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Assessing the intensity of pesticide use in agriculture

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Abstract

In order to lower the risks associated to intensive pesticide use, efforts have been made at the European and the national level of several member countries of the European Union. In Germany, a national reduction programme for pesticides had been set up. The programme makes use of the methods elaborated in the context of the NEPTUN-project. The NEPTUN-approach had introduced several indicators to assess the intensity of pesticide use in agriculture. This approach was exemplarily applied to data from a case study region in north-eastern Germany. The aim of the paper is to discuss the strengths and weaknesses of the presented approach as based on results gained in the chosen case study region.

Keywords: Pesticide use; Agriculture; NEPTUN-approach

1. Introduction

According to the Statistical Office of the European Communities (Eurostat), roughly 320,000 t of pesticides with the total value of around € 6 billion (EC, 2002) were sold in the European Union in 1999. Although the use of pesticides in absolute terms is dropping (the sales in the EU decreased about 8% between 1991 and 1996), this is not necessarily linked to a decrease in pesticide intensity, as the application rate of newer pesticides can be very low (Hoyer and Kratz, 2001). In Germany, pesticide sales had remained at high levels for over 10 years now (SRU, 2004). According to the Statistical Yearbook of the German Federal Ministry of Consumer Protection, Food and Agriculture (BMVEL), 34,678 t of pesticides were put on the market in 2002 (UBA, 2004).

Pesticides can pose a risk on the environment and human health (cf. SRU, 2004; Hapeman et al., 2003; Sørensen et al., 2003). A number of pesticides and their metabolites have been found as pollutants in ground and surface waters (e.g. Worrall and Besien, 2005; Fava et al., 2005; Kolpin et al., 2004), in soils (e.g. Sivanesan et al., 2004; Craven and Hoy, 2005) and in the atmosphere (Duyzer, 2003; Dubus et al., 2000). Furthermore, pesticides are held responsible for contributing to the loss in biodiversity and the deterioration of natural habitats (e.g. Pauli et al., 1999; Grue et al., 1982). Despite the fact that pesticides are also applied in other sectors, agriculture is undoubtedly seen as the most important source of this contamination (Hoyer and Kratz, 2001). The growing awareness of the risks related to the intensive use of pesticides have led to a more critical attitude by the society towards agriculture. At the same time, there is a change in consumer concerns that had put more weight on issues such as environmental friendliness in agricultural production and food safety (Saba and Messina, 2003).

As part of the EU's Sixth Environmental Action Programme, the European Commission had formulated a thematic strategy for a more sustainable use of pesticides, in order to reduce the use of pesticides and minimise its risks.

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As a national instrument in Germany, a reduction programme for pesticides had been set up to complement the current legislation (BMVEL, 2004). In doing so, Germany has followed the example set by other European countries, such as Austria, Denmark, Finland, The Netherlands or Sweden, countries that have introduced specific policies to decrease pesticide use (Lucas and Pau Vall, 2005). The programme encompasses altogether 19 measures. Two of these measures are especially important in regard to the focus of this paper:

- the introduction of a so-called standardised treatment index (STI) as an indicator for the intensity of pesticide use in agriculture (measure 1);
- the integration of the STI into the environmental quality assurance systems for agricultural enterprises (measure 10).

The reduction programme for pesticides makes use of the results of the NEPTUN-project for the above purpose of introducing and integrating the STI (cf. Roßberg et al., 2002). NEPTUN stands for 'Network for the Evaluation of the Pesticide Use in different Natural Areas of Germany'. The project is a co-operation between the German Federal Ministry of Consumer Protection, Food and Agriculture (BMVEL), the Federal Biological Research Centre for Agriculture and Forestry (BBA) and the federal counties in Germany. The methodology for the calculation of the STI was worked out in the context of the NEPTUN-project. Additionally, regionally differentiated average values of the STI ($STI_{average}$) and maximum tolerable levels of pesticide intensity (MTP) were determined, that served as a regional reference system, which took into account the differences in pesticide application due to deviant climate conditions and pest probabilities. The $STI_{average}$ and MTP values would serve as yardsticks for the evaluation of farmers' crop-specific chemical pest management within a region with similar conditions. A scheme was suggested by Burth et al. (2003) and Gutsche and Ganzelmeier (2003) for the calculation of the environmental compatibility value (ECV) at the farm level, that is based on the regional $STI_{average}$ and MTP values, which indicates the farm's pesticide intensity in comparison to the average intensity in its respective region. Therefore, the ECV could serve as a measure for the quality of the production process in terms of pesticide intensity. As discussed by Burth et al. (2003) and Gutsche and Ganzelmeier (2003), an agricultural enterprise with a high ECV could be given an environmental label.

