Roundtable for Sustainable Palm Oil (RSPO): Research project on Integrated Weed Management Strategies for Oil Palm

FINAL REPORT

Compiled by:

M. Rutherford, J. Flood & S. S. Sastroutomo
(CABI UK and Malaysia)

April 2011

www.cabi.org

Acknowledgements

The authors would like to thank the Roundtable for Sustainable Palm Oil (RSPO) for providing financial support to CAB International to enable preparation of this report. This report was produced as part of RSPO funded research project ‘Integrated Weed Management Strategies for Oil Palm’, initiated in January 2009.

This publication is an output of a research project on ‘Integrated Weed Management Strategies for Oil Palm’ funded by the Roundtable for Sustainable Palm Oil (RSPO). The views expressed are not necessarily those of CAB International or of RSPO.

Contents

Executive Summary

The research project ‘Integrated Weed Management Strategies for Oil Palm’ was initiated on 15 January 2009. The project was financed by the Roundtable on Sustainable Palm Oil (RSPO) and administered through the RSPO Secretariat in Kuala Lumpur, Malaysia (by Dr V. Rao, RSPO Secretary General). The research was led by CAB International (CABI Europe – UK Regional Centre, Egham, UK) with local support in Asia provided by CABI Southeast and East Asia Regional Centre (CABI SEARC, Selangor, Malaysia). The CABI scientific team, comprising Dr S. S. Sastroutomo, Dr J. Flood, Dr M. Seier, Mr J. Lamontagne-Godwin and Ms S. Varia, was led by Dr M. Rutherford. The project research was focused on four oil palm producing countries; Malaysia, Indonesia, Papua New Guinea and Colombia.

The overall objective of the project was to investigate and review current herbicide use for weed management in oil palm production. This is intended to support the identification of alternative, improved management approaches having potential for promotion to, and adoption by, RSPO members and the broader oil palm industry. In this context the principle role of CABI was to acquire and collate information on weed management practices in oil palm, the use of chemical herbicides by producers and the toxicological characteristics and fate of herbicides commonly used in oil palm production. This was largely achieved through a review of literature, surveys of producer herbicide practice and producer CASE studies.

A major component of the project was to undertake a review of available literature on the human and environmental toxicities and the environmental and ecological fate of herbicides commonly used in oil palm production. In preparing this review more than 200 literature sources – including peer reviewed scientific journals, review articles, electronic databases (including those collated by CABI), internet websites, pesticide material data sheets (MSDS) and product information – were examined. While many of these originated from European and USA sources, and were not specific to oil palm, the information was nevertheless of considerable value. The literature review provides, in a comparative manner where possible, extensive information on the physical and chemical properties of each herbicide, the mechanisms by which they exert their herbicidal effects as well as purposes for which they are deemed suitable and why. Toxicology, in relation humans, animals, plants and other terrestrial and aquatic organisms, is summarised while an insight is provided (including from an applied perspective) on the hazards and risks associated with each substance. This information is supported by recommended health and safety measures, including the use of protective equipment. The review highlights a diverse range of products known to contain each active ingredient and provides details of known manufacturers of each. The review is therefore an invaluable tool upon which decision-making on the selection and use of herbicidal substances - from a range of perspectives and by stakeholders with contrasting preferences and needs – may be based.

The literature review is available in Part 1 of this report.

Surveys of weed management practices employed by selected producers in Malaysia, Indonesia and Papua New Guinea provided important information on chemical and non-chemical methods used for ground cover management as well as their cost-effectiveness as perceived by the producers. Although the level of response to the survey was lower than anticipated it showed that all participating producers regularly monitored ground cover vegetation on their plantations and all managed growth by planting a cover crop(s) and through application of herbicide. Most producers applied organic mulch while many relied on manual weeding by hand, slashing or the use of a hoe. The use of herbicides, cover crops and mulch by producers was reflected by their perceived cost-effectiveness in comparison with other methods. In contrast, manual approaches to weeding were considered to be much less cost-effective. This may indicate a reliance of producers on approaches - which they acknowledge as less cost-effective - due to limited financial resources and/or preferred alternatives being unavailable, impractical to implement or unaffordable. Similarly a number of approaches, including mechanical weeding, increasing palm density, covering the ground with sheeting and grazing by livestock, were considered to be more cost-effective yet used by few producers. Such approaches may have potential for broader uptake by producers, especially if underlying reasons for the observed poor rate of adoption can be determined.

Fifteen chemical herbicides were confirmed as used by producers for ground cover management and other purposes, of which the systemic substances glyphosate and metsulfuron were used, respectively, by all or almost all. Glyphosate is non-selective while metsulfuron is selective, metsulfuron normally used to control particular species of annual and perennial broadleaf weeds and some annual grasses. Both herbicides, due to their specific mode of action in inhibiting amino acid synthesis, are also recognised internationally (e.g. by the World Health Organisation) as being of low toxicity to animals in comparison with many other herbicides. 2,4-D, triclopyr and paraquat were each used by about half the producers, while the other substances (ametryn, dicamba, diuron, fluazifop-butyl, imazethapyr, MSMA and sodium chlorate) were each used by only one or two respondents. These findings were supported by the extent to which products containing each active substance were chosen for use across the producers consulted, with glyphosate being the active ingredient in more than a quarter of all cases of product use. In total more than 100 different products were identified as used by producers on their plantations. In the time available it was not possible to ascertain specific purposes for which these herbicides are used or why some are used more widely than others.

All producers were using some form of personal protective equipment during herbicide handling and use, although specific measures varied between producers, and all kept chemicals in a secure area when not being used. Most had no need to dispose of prepared herbicide mixtures while most disposed of unwanted or spent herbicide containers by placing them in a registered hazardous waste pit or sending them to an authorised waste disposal company.

For full details of the survey and its findings see Part 2 of the report.

CASE studies undertaken with six producers in Indonesia, Malaysia and Papua New provided further information on individual weed management practices and, specifically, on approaches adopted or being considered as a means of reducing the use of chemical herbicides. Feedback for the CASE studies was also somewhat limited, with only four of six producers providing information. Nevertheless, it is clear that those that did respond had already and successfully introduced measures to reduce or eliminate the use of herbicides, including the relatively toxic substances 2,4-D and paraquat. This has been achieved in part by replacement of herbicides with less hazardous products and substance and/or adoption of non-chemical approaches – specifically, manual and mechanical weed management, application of various mulches and cultivation of cover crops. In many instances the new approaches were considered to not only be safer but also more efficient and (of significance) more cost-effective than the use of herbicides. As such, they may be of value to many other producers facing similar weed problems and weed management constraints. It was apparent that the producers had reviewed and adapted their practices in consideration of the RSPO Principles and Criteria relating to pest management and the use of chemicals, and were striving to identify and introduce other new measures in the future. A report of the findings of the CASE studies is provided in Part 3 of this report.

During the course of the project a meeting was held in Malaysia to provide an opportunity to present the project to oil palm stakeholders and to highlight and openly discuss needs, opportunities and concerns in relation to weed management and the use of chemical herbicides. Presentations were delivered by representatives of CABI, Malaysia Pesticides Board (as pesticide regulators), CropLife and Pesticide Action Network. The meeting enabled participants to learn of, and better understand, the views and requirements of other stakeholder groups in the context of weed management and to appreciate the need for a more integrated and less chemically orientated approach.

For further details of proceedings of the workshop and suggestions/recommendations for improvements in weed management see Part 4 of the report. This is followed, in Part 5, by a summary of other key opportunities for engagement with representatives of the oil palm industry, including the RT7 Annual Conference in Malaysia.

Part 6 provides a summary of the project along with a number of concluding points.

General Introduction

Oil palm (*Elaeis guinensis*) is one of the world's most important commodity crops. It is the highest yielding oil crop in terms of tonnes per hectare per year, providing palm oil and kernel oil for use predominantly in the food industry and, more recently, for production of biodiesel to satisfy a rapidly expanding global market for biofuels.

Countries in which oil palm may be cultivated, such as Malaysia and Indonesia, have benefited greatly from the higher demand. Increasing production, productivity and yields, however, places added pressure on producers to deal with a multitude of agronomic, economic and social challenges. These include the need to minimise the impact that unwanted vegetation (weed growth) may have on oil palm cultivation through competition for water, nutrients and sunlight in particular. Effective weed management can be achieved through a variety of cultural, mechanical and biological approaches, including hand weeding, application of mulch, cultivation of cover crops, the use of a mechanical rotavator and the release of insects, fungi and other organisms that cause damage to weed species. Furthermore, and with numerous highly effective products available on the market, the use of chemical herbicides is a further option on which many producers are already heavily reliant for effective weed control.

As demand for palm oil from the food, fuel and cosmetic markets has increased, so too has the need to manage weed growth more efficiently. This need has been exacerbated as land, labour, water and other resources vital to cultivation have become more limited. Greater use of herbicides is often seen and been adopted as an obvious and relatively straightforward means of ensuring more rapid and effective weed management. However, this has been tempered by increasing public and consumer awareness of the use of pesticides and of their potential health risks and damaging effects on the environment. In the case of oil palm there is also concern over expansion of cultivation and intensification of production in ecologically sensitive areas in Asia and other parts of the world. As a consequence, efforts are being made globally to reduce levels of pesticide use through more strategic product selection and application and by combining chemical use with non-chemical approaches as part of an integrated management approach.

In recognition of the problems associated with pesticides, and as herbicides constitute the major component of all pesticide use in oil palm production, the RSPO in 2006 published Principles and Criteria to guide and encourage the use of good agricultural practice (GAP) by producers. These make reference to good pesticide practice to help avoid the more toxic pesticides, reduce overall use of pesticides and use pesticides in a safe and environmentally more acceptable manner. Subsequently, the RSPO proposed that a study be undertaken to help identify safe and cost effective alternatives to replace herbicides of concern and as components of an integrated weed management (IWM) approach. This report documents the activities and findings of a research project initiated in 2009 to further these aims through an examination of the use and properties of herbicides considered to be commonly used in oil palm.

Objective

To investigate and review current herbicide use for weed management in oil palm production as a means of identifying alternative, improved approaches with potential for promotion to, and adoption by, members of the Roundtable for Sustainable Oil Palm.

Activities

1. To conduct a survey of current herbicide usage in oil palm plantations in Indonesia, Malaysia, Papua New Guinea and Colombia.

2. To conduct a literature review of:
(i) known information on human and environmental toxicities of herbicides commonly used in oil palm production
(ii) known information on environmental and ecological fate of herbicides commonly used in oil palm production.

3. To conduct CASE studies to compare alternative strategies for weed management selected from the four focus countries.

4. To conduct a workshop to discuss the alternatives for weed management and their possible adoption.

Part 1. Review of Literature on the Toxicity and Environmental and Ecological Fate of Herbicides Commonly Used in Oil Palm Cultivation

Roundtable for Sustainable Palm Oil (RSPO): Research project on Integrated Weed Management Strategies for Oil Palm

Review of literature on the toxicity and environmental and ecological fate of herbicides commonly used in oil palm cultivation

Compiled by:

M. Rutherford, J. Lamontagne-Godwin, S. Varia,
M. Seier, J. Flood & S. S. Sastroutomo
(UK and Malaysia)

December 2009

www.cabi.org

Acknowledgements
The authors would like to thank the Roundtable for Sustainable Palm Oil (RSPO) for providing financial support to CAB International to enable preparation of this report. This report was produced as part of RSPO funded research project ‘Integrated Weed Management Strategies for Oil Palm’, initiated in January 2009.

This publication is an output of a research project on ‘Integrated Weed Management Strategies for Oil Palm’ funded by the Roundtable for Sustainable Palm Oil (RSPO). The views expressed are not necessarily those of CAB International or of RSPO**.**

Contents

Introduction

Oil palm production

Oil palm (*Elaeis guinensis*) is one of the world's most important and widely traded commodities. It is a major source of palm oil and kernel oil, extracted from its fruit and seed and used for a variety of purposes including food manufacture and as a component in cosmetics, detergents (including soap) and toiletries. More recently, partly due to costs of petroleum and concerns for the environment, demand for palm oil has increased as a source for biodiesel, a renewable replacement for diesel. Data compiled by the Food and Agriculture Organization of the United Nations (FAO) indicates that, in 2007, total global oil palm fruit production was 192.6 million metric tonnes (MT), while the production of palm oil was 38.6 million MT. The world's largest producers, Indonesia and Malaysia, produced 16.9 and 15.8 million MT of palm oil, respectively. In the same year Colombia produced 0.78 and Papua New Guinea (PNG) 0.40 million MT, respectively (FAO Statistical Database (http://faostat.fao.org/).

Weed management and the nature and role of herbicides

In all areas of the world, oil palm producers are faced with a range of constraints - financial, physical, socioeconomic and biological - that must be managed effectively and in an appropriate manner if cultivation is to remain sustainable. Of the biological constraints pests, diseases and weeds are of major concern and can cause considerable damage, yield reduction and loss of income if not eradicated or at least maintained at an acceptable level.

A variety of approaches may be employed by growers to achieve a satisfactory level of weed control during the cultivation of crops. They include hand weeding, mechanical weeding, slashing, burning, flooding, covering with organic or inorganic materials (e.g. mulch or plastic sheeting) and treatment with chemical or biological substances (herbicides). The selection of approach(es) will depend on many factors including, broadly, perceived effectiveness, availability, costs and the risks associated with their use. Chemical herbicides can be very effective, fast acting, reliable and straightforward to use. As such, they constitute an important component of weed management for many growers, particularly where management by other means proves to be inadequate or where resources, such as labour and appropriate tools, are inadequate or not readily available. As with other weed management approaches the decision as to whether herbicides should be included in the overall management strategy, and precisely what measures should be used and how, will also depend on many factors and requires careful consideration. Key factors influencing decision-making in this regard include: extent and nature of the weed problem (e.g. weed types and accessibility for control); urgency for realising the required level of weed control; availability and cost of herbicide products, required labour and equipment (including recommended personal protective equipment); availability of water (for diluting products); risks involved and possible undesirable effects on the local environment; and perceived benefits, particularly in relation to costs.

Herbicides are widely used in industry and agriculture, to clear waste ground, paths and waterways, kill trees prior to felling and eradicating unwanted weed species in cultivated areas to maximise light, water and nutrients available for crop growth. They constitute a greater component of the global market, and many national markets, than other pesticide types including insecticides and fungicides. In 2004, for example, herbicides, insecticides and fungicides were considered to constitute (approximately) 45%, 27% and 22% of total pesticide sales respectively (4). Glyphosate is considered to be the predominant herbicide, accounting for approximately 67% of the global herbicide market, while paraquat and diquat account for 22% and glufosinate 11% (45, 195). The paraquat product Gramoxone has been reported to be registered and used in the production of 70 crops in more than 100 countries, with global sales estimated to be US$1000 million (6, 7, 20, 77). Annual global sales of paraquat in 2002 were estimated to be in excess of US$ 1000 million (77).

In Malaysia, one of the two largest producers of oil palm (54), herbicides accounted for 67% of total pesticide usage in 2004 while, in 2005, more than 15.6 million litres were applied for oil palm alone (13). Recent figures for a typical plantation company in Papua New Guinea, the world's eighth largest producer, indicate that volume of herbicide usage accounts for more than 90% of all chemicals used. Two herbicides, glyphosate and paraquat, account for 70% of all pesticide use (171).

Herbicides may be selective in that they only act upon, and destroy, certain plant species or groups. This may be by acting upon broadleaved plants while leaving grasses unharmed, or it may involve more refined selectivity in terms of acting on particular broadleaved species. Selective herbicides may also be used to kill unwanted weed species while leaving crop plants unharmed. Non-selective herbicides act upon all plants with which they make contact, and are very useful for general land clearance. Selectivity may, however, be achieved with non-selective herbicides through appropriate timing or placement of the herbicide – by spot treatment of certain weed types for example – or by inclusion of protectants or safeners[1] (herbicide antidotes) in the product formulation, to protect crops for example. It should be noted that all herbicides, including those classed as selective, may be damaging to non-target or tolerant plants if, for example, the dose applied is higher than that recommended.

Herbicides may also be classed as either contact or systemic. Contact herbicides only affect areas of plant tissue with which they come into contact but, as they tend to be fast acting, the beneficial effects of their use are rapidly seen by growers. Systemic herbicides, once in contact with the plant, move (i.e. are translocated) through the plant tissues in an upward and/or downward direction and are usually intended to kill the entire plant. A systemic herbicide applied to the leaves may therefore move down to the roots while herbicide applied to soil will be taken up via the roots and move to aerial parts. Systemic herbicides are more suitable than contact herbicides for treating perennial plants as they will move to, and act upon, roots, tubers and rhizomes located below ground level.

In agriculture, the manner in which herbicides may be applied and the equipment used for application can vary depending on the nature of the vegetation to be controlled, the timing of control and the surrounding environment. They may be applied directly to the foliage to destroy part or all of the plant depending on whether their activity is contact or systemic, either as a blanket application or applied specifically to selected species using appropriate equipment. Blanket application of a non-selective herbicide

---

[1] Chemicals that reduce the phytotoxicity of other chemicals.

can be effective against all species. However, where weed species are present within a crop or amongst other non-target plants, blanket spraying is only appropriate if the herbicide is selective for the weed species or if the crop has been developed to possess resistance or tolerance to the herbicide (e.g. as with glufosinate-ammonium and glyphosate for example, see Section 1). Herbicides may also be applied to, and in some cases incorporated into, soil to kill unwanted species either prior to planting of the crop (pre-plant herbicides), prior to crop emergence to prevent germination and early growth of weeds (pre-emergent herbicides) or after crop emergence (post-emergent herbicides).

Herbicides, as with other pesticides, vary markedly in their toxicity and therefore the level of hazard that they present to those handling and applying them. Depending on the toxicity and specificity of the active ingredient(s) and the level of exposure, they may also contaminate the surrounding air, soil, water and food crops. As a consequence they may have an adverse effect, of an acute or chronic nature[2], on other humans, animals, microorganisms and plants. In humans this may result in a range of health problems, from short-term rashes on the skin to chronic illnesses such as liver, lung or renal failure and cancerous growths. In extreme cases exposure to herbicide may result in death of the individual. The risks of exposure can be greatly reduced through appropriate and strictly enforced regulation regarding the supply, storage, application and disposal of herbicides, a subject that is covered in more detail later in this report.

The information in this report relates primarily to the active ingredients (a.i.) - also referred to as active substances - commonly used for weed management during cultivation of oil palm. In any pesticide product, including herbicides, the active ingredient is the chemical or biological component that, through its biological activity, is intended to kill, or otherwise control, the pest. In the case of a herbicide this is the weed or weeds that need to be controlled. Without the active ingredient a product would not produce the intended effect. Numerous active ingredients, manufactured by a range of companies, are found in a diverse range of herbicidal products marketed throughout the world. Many of these active ingredients and products are registered and authorised on a regional or national basis for use on specific crops, including oil palm, and in a manner intended to safeguard health and protect the environment (i.e. as part of good agricultural practice, or GAP[3]). These products may differ considerably not only in terms of the type of active ingredient(s) they contain, but also the concentration and quantity of each active ingredient, other constituents such as adjuvants[4] and surfactants[5] and also the formulation (the way in which the product is

---

[2] Although some variation exists in the manner by which acute and chronic toxicity is defined, the following reflect the meaning of the terms as used in this report:
Acute toxicity; Adverse effects occurring within a short time of administration of a single dose of an agent, or immediately following short or continuous exposure, or multiple doses over 24 hours or less.
Chronic toxicity; Adverse effects occurring as a result of repeated dosing of an agent on a daily basis, or exposure to that agent, for a large part of an organism's lifespan, usually more than 50%

[3] 'Practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products' (FAO [2003]. Paper COAG/2003/6. Development of a Framework for Good Agricultural Practices. Rome, Food and Agricultural Organization of the United Nations)

[4] An ingredient that improves the properties of a pesticide formulation. Adjuvants include wetting agents, spreaders, emulsifiers, dispersing agents, foam suppressants, penetrants and correctives.

prepared) of the product. As a consequence the purpose for which a product containing a particular active ingredient(s) is supplied, and the manner in which the product should be handled and applied, may vary markedly.

It should be noted that, while the hazard and risks (see definitions under Section 3) associated with a particular active ingredient are based on the properties of that ingredient alone, the hazard and risks associated with a herbicide product are based on the collective constituents in that product. As such, the two may be very different. As an example, the active ingredient glufosinate-ammonium is classed as being neither a skin nor an eye irritant in *The Pesticide Manual* (ref. 53, see below also). However, the Material Safety Data Sheet (MSDS) for the herbicide product Basta 15 SL (56), which includes glufosinate-ammonium but also other constituents, states that the product may cause irritation of the skin and eyes. Hazard and risks associated a product are usually provided on the product container or label and should be referred to when considering the use and selection of herbicides.

Furthermore, recommendations for use of personal protective equipment (PPE) in relation to active substances may differ markedly from those recommended for herbicide products. Where reference is made, either in this report or elsewhere, to PPE recommended for use when handling or applying herbicides, consideration should therefore again be given as to whether this information refers to the active substance or to a particular product. Information provided with a particular product will relate to that product alone.

For any one active ingredient there may be several hundred products containing that ingredient, available on the market and used during oil palm production. As provision of information on a product-to-product basis would therefore be impractical given the total number of products in circulation, for the most part the information provided in this report relates to active ingredients. The few exceptions relate to the provision of names of products containing specific active ingredients, provision of hazard classifications as determined by U.S. Environmental Protection Agency (EPA) – which are product based - and precautionary measures recommended for use of herbicide products.

