The trials on the influence of knapsack sprayer technical condition on operator exposure as an input to the risk assessment for human health

Godyń, A.[1]; Doruchowski, G.[1]; Hołownicki, R.[1]; Świechowski, W.[1]; Ludwicki, J. K. [2]; Wiatrowska, B.[2]; Bankowski, R.[2]

[1]Research Institute of Horticulture, 96-100 Skierniewice, ul. Konstytucji 3 Maja 1/3, Poland

[2]National Institute of Public Health - National Institute of Hygiene, 00-791 Warsaw, ul. Chocimska 24, Poland

DOI 10.5073/jka.2012.439.010

Summary

Operator exposure to spray applied with knapsack sprayers was measured in the open field during the spraying of the low, medium and high plants (strawberries, young apple orchard and bearing fruits one). The samples were attached to the protective clothes in 13 locations. The BSF fluorescent tracer was added to the spray. The operator exposure was expressed as the part of the dose applied (ppm). The data on operator exposure was used to predict the risk for operator. The risk for humans was done by computer modeling according to German BBA model, taking into account field data for different sprayer technical conditions and 15 different pesticides. The most important influence of the sprayer technical condition on the operator exposition and the human health risk was observed for high crops.

Key word: operator exposure, knapsack sprayer, open field, fluorescent tracer, risk assessment

Introduction

Directive 128/2009/EU on sustainable use of pesticides states that by 14 December 2016, Member States shall ensure that pesticide application equipment has been inspected at least once. After this date only pesticide application equipment having successfully passed inspection shall be in professional use (art. 8.1). By way of derogation, following a risk assessment for human health and the environment including an assessment of the scale of the use of the equipment, Member States may exempt from inspection handheld pesticide application equipment or knapsack sprayers.

Spraying with pesticides may become the potential source of the contamination of the operator and of the surrounding areas. The proper functionality of knapsack sprayers depends on its technical condition and may influence the operator exposure. Therefore the knowledge on the influence of the most common sprayer damages on operator exposure may help in deciding on "to inspect" or "not to inspect" such spraying equipment. The risk assessment for human health may be done by in silico modeling (computer modeling). At least two models are suitable for that purpose. The aim of the analysis is to calculate the operator per day exposure expressed in mg/kg of body weight. Then the operator exposure may be compared to the maximum amount of the active ingredient on which the operator may be exposed AOEL (Accepted Operator Exposure Level).

One of the first measurements of operator exposure to plant protection products (PPP) were done by Durham and Wolfe (1962). The measurements were carried out in professional and amateur production (Chester, 1993; Gilbert, 1995). The operator exposure measurements are included in the PPP registration/legalisation procedure. Despite of that only wery few data on that topic are to be found in the scientiffic literature. The review of early tehniques of operator exposure measurements were published by Wolfe (1976).

Nowadays many measurements of operator exposure are done with fluorescent tracers collected on the whole protective overal (Sutherland et al., 1990; Bjugstad and Hermansen, 2009) or on the samples placed on its surface (Bjugstad and Torgrimsen, 1996; Bjugstad and Hermansen, 2009). In some cases the visualisation of fluorecsent tracer in UV light is used or methodes of bio-monitoring basing on quantitative analisis of metabolites of non-toxic pesticides in operator urine (Krieger and Dinoff, 2000). In EU Member States it is accepted for risk assessment of exact PPP applied in exact way to predict the exposure basing on measurements data for field trials for other PPP applied in similar way (Ludwicki et al., 2003).

When the operator exposure is measured in industrial context, the mass units per time units are used (e.g. miligrams per hour). In some cases such units were used in agricultural context (Batel, 1984). However, because of different efficiency of plant protection equipment (different spray volumes sprayed in time unit) such units need to take into consideration the time of application. Therefore the best way of expression of operator dermal exposure during spraying is using of mass units per operator surface units and express it as a percentage of the dose applied (Bjugstad and Torgrimsen, 1996). Such measure enables the comparison of exposure for operators applying different doses of products with different equipment in different crops. Such units were used by Abbot at al. (1987) and Bjugstad and Torgrimsen (1996).