The NEPTUN-approach is presented in the following sections in detail, with emphasis on the calculation of the ECV. As an example, the methodology was applied to a set of data on the pesticide use of 13 farms collected from a case study region in north-eastern Germany. The strengths and limitations of the approach are discussed based on the results of the case study region.

2. Methods

2.1. Standardised treatment index (STI)

The STI is calculated using Eq. (1), that takes the number of active substances per application, the actual application rate in relation to the recommended rate as indicated in the technical data sheets of the pesticide products and the percentage of the treated area into account (Roßberg et al., 2002):

$$STI = \sum AS\,(n) \times AR\,(\%) \times TA(\%) \quad (1)$$

with STI is the standard treatment index per crop, AS the number (n) of active substances per application, AR the actual applications rate in relation to the recommended one (%), and TA is the treated area (%).

Since pest management usually depends on regional conditions, such as soil properties and climate, the calculated value of the crop-specific STI has to be compared to the average STI per crop ($STI_{average}$, Eq. (2)), calculated for a region with similar conditions. For this purpose, the NEPTUN-approach provided reference values related to so-called major regions in terms of the pest probabilities per crop:

$$STI_{average} = MV(\text{all STI per crop and major region}) \quad (2)$$

with $STI_{average}$ is the average standard treatment index per crop and major region, MV the mean value, STI the standard treatment index per crop (see Eq. (1)).

The definition of the major regions was based on a classification system that divided Germany into 34 different soil climate regions (SCR) (Kaule and Schulzke, 1998). The calculation of the $STI_{average}$ values in the NEPTUN-approach was based on surveys conducted on more than 1000 farms throughout Germany in the vegetation period of 1999/2000. According to Gutsche and Ganzelmeier (2003), the vegetation period of 1999/2000 can be seen as somewhat 'representative' for Germany, due to the 'average' weather conditions during this period, where neither droughts nor long rainy seasons occurred.

2.2. Maximum tolerable level of pesticide intensity (MTP)

The MTP is calculated for each crop by adding the standard deviation of all STI values per crop and major region to the $STI_{average}$ value (Eq. (3)):

$$MTP = STI_{average} + S.D.(\text{all STI per crop and major region}) \quad (3)$$

with MTP is the maximum tolerable level of pesticide intensity per crop and major region, $STI_{average}$ the average standard treatment index per crop and major region (see

Eq. (2)), S.D. the standard deviation, and STI is the standard treatment index per crop (see Eq. (1)).

The $STI_{average}$ and the MTP should serve as regional reference values for the crop-specific pest management of individual agricultural enterprises. If the STI for a certain crop on a certain farm is above the $STI_{average}$ or MTP, the farmer needs to question his pest management practice.

2.3. Environmental compatibility value (ECV)

For the calculation of the ECV per crop that can be aggregated at the farm level based on the $STI_{average}$ and the MTP a scheme had been suggested by Burth et al. (2003) and also Gutsche and Ganzelmeier (2003). Thereby, the ECV would be valued between 0 and 1, where an ECV of 1 represents the situation in which no pesticides are applied at all and an ECV of 0 is equal to the transgression of the MTP for any crop (criterion of exclusion). To produce the ECV at the farm level, the arithmetic mean value of all crop-specific ECV values is calculated and weighted by the area each crop is grown on. In order to be awarded an environmental label, the farm has to have a certain ECV score. Two different threshold values have been recommended: an ECV of 0.2 had been suggested by Burth et al. (2003) and a more restrictive one of 0.4 by Gutsche and Ganzelmeier (2003). As a precondition, the calculation of the ECV should be based on a database of STI values from at least three subsequent years, so that yearly differences due to extreme weather conditions and possible pest calamities can be compensated for (Burth et al., 2003). An example of the calculation of the ECV is given in Table 1, where the methodology was applied to the data of a farm in the chosen case study region for the year 2000.

3. Results

The methodology of the NEPTUN-approach was exemplarily applied to a set of data collected during the years 1999–2004 in a case study region in Germany: 'Dedelow', which is situated in north-eastern Germany in the county of Brandenburg. Time precise and plot-specific records of all pest management and cropping activities were kept by all farms of the region. The total area of arable land under investigation was about 8000 ha. The yearly precipitation of the region is about 500 mm and the average annual temperature is 8.3 °C. The most important crops grown in the region are winter wheat, rape seed, winter barley, triticale and winter rye.

