Paraquat

Unacceptable health risks for users

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Executive summary

The chemical herbicide paraquat is used by a large number of farmers and plantation workers. Paraquat is acutely toxic, causes a large amount of suffering and cannot be used safely under common working conditions. Paraquat should be phased out with immediate effect.

Paraquat can be absorbed by the skin, especially if skin has been exposed to the chemical. Acute poisoning may occur, but symptoms are often delayed. Damage to the lungs, for example, may not be evident until several days after absorption. There is no antidote against paraquat poisoning. The outcome can be fatal and in these cases death results from respiratory failure

Localised skin damage or dermatitis, eye injury and nose bleed occur frequently among paraquat users, requiring medical treatment that is often not available. Long-term exposure to low doses of paraquat is linked to changes in the lung and appears to be connected with chronic bronchitis and shortness of breath.

Long-term exposure to paraquat has been associated with an increased risk of developing Parkinson's disease.

The level of exposure to paraquat that workers may experience is high enough to lead to absorption of an amount that can result in acute poisoning. High levels of paraquat found in urine of exposed workers indicate a considerable risk of poisoning. Paraquat's potential damage to skin, and its absorption through skin, is therefore serious.

Fatal poisoning at the workplace (excluding accidental or intentional drinking of paraquat) occurred mostly when paraquat absorption through skin increased after prolonged contact with undiluted or diluted paraquat solution.

Studies found that contamination of skin occurred through spills of the concentrate or from leaking spraying equipment, and could not be prevented by protective clothing. Spray droplets deposited in the nose may be swallowed and spray in the air can be ingested when workers breathe through the mouth. In many countries a high proportion of paraquat poisonings are not reported.

Birds and mammals have also been affected. Deaths of hares and reduced hatching of birds' eggs may arise from the use of paraquat as recommended.

Legislation on occupational safety and health is weak and not implemented in many countries. Education of workers in practices that reduce the risks of using paraquat, or pesticides generally, has reached only a small proportion of users and often not been ongoing.

Field studies have found that an acceptable exposure limit for operators was exceeded; they point to an insufficient safety margin for those applying paraquat from backpack sprayers. Protective equipment often cannot be afforded, is unavailable, or inappropriate and impractical to wear in a hot, humid tropical climate.

General working conditions are frequently incompatible with guidelines for chemical safety, especially in developing countries. During the handling and spraying of pesticides, the potential for high exposure is continually present. All these factors lead to a high risk for workers.

The application of paraquat, and other pesticides in WHO class Ia, Ib or II, by workers who use manual sprayers and who are largely unprotected, poses unacceptable risks to health.

The problem of suicides by the misuse of pesticides is different from that of unintentional poisonings in the workplace. But banning the most toxic pesticides like Paraquat would also be one effective measure, in addition to others, to reduce self-harm.

Governments need to assess the risks of hazardous pesticides under prevailing conditions of use. They should identify measures for reducing risk and consider withdrawing the authorisation of products where the risk to users is high, and standards of protection are not sufficient to reduce the risk. For paraquat this continues to be the case in the majority of countries, especially in the South.

Conclusion and key recommendations

This extensive review of the impacts of paraquat, largely from peer-reviewed studies, concludes that the pesticide causes daily suffering to an extremely large number of farmers and workers. Problems resulting from paraquat exposure are found around the world: from the United States to Japan and from Costa Rica to Malaysia. The injuries suffered are debilitating and sometimes fatal. Associated chronic health problems are now being identified. In developing countries in particular, paraquat is widely used under high-risk conditions. Problems of poverty are exacerbated by exposure to hazardous chemicals, as users have no means to protect themselves. Personal protective equipment is not available; it is costly and impossible to wear in hot working conditions. Loss of wages or income from illnesses caused by occupational exposure to pesticides is rarely compensated. While education, training and information are urgently needed to avoid poisonings, the basic problem is the use of high-risk chemicals like paraquat under poor and inappropriate conditions. The report concludes that alternatives are available and their implementation must become a priority, along with a phase out of paraquat.

Key recommendations (see page 69 for full recommendations) are:

¶ Paraquat should be immediately prohibited in developing countries. This is vital in view of the number of fatal poisonings that have occurred with undiluted and diluted paraquat and the inadequate work safety standards due to lacking resources and tropical climates.

¶ As poisonings with paraquat at the workplace also occur in the North, paraquat clearly presents a serious hazard to humans and the environment wherever it is used. It should be phased out in all countries to prevent unacceptable harm.

¶ As long as it continues to be marketed, paraquat's trade should be regulated at the international level within the PIC procedure. A number of countries have already decided to ban paraquat or severely restrict its availability, and many companies have prohibited its use in crops they grow or purchase, showing that there are less hazardous alternatives to paraquat.

¶ The World Health Organization should reassess the hazard classification of paraquat.

1. Introduction

The use of paraquat has been a subject of controversy for at least two decades, especially regarding the safety of farmers and agricultural workers in developing countries (Madeley 2002; Wesseling et al 2001a; Syngenta 2002). Both intentional and unintentional poisonings with paraquat, mainly among agricultural workers, farmers and inhabitants of rural areas, have led to serious concern among national health authorities, workers' unions and non-governmental organisations.

A number of factors cause work-related (occupational) fatalities to be underestimated, and suicides over-represented. Manufacturers may argue that pesticides contribute significantly to reducing crop losses. But it has become evident that their use may be counterproductive when they are not manufactured, stored and used according to national and international safety standards (Kähkönen 1999).

Acutely toxic pesticides are used in many countries under inadequate conditions and contribute considerably to ill health and unnecessary deaths, both among agricultural workers and the general public.

This paper presents the findings by experts, national and international organisations on the health effects of paraquat and unintentional (accidental and occupational) poisonings with paraquat, and makes recommendations on measures to reduce these negative impacts. Publications in literature on unintentional poisonings were not reviewed comprehensively and therefore the cases discussed below can serve only as an indication of the actual risk. The term «developing countries» includes countries with economies in transition.

1.1 The active substance paraquat

Paraquat was first introduced in Malaysian rubber plantations in 1961; its use has since become widespread (Calderbank & Farrington 1995). It is now used on crops on a worldwide scale. A broad-spectrum (or non-selective) herbicide, paraquat kills both broad-leaved weeds and grasses. It is used on fruit and plantation crops (banana, cocoa, coffee, oil palm), field crops (maize), in direct seeding (or conservation-tillage), in forestry and as defoliant or desiccant to dry crop plants (cotton, pineapple, soy bean, sugar cane, e.g.) (Tomlin 2003).

Paraquat is applied before sowing or planting the crop, in pre-emergence application (following planting) and as a defoliant before harvest (Hall 1995a). In liquid concentrate form, it is usually diluted by agricultural workers in the field before spraying. To kill weeds, paraquat is applied at rates of 0.28 to 1.12 kg/ha (1/4 to 1 lb per acre); for desiccation it may be used twice (Hall 1995a).

Paraquat is a bipyridylium herbicide and classified in WHO class II («Moderately Hazardous») for acute toxicity (WHO 2005). In this respect it differs from most other herbicides, which are less toxic (Marquis 1986).

Based on its toxicological properties - acutely toxic, delayed effects and absence of an antidote - paraquat should be categorized in WHO class Ia or Ib.

Paraquat is sold under various trade names and an extensive list has been compiled (UN/DESA 2004, p. 618). The main product line is «Gramoxone», marketed by Syngenta. Another bipyridylium herbicide is diquat dibromide, also ranked in WHO class II (WHO 2005). Other bipyridylium products are mixtures of paraquat, diquat or other herbicides. Granular (solid) formulations are used less frequently (Hall 1995a).

Products based on paraquat normally use the dichloride salt of paraquat cation (a quaternary ammonium compound). It is the cation that has the herbicidal and toxic effects (Summers 1980).

The liquid concentrates of paraquat contain 25% to 44% of the active substance, and also solvent (water) and wetting agents or adjuvants (CDMS 2001 & 2004).

1.2 Rapid increase in the use of herbicides

Worldwide use of pesticides increased from 500,000 tons in 1960 to around 3 million tons of formulated (end-use) products in 1985 (WHO & UNEP 1990). Nearly two-thirds of global sales are in North America, Europe and Japan. Since 1990, however, sales of pesticides have generally stagnated in Western countries, while in Latin America and Asia, sales have grown rapidly (Halweil 2002). Non-selective herbicides (paraquat and diquat together with glyphosate) accounted for one quarter of herbicide sales and 11% of crop protection sales of the main manufacturer (Syngenta) in 2003.

Paraquat sales in the top 46 markets were US$ 396.2 million in 2001 (or in the latest year available in each country), and US$ 314.9 million in the top 12 markets An increasing percentage of sales are in developing countries. Syngenta is by far the largest paraquat producer, accounting for at least 50% of the market and probably a much higher percentage, even though paraquat no longer has patent protection (Dinham 2003).

Another source, Deutsche Bank, estimates that Syngenta's paraquat sales in 2002 were approximately US$ 430 million (DB 2005).

Pesticides are being used by increasing numbers of farmers in developing countries, and the use of herbicides has increased dramatically during the last decade as the cost of labour in certain developing countries has risen (Pingali & Gerpacio 1998). The intensity of pesticide use (amount used per area), and the proportion of herbicidal, insecticidal and fungicidal products used in agriculture, varies considerably from country to country. High levels of herbicide use occur predominantly in countries where labour forces are more expensive or the ratio of land to labour is high and production is orientated towards the market (Pingali & Gerpacio 1998).

Increasing quantities of pesticides are being used in the Caribbean, a large proportion of which are herbicides. This trend is likely to continue, presumably due to an increase in acreage planted, the replanting of cash crops or heavy rains (Dasgupta & Perue 2003). Paraquat is the main herbicide used in St Lucia, mostly on bananas (Hammerton & Reid 1985). Paraquat was among five pesticides making up the total amount used in the Caribbean between 1998 and 2000. During that time paraquat imports increased by 157% (Dasgupta & Perue 2003).

In 2004 worldwide herbicides comprised 45.4% of the sales of agrochemicals, followed by insecticides (27.5%) and fungicides (21.7%) (Agrow 2005). The industry is a strong driving force for this trend and promotes herbicide-resistant crops and no-till cultivation, which it tries to link to massive herbicide inputs (Dinham 2005).

However, successful no-till systems without herbicide use exist (Petersen 1999, Gallagher 2005). The economic burden of farmers may be greater from herbicides as the costs tend to be higher than those for insecticides or fungicides (Foerster et al 2001).

¶ The high risks to the health of workers and farmers under the working conditions that prevail in many developing countries makes the use of paraquat incompatible with sustainable agriculture.

Residues of paraquat gradually accumulate in soils where it is continually applied at a high rate. The soil's capacity to adsorb paraquat may be limited if the clay content is low and degradation proceeds very slowly - and further applications may cause toxic effects in the crop.

1.3 Unintentional poisonings with paraquat

Pesticide poisonings may be a significant public health problem in developing countries and countries with economies in transition, according to the Fourth Intergovernmental Forum on Chemical Safety (IFCS Forum IV). The Forum identified pesticide poisoning as a priority (IFCS 2003a). Besides organophosphates and carbamates in WHO classes Ia and Ib, endosulfan and paraquat (both in WHO class II) were noted as having caused several fatal poisonings (IFCS 2003b).

An important difference between paraquat and organophosphates is that no antidote against paraquat poisoning is available (Ellenhorn et al 1997). In the case of poisoning with organophoshates, a patient can be treated in the short- to middle term with atropine (Buckley et al 2005). Another difference is the potential delay by several days in the onset of severe signs of paraquat poisoning (Ellenhorn et al 1997).

Following contact of the skin with paraquat, systemic poisoning can occur, especially when skin is injured or diseased. Contact over a longer time may injure skin and cause necrosis, leading to increased absorption (Hall & Becker 1995). Inhalation of paraquat spray rarely appears to result in systemic absorption as the droplets do not enter the alveoli, (which act as the primary gas exchange units of the lung), while local irritant effects in the upper airway occur commonly (Hall & Becker 1995). The airborne spray can be directly absorbed through the mouth. Several studies have noted alterations in the lung function, or mild changes in lung tissue of workers who were occupationally exposed to paraquat over a long period (Schenker et al 2004; Dalvie et al 1989, Castro-Gutierrez et al 1997; Hirose & Hikosaka 1986; Lings 1982; Levin et al 1979).

Surveillance of pesticide-related illnesses in Central America has found:

◂ Exposure to chemicals, and pesticides in particular, was identified as one of three priority health issues in the region, besides water and air pollution (PAHO 2002a).

◂ Paraquat was foremost among twelve pesticides most frequently reported by the surveillance systems for acute pesticide poisoning within Central America (OPS/OMS 2001a).

◂ Health problems related to pesticides were identified as a high-priority problem of occupational health in Nicaragua (OPS-Nicaragua 2001).

◂ Combating pesticide poisoning ranks among public health priorities in Nicaragua and Guatemala (MSN 1998).

◂ In Paraguay one of the main health risks for workers is exposure to pesticides (PAHO 2004).

The International Code of Conduct on the Use and Distribution of Pesticides of the FAO provides a basis for judging whether actions regarding trade or use of pesticides constitute acceptable practices (FAO 2002, Art 1.2). Conclusions in the Revised Version of the Code of Conduct focus on risk reduction, and protection of human and environmental health. The Code calls for adherence to relevant Conventions and international standards.

1.4 Diverging agricultural health and safety standards

Unsafe conditions at work increase the risk of ill health and are estimated to be 10 to 20 times worse in developing countries than in countries with an established market economy. A high prevalence of infectious diseases is an additional problem in certain regions (Eijkemans 2005). Pesticide poisonings were identified as a priority for action by the Third Intergovernmental Forum on Chemical Safety (IFCS Forum III). This stated that poisoning of pesticide users must be prevented, especially among the agricultural workers and smallholders in developing countries and countries with markets in transition (IFCS 2000a). On plantations, workers are given virtually no choice about whether or not to use toxic pesticides.

Many countries in the South do not have the means to either analyse or to register a pesticide. National authorities may, as a result, allow pesticides to be imported and used that are authorised in countries of the North (Akhabuya 2002). But the registration of paraquat for sale in the European Union (EC 2003a) gives a misleading signal to other countries. Restrictions of use in the EU - only trained or certified persons may use knapsack sprayers e.g. (EC 2003b) - may not be followed in developing countries.

The agrochemical industry has carried out programmes to reduce risks by promoting less hazardous practices of pesticide use. But the proportion of farmers involved is tiny compared with the large number of farmers using acutely toxic pesticides. Training programmes for less hazardous forms of pesticide use led some farmers to improve their practices. But it has been found that educational campaigns must be carried out on a continual basis, or farmers eventually revert to old practices. (Atkin & Leisinger 2000).

A widening gap between countries in following chemical safety policies has been identified by the Intergovernmental Forum on Chemical Safety. The Forum recommends that legislation be strengthened to protect the health of workers, and the public, from chemicals, including workers in agriculture (IFCS 2003a). Other recommendations made by the Forum were the implementation of Conventions and Guidelines of the International Labour Office that refer to workers' health and to chemical safety, and also actions such as developing national policies for risk mitigation that restrict availability of toxic pesticides or which establish limitations of use (IFCS 2003a).

But regulations in occupational health or in chemical safety remain limited in scope and are often not implemented. The International Code of Conduct on the Distribution and Use of Pesticides recommends that pesticides on the market should be periodically reassessed, and that industry should cooperate even where a control scheme is in operation (FAO 2002).

1.5 Summary

Deaths caused by unintentional poisoning with pesticides, and the greater number of non-fatal poisonings, are not acceptable and must be prevented. Pesticides have been proved to cause damage to health that may be life-threatening or fatal.

Paraquat, together with organophosphates and endosulfan, has accounted for numerous cases of acute poisoning and a number of occupational deaths. Paraquat continues to be marketed in developing countries where it presents a serious risk. Hot and humid weather, low income, lack of knowledge and control over the workplace, put a large proportion of farmers and workers at risk. Even when protective clothing is worn, there may still be unacceptable risk to workers' health from paraquat

¶ There is an urgent need for regular assessment of the risks to workers for all pesticides in WHO classes Ia, Ib and II, and for the implementation of measures to reduce these risks.

2. Hazardous exposure through inadequate working conditions

Inadequate working conditions - including insufficient protection of workers - occur on a large scale in many countries, both developing and developed. For most workers it is not possible to use sufficient personal protective equipment - this is not available, too expensive or uncomfortable in hot and humid climates. Even when used it does not always provide sufficient protection. The burden of responsibility cannot therefore be placed on workers, as there is compelling evidence of the high risks to workers' health from paraquat exposures during everyday use.

The documentary evidence is largely available to the public and regulators. Stakeholders need to draw on the evidence to formulate the necessary measures to prevent damaging effects on health.

2.1 Insufficient safety standards in agriculture for the use of paraquat

Circumstances where the risks of acute poisoning are high are determined by different factors:

◄ Specific substances that cause adverse biological effects.

◄ Specific situations with a potential for accidents or increased exposure.

◄ Involvement of groups that are more susceptible to toxic chemicals, such as older people, children and pregnant women, people who have ill health or are affected by low standards of living) (WHO 1987).

The combining of any of these factors significantly increases the risk of acute poisoning.

In developing countries, children and adolescents frequently experience acute pesticide poisoning, either accidentally or while working (UNEP 2004). Women suffer pesticide poisoning both as workers or as the spouse of a farmer/worker (Rother 2000). High-risk circumstances are situations where the combined factors significantly increase the risk of acute poisoning.

Prevention programmes aim to avoid the risks that arise because of severe or frequent poisonings. They require that circumstances under which acute poisonings may occur are identified and can be predicted. And also that options for preventing poisonings are identified and assessed. In some circumstances there is a need for emergency response to a risk (WHO 1987).

In 1991 the World Health Organization concluded that in some countries the problem of poisoning with pesticides (all types) was so serious that urgent action was required, and that countries should be supported in assessing the effectiveness of intervention measures. Paraquat was judged to require further evaluation due to potential chronic effects on health (WHO 1991).

Agriculture is one of the three most hazardous industries, (together with mining and construction). A large number of agricultural workers suffer pesticide poisoning, besides injury from accidents, especially seasonal and migrant workers who increasingly have replaced year-round workers on plantations (ILO 2004a).

«Measures shall be taken to ensure that temporary and seasonal workers receive the same safety and health protection as that accorded to comparable permanent workers in agriculture», says the Convention Concerning Safety and Health in Agriculture (ILO 2001). But migrant workers are often unable to benefit from health insurance and frequently do not seek any medical treatment as they cannot afford it, cannot leave work or distances are too great (ILO 2004a). Many migrant workers have no documents and, as a consequence, have no rights.

In terms of occupational safety and health (OSH) «the impact of current up-to-date standards does not seem to level with the importance given to OSH in a human, national and global perspective» (ILO 2003). Voluntary initiatives of the chemical industry were considered useful and well designed. But it is necessary to evaluate how effective they are in the context of national regulation, and to establish an adequate balance between regulatory systems and voluntary initiatives (ILO 2003).

Regardless of formal standards for occupational health and safety, workers who apply pesticides often do not have or use effective equipment for protection, nor are they trained in its use. Workers' exposure to pesticides is greater where no water is available for washing skin that has been contaminated with pesticides (NRDC 2004). In a survey on occupational safety and health in the European Union, eight member states found that there was a need for additional preventive action regarding the handling of chemicals. Chemical risk factors, new chemicals in particular, were among the factors associated with emerging risks (EASHW 2000).

¶ Pesticide exposure is the major chemical hazard in developing countries because of the difficulty to apply protective measures (Wesseling et al 1997). Agricultural workers often wear only partial protection. The compliance with safety regulations at the workplace varies considerably. In most developing countries there is disparity between legislation and the actual situation.

Africa

Regulations for chemical safety were routinely ignored by plantation owners in Tanzania (Mandago 1999). A conference on occupational health in Kenya, Tanzania and Uganda identified risk surveys in agriculture as being of «highest priority». It identified the need to assess the risks of herbicides to plantation workers, particularly for paraquat (FIOH 1999b).

A survey of spraying equipment in Cameroon, where paraquat and glyphosate were the most commonly used herbicides, found that lever-operated knapsack sprayers predominated in two areas, while in a drier area it was mostly CDA (controlled droplet application) sprayers that were used (Matthews et al 2003). CDA sprayers allow the use of a lower volume of spray solution, but the concentration is usually higher, resulting in greater risk from leakage or spray drift (Hurst et al 1991).

Leakages were reported by users of lever-operated knapsack sprayers on several different parts of the sprayer, with faults occurring mainly at the nozzle (blockage) and trigger valve. Leakage increased as the sprayers aged (Matthews et al 2003). About 25% of sprayers were considered by users to be in good condition and another 25% to be well-maintained. Less than a quarter of all farmers had spare parts and newer sprayers were generally on larger farms and plantations. The sprayers of most small-scale farmers were in a poor condition and over 85% of these farmers did not use protective clothing (Matthews et al 2003).

In Kenya pesticide poisoning occurred despite use of personal protection. Protective equipment was either not used properly, it seems, or was soaked with pesticides during spraying, resulting in dermal exposure (Ohayo-Mitoko et al 1999). Most clothing was made of cotton that soaked up pesticides. Wearing boots only improved the level of protection when combined with a coverall made of heavier cloth (Ohayo-Mitoko et al 1999).

Costs of illness among smallholders growing cotton in Zimbabwe were seen to increase significantly due to pesticide-related illness (Maumbe & Swinton 2003). Although health costs caused by pesticide use are high, farmers continue to use pesticides and become trapped in unsustainable practices (Wilson & Tisdell 2001).

Fiftysix per cent of small-scale cotton farmers in Zimbabwe reported pesticide-related health problems. Protective equipment did not present a panacea to health risks from pesticides as it was found that protective practices (e.g. wearing a coverall) explained only a small share of total variance of health effects (Angehrn 1996). The use of protective equipment was low, partly because the benefits of such equipment did not seem overwhelming, and it was connected with discomfort, cost and maintenance (Angehrn 1996).

Asia

In a survey in *Cambodia*, 96% of interviewed farmers had experienced symptoms or signs of acute pesticide poisoning; 89% reported wearing a long-sleeved shirt and long pants during spraying, 11% wore shorts, 61% wore no protective mask (the cotton masks in use may have a limited efficiency) and 79.2% wore no boots (CEDAC 2004). These figures indicate that partial protection does not stop acute poisoning.

Another survey in Cambodia reported that none of the ten farmers surveyed wore protective equipment and that the arms, back and feet of all ten farmers were soaked with pesticides after spraying (Yan et al 2001). A survey of 123 farmers in Thailand found that practically all wore a long-sleeved shirt and long pants, 48% wore a mask made of cloth, 17% a sponge mask and 35% wore no mask; 105 of these farmers used paraquat (IPM Danida 2004). The signs and symptoms of poisoning that farmers reported were moderate in 63.4% of farmers (nausea, blurred vision, tremor, muscle cramps, chest pain or vomiting), mild in 34.1% (dry throat, dizziness, exhaustion, headache, shaky heart, itchy skin, weakness of muscles, skin rashes or sore throat), severe in 1.6% (convulsions or loss of consciousness), while only 0.8% of farmers had no symptoms (IPM Danida 2004).

The distribution of risk among farmers and workers may differ between countries. In Southern India, studies on the hazards of pesticide use found that less than 20% of farmers and sprayers accounted for the total number of lost workdays. 24% of farmers in India reported some health problem due to pesticides. The health risk increased with working time, stage of cropping, incidence of leaks and low hygiene (Angehrn 1996).

In *Malaysia* a survey of 72 female plantation workers found that two-thirds of them had been supplied with some protective equipment: 61.1% had received a respiratory mask, 44.4% gloves, 23.6% boots, 15.3% a cover for eyes and the face, 11% an overall, 1.4% an apron, while a third received no protective equipment. Few workers wore the mask as it was uncomfortable in the heat (Tenaganita & PANAP 2002).

In *Indonesia* it was found that farmers wore long (or knee-high) pants and a long-sleeved shirt in less than half of spray operations (42% and 37%, respectively). Discomfort in the hot climate and the high cost of adequate protective clothing were the reasons. But skin and clothes were considerably contaminated by pesticide solutions and equipment was leaking in over half of the spray operations (Kishi et al 1995).

Studies in *Thailand* on protective clothing for agricultural workers found that it was necessary to combine effective use of protective equipment with precautions for less hazardous handling and good personal hygiene (Chester et al 1990). But conditions in the field often do not allow this.