The aim of the trials was the assesment of the influence of knapsack sprayer technical condition on the sprayer operator exposure during application in three different types of crops. Then the exposure values were used during in sillico modeling with BBA model to predict the possible risk for humans for the application of PPP by means of the knapsack sprayers in different technical conditions.

Material and methods

The field trials were carried out in July 2010 in the experimental orchard of Research Institute of Horticulture, Skierniewice. The efficient undamaged knapsack sprayer and the sprayer with damaged nozzle and with damaged gun valve were used. The measurements were done in low crop (strawberries), medium loose one (young orchard) and in high dense one (bearing fruits orchard). The fluorescent tracer was added to the spray and the samples were attached to the operator overal. The operator exposure was expressed in ppm (parts per million) of the dose applied.

The risk for humans was done by computer modeling (in sillico modeling according to German BBA model) taking into account typical spraying scenarios, different sprayer technical conditions and 15 different pesticides. The pesticides of different NOAEL (No observed adverse effect level) values dependent on chosen PPP's toxicity were used during in sillico modeling. Then the operator exposure achieved in the model was compared to the AOEL (Acceptable Operator Exposure Level) values to find out if the combination of the PPP and the sprayer technical condition makes a risk for human health or not.

Experimental factors – technical condition of the sprayer

Three sprayer conditions were examined:

- efficient – undamaged knapsack sprayer,
- sprayer with gun valve damaged (valve kept opened during the whole test),
- sprayer with damaged nozzle (outlet scratched with sharp tool giving uneven spray stream).

Experimental factors – crop

The measurements were done during spraying of three kinds of crops:

- low crop (strawberries, row spacing 1.0 m),
  - o two neighboring rows were sprayed – plot length 40 m
- medium-loose crop (1.8 m in height young orchard),
  - o one row was sprayed – plot length 30 m
- high-dense crop (3.0 m in height bearing fruits orchard)
  - o one row was sprayed – plot length 20 m.

Sprayers

Two 15 l knapsack sprayers were used for the trials:

- in low crop:
  - o one Kwazar Neptune 15 sprayer, 1.2 m long lance (Kwazar Corporation Sp. z o.o., Poland)
  - o one Solo 425 sprayer, 50 cm long lance (SOLO Kleinmotoren GmbH, Germany)
- in medium and high crops two Kwazar Neptune 15 sprayers were used.

Each sprayer was equipped with one LU 120-04 Lechler nozzle witch nominal flow rate 1.55 l/min (at 3 bar) producing medium drops (VMD ca 240 µm).

Sprayer operators

The treatments were carried out by two operators (height of *ca* 175 cm): experienced (57 years old) and inexperienced one (27 years old). Operators wore DuPont™ Tyvek® overalls.

Spaying liquid

Operators sprayed out the water solution of 0.3% BSF fluorescent tracer (Brilliant Sulfoflavin, WALDECK-Gmbh & Co KG DIVISION CHROMA, Germany). The spray was prepared in the tank of the orchard sprayer, taking 600 g of BSF for 200 l of tap water. For each trial the solution of 5 or 10 liters of BSF was measured out of the tank.

Trials

The separate plots for each operator were set. The single trial constituted of spraying out of 5 then next trial with 10 liters of BSF solution. The plots length were crop depended (20÷40 m) (look at: *Experimental factors – crop)*. The time and the distance taken by each operator during each trial were measured. The manner of spraying was operator depended, no suggestion or instruction were given to the operators, except one indication: the need of spraying the whole height of the high crop trees. During the trials operators wore white DuPont™ Tyvek® overalls produced by DuPont™. On the overalls the measurement points were located according to BBA scheme (tab. 1). In each of the measurement points the Velcro strips (6 cm in length) were attached, on which the Technofil filter fiber samples (5 x 10 cm) were placed (Filtermatten TF-290, Technofil B.V). In each measurement point two samples were mounted giving two 13-samples sets on the overall. The samples were removed in two stages: one set - after spraying out of 5 liters of BSF solution and the other one - after spraying of subsequent 10 liters of solution.. The protective gloves were taken off together with each set of the samples. After each trial the Tank Mix solution was taken in the frame of the controlling procedure and for calibration of the laboratory equipment (Perkin Elmer LS 55). Every trial was repeated twice. In each crop 24 trials were carried out giving 72 trials in total.

