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Operational Risk Assessment of Sprayers by Environmental Impact Analysis

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A method is presented for the assessment of operational risk from the use of sprayers based on environmental impact analysis. The method expresses the risk as a sum of possible negative outcomes on the environment and the operator, considering the effects of a set of factors relating to pesticide applications. Risk assessment has been carried out for the more representative types of sprayers, highlighting the advantages that can be obtained through technological improvements and operational constraints. The method allows a risk to be associated with each sprayer so that a risk classification may be expressed. © 1998 Silsoe Research Institute

1. Introduction

Technology has brought enormous benefits to agriculture but they have not been cost-free; in particular, the use of chemicals has made agriculture one of the most widespread sources of pollution.

Our need to protect crops obliges us to continue with the use of dangerous substances in the form of chemicals employed as pesticides which here includes herbicides, fungicides and insecticides. This exposes a wide range of subjects to the risk of harm, for example, to man (whether he be the operator or a passive subject), animals and beneficial insects, the water, air and soil systems.

The overall problem to face is how best to manage the chemical application system so as to optimize risk–benefit factors. Chemical products give rise to the hazard but they are not the only determining factor. The operator carrying out the treatment is also a determining factor with his knowledge, as is the vehicle used for application which must have characteristics able to respond to the need for effective pest control, to the type of product to be applied and to safeguarding those areas which the product simply must not reach. The operational constraints also play a major role in the safety and effectiveness of treatments.

Many attempts have been made to define codes of practice. The National and International Commissions working on norms for the use of agricultural machinery[1–10] recognize that the means of distribution greatly contribute to the quality and efficiency of chemical application in agriculture. With specific regard to agricultural sprayers, three measures are being taken as follows: (1) periodical checks on existing sprayers; (2) the obligation for new equipment to be certified; and (3) norms and constraints to ensure a correct usage.

Concerning the first two points, some European Nations have already prepared appropriate laws and structures, and a wealth of scientific experience has been accumulated in the form of instruments and procedures. The third point, "norms and constraints to ensure a correct usage", is still at the initial stages of formulation and must be adapted to the specific conditions of each nation individually. In 1991, the CEN/TC144/WG3 had introduced a proposal[1] for the safeguard of the environment, and it was discussed by the various international commissions over the course of 1992.

The aim behind the introduction of norms for the correct employment of sprayers is to improve prospects for operator safety to safeguard a pollution-free environment and to maintain checks on equipment efficiency.

With reference to these problems, research is being done to determine a method of assessing risk associated with the use of machinery for spraying chemicals, based on the potential contamination hazards to operators and the environment.

The British Crop Protection Council, which for years has been promoting scientific exchange in Europe in the sector of safe use of agricultural chemicals, has previously put forward a spray nozzle classification scheme which has received widespread acceptance. Following from this, the BCPC has devised a comprehensive scheme based on

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potential contamination hazard that should be applicable to all forms of pesticide application equipment. The scheme is reported by Parkin *et al.*[11] and is the result of a working group of the BCPC consisting of representatives of equipment manufacturers, chemical manufacturers, regulatory advisers, consultants and research organisations.

In accordance with Italian national legislation and because of the awareness of Regional Government of Tuscany, a study was initiated to define a methodology with which to assess risk related to the use of machinery for pesticide applications. The applications for such a methodology are: to estimate the advantages achievable in terms of risk reduction for both the operator and the environment by mitigating interventions and precautions; to define priorities for technological improvement; and to assist the laying down of norms and control actions.

2. Methodology developed

In accordance with Sage,[12] systems engineering can be defined as a management technology to assist in the enhancement of system quality throughout the entire life cycle through the three fundamental steps of formulation, analysis and interpretation of the impacts that a course of action, policies and controls produce upon perceived need or prefixed objectives. This methodological framework is also used for hazard and risk assessment. Systems associated risk management is in fact one of the tasks to be accomplished in pursuing the total quality approach.

The nature of the risk is fundamentally two-dimensional: the probability or likelihood of a negative outcome and the amount of damage or loss connected with it. A rational theory of risk assessment typically involves giving numerical measures to these two elements and aggregating these numbers into a single index of merit. When, as in many contemporary issues, objective probabilities and loss values are not known, subjective ones are used instead. In this case, the reference model is indicated as a subjective one. The rules of combination, however, remain the same.