In *China*, (around 2000) pesticide poisoning caused about 4,000 deaths per year; an estimated 300 to 500 of these deaths were due to using pesticides in an «improper» manner (overuse, lack of protection) (Huang et al 2000).

Among rice farmers in Zheijang, China, it was estimated that health costs from pesticide-related illness were at least 15% of pesticide costs. They could be higher than the total cost of purchase if health costs for chronic diseases were included; about half of the poisoning cases were related to the use in agriculture (Huang et al 2000).

A study in China found that the knapsack sprayers mostly in use were of inferior quality and leakages occurred frequently (Matthews 1996).

Latin America/Caribbean

In Latin America and the Caribbean the risk of occupational injury or death was particularly high for workers in construction or mining, the informal sector and agriculture, while injuries and illness were seriously underreported (Giuffrida et al 2001).

In *Nicaragua* it was estimated that 25% of workers experienced pesticide poisoning each year and 48% during their life (Keifer et al 1996). A survey of agricultural workers in Yucatan, Mexico, found that in one year 40% had sought health care due to illness from exposure to pesticides (Drucker et al 1999). Many workers on banana plantations use acutely toxic pesticides - including paraquat - without having received appropriate instructions (Foro Emaus 1998).

In *Brazil* a survey of spraying equipment found that all sprayers in use for over two years presented failures: the nozzle was in bad condition in 80.5% of sprayers, 56.6% had leaks and 47% had a damaged hose (Atuniassi & Gandolfi 2005). Technical improvements in spraying equipment have so far not been transferred satisfactorily to field practice (Friedrich 2000).

In the State of S. Paulo, Brazil, it was estimated that 16% of agricultural workers demanded health care during their working life due to pesticide exposure (Garcia-Garcia 1999).

A study with 119 workers who sprayed paraquat in *Costa Rica* investigated the use of personal protective equipment (PPE) and assessed the protective effect by measuring urinary levels and by interviewing workers about symptoms previously experienced. On some of the farms, use of PPE was strictly implemented (Lee et al 2004); its use was not associated in any significant way with self-reported health symptoms. In terms of measured levels of paraquat, the protective effect from the use of coveralls was found to be slight; no similar association was found for other types of PPE (Lee et al 2004).

The wearing of gloves or overalls by plantation workers in Costa Rica did not offer significant protection to wrists and legs. When an apron was worn, the exposure on the back was relatively low but not significantly reduced. Wearing trousers resulted in a significantly lower exposure of the legs. This study indicates that wearing gloves, overalls, aprons and trousers does not necessary result in adequate protection as the spray solution may get under clothing or soak into it. (van Wendel de Joode et al 1996).

In Costa Rica 58% of the application systems on plantations were found to be deficient regarding worker safety, resulting in increased rates of poisoning (Amador 1998). The quantities of paraquat used per hectare each year were similar on both small and large farms (Di Benedetto et al 2000).

USA

In California 13% of farm workers had no access to water, while symptoms reported at work were eye irritation (23% of workers), headache (15%), blurred vision (12%), skin irritation (12%), dizziness (5%), numbness or tingling (6%), nausea/vomiting (2.5%), diarrhoea (2%) and dehydration (1.5%) (CE 2000). Workers re-entering sprayed fields may be highly exposed and even labour contractors often do not know what pesticide was sprayed (Bade 1999).

Inadequate working conditions prevail despite the responsibility of employers to be informed about safety requirements (in regulations and on product labels) and to inform workers about hazards and measures for protection (CDPR 2001). Among illness cases in California due to paraquat, the majority (39.1%) occurred during handling of spray equipment (by cleaning, due to a malfunction such as leakage or splashes during loading); one third of illnesses were due to various factors including 12.4% environmental causes (e.g. change of wind, spray drift), 11% accidents and 7.1% accidental contact with paraquat during the spraying or handling (Weinbaum et al 1995).

The rate of paraquat-related illness cases associated with manual spraying was 18 times higher than with tractor-mounted sprayers. Other factors with a higher risk of illness were the crop type (e.g. fruit trees) and season - the higher illness rates in summer may arise from less protective clothing being worn, increased paraquat absorption, and different physiological response at higher temperatures (Weinbaum et al 1995).

Risks from paraquat use «unacceptable»

The use of pesticides is increasing both in large- and small-scale farming. But long-term exposure, even at low doses, can have chronic effects (ATS 1998).

¶ The extent of pesticide poisoning in developing countries is worrying, and there does not appear to be a viable solution in hot climates to control the occupational risks with protective equipment (Mancini et al 2005)

A general problem in many countries is the overuse of pesticides (Rerkasem 2004). In the least developed countries, occupational health problems differ from those of industrialised countries as hazards at work are aggravated by diseases, poor sanitation and nutrition, illiteracy and general poverty (Hogstedt & Pieris 2000).

Manufacturers have the responsibility to inform users about adequate fabric for specific pesticides (Easter & Nigg 1992). However, in tropical climates there is generally no viable system for protecting workers adequately from acutely toxic pesticide. Gloves and protective overalls can offer a degree of protection but typically their selection and use is poorly managed. Careful removal after use is also required (Semple 2004).

Policy makers, in choosing strategies for reducing the risks related to pesticides, need to ask several questions:

- What are the major factors that contribute to the risk?
- What are the inherent toxic properties of the pesticides concerned?
- What are the exposure patterns under conditions of use?
- What is the acceptable level of risk?
- Who should be responsible to address the risks? (Karlsson 2004).

It is clear that the use of paraquat under working conditions in most developing countries results in unacceptable risks to health.

2.2 General aspects of exposure to pesticides (paraquat)

Routes of exposure

The main route of paraquat exposure for agricultural workers is through the skin. A study of factors influencing skin exposure of workers (based on videotaped observation and tracing with fluorescent dye) found the following factors were associated with increased exposure:

- temperature;
- using a hand-pressurised sprayer;
- volume of sprayed diluted solution;
- spraying with the nozzle directed in front;
- splashing on the feet and gross contamination of hands (Blanco et al 2005).

Factors related to the working practices explained 52% of variability of the total exposure (based on the tracing of dye). In a statistical model the factors relating to equipment and working environment explained 33% and 25% respectively (Blanco et al 2005). A survey in Ecuador found that practices likely to increase pesticide exposure were mixing solutions by hand or with a stick (36 out of 40 farms), leaking sprayers (28/40), absence of protective equipment other than rubber boots (38/40), pesticide storage in the farmhouse (19/40) and unsafe disposal of containers (35/40) (Cole 1998).

During mixing and spraying of pesticides, 87-95% of overall exposure was seen to arise via the skin, while inhalation accounted for 5-13% of exposure, and manual sprayers clearly caused the greatest exposure with a mean rate of 1.040 mg/h. Estimated values for dermal exposure apply to workers wearing long pants, long-sleeved shirt, shoes and socks (Rutz & Krieger 1992).

The mean exposure during mixing/loading from open pouring of liquid formulations was 1.892 mg/h, and this was reduced to 0.398 mg/h when liquids were in containers with closed-system design. With water-soluble packets it was reduced to 0.045 mg/h; exposure was higher (4.144 mg/h) during open handling of granular formulations (Rutz & Krieger 1992).

Studies on banana plantations found that poor working conditions mean workers are continually at risk of high levels of exposure that could lead to severe acute poisoning (van Wendel de Joode et al 1996). During the handling of paraquat concentrate, different parts of the body may be contaminated, and there is evidently a risk of skin exposure (OPS/OMS 2001b).

Granular formulations of paraquat contain 5% paraquat (or diquat and paraquat combined) (Hall & Becker 1995). The percentage of paraquat absorbed through intact human skin (arm, leg or hand) is estimated to be 0.23-0.29% (Wester et al 1984). But skin is more vulnerable when it has been injured or is damaged through contact with paraquat (Garnier 1995). In certain areas of the body, skin is highly permeable, e.g. in the genital area exposure can result in a 50 times greater absorption (Semple 2004). It was found that sweat on skin from perspiration led to increased skin absorption (Williams et al 2004). Absorption via the skin is also higher in workers who have dermatosis (Garnier 1995).

Poisoning with pesticides (all types) may occur from inhaling. From 1989 to 1992 in the UK, for example, 129 cases of non-fatal pesticide poisoning were rated as «confirmed» or «likely»; 41% of confirmed cases were people living beside a sprayed field; 35% were working with a pesticide or standing close to a user and 23% passed by fields that had recently been sprayed (Thompson et al 1995b).

Application technology

Exposure is greater when knapsack sprayers are used rather than tractor-mounted sprayers (IPCS 1984).

More recent studies confirm that exposure is increased with hand-pressurised backpack sprayers and that use of this type of sprayer determined the skin exposure, partly by influencing working practices (spray nozzle held in front of the worker at a short distance or unblocking of nozzle when soil got into it) (Blanco et al 2005). Skin exposure arises from direct contact with solutions or contaminated surfaces and from airborne spray droplets on skin (Boleij et al 1995).

Leaking sprayers and careless handling may have fatal consequences if paraquat is applied without adequate protective clothing, Sprayers must therefore be leak-proof (tank and lever), contaminated clothing must be removed immediately, and skin that is contaminated must be washed. While these seem common sense measures, they can be overlooked due to poor maintenance of equipment, lack of sanitary facilities in the field, ignorance of workers about the health risks or because of heavy workloads.

Improper practices such as refilling pesticides into other containers can be partly addressed at the engineering level (packaging or formulation), and there is also a need to teach users about handling procedures (Bailey 1992). Hygiene measures to reduce risks at the workplace need priority. Manufacturers, regulators and users should work more closely to develop new systems for less hazardous handling of pesticides (Rutz & Krieger 1992).

Tractor-mounted sprayers (used in UK) produce a spray consisting of relatively small droplets. The mean (average) size of spray droplets varies, depending on the type of sprayer used. Hydraulic sprayers produce droplets with diameters of 50-500µm (Hurst et al 1991). This is above 10-15µm and therefore droplets are deposited in the nose, pharynx or throat (DFG 2004; Rando 1999). Exposure of workers to paraquat from inhalation is considered to be usually negligible as the fraction of respirable particles is very low (Garnier 1995). Airborne spray can be directly absorbed through the mouth, however.

In field trials during spraying in Ireland, the concentrations of paraquat in air breathed by sprayers were of the order of 0.01 mg/m^3 and did not exceed 0.05 mg/m^3 in normal use. In airborne spray mist (not produced by hand sprayers) concentrations in the order of 10 mg/m^3 were measured, and about 50% of the droplets had respirable size (Hogarty 1976). In a study in Russia, concentrations of paraquat measured in air were between 0.13 and 0.55 mg/m^3 depending on the mode of application (Makovskii 1972). The latter value is over five times higher than the 0.10 mg/m^3 threshold limit for paraquat in air in most countries (DFG 2004).

The great majority of paraquat spray droplets from manual sprayers are retained in the nose where they irritate mucous tissue, often causing nosebleed; paraquat deposited in the nose may be swallowed and contribute to internal dose (Wesseling et al 1997). Inhalation of spray often occurs in windy weather and when face masks are not worn, and usually this leads to a sore throat or nosebleed (Proudfoot 1993). When a sufficiently high amount of spray is absorbed, e.g. through the mouth, systemic poisoning may occur. In Canada it is recommended not to apply paraquat when it may drift to inhabited areas - neither during periods of dead calm nor in surging winds (PMRA 2004).

Mist-blowers – either mounted on a tractor or carried by workers – produce droplets with relatively small sizes (50-100µm). Typical mists (with a median droplet diameter of 57µm) contain about 0.1% droplets with a size of 15µm (WHO 1990). These enter the bronchi (but not alveoli if greater than 5-7µm (DFG 2004; Rando 1999). As a result of evaporation, which increases with atmospheric pressure (Atkins 1986), the exposure by inhalation may be potentially higher during good weather; this may need to be further assessed. The direct exposure to airborne paraquat spray (or drift) presents a considerable risk as spray can be absorbed by breathing through the mouth (Frumkin 2000). Application methods that produce fine droplets should therefore not be used to spray paraquat (Pasi 1978).

Acceptable levels of exposure

An acceptable daily intake (ADI) denotes «an estimate of the daily exposure dose that is likely to be without deleterious effect even if continued exposure occurs over a lifetime». «Toxicity reference dose» (RfD) is another term for this (WHO 2004a). For paraquat the ADI is 0-0.006 mg per kg body weight (b.w.) per day for the dichloride salt, or 0-0.005 mg/kg b.w. day for the cation (FAO 2004a). The reference dose established in the US is 0.0045 mg cation/kg b.w. day (US EPA 1991).

An acute reference dose (ARfD) refers to short-term exposure; the ARfD for paraquat is 0.006 mg cation/kg b.w. (FAO 2004a). An ARfD is an «estimate of a substance in food or drinking water, expressed on body weight basis, that can be ingested over a short period of time, usually during one meal or one day, without appreciable health risk to the consumer on the basis of all known facts at the time of evaluation» (WHO/FAO 1999).

An ADI or RfD represents a «very low risk» intake, or dose, but it is not possible to define what «very low» means. For susceptible individuals a harmful effect may appear at lower doses than the ADI (Rodricks 1992). The ADI may be inappropriate where synergistic interactions occur; this was observed for paraquat and maneb (Cory-Slechta et al 2005). Toxicological studies have mainly focused on the oral route of uptake (Van Hemmen et al 2001). However, exposure of workers to pesticides (operators and re-entry workers) and the resulting risks need to be assessed based on the primary exposure routes. These include exposure through the skin to diluted and undiluted solutions, and swallowing of spray droplets in the air or deposited in the nose (Wesseling et al 1997; Frumkin 2000).

Pesticide exposures can generally be distinguished by the way in which they occur, by the dose absorbed and the effects that are likely to result (table 1).

Exposure (increasing intensity)	Absorbed total dose	Effect likely to result from exposure
Traces in the air, water or food (environment)	Below μg	No toxic effects expected
Contact with formulated products and treated surfaces (leaves)	Above μg below mg	Pesticide absorbed, metabolised, excreted; usually no effects; daily dose increases risk
Accidents with formulated products or spray (inadequate re-entry interval)	μg to mg	Excessive exposure; cases of poisoning among pesticide sprayers and harvesters
Absorption of toxic to lethal doses: intentional or accidental	mg to g	Extreme exposure (often ingestions, skin exposure); illness or death

Conversion of units: 1 microgram (μg) = 0.001 milligram (mg) = 0.000'001 gram (g)

Table 1 Exposure to pesticides (all types) (adapted from Krieger et al (1992))

Protective clothing

Exposure of agricultural workers during spraying presents considerable acute and chronic risks to health, which could ideally be reduced to a certain extent by good practice and use of adequate protective clothing. But this often cannot be afforded, is not available, or is totally inappropriate for use in hot and humid climates.

Penetration of clothing by various pesticides including paraquat was tested for different types of fabric. It was found that shirting or lightweight fabrics provided the least protection, while heavier-weight fabrics (denim and twill) offered significantly greater protection. Normal work clothing did not give sufficient protection from heavier spray or a spills (Branson & Sweeney 1991). It was found that shirts (cotton/polyester) became wet and clung to the skin, which resulted in significantly greater exposure than with double-layer cotton coveralls. Considerable exposure also occurred through openings at the neck and sleeves (Fenske 1988).

2.3 Measurement of paraquat exposure

Assessment of dermal or general exposure plays an important role in a multidisciplinary, broad approach that aims to achieve efficient interventions in developing countries. But exposure assessment must be based on locally prevailing practices and not on the «best practice» that is current in the industrialised countries (Wesseling et al 2005).

¶ Exposure to paraquat may be chronic. It has been estimated that workers on large plantations spray herbicides such as paraquat during more than 1,400 hours per year (Whitaker 1989). This means that workers spray for over 175 working days a year. Women in Malaysian plantations spray on average 262 days a year.

The potential dermal exposure of workers using knapsack sprayers was found to be too high in Brazil (Machado-Neto et al 1998, study a) below). In field studies, the US Environmental Protection Agency found that margins of exposure to paraquat for workers using low-pressure sprayers or backpack sprayers were «unacceptable» and that the «practicality» of additional personal protective equipment required to reduce health risks was a matter of concern (US EPA 1997) (study d) below).

The probability of death is high when paraquat concentration in urine is above 1.0 mg/l, (Scherrmann et al 1987). Very high urine levels within two hours after ingestion may be compatible with survival. Death is unlikely when levels are below 0.5 mg/l during the first 24 hours after ingestion (Scherrmann et al 1987). But survival is unlikely if the levels are above 80.0 mg/l after 8 hours and above 1.0 mg/l after 24 hours. For an exposure at the threshold limit value (0.1 mg/m3) the expected concentration of paraquat in urine was calculated as 0.7 mg/l (Baselt 1988).

Paraquat is excreted rapidly as long as the kidneys have not been damaged by relatively high doses (Houze et al 1995). For some exposed workers the paraquat levels measured in urine samples were relatively high (studies g) and h) below), indicating considerable risk of poisoning. In a study with workers applying paraquat with knapsack sprayers, the absorbed doses based on dermal exposure were 0.0004-0.009 mg/kg b.w./day, which is up to 18 times higher than the proposed short-term Acceptable Operator Exposure Level (AOEL) of 0.0005 mg/kg b.w./day. The absorbed doses that were estimated from urine and blood analyses were 2 to 8 times above the AOEL (EC 2002 and reference therein: Chester et al 1993, study e) below). In another study the mean absorbed dose was 0.00015 mg/kg b.w./day or 30% of the AOEL (Findley et al 1998).

Within the EU review of paraquat, the Scientific Committee on Plants (SCP) commented on the risk to workers taking into particular account potential inhalation and skin exposure. Estimates - based on exposure models - suggested that exposure of knapsack sprayers to paraquat may exceed the short-term Acceptable Operator Level (0.0005 mg/kg b.w./day) 60 times with protective equipment and 100 times without it (EC 2002a).

Monitoring workers' exposure in the field indicated that exposure estimated in the models was higher than the actual exposure. Also that workers absorbed high doses when they did not use the recommended protection (gloves and other protective clothing) (EC 2002a). It was the opinion of the SCP that risk to workers cannot be assessed only on the basis of modelled exposure, and that when used as recommended under prescribed good working practices, paraquat did not pose a significant health risk for workers (EC 2002a).

¶ It cannot be overstated that «good working practices» are impracticable in tropical climates and in developing countries.

Studies measuring exposure to paraquat among agricultural workers: (studies k to n may not be representative of developing countries).

a) Machado-Neto et al 1998

Studies on the efficacy (efficiency) of safety measures for knapsack sprayers applying paraquat to maize were carried out. It was found that spraying in front of the workers' body was not safe. The potential skin exposure with spray was too high - 1.979.8 and 1.290.4 ml/day for a 0.5 m long lance (shaft) and for a 1.0 m lance, respectively. Based on calculated margins of safety (1),

it was estimated that potential skin exposure needed to be reduced by 50-80% for a 0.5 m lance, and by 37-69% for a 1.0 m lance.

Potential skin exposure was significantly reduced when the spray lance was placed behind the worker (attached to the backpack) as most of the potential exposure arose from sprayed plants contaminating the skin of legs and feet. A longer spray lance alone did not reduce the potential skin exposure enough to provide safe conditions. Workers who mixed solutions and loaded them into tanks received the main exposure at the hands. Although mixing and loading was considered to be safe, it was recommended that impermeable gloves should be used as a further safety measure.

(1) Margin of safety: ratio of the highest estimated (or actual) level of exposure to a pesticide and the toxic threshold level (usually the no-observed effect level) (Holland 1996)

b) van Wendel de Joode et al 1996

A study on banana plantations in Costa Rica measured the exposures of 11 spray applicators to diluted paraquat (0.1-0.2%). Total skin exposures (sum of certain body areas) were 0.2-5.7 mg paraquat per hour (equivalent to doses of 3.5-113.0 mg/kg). Urinary levels (detected in 2 of 28 samples) were <0.03 mg/l and 0.24 mg/l. Respiratory exposure was 0-0.043 mg/l, corresponding to 0.3% of total dermal exposure.

It was found that the risk of high and therefore hazardous exposure was continually present, due to poor working conditions. Health problems recorded were:

◂ blistering and burns on hands, thighs, back, testicles and legs (due to defective equipment or contact with sprayed leaves);

◂ two eye splashes causing redness and burning sensation;

◂ three workers had nosebleeds (in one case frequently);

c) Spruit & van Puijvelde 1998

A study in Nicaragua found lower paraquat levels than in study b (above), but residues on skin were still considerable, especially on the hands. Workers did not use adequate protection.

d) US EPA 1997a, p. 56

In a study in the US on the exposure of workers who mixed, loaded and applied paraquat, it was concluded that the margins of skin exposure (the no observed effect level divided by total daily dose) were unacceptable for backpack applicators and workers who used low pressure sprayers - even when they wore long pants, a long-sleeved shirt, chemical-resistant gloves and shoes with socks as personal protective equipment (PPE).

This type of PPE is required for applicators and other handlers. Additional PPE - a chemical-resistant apron and face shield - is required as minimum standard by the Environmental Protection Agency for mixers and loaders who handle paraquat products. EPA stated that it was «concerned about the practicality of adding another layer of PPE (woven material), due primarily to heat stress considerations».

e) Chester et al 1993

In Sri Lanka a study with 12 workers who applied paraquat at a concentration of 0.03-0.04% (cation wt/vol) with knapsack sprayers measured skin exposure and urinary levels. The mean potential skin exposure for workers who mixed and loaded spray solutions was 66 mg (per day). For spray operators it was 74 mg. The workers did not wear protective clothing.

The proportion of the total potential exposure deposited on skin was estimated to be about 95% for mixer/loaders (86% on the hands) and about 90% for spray operators (on the hands, legs and feet). Urinary paraquat was mostly below 0.1 ug/ml, with a maximum of 0.37 ug/ml. The extent of absorption was low due to the very dilute spray solution and high standard of personal hygiene.

f) Seiber et al 1983

In this study it was found that paraquat residues on cotton plants 4 weeks after application gave rise to concentrations in air of up to 0.47-1.2 µg/m^3 close to the harvesting tractor. These resulted in an estimated maximum exposure by inhalation of 16.3 µg per day (based on an average breathing rate of 1.7 m^3/h for light work and an 8h-working day). The upper value of paraquat air concentrations would result in an exposure corresponding to 43.5% of the Acceptable Operator Exposure Level (see p. 18) for a worker weighing 75 kg. 70% of the airborne paraquat in dust had respirable size. Skin exposure was not measured.

Substantial skin contact with the dust could have considerable impacts on the overall exposure. The residues of paraquat in air surrounding a harvesting tractor were sufficiently high to argue for the required use of closed cabin harvesting tractors.

g) Howard 1982; Howard et al 1981

A study with 14 workers in Thailand who used knapsack sprayers or low-volume spinning disc applicators (with spray concentration 0.15% and 0.2%), measured urinary paraquat of 0.73-10.21 mg/l after 14 days spraying. Levels were significantly higher in unprotected men. And levels in urine increased as the trial progressed. Irritation of unprotected skin was severe (caustic burns to the feet) in workers who used low-volume applicators (higher concentration).

In a study in Malaysia of 27 workers who had sprayed paraquat (0.1% cation content) for at least 1000 hours, 11 reported one or more incidents of rashes or skin irritation that were associated with spraying, mostly on the hand, legs or in the groin, and there was one case of eye injury.

The transfer factor (diffusion in the lung) was 4.9-7.3% lower among the sprayers than among non-exposed or general factory workers, (although not statistically significant).

h) Chester & Woollen 1982

A study in Malaysia detected urinary paraquat in 9 out of 19 workers spraying paraquat (0.1-0.2% solution content of the cation) and in 1 out of 7 mixers (who mixed the solution). Urinary levels were below or equal to 0.05 mg/l in 12 of the 19 spray operators but ranged up to 0.69 and 0.76 mg/l. The contamination of the body was highest on the hands.