Working parameters during trials

The time of single "shorter" trial (spraying out of 5 liters) ranged from *ca* 3 to ca 5 min (182÷298 sec), 6 to 11 min for "longer" (10 liters) trials (367÷650 sec) and the summarized time of "shorter" and "longer" trials (spraying out of 5 + 10 l of BSF solution) ranged from 10 to 15 min (559÷920 sec). The spray volumes per hectare resulting from trials were: 278÷658 l/ha in low crop (strowberries), 114÷219 l/ha in young orchard (medium crop) and 147÷368 l/ha in high crop (fruit bearing orchard).

Laboratory measurements, calculations and modeling

Samples and protective gloves taken off from the operators overalls were closed in the containers. In the laboratory the concentration of the tracer rinsed out from the samples and protective gloves was measured on PerkinElmer LS 55 spectrofluorometer. The rinsing solution was deionized water: 100 ml for Technofil samples an d 300 ml for protective gloves. All samples were shaken for 15 min on a special stand with shaking frequency of 162 Hz and amplitude of 4.0 cm. Then the total spray deposit (mass per location) for each location was calculated taking into account measured tracer concentration, samples area (50 cm^2) and rinsing liquid volume, as well as the body surface area for each location (tab. 1). Then the total operator exposure (basing on deposits in 15 locations) and the partial exposure (total exposure without amounts on lower legs and the gloves) were calculated. The measured values of operator exposure were too small to express it as a percentage of the dose applied, therefore the ppm measure (parts per million) was used for expression of the gathered exposure data.

Tab. 1. Samples location and body surphace based on BBA scheme.

Body Surface Area (cm^2)		Sample no
Location of samples	Area (cm^2)	
1 Chest (front)	3550	1
2 Back	3550	Mean for: 2, 3, 4
3 Shoulder right		
4 Shoulder left		
5 Upper arm right	1455	5
6 Upper arm left	1455	6
7 Forearm right	605	7
8 Forearm left	605	8
9 Thigh right	1910	9
10 Thigh left	1910	10
11 Lower leg right	1190	11
12 Lower leg left	1190	12
13 Head	1300	13
14, 15 Glove right, left		14, 15

Tab. 2. Pesticides used for *in sillico* modeling.

No	PPP name on the Polish market	Active ingredient (a.i.)	The content of a.i.	Group
High-dense crop				
1	Pirimor 500 WG	pirymicarb	500 g/l	Insecticide
2	Sadoplon 75 WP	thiram	75%	Fungicide
3	Redlan 400 EC	chlorpyriphos--methyl	400 g/l	Insecticide
4	Pennfluid 420 SC	mancozeb	420 g/l	Fungicide
5	Owadofos Extra 480 EC	chlorpyriphos	480 g/l	Insecticide
Medium-loose crop				
6	Sparta 250 EW	tebuconazole	250 g/l	Fungicide
7	Ammo Super 100 EW	z-cypermethrin	100 g/l	Insecticide
8	Bumper 250 EC	propiconazole	250 g/l	Fungicide
9	Captan 80WG	captan	80%	Fungicide
10	Mospilan 20 SP	acetamiprid	20%	Insecticide
Low Crop				
11	Roundup max 680 SG	glyphosate	680 g/l	Herbicide
12	Starane 250 EC	fluroxypyr	250 g/l	Herbicide
13	Chwastox 750 SL	MCPA-DMA	750 g/l	Herbicide
14	Amistar 250 SC	azoxystrobin	250 g/l	Fungicide
15	Mythos 300 SC	pyrimethanil	300 g/l	Fungicide

Data analysis

The operator exposure data were analyzed using STATISTICA 7,0 statistical software: ANOVA followed by HSD Tuckey multiple ranging test were carried out. The data for experienced operator exposure was used in National Institute of Public Health - National Institute of Hygiene to calculate the operator risk for 15 pesticides, representing different toxicity. The BBA mathematic model was used to assess the predicted operator exposure level (dermal and inhalation exposure during mixing/loading and spraying), expressing in mg/kg bw/day, taking into account: application method, product and formulation type, PPP dose, level of dermal absorption from product (typical for product), risk during mixing/loading and during spraying, work rate in ha/day and operator body weight 70 kg. The output data from in sillico modeling expressed the operator exposure in milligrams per kg of the operator body weight per day – in the same way as the AOEL data are expressed. Then the percentage ratios of the appropriate "per day exposure" and "per day AOEL's" were calculated. The Exposure/AOEL ratio 100 or less indicated that there is no risk for the operator. The pesticides used for in sillico modeling are listed in the table 2.

