Bull. Environ. Contam. Toxicol. (2001) 67:20–26

DOI: 10.1007/s00128-001-0086-y

Bulletin of Environmental Contamination and Toxicology

Determination of Safe Work Time and Exposure Control Need for Pesticide Applicators

J. G. Machado-Neto

Department of Crop Protection, School of Agricultural and Veterinary Sciences of Jaboticabal, São Paulo State University, Jaboticabal 14870-000, São Paulo, Brazil

Received: 3 April 2000/Accepted: 3 April 2001

Pesticides are highly selected chemical compounds that cause intoxication and death in target organisms. Direct contact with pesticides by non-target organisms, such as workers that handle and apply these toxicants, can lead to harmful effects. Due to the risk of pesticide intoxication, it is necessary to have adequate knowledge of safety in work conditions. The risk of pesticide poisoning depends on the toxicity of the agent and the extent of exposure (Turnbull 1985). Toxicity is an inherent property of pesticides and must be completely assessed before the sale of these chemicals is permitted. Pesticide exposure is dependent on work conditions, and it is determined based on the kind of formulation used, on the type of labor and how it is performed by the worker (Turnbull 1985), and also on the equipment used for pesticide application (Machado-Neto et al. 1996).

Durham and Wolfe (1962) derived the first equation to calculate the risk of intoxication from pesticides considering the toxicity and the exposure. In this equation, the risk was expressed in terms of percentage of toxic dose per hour. From recent studies that assessed occupational exposure to pesticides, it was consistently demonstrated that 99% or more of total exposure occurred by the dermal route and 1% or less via the respiratory route. In view of the greater relative importance of the dermal route, the equation of Durham and Wolfe (1962) was modified so that the respiratory exposure could be substituted by 10% of the calculated dermal exposure (WHO 1975).

The margin of safety (MOS) formula, proposed by Severn (1984), was the first equation to calculate the safety of work conditions for the agricultural handling of pesticides. It related the acceptable exposure (AE) with the quantity absorbed from exposure (QAE). This equation was modified by other authors, resulting in MOS = AE / (QAE x FS), where AE = NOEL (mg/kg/d) x body weight of worker (70 kg); QAE = Dermal absorption + respiratory absorption (mg/d); and FS = safety factor. A safety factor was added to this equation to compensate for the extrapolation of toxicological data from laboratory animals (NOEL) to man (Brouwer et al 1990).

Franklin (1985) proposed the following steps for risk assessment in the use of pesticides: obtain work exposure data and determine dermal/inhalation absorption correction, dosage estimation, NOEL from toxicological data, margin of safety (MOS) or quantitative risk assessment, and acceptability of MOS. Work conditions, according to those risks, can be classified as safe or unsafe, considering the estimated MOS. The use of MOS to classify the safety of work conditions is as

Correspondence to: J. G. Machado-Neto

follows: if MOS $\geq$ 1, the exposure is acceptable, the risk is tolerable and the working conditions are classified as safe; and if MOS < 1, the exposure is unacceptable, the risk is intolerable and the working conditions are classified as unsafe (Kieczka 1993).

In addition to the level of exposure incurred per hour of work, the hazard of pesticide exposure to workers was also related to the amount of time spent under these specified working conditions (Wolfe et al. 1967). Restricting the number of hours working with a pesticide is one way to reduce over-exposures (Turnbull 1985). The determination of safe work time (SWT) and exposure control need (ECN) for unsafe work conditions (MOS < 1) can also be used in management strategies dealing with pesticide risks. The calculation of SWT can be used as a safety measure to control occupational exposure in pesticide use. The calculation of ECN permits the selection of a more appropriate safety measure, in regard to the needs of each set of working conditions.

The aim of this work was to formulate equations to calculate for unsafe work conditions, the exposure control need (ECN) and the safe work time (SWT), to be used as tools to select strategies for pesticide risk management, based on acceptable exposure levels and the use of occupational data from cotton farming.

MATERIALS AND METHODS

Taking into account an earlier formula by Severn (1984), modified for the calculation of MOS, new equations were proposed to calculate the safe work time (SWT) and exposure control need (ECN).

The MOS value was determined as follows: **MOS = AE / (QAE x FS)**,

where AE (acceptable exposure) = NOEL (mg/kg/d) x body weight of worker (70 kg); QAE (quantity absorbed from exposure) = 0.11 x estimated Dermal Exposure (DE) (mg/d), based on a 10% absorption rate for dermal exposure (Jensen 198) plus 1% of dermal exposure for respiratory exposure (Wolfe et al 1967 and 1972); and FS (safety factor) = 10 (Brouwer et al 1990).

The equation proposed to calculate the exposure control need (ECN) for a particular pesticide was based on the following assumptions: if the calculated MOS $\geq$ 1, the work conditions are classified as safe; but if the calculated MOS < 1 ($MOS_{<1}$), the work conditions are classified as unsafe.

