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COMPUTER MODELLING AS A TOOL FOR THE EXPOSURE ASSESSMENT OF OPERATORS USING FAULTY AGRICULTURAL PESTICIDE SPRAYING EQUIPMENT

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ABSTRACT

Background. Faulty but still operating agricultural pesticide sprayers may pose an unacceptable health risk for operators. The computerized models designed to calculate exposure and risk for pesticide sprayers used as an aid in the evaluation and further authorisation of plant protection products may be applied also to assess a health risk for operators when faulty sprayers are used.
Objective. To evaluate the impact of different exposure scenarios on the health risk for the operators using faulty agricultural spraying equipment by means of computer modelling.
Material and methods. The exposure modelling was performed for 15 pesticides (5 insecticides, 7 fungicides and 3 herbicides). The critical parameter, *i.e.* toxicological end-point, on which the risk assessment was based was the no observable adverse effect level (NOAEL). This enabled risk to be estimated under various exposure conditions such as pesticide concentration in the plant protection product and type of the sprayed crop as well as the number of treatments. Computer modelling was based on the UK POEM model including determination of the acceptable operator exposure level (AOEL). Thus the degree of operator exposure could be defined during pesticide treatment whether or not personal protection equipment had been employed by individuals. Data used for computer modelling was obtained from simulated, pesticide substitute treatments using variously damaged knapsack sprayers. These substitute preparations consisted of markers that allowed computer simulations to be made, analogous to real-life exposure situations, in a dose dependent fashion. Exposures were estimated according to operator dosimetry exposure under 'field' conditions for low level, medium and high target field crops.
Results. The exposure modelling in the high target field crops demonstrated exceedance of the AOEL in all simulated treatment cases (100%) using damaged sprayers irrespective of the type of damage or if individual protective measures had been adopted or not. For low level and medium field crops exceedances ranged between 40 - 80% cases.
Conclusions. The computer modelling may be considered as an practical tool for the hazard assessment when the faulty agricultural sprayers are used. It also may be applied for programming the quality checks and maintenance systems of this equipment.

Key words: *exposure models, operator, exposure to pesticides, sprayers, computer modelling, occupational exposure*

STRESZCZENIE

Wprowadzenie. Stosowanie uszkodzonych ale funkcjonujących opryskiwaczy środków ochrony roślin może powodować nieakceptowalne ryzyko zdrowotne dla ich operatorów. Do oceny ryzyka związanego ze stosowaniem uszkodzonych opryskiwaczy można wykorzystać komputerowe modele matematyczne wykorzystywane do oceny narażenia operatorów opryskiwaczy w procesie rejestracji środków ochrony roślin.
Cel. Wykorzystanie modelowania komputerowego do oceny wpływu różnych scenariuszy narażenia na ryzyko dla operatorów stosujących uszkodzone opryskiwacze.
Materiał i metody. Modelowanie narażenia przeprowadzono w odniesieniu do 15 pestycydów (5 insektycydów, 7 fungicydów i 3 herbicydów). Krytycznym efektem działania, na którym oparto ocenę ryzyka, był poziom nie wywołujący dających się zaobserwować szkodliwych skutków (NOAEL). Umożliwiło to szacowanie ryzyka w warunkach różnego narażenia, takich jak stężenie pestycydu w środku ochrony roślin, rodzaj opryskiwanej uprawy i liczba zabiegów. Modelowanie komputerowe przeprowadzano stosując model UK POEM i wyznaczając dopuszczalny poziom narażenia operatora (AOEL),

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co umożliwiło oszacowanie narażenia operatora w zależności od zastosowania środków ochrony osobistej. Dane stosowane w modelowaniu komputerowym uzyskano na podstawie symulowanych zabiegów, w których stosowano płyny modelowe symulujące środki ochrony roślin i celowo uszkodzone opryskiwacze. Płyny modelowe zawierały markery umożliwiające odzwierciedlenie rzeczywistego ilościowego narażenia. Narażenie szacowano zgodnie ze schematem dozymetrycznego badania narażenia operatora w warunkach polowych dla upraw wysokich, średnio-wysokich i niskich.

Wyniki. Wyniki modelowania narażenia wskazują, że ochrona upraw wysokich uszkodzonymi opryskiwaczami powodowała przekroczenie akceptowanego poziomu narażenia operatora (AOEL) niemal w 100% przypadków środków ochrony roślin wykorzystanych do modelowania, niezależnie od stosowania środków ochrony osobistej. W przypadku upraw niskich i średniej wysokości przekroczenia AOEL wahały się od 40 do 80%.

Wnioski. Modelowanie komputerowe narażenia na pestycydy może stanowić praktyczne narzędzie do oceny zagrożeń dla zdrowia wynikających ze stosowania uszkodzonych opryskiwaczy rolniczych. Może także znaleźć zastosowanie przy opracowywaniu programów kontroli i systemów obsługi tego typu sprzętu.