In order to evaluate the risk associated with the use of treatment machinery on a variety of subjects and due to a variety of factors, a method of multicriterion analysis has been used. In particular, a cross-interaction matrix approach normally used when estimating the impact on the environment connected to an alternative course of action was adopted.[13,14] The method is particularly suitable when the effects of environmental changes conditioned by a series of factors are not measurable (many environment changes can be evaluated only after a long time) and only an ordinary scale of importance can be defined, although this may have to be transformed into a numerical one. The results (numbers expressing the total impact) largely depend on the initial subjective assumptions (as for every alternative) so that their validity has to be seen in the comparison of the values and thus as a support for a rational choice among alternative solutions.

In our case, primary consideration is given to the risk associated with different types of treatments (weed control, tree or field crops pest control, etc.), each of which in general, can be carried out by different types of sprayers, either as regards technology or functionality, and each subject to a set of more or less restrictive operational constraints.

The implementation of the method starts by elucidating and listing a series of environmental components that are the most representative or sensitive to damage, here called "subjects at risk", and a series of variables or factors, here called "risk factors", which are thought to have the most influence over the effects produced by the interventions considered. Some of the risk factors are controllable and represent the effects on risk of the course of action that we wish to evaluate.

The subjects at risk and the chosen risk factors are shown in Table 1 which represents the step of issue identification for the formulation of risk assessment. The various items listed are not claimed to be exhaustive, but can be held to be adequate for a first attempt at using this methodology. The chosen factors relate to the need to evaluate the "hazard" for environment and operator inherent in the use of a sprayer, insofar as it is influenced by parameters expressing conditions of the application environment (natural factors), the characteristics of construction of the machine (technological factors) and the operational constraints and controls (operational factors). Also in this sphere, the problem of residue disposal is taken into consideration, as it is directly connected with constraints and facilities concerning both users and manufacturers. Operational factors may be seen as mitigating effects and they can be the result of legislative norms or of operational improvement obtained by giving the farmers suitable tools for logistic support.

Risk factors and subjects are given as headings for the rows and columns of the matrix in *Fig. 1* which is able to represent and assess their reciprocal links. In the matrix of *Fig. 1*, an ordinal scale of A, B and C is used to express three levels of influence: A (direct), B (indirect), C (marginal). Assuming that level A has an influence thrice greater than level C, and level B is twice greater than level C, then

$$A = 3C;\ B = 2C \text{ (and thus } A = 3/2B) \qquad (1)$$

Risk issue formulation should be, and usually is, a group activity which results in a global identification of the

Table 1
List of risk factors and subjects at risk

Risk factors	*Effects*
Natural	
Wind	Off-target airborne drift
Temperature and humidity	Losses as vapour drift
Closeness of the subject at risk to the treatment area	Hazard for human and animal beings and other crops close to the treated area
Target complexity	Off target airborne drift and run-off from target surface
Technological	
Set up devices	Ease and reliability with which the delivered dose can be set
Devices to enhance spray accuracy	Less losses and better accuracy
Mix preparation devices	Spillage of concentrated formulation when loading the sprayer, operator contamination when handling chemicals
Material and manufacture quality	Reliability
Operational	
Constraints on pesticides	Habitat and operator safety
Constraints on operational methods	Habitat and operator safety
Constraints on periodic checks	Sprayer efficiency
Disposal of residuals	Less contamination related to sprayers, cleaning and disposal of unused pesticide
Subject at risk	*Effects*
Operator	Contamination risk
Humans and animals	
Air system	
Water system	
Other crops	
Spraying quality	Achievement of operation purpose

problem. Using the proposed methodology, the group assigns a level of influence to every subject/factor couple of the matrix, which in this case has been done by means of a panel of experts of the Regional Government of Tuscany's agricultural advisory service. The group was made up as follows: (1) from the production sector, one representative from farmers' organizations, one from the chemical industry and one from the sprayer manufacturers; (2) from the scientific sector, a phythopathologist, an environmentalist, and an agricultural engineer; and (3) from the regional government sector, a workers' epidemiologist and a legislative advisor. Furthermore, there was an expert of the methodology acting as the panel chairman.