Paraquat was detected in a small proportion of workers who did not handle paraquat but entered sprayed areas. The average exposure for uncovered skin was an estimated 2.2 mg per hour (ranging from zero to 12.6 mg/h). For unprotected skin and clothing combined it was 66.0 mg/h (range 12.1-169.8 mg/h); the proportion of paraquat from clothing that reached the skin was estimated as 5%. The mean (average) skin exposure was 1.1 mg/kg b.w. per hour, and the highest individual total exposure was 2.8 mg/kg b.w. per hour. In air, the mean paraquat concentration was 0.24-0.97 μg/m^3 (equivalent to 1% or less of the threshold limit value,0.1 mg/m^3).

i) Kawai & Yoshida 1981

Workers who were exposed to concentrations of paraquat in air of 0.011-0.033 mg/m^3, and who had worn gauze masks, had 1.4-2.7 μg/l paraquat in urine 24 hours later. But none was detected in workers who had worn a high-performance mask. The spray concentration was 0.08% paraquat (24% solution diluted 300 times); total skin exposure was about 0.22 mg. The need for protective equipment to reduce skin and inhalation exposure was highlighted.

j) Swan 1969

Paraquat was detected in 24.8% of the urine samples of 30 workers in two studies in Malaysia. The workers sprayed a 0.05% paraquat solution over a 12 week period. Peak (mean) levels measured were 0.32 (0.04) mg/l and 0.15 (0.006) mg/l, respectively.

k) Hayes & Laws 1991

Skin exposure to paraquat measured during proper application with either pressurised hand sprayers or tractor-mounted sprayers (low boom) ranged up to 3.4 mg/h. Practically all of the skin contamination was found on the hands. Inhalation exposure ranged up to 0.002 mg/h.

l) Baselt 1988, and Baselt & Cravey 1989

Studies in the US with workers who applied paraquat (0.25%) over a 12 week period found urinary levels of paraquat between 0-0.15 and 0.32 mg/l (average was below 0.04 mg/l).

m) Staiff et al 1975

In the US an average exposure of 0.40 mg/h (range 0.01-3.40 mg/h) was measured for workers using a tractor-mounted sprayer, and 0.29 mg/h (0.01-0.57 mg/h) for the use of pressurised hand dispensers. Solutions contained 1.2% and 0.2% paraquat, respectively. No detectable levels of paraquat were found in urine (limit of detection was 0.02 mg/l). With both ways of application practically all of the skin contamination was found on the hands. The average exposure by inhalation was below 1 μg/h (range 0-2 μg/h and 0-<1 μg/h).

n) Wojeck et al 1983

In a study with workers using tractor-drawn sprayers (with a drop boom) average exposure to uncovered skin and clothing combined was 168.59 mg/h in tomato fields (spray solution 0.05% paraquat); average inhalation exposure was 0.07 mg/h. Exposure was lower with an enclosed or high-clearance tractor. In citrus groves, average exposures to skin and clothing were 12.16 mg/h (spray 0.05%) and 28.5 mg/h (spray 0.11%). Workers wore a shirt, long pants, socks and shoes/boots. A level of 0.033 mg/l paraquat was measured in one urine sample.

2.4 Summary

Acutely toxic pesticides cannot be applied safely by unprotected workers using hand-held sprayers (Maddy et al 1990). Such conditions are normal in developing countries. In many of these countries adequate personal protection cannot be afforded and is also uncomfortable to wear in hot weather. Appropriate gear to cope with hot and humid climates is not available.

The health of agricultural workers may be impaired by the long-term use of pesticides including paraquat. Skin diseases occur frequently that increase the risk of absorption of paraquat through contaminated skin. Working situations with a potential for high exposure are continually present. Taken together, these factors present a high-risk for workers. The legislation on occupational health and safety in many countries often does not address the risk of pesticides or is not implemented. The standards for occupational health and safety in agriculture are not detailed or implemented in many countries. Education in improved practices of using pesticides could only be provided to a small fraction of the users. Efforts made by the industry for promoting less hazardous practices of pesticide use have had limited impact.

The paraquat levels that were detected in urine samples during the monitoring of workers exposed to paraquat demonstrated that systemic absorption occurred. In several cases urinary levels due to occupational exposure were relatively high, indicating a considerable risk of poisoning. Exposures of workers exceeded the acceptable levels in field trials and in estimates based on models.

Measures of a technical nature - such as providing protective equipment or/and changing the position of the spray lance - would not reduce the risk posed by sprayers that very often leak. Skin contamination is frequently the consequence of leaking knapsack sprayers. Accidental spills and splashes of concentrates or diluted spray solution account for numerous incidents resulting in localised damage to skin or eyes.

¶ Governments should assess the risk of paraquat use under the actual conditions in the field and the general condition of health among workers.

¶ Governments need to identify efficient measures for reducing the risk and put them into operation.

¶ A great number of fatal and non-fatal poisonings at the workplace have occurred with the concentrate. Fatal and non-fatal poisonings have also occured with the diluted paraquat. These poisonings have mainly occured in developing countries. Governments should withdraw authorisation for the sale and use of paraquat.

¶ Developing countries do not have the resources to adequately assess the risks of pesticides. Therefore it is necessary to provide the means for carrying out independent risk assessments.

3. Health effects from occupational exposure to paraquat

3.1 Estimates of the magnitude of occupational poisonings

Exposure of skin to diluted paraquat solution - when spraying equipment was leaking and/or the workers had dermatitis or apparently trivial wounds to their skin (scratches or small ulcers) - has caused poisonings, including fatalities. A review of literature stated that paraquat poisoning due to occupational exposure was a rare occurrence (Hall & Becker 1995). On fatal poisoning it was pointed out, however, that even a comprehensive review of fatal cases published in the literature cannot be used to evaluate the true mortality rate of paraquat poisoning (Pasi 1978).

On all paraquat poisonings, there appears to be considerable under-reporting. One of the reasons for this is in countries that do not have poison control centres and occupational medical services, paraquat poisoning tends to be under-diagnosed. As facilities required for establishing a medical diagnosis are usually poor in the rural areas of developing countries, poisoning may be frequent but often not reported (Pronczuk de Garbino 1995).

The magnitude of illness and injury caused by pesticides is difficult to determine because of underreporting (Ballard & Calvert 2001). Quantification of poisoning with pesticides is impeded by ineffective surveillance at the field level (IFCS 2003b). Data published on pesticide poisonings does not represent the full extent of this problem in many countries, e.g. in the Mediterranean (IFCS 2003a, annex 5).

In Belize, when results of a questionnaire survey in two districts in 2001 were compared with the number of medically recorded cases, 99% of poisonings (fatal and non-fatal) were not reported (Fernandez et al 2002).

In illness-surveillance suicides are generally over-represented and occupational poisonings are underreported (Murray et al 2002; London & Bailie 2001). In some countries a large proportion of hospitalisations for pesticide poisoning are not notified and the circumstances of death can be misdiagnosed (London & Myers 1995).

Worldwide an estimated 3% of agricultural workers each year suffer a poisoning incident with pesticides (all types); a minimum of 3 million severe cases of acute poisoning and 20,000 unintentional deaths per year were estimated, the majority in developing countries (WHO & UNEP 1990). Estimates of the total number of pesticide poisonings (at all severity levels) suggest the number may be much greater than 3 million cases (WHO & UNEP 1990), especially given the figures reported in section 2.1 that 96% of Cambodian farmers interviewed had experienced pesticide poisoning. In 1994 the International Labour Office estimated that there were 2 to 5 million occupational cases of pesticide poisoning and 40'000 fatalities (ILO 1994).

Together with pesticides in the WHO classes Ia and Ib (organophophates and carbamates), endosulfan and paraquat (both in WHO class II) have caused several fatal poisonings (IFCS 2003b). Besides carbamates and pyrethroids, a large proportion of insecticides are organophosphates and most of these are in either WHO class Ia or Ib. Most pesticides in WHO classes Ia and Ib are banned or strictly controlled in the countries of the North. But they are available in developing countries where conditions generally do not allow an appropriate use (Eddleston et al 2002). There has been an increase in the use of acutely toxic pesticides even though adequate protection or safety training for farmers and regulatory measures may be deficient or totally lacking (FAO 1994).

A survey among farmers in Korea found that paraquat was considered to be the most hazardous pesticide, although farmers also used organophosphates and carbamates (Lee 2004).

Central America

In Central America 6,934 acute pesticide poisonings were reported in the year 2000, with the rate of acute pesticide poisoning 19.5 per 100,000 inhabitants; 36% of poisonings in the region were occupational, followed by intentional and accidental poisonings (PAHO 2002b). The circumstances of poisoning differed between countries. Occupational exposure accounted for 60% of cases in Guatemala, 50% in Belize, 41% in Panama, 37% in Costa Rica, 33% in Nicaragua and 27% in El Salvador (PAHO 2002b). The mortality rate due to pesticide poisoning was 2.1 per 100,000 inhabitants in 2000 for the whole region (PAHO 2002b). Paraquat was foremost among 12 pesticides that caused the greatest number of acute poisonings (fatal and non-fatal) (OPS/OMS 2001a).

In Nicaragua the incidence of acute pesticide poisonings during the first six months of 2003 and 2004 was 13 and 10 per 100,000 inhabitants, while mortality was 2.0 and 1.5 per 100,000, respectively (MSN 2004).

In Costa Rica, acute pesticide poisonings (639 cases) occurred on the same order as tuberculosis (689) and malaria (651) (MSCR 2003). Among pesticide-related injuries at work that were reported by plantation workers, skin burn accounted for 28% and systemic poisoning for 21%,. There were also eye injuries and chemical-induced dermatosis or skin infections (Vergara & Fuortes 1998). Again, in Costa Rica from 1996 to 2001, out of 2579 poisonings from an identified agent, paraquat accounted for 898 cases (35%), followed by carbamates (31.5%), organophosphates (21%) and other pesticides (12.5%). In 42% of the total of 4465 pesticide poisonings, the pesticide responsible was not identified; 40% of cases were due to occupational exposure, in 33% the circumstances were not identified, 14% were rated as suicidal, and 13% as non-occupational accidents. Most poisonings (43%) occurred on banana plantations (OPS/OMS 2002b).

Asia and the Pacific

The use of acutely toxic pesticides poses a serious problem in Asia and Africa. In India workers in manufacture and agriculture were seen to be at a high risk from pesticides (ICMR 2001). In Malaysia pesticide sprayers and plantation workers were accorded second and third priority (after construction workers) for occupational health problems among different groups; the main area of concern was chemical poisoning with metals, pesticides and solvents (Sadhra et al 2001).

In China, around the year 2000, pesticide poisonings affected up to 123,000 people each year. Most pesticides were used on rice. In the province Zhejiang 20% of rice farmers reported poisoning symptoms (headache, nausea, painful skin), had a damaged function of the liver or chemical residues in the kidneys (Huang et al 2000). In Korea the proportion of agricultural workers who had been poisoned by pesticides was reported as 12.3% and 28.3%, respectively (Hong 1998; Lim & Zong 1992). In South Africa many poisonings with pesticides have been fatal (Yousefi 1999).

An accurate estimate of the magnitude of poisoning by paraquat is difficult to obtain, in part because it is often not easy to identify paraquat as the causal agent. Poisoning with organophosphates is accompanied by characteristic symptoms, while in poisonings with paraquat acute symptoms may disappear and clinical effects may be delayed (Ballantyne et al 1995). Therefore it is possible that the causal agent is not identified in a greater proportion of poisonings that are caused by paraquat than among poisonings caused by organophosphates. If it is not known with certainty what substance caused a poisoning, the medical diagnosis can be supported by measuring residues (e.g. of paraquat) in urine or blood samples (O'Malley 1997), but this is not always done.

Clinical diagnosis of organophosphate poisoning is confirmed when a test dose of atropine does not produce the characteristic symptoms (Fenske & Simcox 2000). Tests for the presence of paraquat with dithionite (e.g. in urine, limit of detection ca. 1 µg/l) are subject to interference by other compounds. The quantification in blood or urine therefore requires more sophisticated analytical methods (Scherrmann 1995). Due to the lack of methods to determine paraquat, it would not be possible to detect paraquat residues in urine or blood in most of the paraquat poisonings; especially those occurring in rural areas where medical facilities are limited (unless a massive amount was absorbed). This means that paraquat is less likely to be identified than, e.g., organophosphates (OPs).

¶ In order to assess the extent of paraquat poisoning more reliably, cases of poisoning should be registered on the basis of a standardised method (Volans et al 1987).

3.2 Acute health effects of paraquat

3.2.1 Acute systemic poisoning

The exposure of farmers and agricultural workers to paraquat, during mixing and spraying, has acute (immediate) toxic effects and chronic (long-term) effects on health. Acute health effects occur frequently among paraquat users. They include eye injury, nosebleed, irritation and burns of skin or other parts of the body. In case of acute paraquat poisoning, difficulty in breathing may develop with a delay of two to three days; death can occur up to several weeks after absorption.

«Systemic poisoning» denotes an incident of exposure to a toxic substance that is followed by symptoms due to absorption by the system and ensuing damage of organs. The term «poisoning» includes incidents of exposure that lead to skin or eye damage, irritate the upper airway and cause nosebleed, and to exposures that result in the systemic absorption of the toxic agent - referred to more specifically as «acute (systemic) poisoning».

Different circumstances connected to poisonings are:

- ◂ Accidental poisoning: unintentional inhalation, ingestion or skin absorption of substance (spray solution during spraying or spills of concentrate during mixing).
- ◂ Occupational poisoning: unintentional poisoning in a workplace setting.
- ◂ Intentional poisoning: deliberate intake of substance (suicide) or homicide.

The toxic effects of a substance absorbed depend on specific modes of action in an organism (distribution, storage, metabolism, reversible or irreversible effects, excretion), physical state, the amount absorbed (depending on volume, concentration and duration of exposure) and individual susceptibility (body weight, health and other factors) (Frumkin 2000). The route of absorption has an indirect impact, as it influences the amount absorbed, besides causing irritant and harmful effects.

When paraquat is absorbed through skin it can lead to systemic poisoning with the same features as those resulting from ingestion. Prolonged contact with paraquat (from leaking equipment or soaked clothing) damages the skin and greatly enhances absorption (Garnier 1995).

The European Commission has rated the acute hazards of paraquat as follows:

- ◂ Very toxic, by inhalation.
- ◂ Toxic, in contact with skin and if swallowed.
- ◂ Danger of serious damage to health by prolonged exposure if swallowed.
- ◂ Irritant to the eyes, respiratory system and skin (EC 2004).

Depending on the absorption route, the US Environmental Protection Agency classified paraquat dichloride (technical concentrate, 45.6% wt/wt) in different categories - for inhalation in EPA category I (label contains wording «Danger/Poison»), for oral acute toxicity and eye irritation in EPA category II («Warning»), and for dermal acute toxicity in EPA category II («Caution») (US EPA 1997a). Toxicity by inhalation was not considered to be of concern as size of spray particles was «well beyond the respirable range» and as paraquat is non-volatile (US EPA 1997a). Formulated products in the US are in EPA category I, as can be seen from material safety data sheets (SCRC 2005).

Regarding the acute hazards of paraquat, the WHO has noted: «Paraquat has serious delayed effects if absorbed. It is of relatively low hazard in normal use but may be fatal if the concentrated product is taken by mouth or spread on the skin» (WHO 2005). But this position does not reflect sufficiently paraquat's absorption through skin. While absorption is low for intact skin, it is greatly enhanced when skin has been damaged or is covered by clothing contaminated with paraquat for a longer time (Garnier 1995). In many countries of the South working conditions in agriculture do not allow the use of adequate protection. A number of fatalities have occurred following exposure to a dilute spray solution, largely under poor working conditions (see chapter 3.2.4).

Paraquat dichloride is classified in WHO class II for acute hazard based on an oral LD50 in rats of 150 mg per kg body weight (b.w.) (WHO 2005). An estimate of a «minimum lethal dose» for paraquat dichloride is approximately 46 mg/kg b.w. (equivalent to 33 mg cation/kg b.w.) (Pasi 1978). Individuals vary in sensitivity and tolerate different doses. Minimum fatal doses by ingestion of concentrates (12-20%) are 30-50 mg/kg b.w. for paraquat dichloride, corresponding to a single swallow (Bismuth et al 1995).

The intake of 17 mg cation/kg b.w. (equivalent to 23.5 mg/kg b.w. of paraquat dichloride) has been fatal (Stevens & Sumner 1991). After ingestion of more than 15 ml (one tablespoon) of 20% concentrate, the outcome is most likely to be fatal (Pronczuk de Garbino 1995). While the body can dispose of lower doses, a large dose (20 mg/kg b.w.) damages the kidneys, reducing the possibility of disposal (Houze et al 1995).

No antidote against paraquat poisoning has proven clinically useful (Ellenhorn et al 1997). An emetic (induces vomiting) is added in many formulations but it is not clear if this has improved the prognosis in cases of ingestion (Bismuth et al 1995). The emetic does not reduce skin absorption, neither do stenching agents or colour.

Referring to immediate decontamination of the stomach after paraquat ingestion the misleading, if not false, statement has been made that «there is an effective treatment» (Syngenta 2002, p. 27). The use of Fuller's earth as adsorbent has not been demonstrated to be clinically effective (Pond 1995). Activated charcoal to adsorb chemicals appeared to be the best means for stomach decontamination, but no treatment has been shown to produce significant clinical benefit (Meredith & Vale 1995). Dialysis, blood filtration or fusion and antioxidants or anti-inflammatory agents have not proven clinically effective to prevent a fatal outcome of serious poisonings with diquat or paraquat (Vale 2005).

Symptoms of poisoning with diquat or paraquat (Ellenhorn et al 1997) are:
a) Early after ingestion: lesions and pains in the mouth and stomach, nausea, vomiting, diarrhoea, blood in faeces
b) 48-72 hours after exposure (by ingestion, inhalation or dermally): reduced urine volume, jaundice, cough, difficulty in breathing (high frequency), lung oedema (swelling), convulsions, coma.

In cases where skin was contaminated by the concentrate, or in extensive and/or prolonged contact with dilute paraquat (particularly where signs of skin irritation are present), the patient must be assessed for systemic poisoning at a hospital (IPCS 1984).

Paraquat poisoning should be treated as early as possible at a hospital (IPCS 1991) where patients are treated as an emergency even if they show no symptoms of poisoning (Ellenhon et al 1997).

Severity of poisoning can be distinguished as hyperacute after ingestion of massive amounts (the patients usually die after less than 4 days), acute after ingestion of 30-50mg/kg b.w. and subacute with usual recovery after ingestion of lower doses (Bismuth et al 1995). A deceiving feature of paraquat poisoning, provided the absorbed dose was not massive, is that in many cases the acute symptoms disappear after about a day (Ballantyne et al 1995). Kidney failure and severe lung damage (pulmonary fibrosis) develop over several days, leading to a lack of oxygen. Death frequently occurs within one to two (and up to six) weeks and mortality is very high in cases of poisoning with a concentrated (20%) solution (Ellenhorn 1997).

3.2.2 Reports on skin or eye damage and systemic poisoning

Asia

Among 65 occupational pesticide poisonings registered in hospitals in *Japan* during 1998-2002, 53% were acute or subacute poisonings, (followed by acute dermatitis, 24%, chemical burns, 15%, and eye injury, 6%). In 11% of cases, patients did not recover (Nagami et al 2005). Organophosphates accounted for 20% of cases and bipyridylium herbicides (paraquat and diquat) for 8%, followed by lime sulphur, soil fumigants and various pesticides, Factors associated with the occupational cases were insufficient protective measures (in 31% of cases), carelessness (16%) and inadequate information (11%) (Nagami et al 2005).

In *Malaysia* six female plantation workers who had low cholinesterase activities in blood samples were medically examined. Three workers had itching skin or eczema or (diagnosed as contact dermatitis possibly due to pesticide), three reported having occasional pain in the chest, chest tightness and/or difficulty in breathing. Three had nosebleed (occasionally or recently). Giddiness, numbness of hands, headache, abdominal cramp, blackout, nausea and vomiting were sporadic symptoms (Tenaganita & PANAP 2002). While many of these symptoms are non-specific, the chest and nosebleed problems could be due to paraquat. Five of the workers sprayed paraquat, besides other compounds. No organophosphate was identified on the basis of the reported product names, although two of the workers could not name recently used products (Tenaganita & PANAP 2002). It appears that the low cholinesterase activities may have been caused by paraquat exposure (see chapter 3.2.4).

Also in Malaysia (in 1997-1998) paraquat caused a greater proportion (19%) of occupational poisonings than organophosphates (16%) (Sirajuddin et al 2001). In 1987 (1988) among 225 (249) pesticides identified in poisonings, paraquat was the causal agent in 62% (71%) of the total, while organophosphates were identified in 17% (14%) of cases (Tenaganita & PANAP 1992). In the 2002 study the cholinesterase values of the workers were compared to the average in a non-exposed population. A second measurement was carried out in the six workers with low values after they had abstained from spraying for a month; the second values were 38-500% higher than the first (Tenaganita & PANAP 2002). Without baseline values, the levels of cholinesterase in blood plasma must be 30% or more below the normal range to be clinically significant (Fenske & Simcox 2000). This was the case for all six workers. The determination of cholinesterase that was employed is a sensitive and reliable method for measurement (Zenz 1994).

Eleven out of 27 Malaysian workers spraying paraquat (0.5% and 0.25% solutions) had one or more incidents of skin irritation or rash, mostly on the hands, legs, and in the groin or on buttocks (due to leaking equipment); one worker was injured in the eye (Howard et al 1981).

Another study in Malaysia with 30 workers who sprayed paraquat (0.05% solution) continually over 12 weeks found that about half of the workers had irritation of the eyes (from splashes) and skin at some time. Two workers had nosebleeds and there were two cases of scrotal dermatitis (following contamination of trousers and prolonged contact) (Swan 1969). In 2002, in two plantations, 1.2% and 0.9% of women sprayers complained of a burning sensation during urination and of heavy white discharge; 1.7% and 2.7%, respectively, had vaginal pains (Tenaganita & PANAP 2002).

In *Sri Lanka* a larger proportion of 85 spray operators (23.6%) had more skin damages than unexposed factory workers (11.8%) or general workers (15.2%). Incidence of eye damage was similar in spray men and general workers but not reported by factory workers. Nosebleeds occurred in three spray men and one factory worker but not among general workers (Senanayake et al 1993). In the latter study the concentration of paraquat was very low (0.04-0.07%) and the workers practised excellent personal hygiene (washing frequently throughout the day); this explained the lower incidence of damage to skin and nails than reported in other studies (Senanayake et al 1993).

These studies in Sri Lanka and Malaysia may not have observed symptoms of acute systemic poisoning. But they show the occurrence of severe irritating effects, leading to skin damage that is likely to increase the risk of paraquat absorption significantly. Localised irritant effects to skin and mucous membranes, nosebleed, cough, headache or nail damage resulting from paraquat - all indicate overexposure. They should be enough to remove a worker from the area to prevent further overexposure (Zenz 1994).

Latin America

The use of pesticides is high in *Costa Rica* because of banana cultivation. About 175,000 workers were found to be exposed to paraquat and diquat (Partanen et al 2003). In 2001, in 127 cases of 544 notified pesticide poisonings, the most identified causal agent was paraquat. The paraquat poisonings occurred under the following circumstances: 57 rated as suicidal, 29 accidents during work, 24 unknown circumstances, and 17 due to occupational exposure (OPS/OMS 2002a). Between 1996 and 2001 in Costa Rica paraquat was the cause of 35% of all notified poisonings (OPS/OMS 2002b). Reporting by the national surveillance system was incomplete; a study in four Costa Rican districts estimated that between 82.2 and 97.8% of pesticide poisonings were not registered. When these cases were included the proportion of poisonings in an occupational setting was 76.8% (OPS/OMS 2002c). In the banana-growing area most injuries occurred among herbicide sprayers (Wesseling et al 2001b).

Also in Costa Rica (in 1996) occupational exposure accounted for 38.5% of 1,274 pesticide poisonings registered at the national poison control centre, followed by accidental exposure (33.8%) and suicidal ingestion (22.5%). Organophosphates, carabamates and paraquat accounted for 46% of cases, with paraquat the individual agent responsible for the highest percentage of cases (11.6%) (Leveridge 1998).

The average annual rate of hospitalisations in Costa Rica due to pesticide poisoning was found to be between 115 and 130 per 100,000 workers among agricultural workers. Paraquat was the most identified pesticide causing severe poisonings, hospitalisations or fatalities (Wesseling et al 1993).

A survey of 96 families in 1998 in a rural area of *Honduras* found over 80% used pesticides and paraquat was used most often. Safety measures were rare. All workers who used paraquat had at least one symptom potentially related to paraquat exposure, and prevalence of heath problems among children was abnormally high compared with national rates (Cantor & Young-Holt 2002). Paraquat poisoning has also been a major problem in *Ecuador* (Sevilla 1990).

