)”, which indicates Load on a national level divided by a  
86 reference area (conventionally grown and sprayed crops in 2010) and is sometimes used in Denmark.

### 87 **Data availability, requirements, and preparation**

88 Computation of the Pesticide Load and the Environmental Fate, Ecotoxicity and Human Health Load  
89 with the package requires pesticide application data and human health properties (risk statements) on a  
90 product level, as well as information on active ingredients of the applied pesticides, their concentration  
91 and fate, as well as ecotoxicity properties, as indicated above. Data on standard dosages and human  
92 health properties (risk statements) of products is publicly accessible in national pesticide registers.  
93 Substance properties data used for the computation of the ‘Pesticide Load’ indicator is publicly  
94 accessible, e.g. through EU dossiers on the authorization of pesticide products. A central collection of  
95 this information is, for example, provided by the Pesticide Properties database (PPDB, Lewis et al.,  
96 2016). The here presented tool allows users to integrate a database version of the PPDB (licensed) and  
97 automatically draw required information for indicator computation<sup>1</sup> or provide information from other  
98 information sources themselves.

99 Due to the heterogeneity (in quality) of pesticide use data and the low accessibility of national  
100 databases on registered pesticides, the computation of the ‘Pesticide Load’ indicator often requires  
101 substantial work to collect and prepare data. Further tools for data scraping and manipulation,

---

<sup>1</sup> Further, note that the package is regularly updated to account for potential changes in the PPDB so that workload for users with an updated version (i.e. licensed users) is significantly reduced. CRAN further provides the possibility to use previous version of the package, which might be more compatible if older versions of the PPDB are used.

102 complementing the here presented tool for indicator computation should be developed to render  
103 pesticide risk indicators more accessible.

#### 104 **Package structure and functions**

105 The package is publicly accessible to (R) users through the CRAN network. It provides several  
106 functions to compute the Load Index, the Pesticide Load, the Fate Load, the Ecotoxicity Load and the  
107 Human Health Load for application-level pesticide use data:

108 **Table 1.** Functions of the ‘PesticideLoadIndicator’ package

Function	Description
<code>compute_pesticide_load_indicator (...)</code>	Computes indicators based on user supplied tables of pesticide applications and information on their active ingredients, including ecotoxicity, human health and fate properties.
<code>match.ppdb (...)</code>	Expands basic pesticide use data with information on pesticide properties (ecotoxicity, fate and human health), needed to compute the Pesticide Load, based on CAS numbers. Requires access to the Pesticide Properties Database.
<code>compute_risk_score(...)</code>	Compute human health risk sum scores on a product level based on a list of H-Phrases.
<code>check_substance_column_names (...)</code>	Check names of supplied tables with active substance information.
<code>check_products_column_names (...)</code>	Check names of supplied tables with pesticide application information.

109

#### 110 **Reproducible example**

111 Following, we provide a reproducible R code on how to compute the pesticide indicators and discuss  
112 the outcome. We compute the indicators for four pesticide applications in Switzerland (example data  
113 provided in the package):

114 *# Install and load the PesticideLoadIndicator package*

115 *install.packages("PesticideLoadIndicator")*

116 *library(PesticideLoadIndicator)*

```

117 # Load the dataframe containing the pesticide use data.
118 products_user <- products.load()
119 # Load the (user-supplied) dataframe with detailed information on used pesticides.
120 substances_user <- substances.load()
121 # Example for optional changes of reference values and weights: here earthworms (not executed)
122 # substances_user$Reference.Value.Earthworms.Chronic <- 0.3
123 # substances_user$Load.Factor.Earthworms.Chronic <- 3
124 # Compute the Pesticide Load and its sub-indicators using the supplied data.
125 indicators_user <- compute_pesticide_load_indicator(substances = substances_user,
126 products= products_user)
127 This provides us with the following indicator values for the Pesticide Load, Health Load, Ecotoxicity
128 Load, Fate Load, Standard Treatment Index and Load Index for the four pesticide applications (note
129 that the optional adjustments to reference values and weights for earthworms were not executed):

```

Product applied	Crop	Amount applied (kg/ha)	Health Load	Ecotoxicity Load	Fate Load	Pesticide Load	Standard Treatment Index	Load Index
Agora®	Sugar beets	0.4	0.750	0.31	0.18	1.24	0.50	0.62
Alanto®	apple	0.53	0.125	0.57	0.03	0.72	1.67	1.20
Aniten®	wheat	0.25	0.100	0.06	0.14	0.30	0.09	0.03
Artist®	potato	2.0	0.650	0.27	0.15	1.07	0.80	0.85

```

130 Please see the package description for a reproducible example of how to compute the indicators only
131 based on simple pesticide use data, i.e. using the Pesticide Properties Database to expand data with
132 needed information on pesticide properties.