The method of taking decisions was that of "discussion leading to consensus". The assignment of one of the three influence levels at every subject/factor combination corresponds to fixing a likelihood for risk materializing, i.e. specifying one of the two dimensions of risk. Furthermore, differing significance was attached to subjects at risk. In this specific case, three different weights were assumed, equal to 10β, with $\beta = 1$, 2, or 3, which place a relative value on the diverse subjects considered. This means that, for instance, the risk for the operator has been considered to be three times more important than the risk for closed crops or spraying quality. The choice of the constant factor 10 is merely in order to simplify numerical representation. Thus we have the two basic dimensions of risk assigned.

The aggregation of the two dimensions is then done by imposing on each column the relation

$$\sum A + \sum B + \sum C = 10\beta \qquad (2)$$

Together with Eqn (1), this gives the weight of the different factors for the particular value of β that is applied to each subject. The number obtained is shown in the lower right corner of the squares and represents the importance of the factor with respect to the materialization of risk on every subject. When these are summed up in rows, they provide the coefficients of weight which represent an ordinal scale for the overall influences of the factors on the subjects.

Up to this point, the problem has been considered in general, i.e. without referring to any specific treatment of sprayer. For a particular study, a further step is needed which consists of assigning a scale of magnitudes to the risk factors shown in Table 3. Using this scale, it is possible to take into account the importance of the different risk factors in relation to the type of treatment and sprayer and the effectiveness of the mitigating actions.

The characterization of a specific treatment system is carried out by assigning a specific magnitude value to each factor, so that an overall numeric set is eventually obtained for the case under consideration. Magnitude attribution, as for influence specification in the cross-interaction matrix, is a result of the deliberation of the expert panel. An example of magnitude attribution is given in Table 4 where the case of a knapsack sprayer is analysed.

Once a magnitude set has been specified, the product of magnitude and the coefficient of weight of the factor gives the partial risk impact bound with it. Summing up these partial values, the overall risk impact is eventually obtained. If, in particular, these evaluations are done for minimum and maximum values of magnitude the range of the risk impact can be assessed.

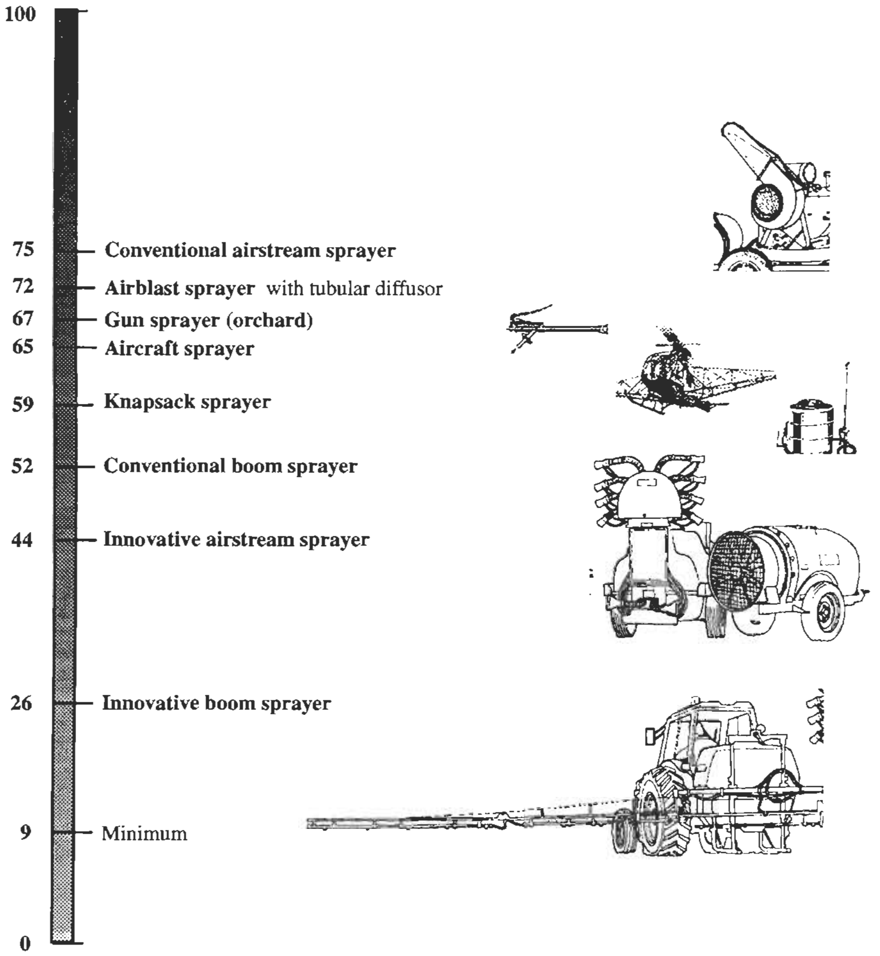

Fig. 1. Position of the types of sprayers under consideration on the percentage risk scale