Table 1
Calculation of the environmental compatibility value (ECV) at the farm level with the example of 'farm 8' in the case study region by area-weighted aggregation of the crop-specific ECV, related to the reference values valid for soil climate region (SCR) No. 14 as listed in Table 2

Crop	Acreage (ha)	Share (%)	STI	ECV (crop-specific)
Rape seed	125	22	4.67	0.47
Triticale	86	15	2.20	0.84
Winter barley	83	14	1.84	0.86
Winter rye	89	15	2.20	0.84
Winter wheat	195	34	4.08	0.60
ECV (at farm level)				0.68

STI: standard treatment index per crop (see Eq. (1)), SCR No. 14: 'Mecklen-Brandenburgische Wald- und Seenlandschaft', ECV (crop-specific): crop-specific environmental compatibility value, ECV (at the farm level): area-weighted aggregation of the crop-specific ECV at the farm level.

Table 2
Average standardised treatment index ($STI_{average}$) and maximum tolerable level of pesticide intensity (MTP) valid for soil climate regions (SCR) Nos. 13, 14 and 16

Crop	SCR No. 13		SCR No. 14		SCR No. 16	
	$STI_{average}$	MTP	$STI_{average}$	MTP	$STI_{average}$	MTP
Rape seed	4.2	5.6	4.2	5.6	3.4	4.9
Triticale	2.0	3.0	2.0	3.0	2.0	3.0
Winter barley	3.4	4.4	2.8	3.9	2.0	2.9
Winter rye	2.8	4.0	2.8	4.0	2.0	3.1
Winter wheat	4.7	6.1	3.6	5.1	2.7	4.1

SCR No. 13: 'Pommersches Küstenland', SCR No. 14: 'Mecklen-Brandenburgische Wald- und Seenlandschaft', SCR No. 16: 'Ostbrandenburger Platten', $STI_{average}$: average standard treatment index per crop and SCR, MTP: maximum tolerable level of pesticide intensity per crop and SCR. *Source*: figures calculated by Burth et al. (2003).

The calculation of the STI and ECV was based on the arithmetic mean of the 6 years period (1999–2004). The $STI_{average}$ and the MTP calculated by Burth et al. (2003) listed in Table 2, were based on the data surveyed in the NEPTUN-project, which serve as the regional reference values (cf. Roßberg et al., 2002). Since the case study region stretches over two different SCR (Nos. 14 and 16) and closely borders on a third to the north (SCR No. 13), indicators have been calculated for all three regional reference systems to allow for comparisons.

The ECV was calculated for two different variants. In the first variant (ECV 1), the methodology suggested by Burth et al. (2003), as well as Gutsche and Ganzelmeier (2003) was applied, taking into account the criterion of exclusion. Which means, if the MTP is exceeded for any crop, the ECV at the farm level would become zero and the farm would no longer be awarded an environmental label. Since the collected data represented the pesticide applications of more than 1 year, the exclusion criterion was only executed for farms exceeding the MTP in each of these years. In the second variant (ECV 2), the criterion of exclusion was neglected. As Figs. 1 and 2 show, the ECV of a single agricultural enterprise varies significantly, depending on the underlying reference system (i.e. SCR No. 13, 14 or 16) and which ECV variant is applied.

In reference to SCR No. 13, which is north of the case study region and represents the region with the highest pesticide intensity, the suggested limiting values of 0.4 and 0.2 for variant 1 (ECV 1, criterion of exclusion) were