```

### 133 Discussion & Conclusion

134 We here describe and discuss the “PesticideLoadIndicator” package. It allows practitioners,  
135 researchers and administrations to straightforward compute potential environmental and health risks of  
136 pesticides, based on the Danish ‘Pesticide Load’ indicator. The ‘Pesticide Load’ indicator has a high  
137 relevance for current debates on pesticide risk reduction (e.g. in the European Union), as it jointly  
138 accounts for potential ecotoxicity, fate and human health effects of pesticides and is easily scalable  
139 across products and aggregation levels.

140 The package thus contributes to i) make the indicator available to a wide range of interested  
141 stakeholders, ii) standardize its computation and make it transparent, and iii) easily assess effects of  
142 changes in default (Danish) reference values and weights.

143 Additional tools to collect and prepare data on pesticide use and properties would complement the  
144 here presented tool for indicator computation. Further, a transfer of the developed tool into a more

145 accessible and interactive format in the future (e.g. an R Shiny application) would make it more  
146 attainable to a broader audience, such as certain groups of practitioners.

147



148 **References**

- 149 Ehlers, M. H., Huber, R., & Finger, R. (2021). Agricultural policy in the era of digitalisation. *Food Policy*, 102019.
- 150 European Court of Auditors (2020). Special Report 05/2020: Sustainable Use of Plant Protection Products:  
151 Limited Progress in Measuring and Reducing Risks.
- 152 European Commission, 2009. Directive 2009/128/EC of the European Parliament and of the Council of 21  
153 October 2009.
- 154 Jørgensen L.N., Kudsk P. & Ørum J.E. (2019). Links between pesticide use pattern and crop production in  
155 Denmark with special reference to winter wheat. *Crop Protection*, 119, 147-157.
- 156 Kovach, J., Petzoldt, C., Degni, J., & Tette, J. (1992). A method to measure the environmental impact of  
157 pesticides.
- 158 Kudsk, P., Jørgensen, L. N., & Ørum, J. E. (2018). Pesticide Load—A new Danish pesticide risk indicator with  
159 multiple applications. *Land Use Policy*, 70, 384-393.
- 160 Lewis, K. A., Tzilivakis, J., Warner, D. J., & Green, A. (2016). An international database for pesticide risk  
161 assessments and management. *Human and Ecological Risk Assessment: An International Journal*,  
162 22(4), 1050-1064.
- 163 Möhring, N., Gaba, S., & Finger, R. (2019). Quantity based indicators fail to identify extreme pesticide risks.  
164 *Science of the total environment*, 646, 503-523.
- 165 Möhring, N., Ingold, K., Kudsk, P., Martin-Laurent, F., Niggli, U., Siegrist, M., ... & Finger, R. (2020). Pathways for  
166 advancing pesticide policies. *Nature food*, 1(9), 535-540.
- 167 Möhring, N., Finger, R., Kudsk, P., Vidensky, L., Schmitt, U., Nistrup Jørgensen, L., & Ørum, J. E. (2021).  
168 PesticideLoadIndicator (R-Package).
- 169 R Core Team (2020). R: A language and environment for statistical computing. R Foundation for  
170 Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- 171 Schebesta, H., & Candel, J. J. (2020). Game-changing potential of the EU's Farm to Fork Strategy. *Nature Food*,  
172 1(10), 586-588.
- 173 Schulz, R., Bub, S., Petschick, L. L., Stehle, S., & Wolfram, J. (2021). Applied pesticide toxicity shifts toward  
174 plants and invertebrates, even in GM crops. *Science*, 372(6537), 81-84.
- 175 Strassemeyer, J., Daehmlow, D., Dominic, A. R., Lorenz, S., & Golla, B. (2017). SYNOPSIS-WEB, an online tool for  
176 environmental risk assessment to evaluate pesticide strategies on field level. *Crop protection*, 97, 28-  
177 44.
- 178 Tang, F.H., Lenzen, M., McBratney, A. and Maggi, F., 2021. Risk of pesticide pollution at the global scale. *Nature*  
179 *Geoscience*, 14(4), pp.206-210.