3. Results and discussion

The proposed method of risk assessement has been applied for six types of sprayers: boom, air stream sprayer, knapsack sprayer, gun sprayer, spraying by helicopter/airplane and last the air blast sprayer with a tubular diffuser widely used in pest control applications. As regards operational constraints and controls, as well as the disposal of residues, those currently in use have been considered.

To highlight the influence of improved technology, the cases of innovative and conventional boom and air stream sprayers have been examined. For this comparison, we refer to the equipment tested by Nordermark and Svensson,[15] who considered an air-assisted boom and a simple boom with fan nozzles.

As innovative air stream sprayers, we considered those equipped with shrouded air stream conveyers properly fitted to the canopy shape, working at medium-low volume rate, whereas as conventional ones, those with a simple circular diffuser working at high volume rate have been considered.

Displayed in Table 5 are the risk values estimated for the eight types of sprayers together with the magnitude attributed to the different sprayers under consideration and the minimum and maximum risk values relative to the minimum and maximum magnitudes, respectively. Table 5 also shows the partial effects on risk values due to the three sets of factors considered as a whole. It can be seen that risk values range from 120 (minimum) to 1366 (maximum). Of course, the meaning and representativeness of all these values have to be examined for comparative purposes.

By a percentage scaling of the hazard values in relation to the maximum value, a classification is reached which is relative to the risk of the different equipment as shown in *Fig. 1*. The position of the sprayers on the "risk scale" shows, for example, that the knapsnack sprayer is more hazardous than the boom sprayers and the innovative air stream sprayer, and that aircraft, and helicopters come

Table 3

Subjects **Factors**	Operator	Humans and animals	Air system	Water system	Other crops	Spraying quality	Weight coefficient
Natural Wind	**A** 3.8	**A** 3.5	**B** 1.5	**A** 2.0	**A** 1.2	**A** 1.1	13.1
Temperature and humidity	**B** 2.5	**B** 2.3	**A** 2.3	**C** 0.7	**C** 0.4	**A** 1.1	9.3
Closeness of the subjects at risk to the treatment area	**A** 3.8	**A** 3.5		**A** 2.0	**A** 1.2		10.4
Target complexity	**C** 1.3	**B** 2.3	**A** 2.3	**B** 1.3	**B** 0.8	**A** 1.1	9.1
Technological Set up devices	**C** 1.3	**B** 2.3	**B** 1.5	**B** 1.3	**B** 0.8	**A** 1.1	8.3
Devices to enhance spray accuracy		**B** 2.3	**A** 2.3	**A** 2.0	**A** 1.2	**A** 1.1	8.9
Mix preparation devices	**A** 3.8			**B** 1.3		**A** 1.1	6.2
Manufacture and material quality	**B** 2.5	**B** 2.3	**B** 1.5	**B** 1.3	**B** 0.8	**A** 1.1	9.6
Operational Constraints on pesticides	**B** 2.5	**A** 3.5	**A** 2.3	**A** 2.0	**A** 1.2	**B** 0.7	12.2
Constraints on operational methods	**A** 3.8	**A** 3.5	**A** 2.3	**A** 2.0	**A** 1.2	**B** 0.7	13.4
Constraints on periodic checks	**B** 2.5	**B** 2.3	**A** 2.3	**A** 2.0	**B** 0.8	**A** 1.1	11.0
Disposal of residues	**B** 2.5	**B** 2.3	**B** 1.5	**A** 2.0	**C** 0.4		8.7
	30	**30**	**20**	**20**	**10**	**10**	

after (are less hazardous than) the gun sprayer and the conventional airstream sprayer.

