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Pesticide Load—A new Danish pesticide risk indicator with multiple applications

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ABSTRACT

Pesticides provide growers with an effective tool for the control of damaging crop pests preventing yield losses that could jeopardise food security. In recent years the potentially adverse effects of their use on human health and the environment has received increasing attention by the public and the competent authorities. In this context reliable pesticide risk indicators are pivotal to assess the potential risk associated with the use of pesticide. Several pesticide risk indicators, serving various purposes, have been developed over the years. Recently, a new pesticide risk indicator, the Pesticide Load (PL), was introduced in Denmark. The PL has replaced the Treatment Frequency Index (TFI) as the official pesticide risk indicator. The PL consists of three sub-indicators for human health, ecotoxicology and environmental fate, respectively. For each of the three sub-indicators a pesticide load (PL) is calculated and expressed as the PL per unit commercial product (kg, L or tablet). PL for human health (PL_{HH}) is based on the risk phrases on the product label, while PL for ecotoxicology (PL_{ECO}) is calculated on basis of the LC/LD/EC_{50} values of the active ingredients for acute toxicity to mammals, birds, fish, daphnia, algae, aquatic plants, earthworms and bees and NOEC values for chronic toxicity to fish, daphnia and earthworms. PL for environmental fate (PL_{FATE}) is calculated on basis of the half-life in soil (DT_{50}), the bioaccumulation factor (BCF) and the SCI-GROW index. PL does not consider the actual exposure, i.e. it reflects the relative risks associated with the use of pesticides. Besides using PL for monitoring the yearly trend in pesticide use and load, the PL was also used for setting up a new pesticide tax scheme and for setting quantitative reduction targets. In Denmark, it is now compulsory for farmers to upload their pesticide use data, i.e. the annual pesticide statistics and the calculation of the PL can be produced on basis of pesticide use data rather than sales data that may not reflect the actual use by farmers. Because pesticide use data is available for each farm, maps providing detailed information on pesticide use in different regions can be produced. From 2010/11 to 2013/14 only minor differences were observed in the PL and, overall, similar trends were observed for the PL and TFI. Significant geographical differences, which could be attributed to differences in crop rotations, were apparent when estimating PL for each of the four major groups of pesticides (herbicides, fungicides, insecticides and plant growth regulators). The maps produced from the pesticide use data revealed significant variation in PL for ecotoxicological effects on aqueous organisms and bees as well as environmental parameters such as leaching potential. It is suggested to use the maps to identify 'hot spots' and design monitoring programmes or to launch initiatives that can reduce the PL. By linking information on mode of action to each commercial pesticide product it was also possible to obtain detailed information on the use pattern of the various pesticide modes of action, which is relevant information assessing the risk of evolution of pesticide resistance.

1. Introduction

In several European countries, including Denmark, an increasing public awareness of the potentially adverse effects of pesticides on human health and the environment has translated into pesticide action plans aimed at reducing or restricting the use of pesticides or the adverse impacts of pesticide use and promoting integrated pest management (IPM) and organic farming practices (Lamichhane et al., 2016). In 2009, the European Union adopted Directive 128/2009EC establishing a framework for EU actions to promote a sustainable use of pesticides (European Commission, 2009). According to the directive EU member states are obliged to promote low pesticide-input pest management defined as IPM or organic farming. The directive lists eight general IPM principles that all professional users of pesticides have had

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to comply with since 1. January 2014 (Barzman et al., 2015).

IPM programmes were in place in Switzerland and Italy (Barzman et al., 2015; Galassi and Sattin, 2014) prior to the adoption of Directive 128/2009EC but otherwise IPM has not previously been promoted in Europe. It is implicit assumed that adoption of IPM by EU farmers will reduce the risks associated with the use of pesticides but the directive does not set specific goals. It is, however, foreseen that harmonised indicators should be developed to provide tools to monitor the beneficial impact of a wider adopting of IPM practices.

Since the 1990′ies, several pesticide risk indicators have been developed and a few studies have compared specific components of some of the pesticide risk indicators (e.g. Reus et al., 2002; Bockstaller et al., 2008). One of earliest and most widely used risk indicators is the Environmental Impact Quotient (EIQ) (Kovach et al., 1992). The EIQ consists of three components, a farm worker component aggregating human toxicity information, a consumer component aggregating human chronic toxicity, pesticide fate in soil and food and leaching to groundwater and an ecological component adding up effects on aquatic and terrestrial organisms. For each parameter evaluated EIQ uses a rating system from 1 (least harmful) to 5 (most harmful). The overall EIQ is expressed as the average value of the three components. The EIQ has been applied in studies assessing trends in impact of pesticides in orchard fruit in the UK over years (Cross, 2012), reduced risk programmes versus conventional pesticide programmes (Biddinger et al., 2014), the environmental impact of glyphosate resistant weeds in Canada (Beckie et al., 2013) and in studies comparing cropping systems based on conventionally bred crops with genetically-modified herbicide resistant crops both *ex-ante* (Tillie et al., 2014) and *ex-post* (Stewart et al., 2011).