Słowa kluczowe: *modele narażenia, operator, narażenie na pestycydy, opryskiwacze, modelowanie komputerowe, narażenie zawodowe*

INTRODUCTION

Faulty but still operating agricultural pesticide sprayers may pose an unacceptable risk for operators. Although such sprayers should not be used, however in practice it is difficult to distinguish it from properly functioning equipment, and sometimes the health risk resulting from the damaged spraying equipment may be underestimated.

Assessing operator safety during pesticide treatment is principally governed by estimating the risks of persons exposed to such substances. In turn, this is determined by the toxicological properties which have been previously evaluated during the proscribed regulatory process of registration [12]. The worker groups so exposed, not only include those employed in the production process, but equally operators who actually perform the pesticide treatments as well as farm workers exposed in areas having been previously treated. As a result, the European Commission now therefore requires [3, 14] that appropriate risk assessment models are used to estimate pesticide risk for all affected persons, be they operators performing treatments, bystanders or those otherwise engaged in cultivation; this forming an indispensable part of the pesticide registration process at Member State level [1].

The main requirement of risk assessment studies are to determine toxicological end-points like the NOAEL or the Acute Reference Dose (ARfD), which assesses the exposure risk of different formulations, together with pesticide dosing and the number of treatments defined by Good Agricultural Practice (GAP) [8]. Agricultural worker exposure to pesticides includes their distribution, mixing and loading, as well as during actual crop treatment with appropriate equipment; affecting both such workers and bystanders. Most countries regulate pesticide registration, not only for consumer protection, but also for those engaged in the agricultural sector [11, 19]. It is necessary to examine both acute and chronic toxic actions of pesticides when estimating risk. Irrespective of acute poisonings following pesticide treatment, the scientific literature shows that nervous system disease and pesticide exposure are likely related [5, 9, 13, 15]. Studies indicate that *Parkinson's* and *Alzheimer's* disease will occur in the elderly when persons are exposed to pesticides. Some pesticides can also act as endocrine disruptors, whilst others suggest an association with brain tumours [2, 4].

Exposure to specific pesticide chemical groups, may cause children suffering from leukaemia whose parents had contact with pesticides due to their occupational profession. Other studies [18], have demonstrated an increase in sister chromatid exchange in the chromosomes from somatic cells in persons performing agricultural pesticide treatment with herbicides. The faulty spraying equipment not only may cause increased operator risk but also result in elevated pesticide residues in crops leading to unacceptable consumer's exposure as well as to alerting Rapid Alert System for Food and Feed (RASFF) [10].

The use of appropriate research methods, together with modelling, enables the risk to be estimated during pesticide treatment 'a priori' thus ensuring a suitable degree of prevention. Modelling studies can also be successfully used in assessing unusual situations such as those related to performing pesticide treatment with defective equipment. This study was indeed aimed at evaluating the predictive value of *'in-silico'* modelling of such operator exposure to pesticides with faulty spraying equipment.

MATERIALS AND METHODS

The modelling of exposure was performed on 15 pesticides (5 insecticides, 7 fungicides and 3 herbicides) that are currently registered in Poland. The following was taken into account for ensuring that the modelling was representative of real life pesticide selection:

Table 1. Active substances in the plant protection products used in computer modelling during treatment of variously sized crops

Active substances	AOEL mg/kg b.w./d	Content of active substance	Category	Type of crops
Pirimicarb	0.035	500 g/L	insecticide	high
Thiram	0.02	75%	fungicide	
Chlorpyrifos-methyl	0.01	400 g/L	insecticide	
Mancozeb	0.035	420 g/L	fungicide	
Chlorpyrifos	0.01	480 g/L	insecticide	
Tebuconazole	0.03	250 g/L	fungicide	medium
Zeta-cypermethrin	0.02	100 g/L	insecticide	
Propiconazole	0.01	250 g/L	fungicide	
Captan	0.01	80%	fungicide	
Acetamiprid	0.124	20%	insecticide	
Glyphosate	0.2	680 g/L	herbicide	low
Fluroxypyr	0.8	250 g/L	herbicide	
MCPA-DMA	0.04	750 g/L	herbicide	
Azoxystrobin	0.1	250 g/L	fungicide	
Pyrimethanil	0.12	300 g/L	fungicide	

(1) crop size; (2) the presence of basic pesticide types (i.e. insecticides, fungicides and herbicides); (3) the need to account for varying NOAELs depending on the toxicity of active substance(s) and (4) required pesticide coverage area.