From the risk scale, it emerges that the most hazardous machine is the conventional air stream sprayer with a value of 75% of the maximum. In the medium-risk category comes the conventional boom sprayer which, in its innovative form, is the least hazardous with a value of 26% of the maximum risk.

To highlight the influence of the three sets of risk factors on the overall risk value obtained for the eight sprayers considered in a better manner, the presentation of *Fig. 2* is employed. It shows that, for instance, treatments by aircraft or helicopter are less hazardous than gun, conventional air stream and air blast sprayers due to stronger restrictions on use and controls (i.e. operational constraints, which account for 33% of the total risk value), and that technological innovations on air stream sprayers greatly reduce their risk. In this latter case, it should be noted that technological improvements, which account for a 15 point reduction, also imply indirect advantages in terms of less sensitivity to natural factors (minus 13 points) and better operational performance

Table 3
Scale of magnitudes for risk factors

Natural risks		*Technological risks*		*Operational risks*	
Factor	*Magnitude*	*Factor*	*Magnitude*	*Factor*	*Magnitude*
Wind		*Set-up devices*		*Constraints on pesticides*	
Sensitivity Very high	15	Absent	10	Absent	1
High	10	Operation Difficult	7·5	Simple	5
Medium	5	Simple	5	Complex	1
Low	1	Automatic	1		
Temperature and humidity		*Devices to enhance spray accuracy*		*Constraints on operative methods*	
Sensitivity Very high	15	Efficacy Low	10	Absent	10
High	10	Medium	5	Simple	5
Medium	5	High	1	Complex	1
Low	1				
Closeness of the subjects at risk to the treatment area		*Mix preparation devices*		*Constraints on periodic checks*	
Sensitivity Very high	15	Manual	10	Absent	10
High	10	Operation Difficult	7·5	Rare	5
Medium	5	Simple	5	Frequent	1
Low	1	Automatic	1		
Target complexity		*Material and manufacture quality*		*Disposal of residues*	
Complexity: High	10	Low	10	Unchecked	10
Medium	5	Medium	5	Checked	5
Low	1	High	1	Appropriate	1

(minus 3·2 points) that, based on the total value of 75 for the conventional air stream, result in an overall risk reduction of 41%. Similar considerations hold for boom sprayers in which case the risk reduction due to technological improvement is around 50%.

In order to assess the validity of the method proposed, and in particular the level of reliability that can be achieved using methods based on subjective assessments, the three different types of treatments and machines considered by Parkin *et al.*[11] were submitted to the same group of experts, but at a later time. In Parkin *et al.* too, the opinion of a group of experts was sought, but the final risk assessment was made using a different methodology. This provided the opportunity to check the degree of comparability of the results obtained with two different groups of experts and a different methodological approach. The results of the analysis are shown in Table 6 where the last three lines show, respectively, the risk value expressed in relative percentage terms, the correspondent classification category according to the ordinal scale adopted by Parkin *et al.*[11] and, on the last line, the risk categories given by Parkin *et al.*[11] It can be noted that the assessments by the two methods, despite their subjectivity, do seem to have a reasonable correspondence.

What emerged in particular from this exercise was that, in order to make this second assessment for the cases considered by Parkin *et al.*,[11] the group of experts wanted to see the magnitude values attributed in the previous calculations. This confirmed the fact that the formulation of a judgement has a typically relative value, since it is the result of a comparison between the terms to be evaluated. Moreover, the panel experienced a certain difficulty in attributing magnitudes for the risk factors (Table 3), finding that the available range subdivision values were too limited to make an adequate differentiation with the previous cases considered. Naturally, there is no particular restraint on adopting a larger and more detailed numerical scale of magnitudes, apart from the difficulties in making them correspond to a suitable attributive adjective. Nonetheless, the final attribution of risk categories may be considered very similar.