Objectives of the report

The primary objective of this report is to collate and present information on the toxicology and fate of herbicide active ingredients considered to be most commonly used for oil palm production. It provides information available on the various substances, their properties and how they are intended to be used in a comparative manner, both in textual and tabular form. While this, depending on viewpoint, helps to highlight the benefits and drawbacks of the substances, it is not the authors’ intention to suggest whether any particular herbicide substance or product should be selected in preference to any other. The report is intended as a tool to assist the Roundtable for Sustainable Palm Oil (RSPO) and stakeholders involved in the oil palm industry to make more informed decisions with regard to weed management practice and the specific role, if any, of herbicides in weed management. It should, for example, assist

---

[5] An ingredient that aids or enhances the surface-modifying properties of a pesticide formulation (wetting agent, emulsifier, or spreader).

in determining which herbicides are more suitable for a particular purpose, how these should be handled and used in the correct manner and how they compare with respect to the risks they present to humans, other animals, non-target plants, micro-organisms and the environment.

This report focuses on the toxicology and fate of herbicides, as related to their chemical and physical properties among other variables. However, it also reviews the level of hazard of each substance as defined by internationally recognised regulatory organizations, and highlights procedures that should be followed to adhere to good agricultural practice (GAP), minimize the risks associated with herbicides and their use and thereby help to safeguard the wellbeing of those handling and using herbicides, others within their community and the local environment.

For many herbicides, a number of different chemical forms exist that may differ, albeit slightly, in their chemical and physical properties (including toxicity) and hence how they behave. Most herbicides also have a common name as agreed by the International Standards Organization (ISO, see http://www.iso.org/iso/home.htm). The majority of the herbicides are referred to in this report by their recognised common name, which is usually the name of the ‘parent’ form – for example, acids such as 2,4-D, fluroxypyr and glyphosate. However, several are referred to by name of the ester or salt form of the parent - examples being fluazifop-butyl and glufosinate-ammonium. Where a herbicide is commonly used in a form other than the parent form, these are identified under Section 1 ‘Chemical and physical properties and mode of action’.

In preparing this report, it was the intention of the authors to provide an independent and informative overview of the herbicides discussed, and to provide information in an accurate and unbiased manner. During preparation it became very clear that extensive information exists on the properties and use of herbicides in agriculture, including those employed for oil palm cultivation. As such, and while the report summarises the information acquired, it is accepted that it is by no means exhaustive and that other information both exists within and outside the public domain that may have a bearing on what is presented here. It should also be noted that much of the information accessed during literature searches was produced by, and relates to, active substances and their regulation and use in Europe and the USA. This, in part, reflects the extent of research undertaken in these regions and the availability of information in the public domain. Consideration must therefore be given as to the extent to which specific information relates to, and may have an impact on, oil palm production and the circumstances and environment in which it is being produced.

It became apparent that information available on a specific characteristic of a herbicide or its use may differ markedly (and perhaps appear contradictory) depending on the source from which the information was obtained. This may, from a scientific perspective, be due to the manner in which analyses and other assessments were undertaken and where they were undertaken. It may also be due to different perceptions among those supplying the information on the potential benefits and drawbacks of herbicide substances and how they should be used. It must be accepted that different perceptions and viewpoints are likely to influence the opinions of, and conclusions drawn by, different stakeholder groups – as producers, traders, consumers, environmental groups and regulatory bodies, for example - on the information presented here.

In order to present up to date information and help maintain consistency across active ingredients, a significant component of the technical data provided on the herbicides has been obtained from *The Pesticide Manual, 14th edition*[6] (version 4.2, 2008-9) (53).

Toxicity classifications are defined by pesticide regulatory bodies based on the findings of standard experimental analyses conducted under strict laboratory conditions. The level of risk associated with the herbicide is then defined on the basis of this data combined with data obtained on exposure to the herbicide during use. It is, however, important to consider that data on exposure is usually collected under conditions of good agricultural practice which may be very different to those prevailing, or achievable, in developing countries (7). It may, for example, be more much more difficult to obtain information, advice and training and to obtain suitable PPE. Furthermore, the use of PPE as recommended may be impractical and perhaps present a health risk in itself due to hot and humid conditions. It may also be much more difficult to adequately maintain herbicide application equipment (5, 129). As a consequence, and unless precautions recommended by regulatory authorities to safeguard health and the environment can be fully adhered to, the risks associated with using the herbicide under such conditions may be considerably higher. It has been suggested that regulatory agencies have not fully recognized the inherent toxicity of herbicides for human beings or the particular risks derived from exposures in developing countries, and that independent risk assessments in developing countries and application of precautionary principles may be necessary to prevent the occurrence of adverse effects of pesticides (7).

Herbicides reviewed in this report

In oil palm production herbicides often constitute an important component of weed management and may be used for a wide variety of purposes, including preparation of land for planting, clearing roads, paths and waterways, ground cover management, maintaining a weed free ‘circle’ around the palm base, treating volunteer oil palm (VOP), killing woody trees (by trunk injection for example) and treating epiphytes. As highlighted above, a range of herbicidal active ingredients may be found in the multitude of products available on the market. A number of these may be applied to meet the needs of oil palm production, albeit at different rates, by a variety of methods, at different stages of palm growth and for control of different weed types – which encompass grasses, sedges, ferns and broadleaf weeds (creepers, non-creepers and woody) (11). The selection of herbicides by palm producers will be based on a range of criteria, including dominant weed flora, cost effectiveness and ground cover policy (62). For example, if a leguminous cover crop is planted - to suppress weed growth, reduce erosion and evaporation and perhaps provide nutrients to the soil - broad-spectrum herbicides may be avoided or used less than other types to ensure that weed species are destroyed while the legume cover remains unharmed (121). A

---

[6] *The Pesticide Manual*, published by the British Crop Production Council (BCPC), is a reference book for those requiring authoritative, impartial and accurate information on crop protection active ingredients. Among other groups, BCPC Committee and Working Group members represent government, farmers’, agrochemical industry, advisory services, environment interests, distributors and research councils.

number of examples of specific uses of herbicides in oil palm are provided in Section 4.

This report is intended to provide information on those active ingredients considered to be most commonly used in oil palm production. While it was originally anticipated that information acquired through a survey of weed management practices in Malaysia, Indonesia, Papua New Guinea and Colombia would be available to inform selection of substances for inclusion in the report, at the time of preparation this information was unfortunately not available. As such, the nine active substances which form the focus of the report were chosen primarily on the extent to which they were referenced in the numerous literature sources consulted. The substances, alphabetically, are: 2,4-D, dicamba, diuron, fluazifop-butyl, fluroxypyr, glufosinate-ammonium, glyphosate, metsulfuron-methyl and paraquat. Of these, glyphosate, glufosinate-ammonium, metsulfuron-methyl and paraquat are considered to be used frequently, particularly in Malaysia (11). 2, 4-D, dicamba, diuron, fluazifop-butyl and fluroxypyr are known to be used alone but also in mixture with other substances.

The toxicity and environmental and ecological fate of a herbicide active ingredient is related to, and may be influenced by, the chemical and physical properties of the active ingredient, its mode of action, the formulation of the product containing it, how it is used and prevailing environmental conditions (this also applies to any additives, such as adjuvants and surfactants, included in a product formulation). Section 1 of this report provides an overview of the chemical and physical properties of each of the herbicides, details of their mode of action and herbicidal activity and the purpose for which they are normally used. Section 2 highlights, for each active ingredient, a range of products produced by different manufacturers, while Section 3 provides an overview of hazard classification systems and the hazard designations assigned to the substances by internationally recognised authorities (e.g. World Health Organization). Section 4 provides information on methods by which the various herbicides are applied in the field, associated hazards, risks and recommended precautionary measures, including PPE. A review of the human and environmental toxicity of each herbicide is provided in Section 5, while Section 6 provides an overview of their environmental and ecological fate.

1. Chemical and physical properties and mode of action

The chemical and physical properties of a herbicide are of major importance in relation to its effectiveness but also in terms of the hazard that it presents to humans (particularly those using the substance), other animals, plants, microorganisms and its potential for causing damaging and prolonged contamination of the environment. Chemical and physical characteristics can also have a significant effect on the movement of a herbicide to its target site, persistence of the substance in the field (including in soil, water and air) and in target and non-target organisms, volatility, mobility and photostability (and hence dispersal and degradation). Based on these characteristics, the potential effectiveness of an active ingredient and the likelihood of damage and undesirable effects on non-target organisms and the environment can be evaluated (174).

The solubility of a substance, for example, is a measure of its ability to dissolve in a liquid solvent, such as water, to form a homogeneous solution. Solubility of a herbicide in water is of particular relevance, as it will affect the transport and fate of the substance in the environment. Substances of high water solubility will tend to remain dissolved and not partition to soil or sediment or accumulate in aquatic organisms. They are therefore less likely to volatize from water but more likely to biodegrade and washout from the atmosphere in rain or fog. As solubility is dependent on the nature of the solvent, temperature, pH and pressure, it is important to consider stated measures of solubility in the context of these variables. Henry's Law Constant, which is related to vapour pressure and solubility, provides an indication of the tendency of a substance to volatilise from an aqueous solution to air (53, 177). For example, due to its low vapor pressure and low Henry's Law Constant, volatilization plays only a minor role in breakdown and dissipation of 2,4-D acid while there is little movement of the substance through the air/water barrier (i.e. between the atmosphere and surface water or soil moisture) into air (144). Volatility can be both a useful property (e.g. for rapid distribution of a herbicide within an environment) but also a drawback (e.g. by resulting in unwanted herbicide drift) (174). Further information on processes influencing the movement and fate of herbicides in the environment following release is provided in Section 6.

A number of metabolic processes occur in a plant that are essential for normal growth, development and functioning of the plant, including: photosynthesis, which uses the energy from light to synthesise carbohydrates; synthesis of amino acids, proteins, fats (lipids), nucleic acids and pigments; and respiration (breakdown of carbohydrates to provide energy for other functions). In order to kill a weed, a herbicide must disrupt one or more of these or the other vital processes. The manner in which a herbicide affects plants, at tissue or cellular level, constitutes the mode of action of that herbicide (189). Depending on the mode of action, herbicides will exert their effects on different target sites within the plant, of which it has been estimated that there are between 15 and 20 sites that have been exploited commercially. Utilization of target sites that are specific to plants and particular plant types can facilitate the development of selective herbicides that show little or no toxicity to non-target plants (e.g. crops) and organisms, including humans. However, in most cases it is considered to be differences in mechanisms of herbicide metabolism by the plant that result to crop plants remaining undamaged by herbicides while weeds are destroyed (174, 175).

Herbicides may be classified into a number of herbicide groups depending on a number of factors, including their mode of action. Designated mode of action groups to which the nine herbicides covered in this report belong are those that:

1. Inhibit amino acid biosynthesis (glufosinate-ammonium, glyphosate and metsulfuron-methyl)

2. Interact with photosynthesis (diuron and paraquat)

3. Inhibit lipid biosynthesis (fluazifop-butyl)

4. Act as auxin-type plant growth regulators (2,4-D, dicamba and fluroxypyr)

Other categories include herbicides that inhibit pigment (including chlorophyll) biosynthesis and those that inhibit cellulose biosynthesis (174). Herbicides with the same mode of action will exhibit the same pattern of movement within the plant (translocation) and will also cause similar symptoms. As mentioned, they will also tend to show similarities in selectivity with respect to weed types or groups that they affect, and will show similar behaviour in soil (189).

A summary of some of the important chemical and physical properties of each of the nine herbicides, along with a description of their mode of action, is provided below. The herbicides are grouped according to their mode of action and, within each group, are treated alphabetically. A summary of this and other information on each substance is also provided in Table 1 while a more comprehensive account of the properties of these and many other herbicides is available in *The Pesticide Manual*, published by the British Crop Production Council (53).

1. Inhibition of amino acid biosynthesis

The biosynthesis of amino acids, as the building blocks of proteins necessary for structural and enzymic functions, is an important process in plants. Unlike animals, plants can synthesise all of their required amino acids, and any chemical that can disrupt synthesis can therefore have an adverse effect on, and kill, plants. Of benefit, as they do not have the same metabolic pathways being inhibited, the same chemicals are unlikely to have an effect on animals. As described below, herbicides can have an adverse effect on amino acid synthesis in plants in several different ways: by inhibiting the enzyme glutamine synthetase; inhibiting the enzyme EPSP synthetase, and hence aromatic amino acid biosynthesis; or by inhibiting the enzyme acetolactate synthetase, and hence branched chain amino acid biosynthesis. Glufosinate-ammonium, glyphosate and metsulfuron-methyl affect amino acid synthesis, respectively, in these three ways (174, 175).

1.1 Amino acid inhibitors (interference with cell detoxification and, indirectly, photosynthesis)

Glufosinate-ammonium

IUPAC name: Ammonium (*S*)-2-amino-4-[hydroxy(methyl)phosphinoyl]butyrate or ammonium DL-homoalanin-4-yl(methyl)phosphinate
Chemical formula: $C_5H_{15}N_2O_4P$

Glufosinate-ammonium is an organophosphorous herbicide. It is also referred to as glufosinate, although this constitutes the acid form (IUPAC: 2-amino-4-[hydroxy(methyl)phosphinoyl]butyric acid or DL-homoalanin-4-yl(methyl)phosphinic acid, chemical formula $C_5H_{12}NO_4P$) (53) as opposed to the ammonium salt derivate. Glufosinate-ammonium is a natural compound isolated from two species of the *Streptomyces* bacterium that acts through inhibition of the enzyme glutamine synthetase, which is responsible for synthesis of the amino acid glutamine from glutamate (utilising ammonia and ATP). Inhibition leads to accumulation of toxic ammonia in the chloroplast, rapid inhibition of photosynthesis and ultimately plant death. As a structural analogue of glutamic acid, the herbicide acts by inhibiting the enzyme at its active site (51, 53, 174). Most organisms contain glutamine synthetase in their cells, with vertebrates using the enzyme in the regulation of glutamate in the brain (52). Glufosinate may also inhibit glutamine synthetase in animals (for further information see Section 5).

Glufosinate-ammonium is a post-emergence, non-selective contact herbicide with some systemic action (53, 101). However, translocation within the plant is limited and perhaps possible only within and between leaves and not throughout the entire plant. The herbicidal action is therefore considered to be primarily due to contact action on the foliage (61, 101). Typical symptoms of ammonia accumulation are leaf chlorosis, necrosis and wilting which become apparent 1-2 days after application. The rate of uptake of the herbicide by the plant and time taken for development of symptoms and death of the plant is temperature dependent, increasing with decreasing ambient temperature. Although plant death usually occurs within a few days, the time taken may vary from 1-3 weeks to 6 weeks in warm and cold conditions respectively (61, 101, 174). The efficacy of glufosinate-ammonium can be reduced by heavy rain during the first 6 hrs after application (101). A number of crop plants, including oil seed rape, soybean and maize, have been genetically modified (under the trade name 'LibertyLink') to contain an enzyme that detoxifies glufosinate and hence for tolerance to the herbicide (61).

In solid form glufosinate-ammonium is crystalline with a white to light brown colour and has a slightly pungent odour. It is highly soluble in water (1370g/l at 22°C), but has low solubility in organic solvents (i.e. acetone 0.16g/l at 22°C). The chemical is stable to light and hydrolysis at pH 5, 7 and 9 (53).

1.2 Amino acid inhibitors (aromatic)

Glyphosate

IUPAC name[7]: *N*-(phosphonomethyl)glycine
Chemical formula: $C_3H_8NO_5P$

Glyphosate, an organophosphorous herbicide, is a weak organic acid (phosphonic acid) and a glycine derivate (53). It exerts its herbicidal effect, mainly in the chloroplast, through inhibition of the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSP synthetase) in the ‘shikimic acid pathway’. This pathway is the route for biosynthesis of the aromatic amino acids phenylalanine, tyrosine and tryptophan, as well as subsequent synthesis of many plant secondary metabolites, including auxins, alkaloids, flavonoids and anthocyanins. The importance of the shikimic pathway is highlighted by the fact that 20% of fixed carbon in green plants is passed along it, with lignins, alkaloids, vitamins and phenolic compounds resulting from products of the pathway (174, 175). The mode of action of glyphosate is unique, in that it is the only herbicide that targets, and is highly effective in inhibiting, EPSP synthetase (103).

Glyphosate is most commonly used in salt form, mainly as isopropylammonium (IUPAC name: *N*-(phosphonomethyl)glycine - isopropylamine (1:1) or isopropylammonium *N*-(phosphonomethyl)glycinate, chemical formula $C_6H_{17}N_2O_5P$). It may also be available in acidic or trimethylsulfonium salt forms.

Glyphosate is a post emergent, non-selective (broad spectrum), systemic herbicide used for control of annual and perennial grasses and broad-leaved weeds. It is rapidly absorbed through the foliage and translocates rapidly through the plant (103), thereby enabling effective control of troublesome rhizomatous, perennial weeds. The herbicide has been described as the most successful agrochemical of all time (in terms of sales and market growth), largely due to it systemacity, low non-target toxicity and low soil residual activity (174). Symptoms can become visible 5-7 days after application as yellowing of green plant tissue followed, after 10-14 days, by necrosis and plant death (191), although some treated plants have taken up to three weeks to die (174). Although glyphosate is rapidly inactivated on contact with soil (53), heavy rainfall following application can reduce its efficacy by between 40-70 % (11).

Although a broad spectrum herbicide previously used solely for total weed control, the development of transgenic crops under the trade name ‘Roundup Ready’ have, as with glufosinate-ammonium and ‘LibertyLink’, enabled selective control of weeds in cropping situations (174).

Pure glyphosate is also a white crystal in solid form while glyphosate salts, such as glyphosate ammonium, are white powders. All substances are odourless, non-volatile and do not photochemically degrade. The salts are readily soluble in water, but not in organic solvents. Glyphosate reacts with bases to liberate heat and releases carbon monoxide, nitrogen oxides and phosphorous oxides upon decomposition (53).

1.3 Amino acid inhibitors (branched chain)

---

[7] The IUPAC name is the systematic chemical name assigned to a chemical according to the rules of the International Union of Pure and Applied Chemistry (http://www.chem.qmul.ac.uk/iupac/).

Metsulfuron-methyl

IUPAC name: Methyl 2-(4-methoxy-6-methyl-1,3,5-triazin-2-ylcarbamoylsulfamoyl) benzoate
Chemical formula: $C_{14}H_{15}N_5O_6S$

Metsulfuron-methyl, like diuron, belongs to the group of urea herbicides but specifically the sulfonylurea herbicides. The herbicide acts through inhibition of the enzyme acetolactate synthase (ALS), located in the chloroplast, which catalyses reactions that lead to synthesis of the branched chain amino acids leucine, isoleucine and valine. Disruption of synthesis results in cessation of cell division and subsequent inhibition of plant growth processes. Although ALS inhibitors, such as metsulfuron-methyl, rapidly inhibit cell division, it may be several days before physical symptoms become visible and plants die. This is possibly due to a pool of amino acids being present in the plant that must be reduced to a certain level before death occurs (174).

Metsulfuron-methyl is a selective systemic herbicide applied after weed emergence used for control of a wide range of sensitive grass and broad-leaved weeds. The herbicide is absorbed through the roots and foliage and translocated to the apex of the plant. Symptoms become visible within days of application notably as stunting, purple discoloration and a ‘bottlebrush’ appearance of the root system in grasses, and red or purple leaf veins and yellowing of new leaf tissue in broadleaf plants (191). Plant death occurs within two to four weeks after treatment. Selectivity shown by ALS inhibitors appears to be due to the ability of crops to rapidly metabolise the herbicides to non-toxic metabolites (174).

Metsulfuron-methyl is off-white crystalline in solid form with a faint ester-like odour. It is highly soluble in water at pH 9 (213g/l at 25° C, but has low solubility at pH 5 (0.548g/l at 25° C). It also has low solubility in organic solvents (i.e. acetone 37g/l at 25° C). The chemical is photolytically stable and stable to hydrolysis at pH 7 and 9 but not at pH5. Metsulfuron-methyl is non-volatile (53, 76, 79).

2. Interaction with photosynthesis

Photosynthesis is the process by which plants, through light absorbing pigments (chlorophyll and carotenoids), utilise sunlight to convert carbon dioxide to synthesise carbohydrates required for growth, reproduction and overall survival. Chemical substances, including herbicides that inhibit or interfere with the process of photosynthesis can therefore have a major effect on a plant and its survival.

Diuron

IUPAC name: 3-(3,4-dichlorophenyl)-1,1-dimethylurea
Chemical formula: $C_9H_{10}Cl_2N_2O$)

Diuron is a member of the urea group of herbicides, specifically the phenylurea herbicides. It is a systemic, selective herbicide which acts through inhibition of photosynthesis, specifically by blocking electron flow at the quinone acceptors of photosystem II (non-cyclic photphosphorylation) by competing for the binding site of plastoquinone normally occupied by Q_B (76, 176). The herbicide is absorbed via the roots and moves upwards with the transpiration stream (i.e. in the xylem).

Diuron is used pre-planting (incorporated), pre-emergence and, to a limited extent, early post-emergence, for selective control of weeds in annual and established perennial crops. Symptoms observed following application include yellowing in or between leaf veins, yellowing of leaf margins and subsequent leaf necrosis and death developing from the base of the plants to the shoots (189, 191).

Technical diuron consists of white odourless crystals when solid (98, 108). Solubility in water is relatively low (0.04 g/l at 25 °C) but higher in some organic solvents (i.e. acetone 53 g/l at 27 °C) (53). The substance is sparingly soluble in hydrocarbons. Diuron is not corrosive and stable in neutral media at normal temperatures (53, 98). It is hydrolysed in the presence of acids and alkalis and at higher temperatures, and decomposes at 180-190 °C (53). Diuron is non-volatile (108).