Results and Discussion

The lowest total operator exposure was measured for low crop sprayed by experienced operator using undamaged sprayer or equipped with damaged nozzle one (103.9 and 104.9 ppm, tab. 3). The highest total exposure (3110.4 ppm) was observed for high-dense crop, sprayed by experienced operator with the sprayer having damaged gun valve. During spraying the medium-loose crop, especially for inexperienced operator, in some cases, the exposure was greater than during spraying high-dense crop. The partial exposure ranged from 24.4 to 2477.6 ppm and the observed relations were similar to those for the total operator exposure (tab. 4). Although big differences of operator exposure measured for experimental combinations, the statistically significant differences were observed only in few cases. One of the most important reasons for lack of significant differences was probably big variability of measured exposition values in individual locations on the overall.

Tab. 3. Total operator exposure of the experienced and inexperienced operators during knapsack sprayer application in low, medium-loose and high-dense crops.

Operator	Sprayer condition	Crop					
		Low		Medium-loose		High-dense	
Experienced	Undamaged	104,9	a	712,1	a-c	209,5	a
	Gun valve damaged	201,3	b	1089,4	bc	3110,4	b
	Nozzle damaged	103,9	a	432,7	ab	931,7	a
Inexperienced	Undamaged	300,8	c	205,3	a	430,0	a
	Gun valve damaged	177,5	ab	1404,1	c	720,7	a
	Nozzle damaged	755,9	d	952,9	bc	366,1	a

Means in columns followed by the same letter do not differ significantly (HSD Tuckey Test, P<5%).

Tab. 4. Partial operator exposure of experienced and inexperienced operators to spray during knapsack sprayer application in low, medium-loose and high-dense crops.

Operator	Sprayer condition	Crop					
		Low		Medium-loose		High-dense	
Experienced	Undamaged	24,4	a	380,0	ab	146,3	a
	Gun valve damaged	38,9	a	378,7	ab	2477,6	b
	Nozzle damaged	30,8	a	273,7	ab	762,4	a
Inexperienced	Undamaged	40,8	a	120,2	a	296,7	a
	Gun valve damaged	31,1	a	732,9	c	373,6	a
	Nozzle damaged	44,5	a	489,4	bc	228,5	a

Means in columns followed by the same letter do not differ significantly (HSD Tuckey Test, P<5%).

The *in sillico* modelling was based on the exposure data for experienced operator from tab. 3. The highest exposure increase was observed in high-dense crop: 14.8 - fold for broken valve and 4.44 times for broken nozzle, less for the medium-loose crop 1.5 and 0.6 and in low crop 1.91 and 0.99 respectively. The values less than 1.0 denotes decrease of the operator exposure for broken sprayer.

The *in sillico* modelling showed that the influence of the sprayer technical condition on the increase of the risk for the operator (exceeding of the AOEL values) depends on the crop height and the Personal Protective Equipment usage (tab. 5). For the case with Personal Protective Equipment, in low and medium-loose crops, there was no influence of the sprayer technical condition on the exceeding of the AOEL values. That conclusion may support the opinion that there is no need to inspect knapsack sprayers in the context of operator risk. In that case it is enough to wear the PPE to protect the operator during application and preparation of spraying mixture. For pesticides 7, 8, 10, 11, 12, 14 there was no need to wear PPE neither for the efficient knapsack sprayer nor for the broken one. For the pesticides 6, 9, 13 and 3 in high crop the PPE should be used also for efficient sprayer.

In the high crops the knapsack sprayers should be used in the limited extent. For pesticides 2 and 5 the knapsack sprayers should not be used in such extent as the BBA model assumes, even for efficient sprayer.