4. Conclusions

By adapting a method of environmental impact analysis, a value structure to assess risk associated with plant protection treatments has been proposed. This makes it possible to transform a qualitative judgement of the effects of each single factor on a variety of subjects, into a number expressing the total risk. The usefulness of the

Table 4
An example of risk factor magnitude attribution for the knapsack sprayer

Factors	*Observations*	*Magnitude*
Natural		
Wind	Low sensitivity owing to closeness of sprayer to target with consequent short passage of the jet through the air	1
Temperature and humidity	Low sensitivity owing to closeness of sprayer to target with consequent short passage of the jet through the air	1
Closeness of the subjects at risk to the treatment area	High risk owing to contact of the tank with the operator's back with consequent likelihood of epithelial absorption or inhalation	10
Target complexity	The closeness of the sprayer and the need to brush the perimeter of the target ensure that the sprayer is pointed towards the target correctly	
Technological		
Set-up devices	Maximum risk owing to the total lack of control and setting devices	10
Devices to enhance spray accuracy	Difficulty in controlling overlaps in the deposition area makes the quality very poor	10
Mix preparation devices	Normally manual and for small dimensions it is done mostly using very approximate and unsafe methods	10
Manufacture and material quality	Simplicity is ambiguous because on the one hand it gurantees functioning, on the other it makes it possible to achieve the quality required for this operation	5
Operational		
Constraints on pesticide	The constraints are those normally applied to sprayers	5
Constraints on operative methods	There are no constraints on the method of operation or the training of operators for this type of sprayer, so the risk is not controlled in this sense	
Constraints on periodic checks	No checks foreseen	10
Disposal of residues	No regulations, technological or legal controls on residue disposal	10

method is primarily for comparison purposes to act as a support for making a choice among alternative courses of action. The numerical values represent the combined judgements of a panel of knowledgeable experts.

The proposed methodology has the advantage of evaluating the sensitivity to the various risk factors of the different types of sprayers, which highlights the benefits to be derived from appropriate action by the manufacturers (technological improvements), the advisers (restrictions on use and checks), and the farmers (choice of suitable conditions for use).

For most sprayers, a good reduction of risk could be achieved by improving technology and by more effective operational restrictions and controls. The improvement in technology can be quantified in the case of boom sprayers and air stream sprayers as a risk reduction in the order of 50 and 41%, respectively. For operational constraints, which account for 33% of the overall risk value (except in the case of treatment using aircraft, where norms for use are rather restrictive), further significant risk reduction can be achieved through legislation and greater sprayer operational controls.

As the initial qualitative evaluations required by the methodology are of a subjective nature, the resulting risk values are inevitably dictated by these initial decisions. This is typical of many contemporary risk issues. Greater objectivity could perhaps be obtained by using experimental data about treatment accuracy, obtainable by innovative devices, so that a better classification could be achieved. At the moment, such studies are not common and are limited in scope.

The present approach and the results obtained should be considered only as a first attempt to demonstrate a possible methodology. Despite that, the application of the methodology to the cases considered by Parkin *et al.*,[11] has shown a substantial homogeneity in the results, which gives encouragement as to the reliability of the procedure.

Table 5

Assessed partial and total risk values of six types of sprayers. The minimum and maximum risk values corresponding to lower and higher magnitude levels are also reported