SYNOPS is a risk indicator developed in Germany to assess environmental risks (Gutsche and Rossberg, 1997). Besides pesticide use data SYNOPS also requires information on crop stage, application technique, soil type, location, topography of the field etc. Based on this information, SYNOPS calculates the Predicted Environmental Concentrations (PEC) for different compartments and compare the PEC values to the LC_{50} and NOEC values for the various target organisms and Exposure Toxicity Ratios (ETR) are calculated for each target organism. In contrast to EIQ, SYNOPS considers the effect of mitigation measures such as buffer zones or low drift spraying equipment because the concept is based on the calculation of PEC values. SYNOPS was developed to assess the environmental risks at farm or regional level but not at national level. Recently, a web-based version of SYNOPS (SYNOPS-WEB) was launched (Strassemeyer et al., 2017). In addition, a modified version of SYNOPS named SYNOPS-TREND has been developed to assess environmental risk based on sales data for comparing the impact of pesticide use over several years (Gutsche and Strassemeyer, 2007).

I-Phy (former name Ipest) was developed by van der Werf and Zimmer (1998) and is a so-called fuzzy expert system. I-Phy calculates the risk of surface water contamination, risk of groundwater contamination and risk of air contamination based on information on pesticide properties, site specific conditions and application conditions. I-Phy has been used to assess the sustainability of cropping systems in France (Bockstaller et al., 2008; Chikowo et al., 2009) and recently an improved groundwater module was published (Lindahl and Bockstaller, 2012).

Another pesticide risk indicator is the Environmental Yardstick for Pesticides (EYP) developed in the Netherlands (Reus and Leendertse, 2000). Like SYNOPS, the EYP also calculates PEC values but rather than comparing these values to $LC/LD/EC/ED_{50}$ and NOEC values they are multiplied by pesticide toxicity data to produce Environmental Impact Points. As the name indicates the EYP only considers environmental effects of pesticides. EYP is not as widely used, as for example EIQ, but has been applied to assess the impact of pesticide use in integrated and conventional potato production in the Netherlands (De Jong and De Snoo, 2002).

In an EU project entitled 'Harmonized environmental indicators for pesticide risk (HAIR)' a set of indicators were developed. In the years following the termination of the project work has been ongoing improving and developing additional indicators that are available online (http://www.pesticidemodels.eu/hair/home). The HAIR indicators are intended for calculating trends in aggregated risks of the agricultural use of pesticides.

The abovementioned risk indicators were developed solely with the purpose to assess the risk of pesticide use. The Norwegian pesticide risk indicator (NERI) was developed with a dual purpose, as a tool to assess the risk of pesticide use and as a method for taxation of pesticides (Stenrød et al., 2008). Like EIQ, NERI is a rating system. For human health NERI classifies products into 4 risk classes (low, medium, high and very high risk) according to the risk phrases on the label. NERI also considers the risk of operator exposure when preparing the spray mixture and when applying the pesticide by multiplying the scores for human health with scores for formulation type and application method. Environmental risk is assessed by adding up scores for effects on earthworms, bees, birds, aquatic organisms, mobility and leaching potential, persistence, bioaccumulation and a score for formulation type. Based on the accumulated score NERI classifies products into three environmental risk classes. By combining the information on human health and environmental risk classifications products are grouped into 7 pesticide tax classes.

As a response to the implementation of Directive 128/2009/EC that requires that the adverse impact of pesticides on human health and the environment and not pesticide use *per se* is reduced the Danish authorities decided to develop a pesticide risk indicator that could serve not only to monitor pesticide load and but also to set quantitative targets. Hence, a new indicator, named the Pesticide Load (PL), has therefore replaced the Treatment Frequency Index (TFI), which has been in use in Denmark since 1986. The TFI expresses the frequency of pesticide treatments and is therefore not a risk indicator but it has been perceived as a proxy for a pesticide risk indicator. The TFI is calculated by dividing the total amounts of active ingredients used in each crop by the standard doses assigned to each use of the active ingredient (Kudsk, 1989; Gravesen, 2003). Pesticides have been subjected to a value added tax in Denmark since 1990 and further objective was to develop an indicator that could enable a change in the taxation system from a tax linked to the costs of a pesticide to a tax linked to the risks.

Until recently, the annual computation of the TFI was solely based on the annual sales figures. Besides being reported per calendar year and not per growing season, the sales figures are also influenced e.g. by stockpiling and weather conditions precluding application of pesticides already purchased by the farmers. Along with the launching of the PL it was decided to make it compulsory for Danish farmers to upload an extract of their spray records to a website administered by the Ministry of Environment and Food. Starting with the growing season 2010/11, it has been compulsory for farmers to submit information electronically on their pesticide use. Farmers with less than 10 ha of land or with a turnover lower than ca. 6700 EUR are exempted from the obligation to report. For each crop, information should be provided on each commercial products used from 1 August to 31 July, the dose applied of each product and the total area treated with the product.

The objective of this paper is to present the underlying principles of the PL, how the PL is applied to monitor pesticide use and load and to provide examples on how the PL, in combination with the information from the spray records, can provide detailed information not only on the pesticide load but also on important agronomic issues. Finally, future uses of the PL intended to target monitoring and mitigation procedures are presented and discussed.