Assessing operator risk and safety depends on exposure to active substance(s) obtained from dosimetry studies, which are compared to theoretical results estimated by computer models. Pesticides were chosen on the following basis:

(1) AOEL values for those performing agrochemical pesticide treatment.
(2) the type of crop protection, (low level crops – i.e. – vegetables, pasture, meadows; medium level crops – i.e. – bushes; high target field crops – i.e. trees, hope as well as orchard crops).

In this study the UK-POEM computer model was used as developed by experts [16] from the Chemicals Regulations Directorate (CRD) - Health and Safety Executive (HSE). This predictive operator exposure model is in fact recommended by the European Commission and is used to assess active substances for their inclusion into Appendix I of the 91/414 EC Directive [3, 14]. Exposure is assessed by the AOEL [7] derived from the NOAEL. The modelling takes into account the amount of dermal absorption, substance dose, duration of treatment, inhalation exposure (if obligatory) and the treatment equipment employed. The estimated exposure thus obtained, is then related to an AOEL reference value which enables the potential risk to be defined for the operators performing pesticide treatments.

Operator exposure was assessed on variously damaged knapsack sprayers as well as ones undamaged. Hand-held sprayers, Kwazar type Neptune 15, were used on medium and high target field crops whilst the Kwazar Solo was used for the low level ones. Measurements were taken when the operator was wearing protective clothing onto which dosimetric patches had been applied. The absorbance of a fluorochrome marker substance present in the test spray liquid was then determined according to the BBA scheme [17], from which exposures to the selected pesticides were assessed [6]. The marker substance being non-toxic to ensure operator safety. The spraying equipment was intentionally damaged in order to simulate the effect that defective equipment might have on operator exposure to the 15 aforementioned pesticides. This exposure was estimated according to methods proposed by the Research Institute of Pomology and Floriculture consisting of dosimetric studies on operator exposure, in the field, for low level, medium and high target field crops shown in Table 1. The amount of absorbed marker substance thus permitted any increases in exposure to be determined according to the type of sprayer damage and the crop size, which could then be compared to those sprayers fully functioning and undamaged.

RESULTS AND DISCUSSION

The calculated NOAEL, derived from the computer modelling, expressed the different toxicities of the 15 pesticides in question. The study estimated the effect that various types of damage to sprayer equipment might have on increasing operator exposure during pesticide treatment depending on crop size. In Table 2, the term 'dosimetric estimation' refers to the amount of pesticide active substance marker as determined on the areas of patch absorbance. Increases in exposure greater than 1, shown in Table 2, indicate that exposures are higher compared to undamaged spraying equipment whereas those less than 1, demonstrate lower exposures for the same comparison.

The use of Personal Protection Equipment (PPE), forms an integral part of assessing exposure. This in-

Table 2. Changes in exposure based on dosimetric studies depending on the crop size and the kind of equipment damage

Types of damage to sprayer equipment	Exposure based on dosimetric field studies* (mg/kg)			Increase of exposure		
	High crops	Medium crops	Low crops	High crops	Medium crops	Low crops
Undamaged	209.5	712.1	104.9	1	1	1
Damaged valve	3110.4	1089.4	201.3	14.8	1.5	1.91
Defective atomizer	931.7	432.7	103.9	4.44	0.6	0.99

*ISiK Skierniewice Report

Table 3. Operator exposure when correctly functioning sprayers are used on high target crops

The active substance / formulation	Operator exposure mg/kg b.w./day	
	without Personal Protection Equipment	with Personal Protection Equipment
Pirimicarb / 500 WG	0.4	0.09
Thiram / 75 WP	3.15	0.48
Chlorpyrifos-methyl / 400 EC	0.09	0.016
Mancozeb / 420 SC	0.04	0.014
Chlorpyrifos / 480 EC	0.2	0.14

Table 4 Increases of risk, expressed as percentage AOEL, with damaged sprayers used for high target crops

The active substance	AOEL [mg/kg bw/day]	% AOEL defective atomizer		% AOEL damaged valve	
		without PPE	with PPE	without PPE	with PPE
Pirimicarb / 500 WG	0.035	5074.29	1141.71	16914.3	3805.7
Thiram / 75 WP	0.02	69930.00	10656.00	233100.0	35520.0
Chlorpyrifos-methyl / 400 EC	0.01	3996.00	710.40	13320.0	2368.0
Mancozeb / 420 SC	0.035	507.43	177.60	1691.4	592.0
Chlorpyrifos / 480 EC	0.01	8880.00	6216.00	29600.0	20720.0

Table 5. Operator exposure when correctly functioning sprayers are used on medium crops

The active substance / formulation	Operator exposure mg/kg bw/day; undamaged sprayer	
	without PPE	with PPE
Tebuconazole / 250 EW	0.58	0.05
Zeta-cypermethrin / 100 EW	0.7	0.08
Propiconazole / 250 EC	0.09	0.01
Captan / 80 WG	1.2	0.13
Acetamiprid / 20 SP	0.15	0.08