Paraquat (cell membrane destroyer)

IUPAC name: 1,1′-dimethyl-4,4′-bipyridinium
Chemical formula: $C_{12}H_{14}N_2$

Paraquat belongs to the bipyridylium or quarternary ammonium group of herbicides (1, 53). It is commonly used as the salt form paraquat dichloride, which has been assigned the IUPAC names: 1,1′-dimethyl-4,4′-bipyridinediium dichloride; 1,1′-dimethyl-4,4′-bipyridinium dichloride; or 1,1′-dimethyl-4,4′-bipyridylium dichloride - chemical formula $C_{12}H_{14}Cl_2N_2$). Paraquat interferes with photosynthesis by interrupting (diverting) electron flow in photosystem I (cyclic photphosphorylation), the herbicide being reduced and reacting with oxygen to form the free radical superoxide. This in turn produces hydrogen peroxide within the chloroplast with very damaging hydroxyl radicals being released. Resultant damage to cell membranes and the cytoplasm leads to rapid loss of chloroplast activity and rapid plant death (2, 175, 176).

Paraquat is a non-selective, contact herbicide used for broad-spectrum control of grasses and broad-leaved weeds in orchards, plantation crops including palms, forestry, ornamental crops and other production systems. Following absorption by foliage, it exhibits limited translocation in the xylem but is very fast acting, causing characteristic browning of leaves within hours of application. As the activity of herbicides that disrupt electron flow in photosystem I is greatly increased by light, weeds may desiccate within as little as 30 minutes after application under strong light conditions. Paraquat is also rain-fast within 15 minutes and, as such, is not normally affected by sudden outbreaks of heavy rainfall (6, 11, 53, 166, 174).

Pure paraquat salt (paraquat dichloride) is colourless and crystalline in solid form. The salt is highly water soluble (2) and paraquat formulations are based on water soluble granules or a soluble concentrate intended for dilution during preparation for application. Liquid concentrates of paraquat contain between 25% and 44% of the active ingredient, water and also wetting agents or adjuvants (4). Paraquat is non-volatile (35, 76). Paraquat salt is incompatible with alkylarylsulfonate surfactant (2).

Paraquat is hydrolytically stable at pH 5, 7 and 9 after 30 days at 25 and 40°C. Water based solutions of paraquat are also photolytically stable at pH 7, with no significant decrease in concentration having been recorded after the equivalent of 37 days of summer sunlight in Florida (3). Evaporation of the aqueous component of formulations can lead to combustion or thermal decomposition which will result in release of toxic and irritant vapours (19).

3. Inhibition of lipid biosynthesis

Lipids are essential to plants as they are components of cellular membranes and cuticular waxes. They are also major seed storage components and can regulate enzyme activity. Lipids are composed of fatty acids, which are synthesised from acetyl coenzyme A. The enzyme acetyl coenzyme A carboxylase (ACCase) is an important factor in this process. Two groups of herbicides can inhibit ACCase, one of which (the aryloxyphenoxypropionates) includes fluazifop-butyl.

Fluazifop-butyl (grass meristem destroyer)

IUPCA name: Butyl (RS)-2-{4-[5-(trifluoromethyl)-2-pyridyloxy]phenoxy}propionate
Chemical formula: $C_{19}H_{20}F_3NO_4$

Distinctions are made in the literature between a herbicide form with mixed isomeric (RS) content (fluazifop-butyl) and a form containing only the purified (R) isomer (fluazifop-p-butyl). As only the R isomer is herbicidally active, some formulations of fluazifop-butyl were previously changed to contain only this active form, fluazifop-p-butyl. It is, however, likely that in some literature the distinction between the mixed and pure isomer forms is not strictly applied. Fluazifop-butyl and fluazifop-p-butyl have been shown to have comparable toxicological properties), although it has been suggested that the two isomers may behave differently in the environment (92). In this report the herbicide will be referred to as fluazifop-butyl.

Fluazifop-butyl belongs to the phenoxy group of herbicides, and specifically to the aryloxyphenoxypropionate herbicides. It acts through inhibition of the enzyme CoA carboxylase (ACCase), thereby inhibiting fatty acid synthesis. Readily absorbed through leaf tissues, fluazifop-butyl is rapidly hydrolysed to the acid form fluazifop which is translocated via the xylem and phloem to accumulate, and disrupt lipid synthesis, in the meristems of grasses and the meristems, rhizomes and stolons of perennial grasses (53, 92).

ACCase inhibiting compounds are used extensively in post-emergence control of grasses, and their activity is greatly increased when the grasses are actively growing (174). Of importance, is it considered to be rendered ineffective under drought conditions, as no new plant growth occurs (92). Some herbicides remain in the plant until new growth resumes, but fluazifop-butyl is metabolized rapidly by the plant and, consequently, is no longer present when growth resumes weeks or months later. Fluazifop-butyl is a selective, systemic herbicide used for post-emergence control of annual and perennial grass weeds in broad leaved crops, to which it is non-phytotoxic (53). Selectivity appears to be due to insensitivity to ACCase and increased metabolism in tolerant plants (174). Symptoms following application generally develop slowly, becoming apparent on average 7-14 days after treatment. Tissues of the growing point(s) become pale, yellow and die. Bases of new leaves become macerated making leaves easy to pull away from the plant. Reddish-blue pigmentation of the stem sheath, leaf margins and/or blades is also frequently observed (191).

Fluazifop-butyl is a pale-straw coloured liquid with an aromatic odour. It has low solubility in water (1 mg/l at pH 6.5), but is miscible with organic solvents such as acetone, cyclohexanone and hexane. Solubility in propylene glycol for example is 24g/l at 20 °C. The active ingredient is reasonably stable in acid and neutral conditions but hydrolyses very rapidly in alkaline media. Stability is also temperature dependent i.e. at 25 °C stable for 3 years, at 37 °C stable for 6 months. (53).

4. Auxin-type plant growth regulators

Many chemicals, including auxins, are known control the growth and differentiation of plants. As such, any substances that are capable of disrupting, inhibiting or, in the case of 2,4-D and dicamba, mimicking their effects may be used very effectively as herbicides. Such substances have been used by farmers for weed control for several decades, 2,4-D being one of the first. Although the precise mode of action of these herbicides is not clear, they are analogues of natural auxins that act as auxins by binding to the auxin receptor site. They also exert a prolonged effect as the plant, unlike with natural auxins, is unable to reduce their concentration. The symptoms that develop in plants following treatment with these herbicides, also referred to as ‘synthetic auxins’ due to the symptoms they induce resembling an exaggerated auxin response, are very similar - namely leaf deformation and epinasty, stem enlargement, callus growth and formation of secondary roots (174, 175). As vapour from these substances tends to drift, they must be applied carefully to avoid damage to non-target plants including crops (191).

2,4-D

IUPAC name: (2,4-dichlorophenoxy) acetic acid
Chemical formula: $C_8H_6Cl_2O_3$

2,4-D belongs to the phenoxycarboxylic acid herbicide group, and is used in the form of either salt derivates or esters. The herbicide constitutes a synthetic auxin and acts as a growth inhibitor like indoleacetic acid. The salts are readily absorbed through the roots, while the esters are readily absorbed by the foliage. After uptake, the substance is translocated within the plant and accumulates principally in the meristimatic regions of shoots and roots (53). 2,4-D has been one component of Agent Orange.

2,4-D, being one of the first selective and reliable herbicides for control of broad-leaf weeds, is used mainly for post emergence control of annual and perennial weeds of this type in cereal crops, grassland and turf. It is also, however, phytotoxic to most broad leaved crops. The herbicide is also used to control broad-leaved aquatic weeds (53, 174).

In solid form 2,4-D is a colourless powder with a slightly phenolic odour. It dissolves increasingly well in water with increasing pH (i.e. 20 mg/l for pH 5, 34 g/l for pH 9 at 25 °C), and has high solubility in some organic solvents (i.e. ethanol 1250 g/l at 25°C). 2,4-D is insoluble in petroleum oils. 2,4-D is a strong acid that forms water soluble salts with alkali metals and amines. A sequestering agent is included in the herbicide formulation to prevent precipitation of calcium and magnesium salts in hard water. The photolytic DT_{50} (simulated sunlight) is 7.5 days. (53). Appearance of the ester and salt derivates of the acid form of 2,4-D varies from powder to liquid form and from white to amber in colour. The solubility of the derivates in water and organic solvents is variable depending on their chemical composition, the esters being insoluble in water. 2,4-D is incompatible with strong oxidizers such as chlorine, bromine and fluorine and toxic gases and vapours of chlorine or fumes of chlorides may be released upon combustion (157). 2,4-D is corrosive to metals (76).

Dicamba

IUPAC name: 3,6-dichloro-*o*-anisic acid or 3,6-dichloro-2-methoxybenzoic acid.
Chemical formula: $C_8H_6Cl_2O_3$

Dicamba belongs to the group of aromatic acid herbicides and here specifically to the benzoic acid herbicides. It acts as a plant growth regulator (134), mimicking auxin (indoleacetic acid) and again causing abnormal growth by affecting cell division and leading to plant death (53).

Dicamba is a systemic, selective herbicide used to control annual and perennial broadleaved plants. It is absorbed through leaves and roots and transported throughout the entire plant. At the recommended application rates most legumes are sensitive to dicamba but the herbicide does not affect grasses (53).

In solid form dicamba consists of colourless crystals. The substance is fairly soluble in water (> 250g/l at pH 4.1, 6.8, 8.2 at 25° C) but has higher solubility in some organic solvents i.e. ethanol 922 g/l, acetone, 810 g/l at 25° C. Dicamba is resistant to oxidation and hydrolysis under normal conditions and is also stable in acids and alkalis. It decomposes at around 200° C and DT_{50} for aqueous photolysis is 14050 days (53). Dicamba has been found to be relatively volatile, which may contribute significantly to dispersion of the substance in the environment (124).

Fluroxypyr

IUPAC name: 4-amino-3,5-dichloro-6-fluoro-2-pyridyloxyacetic acid
Chemical formula: $C_7H_5Cl_2FN_2O_3$

Fluroxypyr belongs to the pyridine herbicides and is a pyridine carboxylic acid. It is applied as an ester, commonly also referred to as fluroxypyr, such as fluroxypyr-meptyl (IUPAC name (*RS*)-1-methylheptyl 4-amino-3,5-dichloro-6-fluoro-2-pyridyloxyacetate (134), chemical formula $C_{15}H_{21}Cl_2FN_2O_3$) which is hydrolysed within the plant to the parent acid (fluroxypyr), the active form of the herbicide. Uptake of the ester is predominantly foliar, followed by rapid translocation to other parts of the plant (53, 75). The substance constitutes a synthetic auxin and acts by mimicking the effects of the plant hormone auxin (indoleacetic acid) by inducing typical auxin-type responses after application. These include leaf and stem curling, abnormal roots and root formation on dicot stems (53, 189).

Fluroxypyr is a systemic, selective herbicide used post-emergence for control of a range of economically important broad leaved weeds (53).

Fluroxypyr is a white crystalline solid which is soluble in water (57 g/l at pH 5.0 and 73 g/l at pH 9.2 at 20°C) as well as some organic solvents i.e. 51 g/ml in acetone. The substance is acidic and reacts with alkaline substances to form salts (53, 71). The commonly applied ester of fluroxypyr, fluroxypyr-meptyl, has an off-white colour. It has extremely low solubility in water (0.09 mg/l at 20°C) but high solubility in organic solvents i.e. 867 g/l in acetone. The ester is stable under normal storage conditions but decomposes above melting point. It is stable in visible light and to aquatic photolysis (53).

Table 1. Nomenclature and physical properties of herbicide active ingredients

Common Name[1]	IUPAC Name[2]	Physical form, appearance and odour	Melting point (°C)	Henry's Constant[3] (Pa m$^{3/}$mol)	Solubility in water (g/l)[4]	Stability
2,4-D	(2,4-dichlorophenoxy)acetic acid	Colourless powder. Slight phenolic odour.	140.5	1.32 × 10^{-5}	0.311 (pH 1) 20.03 (pH 5) 23.18 (pH 7) 34.2 (pH 9) (25 °C)	Forms water-soluble salts with alkali metals and amines
Dicamba	3,6-dichloro-*o*-anisic acid	Colourless crystals	114–116	6.1 × 10^{-5}	6.6 (pH 1.8) >250 (pH 4.1, 6.8, 8.2) (25 °C)	Resistant to oxidation and hydrolysis under normal conditions. Stable in acids and alkalis. Decomposes at c. 200 °C.
Diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea	Colourless crystals	158–159	-	0.04 (25 °C)	Stable in neutral media at normal temperatures, but hydrolysed at elevated temperatures. Hydrolysed by acids and alkalis. Decomposes at 180–190 °C
Fluazifop-butyl	butyl (RS)-2-[4-(5-(trifluoromethyl)-2-pyridyloxy)phenoxy]propionate	Pale straw coloured liquid	13	2.11 × 10^{-2}	0.001 (pH 6.5)	Stable for 3 years at 25 °C, and for 6 months at 37 °C. Reasonably stable in acidic and neutral conditions, but rapidly hydrolysed in alkaline media (pH 9).
Fluroxypyr	4-amino-3,5-dichloro-6-fluoro-2-pyridyloxyacetic acid	White, crystalline solid	232–233	-	5.7 (pH 5.0) 7.3 (pH 9.2) (20 °C)	Stable in acidic media. Being acidic, fluroxypyr reacts with alkalis to form salts. Stable at temperatures up to melting point. Stable in visible light

Glufosinate-ammonium	ammonium (S)-2-amino-4-[hydroxy(methyl)phosphinoyl]butyrate; ammonium DL-homoalanin-4-yl(methyl)phosphinate	Crystalline solid. Slightly pungent odour	215	-	1370 (22 °C)	Stable to light and to hydrolysis at pH 5, 7 and 9
Glyphosate	N-(phosphonomethyl)glycine	White crystals. Odourless	Decomposes at 200	$<2.1 \times 10^{-7}$	10.5 (pH 1.9) (20 °C).	Glyphosate and its salts are non-volatile, do not photochemically degrade in buffered water and are stable in air. Glyphosate is stable to hydrolysis at pH 3, 6 and 9 (5–35 °C).
Metsulfuron-methyl	methyl 2-(4-methoxy-6-methyl-1,3,5-triazin-2-ylcarbamoylsulfamoyl)benzoate	Colourless crystals (tech. grade off-white solid). Faint ester-like odour.	162	4.5×10^{-11} (at pH 7, 25 °C)	0.548 (pH 5) 2.79 (pH 7) 213 (pH 9) (25 °C)	Photolytically stable.
Paraquat dichloride	1,1′-dimethyl-4,4′-bipyridinediium dichloride	Colourless, hygroscopic crystals	Decomposes c. 340	$<4 \times 10^{-9}$	620 (20 °C)	Hydrolytically stable in alkaline, neutral and acidic media. Photochemically decomposed by UV irradiation in aqueous solution.

Source: *The Pesticide Manual*, 14th edition (Reference 53)
1 - According to standards organisations e.g. ISO
2 - The IUPAC name is the systematic chemical name assigned to a chemical according to the rules of the International Union of Pure and Applied Chemistry (http://www.chem.qmul.ac.uk/iupac/)
3 - Henry's Constant is a measure of the tendency of a substance to volatize from aqueous solution to air
4 - Solubility of a substance is the measure of the ability of the substance to dissolve in a liquid solvent, in this case water, to form a homogeneous solution. Solubility will depend on the nature of the solvent as well as variables such as temperature, pH and pressure, and is specified accordingly.
- = denotes data not available

2. Herbicide products

The nine active ingredients are marketed worldwide as a range of formulated products. Table 2 provides a comprehensive list, for each active ingredient, of products known to be available on the market. Although this information was compiled by a European (UK)-based organization, many of the products are marketed in other parts of the world and some will be used for oil palm production, including in Malaysia, Indonesia, Papua New Guinea and Colombia.

The information in Table 2 has been extracted from that compiled by the BCPC (53). For each active ingredient, the names of up to three product names are provided of the company (or its successor) that invented or introduced the product under ‘Selected products’. The company marketing the formulation is shown in parentheses (e.g. ‘Agriphar’). This is followed by the main formulation name of other companies known to market a product based on the ingredient. Listed under ‘mixtures’ are products that contain other active ingredients as a mixture, the other ingredient(s) denoted in parentheses after the product name (e.g. + butachlor). Further products, which may not be verified by the company, are listed under ‘Other products’. Products that are discontinued are listed separately under ‘Discontinued Products’ and are also denoted by an asterix. It is possible that, although discontinued, some of these products may still be available and used in some areas.

Table 2. Examples of herbicide products containing specific active ingredient(s) of herbicides used in oil palm production

Common Name[1]	Products	Discontinued Products
2,4-D	**Selected products:** 'Damine' (Agriphar); 'Deferon' (Milenia); 'Dikamin' (Agro-Chemie); 'Dymec' (PBI/Gordon); 'Herbextra' (amine salt) (Baocheng); 'Kay-D' (mixture of sodium and amine salts with ethyl ester) (Krishi Rasayan); 'Palormone' (Unicrop); 'SunGold' (Sundat); 'Yerbisol' (amine salt) (Ingeniería Industrial); **mixtures:** 'Rogue' (+ butachlor) (Monsanto). **Other products:** 'AG-24' (Zagro); 'Aminex' (Protex); 'Capri' (Makhteshim-Agan); 'Dicopur 500' (Nufarm GmbH); 'Dicotox' (Bayer CropScience); 'Dikocid' (amine salt) (Herbos); 'DMA-6' (Zagro); 'Dormone' (Bayer CropScience); 'Harapmine' (Zagro); 'Hardball' (Helena); 'Hedonal' (Bayer CropScience); 'Helena 2010' (Helena); 'Herbamine' (Agrochem); 'HM-2010' (Helena); 'Kay-m' (amine salt) (Krishi Rasayan); 'King' (ester) (Chemiplant); 'Malerbane Cereali' (Chimiberg); 'Maton' (Marks, Headland); 'Mortal' (CAS); 'Orchard Clean' (unspecified amine salt) (Nufarm Americas); 'Patonok' (Pato); 'Statesman' (Dow AgroSciences); 'Syford' (Vitax); 'Taniamine' (Zagro); 'U2-46' (Zagro); 'U 46 D' (Nufarm SAS); 'U 46 D' (acid) (Nufarm SAS); 'Unison' (Helena); 'Weedar' (Bayer CropScience, Nufarm SAS); 'Weedtox' (Aimco); 'Zura' (amine salt) (Atul)); **mixtures:** 'Aniten Duo' (+ cinidon-ethyl + mecoprop-P) (Nufarm GmbH); 'Brush-Rhap' (+ dicamba) (Helena); 'Camppex' (+ dichlorprop-P + MCPA + mecoprop-P) (United Phosphorus Ltd); 'D-638' (+ 2,4-D-butotyl) (Albaugh); 'Damex' (+ MCPA) (Protex); 'Débroussaillant 2D-P' (+ dichlorprop-P) (unspecified esters) (Nufarm SAS); 'Debroussaillant 3 Voies' (+ dichlorprop-P + triclopyr) (unspecified amine salts) (Nufarm SAS); 'Dicotex' (+ dicamba + MCPA + mecoprop-P) (Protex); 'Drago 3.4' (+ flufenacet) (Bayer CropScience); 'Dragopax' (+ ametryn) (Agricultura Nacional); 'Duplosan KV neu' (+ mecoprop-P) (Nufarm GmbH); 'Esteron 638' (+ 2,4-D-butotyl) (Dow AgroSciences); 'Granaplouse' (+ dicamba) (unspecified amine salts) (Nufarm SAS); 'HM-0335 A' (+	Chardol 40' * (ethanolamine salt) (Sedagri); 'Cloroxone' * (amine salt) (Sopra); 'Crisalamina' * (Crystal); 'Dacamine' * (GB Biosciences); 'Destox' * (MTM); 'Easel' * (2,4-D as an ester) (Nufarm UK); 'Fernimine' * (amine salt) (Solplant); 'For-ester' * (Vitax); 'Herbifen' * (Compañía Química); 'Justice' * (Dow AgroSciences); 'Pennamine D' * (octylammonium salt) (Cerexagri); 'Quinoxone Liquide' * (amine salt) (La Quinoléine); 'Ragox' * (ester) (Nufarm UK); **mixtures:** 'Aniten DS' * (+ flurenol-butyl) (Cyanamid, Pinus); 'Aniten MPD' * (+ flurenol-butyl + mecoprop) (Cyanamid, Pinus); 'Atladox HI' * (+ picloram) (Nomix-Chipman); 'Best One-Shot' * (+ dicamba + dithiopyr + mecoprop-P) (Simplot); 'Broadshot' * (+ dicamba + triclopyr) (Cyanamid); 'Broadstrike Post' * (+ clopyralid + flumetsulam) (Dow AgroSciences); 'Camppex' * (+ dichlorprop + MCPA + mecoprop) (United Phosphorus Ltd); 'Cleanrun' * (+ mecoprop) (Zeneca); 'Novermone' * (+ dichlorprop) (Nufarm SAS); 'Scorpion III' * (+ clopyralid +