For unsafe work conditions it is necessary to control the exposure. If MOS $\geq$ 1, the work conditions are 100% safe. If MOS < 1 ($MOS_{<1}$), the work conditions are classified unsafe, and to make them safe, there is a need of control of a certain percentage of the exposure. Thus, the need of control of the exposure (ECN), enough to render these work conditions safe, can be calculated using the following equation: **ECN = (1 - $MOS_{<1}$) x 100** (%).

The equation proposed to calculate the safe work time (SWT) was based on the following assumptions. If QAE x FS occurs within an effective work time (EWT, in hr/d), then NOEL x 70 will occur within a safe work time (SWT). Therefore, SWT = (NOEL x 70)/(QAE x FS) x EWT. Since (NOEL x 70)/(QAE x FS) = MOS. Then, **SWT = MOS x EWT** (hr/d).

Data on the evaluation of potential dermal exposure (PDE) for tractor drivers and knapsack sprayer applicators in pesticide use on cotton crops was used to test the derived equations. To evaluate the PDEs of field workers, a copper fungicide spray solution was prepared (copper oxychloride, 252 g/100 L water), whereby the Cu^{+2} cation served as a tracer. PDEs of the workers to the copper fungicide were used as surrogate data (Jensen 1984) to estimate exposures to the spraying solution.

Evaluations of PDEs were performed with two types of sprayers: the knapsack sprayer, normally used by small farmers; and the tractor-mounted boom sprayer, generally used for larger farm areas. The PDEs for tractor drivers and applicators were performed during time periods of 30 minutes and extrapolated to a whole five-hour work day of effective exposure. The PDEs were determined in cotton fields during the "green boll" growing stage.

Applicators worked with knapsack sprayers, Model PJH - Jacto, with a 20-L tank and nozzle Type JD-12, spraying 150 L/ha. During these evaluations, temperature varied between 27 and 29 °C, relative humidity was between 75 and 82%, and the wind speed was under 9 km/hr. Applications were performed on plants of the second lateral line of the crop, and not on the lines where the worker walked, as is commonly done.

The tractor driver worked with a tractor-mounted boom sprayer Model Condor - Jacto, with a tank of 600 L, containing a bar of 12 m, with 23 nozzles Type JA2 at a height varying 1.3 to 1.6 m from the ground. The spraying pressure used was 5 bars while spraying 150 L/ha. These evaluations were performed during two days, in which the temperature varied between 25 and 35°C, relative humidity, between 56 and 82%, and wind speed between 3 and 4 km/hr.

Female sanitary pads (Carefree) were used as samplers for PDE measurements by placing them on 20 different parts of the worker's body (Machado-Neto and Matuo 1989; Machado-Neto 1990; Machado-Neto et al. 1992). They were fixed onto the following parts: V neckline, arms, forearms, chest, back (right/left), thighs and legs (right/left and front/back). Samplers were attached externally to the overalls on the parts mentioned above and also on the top of the head (attached to the hood), on the face (attached to disposable masks), and on the upper medium part of the feet (attached with an elastic band measuring 3 cm in width). New cotton gloves were used as samplers for the hands.

Cu^{+2} was extracted in 0.1 N hydrochloride acid and determined with a GBC atomic absorption spectrophotometer (using 5.0 mA lamp current, air acetylene flame, 324.7 nm wavelength, 0.5 nm slot width). The recovery of the Cu^{+2} tracer from these samplers was 99.99% (Machado-Neto and Matuo 1989). PDE values for the spray solutions were estimated by extrapolating the amounts of Cu^{+2} recovered from the samplers from the various areas of the body represented by the samplers, which were then compiled to obtain the final value.

PDEs for the pesticides listed in Table 1 were determined based on the concentrations recommended for preparing spray solutions for pest control and on the quantity of spray solution estimated from the samplers. These pesticides can be used for chemical control of the following pests in cotton crops: boll weevil

(*Anthonomus grandis*), pink bollworm (*Pectinophora gossypiella*), and cotton bollworm (*Heliothis virescens*).

Table 1. Main insecticides recommended for the control of boll weevil (*Anthonomus grandis*), pink bollworm (*Pectinophora gossypiella*), and cotton bollworm (*Heliothis virescens*), with their respective characteristics.