United States

Between 1971 and 1985 in California 231 cases of illness due to paraquat were reported; the majority of cases (38.5%) associated with paraquat were systemic (with symptoms of acute poisoning and respiratory symptoms). Eye and skin illnesses occurred in 32% and 26% of cases, respectively, and local respiratory symptoms accounted for 3.5% of cases; 55 of the 231 cases were associated with loss of workdays and 11 cases were hospitalised (Weinbaum et al 1995).

Also in California, (1998 to 2000), 15 agricultural poisonings with paraquat were reported. Ten of these cases were rated as definite or probable (1 with systemic and respiratory effects, 4 with eye effects, 5 with skin effects), five were rated as possible. In 2001 there were 4 poisonings reported due to paraquat, 2 cases with systemic/respiratory effects (both definite/probable) and 2 cases with localised (topical) effects (involving only eyes and/or skin, one definite/probable and one possible case). Three poisonings due to paraquat were reported in 2002 with topical effects (two definite/probable cases and one possible) and in 2003, 4 poisonings were reported, 3 with systemic/respiratory effects (two definite/probable, one possible) and one definite/probable case with topical effects (CDPR 1998-2003).

Europe

After skin absorption of paraquat another worker suffered poisoning and prolonged damage to the gall (Bataller et al 2000). In *Italy* paraquat was among six pesticides most frequently associated with non-fatal poisonings referred to the main poison centre in 2000-2001 - 46 poisonings out of 872 were due to paraquat (Davanzo et al 2004).

In Crete (*Greece*) pesticide poisonings increased during 1991-2001 to 1700 cases (fatal and non-fatal) per year, with organosphates and paraquat causing concern; 45% of the cases were accidental, 40% occupational and 12% suicidal (Bertsias et al 2004). One worker was acutely poisoned by paraquat absorbed through skin during spraying (Bertsias et al 2004). Another developed fibrosis of the lungs due to paraquat poisoning by absorption via skin; he survived with residual lung fibrosis (Papiris et al 1995).

Among 274 fruit growers in *Scandinavia*, where paraquat was the second-most used pesticide, 41% developed coughs with expectoration, 37% headaches, 30% nose discharge, 25% langour (weariness), 25% general malaise, and 21% breathlessness. Also various symptoms such as dizziness, palpitations, nausea, skin complaints or itching of the skin or eyes. A protective mask was used by 39% of the growers (Lings 1982). Among a subgroup of 181 fruit growers who were examined medically, those who used paraquat (62.4%) had lung symptoms more frequently (not statistically significant): coughing and breathlessness. It was concluded that the professional use of biocides can give rise to lung disease comprising pneumonia and chronic progressive lung fibrosis (Lings 1982). After applying paraquat another worker developed tiredness, mild breathing distress, swollen ankles and anaemia, and decreased diffusing capacity of the lungs and nephritis - an inflammatory impairment of the kidney (Strata et al 1988).

In the *UK* between 1981 and 1986 paraquat accounted for 26 admissions to the poison treatment centre in Edinburgh; two of these occurred as a consequence of occupational exposure (leaking back canister; inhalation during spraying) and one case was due to accidental ingestion (removal of the bottle top with teeth) (Proudfoot & Dougall 1988).

Acute poisoning by inhalation of paraquat has been documented in greenhouses. A study found that «stronger than usual solution» led to transitory failure of kidneys (Malone et al 1971). Application of paraquat by air has caused respiratory symptoms. Depending on the sprayer type, the sizes of spray droplets could have been relatively small and may have decreased further during drift (Ames et al 1993).

The symptoms cited in this section are an indication that work practice should be reviewed (IPCS 1984). They explain the need for strict personal hygiene and rigourous adherence to required handling procedures (IPCS 1991). However, in many countries this may represent an ideal guideline that only a minority of workers is able to follow, as it is not feasible due to inadequate conditions in the field or the hot climate.

3.2.3 Skin and eyes

Paraquat acts as a strong irritant, especially in concentrated formulations, Contact with skin causes redness, blistering or ulceration and can lead to dermatitis. Diluted paraquat can cause irritation after prolonged exposure through soaked clothes (Bismuth et al 1995).

When skin is intact, the absorption of paraquat is generally low. But it is greatly enhanced when skin is damaged. Prolonged contact with paraquat solution may itself damage the skin and allow increased absorption, leading potentially to severe poisoning (Garnier 1995). The single exposure of healthy skin to paraquat solutions has been reported to cause local lesions in skin but no systemic effect.

Among 15 cases of accidental exposure to paraquat solutions, skin burns (grade I to III) occured in six cases, vesicles in 4 cases and contact dermatitis in one case. In 2 two cases where the face was exposed the worker suffered from conjunctivitis (Hoffer & Taitelman 1989).

When skin is covered and is in contact with paraquat solution, or when it is applied repeatedly, this causes irritation that is likely to increase permeability of skin (Garnier et al 1995).

Prolonged exposure to solutions containing more than 5% paraquat might lead to fatal poisoning. Exposure to less concentrated solutions may also be fatal if there are pre-existing skin lesions and if the skin is not washed immediately after exposure, or if contaminated clothing is not changed immediately (Winchester 1995; Smith 1988). The poisoning symptoms following skin absorption of paraquat are similar to symptoms after ingestion, except for local effects to the skin (Garnier 1995). Paraquat may cause contact dermatitis (Villaplana et al 1993; Botella et al 1985) while diluted solutions can cause severe skin burns (Ronnen et al 1995). Burns must be treated or else the risk of skin absorption may be increased.

Paraquat has a skin notation (IPCS 2001a; NIOSH 1996), signifying that uptake via unbroken skin can contribute substantially to total body burden and can cause serious systemic health effects (Semple 2004).

Eye contact with paraquat solution may lead to an inflammation of the cornea. Treatment usually results in recovery after prolonged healing but is not always complete and vision can be impaired if patients wait too long (Bismuth et al 1995). Other consequences of eye contact can be conjunctivitis, an irritant inflammation of conjunctivae, and long-lasting or permanent opacity of the cornea (Mc Keag et al 2002; Ellenhorn et al 1997). Skin or eyes that have been contaminated with paraquat solution urgently need to be rinsed, preferably under running water for at least 10 minutes. Eye injuries should always be attended medically (IPCS 1984).

3.2.4 The nerve system

Paraquat was found to inhibit the activity of certain enzymes in blood serum (El-Demerdash et al 2001). In tests with fish, paraquat inhibited cholinesterase, (an enzyme needed for the proper functioning of the nervous system) (Láng et al 1997). In another study with fish, cholinesterase inhibition was not observed at sub-lethal concentrations (Di Marzio et al 1998). In earlier studies, paraquat had been seen to have an inhibitory effect on cholinesterase (Tkachenko et al 1988; Seto & Shinohara 1987).

Pesticides that inhibit the enzyme cholinesterase act as nerve poisons. Symptoms include tremors and nausea. Paralysis or death can occur at higher doses. The inhibition by organophosphates and the neurotoxic effect are stronger than that caused by carbamates (Stine et al 1996). Paraquat presents a chronic health risk to workers due to its neurotoxic properties (Vega Bolaños et al 1997).

The question was raised whether cholinesterase inhibition is caused by paraquat or by related compounds present as impurities (Lin-Shiau & Hsu 1994). Impurities are not fully separated from the bulk formulations, however (Ambrus et al 2003). Several distinct forms of cholinesterase exist and it appears these are selectively inhibited by different substances (Marquis 1986). When cholinesterase levels in blood are found to be below the average level for people who are not exposed to pesticides, this is an indication of potential exposure to any cholinesterase-inhibiting substance.

It is not possible to identify which group of substances (or which individual substance) is the likely causal agent by measuring a depressed cholinesterase level. Evidence of cholinesterase inhibition by paraquat appears inconclusive and it is necessary to investigate and clarify if paraquat inhibits cholinesterase.

3.2.5 Acute respiratory effects (lung)

After absorption of a large quantity (ca. 30 mg/kg b.w.) of paraquat dichloride - by any route - pulmonary fibrosis develops. This pathological thickening of connective tissue in the lungs leads to a decrease in the diffusing capacity of carbon monoxide in the alveoli that can be detected from the first day. This leads to interstitial fibrosis (thickening of tissue between alveoli) and inflammation of alveoli, causing lack of oxygen, frequently resulting in death after a few days to several weeks (Bismuth et al 1995).

Abnormalities in the lung may not be detected on chest x-rays at an early stage. But images become patchy later on. Testing lung functions can be used for a diagnosis before the stage of decreased oxygen levels is reached (Bismuth et al 1995). If doses below 30 mg/kg b.w. are absorbed, pulmonary fibrosis rarely becomes clinically severe, and recovery of the lung function is usual. In some cases a restrictive dysfunction of the lung persists. Impairments may improve over several years (Bismuth & Hall 1995).

But in follow-up studies of survivors of paraquat poisoning, total lung capacity was significantly decreased (Yamashita et al 2000). The destructive effects on lung tissue are a consequence of paraquat being accumulated in epithelial (tissue) cells of alveoli.

Paraquat and diquat differ in the mechanism of toxicity. Diquat is not accumulated in the lung and does not lead to pulmonary fibrosis (Rose & Smith 1977). Paraquat damages the cell membranes (lipids) by peroxidation. Levels of important enzymes are decreased, followed by an inflammatory response (Lewis & Nemery 1995). Lipid peroxidation has been associated with chronic obstructive pulmonary disease (COPD) (Santus et al 2004).

Exposure to paraquat was associated with a higher risk for chronic bronchitis in Colombia (Forget 1990). Levels of antioxidants in blood samples of pesticide sprayers were increased, indicating oxidative stress (Prakasam et al 2001). In farmers the risk of respiratory disease and mortality due to this is significantly increased. Rhinitis (inflammation of tissue in the nose) can also be caused by paraquat (ATS 1998).

3.3 Fatal unintentional poisonings with paraquat

It has been asserted that the application of paraquat will not be a hazard with reasonable work practices, including safety precautions, hygiene measures and proper supervision, and also that improper work practices during handling of undiluted concentrate may result in skin contamination and absorption through skin (IPCS 1991). Fatal unintentional poisonings have been linked with accidental intake and inappropriate behaviour, namely insufficiently diluted paraquat combined with leaking sprayers, which may lead to prolonged skin contact, severe skin lesions and paraquat absorption via skin (IPCS 1991). A number of poisonings with diluted spray solutions containing paraquat have been described. The presence of scratches to skin or small ulcers can be enough to result in absorption of a fatal dose of paraquat from the diluted spray solution.

However, fatal unintentional poisoning has resulted from the accidental contamination of the body with paraquat (20%) (Waight 1979), from swallowing a mouthful of paraquat concentrate (due to confusion of bottles), and from a smaller amount ingested (Wesseling et al 1997). Workers died after accidentally having ingested a mouthful or sip of paraquat; in one of these cases poisoning occurred during the decanting of the concentrate (Cassidy & Tracy 2005; Ochoa Gomez & Gil Paraiso 1993).

Three fatal poisonings were caused by accidental ingestion of diluted solutions of paraquat when workers sucked on a blocked sprayer jet (Fitzgerald 1978). Drinking from an empty bottle of Gramoxone after refilling it with water was fatal (Fernando et al 1990). A worker who spilled a mixture of diluted paraquat and 2,4-D (WHO class II) on the face and mouth - which would appear to lead to the ingestion of a very small amount of paraquat - died from acute pulmonary failure, typical for paraquat poisoning (Wesseling et al 1997).

A review of 12 unintentional fatal poisonings resulting from skin exposure that were reported between 1974 and 1988 concluded that prolonged skin contact with paraquat solutions at concentrations as low as 5% (cation weight per volume) can cause systemic poisoning that may be fatal. It was recommended that paraquat labels should contain a warning against the use of this herbicide in knapsack sprayers (Smith 1988). Fatal poisonings have occurred following the exposure to diluted paraquat spray with much lower concentrations (see below).

Among several work-related fatalities following dermal exposure to diluted paraquat, three deaths were due to a leaking sprayer (one of the workers also had dermatitis) (Athanaselis et al 1983; Wohlfahrt 1982; Fitzgerald et al 1978). Another two deaths occurred when the head and mouth of one worker and the back of another were accidentally contaminated during spraying (Wohlfahrt 1982).

Asia

In *Japan* out of 346 pesticide poisonings (90% of these systemic) that were recorded during 1998 to 2002 in several hospitals, 25% of cases proved fatal. Of these 346 cases, 36% were due to organophoshates and 20% to paraquat and diquat (Nagami et al 2005); 65 cases (18.8% of the total) occurred during spraying, preparation, settlement, or re-entry during spraying (Nagami et al 2005).

In the *Philippines* two workers were hospitalised after spraying paraquat and one of them died (Quijano 2002). Two deaths occurred as a consequence of skin exposure to insufficiently diluted paraquat solutions (5% and 2.8%) and as spraying equipment was leaking (Levin et al 1979; Jaros 1978).

In *Thailand* a worker who had sprayed paraquat during three months developed skin burns; he died after three more months of spraying (IPM Danida 2003).

A woman who applied paraquat - appropriately diluted - contaminated the scratches she had on arms and legs from branches (she had worn no protection and did not shower after spraying). Later the woman developed headaches, breathlessness, skin lesions and died several weeks after from respiratory failure (Newhouse et al 1978). Three fatal poisonings following skin absorption occurred in *Papua New Guinea*. It was stated that many other cases of paraquat poisoning had not been recorded as reporting systems were inadequate (Wohlfahrt 1981).

Europe

Among 11 paraquat poisonings in *Crete* that were reviewed by a poison centre, 5 were fatal; six of the 11 cases were suicidal, four accidental and one occupational (Bertsias et al 2004). In *Spain* a survey of data on 184 deaths by pesticide poisoning, between 1991 and 1996, found that organophosphates and carbamates accounted for most cases, followed by endosulfan and paraquat (identified as the causal agent in 11.5% of fatal poisonings) (Garcia-Repetto et al 1998).

Costa Rica

Between 1996 and 2001 in Costa Rica 133 deaths from pesticide poisoning were registered. Of these deaths, 112 were classified as suicides, 9 as non-occupational accidents, 3 from occupational exposure; for 9 deaths the circumstances were not established. Paraquat caused 68% of all deaths and 72% of 86 suicides where the pesticide was identified (OPS/OMS 2002b). A study of occupational fatalities in Costa Rica revealed that three deaths occurred as a consequence of the exposure to diluted paraquat solution. The death of a child worker who entered a recently sprayed plantation may have arisen from absorption of diluted paraquat spray through skin and the mouth (pre-existing small ulcers on his leg would have facilitated absorption, and possibly he chewed sprayed leaves). Two deaths occurred after diluted paraquat solution was absorbed through skin only - in one of these cases systemic poisoning was delayed and in the other the backpack containing the solution was leaking (Wesseling et al 1997).

In two fatal cases the route of absorption could not be identified - the suggestion was made that spray droplets could have been inhaled (Wesseling et al 1997). A possible absorption route could be the ingestion of airborne spray solution when the worker changed from nose breathing to mouth breathing, which occurs normally during physical exertion (Frumkin 2000). The spraying of paraquat in a greenhouse has resulted in fatal poisoning (with characteristic features of kidney failure and lung injury) (Kishimoto et al 1998). This case indicates that in certain situations the exposure by inhalation may be sufficiently high to cause poisoning.

A worker who suffered severe burns after a plane crash during the aerial application of paraquat - and whose skin had been exposed to paraquat over a long period - died from paraquat poisoning (Gear 2001).

3.4 Summary

The active substance paraquat is acutely toxic to humans. Contact of skin with paraquat solution can cause skin lesions and dermatitis. While healthy, intact skin may absorb paraquat to a very low extent, absorption is much greater when skin has been damaged through minor injuries or from contact with paraquat solution.

Absorption of a sufficiently high dose of paraquat results in acute (systemic) poisoning, independently from the route of absorption (ingestion, inhalation or skin absorption). The symptoms of acute poisoning are often delayed if a large quantity is not ingested. No antidote is available.

An inhibitory effect of paraquat on the nerve system (cholinesterase activity) has been documented in fish. As a consequence of exposures to paraquat at the workplace numerous cases of non-fatal acute poisoning and a number of fatalities have occurred. In most cases where occupational fatalities have been documented, paraquat was absorbed through skin but several deaths were caused either by combined dermal absorption and ingestion of smaller amounts, or by the swallowing of airborne spray droplets deposited in the nose or direct absorption through the mouth.

Factors contributing to increased absorption were prolonged skin contact with undiluted or diluted paraquat solution, which may cause skin damage or dermatitis, and minor skin injury such as scratches or ulcers, together with inadequate personal protection. Eye injuries, even if treated, do not always heal. Skin lesions increase the risk of acute poisoning significantly.

Fatal occupational poisonings with paraquat have been misclassified as suicides.

4. Chronic health effects of paraquat

Exposure to relatively low doses of paraquat but over a longer period of time can affect the lungs, nerve system, brain and skin. Just over 30% of fruit farmers in Taiwan had dermatitis of the hand, more often on the right hand (Guo et al 1996). Half the farmers used paraquat.

Contact dermatitis is a significant health problem for banana workers in Panama, who are exposed to paraquat (Penagos 2002). This condition increases the risk for skin absorption. In epidemiological studies the long-term exposure to low doses of paraquat was linked to small changes in gas exchange of the lung and was associated with an increased risk of developing Parkinson's disease.

Chronic exposure can affect reproduction. Birth defects may result. The exposure of male workers to paraquat and diquat was associated with a relative risk of 2.77 (95% confidence interval 1.19-6.44) of congenital malformations and birth defects occurring in their children (Garcia et al 1998). Paraquat was found to adversely affect embryonal development in animal tests (Hausburg et al 2005).

4.1 Chronic respiratory effects (lung)

In test animals, the repeated exposure to small quantities of paraquat in diet or via skin can cause pulmonary fibrosis, and exposure to respirable-size droplets caused direct injury to the lung (Bismuth et al 1995). Droplets of a respirable size have an increased toxicity to the lung but most sprayer types produce droplets that are too large to enter the alveoli. But irritant effects on the upper airway are common (Hall & Becker 1995).

Chronic exposure of workers to paraquat and potential impacts on the lung have been the subject of several studies. Two studies found no association of paraquat exposure with respiratory effects, while three others observed a positive association with small alterations in gas exchange (see chapter 4.2).

Damages to the lung cannot always be recognised in chest x-rays or respiratory tests at an early to intermediate stage (Bismuth et al 1995; Vale et al 1987). Evaluating total lung capacity (from a single breath) and measuring diffusion capacity (for carbon monoxide) are more sensitive methods than spirometric tests to assess potential restrictive lung conditions (ATS & ERS 2000). Measurement of oxygen uptake during maximum exercise further increases the sensitivity (Schenker et al 2004). In tests on rats exposure via the skin to repeated doses of paraquat solution (0.8-2.85%) led to an increase in the thickness of lung arteries and haemorrhage (Levin et al 1979).

4.2 Studies of chronic effects on the lung

A WHO study identified paraquat as among the pesticides with a priority for further examination - due to its wide use and numerous severe and fatal poisonings (WHO & UNEP 1990). While many cases were accidental, acute poisoning with paraquat is characterised by delayed pulmonary fibrosis, and it could not be excluded that chronic exposure to low (non-fatal) doses could have an influence on the lung function (WHO & UNEP 1990, chapter 4).

In two studies with plantation workers who had sprayed paraquat over longer periods of time, it was concluded that the long term occupational use of paraquat is not associated with lung damage or adverse effects in exposed workers (Senanayake et al 1993). Also that it was not possible to show any differences in the lung function between spray workers and general or factory workers (Howard et al 1981).

Methods for medical examination in these studies (chest x-rays and spirometric tests of lung function) were insufficient to diagnose paraquat poisoning, except for measurement of the diffusion capacity of carbon monoxide. Two other studies with workers who had sprayed paraquat over a longer period concluded that working with paraquat under field conditions is associated with desaturation of arterial oxygen during maximum exercise in a dose dependent fashion (Dalvie et al 1999), and that the increased prevalence of respiratory symptoms in the exposed workers suggested an effect of long-term paraquat exposure on respiratory health (Castro-Gutiérrez et al 1997).

The hypothesis presented was that sub-acute exposure to paraquat (to lower doses, possibly over a longer time) may lead to decreased diffusing capacity, and that lung fibrosis is not caused except in cases of an acute and substantial exposure (Castro-Gutiérrez et al 1997; and reference therein: Levin et al 1979). In more intensely exposed workers the relative risk for chronic bronchitis was twice as high (not statistically significant), while for episodic shortness of breath accompanied by wheezing it was 2.9 (95% confidence interval 1.4-6.3) (Castro-Gutiérrez et al 1997).

A third study with 338 workers from plantations in Costa Rica found that paraquat exposure was associated with small but statistically significant changes in gas exchange in the lung. Levels of exposure could be different on small farms with fewer workers; these were not included in the study (Schenker et al 2004).

Ventilatory equivalent for CO_2 (respired air volume for uptake of certain amount of oxygen), arterial oxygen desaturation (difference between oxygen saturation of blood at rest and maximum exercise) and carbon monoxide diffusion capacity were measured, the lung function was tested and cumulative exposure to paraquat was estimated for individual workers (Schenker et al 2004). The diffusion capacity and lung function in spirometric tests did not differ between paraquat handlers and non-handlers, and no clinically significant increases in restrictive lung disease or interstitial thickening were observed (Schenker et al 2004).

Cumulative exposure to paraquat was associated with an increased relative risk for chronic cough of 1.8 (95% confidence interval (CI) 1.0-3.1) and with an increased relative risk for shortness of breath accompanied by wheeze of 2.3 (95% CI 1.2-5.1) (Schenker et al 2004). Cumulated paraquat exposure was associated with an increase in the ventilatory equivalent for CO_2 in a statistically significant manner (this factor accounted for a small portion of total variance); paraquat exposure was associated with oxygen desaturation (5% or more) with a relative risk of 1.7 (95% CI 0.9-3.0) (Schenker et al 2004). The latter findings suggest that exposure to paraquat may be associated with sub-clinical abnormalities in gas exchange of the lung (Schenker et al 2004; Dalvie et al 2005).

Farmers (non-asthmatics) in the US who used paraquat had over a threefold relative risk for wheeze (whistling in the chest). When asthmatics were included the risk increased by 27%, a significant rise (Hoppin et al 2002). Nine workers in South African vineyards whose trousers had been soaked with paraquat spray developed redness and burning of legs. For six of these workers diffusion in the lung of carbon monoxide was reduced, while two of the workers reported chronic coughing and expectoration,, and one had difficulty in breathing (Levin et al 1979).

In Antioquia, Colombia, 11% of 5,483 people interviewed in 1986 used paraquat (15.2% of the rural and 4.4% of urban population), normally with knapsack sprayers. 17% reported having experienced illness during the 2 weeks before the study and 7.2% of the problems were related to the respiratory system (mostly coughing, runny nose, expectoration, dyspnea or shortness of breathing) (Arroyave 1990). 62.5% of participants had the problems for less than 15 days, 22.7% between 2 and 12 weeks and 10.1% for at least 1 year. A sub-sample of 896 people was medically examined and a physician diagnosed chronic bronchitis (accounting for 12.8% of the effects), asthma (2.7%) and tuberculosis (0.2%) (Arroyave 1990).

In the sub-sample the relative risk for chronic obstructive pulmonary disease in paraquat users was three times higher than in non-users and the association was highly significant for smokers, indicating a combined effect. Chronic bronchitis was more prevalent among paraquat users than non-users in smokers and non-smokers (Arroyave 1990). In a follow-up study in the same area with 1,157 children of paraquat users, exposure to paraquat was associated with the incidence of chest colds. The relative risk was almost three times higher in the group of children with a high level of paraquat exposure, and increased by a factor two or more for the group with low and moderate levels of exposure (IDRC 2003).

4.3 Carcinogenic potential

Tumours occurred in one out of three long-term studies with rats; the weight of evidence suggested paraquat was not carcinogenic in rats. Another conclusion was that paraquat is unlikely to pose a genotoxic risk to humans (FAO 2004). Positive test results for mutagenicity were found in human lymphocytes and lung cells of hamsters (FAO 2003).

The available evidence indicates that reactive oxygen species produced by paraquat are responsible for its genotoxicity. It was assumed that genotoxic effects will not be evident below a certain threshold concentration, provided that the antioxidant defence mechanisms of the organism have not been overwhelmed (FAO 2004). In animal studies, however, genotoxic effects of paraquat have been observed even following the absorption through skin (D'Souza et al 2005).