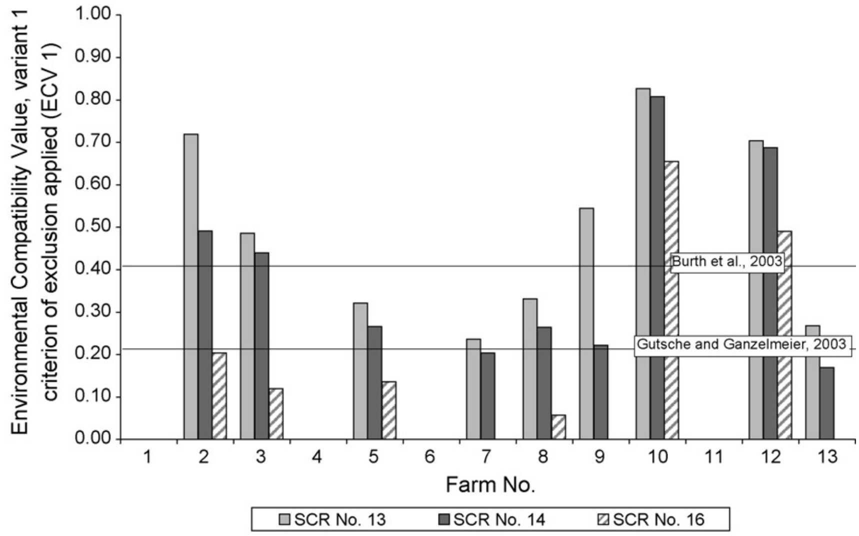

Fig. 1. Environmental compatibility value by variant 1 (ECV 1), considering the criterion of exclusion, at the farm level (mean value over all 6 years) for all 13 farms in the case study region with reference to the different soil climate regions (SCR). SCR No. 13: 'Pommersches Küstenland'; SCR No. 14: 'Mecklen-Brandenburgische Wald- und Seenlandschaft'; SCR No. 16: 'Ostbrandenburger Platten'.

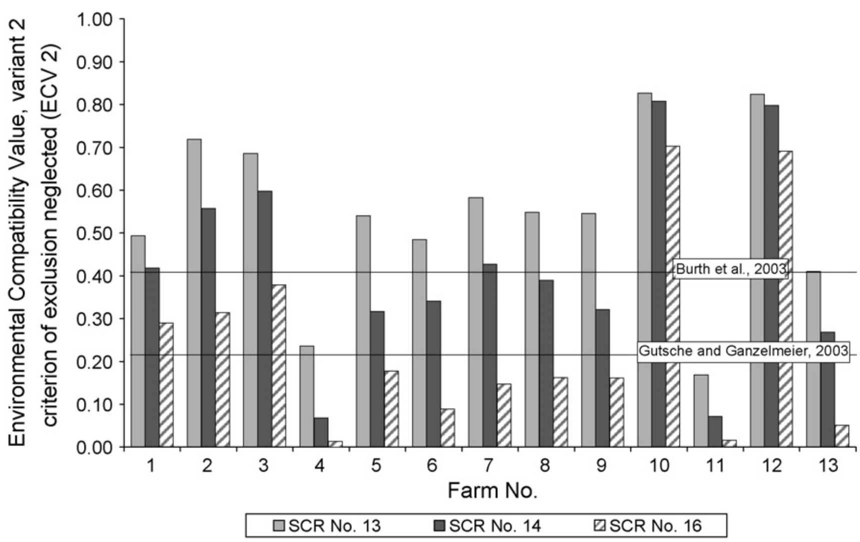

Fig. 2. Environmental compatibility value by variant 2 (ECV 2), neglecting the criterion of exclusion, at the farm level (mean value over all 6 years) for all 13 farms in the case study region with reference to the different soil climate regions (SCR). SCR No. 13: 'Pommersches Küstenland'; SCR No. 14: 'Mecklen-Brandenburgische Wald- und Seenlandschaft'; SCR No. 16: 'Ostbrandenburger Platten'.

exceeded by 5 and 9 farms, respectively, out of the total 13. The criterion of exclusion was executed for 4 farms. For variant 2 (ECV 2, criterion of exclusion neglected), 11 and 12 farms, respectively, scored above the threshold values of 0.4 and 0.2.

In reference to SCR No. 14, in which a part of the case study region is situated, 4 and 7 farms scored higher than the limiting value of 0.4 and 0.2, respectively, for variant 1 (ECV 1). The criterion of exclusion affected 4 farms. For variant 2 (ECV 2), 6 and 11 farms scored higher than the limiting value of 0.4 and 0.2, respectively.

Although the case study area is partly situated in SCR No. 16, the pesticide intensity of the case study area is much higher in comparison to this regional reference system. In the case where the criterion of exclusion was applied (ECV 1), only 2 farms scored above the limiting values of 0.4 and 0.2. In the case of neglecting the criterion of exclusion (ECV 2), 2 and 5 farms exceeded the threshold values of 0.4 and 0.2, respectively.

4. Discussion and conclusions

4.1. Suitability of the STI as an indicator for environmental risks due to pesticide usage

Three aspects might be relevant when discussing the environmental risks associated with pesticide application.