Common name	Commercial name	Conc. of a. i. (%)	Dosage (g/ha)	NOEL (mg/kg/d)
Boll weevil (*Anthonomus grandis*)				
fenvalerate	Belmark 75 CE	7.5	90.0	12.50
cypermethrin	Ripcord 100 CE	10.0	75.0	5.00
methidathion	Supracid 400CE	40.0	400.0	4.00
endosulfan	Thiodan CE	35.0	700.0	1.50
Pink bollworm (*Pectinophora gossypiella*)				
monocrotophos	Azodrin 400	40.0	600.0	1.00
fenvalerate	Belmark 75 CE	7.5	63.75	12.50
cypermethrin	Ripcord 100 CE	10.0	50.0	5.00
delthamethrin	Decis 25 CE	2.5	7.5	0.10
endosulfan	Thiodan CE	35.0	700.0	1.50
Cotton bollworm (*Heliothis virescens*)				
monocrotophos	Azodrin 400	40.0	900.0	1.00
fenvalerate	Belmark 75 CE	7.5	90.0	12.50
cypermethrin	Ripcord 100 CE	10.0	75.0	5.00
permethrin	Talcord 250 CE	25.0	125.0	5.00
profenophos	Curacron 500	50.0	500.0	0.16
delthamethrin	Decis 25 CE	2.5	10.0	0.10
endosulfan	Thiodan CE	35.0	875.0	1.50

The accepted variation in values of PDEs for repeated measurements of each body part was equal to the mean ± two times the standard deviation (WHO 1975).

RESULTS AND DISCUSSION

Table 2 displays the values of the exposure control need (ECN) and safe work time (SWT), calculated using the derived equations, for pesticide applicators working in cotton fields, using either the knapsack sprayer or tractor-mounted boom sprayers to apply the main recommended insecticides for controlling boll weevil (*Anthonomus grandis*), pink bollworm (*Pectinophora gossypiella*), and cotton bollworm (*Heliothis virescens*).

According to the results in Table 2, it was found that PDEs for applicators using knapsack sprayers were 5 times greater than for tractor drivers. Greater PDE values for pesticides were obtained when larger dosages were used (Table 1), assuming that PDEs for the spray solutions were the same.

The dose and the toxicity of the insecticides also influenced the safety of work conditions, as indicated by the values for MOS (Table 2). Applications of the insecticides fenvalerate, cypermethrin and permethrin were classified as safe (MOS > 1) for both application methods. In this case, using the proposed equations, the calculated SWT values were then much greater for one day of work, and it was therefore not necessary to control the exposure.

Applications of methidathion and delthamethrin were found to be safe only for tractor drivers that used a tractor-mounted boom sprayer. Using the proposed equations to classify the safety of these work conditions, it was shown that there was in the need to control the exposure (NCE) and the maximum team that applicators could work under unsafe conditions.

Applications of methidathion and delthamethrin were found to be unsafe for applicators with knapsack sprayers. For methidathion, the ECN value calculated was 54.2% for boll weevil control. For delthamethrin, the ECN value calculated was 38.9% for pink bollworm and 54.2% for cotton bollworm control. These control levels can be easily obtained by reducing the time of work, in agreement with Turnbull (1985). The SWT values calculated were 2.3 hr for both methidathion (boll weevil) and delthamethrin (cotton bollworm) and 3.1 hr for delthamethrin when applied to control pink bollworms. Another way to achieve these controls would be by the use of personal protective clothing.

Table 2. Estimated values of potential dermal exposures (PDE), margin of safety (MOS), exposure control need (ECN), and safe work time (SWT) for application of the main recommended insecticides on cotton crops to control boll weevil, pink bollworm, and cotton bollworm, using knapsack (KS) and tractor-mounted boom (TMB) sprayers.

Common name	PDE (mg/day)		MOS		ECN (%)		SWT (hr)	
	KS	TMB	KS	TMB	KS	TMB	KS	TMB
Boll weevil (*Anthonomus grandis*)								
fenvalerate	124.93	24.82	6.367	32.049	0.0	0.0	31.8	160.3
cypermethrin	104.11	20.69	3.056	15.379	0.0	0.0	15.3	76.9
methidathion	555.24	110.34	0.458	2.307	54.2	0.0	2.3	11.5
endosulfan	971.66	193.09	0.098	0.494	90.2	51.0	0.5	2.5
Pink bollworm (*Pectinophora gossypiella*)								
monocrotophos	832.85	165.50	0.076	0.385	92.4	61.5	0.4	1.9
fenvalerate	88.49	17.58	8.989	45.248	0.0	0.0	44.9	226.2
cypermethrin	69.40	13.79	4.585	23.073	0.0	0.0	22.9	115.4
delthamethrin	10.41	2.07	0.611	3.074	38.9	0.0	3.1	15.4
endosulfan	971.66	193.09	0.098	0.494	90.2	51.0	0.5	2.5
Cotton bollworm (*Heliothis virescens*)								
monocrotophos	1,249.28	250.42	0.051	0.254	94.9	74.6	0.3	1.3
fenvalerate	124.93	25.04	6.367	31.767	0.0	0.0	31.8	158.8
cypermethrin	104.11	20.87	3.056	15.246	0.0	0.0	15.3	76.2
permethrin	173.51	34.78	1.834	9.148	0.0	0.0	9.2	45.7
profenophos	694.05	139.12	0.015	0.073	98.5	92.7	0.1	0.4
delthamethrin	13.88	2.78	0.458	2.289	54.2	0.0	2.3	11.5
endosulfan	1,214.58	243.46	0.079	0.392	92.1	60.8	0.4	2.0