In human lymphocytes (white blood cells), paraquat induced slight but significant increases in the frequency of sister-chromatid exchanges (Ribas et al 1997-98). This indicates damage to chromosomes (structure carrying genetic information) leading to an increased susceptibility to malignant tumours (Segen 1992).

Paraquat has been rated as «Unlikely to be carcinogenic» (category E) by the US Environmental Protection Agency (US EPA 1997). It had previously been rated as «possible carcinogen» (category C) based on the induction of squameous cell carcinoma (one of the three main types of skin cancer) in rats (US EPA 1993). Among factory workers who had manufactured 4,4'-bipyridyl (a precursor used in paraquat production) the incidence of skin lesions was increased and these progressed to Bowen's disease (precancerosis of the skin) and, in fewer cases, to squameous cell carcinoma. It appears that exposure to sunlight was a cofactor and production has been modified in the meantime (Hall & Becker 1995).

Paraquat contains 4,4'-bipyridyl as an impurity in concentrations of up to 0.2% (Ambrus et al 2003). The maximum allowed concentration is 0.1% and levels were normally below 0.05% (FAO 2003b). It has not been clearly established so far whether carcinogenic effects are caused by paraquat or by related bipyridylium compounds (Li et al 2004). A test in mouse lymphoma cells was positive with paraquat (US NTP 2005).

The risk for malignant melanoma (skin cancer) was increased among male agricultural workers exposed to paraquat. In eight out of ten cases melanoma were situated on the lower limbs, where exposure to sunlight is less plausible than skin contact with pesticides - DBCP and paraquat in particular (Wesseling et al 1996). Total pesticide use (indexed per agricultural labourer) on coffee and banana was associated with increases in the relative risk for skin melanoma, lung and penile cancer in male workers. Paraquat is used extensively on banana and coffee. The increase could not be explained by smoking (Wesseling et al 1999). Further studies at the individual level are necessary.

4.4 Neurological effects (brain)

There is growing evidence that paraquat has chronic effects on the brain. In Taiwan the risk of Parkinson's disease among farmers was greater for subjects who had used paraquat and other herbicides/pesticides than those who had used herbicides/pesticides other than paraquat (Liou et al 1997). Another study found paraquat exposure was associated with Parkinson's (Hertzmann et al 1990).

In epidemiological studies it was found that exposure to pesticides (all types) and prevalence of Parkinson's disease were associated; the relative risk was between 1.74 and 2.16 for all pesticides - not statistically significant when analysed for individual pesticides. (Engel et al 2001; Kirkey et al 2001; Priyadarshi et al 2001).

A study on factors influencing Parkinson's disease reported relative risks of 1.41 and 1.67 again, not statistically significant - for herbicide and paraquat exposure, respectively (Firestone et al 2005). Workers in these studies were exposed to different pesticides however, which makes it more difficult to establish a significant association for individual pesticides.

Parkinsonism has been linked to insufficient levels of dopamine in the brain. Paraquat was found to be toxic to dopamine-producing nerve cells in animal studies (Bonneh-Barkay et al 2005; Li et al 2005; McCormack et al 2005; Ossowska et al 2005; Richardson et al 2005; Wu et al 2005). It appears that paraquat produces synergistic effects when used together with maneb, a fungicide (Cory-Slechta et al 2005). Acute and persistent parkinsonism has followed exposure to diquat (Sechi et al 1992).

4.5 Summary

In epidemiological studies the long-term exposure to low doses of paraquat was linked to small but significant changes in the gas exchange of the lung and was also associated with increased risk for developing Parkinson s disease.

In animal studies it was found that paraquat damaged dopamine-producing brain cells, while insufficiency of dopamine is known to be one of the major factors in the development of Parkinson's. There is evidence, that paraquat is genotoxic (mutagenic), and a number of studies indicated a possible potential for carcinogenicity.

5. Regulatory controls and guidance for the users

5.1 International standards regarding acutely toxic pesticides (paraquat)

At the international level the UN Food and Agriculture Organization (FAO), the World Health Organization and the International Labour Office (ILO) make recommendations on the distribution and use of pesticides and establish standards for workers' protection. These provide guidance to countries in the establishment of national health and safety standards. Part of international policy is based on voluntary adherence of governments, retailers, producers and industry. The FAO has made specific recommendations for the use and marketing of pesticides in the International Code of Conduct. ILO conventions ratified by the member states of the United Nations represent international agreements. (see below)

The central place of health in the international agenda for sustainable development is reconfirmed in the Plan of Implementation of the World Summit on Sustainable Development (September 2002), which also emphasises the importance of the precautionary principle. It presents actions for changing unsustainable production/consumption patterns:

◂ Sound management of chemicals. By 2020, aim to achieve that chemicals are used and produced in ways that lead to the minimisation of significant adverse effects on human health and the environment, using transparent science-based procedures of risk assessment and risk management, taking into account the precautionary approach. Support developing countries to strengthen their capacity for sound management of chemicals. Include action at all levels to further develop a strategic approach to international chemicals management based on the Bahia Declaration and Priorities for Action beyond 2000 of the IFCS.

◂ Strengthen and promote programmes of the ILO and WHO to reduce occupational deaths, injuries and illnesses, and link occupational health with public health promotion.

◂ Promote and improve science-based decision-making and reaffirm the precautionary approach as set out in the Rio Declaration on Environment and Development (UN/DESA 2002, items 23, 23b, 54m and 109f).

The UN Commission on Human Rights has discussed issues of general and illegal traffic in toxic substances in Latin America and Africa. It found that the most serious concerns raised were in connection with the excessive or uncontrolled use of toxic agricultural products such as paraquat and dibromochloropropane (UNESCO 1999). Both at the national and international level there is a continuing need for regulation of the trade and use of chemicals.

5.1.1 International Programme on Chemical Safety

The International Programme on Chemical Safety has pointed out that fatalities have resulted from inappropriate behaviour during the use of paraquat, such as using a leaking sprayer which may lead to severe skin lesions and absorption. Further, that damage to skin or eyes and nosebleed through the irritant action of paraquat illustrate the need for strict personal hygiene and rigourous adherence to safe handling procedures (IPCS 1991). It recommended:

◂ that the summary of the safety guide on paraquat should be easily available to users and to all health workers concerned with the issue;

◂ the safety guide be displayed on equipment at, or near, entrances to areas where there is potential exposure to paraquat, and be translated into the appropriate language (IPCS 1991, point 6).

Regarding the distribution and use of paraquat, it recommended that where practical and reasonable, the availability and use of the 20% liquid product should be limited to bona fide agriculturalists, horticulturalists, and professional users, who work with trained personnel, properly maintained equipment, and adequate supervision (IPCS 1991, section 3.2).

Recommendations on personal protection during the use of paraquat are:

◂ Avoid all contact with skin, eyes, nose, and mouth, when handling concentrated paraquat.

◂ Wear PVC-, neoprene- or butyl-rubber gloves (preferably gauntlet form), neoprene apron, rubber boots and face-shield.

◂ Wear a face-shield when handling and applying the diluted formulation. (...)

◂ Paraquat should not be sprayed with inadequate dilution, e.g., by hand-held, ultra-low-volume application.

◂ Paraquat should not be used by people suffering from dermatitis or by people with wounds, notably on the hands, until these have healed (IPCS 1991, section 4.1).

It was also specified that protective clothing should be impervious to liquids (IPCS 1991, section 6). However, besides putting the responsibility on the worker the use of clothing made of waterproof fabric is not practicable in hot and humid climates.

5.1.2. Food and Agriculture Organization of the United Nations; World Health Organization

The UN Food and Agriculture Organization (FAO) and the World Health Organization have recommended restrictions on availability of toxic pesticides. Paraquat is placed in category 4, which means it should be available only to commercial users (farmers, orchardists etc) and not to the general public (WHO & UNEP 1990, annex 2).

The use categories do not include prohibition of the use of very dangerous compounds, and the WHO and FAO stated earlier that this needed to be decided at the national level in view of the circumstances (Ekström & Åkerblom 1992). It was recommended that concentration of paraquat in spray solutions should not exceed 5 g cation per litre, equivalent to 0.5% (weight of cation per volume of solution), in order to avoid skin damage and absorption through skin (IPCS 1991). Further it was pointed out that the undiluted concentrate must be handled with great care and that persons with skin lesions (present in advance or following skin contamination with paraquat) should not be permitted to spray paraquat until the skin has healed (IPCS 1991).

The FAO demanded 20 years ago that farmers in the tropics should abstain from using pesticides that would require impractical and expensive protective equipment (FAO 1986; FAO 1990a). In the International Code of Conduct on the Distribution and Use of Pesticides and in the Provisional Guidelines on Tender Procedures for the Procurement of Pesticides, the FAO renewed these recommendations:

◂ Pesticides whose handling and application require the use of personal protective equipment that is uncomfortable, expensive or not readily available should be avoided, especially in the case of small-scale users in tropical climates (5). Preference should be given to pesticides that require inexpensive personal protective and application equipment and to procedures appropriate to the conditions under which the pesticides are to be handled and used. (FAO 2002, Art 3.5; reference 5: FAO 1990b).

◂ Although pesticide formulations in WHO class II are less hazardous than those in class I, precautionary methods proven effective under field conditions in developing countries are required. Therefore, pesticide formulations in WHO class II should only be provided if it can be demonstrated that users adhere to the necessary precautionary measures (9). (FAO 1994, Art 3.2; reference 9: FAO 1992).

On the distribution and use of acutely toxic pesticides in developing countries, the positions of the FAO, the World Health Organisation and of the Organisation for Economic Cooperation and Development largely correspond to each other:

«Pesticides belonging to WHO Acute Toxicity Class Ia or Ib, respectively, should not be used in developing countries, and if possible pesticides of class II should also be avoided» (Plestina 1984).

«Extremely and highly hazardous pesticides of the WHO Class Ia and Ib (11) and compounds which are highly persistent in the environment should not be provided. Exceptions could only be considered if all three of the following criteria are met: a) there are urgent reasons to use these pesticides; b) there are no safer alternatives; and c) their safe and controlled application can be guaranteed. Pesticides of Class Ia, Ib and the more toxic range of class II, are generally considered to be unsuitable for use by small-scale farmers» (OECD 1995; reference 11: WHO 1992).

The FAO has further recommended that integrated pest management (IPM) should be promoted by governments and other stakeholders and that even where a control scheme is in operation, the pesticide industry should cooperate in the periodic reassessment of the pesticides which are marketed. Also that industry halt sales and recall products when handling or use pose an unacceptable risk under any use directions or restrictions (FAO 2002, Art 5.2).

The agrochemical industry made certain, albeit limited, efforts in training workers in less hazardous practices of use (see chapter 5.4). Industrialised countries have provided detailed schemes for compulsory identification of chemical hazards at the workplace to be followed by assessment of the risk and control measures to reduce risk to an acceptable level (Herber et al 2001). However, many countries do not have the facility for assessing the risks of a growing number of chemicals that workers are exposed to. Legislation for occupational safety is frequently either not detailed or not implemented. Many workers use acutely toxic pesticides on a regular basis without sufficient measures for mitigating risk being taken.

Paraquat and other acutely toxic pesticides are used extensively in countries where no proper risk assessments have been carried out.

The most hazardous pesticides (certain organophosphates and carbamates, endosulfan, paraquat) are not restricted or banned, and acute poisonings continue to occur in many countries, e.g. in South America (Wesseling et al 2005).

5.1.3 Intergovernmental Forum on Chemical Safety

The fourth Intergovernmental Forum on Chemical Safety (Forum IV) pointed out that certain aspects of the problem of pesticide poisoning will be addressed by the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade.

Forum IV requested that the Forum Standing Committee provide information on the extent of acutely toxic pesticides, and provide guidance for sound risk management and reduction, including options for phasing out where appropriate (IFCS 2003a). But at the international level in general, only broad requirements are referred to in laws. Requirements are met on a voluntary basis by the responsible users, producers or transporters (IPCS 2004).

Forum IV recommended that Conventions and Guidelines of the International Labour Office regarding occupational health and chemical safety be implemented - such as Convention 169 on the work conditions of indigenous populations to prevent the use of specially dangerous pesticides (IFCS 2003a). The Forum made several recommendations to governments for regulatory actions aimed at reducing the risks from acutely toxic pesticides:

◂ prohibit or restrict availability (including the use of import and/or export controls as desirable) and use of acutely toxic pesticides (such as formulations classified by WHO) as Extremely Hazardous (class Ia) and Highly Hazardous (class Ib) and/or those pesticides associated with frequent and severe poisoning incidents;

◂ substitute acutely toxic pesticides with reduced risk pesticides and non-chemical control measures;

◂ encourage industry to extend product stewardship and to voluntarily withdraw acutely toxic pesticides when poisoning incidents occur. (IFCS 2003a, p. 11; WHO 2001b).

As paraquat has been associated with «frequent and severe poisoning incidents», urgent action is needed to implement the necessary measures to eliminate or minimise the occurrence of poisonings. This is required to prevent harm.

At the third Intergovernmental Forum on Chemical Safety (Forum III) a commitment to the Rio Declaration on Environment and Development, including the precautionary approach, had been reaffirmed. The Recommendations of Forum III in the Bahia Declaration and Priorities for Action beyond 2000 were the following:

◂ Control of chemicals and pollution control initiatives should be closely integrated and the precautionary approach, as outlined in principle 15 of the Rio Declaration (1992), should be applied. The full range of risk reduction options should be considered, including encouraging, in particular, replacing more dangerous chemicals with less dangerous ones or using alternative processes.

◂ To protect the health of workers, special attention should be paid to occupational safety and health concerns caused by chemicals (...) (IFCS 2000b).

5.1.4 International Labour Office

The issue of workplace safety in agriculture is addressed by several recommendations, conventions and codes of practice established by the International Labour Office (ILO 1958-2002).

The ILO Chemicals Convention of 1990 provides that employers shall assess the risks arising from the use of chemicals at work and shall protect workers against risks by appropriate measures, such as the choice of chemicals and practices that eliminate or minimise the risk - engineering controls and occupational hygiene.

The Chemicals Convention also provides that when an exporting member State prohibits all or some uses of hazardous chemicals, for reasons of safety and health at work, this fact and the reasons for it shall be communicated by the exporting to importing country. This convention has been ratified by 12 countries to date (in 2005) (ILO 1990).

These instruments refer to national policy and legislation on occupational safety and health (OSH) of countries that have signed or ratified them. The International Commission on Occupational Health (ICOH) has not always been scientifically objective in policy recommendations, particularly in regard to pesticides. It should be recognised by the WHO and ILO as an industry body (Ashford et al 2002) .

A new instrument needs establishing which would ensure that national agendas give priority to OSH and foster political commitments in a tripartite context for improving OSH. Its purpose would be to promote a preventive approach to safety and health at work and to strengthen formulation and implementation of national OSH programmes based on the principles of assessment and management of hazards and risks (ILO 2004b, Art 13).

While there has been an improvement in industrialised countries, the same evidence about hazardous conditions at the workplace in developing countries is too often not translated into strategies for eliminating or substantially reducing hazardous exposures (Verma et al 2002). Shortcomings in occupational health and safety in developing countries are usually not highlighted by these countries.

The Occupational Safety and Health Convention (ILO 1981) - possibly the most important ILO convention in OSH - has been adopted by only 48 of the 178 ILO member states. Safer working conditions can make an important contribution to the reduction of poverty; a joint effort of the WHO, ILO and other partners on health and safety at work aims to improve the health of workers in Africa (Eijkemans 2003).

5.1.5 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade

The Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade regulates import and export of pesticides. For a substance to come under the regulation of the Rotterdam Convention the criteria are that it is «a chemical formulated for pesticidal use that produces severe health or environmental effects observable within a short period of time after single or multiple exposures, under conditions of use» (PIC Convention 1998, Article 2 (d)).

Paraquat fulfils the criteria for chemicals under the PIC Procedure and has been banned by more than the required minimum of two governments (in two different regions of the world).

Malaysia has notified paraquat for the inclusion in the Rotterdam Convention and another country may submit a notification in the near future. As soon as the Chemical Review Committee has reviewed the notification for paraquat it can be included in annex III of the Rotterdam Convention at a Conference of the Parties. Governments have to state whether they prohibit or consent to imports of a substance under PIC. The Rotterdam Convention therefore indirectly supports pesticide regulation at the national level.

5.2 Reassessment of the WHO hazard classification and measures for risk mitigation

The current lethal dose for paraquat dichloride is 150 mg per kg of body weight (oral LD50 in rats) (WHO 2005). Solid active substances in WHO class II have LD50 values of 50 to 500 mg/kg b.w. (WHO 2005). Paraquat belongs to the more toxic range of pesticides within WHO class II.

The WHO classifies pesticides based on tests with the active substances, not formulated products. At least two companies have classified products with paraquat (27.6% and 13% content) in toxicity class Ib (Helm/Anasac 2005; Crop Protection 2004), which correspond to a higher toxicity class than current classification by the WHO. An oral LD50 (rats) of 57 mg/kg b.w. for paraquat was reported in an earlier study (Bailey & White 1966). Manufacturers of paraquat have reported oral LD50 values (in rats) for the formulated product that are close to or below the cut-off value for WHO class Ib (50 mg/kg b.w. for active substance in the solid state) (GIL 1993; CSI 1990).

Among 211 herbicides classified for acute toxicity by the WHO (2005), based on the LD50 value, paraquat is among the eight most toxic (following acrolein, allyl alcohol, dinoterb, DNOC, PCP, endothal sodium and ioxynil). Four of the five most toxic herbicides (in WHO class Ib) are not registered in the EU (Neumeister 2005). Dinoterb, DNOC and PCP have been banned in several countries (PANNA 2002).

In Japan the mortality from paraquat poisoning is extremely high: physicians in intensive care units are hoping it will be banned. It was suggested to assign paraquat to WHO class Ia or Ib (Nagami et al 2005). The delay in the onset of toxic symptoms and absence of an antidote are factors that should be taken into account in hazard assessment of pesticides (Ticknell 1985).

The hazard classification of paraquat should be reassessed by the WHO on the basis of current knowledge, taking into account the delayed effects and the absence of an antidote.

5.3 Recommendations for risk reduction

Effective measures at the engineering level for minimising exposures would have to be implemented on a broad basis. Changing the position of the spray lance to the back of the worker could contribute to reducing the exposure (Machado-Neto et al 1998). However, it appears unlikely that this measure would be adopted by a large enough number of workers to substantially reduce the overall risk. Neither would it reduce exposure to spray drift or solution leaking from the equipment. Leakages occur very frequently with pressurised (knapsack) sprayers.

Standardisation of spraying equipment, e.g. on the basis of EU quality standards, offers a means of reducing the risks for workers (Herbst & Ganzelmeier 2002). However, as long as the standards are either not implemented. or partially implemented, only a limited reduction in risk can be achieved. In Belgium it was found that the condition of sprayers improved when inspection of sprayers became mandatory and the adherence to standards was linked with financial consequences (Langenakens & Braekman 2001).

Symptoms of poisoning by bipyridyls (diquat and paraquat) may be delayed by 3 to 14 days (Hallenbeck & Cunningham-Burns 1985). Because of this - and as there is no antidote - paraquat presents an occupational hazard that may be high risk where protective measures are not sufficient to minimise exposures. It has been recommended that dipyridyl herbicides and most hazardous organophosphates are limited in availability, or substituted with less toxic alternatives (Kotwica et al 1997; Bertsias et al 2004; Nesime et al 2004).

A tax on pesticides based on their toxicity has been suggested to create incentives for substitution (Muñoz Piña & Forcada 2004). In Sweden the withdrawal of the most toxic pesticides including paraquat from the market - together with mandatory training of workers - resulted in a decline of poisonings at the workplace (Ekström et al 1996).

To reduce acute poisonings and fatalities in developing countries, recommendations have been made that pesticides in WHO classes Ia, Ib and II are phased out almost immediately through national policies and enforcement.

This short-term measure would need to be supported by medium- and long-term objectives for substituting pesticides with less or non-hazardous and cost-effective alternatives (Konradsen et al 2003). The German Agency for Technical Cooperation states that the use of paraquat is not recommended because of the high toxicity for humans and animals, a recommendation further strengthened by the high persistence in soil (GTZ. no year). As a measure to assure worker safety, the least toxic pesticide possible has been recommended (based on the acute LD50 value) (Knapp 1982). Various non-chemical alternatives to paraquat exist.

5.4 National authorisation of paraquat and health and safety legislation

Several countries have established laws requiring registration and authorisation of new pesticides. In the US and the EU, older pesticides are subject to review. The aim is to ensure that they meet current scientific and regulatory standards.

In the US the EPA considers the human health and ecological effects of pesticides and takes actions to reduce risks of concern. Paraquat has been re-registered in the US and authorised in the EU under the condition that risk mitigation measures are applied (restriction of its availability, requirements for users, limitation of the type of application and the spray concentration, measures to reduce wildlife exposure). The decision in the EU has been challenged by the government of Sweden, unions and NGOs.

However, in the majority of countries where paraquat is used no such measures are provided. Certain countries have established regulatory measures to reduce risks posed by paraquat (table 2 - 4). The Pan American Health Organization's project group on pesticide-related, occupational and environmental health problems, toget-

Country (Effective date)	**Description of action taken. Grounds for decision** Reference (if not stated otherwise): UNEP/FAO 1999
Belgium	Class A product: Use by professionals only (Phytoweb (no year))
Belize	'No antidote available. Restricted to ground application for weed control; other uses must first be approved by the Pesticides Control Board' (PCB 2002/2003)
Caribbean	Local Restricted (PCC 1999)
Chile (2001)	Restricted use; not authorised for aerial application (SAG 2005)
European Union (2003)	Availability limited to professional users; maximum spray concentration of 0.2%; recommendation to limit knapsack application to trained/certified persons; no aerial application; risk assessment and mitigation of risks to wildlife (EC 2003)
Germany (11 Aug 1993)	Severely restricted for use as plant protection product. Use still allowed for treatment against: weeds and cover crops in maize before emergence and for treatment against weeds and cover cops in sugar beet before drilling, on the same area every fourth year; weeds in nursery seedbeds on the same area every fourth year at maximum; weeds in viticulture in the year of planting and up to the third year of stand. Extremely high persistence of paraquat in soil (estimated half life time approx. 17 years); limitation on areas of application - where alternative plant protection product are not available - was necessary to prevent accumulation of paraquat in soil; the action is based on a national review of scientific data. (p. 242)
Hungary (30 Sep 1991)	Severely restricted for use as a pesticide. The only registered use, as liquid formulation, was cancelled. Registrati on of other formulations is under evaluation. No remaining uses are currently allowed. Accidental poisoning. The mortality rate was unacceptably high. (p. 244)
Indonesia (1 Feb 1990)	Severely restricted use under professional supervision. Paraquat dichloride is the only form of paraquat registered to the Minister of Agriculture and permitted for use. So far, no other forms of paraquat have ever been registered yet. Registration for new products containing paraquat is no longer accepted. Paraquat dichloride can only be use for certain crops by professional users possessing special permit from the Minister of Agriculture through the Pesticides Committee. The issuance of special permit is based upon recommendations given by the Provincial Representative Office of Ministry of Man Power and the Provincial Representative Office of Health who have evaluated the users to be eligible for applying this chemical. May induce late symptoms to affected humans that is considered too late to cure. (p. 251)
Korea (9 Aug 1991)	Paraquat dichloride: Due to high acute mammalian toxicity, it is subject to special labelling requirement, and the for mulations are required to contain an emetic, stenching agent and a distinguishing colour. High acute mammalian toxicity. (p. 270) Paraquat: Banned for production, import, use and sale of both this substance and preparations containing it or its salt. Permitted in agricultural chemicals. Action taken due to its high toxicity. (p. 272)
New Zealand (1983)	'Under the Toxic Substances Act, liquid preparations and solid preparations containing 5% or more of this product are restricted to commercial users and are labelled "dangerous poison". Other solid preparations are labelled "poison". Under the provisons of the Pesticides Regulations (1983) a "suitable" emetic and stenching agent must be added to this product' (UN/DESA 2004).
Philippines	Restricted pesticide, class C: For Institutional Use Only. Strict compliance with the FPA guidelines on pesticides for institutional use (FPA 1989)
Slovakia	Intended only for professional users (MASR)
USA (1997)	Restricted Use Pesticide. Certified applicators only (purchase and use) (CFR 2003; US EPA 1997)

Table 2 Restriction of the distribution and use of paraquat (paraquat dichloride)
Not included in table 2: Ban of aerial application of paraquat in Colombia (MADR 1989); restriction of the aerial application in Costa Rica (DSV (no year)); direction for users in Canada not to apply paraquat by air (PMRA 2004); ban in the Dominican Republic (Federal Government, Decreto No. 217-91 of 4 June 1992 (not implemented))(31December 1983)

Country (Effective date)	Description of action taken. Grounds for decision Reference (if not stated otherwise): UNEP/FAO 1999
Austria (1 Jan 1993)	All uses banned. The control action applies to all forms of paraquat, i.e. parent cation and/or any possible formula tion. Paraquat is banned because of its high acute toxicity, irreversible toxic effects (paraquat injures the lungs more than other organs - e.g. epithelial proliferation) and numerous fatal accidents. (p. 180)
Cambodia (15 December 2003)	Banned for use (MAFF 2003)
Denmark (1 Jul 1995)	Authorizations for products containing atrazine [paraquat; corr. R.I.] as an active substance have been withdrawn from the market in 1995 and a further use has been prohibited from 01 July 1995. No uses are allowed. For other categories than agriculture a written authorization has to be obtained. No authorization are today given for other purposes. Paraquat is persistent in soil. In various studies, half-lives were assessed to be between 6 and 20 years. Paraquat is also very toxic to non-target organisms, and deaths have been documented among hare and rabbit which have eaten or walked on grass sprayed with paraquat. Calculations of risks demonstrate that even by normal use, paraquat is very dangerous for chaseable game. (p. 217)
Finland (30 Aug 1986)	The Pesticide Board decided 24.04.1985 that the import of pesticides containing paraquat was to be banned imme diately. The marketing of the pesticide already imported was allowed until 30.08.1986 but the labelling had to be changed within a month from the decision. Presently paraquat is totally banned for import, manufacture, and use as a pesticide. Any other products containing paraquat as an active ingredient were and are not registered in Fin-land and thus the use and import of other formulations are not allowed. Paraquat is very toxic also in small doses and can cause death, because there is no effective method of nursing treatment available for cases of poisoning. Some of the symptoms may occur only some weeks after the exposure. In the decision it was also stated that the pesticides already in stock in Finland, at the time the decision was made, could be used, because there had not been any cases of occupational poisoniong. (p. 234; FINPB 1986)
Kuwait (1 Jan 1985)	The substance is banned for use. No remaining uses allowed. Action was taken for health and environmental rea sons. (p. 283)
Slowenia (13 June 1997)	Banned for use in agriculture. This chemical was banned from the use in agriculture due to the effect of its toxic properties on human health and the environment according to the opinion given by the Commission on Poisons. The need for paraquat is small in Slovenia, as well as its benefits. Slovenia has unfortunately one of the highest per capita suicide rates in Europe. The Commission on Poisons is concerned over the possible misuse of paraquat for suicides. Considering this and due to the fact that paraquat is a deadly toxic in small amounts and that there is no antidote, the Commission on Poisons passed an opinion that this chemical should be banned in Slovenia. (p. 321)
Syria	Banned (MSEA 2005)
Sweden (31Dec. 1983)	Banned for use as a pesticide. No remaining uses allowed. The substance is suspended because of its high acute toxicity, irreversible toxic effects and imminent risk of accidents. (pp. 342-343; PKB 1983).