		Risk factor magnitudes and risk values for various spraying systems																			
		Min		*Boom innovative*		*Air stream innovative*		*Boom conventional*		*Knapsack*		*Aircraft*		*Gun sprayer*		*Air blast tubular diff.*		*Air stream conventional*		*Max*	
Factors	*Weight coefficient*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*
Natural																					
Wind	13·1	**1**	13·1	**1**	13·1	**5**	65·5	**5**	65·5	**1**	13·1	**15**	196·5	**5**	65·5	**10**	131·0	**10**	131·0	**15**	196·5
Temperature and humidity	9·3	**1**	9·3	**1**	9·3	**5**	46·5	**5**	46·5	**1**	9·3	**15**	139·5	**5**	46·5	**10**	93·0	**10**	93·0	**15**	139·5
Closeness of subjects at risk	10·4	**1**	10·4	**1**	10·4	**5**	52·0	**5**	52·0	**10**	104·0	**15**	156·0	**5**	52·0	**10**	104·0	**10**	104·0	**15**	156·0
Target complexity	9·1	**1**	9·1	**1**	9·1	**10**	91·0	**1**	9·1	**1**	9·1	**10**	91·0	**10**	91·0	**10**	91·0	**10**	91·0	**10**	91·0
Partial total			42		42		255		173		136		583		255		419		419		583
Technological																					
Set-up devices	8·3	**1**	8·3	**1**	8·3	**1**	8·3	**7·5**	62·3	**10**	83·0	**7·5**	62·3	**10**	83·0	**7·5**	62·3	**7·5**	62·3	**10**	83·0
Devices for spray accuracy	8·9	**1**	8·9	**1**	8·9	**5**	44·5	**5**	44·5	**10**	89·0	**10**	89·0	**10**	89·0	**10**	89·0	**10**	89·0	**10**	89·0
Mix preparation devices	6·2	**1**	6·2	**1**	6·2	**1**	6·2	**10**	62·0	**10**	62·0	**5**	31·0	**10**	62·0	**5**	31·0	**5**	30·8	**10**	62·0
Material/manufacture quality	9·6	**1**	9·6	**1**	9·6	**1**	9·6	**5**	48·0	**5**	48·0	**5**	48·0	**10**	96·0	**10**	96·0	**10**	96·0	**10**	96·0
Partial total			33		33		69		217		282		230		330		278		278		330
Operational																					
Constraints on pesticide	12·2	**1**	12·2	**5**	60·9	**5**	61·0	**5**	61·0	**5**	61·0	**1**	12·2	**5**	61·0	**5**	61·0	**5**	61·0	**10**	122·0
Constraints on operative methods	13·4	**1**	13·4	**5**	67·2	**5**	67·0	**5**	67·0	**10**	134·0	**1**	13·4	**5**	67·0	**5**	67·0	**5**	67·0	**10**	134·0
Constraints on periodic checks	11·0	**1**	11·0	**10**	110·0	**10**	110·0	**10**	110·0	**10**	110·0	**1**	11·0	**10**	110·0	**10**	110·0	**10**	110·0	**10**	110·0
Disposal of residues	8·7	**1**	8·7	**5**	43·5	**5**	43·5	**10**	87·0	**10**	87·0	**5**	43·5	**10**	87·0	**5**	43·5	**10**	87·0	**10**	87·0
Partial total			45		282		282		325		392		80		325		282		325		453
Totals			120		357		606		715		810		893		910		979		1022		1366

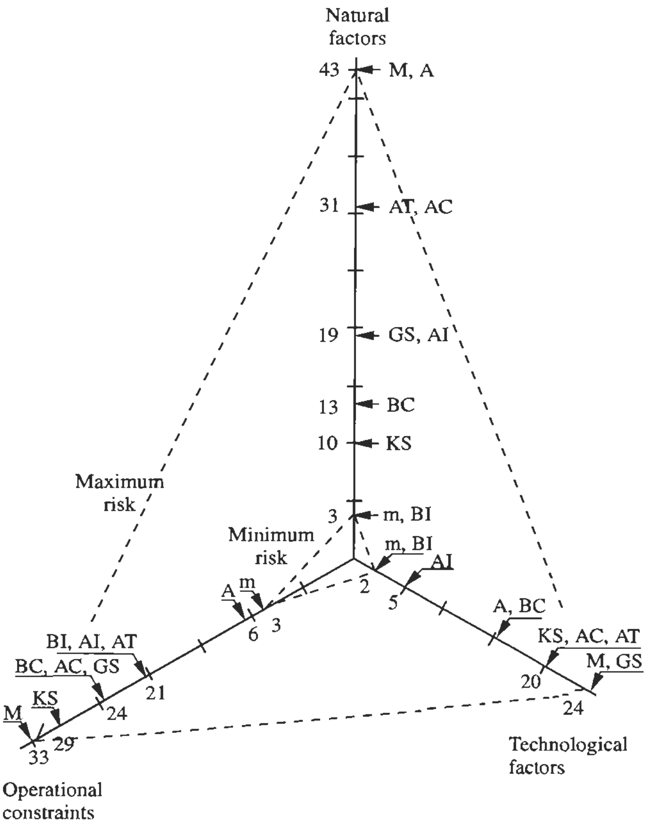

Fig. 2. Evaluation of partial degree of risk for each type of risk factors: AC airstream sprayer conventional; AT airblast sprayer with tubular diffusor; GS gun sprayer; A aircraft sprayer; KS knapsack sprayer; BC boom conventional; AI airstream sprayer innovative; BI boom innovative; m minimum value; M maximum value

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Table 6

Assessed partial and total risk values of the same cases considered by Parkin *et al.* Risk categories, according to the ordinal scale adopted by Parkin *et al.*, are composed in the last two rows. (VL, very low; L, low; M/L, medium-low; M, medium; M/H, medium-high; H, high)