Tab. 5. The operator exposure as a percentage of the AOEL value (%) for three technical conditions of the knapsack sprayer and three heights of the crops. Cases: without and with Personal Protective Equipment (No PPE / with PPE).

AOEL mg/kg/ day	Pesticide [nunber] name	Efficient Sprayer	Damaged Nozzle	Damaged Valve
High-dense crop – No PPE / with PPE				
0,035	[1] Pirimor 500 WG	83/17	368/76	1226/254
0,02	[2] Sadoplon 75 WP	2400/315	10656/1399	35520/4662
0,01	[3] Redlan 400 EC	200/50	888/222	2960/740
0,035	[4] Pennfluid 420 SC	46/23	710/355	2368/1184
0,01	[5] Owadofos Extra 480 EC	900/140	1142/178	3806/592
Medium-loose crop – No PPE / with PPE				
0,03	[6] Sparta 250 EW	267/10	160/6	400/15
0,02	[7] Ammo Super 100 EW	50/2,5	30/2	75/4
0,1	[8] Bumper 250 EC	10/0,8	6/0	15/1
0,1	[9] Captan 80WG	200/30	120/18	300/45
0,124	[10] Mospilan 20 SP	15/1,6	9/1	23/2
Low Crop – No PPE / with PPE				
0,2	[11] Roundup max 680 SG	25/5	25/5	48/10
0,8	[12] Starane 250 EC	21/1	21/1	41/2
0,04	[13] Chwastox 750 SL	200/17,5	198/17	382/33
0,1	[14] Amistar 250 SC	40/2,7	40/3	76/5
0,12	[15] Mythos 300 SC	92/14	91/14	175/27

Conclusion

The methodology used for risk assessment during PPP registration procedure may help in deciding about the need of knapsack sprayer inspection. The scale/extent of use in particular crop types/ heights should be taken into account before taking the final decision on the exemption of the knapsack sprayers from the inspection.

Bibliography

Abbott, I. M., Bonsall, J. L., Chester, G., Hart, T.B., Turnbull, G. J., 1987: Worker exposure to herbicide applied with ground sprayers in the United Kingdom , American Industrial Hygiene Association Journal 1987 , 48 : 167 – 175.

Batel, W., 1984: Operator exposure while spraying in plants—a summary of existing results, Grundlagen der Landtechnik 1984 , 34 : 33 – 53.

Bjugstad, N., Hermansen P., 2009: Operator Exposure when spraying in a Strawberry and Raspberry tunnel system. Agricultural Engineering International: the CIGR Ejournal.

Bjugstad, N., Torgrimsen, T., 1996: Operator Safety and Plant Deposits when using Pesticides in Greenhouses. Journal of Agricultural Engineering Research 65: 205 – 212.

Chester, G., 1993: Evaluation of agricultural worker exposure to, and absorption of, pesticides. Ann. Occup. Hyg. 37, 509–523.

Directive 128/2009/EU

Durham, W. F., Wolfe, H. R., 1962: Measurement of the exposure of workers to pesticides Bulletin WHO, 26, 75–91.

Gilbert, A. J., 1995: Analysis of exposure to pesticides applied in a regulated environment. In: Best G.A. and Ruthven A.D. (Eds.) Pesticides – Developments, Impacts, and Controls. Royal Society of Chemistry.

Krieger, R. I., Dinoff, T. M., 2000: Malathion deposition, metabolite clearance, and cholinesterase status of date dusters and harvesters in California. Archives of Environmental Contamination and Toxicology, 38, 546–553.

Ludwicki, J.K., Bańkowski, R., Wiatrowska, B., 2003: Ocena ryzyka narażenia na pestycydy operatorów zabiegów agrochemicznych. Roczniki Państwowego Zakładu Higieny, vol. 54 no 2, 2003, s. 45-47.

Manuscript BC 1049. Vol. XI. August, 2009.

Sutherland, J. A., King, W. J., Dobson, H. M., Ingram, W. R., Attique, M. R., Sanjrani, W., 1990: Effect of application volume and method on spray operator contamination by insecticide during cotton spraying. Crop Protection, 9, 343–350.

Wolfe, H. R., 1976: Field exposure to airborne particles. In Lee R E. (Ed.) Air Pollution from Pesticides CRC Press, Cleveland. 137–161.