	dicamba) (Helena); 'Laingorde' (+ 1-naphthylacetic acid) (Lainco); 'Laiteca' (+ 1-naphthylacetic acid + gibberellic acid) (Lainco); 'Latigo' (+ dicamba) (Helena); 'Mannejo' (+ picloram) (Dow AgroSciences); 'Nox-D' (+ propanil) (Crystal); 'Pasture MD' (+ dicamba + metsulfuron-methyl) (Nufarm Americas); 'Phenoxy 088' (+ 2,4-D-butotyl) (Agriliance); 'Recoil' (+ glyphosate-isopropylammonium) (Nufarm Americas); 'Restore' (+ aminopyralid) (Dow AgroSciences); 'Selectyl' (+ mecoprop-P) (Sintagro); 'Sitar' (+ MCPA) (Agrimport); 'Sound' (+ metosulam) (Bayer CropScience, Dow AgroSciences); 'Supertox' (+ mecoprop) (Bayer CropScience); 'Top Gun' (+ metribuzin) (Loveland, UAP); 'UPL Camppex' (+ dichlorprop-P-potassium + MCPA-sodium + mecoprop-P-potassium) (United Phosphorus); 'Weedone 638' (+ 2,4-D-butotyl) (Nufarm Americas).	flumetsulam) (Dow AgroSciences); 'SWK 333' * (+ dicamba) (Keychem); 'Sydex' * (+ mecoprop) (Vitax); 'Weed and Brushkiller' * (+ dicamba + mecoprop) (Vitax).
Dicamba	**Selected products:** 'Camba' (Agrimix); 'Diptyl' (Agriphar); 'Suncamba' (Sundat); **mixtures:** 'Hyprone-P' (+ MCPA + mecoprop-P) (as mixed sodium and potassium salts) (Agrichem Int.); 'Super Selective Plus' (+ MCPA + mecoprop-P) (Rigby Taylor). **Other products:** 'Tracker' (BASF); 'Camelot' (Sipcam S.p.A.); 'Dicamax' (ACA); 'Diedro' (Afrasa); 'Mondin' (Chemia); 'Reset' (Agrimport); 'Vision' (Albaugh, Helena); **mixtures:** 'OpTill' (+ dimethenamid) (BASF); 'Alltex' (+ amitrole + diuron + mecoprop-P) (Protex); 'Aminex D' (+ MCPA) (Istrochem); 'Aniten Combi' (+ flurenol + MCPA) (Stähler); 'Banlene Super' (+ MCPA + mecoprop-P) (as mixed sodium and potassium salts) (Bayer CropScience); 'Blespring Combi' (+ bromoxynil octanoate + MCPA + mecoprop) (Siapa); 'Broadside' (+ bromoxynil octanoate + MCPA-2-ethylhexyl) (Nufarm Ltd); 'Brush-Rhap' (+ 2,4-D) (Helena); 'Cool Power' (+ MCPA-2-ethylhexyl + triclopyr-butotyl) (Nufarm Americas); 'Dicotex' (+ 2,4-D + MCPA + mecoprop-P) (Protex); 'Escalade' (+ 2,4-D-dimethylammonium + fluroxypyr-meptyl) (dicamba as acid) (Nufarm Americas); 'Field Marshall' (+ MCPA + mecoprop-P) (United Phosphorus Ltd); 'Glykamba' (+ glyphosate-isopropylammonium) (Nufarm Americas); 'Granaplouse' (+ 2,4-D) (unspecified amine salts) (Nufarm SAS); 'Grassland Herbicide' (+ MCPA + mecoprop-P) (United Phosphorus Ltd); 'Greengard' (+ 2,4-D-2-ethylhexyl + triclopyr-butotyl) (Barclay); 'Green Up Weedfree' (+ 2,4-D-isoctyl) (Vitax); 'HM-0335 A' (+ 2,4-D) (Helena); 'Holster' (+ 2,4-D-2-ethylhexyl + fluroxypyr-meptyl) (Barclay); 'Koril' (+ bromoxynil octanoate + mecoprop) (Nufarm SAS); 'Latigo' (+ 2,4-D) (Helena); 'Mamba-Due' (+ MCPA) (Sintagro); 'New Estermone' (+ 2,4-D-isoctyl) (Vitax); 'Outlaw' (+ 2,4-D-2-ethylhexyl) (Albaugh, Helena); 'Pasture MD' (+ 2,4-D + metsulfuron-methyl) (Nufarm Americas); 'Pasturol Plus' (+ MCPA + mecoprop-P) (Nufarm UK); 'Quincept' (+ 2,4-D-dimethylammonium + quinclorac) (Nufarm Americas); 'Relay P' (+ MCPA + mecoprop-P) (Headland); 'Swift' (+ mecoprop-P) (Headland); 'Task' (+ rimsulfuron) (DuPont); 'Transfer' (+ MCPA + mecoprop-P) (Headland); 'Trinity' (+ MCPA + mecoprop-P) (Headland); 'Triton Duo' (+ MCPA-dimethylammonium) (Istrochem).	Mediben' * (Sandoz); 'Tracker' * (PBI); 'Trooper' * (Monsanto); **mixtures:** 'Condox' * (+ mecoprop) (Syngenta); 'Quickstep' * (+ bifenox) (Novartis); 'Aniten I' * (+ flurenol-butyl + MCPA) (Istrochem); 'Banlene Plus' * (+ MCPA + mecoprop) (AgrEvo, Schering, Stefes); 'Best One-Shot' * (+ 2,4-D + dithiopyr + mecoprop-P) (Simplot); 'Broadshot' * (+ 2,4-D + triclopyr) (Cyanamid); 'Camber' * (+ mecoprop-P) (Headland); 'Docklene' * (+ MCPA + mecoprop) (Stefes); 'Docklene Super' * (+ MCPA + mecoprop-P) (Stefes); 'Fettel' * (+ mecoprop + triclopyr) (Zeneca); 'Grassland Herbicide' * (+ MCPA + mecoprop) (United Phosphorus Ltd); 'Herrisol' * (+ MCPA + mecoprop) (Bayer); 'Holdfast D' * (+ paclobutrazol) (Zeneca); 'Korilene' * (+ bromoxynil + mecoprop) (Ciba); 'MSS Mircam' * (+ mecoprop-P) (Mirfield); 'MSS Mircam Plus' * (+ MCPA + mecoprop-P) (Mirfield); 'Pasturol' * (+ MCPA + mecoprop) (FCC); 'Quad-Ban' * (+ MCPA + mecoprop) (Quadrangle); 'Relay' * (+ MCPA + mecoprop) (Headland); 'Springcorn Extra' * (+ MCPA + mecoprop) (FCC); 'SWK 333' * (+ 2,4-D) (Keychem); 'Tribute' * (+ MCPA + mecoprop) (Nomix-Chipman); 'Weed and Brushkiller' * (+ 2,4-D + mecoprop) (Vitax).
Diuron	**Selected products:** 'Karmex' (DuPont); 'Direx' (DuPont, Griffin); 'Diurex' (Makhteshim-Agan); 'Sanuron' (Dow AgroSciences); 'Unidron' (Unicrop); 'Vidiu' (Vipesco); **mixtures:** 'Amigo' (+ amitrole) (Nufarm España, Nufarm SAS); 'Rapir Neu' (+ amitrole) (Bayer CropScience). **Other products:** 'Andiuron' (Ancom); 'Cañex' (Agricultura Nacional); 'Cention' (Lanxess); 'Crisuron' (Crystal); 'Dinurex' (Phyteurop); 'Ditox' (Pyosa); 'Diuranex' (Aragro); 'Divide' (Headland); 'Dorac' (Lanxess); 'Dorian' (Efal); 'Durasheld' (Ancom); 'Dynex' (Makhteshim-Agan); 'Faediuron' (Cequisa); 'Freeway' (Bayer CropScience); 'Sadiuron' (ÉMV); 'Sanduron' (Dow AgroSciences); 'Seduron' (Lanxess); 'Striker' (Sanonda); 'Toterbane' (Chimiberg); 'Valtri D-80' (LUQSA); 'Zee-Uron' (United Phosphorus); 'Zueron' (Zagro); **mixtures:** 'Krovar' (+ bromacil) (DuPont); 'Layby' (+ linuron) (DuPont); 'Velpar AlfaMax' (+ hexazinone) (DuPont); 'Velpar K-4' (+ hexazinone) (DuPont); 'Adios Cotton Defoliant' (+ thidiazuron) (Arysta LifeScience N. America); 'Alltex' (+ amitrole + dicamba + mecoprop-P) (Protex); 'Ametron' (+ ametryn) (Makhteshim-Agan); 'Amok' (+ glyphosate-isopropylammonium) (Cerexagri SA); 'Anibal' (+ atrazine) (Aragro); 'Arlen D' (+ amitrole) (Nufarm SAS); 'Arlen EV-P' (+ amitrole + dichlorprop-P) (Nufarm SAS); 'Bareground' (+ bromacil + sodium chlorate + sodium metaborate) (Pro-Serve); 'Borocil K' (+ bromacil) (Bayer CropScience); 'Clairsol Doble' (+ amitrole) (Cequisa); 'Cottonex D' (+ fluometuron) (Makhteshim-Agan); 'Dasaflo' (+ 2,4-D-sodium + DSMA) (Ancom); 'Dasatox' (+ 2,4-D-sodium + DSMA) (Ancom); 'DiBro' (+ bromacil) (Nufarm Americas); 'Dirimal' (+ oryzalin) (France) (Dow AgroSciences); 'Diumate' (+ MSMA) (Drexel); 'Donjon' (+ flumioxazin) (Philagro, Sumitomo Chemical); 'Dropp Ultra' (+	Baron' * (Chemiplant); 'Cekuron' * (Cequisa); 'Inquiron' * (Inquiport); 'Rescind' * (Aventis); **mixtures:** 'Anuron' * (+ paraquat dichloride) (Ancom); 'Atlas Pink C' * (+ chlorpropham + propham) (Atlas); 'Crisquat D' * (+ paraquat dichloride) (Crystal); 'Dexuron' * (+ paraquat dichloride) (Nomix-Chipman); 'Diquick' * (+ MSMA) (Agriliance); 'Duopan' * (+ oryzalin) (Switzerland) (Novartis); 'Herboxone D' * (+ paraquat dichloride) (Crystal); 'Kytrol G' * (+ amitrole + bromacil) (Nufarm SAS); 'Novorail' * (+ amitrole + ethidimuron) (CFPI); 'Uracom' * (+ amitrole) (Luxan); 'Weedfree 365' * (+ amitrole + simazine) (Agrichem Int.); 'Xanadu' * (+ glyphosate) (Monsanto).

	thidiazuron) (Bayer CropScience); 'Fouce' (+ amitrole) (Nufarm España); 'Ginstar' (+ thidiazuron) (Bayer CropScience); 'Glaive' (+ amitrole) (Phyteurop); 'Glidus' (+ glyphosate-isopropylammonium) (Makhteshim-Agan); 'Gramocil' (+ paraquat dichloride) (Syngenta); 'Granusol' (+ amitrole) (Nufarm SAS); 'Herbamide' (+ glyphosate-isopropylammonium + MCPA) (MCPA as unspecified amine salt) (Nufarm SAS); 'Hexaron' (+ hexazinone) (Makhteshim-Agan, Milenia); 'Hockey Pro' (+ glyphosate-isopropylammonium) (Monsanto); 'Jardiflow' (+ glyphosate-isopropylammonium + MCPA) (MCPA as unspecified amine salt) (Nufarm SAS); 'Korason' (+ simazine) (Premier.Shukuroglou); 'Mascot' (+ glyphosate-potassium + terbuthylazine) (Syngenta); 'Monex' (+ MSMA) (Ancom); 'Nomix TH 20' (+ glyphosate-isopropylammonium) (Monsanto); 'Pardy' (+ paraquat dichloride) (Agricultura Nacional); 'Redi-Pik' (+ thidiazuron) (Makhteshim-Agan); 'Ronstar D Flo' (+ oxadiazon) (Bayer CropScience); 'Sago' (+ amitrole) (Nufarm SAS); 'Sahara' (+ imazapyr) (BASF); 'Samba' (+ glyphosate-isopropylammonium) (Makhteshim-Agan); 'Simazol Plus' (+ amitrole + simazine) (Makhteshim-Agan); 'Sornic' (+ MSMA) (Ancom); 'Surefire' (+ paraquat dichloride) (Loveland); 'Topanex Ter' (+ glyphosate + terbuthylazine) (Aragro); 'Topsite' (+ imazapyr) (BASF); 'Touché' (+ glyphosate-isopropylammonium) (Nomix Enviro); 'Trevissimo' (+ glyphosate-isopropylammonium) (Arysta LifeScience); 'Trik' (+ 2,4-D-sodium + amitrole) (Nufarm UK); 'Ustinex G' (+ glyphosate-isopropylammonium) (Bayer CropScience); 'Xanadu' (+ glyphosate) (Bayer CropScience).	
Fluazifop-butyl	**Selected products:** 'Hache Uno' (Ishihara Sangyo); 'Onecide' (Ishihara Sangyo). **Other products:** 'Fusilade' (Syngenta).	-
Fluroxypyr	**Selected products:** 'Kuo Sheng' (Flagchem); **mixtures:** 'Greenor' (+ clopyralid + MCPA) (Rigby Taylor). **Other products:** 'Fernpath Hatchet' (Agriguard); 'Gartrel' (Sipcam S.p.A.); 'Patrol' (fluroxypyr as unspecified ester) (Herbos); **mixtures:** 'Ariane II' (+ clopyralid + MCPA-potassium) (Dow AgroSciences); 'Hotshot' (+ aminopyralid) (Dow AgroSciences); 'EF1166' (+ metosulam) (Interfarm); 'Fox' (+ bromoxynil octanoate + clopyralid) (fluroxypyr as unspecified ester) (Herbos); 'Vega' (+ clopyralid) (Herbos)	Crusader S' * (+ bromoxynil + clopyralid + ioxynil) (Dow); 'Hotspur' * (+ clopyralid + ioxynil) (Dow); 'Sickle' * (+ bromoxynil) (Dow); 'Advance' * (+ bromoxynil + ioxynil) (Dow, Zeneca).
Glufosinate-ammonium	**Selected products:** 'Basta' (Bayer CropScience); 'Liberty' (Bayer CropScience); 'Phantom' (Rocca). **Other products:** 'Buster' (Bayer CropScience); 'Challenge' (Bayer CropScience); 'Conquest' (Bayer CropScience); 'Dash' (Bayer CropScience); 'Derringer F' (Bayer CropScience); 'Eagle' (Bayer CropScience); 'Finale' (Bayer CropScience); 'Harvest' (Bayer CropScience); 'Ignite' (Bayer CropScience); 'Rely' (Bayer CropScience); 'Remove' (Bayer CropScience); 'Tepat' (Bayer CropScience); 'Genee' (Ancom); 'Glusar' (Vapco); 'Pilarneto' (Pilarquim); 'Travel' (Chemia); 'Troy' (Ancom); **mixtures:** 'Liberty ATZ' (+ atrazine) (Bayer CropScience); 'Groundboy' (+ flumioxazin) (Sumitomo Chemical); 'Tsubasa' (+ flazasulfuron) (Ishihara Sangyo).	Touchweed' * (Nomix-Chipman).

Glyphosate	**Selected products:** 'Gladiator' (Devidayal); 'Glyfall' (Hermoo); 'Karda' (Lainco); 'Maxweed' (Crop Health); 'Nasa' (Agria); 'Pilarsato' (Pilarquim); 'Rinder' (Inquiport); 'Rophosate' (Rotam); 'Seccherba' (Agrimix); 'Sharp' (Baocheng); **mixtures:** 'Folar' (+ terbuthylazine) (Syngenta). **Other products:** 'AllOut' (United Phosphorus); 'Ancosate' (Ancom); 'Bounce' (Zagro); 'Brake' (Biostadt); 'CDA Vanquish' (top fruit, etc.) (Bayer CropScience); 'Control' (Premier.Shukuroglou); 'Crunch' (Zagro); 'Egret' (United Agri); 'Eversate' (Zagro); 'Fez' (Zagro); 'Fireball' (Helena); 'Galika' (Efal); 'Glialka' (Agro-Chemie, Protex); 'Glifene' (Chimiberg); 'Glifocas' (CAS); 'Glifogold' (Agrimport); 'Glifotox' (Pyosa); 'Glyagro' (Agropharm); 'Glyf' (Chemia); 'Glyfatex' (Protex); 'Glygran' (Industria Prodotti); 'Glyweed' (Sabero); 'Grassato' (Hui Kwang); 'Gypsy' (GreenCrop); 'Herbanil' (Papaeconomou); 'Herb Neat' (Zagro); 'Herphosate' (Agrochem); 'HM-2028' (Helena); 'Kalach' (Arysta LifeScience); 'Kawal' (Zagro); 'Krup' (Krishi Rasayan); 'Lafam' (Agricultura Nacional); 'Manah' (Zagro); 'Misa' (Zagro); 'Noweed' (Dhanuka); 'Perzocyd' (Azot); 'Pin Up' (Zagro); 'Pounce' (Zagro); 'Pounder' (Zagro); 'Powex' (Zagro); 'Punch' (Zagro); 'Quickdown' (Stähler); 'Rhizeup' (Clayton); 'Sarang' (Zagro); 'Selang' (Zagro); 'Silglif' (Siapa); 'Slash' (Zagro); 'Stacato' (Sipcam S.p.A.); 'Sunup' (Sundat); 'Sweep' (United Phosphorus); 'Tamrok' (Phyteurop); 'Tecoglif' (Tecomag); 'Total' (AgroSan, Chemiplant); 'Trinnashi' (Hindustan); 'Velox' (Siapa); 'Wipe Out' (Zagro); 'Wipe-Out CT Elite' (Farmoz); **mixtures:** 'Arimo' (+ MCPA) (Makhteshim-Agan); 'Butazin' (+ terbuthylazine) (Makhteshim-Agan); 'Clipper' (+ isoxaben + oryzalin) (France) (Dow AgroSciences); 'Coctel' (+ MCPA) (Lainco); 'Engame' (+ urea sulfate) (Arysta LifeScience); 'Fosmazina' (+ simazine) (Probelte); 'Glifazin' (+ terbuthylazine) (Makhteshim-Agan); 'Glifo-Pop S' (+ MCPA) (Agrimport); 'Glisompa' (+ MCPA) (Probelte); 'Pavanett' (+ dichlorprop-P + MCPA) (unspecified amine salts) (Nufarm SAS); 'Rondo-M' (+ MCPA) (Crystal); 'Starmix' (+ triclopyr) (Dow AgroSciences); 'Topanex Ter' (+ diuron + terbuthylazine) (Aragro); 'Weemax' (+ amitrole) (Nufarm SAS); 'Xanadu' (+ diuron) (Bayer CropScience); 'Zapper' (+ oxadiazon) (Bayer CropScience); 'Zoomer' (+ oxyfluorfen) (Makhteshim-Agan). Discontinued products 'Chimarix' * (Monsanto); 'Clarion' * (Zeneca); 'Stampede' * (Zeneca); 'Alpha Glyphogan' * (Makhteshim-Agan); 'Arbex' * (Crystal); 'Banox' * (Crystal); 'Caoganlin' * (Shenzhen Jiangshan); 'CDA Spasor' * (top fruit, etc.) (Aventis); 'Comet' * (P I Industries); 'Complete' * (Stefes); 'Fozzate' * (Cedar); 'Glennon' * (Barclay); 'Glider' * (Portman); 'GLY-480' * (Powaspray); 'Glyper' * (PBI); 'Kickdown' * (Stefes); 'Nomix G' * (Nomix-Chipman); 'Nomix Nova' * (Nomix-Chipman); 'No-Weed' * (Dow AgroSciences); 'Poise' * (Unicrop); 'Supex' * (Crystal); 'Wipe-Out' * (Farmoz); **mixtures:** 'Xanadu' * (+ diuron) (Monsanto); 'Flier' * (+ imazethapyr) (IPESA). 'Glifogold' (Agrimport); 'Glifotox' (Pyosa); 'Glyagro' (Agropharm); 'Glyf' (Chemia); 'Glyfatex' (Protex); 'Glygran' (Industria Prodotti); 'Glyweed' (Sabero); 'Grassato' (Hui Kwang); 'Gypsy' (GreenCrop); 'Herbanil' (Papaeconomou); 'Herb Neat' (Zagro); 'Herphosate' (Agrochem); 'HM-2028' (Helena); 'Kalach' (Arysta LifeScience); 'Kawal' (Zagro); 'Krup' (Krishi Rasayan); 'Lafam' (Agricultura Nacional); 'Manah' (Zagro); 'Misa' (Zagro); 'Noweed' (Dhanuka); 'Perzocyd' (Azot); 'Pin Up' (Zagro); 'Pounce' (Zagro); 'Pounder' (Zagro); 'Powex' (Zagro); 'Punch' (Zagro); 'Quickdown' (Stähler); 'Rhizeup' (Clayton); 'Sarang' (Zagro); 'Selang' (Zagro); 'Silglif' (Siapa); 'Slash' (Zagro); 'Stacato' (Sipcam S.p.A.); 'Sunup' (Sundat); 'Sweep' (United Phosphorus); 'Tamrok' (Phyteurop); 'Tecoglif' (Tecomag); 'Total' (AgroSan, Chemiplant); 'Trinnashi' (Hindustan); 'Velox' (Siapa); 'Wipe Out' (Zagro); 'Wipe-Out CT Elite' (Farmoz); **mixtures:** 'Arimo' (+ MCPA) (Makhteshim-Agan); 'Butazin' (+ terbuthylazine) (Makhteshim-Agan); 'Clipper' (+ isoxaben + oryzalin) (France) (Dow AgroSciences); 'Coctel' (+ MCPA) (Lainco); 'Engame' (+ urea sulfate) (Arysta LifeScience); 'Fosmazina' (+ simazine) (Probelte); 'Glifazin' (+ terbuthylazine) (Makhteshim-Agan); 'Glifo-Pop S' (+ MCPA) (Agrimport); 'Glisompa' (+ MCPA) (Probelte); 'Pavanett' (+ dichlorprop-P + MCPA) (unspecified amine salts) (Nufarm SAS); 'Rondo-M' (+ MCPA) (Crystal); 'Starmix' (+ triclopyr) (Dow AgroSciences); 'Topanex Ter' (+ diuron + terbuthylazine) (Aragro); 'Weemax' (+ amitrole) (Nufarm SAS); 'Xanadu' (+ diuron) (Bayer CropScience); 'Zapper' (+ oxadiazon) (Bayer CropScience); 'Zoomer' (+ oxyfluorfen) (Makhteshim-Agan).	Chimarix' * (Monsanto); 'Clarion' * (Zeneca); 'Stampede' * (Zeneca); 'Alpha Glyphogan' * (Makhteshim-Agan); 'Arbex' * (Crystal); 'Banox' * (Crystal); 'Caoganlin' * (Shenzhen Jiangshan); 'CDA Spasor' * (top fruit, etc.) (Aventis); 'Comet' * (P I Industries); 'Complete' * (Stefes); 'Fozzate' * (Cedar); 'Glennon' * (Barclay); 'Glider' * (Portman); 'GLY-480' * (Powaspray); 'Glyper' * (PBI); 'Kickdown' * (Stefes); 'Nomix G' * (Nomix-Chipman); 'Nomix Nova' * (Nomix-Chipman); 'No-Weed' * (Dow AgroSciences); 'Poise' * (Unicrop); 'Supex' * (Crystal); 'Wipe-Out' * (Farmoz); **mixtures:** 'Xanadu' * (+ diuron) (Monsanto); 'Flier' * (+ imazethapyr) (IPESA).