Table 6. The risk, expressed as percentage AOEL, with damaged sprayers used for medium field crops

The active substance	AOEL [mg/kg bw/day]	% AOEL defective atomizer		% AOEL damaged valve	
		without PPE	with PPE	without PPE	with PPE
Tebuconazole / 250 EW	0.03	1160.00	100.00	2900.0	250.0
Zeta-cypermethrin / 100 EW	0.02	2100.00	240.00	5250.0	600.0
Propiconazole / 250 EC	0.1	54.00	6.00	135.0	15.0
Captan / 80 WG	0.1	720.00	78.00	1800.0	195.0
Acetamiprid / 20 SP	0.124	72.58	38.71	181.5	96.8

cludes putting on goggles, gloves, overalls etc. whose function is to create a protective barrier between the treatment environment and the operator. Recommendations for their use depend on the individual characteristics of a given pesticide under which it had been officially registered. An assumption is made that any agrochemical spraying equipment functions correctly. It is however, often the case in practice that operators make light of using any PPE which, when combined with faulty sprayers, can lead to significant exceedance of any permitted exposures. In such instances where PPE are not used, it becomes necessary to measure the increase in exposure when spraying equipment is functioning correctly.

The increase in exposure from treatments performed by correctly functioning equipment without PPE, in high target crops are shown in Table 3. These increases form the basis on which risk estimates are made when faulty spraying equipment are used.

The Table 4 results indicate that the AOEL limits are exceeded for all the pesticides tested, when damaged sprayers are used, irrespective of whether PPEs are adopted. Using damaged sprayers, thus constitutes an unacceptable risk. Importantly, it was however observed, that the safety of treatment could not be guaranteed when using the pesticide Thiram, (75WP formulation), despite using correctly functioning equipment together with PPE measures (Table 3).

Analogous modelling was undertaken for low level and medium crops. Results are respectively shown in Tables 5, 6 and Tables 7, 8.

In damaged sprayer devices, AOEL limits were exceeded for treatments on medium crops using Tebuconazole and Zeta-cypermethrin pesticides, irrespective of whether PPEs were worn. Likewise, with damaged valves, treatment with Tebuconazole, Zeta-cypermethrin and Captan pesticides also exceeded the AOELs notwithstanding the use of PPEs. As aforementioned, the results of exposure modelling for treating Low Level crops are provided in Tables 7 and 8.

Table 7. Operator exposure when correctly functioning sprayers were used on low level field crops

The active substance / formulation	Operator exposure mg/kg bw/day; undamaged sprayer	
	without PPE	with PPE
Glyphosate / 680 SG	0.59	0.09
Fluroxypyr / 250 EC	0.9	0.17
MCPA-DMA / 750 SL	1.01	0.17
Azoxystrobin / 250 SC	0.24	0.02
Pyrimethanil / 300 SC	0.5	0.09

Table 8. The risk, expressed as percentage AOEL, with damaged sprayers used for low level field crops

UK-POEM Model	AOEL [mg/kg bw/day]	% AOEL defective atomizer		% AOEL damaged valve	
The active substance		without PPE	with PPE	without PPE	with PPE
Glyphosate / 680 SG	0.2	292.05	44.55	563.5	86.0
Fluroxypyr / 250 EC	0.8	111.38	21.04	214.9	40.6
MCPA-DMA / 750 SL	0.04	2499.75	420.75	4822.8	811.8
Azoxystrobin / 250 SC	0.1	237.60	19.80	458.4	38.2
Pyrimethanil / 300 SC	0.12	412.50	74.25	795.8	143.3

These results demonstrate that all AOELs can be significantly exceeded, when defective spraying equipment is used, even on low level field crops where exposures are expected to be lower, compared with medium and high target crops.

In all 15 pesticide cases tested by this simulation modelling (i.e. 100%), treatment of high target crops with defective equipment led to the AOEL being exceeded, independent of the type of damage or whether PPEs had been used, thus compromising safety as defined by the AOEL. The AOEL was however exceeded respectively in 40% and 80% cases for low level and medium crops.

CONCLUSIONS

1. The UK POEM modelling system can be used for assessing health hazard risks arising from faulty spraying equipment. Results so obtained, indicate that such modelling could also be used for assessing potential health risks to operators whenever results from other methods used for plant protection deviate from the norm.
2. The use of damaged hand held sprayers from knapsacks on high target field crops are related with an unacceptably high exposure to the operator. Regular and frequent checking of such equipment is therefore necessary.
3. The health hazard risk to the operator, performing agrochemical treatment, using defective knapsack sprayers depends on the type of crops and is especially significant for high target field crops.

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Conflict of interest

The authors declare no conflict of interest.

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