Table 3 Prohibition of the distribution and use of paraquat (paraquat dichloride)

Country (Effective date)	Description of action taken. Grounds for decision
Malaysia (27 August 2002)	Registration of all pesticide products containing paraquat and calcium cyanide was ended; re-registration for pesti cides containing paraquat will be stopped. The decision was made on the basis that there are other more cost-effec-tive and less harmful alternatives for users (PCD 2002).
Norway (1981)	'The product has been voluntarily withdrawn from the market' (UN/DESA 2004)
Switzerland	Not registered for use (due to acute toxicity and misuse) (SFC 2002)
USSR (GUS) (August 1988)	'Paraquat dichloride is not approved for use as a pesticide because it is persistent, causes fibrosis of the lungs and acute, lethal poisoning in humans' (UMH 1986).

Table 4 Withdrawal or non-authorisation of paraquat (paraquat dichloride)

her with the ministries of health, have proposed a harmonised list of banned or restricted pesticides in Central America. The list includes eight insecticides in WHO class Ia or Ib, one fumigant (not classified), two insecticides (chlorpyrifos, endosulfan) and one herbicide (paraquat) in WHO class II (OPS/OMS 2001a). The aim of the Central American health ministries is to prohibit products regionally where they have been banned in a single country, while the industry wants a lower safety standard by registering a pesticide in all countries of the region if it is registered in a single country (Murray & Taylor 2001).

In most countries the threshold limit value for paraquat in air is 0.1 mg/m³; this limit is under review in Germany and may be revised (DFG 2004). In the UK the occupational exposure limit is 0.08 mg/m³ (HSE 2003). In the US, the concentration «immediately dangerous to life or health» (IDLH value) is established at 1.0 mg/m³; it is recommended that workers exposed to concentrations above the IDLH wear the most protective respirators (NIOSH 1994). Up to 1.0 mg/m³ of paraquat it is recommended that a chemical cartridge respirator (in combination with a dust or mist filter) be worn (NIOSH 2004a). The recommendation is made in the US to prevent skin contact during handling of paraquat (NIOSH 2004b).

Appropriate personal protective equipment to be worn consists of clothing that is impervious to liquids, gloves, face shields and other appropriate clothing, and employees should be provided with safety goggles where paraquat solutions may contact the eyes; where exposure to solutions may occur facilities for drenching the body should be provided within the work area; it is recommended that non-impervious clothing that becomes contaminated should be removed immediately and not be worn again until paraquat has been removed (NIOSH 1978).

In the US paraquat is a restricted use pesticide (CFR 2003). It is listed in the Toxic Release Inventory of toxic chemicals as it causes respiratory effects (chronic pneumonitis) (US NTP 1995). In Germany during application of paraquat workers are required to wear a coverall, a respiratory mask with a filter, closely fitting goggles, gloves and solid shoes (BVL 2005).

Pesticides to be authorised within the European Union are evaluated on the basis of a uniform set of risk assessment principles and criteria provided by Council Directive 91/414/EEC. The procedure requires that substances are deemed acceptable for the environment, human and animal health (EC 2005). The European Commission position is that the Community has the right to establish the level of protection that it deems appropriate. Also that the precautionary principle may be invoked where scientific information is insufficient, inconclusive, or uncertain, and where there are indications that possible effects on the environment, human, animal, or plant health may be potentially dangerous and inconsistent with the chosen level of protection (EC 2000, p. 3 and pp. 8-9). The Commission has authorised paraquat in the EU. It has identified several issues as requiring attention from all Member States, «in the framework of any authorisations to be granted, varied, or withdrawn» (EC 2003b, p. 6).

EU Member States must pay particular attention to the protection of operators, in particular for knapsack and handheld applications. Use restrictions and risk mitigation measures should be used where appropriate. The following specific measures should be implemented:

◂ the availability of the product should be limited to bona fide agriculturalists, horticulturalists, and professional users;

◂ the maximum spray concentration must not exceed 2 g bipyridyl/litre for knapsack and handheld applications [i.e. a maximum concentration of 0.2%]. (.....)

In addition to the above issues, EU Member States also have to consider limiting knapsack and handheld use to trained/certified persons «where appropriate training and certification schemes are in operation at Member State levels» (EC 2003b, p. 6).

Within the EU review of paraquat, the Scientific Committee on Plants commented on several questions of the European Commission (EC 2002a). Measures identified to partially reduce risks to hares are - no aerial application, avoid spray patterns that would trap hares within spray area, avoid spraying of whole field on the same day if there is no alternative forage adjacent to the field (EC 2003b). In case of potential exposure to the eggs of ground nesting birds it is required that a risk assessment must demonstrate that there is no unacceptable impact, and that risk mitigation measures are a condition for approval of use. The protection of aquatic organisms must be given particular attention (EC 2003b).

EU Directive 76/769 provides a general framework for prohibiting or restricting the marketing and use of dangerous substances. Directive 91/414 includes criteria for human health impacts, as no pesticide is authorised if workers are exposed above the Acceptable Operator Exposure Level (EU 1999). The decision of the European Commission to authorise paraquat in Europe is being challenged in by the government of Sweden and an alliance of workers' unions and non-governmental organisations in two independent legal cases before the European Court of Justice.

Sweden claims that the inclusion of paraquat as an active substance in annex 1 to Council Directive 91/414/EEC should be annulled because the European Commission did not apply the precautionary principle in the risk assessment and management of paraquat, both regarding human and animal health (SMFA 2004). The unions and NGOs demand an annulment of the authorisation because the necessary research was not carried out properly to address the issues at stake, and as publicly available data on the environmental and health effects of the use of paraquat were either ignored or not studied in a satisfactory way (EEB et al 2004).

A proposed EU strategy for a sustainable use of pesticides provides that national plans be established to reduce hazards, risks and dependence on chemical control, improve knowledge of risks (by monitoring workers' health, collect data about health impacts and pesticide use), and improve control on use and distribution of pesticides (including mandatory training and certification of users). Also that harmful substances be reduced by the substitution of the most dangerous with safer, including non-chemical, alternatives, and encouragement of low-input or pesticide-free farming (EC 2002b).

In the EU, risk reduction is typically achieved by elimination, substitution, separation and protection. This means that only when all organisational and technical measures have been implemented should the issue of personal protective equipment (PPE) be considered. One report found that a higher than average proportion of workers in agriculture and construction reported that PPE was either missing or not used on a regular basis (EASHW 2000).

5.5 Label instructions and education in less hazardous practices

In the US the maximum application rate of paraquat has been limited to 1.12 kg cation per hectare; broadcast applications with backpack sprayers should not exceed the rate of 0.7 kg/ha. This is to be applied in a maximum concentration of 0.37% (cation weight per volume), while for spot treatments the maximum concentration is 0.23% (US EPA 1997a). «Spot treatment» refers to application to an area of less than 0.1 acre (IANR 2002). On labels the maximum recommended concentration for paraquat when applied with a backpack sprayer is 0.2% (CDMS 2001 & 2004). The manufacturer has stated that paraquat should not be used in mist-blowers or low-volume sprayers, and that for knapsack sprayers the concentration should not be higher than 0.50% (or 0.5 litres of the 20% concentrate in 20 litres of water) (Syngenta 2002). (Recommendation on product labels may differ.)

During application and handling of the product «Cyclone Max» (43.8% paraquat content wt/vol), US workers are required to wear a long-sleeved shirt, long pants, shoes plus socks, eye protection, chemical resistant gloves, plus a respirator with dust or mist filter. Mixers and loaders must also wear a face shield and chemical resistant apron (CDMS 2004). Workers using «Gramoxone» (ca. 20% paraquat cation content) in the US must wear «protective clothing as needed», impervious gloves, apron and arm covers (impermeable under normal use conditions) and an approved respirator (CDMS 2003).

In Malaysia the label of one paraquat product gave the following directions: «When using product, wear protective clothes including gloves, mask». The recommended spray concentration was 0.12%, while eye protection and a respirator (breathing mask with filter) were not prescribed (Crop Protection 2004). On the labels of paraquat products sold in Thailand it was prescribed to wear footwear, mask and gloves while spraying, to wear mask and gloves during mixing and to wear boots, eyeglasses and gloves when holding or transporting the product. Maximum recommended concentration was 0.17% and it was stated that mixing should be done with a stick (SCP 2005; ASU 2001; ACI (no year); CG (no year)).

The label of a paraquat product sold in Mexico requires use of industry glasses and a mask for dusts or mists, chemical-resistant gloves, an overall, hat and rubber boots. The recommended application is 25% paraquat dichloride wt/vol at a rate of 2.0 to 3.0 l/ha «in the sufficient quantity of water» (SA 2004). It would be inexcusable if no maximum concentration were recommended on the label of the product as farmers are not likely to know appropriate dilutions. Two other paraquat products sold in Mexico prescribe similar protective equipment but give no details regarding what type of mask or gloves are required. Directions of use include the maximum concentration (0.13%) and state that mixing should only be carried out with a stirrer (ANJ 2004; IdP 2004).

In Malaysia, Thailand and Mexico, maximum recommended concentrations were below or equal to the maximum recommended concentration in the US for backpack application. However, on all products the information was less comprehensive and the personal protective equipment required was generally less extensive than in either the US or Germany.

The agrochemical industry has made efforts to promote improved pesticide use practises in developing countries. However, it was concluded that ensuring greater responsibility in the use of pesticides was an immense task, and that significant progress could be made only if academia, aid donors, government, industry, international organisations and NGOs pooled their resources, and the process was institutionalised (Vlahodimos 1999).

In 1991 the pesticide industry carried out «Safe Use Pilot Projects» in Guatemala, Kenya and Thailand to educate and train farmers, retailers and doctors, protect people and the environment, prevent and treat contamination, and recycle or dispose of empty containers (Croplife International 1998). Objectives of the projects were to achieve a significant and measurable improvement in meeting the latest international safety standards. Also that other organisations should be stimulated to develop similar initiatives in other countries (Croplife International 1998).

The industry claims that 956,000 farmers, 3,875 retailers, 5,000 extension staff or trainers and 3,350 doctors or medical staff were reached. The task is too large to be met by industry alone; in countries where the need for improvement is greatest, the possibilities for providing modern technology are limited. Industry needs the full cooperation of governments (at the national and local level), international agencies, retailers, local communities, farm owners and workers (Vlahodimos 1999). Ultimately the success of this and similar programmes appears to depend largely on the ability of the industry to integrate workers and public health scientists into the design, implementation and evaluation stages of the project (Fenske & Simcox 2000).

Similar programmes were carried out in China, India, Mexico, Philippines and Malaysia (Syngenta 2003). But it appears that the proportion of farmers reached by this programme was very low.

A large-scale project in India, Mexico and Zimbabwe studied how less hazardous ways of using pesticides could be achieved in developing countries. Farmers' knowledge, attitudes, and practices regarding personal safety during spraying, storage of pesticides, disposal of empty containers, identification of pests and product selection were assessed and the impact of communication campaigns was evaluated. Some improvements were noted (Atkin & Leisinger 2000). However, a large number of farmers did not improve practices even though they were aware of the health risks. Reasons for this included the need for more time, aversion to taking financial risks from change in practices (due to poverty) and external factors (weather, climate and economic situation) (Atkin & Leisinger 2000).

It was found that communication campaigns needed to be carried out continually so that changes in practices persisted, and that the family of farmers and community needed to be included in programmes to have an impact. Many if not most farmers appeared to give low priority to safety and did not adopt the necessary precautions to reduce health risks, indicating that there were limits to the extent to which changes will be adopted within a generation (Atkin & Leisinger 2000).

Given the finding that not everyone can adopt relatively simple changes in behaviour - while recognising the need for educating farmers in practices that reduce the risks - it was concluded that besides subsidising suitable protective clothing, manufacturers who could not guarantee that pesticides in WHO class Ia and Ib can be used safely should withdraw these products from the market (Atkin & Leisinger 2000).

Training related to pesticides needs to be set in the broader context of sustainable agriculture and IPM, in a manner which does not engender a false sense of security that toxic chemicals are «safe». The message should remain focused on the hazards of pesticides - namely that pesticides are the problem, not the farmer (Dinham 1995). It has been argued that knowledge was inadequately linked with structural constraints on behaviour in the industry's «Safe Use» campaign. Industrial hygiene approaches could be applied to reducing pesticide hazards (Murray & Taylor 2000).

While educational programmes in some regions may have raised working standards, they must reach other major user groups with a high exposure and need to be evaluated by an independent agent if the outcome is to be sustained (Hurst 1999). In Indonesia a health module used in IPM farmer field schools aimed at the prevention of pesticide poisoning. This was defined as the exposure through low use (or none) of only the least hazardous pesticides (WHO class III or class U). It was based on the assessment that training farmers could not guarantee reduced exposure in the local setting (Murphy et al 1999). Clearly the best means of protection from hazardous pesticides is not to use pesticides or to use non-toxic pesticides (Watterson 1988).

Industry has repeatedly asserted that paraquat is safe to users under «normal conditions» (Syngenta 2005; Kurniawan 1996). But under the prevailing working conditions in developing countries, paraquat poisoning poses a severe health problem in many countries and there is a need for independent risk assessment (Wesseling et al 2001; Hurst 1999).

The availability of products responsible for poisonings needs to be restricted (IFCS 2003). A number of companies adhering to a responsible care programme for the chemical industry have pledged to limit the marketing of products or cease production, regardless of economic interests, if the results of a risk assessment call for such limitation or cessation as a precautionary measure to protect human health and the environment (CSC 2005). The global «Responsible Care» programme asserts that companies evaluate their products in a rigourous manner to protect public health and the environment (ACS 2005). This has obviously not been done for paraquat.

5.6 Summary

The FAO has made specific recommendations for the use and marketing of pesticides in the International Code of Conduct. The Code of Conduct has influenced most national regulations, however many developing countries do not have the resources to implement all its recommendations. ILO conventions ratified by the member states of the United Nations represent international agreements. ILO conventions have not been ratified and implemented in many countries.

Compliance with standards for spraying equipment should be compulsory. This may be difficult to implement, however, where a large proportion of sprayers are defective, and where spare parts are often missing. In view of the properties of paraquat - acutely toxic, harmful effects on skin and potential for skin absorption, delayed effects and absence of an antidote - the WHO hazard classification of paraquat should be reassessed by the WHO on the basis of current knowledge.

Education of farmers in less hazardous practices is an important factor for reducing risks of pesticide use, but does not offer a viable alternative to phasing out the most dangerous pesticides. Paraquat is clearly among the pesticides with the highest priority for prohibition of use and substitution by less hazardous alternatives.

6. General: other problems associated with the use of paraquat

6.1 Suicides by ingestion of paraquat and other pesticides

Suicidal ingestion of paraquat on the one hand and unintentional paraquat absorption on the other vary in different countries. The incidence and severity of cases is also difficult to compare as the methods of recording differ (Onyon & Volans 1987). Epidemics of paraquat poisoning have been very pronounced in certain countries, such as Japan, and the proportion of poisonings with fatal outcome is closely related to suicidal intent. For example in Fiji the mortality from paraquat poisoning during 1980 to 1984 was 58% (among all cases 66% had suicidal intent), while in the USA mortality was 0.6% (and 88% of cases were accidental) (Onyon & Volans 1987).

The ingestion of a lethal amount of paraquat leads to an extremely painful and prolonged death.

Asia

In *Papua New Guinea* the restriction of the availability of paraquat and other toxic pesticides has been demanded because of the relatively high proportion of suicides (Mowbray 1986). Restricting the availability of paraquat was effective in reducing suicidal deaths in Western Samoa (Bowles 1995; WHO 2002).

Out of 346 pesticide poisonings recorded during 1998 to 2002 in several hospitals in *Japan* (20% of them due to paraquat and diquat), 70% of cases were suicides, 65 (or 18.8%) were occupational and 8% were due to accidental ingestion. 25% of cases were fatal and paraquat was the main cause of deaths (Nagami et al 2005). A review of 97 reports on paraquat poisoning throughout the world rated 60 cases as accidental and 37 cases as intentional. Small farmers may be at a greater risk for accidental intake as a consequence of refilling paraquat concentrate into other containers than the original (Pasi 1978). Estimates of the magnitude of paraquat poisoning are unreliable as occupational poisonings are underreported in rural areas where medical services are lacking.

Paraquat has been used for 3 decades in *Korea*. It has caused an estimated 2,000 intoxications annually; the annual mortality among those intoxicated is 40-50%. One hundred seventy-five patients, poisoned by pesticides, were admitted to the Institute of Pesticide Poisoning (IPP) in Korea, from January through December 1999. Of those 175 patients, 154 (88.8%) were intoxicated by paraquat 73.4% of cases were intentional; these cases represented a significantly higher mortality (53.2%) than accidental poisoning (19.1%) (Hwang et al 2002).

When the amount ingested was included in statistical analysis the association between suicides and mortality rate was no longer significant, neither was the time from absorption until medical treatment significantly associated with death. The risk of a fatal outcome increased significantly with the amount of paraquat ingested and absorbed, presumably due to the potent lethality of paraquat (Hwang et al 2002).

A number of poisonings treated in 1999 at this Korean hospital occurred as a consequence of accidents or lack of safety measures. Among 54 farmers who were treated for paraquat poisoning, 32 of the cases were intentional, 17 accidental and 5 occupational (Hwang et al 2002). The number of intentional poisonings increased significantly in Korea between 1991 and 2001. Pesticides and herbicides accounted for the largest proportion of fatal cases (Shin et al 2004).

Pesticides provide a convenient means of attempting suicide in rural areas. In many countries, however, the major hazard is poisoning of workers through high acute or chronic exposure due to occasional misuse of pesticides (Ray 2000). Pesticide poisonings (non-fatal and fatal) were recorded in a selected number of hospitals during 1999-2000 in South-East Asia. In Indonesia 44.4% of the cases were suicidal; in Thailand 61.5%; and in India 85.2% (WHO 2001a). These estimates are based on records in a selected number of hospitals; the proportion of occupational cases is likely to be higher.

Suicides by ingestion of pesticides present a major public health problem also in *Sri Lanka* (Konradsen et al 2005). Self-harm was found to be high in Sri Lanka; around 2001 organophoshates in WHO class II and paraquat accounted for the majority of poisonings (Roberts et al 2003). Mortality was high with endosulfan and paraquat, while risk factors for intentional self-poisoning were unemployment, lower educational status, problems in the family and a history of pesticide poisoning (van der Hoek et al 2005).

Among 97 patients admitted to a hospital in the capital city Colombo in 1989 for self-poisoning only about 60% had stated that they actually wished to die and less than half (46%) knew that the agent was potentially lethal. In 59% of cases the agent was an agrochemical, in 29% of cases it was paraquat (Hettiarachchi & Kodithuwakku 1989). However, illness from occupational exposure to chemicals, in particular pesticide-related illness, is underreported in Sri Lanka (Kulendran 1997).

In Andhra Pradesh, *India*, suicide epidemics among farmers were strongly related to poverty or indebtedness connected to an increased reliance on cash crops where pesticide use is high (Chowdhury & Banerjee 2001).

A forensic institute in Turkey registered 843 deaths by pesticide poisoning (all types) between 1997 and 2001. Among the 205 cases where circumstances of death were established, suicide accounted for 75%. (Nesime et al 2004)

Central America

In *Costa Rica*, paraquat was the main cause of 283 deaths due to pesticide poisoning that the Forensic Medical Department (MFD) registered between 1980 and 1987. Out of the 198 deaths where the cause was defined, 62% were suicides, 26% were fatalities due to non-occupational accidents (confusion of paraquat with beverages or medicine, children handling the container/equipment or present in the field, consumption of recently sprayed food); 11% were fatalities during work (Wesseling et al 1993). However, it is difficult to distinguish between suicides and accidents (Brook 1974). In Costa Rica deaths were obviously misclassified in several cases (Wesseling et al 1993).

Between 1996 and 2001 in Costa Rica, 40% of 3,865 pesticide-related deaths were due to occupational exposure. In 33% of deaths the circumstances were not identified, 14% were suicides and 13% accidents; paraquat accounted for 68% of all deaths and 72% of suicides (OPS/OMS 2002b).

In *Brazil* it was estimated that pesticide poisonings were intentional in 31.3% of cases (1997-2001) or 37.3% of cases (1992-2002, Mato Grosso do Sul) (Recena et al 2005). The incidence of suicides by ingesting pesticides is relatively high in Trinidad and Tobago (Hutchinson et al 1999).

Europe

Between 1945 and 1989 in *England* and *Wales*, 570 out of 1,012 deaths from pesticide poisoning were due to paraquat and 73% or more of these deaths were suicides (Casey & Vale 1994). In 1990 and 1991 paraquat accounted for 33 out of 44 fatalities and more than 66% were suicides (Thompson et al 1995a). In the USA, poison centres recorded 18 deaths due to paraquat and 2 deaths due to diquat between 1983 and 1992; 15 of these 20 deaths were rated as intentional and 5 as accidental, while the majority of recorded exposures (non-fatal cases included) were accidental (Hall 1995b).

In *Germany*, between 1978 and 1983, 17 poison control centres (not all hospitals included) recorded 92 poisonings with paraquat (31 of these fatal): 44 suicide attempts (24 fatal), 21 accidents (4 fatal), 15 occupational cases (1 fatal), and 12 cases (2 fatal) where circumstances were not identified (Heyll 1988). Among 872 non-fatal pesticide poisonings referred to the main poison centre in Italy in 2000-2001, 86% were unintentional; paraquat accounted for 46 cases or 5% of the total (Davanzo et al 2004).