Metsulfuron-methyl	**Selected products:** 'Allié' (DuPont); 'Ally' (DuPont); 'Escort' (DuPont); 'Gropper' (DuPont); 'Malban' (IPESA, Makhteshim-Agan); 'Metsulsun-M' (Sundat); 'Nicanor' (Makhteshim-Agan); 'Quit' (Sanonda); 'Retador' (Reposo); 'Rosulfuron' (Rotam); 'Stretch' (Agria); 'Timefron' (Tide); **mixtures:** 'Sindax' (+ bensulfuron-methyl) (DuPont). **Other products:** 'Battle' (DuPont); 'Brush Off' (DuPont); 'Cimarron' (DuPont); 'Gaio' (DuPont); 'Gem 690' (DuPont); 'Jubilee' (DuPont); 'Laren' (DuPont); 'Lorate' (DuPont); 'Saber' (DuPont); 'Simba' (DuPont); 'Accurate' (Cheminova); 'Alimaz' (Ancom); 'Alimo' (Ancom); 'Associate' (Nufarm Ltd); 'Brushkiller 600' (Nufarm Ltd); 'Convo' (Atul); 'Forge' (Interfarm); 'Luger' (Chemiplant); 'Manor' (Nufarm Americas); 'Metgard' (Makhteshim-Agan); 'Metsul-M' (Ancom); 'Metsy' (United Phosphorus); 'Minx PX' (Nufarm UK); 'Patriot' (Nufarm Americas); 'Pike' (Nufarm UK); 'Pilarscort' (Pilarquim); 'Plotter' (Rotam); 'Purestand' (Nufarm Americas); 'Rozar' (Makhteshim-Agan); 'Society' (Indofil); 'Teg' (Rallis); 'Triticas' (CAS); 'Valuron' (Makhteshim-Agan); **mixtures:** 'Agility' (+ dicamba-sodium + thifensulfuron-methyl + tribenuron-methyl) (DuPont); 'Allié Express' (+ carfentrazone-ethyl) (DuPont); 'Ally Express' (+ carfentrazone-ethyl) (DuPont); 'Ally Extra' (+ thifensulfuron-methyl + tribenuron-methyl) (DuPont); 'Almix' (+ chlorimuron-ethyl) (DuPont); 'Cimarron Max' (+ 2,4-D-dimethylammonium + dicamba-dimethylammonium) (DuPont); 'Cimarron Plus' (+ chlorsulfuron) (DuPont); 'Cimarron X-tra' (+ chlorsulfuron) (DuPont); 'Ciral' (+ flupyrsulfuron-methyl-sodium) (DuPont); 'Concert' (+ thifensulfuron-methyl) (DuPont); 'Finesse' (+ chlorsulfuron) (DuPont); 'Harmony M' (+ thifensulfuron-methyl) (DuPont); 'Lexus XPE' (+ flupyrsulfuron-methyl-sodium) (DuPont); 'Oust Extra' (+ sulfometuron-methyl) (DuPont); 'Pull' (+ bensulfuron-methyl) (DuPont); 'Scoop' (+ thifensulfuron-methyl) (DuPont); 'Spéléo' (+ flupyrsulfuron-methyl-sodium) (DuPont); 'Accurate Extra' (+ thifensulfuron-methyl + tribenuron-methyl) (Cheminova); 'Chisum' (+ chlorsulfuron) (Cheminova Inc); 'Londax Plus' (+ bensulfuron-methyl) (DuPont, United Phosphorus); 'Neptune' (+ mecoprop-P) (Headland); 'Pasture MD' (+ 2,4-D + dicamba) (Nufarm Americas); 'Pennant' (+ thifensulfuron-methyl) (Headland); 'Potent' (+ bensulfuron-methyl) (Doğal); 'Report Extra' (+ chlorsulfuron) (Cheminova Inc); 'Sigma' (+ bensulfuron-methyl) (Siapa); 'Sulfonil' (+ propanil) (Crystal); 'Total' (+ sulfosulfuron) (United Phosphorus); 'Trounce' (+ glyphosate-ammonium) (Nufarm Ltd).	Alrip' * (DuPont); 'Flumen' * (Barclay); 'PartiSan' * (Sanonda); **mixtures:** 'Canvas' * (+ thifensulfuron-methyl + tribenuron-methyl) (DuPont); 'DP 911' * (+ tribenuron-methyl) (DuPont); 'DP 928' * (+ thifensulfuron-methyl)
Paraquat dichloride	**Selected products:** 'Gramoxone' (Syngenta); 'Efoxon' (Efthymiadis); 'Gramoquat Super' (Baocheng); 'Herbaxon' (Westrade); 'Herbikill' (Vapco); 'Paraqate' (Mobedco); 'Pilarxone' (Pilarquim); 'Sunox' (Sundat); 'Total' (Barclay); 'Weedless' (Sanonda); **mixtures:** 'Seccatutto' (+ diquat dibromide) (Syngenta). **Other products:**: 'Bren' (Efal); 'Destroyer' (Doğal); 'Dextrone' (Nomix Enviro); 'Dhanuxone' (Dhanuka); 'Dipaxone' (Papaeconomou); 'Dipiril' (Afrasa); 'Dragocson' (Agricultura Nacional); 'Everzone' (Zagro); 'Fernpath Graminite' (Agriguard); 'Firestorm' (Chemtura); 'Forwazone' (Zagro); 'Fuego' (Zagro); 'Goldquat' (Zagro); 'Herboxone' (Crystal, Premier.Shukuroglou); 'Kapiq' (Krishi Rasayan); 'Lucaquat' (Lucava); 'Nuquat' (Nufarm Ltd); 'Parachute' (Devidayal); 'Paradox' (Sinon); 'Paragon' (Hui Kwang); 'Paraxone' (Hektaş); 'Parazone' (Makhteshim-Agan); 'Priquat' (Efthymiadis); 'Scythe' (BASF); 'Sipquat' (Unichem); 'Uniquat' (United Phosphorus); 'Weedol' (Scotts UK); **mixtures:** 'Gramocil' (+ diuron) (Syngenta); 'Gramoxone Plus' (+ diquat dibromide) (Syngenta); 'PDQ' (+ diquat dibromide) (Syngenta); 'Preeglox L' (+ diquat dibromide) (Syngenta); 'Preglone' (+ diquat dibromide) (Syngenta); 'Preglox' (+ diquat dibromide) (Syngenta); 'Fernpath Pronto' (+ diquat dibromide) (Agriguard); 'Myzet' (+ diquat dibromide) (Otsuka); 'Pardy' (+ diuron) (Agricultura Nacional); 'Pramato' (+ bentazone) (Iharabras); 'Revolver' (+ diquat dibromide) (Nufarm Ltd); 'Spray Seed' (+ diquat dibromide) (Crop Care); 'Surefire' (+ diuron) (Loveland).	Cyclone' * (Syngenta); 'R-Bix' * (Syngenta); 'Speedway' * (Zeneca); 'Starfire' * (Syngenta); 'Sweep' * (Zeneca); 'Boa' * (Griffin); 'Cekuquat' * (Cequisa); 'Crisquat' * (Crystal); 'Osaquat' * (Productos OSA); 'Plusquat' * (Productos OSA); **mixtures:** 'Gramonol' * (+ monolinuron) (Zeneca); 'Parable' * (+ diquat dibromide) (Zeneca); 'Prelude' * (+ linuron + metolachlor) (Syngenta); 'Antox' * (+ MSMA) (Ancom); 'Anuron' * (+ diuron) (Ancom); 'Azote' * (+ amitrole) (Productos OSA); 'Crisquat D' * (+ diuron) (Crystal); 'Dexuron' * (+ diuron) (Nomix-Chipman); 'Duplex' * (+ amitrole) (Productos OSA); 'Giror' * (+ amitrole) (with ammonium thiocyanate) (Sopra); 'Herboxone D' * (+ diuron) (Crystal) 'Priglox' * (+ diquat dibromide) (Nihon Nohyaku).

---

1 - According to standards organisations e.g. ISO

3. Hazard classification

The terms hazard and risk are often used in relation to a pesticide substance or product, each having a specific meaning where:

Risk = Hazard x Exposure

Hazard is considered to be the intrinsic hazard classification, while exposure is based on both the level and the duration of exposure to the hazard. Herbicides, as pesticides, are classified and rated by a number of official bodies according to the risk they pose to humans and the environment. They are also subject to various international conventions, as described below.

The World Health Organization (WHO) system, 'WHO Recommended Classification of Pesticides by Hazards, 2004', distinguishes five classes of hazard based on the acute oral and dermal toxicity (as LD_{50} values) of a substance to rats (see Appendix 1). In the context of these recommendations, the term 'hazard' is defined as; *'the acute risk to health (that is, the risk of single or multiple exposures over a relatively short period of time) that might be encountered accidentally by any person handling the product in accordance with the directions for handling by the manufacturer or in accordance with the rules laid down for storage and transportation by competent international bodies.'* The WHO classification recognizes a four-fold reduction in hazard for solid formulations in comparison with liquid formulations (9).

The United States Environmental Protection Agency (EPA; http://www.epa.gov/) also classifies pesticides according to their toxicity to rats and assigns them a precautionary label *'designed to provide the pesticide user with information regarding the toxicity, irritation and sensitization hazards associated with the use of a pesticide, as well as treatment instructions and information to reduce exposure potential'* (see Appendix 2 and http://www.epa.gov/oppfead1/labeling/lrm/chap-07.htm). Although EPA classifications should be based on herbicide formulations (i.e. products), sufficiently detailed information is not always available to the EPA.

In the European Union (EU) the evaluation, marketing and use of pesticides, including herbicides, for plant protection are regulated under European Commission Council Directive 91/414/EEC. Under this Directive only those active ingredients shown, through a comprehensive risk assessment and authorisation procedure involving the European Food Safety Authority (EFSA), to have no harmful effect on human or animal health and no unacceptable influence on the environment may be marketed or used within the EU. If approved, a substance is included on an EU list of approved active ingredients, Annex I to Directive 91/414/EEC (for further information see 78). EU Member States may only authorise plant protection products containing active ingredients included in Annex 1.

A new directive on the sustainable use of pesticides, of which integrated pest management (IPM) is a key feature, has also been put forward for consideration by the European Parliament. If approved, this legislation will introduce new regulations within the EU governing; the promotion of non-chemical pest control methods; reducing the risks and impacts of pesticide use; protecting aquatic environments and drinking water supplies; prohibiting pesticide use in public areas such as parks and

public gardens; and introducing training on pesticides. With some exceptions, aerial crop spraying will also be prohibited. If approved, this directive must be implemented by EU Member States by 2011. For further information see;
http://www.europarl.europa.eu/news/expert/infopress_page/066-45937-012-01-03-911-20090112IPR45936-12-01-2009-2009-false/default_en.htm)

The Rotterdam Convention (2004) deals with pesticides which are banned or severely restricted due to recognized health or environmental reasons by the Parties (as listed in Annex III of the convention) and which are subject to the ‘Prior Informed Consent (PIC) Procedure’. The Rotterdam Convention follows on from several initiatives that date back to the mid 1980s, such as the International Code of Conduct on Distribution and Use of Pesticides (1985) and the London Guidelines for the Exchange of Information on Chemicals in International Trade (1987). These were focused on during the 1992 Rio Earth Summit, and a provisional text of the Rotterdam Convention On the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade was adopted at the Diplomatic Conference held in Rotterdam on 10 September 1998.

The PIC procedure allows the Parties to take informed decisions on whether to allow any future imports of hazardous substances, by being made aware of products which have been banned or severely restricted in other countries on the basis of unacceptability to human health and/or the environment (129, 190). These decisions are made based on the PIC procedure and a regulated Information Exchange Network which facilitates information exchange among Parties for a very broad range of potentially hazardous chemicals. There are 40 chemicals listed in Annex III of the Convention, including 25 pesticides, 4 severely hazardous pesticide formulations and 11 industrial chemicals. Many more chemicals are expected to be added in the future. Four other chemicals are under the Chemical Review Committee at present. None of the herbicides referred to in this report are currently included in Annex III.

A summary of the classifications assigned to herbicide substances commonly used in oil palm plantations by WHO, EPA, EU and the Rotterdam Convention is provided in Table 3 (9, 12, 53). Table 4 provides information on countries where substances are prohibited (banned) or where special restrictions apply.

Table 3. Classification of pesticides by toxicity hazard by the World Health Organisation, European Union and Environmental Protection Agency, and by prohibition or restriction by the Rotterdam Convention.

Active ingredient	**WHO**[1]	**EU** (included in Annex 1 of Directive 91/414/EEC)[1]	**EPA**[2]	**Rotterdam Convention** (included in Annex III)
2,4-D	II	Yes	II	No
Dicamba	III	Yes	III	No
Diuron	U	Yes	III	No
Fluazifop-butyl	III	No	II (oral) III (dermal)	No
Fluroxypyr	U	Yes	No consensus across products. Product Vista classified as II (69)	No
Glufosinate-ammonium	III	Yes	III	No
Glyphosate	U	Yes	III	No
Metsulfuron-methyl	U	Yes	IV	No
Paraquat dichloride	II	No[3]	II (oral) III (dermal)	No, but under review

1 - Relates to active ingredient. See Appendix 1 for classifications.

2 - Relates to formulation. See Appendix 2 for classifications.

3 - Inclusion in Annex 1 (2003/112/EC) annulled by Judgement of the (EC) Court of First Instance, 11 July 2007

- = indicates data not available

Table 4. Countries where herbicide substances are or have been known to be prohibited or where special restrictions apply.

(date of introduction of restrictions, where known, and ref. no. of source of information are shown in parentheses).

Active Ingredient	Countries where banned	Countries where restricted
2,4-D	**USA (2005):** Oregon and Washington states (112) **Norway (2001)** (190)	**USA (2005)** not approved for invasive species management in national forests (112)
Dicamba	-	**USA** not approved for invasive species management in national forests (112)
Diuron	**EU (2008) banned** as plant protection agent but reincluded in Annex 1 of Directive 91/414 EEC in October 2008 (78)	-
Fluazifop-butyl	**Norway (1999)** danger to human health and environment (190)	**No restrictions**
Fluroxypyr	-	-
Glufosinate-ammonium	-	-
Glyphosate	**Denmark (2003)** due to concerns over groundwater but subsequently lifted (63)	**Australia (2003)** product restrictions for aquatic applications subsequently lifted (46)
Metsulfuron methyl	-	-
Paraquat/paraquat dichloride (4, 7, 17, 49, 77, 78, 166, 167, 190)	**Austria: (1993)** **Cambodia (2003)** **Denmark (1995)** **EU (2008)** **Finland (1986)** **Korea (1991)** **Kuwait (1985)** **Malaysia[8] (2002)** **Saudi Arabia (2008)** **Slovenia (1997)** **Syria (2005)** **Sweden (1983)**	**Belgium:** limited to professionals **Caribbean:** local restrictions **Chile:** unauthorised aerial application **Europe:** limited to professionals **Germany:** severely restricted **Hungary:** severely restricted **Indonesia:** limited to professionals **Philippines:** institutional use only **Slovakia:** limited to professionals **Sri Lanka:** limited concentration of product **Togo:** must contain emetic, colorant, stenchant **Uruguay:** limited concentration of product **USA:** limited use by certified applicators only

---

[8] In 2002 the Malaysian government (Pesticide Control Division) stopped the registration of new products and indicated that the re-registration of existing products containing paraquat would stop. This decision was subsequently lifted, permitting registration of paraquat for all crops (60, 77) but with a reduction in the concentration of paraquat permitted in products.

4. Application of herbicides

Many definitions exist in terms of what constitutes a weed, but it is essentially any plant or vegetation that interferes with the objectives or requirements of people (33). In terms of agriculture, and oil palm specifically, this would include any plants or vegetation that interfere, in any way, with the production of the palms and therefore result in a reduction in yield or quality. Weeds may interfere in many ways, including restricting the undertaking of management practices, acting as parasites, reducing light, water and nutrients available to the crop, producing toxins and providing habitats for pests and diseases (33).

The weed types that tend to occur and cause problems during oil palm production fall into designated into groups as outlined below (see 11 also).

Grass-type weeds reproduce through seeds and rhizomes, and can affect the level of nitrogen in the soil. *Ischaemum muticum* is a particularly nefarious grass that can reduce oil palm yield significantly (up to 22%).

Sedge-type weeds. Like grass type weeds, sedges reproduce through seeds and rhizomes. They are hardy and difficult to eradicate through the use of chemicals.

Creeper broadleaf weeds can be very aggressive and grow well in wet conditions. They compete for nutrients in the soil, may limit soil micro-organism nitrification and affect oil palm growth.

Non-creeper broadleaf weeds are able to flower and produce many seeds. They grow rapidly and compete with oil palm for many vital nutrients in the soil. They compete with immature to young oil palm plants (3-4 years old) and, if left untreated, may grow up to one metre in height.

Woody broadleaf weeds have strong stems and live longer than the average weed. They are prolific if given the chance to grow, and are therefore considered very undesirable in oil palm plantations.

Ferns and brackens grow well in wet conditions. They are not generally considered to be detrimental to oil palm plantations, and can be of benefit in terms of controlling the water level in the soil.

Weeds are generally more problematic during the immature stages of growth of oil palm as the palm fronds are small and, as the ground is readily exposed to sunlight, a suitable environment is created for prolific plant growth, including that of weeds. However, as the palms mature the fronds enlarge and the canopy closes, reducing the amount of sunlight reaching ground level and therefore creating conditions less favourable for plant growth. As a result the growth of ground cover vegetation, including weeds, tends to be suppressed.

Herbicides can be used very effectively to control or eradicate the various weed types that occur in oil palm plantations. However, the selection, application rate and method of application of herbicides may vary markedly depending on a number of factors including: the specific weed problem to be tackled (weed species, extent of growth and weed succession); efficacy, specificity, phytotoxicity and risks associated with using the herbicidal substances/products; size and age of the plantation; climatic conditions; and the economic benefits in comparison with other herbicides and alternative weed management methods (62, 68, 121). Where costs are taken into consideration, and compared with those of non-chemical approaches, these should include all costs associated with obtaining, using and disposing of a herbicide (e.g. equipment, labour, disposal facilities) and not the cost of purchase alone. Due to their potentially damaging effects on the oil palm, some herbicides may be applied at the immature stages of oil palm growth, others at the mature stage whilst some do not have an adverse effect at any stage of growth. This is partly due to selectivity of the particular herbicide.

Herbicides and their use for specific weeds

Selective herbicides:
2,4-D is a selective broad leaf weed herbicide that will affect particular species from various weed groups, such as creeper (*Passiflora foetida, Mikania micrantha*) and non creeper type broadleaf weeds (*Asystasia gangetica*), woody broadleaf weeds (*Asystasia intrusa; Ageratum conyzoides, Costus speciosus*), sedges (*Cyperus rotundus*), ferns and bracken (*Dicranopteris linearis*) (11, 114, 118, 158). It is not advisable to use this herbicide for immature oil palm as it rapidly scorches leaves (11).

Dicamba can be applied to foliage or soil and may be used to control a wide variety of annual and perennial broadleaf weeds, brush, vines and brackens, including the woody creeper *Mimosa invisa*. It will kill broadleaf weeds before and after they sprout. It may be used in cropped and non-cropped areas, including in combination with other herbicides such as 2,4-D, and may be applied in immature oil palm. Most legumes are sensitive to dicamba (11, 53, 98, 108, 118, 121, 124).

Diuron may be used, pre-emergence, for total control of weeds and mosses in non-crop areas, and for selective control of both grass and broadleaf weeds in crops (53).

Fluazifop-butyl is effective for annual and perennial grasses including *Pennisetum, Eleusine indica* (11) and crabgrass, *Panicum* species and foxtail (121).