				Risk factor magnitudes and risk values for various spraying systems																			
				Scenario A: tree crop spraying						*Scenario B: boom with different*						*Scenario C: weed control around* buildings							
		Min		*Un-shrouded axial-flow sprayer*		*Vertical axis cross-flow sprayer*		*Tunnel sprayer*		*Fine spray*		*Medium spray*		*Coarse spray*		*Knapsack sprayer*		*CDA application shrouded*		*Granular spot application*		*Max*	
Factors	*Weight coefficient*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*	*Mag.*	*Risk value*
Natural																							
Wind	13·1	**1**	13·1	**15**	196·5	**5**	65·5	**1**	13·1	**10**	131	**5**	65·5	**1**	13·1	**1**	13·1	**1**	13·1	**1**	13·1	**15**	196·5
Temperature and humidity	9·3	**1**	9·3	**10**	93	**5**	46·5	**1**	9·3	**10**	93	**5**	46·5	**1**	9·3	**1**	9·3	**1**	9·3	**1**	9·3	**15**	138·8
Closeness of subjects at risk	10·4	**1**	10·4	**15**	156	**10**	104	**1**	10·4	**5**	52	**5**	52	**1**	10·4	**10**	104	**5**	52	**1**	10·4	**15**	156·2
Target complexity	9·1	**1**	9·1	**10**	91	**5**	45·5	**1**	9·1	**1**	9·1	**1**	9·1	**1**	9·1	**1**	9·1	**1**	9·1	**1**	9·1	**10**	90·7
Partial total			42		536·5		261·5		41·9		285·1		173·1		41·9		135·5		83·5		41·9		582
Technological																							
Set-up devices	8·3	**1**	8·3	**10**	83	**7·5**	62·25	**5**	41·5	**5**	41·5	**5**	41·5	**5**	41·5	**10**	83	**1**	8·3	**1**	8·3	**10**	83·0
Devices for spray accuracy	8·9	**1**	8·9	**10**	89	**5**	44·5	**1**	8·9	**5**	44·5	**5**	44·5	**5**	44·5	**10**	89	**1**	8·9	**1**	8·9	**10**	88·9
Mix preparation devices	6·2	**1**	6·2	**7·5**	46·5	**7·5**	46·5	**7·5**	46·5	**7·5**	46·5	**7·5**	46·5	**7·5**	46·5	**10**	62	**7·5**	46·5	**1**	6·2	**10**	61·5
Material/manufacture quality	9·6	**1**	9·6	**10**	96	**5**	48	**5**	48	**5**	48	**5**	48	**5**	48	**10**	96	**1**	9·6	**1**	9·6	**10**	95·5
Partial total			33		314·5		201·25		144·9		180·5		180·5		180·5		330		73·3		33		329
Operational																							
Constraints on pesticide	12·2	**1**	12·2	**5**	61	**5**	61	**5**	61	**5**	61	**5**	61	**5**	61	**5**	61	**5**	61	**5**	61	**10**	121·8
Constraints on operative methods	13·4	**1**	13·4	**5**	67	**5**	67	**5**	67	**5**	67	**5**	67	**5**	67	**10**	134	**5**	67	**5**	67	**10**	134·3
Constraints on periodic checks	11·0	**1**	11·0	**10**	110	**10**	110	**10**	110	**10**	110	**10**	110	**10**	110	**10**	110	**10**	110	**10**	110	**10**	109·9
Disposal of residues	8·7	**1**	8·7	**5**	43·5	**5**	43·5	**5**	43·5	**5**	43·5	**5**	43·5	**5**	43·5	**5**	43·5	**5**	43·5	**5**	43·5	**10**	87·5
Partial total			45		281·5		281·5		281·5		281·5		281·5		281·5		348·5		281·5		281·5		454
Totals			120		1132·5		744·25		468·3		747·1		635·1		503·9		814		438·3		356·4		1365
Risk value (%)			**9**		**83**		**55**		**34**		**55**		**47**		**37**		**60**		**32**		**26**		**100**
Hazard category (from risk values above)					*H*		*M*		*L*		*M*		*L*		*L*		*M*		*L*		*L/VL*		
Hazard category (Parkin et al. method)					*H*		*H/M*		*VL*		*M/L*		*L*		*VL*		*M*		*VL*		*VL*		