Table 3
The effect on the environmental compatibility value (ECV) by two variants: considering the criterion of exclusion (ECV 1) or neglecting it (ECV 2), and percentage of arable land on which the maximum tolerable level of pesticide intensity (MTP) was exceeded leading to an ECV 1 = 0 (total number of farms = 13)

	SCR No. 13	SCR No. 14	SCR No. 16
ECV 1			
No. of farms that are excluded due to ECV 1 (*n*) (threshold value of 0.4)	8	9	11
No. of farms that are excluded due to ECV 1 (*n*) (threshold value of 0.2)	4	6	11
Thereof farms that are given an ECV 1 = 0 due to the transgression of the MTP for certain crops (*n*)	4	4	7
Average percentage of arable land on which the MTP was exceeded (minimum–maximum) on farms where ECV 1 = 0 (%)	44 (27–69)	56 (32–84)	74 (49–95)
ECV 2			
No. of farms that are excluded due to ECV 2 (*n*) (threshold value of 0.4)	2	7	11
Number of farms that are excluded due to ECV 2 (*n*) (threshold value of 0.2)	1	2	8

SCR No. 13: 'Pommersches Küstenland', SCR No. 14: 'Mecklen-Brandenburgische Wald- und Seenlandschaft', SCR No. 16: 'Ostbrandenburger Platten'.

Firstly, the quantity in which a certain active substance is applied, secondly, the chemical and physical properties influencing the pesticide's effect on the environment, and thirdly, the toxicity effect of the pesticide on different organisms (cf. Hapeman et al., 2003; Jahnel et al., 2001; Meyer, 2002). A major limitation of the STI is that it tackles only the first quantitative aspect of the risks (cf. Reus et al., 2002). Nevertheless, the STI provides more information compared to the commonly used indicator 'amount of pesticides', as it also includes information about the number of active substances used, the ratio between actual and recommended application rate and the percentage of the treated area. Therefore, the STI is a relevant indicator for monitoring an action plan to reduce the amount of pesticide used. Its strength in comparison with an indicator based only on the applied amount of pesticides is that it reflects farmers' efforts to reduce their pesticide use in either reducing the rate per treatment, the number of treatments or the treated area (cf. Hoyer and Kratz, 2001; Prueger et al., 1999).

4.2. Influence of the regional reference system

The results proved that the choice of the regional reference system has an immense influence on the assessment of the ecological performance of farms in terms of pesticide intensity. As Fig. 2 shows, in SCR No. 13, 11 out of 13 farms met the threshold value of 0.4 for ECV 2, while for SCR No. 14 only 6 and for SCR No. 16 only 2 farms scored well enough to reach the threshold. However, the results also showed that the choice of different regional reference systems did not affect the assessment of the 'best' farms in terms of a low pesticide intensity or of those with a very high pesticide intensity.

4.3. Application of the criterion of exclusion

The ECV was calculated for two different variants. In variant 1, where the criterion of exclusion was considered, every transgression of the crop-specific MTP resulted, in principle, in the farm's loss of the environmental label, as the ECV 1 would be zero. This implies that in some cases, the intensive pesticide management of only small parts of the arable land may lead to the exclusion of the whole farm. In Table 3 the ratio of arable land that exceeded the respective MTP was analysed for farms that would be excluded from environmental labelling due to an ECV 1 of zero.

Altogether, ECV 1 seems to be a very strict standard. This is particularly true, when the crop that exceeds its MTP is only produced on a relatively small part of the farmland and the pesticide intensity of all other crops is below the related MTP or even below the $STI_{average}$. In this case variant 2 seems to be the better option.

4.4. Choice of the limiting value

In order to get an environmental label, the farms have to score above a certain threshold. Gutsche and Ganzelmeier (2003) have proposed a limiting value of 0.2, while Burth et al. (2003) suggested a threshold of 0.4 for the ECV at the farm level. It is not in the focus of the paper to validate the scientific justification or the ecological background of both limiting values but to highlight some effects due to the choice of threshold values on the evaluation of the farms. The effects of the two different thresholds vary depending on the SCR being referred to. For instance in case of ECV 2, for SCR No. 13 almost all farms met the threshold of 0.4. Only one farm would have benefited from a weaker threshold of 0.2. However, for SCR Nos. 14 and 16, 5 and 3 farms would have benefited from a lower threshold, respectively. With the exception of SCR No. 13, the effects of the two different thresholds were considerably high which showed the importance of the choice of a consistent threshold. But, whether the lower threshold value is presumed to be ecologically objectionable or not, the choice of the referring SCR within the investigation area has a greater influence than the choice of the proposed thresholds. For instance, when SCR No. 16 is chosen instead of SCR No. 13, 9 additional farms would not meet the strict threshold of 0.4. By contrast, when the threshold is increased from 0.2 to 0.4, this affects only one farms (SCR No. 13) and three farms (SCR No. 16), respectively (see Table 3).

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