Fluroxypyr is effective in controlling creeper type broadleaf weeds, particularly *Mikania micrantha*, and can also act upon tough grasses and legume cover plant weeds (11, 118). This herbicide should be kept away from young and immature oil palms (11).

Metsulfuron-methyl is a selective herbicide that, used pre-and post-emergence, will control particular species of annual and perennial broadleaf weeds and some annual grasses, including *Pennisetum, Mucuna bactreata, Asystasia gangetica, Mimosa invisa, Asystasia intrusa, Melastoma malabatrichum, Ageratum conyzoides, Chromolaena odorata*, and *Nephrolepsis biserrata* (11, 148, 196). It is effectively used against ferns, sedges, brackens and soft grasses (118).

Non-selective herbicides:
Glufosinate-ammonium is a non selective herbicide used for woody type weeds and also grasses, sedges, ferns, bracken and non creeper type weeds. These include *Adiantum latifolium*, *Asystasia intrusa*, *Calapogonium caeruleum*, *Eleusine indica, Mimosa invisa, Mucuna bactreata, Ottochloa nodosa*, *Paspalum conjugatum* and *Scleria sumatrensis.* It may cause scorching if inadvertently applied to oil palm leaves but may be used for immature and mature stages of oil palm growth (11, 38, 118, 148, 196).

Glyphosate may be used at varying rates of application on soft and tough grasses, broadleaves, and legume cover plants (118, 148). It is generally not advisable to use this herbicide close to immature oil palms but to apply it outside a pre-defined circle around each immature plant (11). Glyphosate has been found to be effective against weeds such as *Axonopus compresus*, *Chromolaena odorata*, *Cyperus iria, Digitaria ciliaris, Eleusine indica, Imperata cylindrica, Ischeamum muticum, Mikania micrantha, Mimosa invisa, Mucuna bactreata, Ottochloa nodosa*, *Paspalum conjugatum*, *Pennisetum* spp and *Pueraria phaseloides* (11, 110, 196).

Paraquat dichloride, a non-selective herbicide, may be applied to young but not immature palms (to which it is toxic) (11). Regular spraying in oil palm plantations is necessary when palms are still young and with less canopy (22). Grasses, sedge weeds, ferns and bracken, woody type, such as *Chromolaena* spp., and soft broadleaf weeds are all eradicated particularly well when sprayed with paraquat dichloride (62, 118). Paraquat dichloride is particularly useful for killing *Nephrolepis biserrata*, and volunteer oil palm seedlings (11, 118).

Table 5 provides examples of how the different herbicidal active ingredients have been used, and are recommended for use, during cultivation of oil palm and the stages of palm growth at which they should or should not be used.

Table 5. Examples of the herbicide active ingredients suitable for use against weed types and species in oil palm cultivation.

Active ingredient (a.i.)	Selectivity[1]	Weed group											
		Grass		Creeper broadleaf		Non-Creeper broadleaf		Woody Broadleaf		Sedge		Fern and bracken	
		Weed	Oil palm stage[2]	Weed	Oil palm stage[2]	Weed	Oil palm stage[2]	Weed	Oil palm stage[2]	Weed	Oil palm stage[2]	Weed)	Oil palm stage[2]
2,4-D	**S**	-	-	*Passiflora foetida**	M	*Asystasia gangetica**	M	*Asystasia intrusa*	M	*Cyperus rotundus* (114)	-	*Dicranopteris linearis*	M
				Mikania micrantha (118)	-	-	-	*Ageratum conyzoides*	M				
Dicamba		-	-	-	-	*Mimosa invisa* (121)	-	-	-	-	-	-	-
						Asystasia gangetica (192)							
Fluazifop-p-butyl		*Pennisetum*	-	-	-	-	-	-	-	-	-	-	-
		Eleusine indica	-										
Fluroxypyr		-	-	*Mikania micrantha**	M	-	-	-	-	-	-	-	-

Metsulfuron-methyl		*Pennisetum*	-	*Mucuna bracteata* (148)	Mainly for low rainfall months for control (148)	*Asystasia gangetica*	IM	*Asystasia intrusa*	IM	-	-	*Nephrolepsis biserrata*	IM + M
								Ageratum conyzoides					
						Mimosa invisa	IM	*Melastoma malabathrichum*	IM + M				
								Chromolaena odorata					
Glufosinate-ammonium	**NS**	*Eleusine indica* (11, 196)**	-	*Mucuna bracteata* (148)	-	*Mimosa invisa***	IM+M	-	-	*Scleria sumatrensis***	M	*Adiantum latifolium***	M
		Paspalum sp.(118, 196)	-									*Dicranopteris linearis***	
		Ottochloa nodosa (196)	-	*Calopogonium caeruleum* (196)	-	-	-	*Asystasia intrusa* (196)	-	-	-	-	-
Glyphosate		*Imperata cylindrica**	Outside circles of IM	*Mucuna bracteata* (148)	Outside circles of IM + M (148)	*Mimosa invisa**	M	*Chromolaena odorata* (110)	IM	*Cyperus iria**	IM+M	-	-

		*Ischaemum muticum**	Outside circles of IM					*Melastoma* (118)	-				
		*Pennisetum**	Outside circles of IM										
		Paspalum conjugatum (196)	-	*Mikania micrantha* (196)	-	-	-	-	-	-	-	-	-
		Eleusine indica (196)	-	*Pueraria phaseoloides* (196)	-	-	-	-	-	-	-	-	-
		Ottochloa nodosa (196)	-	-	-	-	-	-	-	-	-	-	-
		Axonopus compessus (196)	-	-	-	-	-	-	-	-	-	-	-
		Digitaria cilaris (196)	-	-	-	-	-	-	-	-	-	-	-
Paraquat dichloride		*Ischaemum* (172)	-	*Mikania* (172)	-	*Borreria* (172) *Mimosa invisa* *Ageratum* (172) *Climedia* (118, 172) *Asystasia gangetica* (172)	-	*Melastoma* (118)	-	*Cyperus* (172)	-	*Stenochlaena* (118)	-

Note: 1 - S, selective; NS, non-selective; 2 - IM, immature planting (<5 years old); M, mature planting (> 5 years old) (116); * Not safe to use in immature palm; ** May cause scorching; Information in table obtained from references: 11, 110, 114, 118, 121, 148, 172, 192, 196 with numbers in parentheses denoting reference numbers. Unless denoted otherwise, information in the above table was obtained from reference no. 11. Several of the references cited also provide information on rates of herbicide applied.

Recognizing the risk of exposure to herbicides by the user as well as the risk to the environment, the FAO has produced an 'International Code of Conduct on the Distribution and Use of Pesticides' (173). The Code is supported by the pesticide industry and its obligations are implemented by the industry through product stewardship activities. To avoid exposure, the Code recommends that pesticide users wear PPE[9] and that manual spraying of any pesticide should only be undertaken while wearing boots or covered shoes, long-sleeved garments and garments that cover the legs. Mixing of the formulation and loading of spray equipment should be undertaken using skin protection (i.e. gloves) and eye protection (i.e. face shield or tight-fitting goggles). Further measures to reduce the risk of exposure are the use of items such as a filter or respiratory mask and an impermeable apron.

The highest risk of human exposure and intoxication generally occurs when mixing and loading the herbicide product into the spraying equipment as well as during its subsequent application. Handling guidelines and precautionary measures to be taken are given by the herbicide manufacturers on the product labels as well as instruction manuals for the respective herbicide. However the uptake and use of this information, as well as the use of recommended personal protective equipment (PPE), varies between and within countries and region. It will depend, for example, on training of dealers or distributors, availability and maintenance of application equipment and availability and affordability of PPE. Climatic conditions are also an important factor, as protective clothing may cause considerable discomfort in warm or humid climates. As a consequence, good working practices are often not adhered to in developing countries and tropical climates (5).

Summaries of application practices and examples of PPE recommended for products that contain the different herbicide active ingredients are given below. It should be noted that PPE is recommended on the basis of all constituents of a product, some of which may be more hazardous than the herbicide active ingredient that it contains.

2,4-D

2,4 D is distributed in a range of chemical formulations, including emulsifiable or soluble concentrates, granules, water soluble powder or wettable powder (53). Most commonly the chemical is formulated as an amine salt in aqueous solution or as an ester in an emulsifiable concentrate. 2,4-D is used either as the sole active ingredient of a herbicide, but frequently also in conjunction with other active ingredients (139). Commercial 2,4-D herbicides may contain inert ingredients, which may not always be identified on the respective pesticide label and not included in any health and safety testing (156). 2,4-D may be applied from the ground and aerially using a range of equipment, including hand held sprayer, injection equipment, backpack sprayer, band sprayer, boom sprayer, granule applicator – in some cases tractor mounted - or by fixed-wing aircraft or helicopter (139). Drift is a common problem associated with the application of 2,4-D (156).

---

[9] PPE is defined under the Code as any clothes, materials or devices that provide protection from pesticide exposure during handling and application, and including both specifically designed protective equipment and clothing reserved for pesticide application and handling.

2,4-D is classified in the WHO system as ‘moderately hazardous’ (category II, see Table 3 and Appendix 1), placing it in the same class as paraquat. Recommended PPE includes long trousers, long-sleeved shirt, socks, shoes plus an outer protective chemical resistant layer, i.e. apron or encapsulating suit, as well as chemical resistant gloves, chemical goggles or shielded safety glasses. Safety showers and emergency eye wash stations should be closely located to where handling of the chemical occurs. Protective clothing should be kept free of oil and grease and should be inspected and maintained regularly to preserve its effectiveness. Respiratory protection is not generally required unless vapour or mists of the substance exceed acceptable levels (89, 157).

Dicamba

Dicamba is distributed as soluble concentrates, water dispersible granules and wettable powders (53, 120). Herbicide products containing dicamba may also contain ‘inert’ substances (e.g. ethylene glycol, which shows acute and chronic toxicity effects in humans), which may not be specified on the label, as well as contaminants (e.g. 2,7-dichlorodibenzo-p-dioxin (126). Dicamba is available in mixtures with other herbicides (e.g. 2,4-D, fluroxypyr or triclopyr) (39). Dicamba may be applied from the ground using backpack sprayers, push-type broadcast spreaders, groundbooms, turfguns and tractor-drawn broadcast spreaders, as well as aerially by fixed-wing aircraft (in USA) (120). In Malaysia knapsack sprayers are commonly used for application (23). Dicamba-based herbicides are usually applied at a rate of 0.56 kg acid equivalent (a.e.)/ha, although higher doses are required in young palms, especially where leguminous cover crops are not present (121).

Dicamba is classified by the WHO categorization as ‘slightly hazardous’ (category III, see Table 3 and Appendix 1). Occupational exposure may be significant via the dermal and inhalation routes, when loading, spraying or handling the dicamba mixture (128), and recommended PPE for handling the chemical includes goggles, chemical-resistant gloves, coveralls, socks and chemical resistant footwear (125). Dilution of the herbicide with water prior to application reduces the toxicity by all routes of exposure (149).

Diuron

For use as a herbicide, diuron is known to be formulated as a wettable powder, water dispersible granule, emulsifiable concentrate, dry flowable, suspension (flowable) concentrate), in granular, pellet or tablet form and also as a ready-to-use solution (53, 98). It may be applied from the ground as well as from the air using a variety of equipment, including boom sprayer, high- and low pressure hand wands, tractor-drawn spreaders, granular backpack spreaders an sprayers, push-type spreader, airless sprayer, paintbrush, shaker-type applicator as well as by hand (98).

Although, as with all herbicides, there is a risk of occupational exposure during mixing, loading and application, the WHO classifies diuron as unlikely to present an acute hazard (category U, see Table 3 and Appendix 1) under normal use. Recommended PPE when using diuron products includes long sleeved upper garments, long lower garments, shoes, socks, chemical resistant gloves made of any waterproof material (such as polyethylene or polyvinyl chloride) and protective eyewear. In enclosed environments approved dust or mist respirators may be required (100, 147). It should be noted that diuron has been reported to contain trace amounts of the manufacturing impurity tetrachloroazobenzene (TCAB), which has been shown to have a toxic effect on rodents (98).

Fluazifop-butyl

Fluazifop-butyl is distributed as an emulsifiable concentrate which is mixed with water before spray application. Fluazifop-butyl can be applied at rates of 125-375 g/ha for control of grasses in oil palm (93). In the USA the herbicide is typically applied as a broadcast, banded, directed or spot treatment with groundboom sprayers and aerial equipment (91). Evaluation of mixtures of fluazifop-butyl and other herbicides have shown complimentary and synergistic effects, a combination of sethoxydim and fluazifop providing better control of grass weed species, including foxtail, wheat and barley, in canola than that expected from an additive effect (135). Synergistic effects of mixtures such as this offer possibilities for reducing herbicide application rates, associated purchase and usage costs and also negative impacts on the environment (135). However, antagonistic effects have been reported when fluazifop-butyl and auxin mimic herbicides (e.g. 2,4-D) are applied together, resulting in a loss of grass weed control normally achieved with fluazifop-butyl alone (92).

Fluazifop-butyl is classified by the WHO as slightly hazardous (category III, see Table 3 and Appendix 1). Recommended PPE when handling products containing the herbicide include chemical splash goggles, chemical-resistant gloves, coveralls, socks and chemical-resistant footwear. For overhead application chemical-resistant headwear should also be worn and an organic vapour respirator may be required. In the case of accidental spillage, or when exposure levels are unknown, self contained breathing apparatus should be used (90). There is considered to be little risk to those using the herbicide if the recommended protective clothing and equipment is used. Commercial products of fluazifop-butyl may include naphthalene as a wetting agent as well as petroleum products that are considered harmful e.g. ‘Fusilade II Turf and Ornamental’ (90).

Fluroxypyr

The active ingredient fluroxypyr is classified by the WHO categorization as ‘unlikely to present acute hazard in normal use’ (category U, see Table 3 and Appendix 1). Classification of fluroxypyr by EPA, however, is dependent on the particular product. Fluroxypyr is often supplied as an emulsifiable concentrate or as an emulsion of oil in water or a suspo-emulsion which, once prepared, is usually applied as a spray (53, 76). Herbicide containing fluroxypyr may be applied by various ground and aerial methods including hand sprayers, tank sprayers, boom application and helicopter (69, 75). Fluroxypyr is considered to have an advantage over other herbicides due to its effectiveness at low doses (88). Recommended PPE to be used when handling herbicides containing fluroxypyr include cotton overalls buttoned to the neck and wrist, a washable hat, elbow-length PVC gloves and a face shield or goggles (70).

Glufosinate-ammonium

Glufosinate-ammonium is distributed as a blue-green soluble concentrate intended for mixing with water before application as a foliar spray at concentrations, and usually at concentrations of 100-500 mg/l (51). The surfactant sodium polyoxyethylene alkylether sulphate (AES), shown to have toxic effects, and the solvent propylene glycol monomethyl ether are included in product formulations (55, 56). Glufosinate-ammonium is compatible with, amongst other herbicides, diuron, simazine and MCPA (53). Being a non-selective herbicide, it is recommended that care be taken not to contaminate non-target plants and that use of the herbicide in windy conditions should be avoided (101).

Glufosinate-ammonium can be applied with many different types of equipment, which deliver water volumes of between 50-1000 l/ha. In Malaysia a semi-mechanised spraying system comprising specialised equipment, Basta 15 + Serena, has been developed for circle spraying in sensitive oil palm and delivering Very Low Volume (VLV) as low as 50 l/ha of herbicide. In France an Ultra Low Volume (ULV) system has also been developed to permit deliveries in asparagus and tomato of only 20-25 l/ha. (101).

Glufosinate-ammonium is classified by the WHO as ‘slightly hazardous’ (category III, see Table 3 and Appendix 1). PPE recommended for use when applying products containing the herbicide include washable, long overalls covering the neck and wrists, elbow length protective PVC or nitrile gloves, and a hat as well as eye protection (a face shield or goggles). If working in a poorly ventilated area or if acceptable occupational exposure levels are likely to be exceeded, a respirator suitable for organic vapours should be worn. It is recommended that gloves, face shield or goggles, respirator and contaminated clothing should be washed after each daily use (56).

Glyphosate

Glyphosate is distributed as a water-soluble granules/powder or a soluble concentrate containing up to 41% active ingredient (1, 24, 53). Commercial formulations are generally aqueous mixtures of the isopropylamine (IPA) salt of glyphosate, a surfactant, and various minor components including anti-foaming and colour agents, biocides and inorganic ions to regulate pH (24). The herbicide may be applied from the ground using spray tanks. Aerial application is also possible. As a non-selective herbicide it is recommended that appropriate measures be taken to avoid exposure of non-target plants to spray drift during spray application of products containing glyphosate (47).

Glyphosate is classified in the WHO categorization as ‘unlikely to present acute hazard in normal use’ (category U, see Table 3 and Appendix 1). The recommended PPE includes eye goggles or a shield to prevent eye damage, chemical resistant gloves made of waterproof material and long trousers and shirts to protect the skin (44).

Metsulfuron-methyl

Metsulfuron-methyl is distributed as water soluble granule, tablet or water dispersible granule (53). Commercial formulations usually contain one or more inert substances (80, 82). The herbicide may be applied from ground as well as aerial equipment (80). As metsulfuron-methyl is harmful to non-target plants at low concentrations it should be sprayed at large droplet size (150 microns or larger) and under favourable weather conditions to avoid spray drift (82). In oil palm production, the herbicide can provide effective control of certain weeds at lower doses (e.g. 15g a.i./ha) in immature oil palm in comparison with other herbicides (88).

Metsulfuron-methyl is classified by the WHO categorization as ‘unlikely to present acute hazard in normal use’ (category U, see Table 3 and Appendix 1). When handling products containing this substance - opening containers, preparing the spray and during application – recommended PPE includes long cotton clothing covering up to the neck and wrist should be worn with elbow length PVC gloves, goggles and a washable hat. The herbicide should only be handled in areas with good ventilation (89).

Paraquat

Paraquat is marketed either as water soluble granules or as a soluble concentrate. In order to increase the safe use of the substance, avoid accidental ingestion and deter misuse, three safening agents are added to paraquat formulations manufactured by Syngenta - a blue dye and an alerting agent (a strong and deterring odour) as warnings, as well as an emetic to induce vomiting. FAO/WHO Specifications and Evaluations for Agricultural Pesticides (2008) states that paraquat must contain an effective emetic and may also include colorants and olefactory alerting agents (2, 5, 109) (see also http://www.fao.org/agriculture/crops/core-themes/theme/pests/pm/jmps/ps/ps-new/en/)

The supply and use of paraquat is prohibited or restricted in a number of countries. Restrictions may include unauthorised aerial application (e.g. Chile, Colombia, Costa Rica, EU), restricted handling and use to trained/certified professionals (e.g. Europe, USA, Indonesia) and limiting concentrations of the herbicide (e.g. Sri Lanka, Uruguay, EU, USA) (4, 5; see also Table 4).

Paraquat is classified in the WHO classification as ‘Moderately hazardous’ (category II see Table 3 and Appendix 1) and as such recommendations for precautionary measures when handling the chemical are particularly stringent. The classification notes that paraquat has serious delayed effects if absorbed and, while it is of relatively low hazard in normal use, may be fatal if the concentrated product is taken by mouth or spread on the skin (9). Syngenta, a major manufacturer and retailer of paraquat, recommends the use of gloves (elbow length, PVC), footwear and eye protection (goggles or face shield) when handling concentrated formulations (e.g. Gramoxone 250), while a long-sleeved shirt, long trousers and boots should be worn during herbicide application. Clothes used during spray operations should be washed separately from other items and attention paid to personal hygiene by those handling all pesticides (6). In situations where heavy exposure may occur, wearing of a dust mask, goggles, chemical resistant gloves and heavy duty cotton overalls is recommended (19).

In a survey undertaken in 2007 of pesticide dealers selling paraquat in China, Pakistan and Indonesia it was shown that, although paraquat (as the product Gramoxone) was being sold, most dealers did not stock the recommended PPE. This was reflected by observations that farmers and agricultural workers generally did not use PPE, despite the fact that in some areas it was considered to be affordable for them. Of those retailers selling PPE - which was mainly gloves, mask and boots - they were unaware that this had to be of a required standard (e.g. gloves must be strong and impervious). Furthermore, they were unaware of the importance of advising on PPE, most had not received training in the products they sell, had limited knowledge and were unable to give advice to their customers. Many of those who purchased PPE products, which were considered to be expensive, also lacked awareness of their importance (5). On the basis of the findings it has been recommended that greater efforts should be made to monitor availability of PPE and conditions of use to avoid use of hazardous products in unsuitable circumstances and to help meet the requirements of the FAO Code of Conduct (173).

5. Human and environmental toxicity

As indicated in Section 3, the hazard classification of herbicides and their inclusion in pesticide directives and international conventions is based on established toxicological data and risk assessments. Herbicide toxicity to humans, other mammals, birds, fish, invertebrates and the environment is related to the chemical properties and the mode of action of a respective active ingredient as well as to their physical properties. Toxic effects of any substance generally also depend on the amount absorbed, which is influenced by the route of absorption, as well as the susceptibility of the individual (4). Exposure to an active ingredient can be short-term or long-term and may occur through inhalation, contact with the skin or ingestion. Poisoning may be localized or systemic and either acute, as an immediate result of a high level of exposure to the active ingredient, or chronic, due to long-term lower usually to lower exposure rates. This section provides an overview of information available on the toxicity of each of the herbicides commonly used in oil palm plantations with respect to humans and the environment.