Endosulfan applications were classified as unsafe (MOS <1) for both methods of application evaluated. However, for the tractor drivers we calculated ECN values of 51% when this pesticide was used to control boll weevil and pink bollworm and 60.8% for cotton boll control. As with the above-mentioned insecticides, these control levels can easily be obtained by reducing the time of work, in agreement with Turnbull (1985). The SWT values calculated were 2.5 hr for boll weevil and pink bollworms and 2.0 hr for cotton bollworm control. Another way to achieve these controls would be to also use personal protective clothing. For applicators with the

knapsack sprayer, there was a need for 90.2 % and 92.1% exposure control, which could not be obtained with the use of personal protective clothing. In this case, it is recommended that endosulfan be substituted by other safer insecticides such as fenvalerate, cypermethrin or permethrin.
In the case of monocrotophos, it should not be applied with knapsack sprayers because the calculated ECN values were extremely high (92.4 and 94.9%), and thus impossible to achieve by any safety measure. This insecticide could be applied with a tractor-mounted boom sprayer, since the ECN values calculated were 61.5% for pink bollworm and 74.6% for cotton bollworm control. This control could also be achieved with the use of personal protective clothing.

For profenophos, it should not be applied for controlling cotton bollworm, since it presented the most unsafe working conditions, with calculated ECN values of 98.5% for the applicators with knapsack sprayers and 92.7% for tractor drivers. Therefore, it would be very difficult to prevent dangerous exposure by any safety measure.

Our data indicated that the equations proposed here to calculate ECN and SWT are very important tools for selecting safety measures to manage the risk of working with pesticides.

REFERENCES

Brouwer DH, Brouwer R, Vreede JAF, Mik G, Van Hemmen JJ (1990) Respiratory exposure to field-strength dusts in greenhouses during application and after re-entry. TNO Health Research, Amsterdam, pp 183-184 Annual Report 1990

Durham WJ, Wolfe HR (1962) Measurement of the exposure of workers to pesticides. Bull World Hlth Org 26:75-91

Franklin CA (1985) Occupational exposure to pesticides and its role in risk assessment procedures used in Canada. In: Honeycutt RC, Zweig G, Ragsdale NN (eds) Dermal exposure related to pesticide use. ACS, Washington, pp 429-442 ACS Symposium Series, n. 273

Jensen JK (1984) The assumptions used for exposure assessments. In: Siewierski M (ed) Determination and assessment of pesticide exposure. Elsevier Science Publishers B.V., Amsterdam, pp 147-152 Studies Environ Sci, n. 24

Kieczka, H (1993) Requirements for safe-guarding the health of applicators of plant protection products – an overview. In: Second International Symposium on Pesticides Application Techniques, Strasbourg, Annals, n. 2/2. BCPC, Strasbourg, pp 455 – 462

Machado-Neto JG, Matuo T (1989) Avaliação de um amostrador para o estudo da exposição dérmica potencial de aplicadores de defensivos agrícolas. Ciên Agron Jaboticabal 4:21-22.

Machado-Neto JG (1990) Quantificação e controle da exposição dérmica de aplicadores de agrotóxicos na cultura estaqueada de tomate (*Lycoppersicon esculentum* Mill.), na região de Cravinhos, SP. FCAV/UNESP, Jaboticabal, 112p Tese de Doutoramento

Machado-Neto JG, Matuo T, Matuo YK (1992) Dermal exposure of pesticide applicators in staked tomato (*Lycoppersicon esculentum*) crops: efficiency of a safety measure in the application equipment. Bull Environ Contam Toxicol 48:529-534

Machado-Neto JG, Matuo T, Matuo YK (1996) Semiquantitative evaluation of dermal exposure to granulated insecticides in coffee (*Coffea arabica* L.) crop and

efficiency of individual protective equipment. Bull Environ Contam Toxicol 57:946-951
Severn DJ (1984) Use of exposure data for risk assessment. In: Siewierski M (ed) Determination and assessment of pesticide exposure. Elsevier Science Publishers B.V., Amsterdam, pp13-19 Studies Environ Sci, n. 24
Turnbull GL (1985) Current trends and future needs. In: Turnbull GL (ed) Occupational hazards of pesticide use. Taylor & Francis, London, pp 99-116
WHO (1975) Survey of exposure to organophosphorus pesticides in agriculture - standard protocol. WHO, Geneva, 25p Document VBC/75.9
Wolfe HR, Durham WF, Armstrong JF (1967) Exposure of workers to pesticides. Arch Environ Hlth 14:622-633