In *Poland* it was found that poisonings with organophosphates and dipyridylium herbicides (diquat and paraquat) were more often linked to suicide attempts than to accidents (e.g. due to storage in unlabelled containers) (Kotwica et al 1997). Another survey of 140 poisonings with pesticides (all types) in Poland in 1997 found that 36.4% of cases were accidental, 34.3% intentional and 28.6% resulting from occupational exposure. The pattern was similar for 107 cases in 2000: 43.0% of cases were accidental, 28% suicidal, 15.9% related to agricultural work, and intake with food occurred in 3.7% of cases (Przybylska 1999 & 2000).

In *Portugal*, from 2000-2002, paraquat was identified as the causal agent in 31 requests for pesticide analysis at a forensic institute (mainly cases from autopsies); in 528 of the 639 requested analyses no pesticide was detected (Texeira et al 2004).

Banning certain pesticides would be an effective measure to reduce suicides (Bowles 1995, WHO 2002). In the long run, however, further measures are necessary to avoid new poisons replacing the old. Measures are needed to reduce harmful behaviour through community-level mental health care, also improved medical management, improved storage of pesticides or medicines and the requirement of a prescription for the purchase, as well as overall reduced use of agrochemicals (Eddleston 2000). The reported figures indicate that severe and fatal poisonings are strongly related to suicides, and that the extent is more pronounced in certain countries. In some countries the proportion of fatal poisonings presumably due to pesticides where the causal agent is not identified is high.

The actual proportions of suicides and occupational deaths may differ from the recorded data. Misclassification of unintentional poisonings as intentional occurs.

Pathologists classify suicides by the main criterion of lesions being present in the stomach, based on the premise that unintentionally absorbed amounts are negligible in general (Wesseling et al 1997). Obstacles to identifying paraquat as the cause of occupational poisonings, and to taking into account the risks associated with its use, are the unawareness of the workers themselves, misdiagnosis by medical personnel in areas where facilities are lacking, and a reluctance of investigators to publish their findings in view of the small number of cases documented (Wesseling et al 1997).

It is difficult to say what significance reporting by media and public awareness of the hazard of paraquat has on the trend of using it for committing suicide (Onyon & Volans 1987). It is however essential to warn users of paraquat's high risk and to stress that a prerequisite for any pesticide use is to take appropriate safety measures.

6.2 Workers' compensation for occupational illness and injury

The use of paraquat under the normal prevailing conditions of work on plantations in South America causes skin or eye damage and may result in acute poisoning. Companies profiting from this situation should be liable for these consequences (Umaña 1998).

Large companies employ workers on a temporary basis and have more often relied on rotating their workers rather than improving the working conditions and reducing pesticide use (Chambron 1999). Campaigns for selling pesticides have also become more aggressive over the last two decades (Osorio & Travaglini 1999). Manufacturers who distribute pesticides in countries where usual working conditions preclude safe application among a large proportion of the users, share in the responsibility for health effects that result from the use of these products under the prevailing conditions. Numerous studies by independent researchers, national health authorities and international organisations have provided evidence of inadequate conditions at the workplace in many different countries, especially in the South.

The international classification of diseases does not classify paraquat poisoning separately. But it has established a class for «toxic effects of herbicides or fungicides» (and a class for illness or sequelae of toxic effects) (WHO 2003). Among the external causes of injuries there is a distinct class «weedkiller, herbicide» (WHO 2004b). Chronic obstructive pulmonary diseases, skin and other diseases caused by a chemical agent (where a direct link between exposure of a worker to the chemical and the disease is established) are listed as «occupational diseases» (ILO 2002b).

In most countries the recording of occupational diseases requires they are listed as prescribed diseases, while some countries also require that a wider range of diseases or incidents of ill health are recorded and notified. Responsibility for notification of occupational diseases can lie with the employer, a physician or both (ILO 2002c). Generally workers are asserted the right to receive compensation for occupational diseases. In countries where the loss of income is replaced only when it is related to work, the extent to which evidence has to be produced differs. It ranges from the necessity to prove a direct causal link (100% probability), e.g. in Germany, to a preponderance of evidence (greater than 50%), e.g. in the US (Boden 2000). In the latter case it is necessary that a worker claiming compensation for occupational disease can prove that it is more likely than not that the exposure to a certain substance caused a particular disease. As this is difficult, the proportion of workers who receive compensation is very low (Caldart 1985).

Alternatively, workers can claim that employers or manufacturers of toxic products are liable for negligence for intentionally exposing them to a toxic substance. But workers could lose wages in this process, and compensation may be inadequate. This underlines the need for preventive measures (Caldart 1985). A law was passed by the parliament of Nicaragua which stated that the chronic kidney insufficiency of 1,500 workers was a consequence of the use of pesticides including paraquat. But the president used his veto against it (Cabrera 2003). This exemplifies that workers may not be able to claim compensation for occupational illness.

The fourth Intergovernmental Forum on Chemical Safety recommended that the scope of insurance coverage and compensation systems for workers be expanded (IFCS 2003). The need for this in agriculture is clear. It has been suggested that a minimum standard of compensation insurance for all workers could be integrated within the framework of the World Trade Organization (LaDou 2005). Representatives of the private sector and of non-governmental organisations have pointed out that the accountability in the pesticide industry in particular needs to be improved.

Initiatives on the financial risks related to continued pesticide use can be developed for promoting sustainable agriculture. They demand more corporate responsibility and institutional reforms (Riggs & Waples 2003).

6.3 Residues of paraquat in food

Paraquat residues in soybeans were above the maximum recommended limit (MRL) of 0.1 mg/kg in several cases (FAO & WHO 1981). The MRL is lower for certain types of produce (e.g. 0.05 mg/kg for vegetables) and higher for others (10 mg/kg for rice) (FAO 2004b).

In potatoes treated with paraquat (as desiccant) small residues have been found (Desgupta

& Perue 2003). The acceptable daily intake (ADI) for paraquat dichloride is 0-0.006 mg per kg body weight and day (FAO 2004a). Regarding the long-term intake of paraquat from residues in food it was estimated that this ranged from 20% to 140% of the ADI, but available data did not allow any conclusion to be drawn whether dietary intake would be below the ADI or not (FAO 2004a, pp. 18 & 213).

In an agricultural area in South Africa the intake of paraquat in food was found to be three times above the acceptable daily intake (Rashke & Burger 1997). Of major concern are minor crops as for many of these no MRLs have been established (Racke 2004). Residues of paraquat found in marijuana were high but inactivated through smoking (Hall 1995a). A widespread practice that puts workers and the general public at a considerable health risk is the application of pesticides right up to the time of harvest, e.g. on cotton or vegetables (CEDAC 2004; Gill 2004).

6.4 Summary

Suicide with paraquat is widespread and leads to an extremely painful and prolonged death.Self-harm (suicides) by the misuse of pesticides present an entirely different problem from unintentional poisonings at the workplace and this issue requires various measures such as improvements in (mental) health services at the community level, besides restricting the availability or banning of acutely toxic pesticides. In epidemiological surveys suicides tend to be over-represented and poisonings from paraquat exposure at the workplace under-represented. This is due to the lack of facilities for treating and recording poisonings, as well as misdiagnosis of unintentional poisonings as intentional.

Workers rarely get compensation for occupational disease and where they have succeeded the sum paid out is usually disproportionately low.

The risk to consumers from the intake of paraquat residues in food needs to be evaluated further, and there is a need to monitor food residues, especially where it is used on established crops, as a desiccant on soy beans, for example.

7. Implications for wildlife and the environment

7.1 Degradation of paraquat in soil and water

In certain soils paraquat is biologically inactive and is not available to plants or micro-organisms. When strongly bound to soil it has no phytotoxic effects and may persist indefinitely (Mordaunt et al 2005; Hall 1995a). Paraquat is adsorbed (held) to a greater extent by soil with high cation exchange capacity (CEC); this increases with clay content. The strong adsorption capacity (SAC), or maximum amount of paraquat that could be inactivated by a soil, was estimated to be several hundred times higher than the amount of paraquat that is normally applied during one year (Smith & Oehme 1991).

The SAC or capacity of a soil for inactivating paraquat is lower than the CEC (Damanakis 1970). For several soils the SAC was only 10-30% of overall CEC (Summers 1980). The desorption of soil-bound paraquat depends on the soil's CEC and the desorbing cation. Paraquat is slightly mobile in sandy loam soil and potentially mobile in sandy soils with extremely low organic matter content (US EPA 1988).

In the presence of other cations the desorption may potentially increase, e.g. as a consequence of salinisation in irrigated soils or fertilisation. When the calcium or sodium concentration in soil pore water increased tenfold the SAC for paraquat decreased by 17% to 40% (Kookana & Aylmore 1993). Fine clay fractions and (solid) organic matter can contribute significantly to the SAC (Hseu et al 2003; Spark & Swift 2002).

Certain clay minerals adsorb paraquat less strongly than others. It was seen with kaolinite clay that paraquat slowly became available to plant roots and killed cucumber plants, while paraquat adsorbed on soil with 1% content of montmorillonite was not available to plants as long as the amount was below the SAC. Adsorption of paraquat on clay minerals affects their capacity for holding water or nutrient elements in a beneficial or deleterious manner (Weber & Scott 1966).

In laboratory trials, paraquat was mobile to a limited extent in a soil containing mainly kaolinite and vermiculite clay when the SAC was exceeded (at very high application rates) (Helling et al 1971). In a field trial where paraquat had been applied at very high rates over ten years, it was found that the residues of paraquat in soil reached a maximum level and declined after some time due to degradation in soil pore water. It was concluded that under normal use (good agricultural practice) no toxic effects on the crop plants or soil organisms occur (Roberts et al 2002). The FAO does not consider potential phytotoxicity from paraquat residues in soil to be a relevant problem (FAO 2000). For several crops in Germany, it is prohibited to apply paraquat in successive years (BLV 2005).

In one study, paraquat was applied to a sandy loam soil over six years at an annual rate of 4.48 kg/ha. Soil analysis after seven years revealed that essentially all of the applied paraquat was still present. A significant amount had penetrated to soil layers of 25-36 cm (probably due to a lower clay content), while most of the paraquat remained in the topmost 5 cm (Fryer et al 1975). No significant degradation occurred (neither through light nor micro-organisms).

Although paraquat residues caused no phytotoxic effects, calculations of the long-term ability of soils to inactivate paraquat should not make allowances for possible degradation unless specific information is available for the local site (Fryer et al 1975). It was deemed unlikely that accumulation of paraquat in medium and heavy soils with a relatively high clay content would damage the crop but in lighter sandy soils loosely bound (extractable) paraquat was available to plants (Riley et al 1976) and led to phytotoxic effects (Tucker et al 1967). For seven different soils the estimated SAC of the top 2.5 cm layer ranged from 63 to 3228 kg/ha with median and mean values of 280 kg/ha and 889 kg/ha, respectively (Knight & Tomlinson 1967).

Soils from 20 coffee plantations had an average inactivation capacity of 0.1-0.5 g paraquat per kg of soil. Where paraquat had been applied at a rate of 2.6 kg/ha per year over 20 years, the total residues present in the soil comprised up to 10% of the soil's inactivation capacity (Constenla et al 1990). The topmost 2.5 cm layer of these soils constitutes an inactivation capacity for paraquat of 25 to 125 kg/ha. With an annual input of paraquat as stated (2.6 kg/ha,) the inactivation capacity of the topmost 2.5 cm in the soils would be expected to be saturated after 9.6 to 48 years without degradation. Input of paraquat is very high on some sites, e.g. on banana plantations where it is sprayed monthly (OPS/OMS 2001b).

Paraquat was found to have accumulated in sediments of lakes with drainage ditches that had been treated with 1.6 kg/ha of paraquat (more on overgrown sites) each year. Suspended soil particles with adsorbed residues were transported into the lake and deposited on the ground of drainage ditches and in lake sediment. No significant degradation occurred (Betz 1975). Based on chemical extraction of bound residues, the SAC of the top 15 cm sediment layer (10% clay content) for paraquat was estimated at 182 kg/ha (or 1.07 g per kg of soil, dry weight) on average, comprising only 1.4-2.8% of the sediment's CEC (Wegmann 1977).

In biological assays the amount of paraquat in the sediment required to inhibit root growth of plants by 50% was determined as 0.73 g/kg, equivalent to 124 kg/ha (for top 15 cm layer). This was taken to be a more realistic estimate of inactivation capacity (with significant inhibition already occurring). The inactivation capacity would be saturated by the continued input of paraquat after over 100 years - at the given rate - but much earlier if the rates were increased. It was recommended to discontinue application to drainage ditches over a longer period to avoid putting the ecosystem at danger sooner or later (Wegmann 1977).

In water, paraquat is adsorbed on the sediment, plants or suspended particles (Summers 1980). But paraquat in surface waters could be transported if soil particles with adsorbed paraquat are carried off-site as a consequence of erosion (US EPA 1997a). It appears that the inactivation capacity of soils could be saturated within the foreseeable future where the annual application rate of paraquat is above usual rates, or on soils with a low clay content or again where cation concentrations are high.

Fertiliser may increase the mobility of paraquat (Smith & Mayfield 1978). In loam and kaolinite soils the amount of adsorbed paraquat decreased with increasing concentrations of ammonium (Wagenet et al 1985).

The half-life of paraquat in soil has been determined as 6.6 years (Hance et al 1980). Depending on site conditions, degradation may proceed more rapidly or more slowly. Half-life in fields ranged up to 13 years (USDA 1995). Provided that the net input rate exceeds the net degradation rate, which appears feasible due to the very high persistence of strongly adsorbed paraquat, the capacity of any soil to inactivate paraquat will be saturated sooner or later through continued input.

As paraquat is unlikely to be uniformly distributed in the soil, its concentrations can be high locally, e.g. on sites where sprayed plants have decomposed. Crops could be damaged by direct contact with the remains of sprayed vegetation and also paraquat remains in plants that were available to the crop, - for example in direct drilling (or no-tillage) and on sandy soils with a low SAC (Damanakis et al 1970).

In peat soils (with a high organic content) paraquat remained in a thin top layer at a high concentration and it was concluded that its application was only acceptable when it was mechanically incorporated into the soil to a depth of 6-10 cm (Damanakis et al 1970). The authors stated: «Rainfall seems unable to move paraquat into soil. After repeated applications of paraquat on an undisturbed soil, occurrence of a thin layer of high concentration of paraquat is to be expected» (Damanakis et al 1970). This means that the use of paraquat in no-tillage systems is likely to be associated with an increased risk of toxic effects on crop plants after a prolonged period of applications.

A review on the fate of paraquat in soil found that the addition of small amounts of organic matter, kaolinite, vermiculite and montmorrilonite to soil reduced the availability to plants at an increasing rate, The bio-availability of paraquat was increased by the addition of lime (Weber et al 1993). Tropical soils are more varied in the type of clay minerals. While microbial degradation of pesticides generally proceeds at higher rates - due to the higher temperature than in the temperate zone - degradation rates in both zones may be comparable in the dry season (Racke et al 1997).

Weathered kaolinite soils in the humid tropics had a decreased capacity to inactivate paraquat when compared to soils of high montmorillonit (clay) content (Wagenet et al 1985). In organic soils the primary inactivator for diquat and paraquat is organic matter (Weber et al 1993). Dissolved organic matter (humic acids) in soil interacts with adsorbed species including paraquat and may promote desorption following heavy rainfalls (Andersohn 2002).

In Spain surface water was analysed for bipyridylium herbicide. In a wetland, paraquat was detected in 2.4% of samples (2 out of 84), in the lagoon in 6.3% of samples (18 out of 288), while in marsh water paraquat was measured in 9.0% of samples (13 out of 144). Diquat was detected more frequently and maximum concentrations of paraquat were measured near rice fields (Fernandez et al 1998). The average concentration of samples where paraquat was detected in was 0.78 ug/l, which is 7.8 times above the drinking water limit in the EU (0.1 ug/l), while the highest concentration was 39.5 times above the limit.

It was concluded that diquat and paraquat are ubiquitous in the Mediterranean environment and that their use on rice and other crops should be controlled (Fernández et al 1998). Paraquat was also present in surface and groundwater in Andalusia, Spain (Vidal et al 2004).

In St. Lucia, in the Caribbean, residues of paraquat measured in drinking water were above 0.1 µg/l in several samples, ranging up to 5.3 µg/l - more than fifty times above the EU limit (Boodram 2002).

7.2 Risks to vegetation, wildlife and soil micro-organisms

The hazards of paraquat to the environment are rated in the EU as follows:

- dangerous for the environment;
- very toxic to aquatic organisms;
- may cause long-term adverse effects in the aquatic environment. (EC 2004).

Among 40 herbicides commonly used on field crops in Australia, paraquat has the highest acute toxicity (based on the acute oral LD50 in rats) (DPI 2004). Risk assessment of pesticides based on the «environmental impact quotient» (EIQ) ranked paraquat as the seventh most hazardous pesticide (besides six organophosphates) among 85 pesticides and as second most hazardous (out of 38) due to its ecological impacts and effects on farmworkers. More recently, paraquat was among the 15 most hazardous herbicides out of 129 (Kovach et al 1992 & 2004). Several of the more toxic herbicides have been banned in some countries or are not commonly used, (such as dinoseb and dalapon).

While paraquat is not volatile as a solid, the drift of spray solutions could potentially be a problem for animals due to its toxicity (US EPA 1997). In wildlife, the sub-lethal effects from exposure to lower doses of pesticides can be important, as altered behaviour as a consequence of low-level pesticide exposure may be almost as fatal in nature as an acute lethal dose (Kjolholt 1990).

Paraquat is moderately hazardous to bird species based on LD50 values (Tomlin 2003) and rated by the WHO Ranking of Acute Hazard (WHO 2005). An acute LD50 of 35 mg/kg b.w. for birds signifies that paraquat can be highly hazardous to some bird species (EC 2003).

On embryotoxicity to birds' eggs it was observed that the exposure of eggs from chicken and Japanese quail to a spray solution of 0.4% caused mortality and defects of the lung in young birds. Immersion in a 0.05% solution led to a decrease in hatching success. Paraquat appeared to be the most highly embryotoxic and teratogenic (causing malformations of an embryo or foetus) herbicide. The lethal concentration (LC50) for immersion of mallard eggs in a solution was 0.18% (Hoffman 1990).

The US EPA found that its level of concern is exceeded at recommended application rates of 1.12 kg paraquat per hectare. But it asserted that a risk to birds only exists shortly after application until spray solution has dried; it was concluded that the uses that are registered in the US are not expected to pose significant acute risk to bird species (US EPA 1997a). Regarding chronic risk to birds, the level of concern was exceeded at recommended rates. The EPA was concerned that direct use of paraquat may affect reproduction of birds but estimated that concentrations reaching eggs are not expected to be enough to cause significant mortality, or reductions in the proportion of eggs that hatched and again in the growth of birds (US EPA 1997a).

To mammals, paraquat is highly to moderately hazardous, based on WHO ranking and LD50 values ranging from 22 to 157 mg/kg b.w. (Smith & Oehme 1991). Some of the EPA's risk quotients for acute and chronic risks to mammals were exceeded but it was asserted that data on environmental fate indicate that paraquat is not available to mammals once it dries (US EPA 1997a).

In the EU review for authorising paraquat, it was found that hares died and small mammals were affected, but the extent could not be estimated (EC 2002a). Residues of paraquat on leaves are partially degraded by sunlight - over half of the applied paraquat could be recovered from plants that had been directly exposed to sunlight after spraying (Slade 1966). Ingestion of sprayed plants could present a serious risk to wildlife.

Paraquat is slightly toxic to fish species based on LC50 values (Tomlin 2003) and narrative rating according to Kamrin (1997). It was found to be moderately hazardous to some fish species in the juvenile stage (de Silva & Ranasinghe 1989). At recommended paraquat concentrations for control of aquatic weeds (0.1-2.0 mg/l), LC50 values were not exceeded but toxicity was increased by erratic swimming, arhythmic heart beat or nerve pulses, gill lesions and bleeding points in the fins and tail (Tortorelli et al 1990). In carp, paraquat accumulated in all organs studied and accumulation increased with the water temperature. Paraquat was seen to inhibit acetylcholinesterase (an enzyme that stops signalling in the nervous system). Susceptibility to infectious diseases increased with long-term exposure, indicating induced stress (Láng et al 1997; Nemcsok et al 1987).

At water concentrations above 0.2 mg/l, paraquat caused malformations in all frog tadpoles of a batch, whereas growth was reduced at concentrations of 0.1 mg/l and above. It was concluded that paraquat should be classified as a teratogen (Osano et al 2002). The LC50 (96 hours) for frog tadpoles was 22 mg/l and changes in gill tissue were noted. Results indicated that populations of frog species could be affected by paraquat at concentrations below the LC50 value and pesticide use near surface waters caused concern (Lajmanovich et al 1998).

For two species of daphnia, paraquat was moderately toxic based on median effective concentrations (EC50) of 2.57 and 4.55 mg/l, respectively; chronic exposure may be dangerous for natural populations (Alberdi et al 1996). Application of paraquat to water (at 1 mg/l) led to uptake by water snails, which contained 0.43 mg/kg (NLM 1994). It was found that rates recommended for paraquat application against aquatic weeds would affect the population growth of phytoplankton species in rivers, which would affect other species (Sáenz et al 2001). A recommendation was made to limit the use of paraquat to water courses where it could pass easily into natural waters (Láng et al 1997).

It has been asserted that paraquat does not bioaccumulate (Tomlin 2003). A bioconcentration factor (BCF) of 0.3 was calculated for paraquat based on its water solubility, and a BCF of 1600 was predicted from its soil adsorption coefficient (NLM 1994). The octanol-water partition coefficient (logKOW) has been calculated for paraquat as 2.2 (Verschueren 2001). In the EU the trigger value for bioaccumulation is a logKOW value above 3 or a BCF above 1000; trigger values for classifying a substance as persistent or as bioaccumulative can vary between different countries (OECD 2005). It has been reported that paraquat accumulated in aquatic plants, phytoplankton and fish (PANNA 2002, and references therein).

The data is not conclusive. There is evidence that paraquat has a potential for bioaccumulation in aquatic plants and fish. The flow of carbon from plant roots to the surrounding soil was increased by paraquat, indicating that metabolic stress was induced in the plant (Porteous et al 2000). Paraquat led to the build-up of fungi and bacteria in soil, but cellulose degradation and nitrogenase activity were reduced. Treatment with diquat and paraquat altered the species composition of micro-organisms in soil, which can damage crop health (Sims 1990).

7.3 Summary

When strongly adsorbed to clay minerals in soil, paraquat has no biological activity. The inactivation capacity is lower in soils with a lower content of clay minerals or with certain types of clay. Desorption of soil-bound paraquat may increase in soils with kaolinite clay, a low clay content, or in the presence of other cations such as ammonium (from fertilisers) or calcium ions.

Once paraquat has come in contact with soil, the major route of environmental transport is through erosion and movement of paraquat adsorbed to soil particles. Adsorbed paraquat has a very high persistence in soil. Degradation proceeds very slowly and requires several years (up to 13 years or more) for 50% reduction depending on site conditions. Continued application of paraquat at relatively high rates on certain types of soil, especially when large amounts of fertiliser are used or salinity is increased, may lead to the saturation of the soils' inactivation capacity in the long run.

Where the topmost soil is not incorporated into deeper soil layers (e.g. with minimum tillage), further application of paraquat may lead to toxic effects in crop plants within a shorter time.

Significant levels of paraquat have been measured in rivers and coastal waters. Because of its acute toxicity to mammals, birds, fish, aquatic invertebrates and plants (e.g. plankton) the use of paraquat in the field may have negative impacts on the exposed individuals of different species.

Paraquat was seen to accumulate in aquatic plants and fish, but the data is not conclusive. Vegetation sprayed with paraquat presents a significant risk of fatal poisoning to small mammals and hares; several deaths of hares have been documented. Exposure to the spray also presents a risk for ground-nesting birds.

8. Alternatives to paraquat and voluntary certification

8.1 Alternatives to the use of paraquat

The paper «Weed management for developing countries» (FAO 1994) and its addendum by Bàrberi (2003) give a very good overview of current practices for weed management and alternatives to the use of herbicides.