2,4-D

Human toxicity
Exposure to 2,4-D is predominantly through the dermal and inhalation routes and the substance is classified on the Material Safety Data Sheets of different commercial herbicides as harmful if swallowed, inhaled or absorbed through the skin (89, 159). In general, the toxic effects of the acid 2,4 D and its derivates are regarded as similar (161). Acute toxicity of 2,4-D and all derivates is considered to be low to slight via all exposure routes. The exception is toxicity to the eye, for which the acid 2,4-D and its salts are classed as severely irritating. The ester-derivates, however, are considered to be non-irritating (139).

In soil, 2,4-D esters and salts are metabolised to the parent acid (2,4-dichlorophenol, 2,4-DCP) prior to degradation, which has been reported to cause reduced levels of glutathione (an antioxidant and important component of the body’s natural detoxification system that protects cells from toxins, such as free radicals) in human erythrocytes (136).

At high doses 2,4-D damages the liver and kidney and irritates mucous membranes (138). 2,4-D and its main metabolites are also known to reduce levels of glutathione in human red blood cells (resulting in significant changes in antioxidant enzyme activities (136). The substances are further suspected to have endocrine disruption potential (97, 139, 156).

Eye damage can be irreversible (159). Exposure via the dermal route causes rashes, although 2,4-D is not readily absorbed from most areas of the skin. Absorption does, however, vary with exposure time and body area (160). Chlorophenoxy compounds such as 2,4-D are generally well absorbed from the gastrointestinal tract, but less so from the lung (162). Apart from irritation and inflammation of eyes and skin, symptoms of 2,4-D poisoning include nausea, vomiting, throat irritation, headache, dizziness, coughing and breathing difficulties (156). Substantial dermal exposure as well as occupational inhalation exposure can lead to gastro-intestinal irritation as well as several neurological problems, which include stiffness of arms and legs, lethargy, anorexia, stupor and coma in humans (137, 140). However, 2,4-D and its derivates have been claimed to have low potential for neurotoxicity (161).

While there have been no deaths reported from dermal or inhalation exposure to 2,4-D and its derivates, deliberate suicidal ingestion of large quantities of these chemicals can be fatal due to renal failure, acidosis, electrolyte imbalance and resulting multiple organ failure (137, 163). Between January 1962 and January 1999, 66 cases of chlorophenoxy herbicide poisoning following ingestion were reported in the literature, 22 of which were fatal. A role of adjuvants in these fatalities cannot be excluded (137).

The status of 2,4-D and its derivates as carcinogens is unclear (76, 156, 157, 161). In 1987 the International Agency for Research on Cancer (IARC) classified the chemicals as ‘possibly cancer causing’ (156). In 1997, EPA classed 2,4-D as Group D ‘not classifiable as to human carcinogenicity’ (139). In 2001 an EU assessment classed 2,4-D as having ‘no evidence of carcinogenicity’ (142). Research is ongoing to assess possible links between 2,4-D and its derivates and soft tissue sarcomas, non-Hodgkin's lymphoma and Hodgkin's disease, but there would appear to be little evidence to suggest that exposure to 2,4-D is associated with these or any other cancer (138).

While several sources claim 2,4-D and its derivates to have reproductive and developmental effects (76, 156, 157, 164), other sources regard their potential for reproductive toxicity and mutagenic effects to be low (160, 161).

Environmental toxicity
On an acute oral basis, 2,4-D is classified as being slightly toxic to small mammals and moderately to practically non-toxic to birds (139, 141). It is classed as toxic to aquatic organisms with two products, ‘Headland’ and ‘Herboxone’, considered to be very toxic to aquatic organisms (39, 156). Some products based on the ester form of the herbicide are toxic to fish, whilst others have no toxic effect (53). Thus, 2,4-D can be used to control aquatic weeds in the presence of fish if applied in strict accordance with directions and precautions provided (39). 2,4-D and its salts and esters are considered to present minimal risk to pollinators and other beneficial insects (139). 2,4-D is toxic to aquatic plants and will have a greater impact on vascular as opposed to non-vascular forms. Although also toxic to terrestrial plants 2,4-D exhibits selectively to dicotyledons (141). Studies have shown that 2,4-D had no adverse effects on soil microorganisms (as indicated by extent of nitrogen and carbon mineralization) at rates up to 10 kg a.i./ha over a 28 day period (142).

Dicamba

Human toxicity
Acute toxicity of dicamba is visible as moderate irritation to the skin, but the chemical is extremely corrosive to the eyes, causing potentially irreversible damage (53, 150). Acute toxicity via inhalation is considered to be very low (151). The Material Safety Data Sheet provided by Syngenta for the herbicide ‘Cadence’, which contains

dicamba, specifies ‘low toxicity’ if swallowed, inhaled or for dermal absorption (149). The data sheet further specifies that, while inhalation is a possible route of exposure, there is no significant skin uptake of the herbicide and the dilution with water prior to application reduces toxicity by all routes of exposure (149). The occupational risk of exposure to a toxic concentration for reproductive effects - assuming that workers comply with personal protection standards - is considered to be ‘low’ or ‘negligible’ for aerial and tank truck mixers/loaders, but ‘moderate’ for backpack spray and hack-and-squirt applicators, as commonly employed in developing countries (124).

Acute toxic effects upon ingestion of dicamba have been documented from feeding trials with sheep where congested lungs, haemorrhages, poor digestion, inflamed kidneys and engorged livers were observed at doses of 500 mg/kg (152). Effects of acute poisoning in exposed humans reported to EPA are listed as muscle cramps, shortness of breath, nausea, vomiting, skin rashes, loss of voice, swollen glands, coughing and dizziness (124, 153).

Dicamba is known to inhibit the enzyme acetylcholinesterase, which is present in nervous systems of most animals, thereby leading to accumulation of the neurotransmitter acetylcholine and interfering with the transmission of nerve impulses. Neurotoxicity signs have been shown in feeding tests in rats, dogs and chicken (126, 154).

Dicamba has been associated with reproductive effects as evidenced in rabbits at doses above 3 mg/kg per day (126), and there is concern about potential reproductive effects on humans, particularly when PPE is not used as recommended (124).

There has been some discussion on whether dicamba is carcinogenic and, in particular, whether chronic exposure to the chemical elevates the risk to contract non-Hodgkin’s lymphoma. However, a recent study revealed that exposure of pesticide applicators to dicamba was not associated with overall cancer incidence, nor was there a strong association with any specific type of cancer but patterns of associations found for lung and colon cancers did suggest that further investigation is warranted (130, 131). The Material Safety Data Sheet for ‘Cadence WG Herbicide’ states that no evidence of mutagenic, carcinogenic, reproductive or teratogenic (interfering with development of, or causing malformation in, an embryo or foetus) effects was obtained in laboratory mammal and test-tube systems testing (149).

Environmental toxicity

EPA classifies dicamba, in terms of acute toxicity, as being ‘practically non-toxic for small mammals’ (120), while experimental studies indicate that the herbicide is ‘slightly toxic to mammals’ (124). Although laboratory studies have shown that high rates of exposure to dicamba reduced the survival and hatchability of mallard ducks (112), acute toxicity to birds is considered to be low (124 and no chronic developmental and/or reproductive effects are expected for birds if the herbicide is applied as recommended (120).

Dicamba is classed by the EPA as having ‘slight to practically no’ acute toxicity to fish and aquatic invertebrates (120). However, studies have shown that there are wide variations with respect to acute toxicity, depending on the species, the delivery of the herbicide, the physiological situation of the non-target species and the adjuvants used in dicamba formulations (126).

Dicamba is not toxic to bees (53) and, according to one study, there is no evidence for a prolonged impact of the herbicide on soil microbial activity with respect to nitrification (124). Some researchers do, however, assume a potentially negative impact by the herbicide on soil fertility (126).

Dicamba is toxic to most broad-leaved plants and thus unintended exposure can have a negative impact on native as well as crop plants (124). Its effect on a wide range of crops (soybeans, corn, wheat) as well as non-agricultural plants have been reported in the USA, with specific impact varying from browning and plant damage to mortality of all plants within the treated area (120). Although it has been reported that the herbicide presents no risk to aquatic vascular plants, aquatic non-vascular plants would potentially be at risk with respect to their growth and development (120).

No published information has been obtained on the chronic toxicity effects of herbicides containing dicamba on wildlife species. As such, its impact on survival, growth and reproductions rates of such species remain unclear (120, 124)

Diuron

Human toxicity

Diuron is considered to have low acute toxicity via oral, dermal or respiratory exposure routes (53, 98). The substance can be irritating to eyes and skin, particularly broken skin, upon contact, but diuron is not considered as a skin sensitizer (53, 98). The Material Safety Data Sheet for the herbicide Diuron 4 L reports diuron to be slightly toxic to humans upon ingestion but potentially fatal following ingestion of 0.5 pounds or more of the substance, based on animal studies. Overexposure to the substance through inhalation may also cause liver enlargement, spleen and thyroid effects, red blood cell destruction and cyanosis (blue coloration of skin and mucous membranes due to lack of oxygen in blood supply) and weakness (147). However, according to available studies researched during the USA EPA re registration process for diuron in 2003, no adverse effects attributed to a single exposure to the chemical have been identified (98). In animal studies conducted with rabbits, a short-term effect due to exposure to diuron substance via oral and inhalation routes was shown to be a reduction in body weight as well as food consumption (98).

Diuron is known to have subchronic and chronic systemic toxicity, with the blood, bladder and kidney being the main organs being targeted. Studies conducted with rats showed that anaemia caused by abnormal loss of red blood cells is prevalent. Rat and mouse studies also revealed that there was a significant swelling of the bladder and thickening of the bladder wall in response to high doses of diuron (98).

While evidence for or against diuron being carcinogenic and inducing tumours in the bladder and kidneys is conflicting, the herbicide is considered as a ‘known/likely’ carcinogen by EPA and the EU (97, 98). Diuron is also recognised by the EU as having the ‘potential for endocrine disruption’ (76, 97).

Environmental toxicity
Diuron has been shown to be toxic to aquatic organisms, i.e. freshwater fish, freshwater invertebrates as well as aquatic plants (99). For the 'Environmental Risk Assessment for the Re-registration of Diuron', the USA EPA concluded that diuron is moderately toxic for the majority of aquatic organisms assessed, but highly toxic to Cutthroat trout and the amphipod scud as well as to algae (*Scenedesmus quadricauda*) (76, 99). From chronic studies, diuron has been shown to impact negatively on the growth and survival of Sheepshead minnow and on growth and reproduction of Mysid shrimp (99). The potential risk for aquatic plants has been classed as high (99). Material Safety Data Sheet for the two herbicides Diuron 4L and Diuron 80 WDG Weed Killer (147, 100) state explicitly that these formulations are for terrestrial use only and must not be applied directly to water. Care must therefore be taken not to contaminate water bodies when handling or applying these herbicides.

In terms of acute toxicity, diuron is considered to be practically non-toxic or only slightly toxic to birds. It may present a risk of chronic toxicity to birds, in terms of reproductive impairment, due to its persistence in the environment, but additional data is required for this to be confirmed. The herbicide also presents a potential acute risk to small mammals feeding in short grass treated with diuron at a rate of 12 lbs a.i./A (99). Although the herbicide poses a potential risk to terrestrial plants and a chronic risk to all mammals (99), diuron is practically non-toxic to honeybees and the risk to non-target insects is considered to be minimal (98).

Fluazifop-butyl

Human toxicity
Fluazifop-butyl shows low acute toxicity if exposure occurs via ingestion, skin contact or inhalation. Animal studies have, however, shown that the active ingredient is mildly irritating to eyes and skin (72, 76) as well as to the respiratory passage (92). Fluazifop-butyl has also been shown to cause mild skin sensitisation in guinea pigs (53), and prolonged or repeated exposure to the chemical is expected to cause allergic contact dermatitis (72). The Material Safety Data Sheet for the Syngenta product 'Fusilade II Turf & Ornamental' states the herbicide is 'harmful if inhaled or swallowed' and that 'exposure to high vapour levels may cause headaches, dizziness, numbness, nausea, uncoordination or other central nervous system effects' (90). This commercial herbicide also contains naphthalene as a wetting agent, as well as petroleum distillates and petroleum solvent as other additives. Naphthalene is known to cause liver damage, kidney failure, respiratory failure, damage to red blood cells or coma and is a suspected carcinogen, while high concentrations of petroleum solvent vapours can affect the central nervous system (90).

Subchronic and chronic toxicity studies with fluazifop-butyl have demonstrated that rats are more sensitive to toxic effects than dogs, rabbits or hamsters, possibly due to a longer retention time of the major metabolite fluazifop acid. The kidneys and liver are the main target organs of this chemical, but effects on the skin, eyes, bone marrow, blood and reproductive system have also been documented (90). The toxicity of the substance is expressed as exacerbation of age related liver and kidney toxicity in the presence of peroxasome proliferation. However, results with respect to kidney damage were less conclusive than those for the liver (96). During studies concerning chronic poisoning with fluazifop-butyl the highest doses of the chemical tested caused haematological effects, gastrointestinal lesions, cholesterol depression and cataracts in dogs. Generally, longer duration studies show effects of the active ingredient at lower dose levels (96). Formulations of fluazifop-butyl are also known to have reproductive and developmental effects (90, 95).

Oral intake of the active ingredients by humans results in rapid excretion of fluazifop acid in the urine and almost no excretion in the faeces (96). Fluazifop-butyl is considered to have low human toxicity. Fluazifop-butyl is classified as ‘not likely to be carcinogenic to humans’ and no mutagenic potential was observed in adequate *in vivo* and *in vitro* studies with fluazifop-butyl (96).

Environmental toxicity

Fluazifop-butyl has been shown to be slightly to non-toxic to mammals and birds upon ingestion and slightly toxic to animal skin and eyes (92). The herbicide is considered to have low-toxicity to bees, both orally and by contact (53). The chemical can pass readily into fish tissue and is considered to be very toxic to fish and other aquatic organisms, including invertebrates, with high toxicity shown to bluegill sunfish (96 hr LC_{50} 0.53 mg/l), rainbow trout (*Oncorhynchus mykiss*) (96 hr LC_{50} 1 .37 mg/l) and Daphnia 48 hr LC_{50} >10 mg/l) (1, 53, 90, 92). Due to its possible effects on aquatic organisms, fluazifop-butyl is not registered for use in aquatic systems (92, 95). Although fluazifop-butyl has been found to inhibit fungal growth, it does not appear to have a significant effect on fungal populations when applied at recommended field rates (92).

Due to its high selectivity, broadleaf non-target plants remain unaffected by fluazifop-butyl (53). However, a recent research paper reported that the herbicide, when applied at half to quadruple the recommended field rate, adversely affected development of Australian native and introduced grass and non-grass species in terms of seed germination and seedling development (94).

Fluroxypyr

Human toxicity

Fluroxypyr is considered to have low acute toxicity where individuals accidentally consume residues or get them on their skin and very low to moderate toxicity if the chemical is inhaled (69, 74). Occupational exposure is reported to occur mainly through the dermal and inhalation routes (72). The substance is classed as being non to mildly irritating to the eye, but neither an irritant nor sensitizer of the skin (53, 66). However, when exposed to fluroxypyr, rabbit skin showed slight but temporary irritation, while application to the eyes of rabbits led to severe irritation which resolved in three weeks (69). Some products containing fluroxypyr (e.g. Vista) may cause substantial, albeit temporary, eye injury and are also considered to be harmful if swallowed or absorbed through the skin (69).

In rats and mice fed fluroxypyr for 2 years, kidney abnormalities (and decreased body weight gain in male mice) were observed at high doses. No effect was seen in dogs (69). Although it has been reported not to demonstrate developmental or reproductive toxicity (73), some studies with rats did reveal reproductive and developmental effects at high doses (69). Fluroxypyr does not appear to be mutagenic (69), carcinogenic to humans (66, 69, 73, 74), teratagenic (66) nor a neurotoxin (66, 74).

Symptoms characteristic of poisoning due to exposure to fluroxypyr are headache, giddiness, nervousness, blurred vision, weakness, nausea, cramps, diarrhoea, chest discomfort, sweating, mitosis (contraction of the pupil), tearing, salivation and other excessive respiratory tract secretion, vomiting, cyanosis, papilledema (swelling of the optic nerve head), uncontrollable muscle twitches followed by muscular weakness, convulsions, coma, loss of reflexes, and loss of sphincter control (71). The target organ for this herbicide following oral exposure is the kidney, in terms of both short and long-term toxicity (66, 74). Cases of severe fluroxypyr poisoning may result in acute renal failure (71).

In humans and animals fluroxypyr is rapidly metabolized and excreted, primarily as expired carbon dioxide and to a lesser degree as metabolites, in the urine and faeces. It does not bioaccumulate in mammals (66, 69).

Environmental toxicity

The acid fluroxypyr has been shown to be relatively non-toxic to terrestrial wildlife, but highly toxic to aquatic organisms, in particular to freshwater fish and aquatic invertebrates (i.e. sheepshead minnow, grass shrimp, pink shrimp, oystershell, sliverslide (39, 75). For the ester form fluroxypyr-meptyl, commonly applied as a herbicide (see Section 1), the acute oral LD_{50} values for the aquatic organisms rainbow trout, golden orfe, Daphnia and green algae are above its water solubility limit (which is relatively low, see Section 1). However, upon release into the environment the ester is rapidly hydrolysed into the parent acid in all soil types and water. Due to the high aquatic toxicity of fluroxypyr it may therefore be prohibited to apply the chemical directly to water, in areas where surface water is present or in intertidal areas below the mean high water mark (75). The substance is considered to be non-toxic to bees (53). It has very low acute toxicity to earthworms, and no adverse effect on soil micro-organisms has been shown (66). It is not recommended to apply fluroxypyr in close proximity to non-target plants. With respect to seedling emergence, cucumber has been shown to be particularly sensitive to fluroxypyr-meptyl while cotton is particularly sensitive to the acid fluroxypyr (73). Vegetative vigour of cotton is also highly sensitive to fluroxypyr-meptyl (73).

Glufosinate-ammonium

Human toxicity

Glufosinate-ammonium may be harmful if inhaled or ingested and through dermal contact, considered to be a non- to mild-irritant of the eye but neither a sensitizer nor irritant of the skin (53, 64, 101). Although the herbicide is not considered to be carcinogenic, mutagenic, neurotoxic or teratogenic (53, 56, 64, 101), some effects have been reported (see below).

In plants glufosinate-ammonium acts through inhibition of the enzyme glutamine synthetase (see Section 1), an enzyme which is also present in vertebrates. Glufosinate-ammonium administered to rats or mice has been shown to cause marked inhibition of this enzyme in the kidney and liver (132). Glufosinate-ammonium can also have an effect on the nervous system through interference with neurotransmitter functions involving glutamate (52, 133). Signs of neurotoxicity, such as convulsions, trembling and irregular respiration, have been seen in most species of laboratory animals after exposure to glufosinate or herbicide products containing glufosinate (133). Those effects can be relatively persistent, lasting up to 4-5 days with developing brains in young laboratory animals being particularly at risk (133). Furthermore, there is some evidence to show that chronic exposure to glufosinate-ammonium in mice can result in partial memory loss and changes in the cerebral cortex (52). A brief review of a suicide attempt by ingesting glufosinate in Japan indicated that memory loss may also occur in patients who suffer from acute poisoning (58). Although glufosinate-ammonium has been associated with neurogenic and teratogenic effects (e.g. in laboratory studies with rabbits, rats) (76, 133), other sources indicate that the herbicide does not exhibit teratogenic, neurogenic, carcinogenic or mutagenic effects (53, 101).

Some products (e.g. Basta, see below) that contain glufosinate-ammonium have greater toxic effects than the active ingredient alone (133). Symptoms of localized acute poisoning with glufosinate-containing products (i.e. ‘Ignite’) are similar to those associated with poisoning with other herbicides i.e. irritation to the eyes, skin and the respiratory tract. The safety data sheet for the product ‘Finale SL’, for example, specifies risks of skin irritation and eye injuries based on research on rabbits (67).

Systemic poisoning with products containing glufosinate-ammonium manifests itself as shivering, cramps, gastrointestinal complaints, hyperthermia, dyspnoea, bradycardia/tachycardia, convulsions, respiratory depression, amnesia, drowsiness and/or loss of consciousness. The onset of these symptoms may be delayed for some time (e.g. up to 48 hours with Basta) after exposure (56). Accidental exposure to the herbicide can occur if PPE is not used or if damaged or worn incorrectly. There is a slight risk of accidentally exposure of unprotected bystanders during herbicide application.

Environmental toxicity

Glufosinate-ammonium is considered to be of low toxicity to birds, fish (64, 101). A study in the USA applied a glufosinate-ammonium based herbicide (IgniteR) to juvenile Great Plains toads and New Mexico spadefoots under laboratory conditions to better understand effects on amphibian survival. The result was that survival remained the same, suggesting low toxicity to this substance (57). Birds’ offspring, behaviour, reproduction and physical development of the offspring were largely unaffected (101)

Commercial products of glufosinate-ammonium may be more toxic than the active ingredient. The Material Safety Data Sheet for Basta indicates increased toxicity when compared to the active ingredient. For example, the LD_{50} for rainbow trout is 710 mg/l for glufosinate-ammonium in comparison to 34 mg/l for the product Basta 15 SL 150. A similar situation has been reported with respect to the water flea (*Daphnia magna*) and algae (56). Both algae and higher aquatic plants can be adversely affected by glufosinate-ammonium, with laboratory tests on green algae and duckweed showing moderate sensitivity (101). As a broad-spectrum herbicide, it may also have a destructive effect and lead to mortality in non-target terrestrial plants with which it comes into contact (133).