In his article on preventive and cultural methods for weed management, Paolo Bàrberi states that in many agricultural systems around the world, competition from weeds is still one of the major factors reducing crop yield and farmers' income. At worldwide level, the limited success in weed control is probably the result of an over-simplification in tackling the problem. Too much emphasis has been given to the development of weed control, especially synthetic herbicides, as the ultimate solution to all weed problems, while the importance of integrating different tactics (e.g. preventive, cultural, mechanical, and chemical methods) in a weed management strategy based on the crop system has long been neglected (Bàrberi 2003). Agricultural practice has demonstrated that the philosophy of integrated management used in insect control needs to be similarly adopted in weed control (Labrada 2003).

Integrated weed management is based on the knowledge of the biological and ecological characteristics of weeds. This knowledge can increase understanding of how weeds can be regulated by cultural practices. A long-term effective weed management strategy is based on the practical application of the concept in ecology of «maximum diversification of disturbance», which means diversifying crops and cultural practices in a given agro-ecosystem as far as possible (Bàrberi 2003).

The highest diversification of the cropping system (i.e. crop sequence and associated cultural practices) based on agro-ecological principles is the key to effective long-term weed management in any situation. In this respect, the syste-

Cultural practice	Category	Prevailing effect	Example
Crop rotation	Preventive method	Reduction of weed emergence	Alternation between winter and spring-summer crops
Cover crops (used as green manures or dead mulches)	Preventive method	Reduction of weed emergence	Cover crop grown in-between two cash crops
Primary tillage	Preventive method	Reduction of weed emergence	Deep ploughing, alternation between ploughing and reduced tillage
Seed bed preparation	Preventive method	Reduction of weed emergence	False (stale)-seed bed technique
Soil solarization	Preventive method	Reduction of weed emergence	Use of black or transparent films (in glasshouse or field)
Irrigation and drainage system	Preventive method	Reduction of weed emergence	Irrigation placement (micro/trickle-irrigation), clearance of vegetation growing along ditches
Crop residue management	Preventive method	Reduction of weed emergence	Stubble cultivation

Cultural practice	Category	Prevailing effect	Example
Sowing/planting time and crop spatial arrangement	Cultural method	Improvement of crop competitive ability	Use of transplants, higher seeding rate, lower inter-row distance, anticipation or delay of sowing/transplant date
Crop genotype choice	Cultural method	Improvement of crop competitive ability	Use of varieties characterised by quick emergence, high growth and soil cover rates in early stages
Cover crops (used as living mulches)	Cultural method	Improvement of crop (canopy) competitive ability	Legume cover crop sown in the inter-row of a row crop
Intercropping	Cultural method	Reduction of weed emergence, improvement of crop competitive ability	Intercropped cash crops
Fertilization	Cultural method	Reduction of weed emergence, improvement of crop competitive ability	Use of slow nutrient-releasing organic fertilizers and amendments, fertilizer placement, anticipation or delay of pre-sowing or top-dressing N fertilization
Cultivation	Curative method	Killing of existing vegetation, reduction of weed emergence	Post-emergence harrowing or hoeing, ridging
Herbicide application	Curative method	Killing of existing vegetation, reduction of weed emergence	Pre- or post-emergence spraying
Thermal weed control	Curative method	Killing of existing vegetation,reduction of weed emergence	Pre-emergence or localized post-emergence flame-weeding
Biological weed control	Curative method	Killing of existing vegetation	Use of (weed) species-specific pathogens reduction of weed emergence

Table 5 Classification of cultural practices potentially applicable in an integrated weed management system, based on their prevailing effect (Bàrberi 2003)

matic inclusion of preventive and cultural methods for weed management must always be pursued (Bàrberi 2003). An overview of cultural methods of weed control is presented in table 5.

In humid climates, weeds are more of a problem than in the temperate zones. Parasitic weeds (Striga, Orobranche or Cuscuta) in the tropics can damage the crop. Weeds can generally be controlled effectively through an appropriate crop rotation, trap crops and good soil management (Neubert & Knirsch 1996). Maize and other crops have been found to display tolerance (lower yield loss) and even resistance towards Striga species and cultivating tolerant and resistant crops is a viable pesticide-free option of controlling Striga (Pingali & Gerpacio 1998).

In minimum tillage systems, paraquat is used to kill vegetation before direct seeding of the crop (Bromilow 2003). But large areas are cultivated by minimum tillage without the use of paraquat (BLW 2001). Mechanical removal of cover crops was shown to be more economical than the use of paraquat in the US (Ashford & Reeves 2001). Furthermore at least 23 weeds are reported to be resistant to paraquat (WSC 2005).

Alternatives to herbicides are commonly used in organic farming. An area of over 8,000,000 ha worldwide is farmed organically, with no use of synthetic herbicides at all (Labrada 2003). Alternatives are also part of Integrated Pest Management (IPM), which reduces the use of pesticides as much as possible. The IPM Danida project in Thailand has a very clear standpoint regarding the use of paraquat in IPM: «The most dangerous chemicals, including all class Ia and Ib pesticides and paraquat should be banned immediately. They have no place in IPM because less risky alternatives are available» (IPM DANIDA 2004b).

In Indonesia, from 1993 to 1998, IPM lowered the health costs associated with pesticide poisoning by nearly 2%. For rice farming, total health costs related to pesticide poisoning dropped by about 5% - and the efficiency of rice production improved in the same period. (Resudarmo 2000).

More proof of viable alternatives to paraquat is provided by the timber from millions of hectares which is certified by the Forest Stewardship Council and from crops certified by the Rainforest Alliance (banana, coffee, citrus, cacao), and the Fairtrade Labelling Organizations (coffee, tea, cocoa, sugar, honey, banana, fruit, vegetables, rice, wine, nuts, oilseed, flowers and cotton).

Clashing with experts, it was argued in the business newsletter Crop Protection Monthly that «some 40 years after its launch, no super safe paraquat replacement is on the horizon, or indeed a new generation glyphosate» (CPM 2002). At least it was also seen that there is «a need for this or some radical new approaches to weed control and no doubt some glittering rewards for any company achieving it» (CPM 2002).

A closer look at alternatives to herbicides in general, and paraquat in particular, requires that the situation be analysed separately for each crop. A comprehensive overview is not possible within this report, but coffee and banana are presented below as examples for the discussion. Another crop with a large potential for reducing pesticide use by better management practice is cotton (UNEP 2004).

Coffee

A survey covering 34 farms and plantations in Latin America showed that 59% relied only on mechanical weeding (machete, hoe or motor scythe), 41% relied on mechanical weeding and herbicides, 12% were using paraquat. Another 12% of respondents said they used paraquat before but not anymore (Menet 2002).

The recommendations for agrochemicals of the Common Code of the Coffee Community (4C) state that in well-established plantations, when working with mulch as soil cover, there is normally no need for herbicides (Jansen 2005). The situation is different during establishment of plantations, especially for sun-grown coffee or while shade trees are not fully developed. At this stage the crop is more sensitive to competing weeds and cannot suppress them. The growth of weeds, says the Code, should normally be controlled with cover crops as far as possible. Hand weeding should be employed as far as labour is available and the costs are reasonable. This strategy may be complemented by a herbicide of relatively low acute toxicity (in WHO class III or U) and with a low potential of leaching to avoid groundwater contamination.

To reduce the use of pesticides, specific IPM recommendations were developed for farmers in Tanzania on how to manage their most important problems with coffee (Jansen 2005). They include shade management, intercropping with bananas, organic manure and mulching, irrigation techniques and weeding when ground cover is over 50%, i.e. about 4-5 times per year. Nishimoto (1994) has pointed out that the most promising practices for an appropriate low input or sustainable scheme of weed control in coffee plantations are the use of shade trees, leguminous cover crops and mulching. In South and Central America cover crops are often legumes, which have an additional bonus of nitrogen fixation from the air, besides being beneficial for the coffee crop (PAN UK 1998).

One of the biggest coffee traders worldwide, Volcafe, has stopped using a paraquat on its plantations. A company representative told the Berne Declaration: «We are of the opinion that paraquat is not a suitable product to control weeds. In particular its toxicity causing high risks for users, but also economical reasons speak against the product. There are alternatives today which are cheaper and more secure.» (Volcafe 2003)

Bananas

Weeds are a problem in bananas and plantains because they compete for water, nutrients and light. Practices commonly used for weed management are described by FAO as:

◄ Mechanical weed control: Slashing the weeds 3-4 times a year and leaving the weed mulch on the surface will help avoid soil erosion, delay fresh weed growth (but not eliminate weeds) and allow access. Slashing has to be done with care, or else banana stems and suckers will be damaged.

◄ Cultural weed control (healthy planting material and close spacing of the crop, cover plants and mulch). Cover plants can be used to suppress weed growth and have been widely recommended. Small farmers are likely to want cover plants that can be utilised. Good results have been achieved with watermelons in West Africa, cowpeas in India or with sweet potatoes. Kotoky and Bhattacharyya (quoted by Terry (1994) showed that the bunch weight and yield could be significantly increased when mulch was applied (36 tons of rice straw per hectare).

◄ Chemical weed control: Economics of herbicide use varies around the world. Herbicide use is often impractical or inappropriate, especially in poorer developing nations. Using glyphosate is an option but should not be perceived as a panacea for all weed problems in bananas. Herbicides have the capacity to solve problems as well as to create them. (Terry 1994)

Chiquita made some substantial achievements in reducing herbicide use during the last few years. Under the Better Banana Project of the Rainforest Alliance, the use of paraquat was phased out in all their plantations. Chiquita officials stated that production has not suffered and that the programme achieved cost savings by getting so many farms involved in common practices, including a reduction in herbicide use by as much as 80 percent (WSJ 2000). This reduction has been possible trough Integrated Crop Management practices such as shade growing, mulching and ground cover with cover crops such as Geophila repens. Chiquita found that manual weed control (by machete) is efficient, but linked with increased costs. Where difficulties occurred in establishing a ground cover, the weed species were either aggressive or high rainfall favoured the rapid growth of weeds. The herbicide used most often was glyphosate (Jaksch 2002). But this is not a harmless alternative to paraquat (PAN 2004). Chemical control should be reduced to the minimum, and preferably replaced entirely by cultural methods.

In banana plantations certified by Fairtrade Labelling Organizations International (FLO) the use of herbicides is banned. In one such plantation in Colombia, weed management is carried out with a machete about every 40 days (Mercado 2002). An organic banana producer in the Philippines controls weeds every 3-4 weeks, especially when plants are newly planted. Plant residues are left to decompose around the stem, without coming into contact with the body of the standing plant. Additionally weeds are suppressed by mulching with cut grass and leaves (Astorga 1998).

8.2 Voluntary standards prohibiting the use of paraquat

To support sustainable agriculture on an ecological and social basis, numerous organisations have initiated labels and certificates during the last 15 years. And many producers now fulfil the specified requirements for receiving these labels. All the main initiatives have integrated specific requirements for pesticides in their criteria, and all prohibit the use of paraquat.

Forest Stewardship Council

The Forest Stewardship Council (FSC) is an international network for promoting a more sustainable management of timber plantations and forests. Over the past ten years, 50 million hectares in more than 60 countries have been certified on the basis of FSC standards, while several thousand products made from FSC-certified wood carry the FSC label.

The FSC criteria Chemical Pesticides in Certified Forests prohibit pesticides for which any of the following applies:

◄ WHO class Ia and class Ib (e.g. aldicarb, parathion or warfarin)

◄ Chlorinated hydrocarbons (e.g. aldrin, DDT, dieldrin or lindane)

◄ Persistent, bioaccumulative, acutely/chronically toxic pesticides, identified by their characteristics and defined thresholds (including heavy metals),

Paraquat is listed in Annex 1 (Chemical pesticides prohibited under the FSC rules of voluntary forest certification) because the following criteria apply:

◄ Persistence: DT50 > 1000 days (FSC threshold is a half-life of 100 days)

◄ Toxicity: Reference dose (RfD) 0.0045 mg/kg/day (FSC threshold is 0.01 mg/kg/day)

◄ Biomagnification: Octanol-water partition coefficient (logKow) 4.47 (FSC threshold is a logKow value of 3)

The FSC criteria are available at:
http://www.fsc.org/keepout/en/content_areas/77/28/files/FSC_POL_30_601_FSC_Chemical_Pesticides_Policy_July_2002_07.pdf

Rainforest Alliance

In their self-description the Rainforest Alliance says that sustainable agriculture is at the centre of their objectives of conserving ecosystems by protecting agricultural soils, rivers and wildlife, and promoting dignified living conditions for farm workers and rural communities. Its sustainable agriculture programme aims to integrate productive agriculture, biodiversity conservation and human development. These Farmers, companies, cooperatives and landowners who participate in the programmes are required to meet rigourous social and environmental standards. (These achievements have been questioned by NGOs and the way the Rainforest Alliance is communicating their work to the public is being challenged by an NGO in Sweden.)

The area certified by the Rainforest Alliance in Latin America comprises 129.097 hectares. The majority are banana plantations - including all Chiquita plantations - with 46% of the total area, followed by coffee (42%), cacao (7%) and citrus (5%).

The Sustainable Agriculture Standard with Indicators of the Rainforest Alliance define criteria for prohibiting certain pesticides:

◄ chemical products listed by international agreements, including the «Dirty Dozen» listed by Pesticide Action Network (PANNA 1995);

◄ products banned by the US Environmental Protection Agency (US EPA) or the European Union, and any products whose license for the crop is no longer valid.

This standard is applied for coffee, banana, cacao, flowers and citrus. Paraquat is prohibited for use in all plantations and farms certified by Rainforest Alliance because it ranks among the «Dirty Dozen».

The Sustainable Agriculture Standard with Indicators of the Rainforest Alliance are available at:
http://www.rainforest-alliance.org/programs/agriculture/certified-crops/documents/standards_indicators_2005.pdf

Fairtrade Labelling Organizations (FLO)

FLO is the organisation that sets worldwide standards for fair trade products. It certifies qualifying products with the FAIRTRADE MARK. FLO fair trade standards exist for coffee, tea, cocoa, sugar, honey, banana, fresh fruit and vegetables, dried fruit, fruit juice, rice, wine, nuts and oilseed, cut flowers, ornamental plants, cotton and footballs. FLO is working with 389 certified producer organisations, representing almost 500 producer structures, and over 800,000 families of farmers and workers in over 48 countries in Africa, Asia and Latin America (status in May 2004).

The Fairtrade Labelling Organization's Generic Standards for small farmers prohibit the use of pesticides that are either in WHO class Ia and Ib, listed among the «Dirty Dozen», and pesticides under the Prior Informed Consent Procedure of the UN (taking notice of updates). Similar criteria apply within the Contract Production Standards. In the more specific fair trade standards for bananas, the use of herbicides is generally not allowed. Paraquat is prohibited in the production of all goods with a fair trade label. It is also rated as a

PAN «Bad Actor» (PANNA 2002). The fair trade standards for agriculture are available at:

http://www.fairtrade.net/sites/standards/sp.html

The Common Code for the Coffee Community (CCCC)

The Common Code for the Coffee Community is a joint initiative of coffee producers, trade and industry (including Nestlé, Kraft Foods, Sara Lee and others), trade unions and social or environmental NGOs. Its objective is to establish a global code of conduct aiming at social, environmental and economic sustainability in the production, post-harvest processing and trading of mainstream green coffee. The CCCC was launched in September 2004.

Based on the concept of continuous improvement, the code applies a rating within a «traffic-light system». Conditions and improvements in the coffee production system are rated either as unwanted practices (red criterion), intermediate status (yellow criterion) and desirable (green criterion). «Red» means that the practice in question needs to be discontinued within a period of 3 to 5 years, «yellow» that this practice needs to be improved within the next 10 years. The evaluation «Green» indicates a practice considered as adapted to sustainable production of mainstream coffee.

The agrochemicals used in different coffee producing countries are listed and classified into red, yellow or green according to their toxicological characteristics. The recommendations of the CCCC on agrochemicals point out that the majority of farmers are smallholders who are not familiar with the use of agrochemicals and often do not know how to use them correctly and protect themselves. For this reason the categorisation of different agrochemicals is mainly based on their acute toxicity. The herbicides paraquat, 2,4-D, acetochlor, alachlor and diuron are classified as red. These herbicides have to be substituted within a period of 3 to 5 years. The recommendations state explicitly that paraquat should be banned as soon as possible.

The CCCC Recommendations on plant protection in coffee are available at:

http://www.evb.ch/p25008925.html

8.3 Summary

Integrated management of weeds, based on diversified cultural practices and crops, presents a viable method of control. It includes cover crops, mulching, mechanical control, selection of resistant or tolerant crops and further cultural practices. The use of paraquat has been prohibited on a voluntary basis by major certification organizations (Fairtrade Labelling Organizations, Forest Stewardship Council, Rainforest Alliance), companies (Chiquita) and international initiatives (Common Code for the Coffee Community). A large number of producers certified by these initiatives for voluntary standards have demonstrated that effective and economic alternatives to paraquat exist.

9. Conclusions and recommendations

9.1 Conclusions

1. Paraquat is acutely toxic and may damage the lung several days after absorption. Workers who come into contact with paraquat solutions over a longer time frequently contract localised injuries to skin or dermatoses, which increase the risk of paraquat absorption through skin significantly. There is no antidote against paraquat poisoning.

Acute health effects that occur frequently among paraquat users include eye injury, nosebleed, irritation and burns of skin or other parts of the body. Chronic exposure to paraquat is likely to increase the risk of developing Parkinson's disease and may lead to small but significant alterations of gas exchange in the lung. There is evidence that reproductive health can be affected, and that paraquat is genotoxic and may cause lymphoma and precancerosis of the skin.

2. In developing countries, paraquat is used under high risk conditions. Personal protective equipment is not available to a large enough number of workers or is impossible to wear in warm and humid climates. Spraying equipment may lack maintenance and there may be insufficient facilities for hygiene. In these countries, inadequate safety measures and hazardous working conditions represent the norm rather than the exception. The recommended or required practice, and practice in the field are separate worlds - they too often do not correspond and may even be incompatible. Paraquat exposure of workers using backpack sprayers was studied in the US and it was found that margins of exposure were unacceptable and the practicality of additional protective clothing was questioned.

3. A large proportion of workers who use paraquat have insufficient knowledge about the health risks and the effects of chronic exposure to pesticides including paraquat. Among agricultural workers there is a high prevalence of skin disease that leads to an increased absorption of paraquat even where protective clothing is used. Often skin and clothing are contaminated with spray solution leaking from sprayers or from accidental spills, or the spray collects in the boots. Medical facilities in most rural areas are under-equipped or are totally unavailable with regard to the possible treatment of acute poisonings or injuries caused by pesticides. For paraquat poisoning there is no effective treatment.

4. As a consequence of the above three factors, localised skin damages and acute poisoning from occupational exposure to paraquat occur again and again. In several countries paraquat is the active ingredient, which leads to more reported poisoning cases, than any other pesticide. Non-fatal poisonings are numerous and fatalities are recurrent. In Central America it was estimated that 82.2-97.8% of non-fatal acute poisonings were not reported. This is a common and widely known problem in many developing countries.

In view of the hazardous, acutely toxic properties of paraquat - such as damage to skin with enhanced absorption, delayed effects and absence of an antidote - its use is not practicable without unacceptable health risks under the conditions that prevail in many countries.

5. Safety standards in the countries of North and South are divergent. But national health and safety legislation is often insufficient. Exposure to acutely toxic pesticides including paraquat poses a significant risk both to plantation workers and smallholders. Many countries have not ratified conventions of the International Labour Office in the area of occupational safety and health. Accepted standards have often not been implemented.

Suicide with paraquat is widespread and leads to an extremely painful and prolonged death. Self-harm (suicides) by the misuse of pesticides present an entirely different problem from unintentional poisonings at the workplace and this issue requires various measures such as improvements in (mental) health services at the community level, as well as restricting the availability or banning of acutely toxic pesticides commonly used to inflict self-harm.

Workers are often not compensated for wage losses or costs of illness caused by pesticides, especially hired labour and migrant workers. Workers who sue employers or manufacturers for occupational diseases rarely succeed in getting payment. When they do succeed, the money gained is generally disproportionate.

6. Educational programmes about less hazardous practices for workers who use pesticides are very important. A focus should be on IPM programmes reducing the use of pesticides. The projects carried out by the industry have not reached a significant proportion of farmers and agricultural workers. It appears unlikely that education alone can achieve a reduction of risk to acceptable levels, especially regarding the use of pesticides in WHO classes Ia, Ib and II in developing countries. Standards for spraying equipment, or changes in design aiming to reduce exposures, have limited scope and are difficult to implement on a large scale, especially in the South.

7. Paraquat is an acute hazard to small mammals, birds, beneficial insects and fish (when applied in or near surface waters). Hares have died after they ate or came into contact with plants that were sprayed with paraquat. Ground-nesting birds were affected in their reproduction. Residues of paraquat above the drinking-water limit have been measured in surface waters and in drinking water.

8. The very low degradation rate of paraquat in soil may lead to an accumulation in soil. The soil's capacity for strong adsorption and inactivation of paraquat is limited, especially in soil containing certain types of clay or soil with a low content of clay. The inactivation capacity may be further reduced if other cations are present, e.g. from a high input of fertiliser. No-till systems facilitate accumulation of paraquat in the topmost soil layer. In soils where paraquat degradation proceeds slowly, and the adsorption capacity is reduced, the latter can become saturated over time, rendering soil unable to inactivate further paraquat. This would then become available to crop plants and cause toxic effects.

9. In view of the numerous occupational poisonings with paraquat and recurrent deaths and in view of the environmental impact of paraquat, its continued use is not compatible with sustainable development. It has been demonstrated in practice that there are less hazardous but effective and economic alternatives to paraquat.

9.2 Recommendations

1. The Intergovernmental Forum on Chemical Safety recommended prohibition of (or restriction on the availability and use of) acutely toxic pesticides and/or those associated with frequent and severe poisoning incidents (IFCS 2003). Frequent poisonings and recurrent fatalities from occupational exposure to paraquat continue to occur, predominantly in developing countries. It is necessary to take action to prohibit the distribution and use of paraquat immediately in developing countries. In view of the ecological and health risks resulting from the long-term use and exposure to paraquat, and in view of the misuse, industrialised countries should also phase out paraquat to prevent unnecessary harm.

2. In view of the hazardous properties of paraquat - acutely toxic, potential for damaging skin and being absorbed through skin, delayed effects and absence of antidote - the (acute) hazard classification of paraquat should be reassessed by the World Health Organization on the basis of current knowledge.

3. Governments have the responsibility to assess the risk of pesticide use under the prevailing conditions, taking notice of the general condition of workers health and of the standards in occupational health, and to implement measures for reducing risk.

Highest priority needs to be given to the reduction of risks to agricultural workers resulting from exposure to pesticides and paraquat in particular, especially in developing countries. Residues in food, drinking water and the environment need to be monitored. Governments should withdraw the authorisation of a pesticide such as paraquat where the risk to workers or the general public is not acceptable. Decisions within risk management should be based both on available evidence (published by scientific experts, unions or NGOs, national and international authorities), and on a precautionary approach where there is only incomplete knowledge but a clear indication of potential hazards.

4. In accordance with the FAO Code of Conduct, manufacturers have the responsibility to periodically reassess the risks of their products, including paraquat, under actual conditions of use, not as stated on paper, and to base their policy on the conclusions in the assessment. In view of the facts presented in this report, such an assessment could only lead to the withdrawal of paraquat from the market on a worldwide scale.

5. Workers have the responsibility to strictly follow directions of the manufacturer and to use appropriate protective equipment, This may not however be feasible under the prevailing conditions. Workers need to rely therefore on additional protection by national legislation provided through the restriction of the availability of particularly hazardous pesticides such as paraquat.

6. International organisations take a leading role in providing guidance on the mitigation of risks related to the use of pesticides and in establishing standards for occupational safety and health. Programmes at the international level for the monitoring of public health and workers health and promotion of chemical safety, and in particular the International Code of Conduct on the Distribution and Use of Pesticides of the FAO, prove invaluable, especially to countries who do not have the facilities themselves for addressing these issues. The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade is one of the central instruments for regulating the global flux of chemicals that are dangerous to the environment and health. As long as it remains in use the distribution of paraquat needs to be regulated at the international and national level.

7. Pesticide Action Network International (PAN) and the Berne Declaration together with several other non-governmental organisations and unions including the International Union of Food, Agricultural, Hotel, Restaurant, Catering, Tobacco and Allied Workers Associations (IUF) demand a global ban of paraquat.

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