Glufosinate-ammonium has been shown to be toxic to some life stages of several beneficial arthropods including predatory mites, parasitic wasps and harlequin ladybirds (101, 169). When applied at field application rate, larvae and nymphs of insect predators died within 12 hours of glufosinate-ammonium being directly applied (169). Other studies in which the herbicide was applied to foliage have shown toxic effects on a predatory mite, although these effects were considered to be transient due to recolonisation by the mites from untreated areas (101).

The effect of glufosinate-ammonium on soil microorganisms such as aerobic bacteria and fungi has also been investigated, in which both stimulatory and inhibitory effects with different concentrations and exposure periods were observed. It was concluded that application of the herbicide may result in changes in the community structure of microorganisms and lead to detrimental environmental effects (59). Application of the herbicide at a maximum field rate of 1.5 kg/ha has been reported to have negligible effects on soil microorganisms, while a rate of ten times the maximum field rate resulted in a transient effect (101).

Glyphosate

Human toxicity

Glyphosate is considered by the USA EPA as being of ‘relatively low oral and dermal acute toxicity’ to humans (43), and one of the least toxic pesticides with regard to animals (103). The low mammalian toxicity is based on the absence of the plant enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) which is inhibited by glyphosate. Glyphosate is poorly absorbed in the gut or through the skin with, after oral intake, between 30% and 36% absorbed in most test animals and the majority of absorbed chemical being excreted in the urine (7). Likely routes of exposure to the chemical are via skin, eyes and through accidental ingestions. Exposure through inhalation is considered to be minor, although spray mist of glyphosate formulations may cause oral or nasal discomfort, an unpleasant taste in the mouth, tingling and throat irritation (24).

It has been shown that surfactants used in commercial formulations of glyphosate contribute to the acute toxicity of these products and that human poisoning is due to the complex and variable mixtures of substances in marketed glyphosate products (24, 42). The surfactant (wetting agent) polyoxyethyleneamine (POEA), added to many glyphosate products, is considered to be more toxic than glyphosate and has been identified as a major cause of some of the observed acute and chronic toxic effects (32). Studies have also shown that a combination of glyphosate and POEA is more toxic than POEA alone (32, 42). POEA is a serious irritant of eyes, the respiratory tract and the skin, and has been found to contain dioxane contaminants which are suspected to be carcinogenic (170). It has however been reported that accidental ingestion of glyphosate formulations is generally associated with only mild, transient, gastrointestinal features, and that reported cases of poisoning have resulted from the deliberate ingestion of the concentrated formulations of Roundup 1, containing 41% glyphosate as the isopropylamine salt and also 15% POEA (24). New surfactants have been developed by Monsanto that lack these toxic effects and, while products containing these surfactants are recognised by approval authorities as being non-irritant, they may be more expensive (32, 170). Based on its own tests, the company found glyphosate to have low acute toxicity and few long-term chronic effects.

Skin exposure to the glyphosate formulations can lead to irritation and occasional cases of photo-contact dermatitis are known, effects which are likely to be due to the added preservative Proxel(R) (benzisothiazolin-3-one). Severe skin burns are very rare (24). Eye contact can cause mild conjunctivitis with potential superficial injury to the cornea if decontamination is delayed (24). Accidental ingestion of glyphosate-surfactant herbicide commonly leads to a sore throat and mild, transient gastrointestinal symptoms, i.e. nausea with or without vomiting and diarrhoea (24, 25, 27). Data available on occupational exposure indicates that exposure levels for workers applying glyphosate as the herbicide formulation Roundup are low (40).

If glyphosate-surfactant-herbicide is ingested deliberately (e.g. in an attempt to cause harm or commit suicide), the severity of symptoms is correlated with the amount ingested and increasing ages of the victim, but this cannot be taken as an absolute indicator of severity of glyphosate-surfactant-herbicide (27). Moderate to severe acute poisoning with glyphosate-surfactant herbicide is characterized by gastrointestinal corrosive effects and haemorrhage, oral ulceration, pulmonary dysfunction hepatic or renal damage, cardiac arrest, coma and seizures. If a large amount of the formulation is ingested, death can occur within 72 hours (27).

Monsanto considers technical grade glyphosate to have few long-term chronic effects (32). Long-term feeding studies of high doses of glyphosate have shown to impact on liver and kidney function, reduce weight gain and cause degradation of the eye lens in laboratory animals. Lower doses cause inflammation of the mucous lining of the stomach (40, 42). Glyphosate is not considered to be carcinogenic nor a reproductive toxin (43, 53, 103).

Environmental toxicity

Glyphosate is considered to have low toxicity to mammals and birds (43, 170). Most at risk are vegetation-eating and insect-eating mammals and birds (112). Indirect effects on small mammals by glyphosate applications due to destruction of their habitat, i.e. the vegetation used for food and shelter have also been reported (42). Glyphosate itself is slightly to moderately toxic to fish and aquatic invertebrates. However, glyphosate-surfactant herbicides must be labelled as hazardous to fish due to the toxicity of the surfactants present in the individual products (40, 43). Such products can also cause adverse effects to non-target aquatic plants (43). Adverse effects of products on amphibians have been noted, although these did not differentiate between effects of glyphosate and other formulation ingredients (103). In Australia high concentrations of glyphosate-containing herbicides are not permitted to be used to control weeds near or in water due to the surfactant's toxicity to aquatic life (46). Glyphosate-containing products are hazardous to arthropods, including beneficial insects (42). The Material Safety Data Sheet for the herbicide Quali-Pro Glyphosate T&O states that the product is slightly toxic to invertebrates but has practically no toxicity to bees (44). Although formulations of glyphosate are not considered to be toxic or repellent to carabid beetles, treatment with glyphosate products has reduced beetle numbers, albeit temporarily and including through avoidance of treated areas. It has been suggested this may be due migration due to destruction of plant material, and that absence of these predators reduce predation on lepidopteran pests of crop fields (41, 53). It has also been reported that nitrogen fixation by nitrogen fixing bacteria when is reduced when glyphosate is applied at high concentrations (20kg/ha) (48).

Metsulfuron-methyl

Human toxicity
Metsulfuron-methyl and metsulfuron-methyl containing products, such as Escort, Ally or Innova, have particularly low human toxicity although eye contact may cause eye irritation with tearing, pain or blurred vision. Repeated dermal contact may cause skin irritation with itching, burning, redness, swelling or rash. Inhalation may irritate the throat (79, 80).

The risks of acute or chronic poisoning are low and no cases of poisoning had been reported by 1995 (80). In contact with skin or eyes washing or flushing with copious amounts of water is recommended. If the substance is swallowed, no specific treatment is advised as this compound is not likely to be hazardous by ingestion (80). The herbicide is not considered to be a carcinogenic, mutagenic, teratogenic or a reproductive inhibitor (53, 79, 80). An internal Syngenta study based on animal testing found that long term administration of metsulfuron-methyl did cause body weight loss (79).

Environmental toxicity
Metsulfuron-methyl is generally classed as non-toxic or having low toxicity to mammals and birds. It also shows low toxicity to bees and has very low acute toxicity to worms (53, 79, 80). Metsulfuron-methyl has been shown to have no negative impact on soil and litter invertebrate communities (143). It is known to be toxic to algae, while data on its effect on soil micro-organisms is considered to be insufficient (79, 82). Metsulfuron-methyl exhibits very low toxicity to aquatic organisms, with LC50 values greater than 150 mg/l for rainbow trout, bluegill and the freshwater invertebrate *Daphnia magna*, which included a 21-day life-cycle test for the latter (1, 200).

Metsulfuron-methyl containing products are harmful even at low concentrations to non-target plants, such as indigenous, possibly rare plant species and/or non-target crops, and precautions must be taken to avoid drift due to small droplet sizes and adverse weather conditions (82). However, a study on the effect of the herbicide on 12 aquatic plants, including *Lemna minor*, showed a high tolerance of these plant species in comparison to oil-seed rape (86).

Paraquat

Human toxicity
Although the WHO hazard classifications place paraquat in Group II (moderately hazardous, based on an acute oral LD_{50} of 157 mg/kg for rats, the organisation did note that paraquat has serious delayed effects if absorbed. It therefore considered that, while it presents a relatively low hazard in normal use, it may be fatal if the concentrated product is ingested orally or spread on the skin (9). The highest risk of

occupational paraquat poisoning for humans occurs whilst handling the highly toxic concentrate i.e. during mixing and loading of spray tanks (5). Unnecessarily high exposure to paraquat is often due to lack, or poor standard of, recommended PPE and/or faulty and leaking spraying equipment. The routes of exposure responsible for accidental poisoning with the active ingredients are via the skin, the eyes or through inhalation. As paraquat is poorly absorbed through intact skin, using the herbicide as recommended and employing normal hygiene practices is reported to prevent harmful effects on the skin (6, 8). However, absorption of paraquat in body areas where the skin has high permeability (e.g. genital area) may be considerably higher (4). Localized damage to the skin can occur through accidental contact with concentrated paraquat, resulting in skin irritation, burns and nail loss or discoloration (8). The presence of broken skin, due to sores, cuts or scratches, increases the risk to the user substantially and systemic poisoning can occur through significant exposure of damaged skin. Systemic paraquat poisoning can also be due to prolonged contact with the substance (due, for example, to leaking knapsack sprayers or contaminated clothing) as well as contamination of large skin areas with concentrated paraquat, even when washed (8). Systemic poisoning is reflected by the presence of paraquat in urine and/or blood and manifests itself by symptoms identical to those caused by ingestion (4).

Eye contact with concentrated paraquat can lead to severe inflammation of the cornea and conjunctiva (8) and cataracts have been implicated as a long-term effect (3). While paraquat is reported to be highly toxic by inhalation (2), the lungs are not considered to be a major route of uptake of the active ingredient due to lack of volatility and the size of droplets normally produced by agricultural equipment being too large to be respired (absorbed by lung tissues) (4, 6, 8, 17). If paraquat is applied as a fine mist, exposure can lead to irritation of the upper airways. Pyridine bases added as alerting agents producing a stench can cause nausea and headaches. Nosebleeds are another common occupational hazard due to contact of paraquat with the mucous membranes.

In recent years, due to observed correlation between exposure and disease incidence as well as results of clinical and experimental studies, it has been suggested that exposure to paraquat may be an environmental factor linked or contributing to Parkinson’s disease, a neurodegenerative disease known to be influenced by age and genetic and environmental factors. Although a synergistic effect with other factors rather than a direct effect may be involved, and while the biochemical mechanism by which paraquat causes the neurodegeneration observed in Parkinson’s disease is not fully understood, the destructive effect of paraquat on lipid membranes and consequent cell death of (dopamineric) neurons can be responsible for the onset of Parkinsonian syndrome. As such, it is suggested that paraquat may induce Parkinson’s disease or influence its natural course. Aging has been shown to enhance sensitivity of the dopamine pathway to pesticides and pesticide combinations, including paraquat and maneb, resulting in irreversible and progressive neurotoxicity. Paraquat has also recently been studied as an eligible candidate for inducing the Parkinsonian syndrome in laboratory animals. Despite the suggestive results of epidemiological studies, inconsistencies between results of different studies, the role of genetic and other environmental risk factors (including other pesticides in combination with paraquat) and the possibility of compensatory mechanisms operating to counteract tissue damage highlight the need for more detailed information on the association between paraquat exposure and the disease. These include development of biological markers for the disease and corroboration of data on paraquat use and direct-exposure assessments (4, 34, 102, 166, 193, 194).

Ingestion of paraquat is fatal in most cases as there is no antidote (4). Accidental ingestion was a concern in the 1960s and 1970s mostly due to storage of the herbicide in inappropriate containers. Although the addition of alerting agents (blue dye, pyridine bases and an emetic) has been reported to result in almost complete elimination of such fatalities (127, 172), inclusion of these agents may not be practiced by all manufacturers. In contrast, voluntary ingestion of paraquat with the intention to commit suicide is still common (4, 7). For humans, the lowest fatal dose recorded is 17 mg cation/kg body weight (equivalent of 23.5 mg/kg body weight of paraquat dichloride) (4, 7, 166). The LD_{50} in humans is approximately 3-5 mg/kg, equivalent to 10-15 ml of a 20% paraquat solution. Symptoms of acute systemic paraquat poisoning, such as breathing difficulties, can be delayed if smaller quantities have been ingested. Initial characteristic symptoms of acute poisoning are mouth and throat ulcerations, abdominal pains, vomiting and diarrhoea, kidney failure, liver impairment, hypotension and rapid heartbeat and deteriorating lung function. Death usually occurs from pulmonary failure within 2-3 weeks (8). Severe poisoning due to ingestion of high doses of paraquat (>40 – 55 mg paraquat ion per kg body weight) can lead to death due to cardiogenic shock and multiple organ failure within 1-4 days. While chronic paraquat poisoning has been associated with effects on the lungs, the nervous system, brain and the skin (4, 14, 166), evaluations and reviews by U.S. EPA, WHO and EC conclude that the herbicide is neither carcinogenic, mutagenic, neurotoxic nor teratogenic and does not have an effect on reproduction (3, 17, 109).

Environmental toxicity

EPA consider paraquat to be moderately toxic to terrestrial animals (mammals and birds) and also non-target terrestrial and semi-aquatic plants, while EPA and the European Commission have expressed concern over the adverse effects of paraquat on wildlife, particularly hares and birds. Although less toxic to birds than mammals, the herbicide has been shown to reduce egg viability, the number of normal hatchlings and chick survival in ducks (at doses above 100 ppm), while high doses of paraquat in drinking water caused abnormal egg development in hens. Exposure to paraquat is considered possible through drift of herbicide spray during or following application, with the suggestion that drift of spray to nesting sites may lead to contamination of eggs, reduced hatching and serious abnormalities. Acute toxicity to terrestrial birds and small mammals, however, is reported to exist only immediately or for a short time after application. Once the herbicide dries or becomes bound the risk is greatly reduced. As a consequence, EPA concludes that registered uses of paraquat are not expected to pose a significant risk to birds or to mammals (1, 17, 35, 166).

EPA LOCs have been exceeded for non-endangered and endangered non-target terrestrial and semi-aquatic plants. Depending on the application method and application rate, risk quotients ranged from acceptable to acute effects. To mitigate these risks, EPA has requested registrants to lower maximum rates of use and include warnings on product labels about possible adverse effects on non-target and semi-aquatic plants due to drift (17).

Paraquat is reported to be embryotoxic and teratogenic to frogs (166), although animal studies revealed no teratogenic effects at doses of paraquat lower than the maternal toxicity dose. Its use is also considered to present some risk to non-target terrestrial and aquatic plants (17). Paraquat is considered to be practically non-toxic to honey bees or earthworms (3, 17). The herbicide has been found to be toxic to beneficial nitrogen-fixing blue-green algae and the nitrogen fixing cyanobacteria found in rice paddy fields (168).

WHO hazard classifications place paraquat in Group II (moderately hazardous), based on an acute oral LD_{50} of 157 mg/kg for rats. Acute oral toxicity is reported to be higher in other mammals, for example guinea pigs (22-30 mg/kg), monkeys (50 mg/kg), cats (40-50 mg/kg) and dogs (25-50 mg/kg), cow (50-75 mg/kg), sheep (50-75 mg/kg (166).

Table 6 and Table 7 summarise some of the more important toxicological characteristic of the different herbicide active ingredients, with respect to mammals and other organisms respectively.

Table 6. Summary data of mammalian toxicology of herbicide active ingredients commonly used in oil palm.

Common Name[1]	**Acute Oral Toxicity**[2] (LD_{50} for rat, mg/kg)	**Skin and Eye**				**Inhalation**[4] (for rat, acute inhalation LC_{50}, mg/l)	**ADI/RfD**[5] (mg/kg)	
		Acute percutaneous[3] LD_{50} (mg/kg)	**Eye irritation**	**Skin irritation**	**Skin sensitizer**		**EC**	**EPA - RfD**
2,4-D	639–764	>1600 (rats) >2400 (rabbits)	Irritant	Irritant	Yes	>1.79 (24 h)	0.05	0.025 (acute) 0.005 (chronic)
Dicamba	1707	>2000 (rabbits)	Extremely corrosive, Severe	Moderate	No	>9.6	0.3	1.0 (acute) 0.45 (chronic)
Diuron	>2000	>2000 (rabbits)	Mild	None to intact skin	No	>7	0.007	0.003
Fluazifop-butyl	>3030 (male) 3600 (female)	>6050 (rats) >2420 (rabbits)	Practically none	Mild	Mild	>5.24	-	0.01
Fluroxypyr	2405	>5000 (rabbits)	Mild	No	No	>0.296	0.8	0.5
Glufosinate-ammonium	2000 (male) 1620 (female)	4000 (rats)	Mild	No	No	1.26 (male) 2.60 (female)	0.021	0.063 (acute) 0.02 (chronic)
Glyphosate	>5000	>5000 (rabbits)	Irritant	No	No	>4.98	0.3	2

Metsulfuron-methyl	>5000	>2000 (rabbits)	Mild	Mild	No	>5	0.22	0.25 (chronic)
Paraquat dichloride	157–129	911 (rats)	Irritant	Irritant	No	No vapour toxicity	0.004	0.0045 (chronic)

Source: *The Pesticide Manual*, 14th edition (Reference 53)

1 - According to standards organisations e.g. ISO
2 - Values given for rats, as mg active ingredient per kg body weight
3 - Values given as mg active ingredient per kg body weight
4 - Data relates to rat exposed to the substance for 4 hrs unless stated otherwise († = duration of exposure unknown)
5 - Acceptable Daily Intake (ADI) and Reference Dose (RfD), expressed as mg/kg body weight. ADI is defined by the EC as ‘the amount of a chemical which can be consumed every day for an individual's entire life span with the practical certainty, based on all available evidence, that no harm will result’. RfD is defined by the EPA as ‘an estimate, with uncertainty spanning perhaps an order of magnitude, of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime’. EPA RfD values are estimated for both acute and chronic exposure, and exclude cancer risks. Where a single RfD is given, it is the chronic value.
- = indicates data not available

Table 7. Summary of toxicology of herbicides to birds (mallard duck), fish (rainbow trout), bee, worms and *Daphnia* species (*D. magna*)

Common Name[1]	Acute Oral LD_{50} (for bee, µg/bee)	Acute Oral LC_{50}		Dietary LC_{50} (for mallard duck, mg/l)	LC_{50} (for Daphnia, mg/l)
		Worms (in soil, mg/kg)	Rainbow trout (96 hours, mg/l)		
2,4-D	104.5	(7 d) 860	>100	(96 h) >5620	(21 d) 235
Dicamba	Not toxic (LD_{50}>100 (oral and contact)	-	135	(8 d) >10000	(48 h) 110
Diuron	145 mg/kg (contact)	(14 d) >400	14.7	(8 d) 5000	-
Fluazifop-butyl	Very low toxicity	-	1.37	(5 d) >25000	(24 h) >316
Fluroxypyr	>25	-	>100	-	(48 h) >100
Glufosinate ammonium	>100	>1000	710	-	(48 h) 560–1000
Glyphosate	(48 h) 100 (oral and contact)	-	86	(5 d) >4640	(48 h) 780
Metsulfuron-methyl	>44.3 (oral) >50 (contact)	>1000	>150	(8 d) >5620	-
Paraquat dichloride	(72 h) 36	>1380	26	(5 d) 4048	-

Source: *The Pesticide Manual*, 14th edition (Reference 53)Source: ref. 53

1 - According to standards organisations e.g. ISO

- = indicates data not available

6. Environmental and ecological fate

Once herbicide is released into the environment it is subject to onward transport and/or degradation involving a number of processes. Degradation, a process of biotic or abiotic chemical modification, will usually convert a herbicide to less toxic or less active compounds, although in some instances more toxic or more active substances may be produced. Irrespective of whether the herbicide is deliberately applied to a target organism (i.e. for weed management) or accidentally released (e.g. through spillage) these processes, which constitute environmental fate, will ultimately remove the chemical from its original site of release. Where a herbicide is intercepted by plants it may be taken up, fall or run off (including by rainfall or irrigation), undergo photochemical degradation (photolysis) on the plant surface, volatize into the atmosphere or remain on the plant surface. Herbicide that falls, washes onto or is applied to soil may be degraded biologically, by organisms such as fungi and bacteria, or through abiotic chemical and photochemical processes. It may also be transported downward through the soil (leaching), across the soil surface (runoff) or into the air (volatization).

Soluble herbicides will tend to move through soil dissolved in water (solutes) while volatile compounds will move through the air spaces. Leaching, or movement of a substance through soil with water, is usually (but not always) in a downward direction. Leaching of herbicides is of importance from an environmental perspective, as it may lead to contamination of groundwater[10] and may also move herbicide away from areas, such as the rhizosphere (root zone) where it will have an impact on plant growth. As leaching is generally indirectly related to the organic matter and clay content of soil, and hence to the extent of adsorption, increased adsorption will usually result in reduced leaching. However, leaching may also be influenced by other factors, including the texture and permeability of the soil, the water solubility of the herbicide and the volume of water flow.

Adsorption[11], the accumulation of herbicide particles at soil-water or air-water interface, is a very important process as it removes herbicide from the soil water phase and generally makes it less available for onward transport, degradation or uptake by plants. As a consequence herbicidal activity, which is directly related to the amount of herbicide adsorbed to soil particles, is reduced.

Runoff is a means by which herbicides may be rapidly removed in significant quantities from their site of release, thereby reducing herbicide concentration and efficacy and possibly leading to contamination of the environment, particularly ponds, lakes, stream and rivers which are usual sinks for runoff. Herbicides may be carried in runoff water as dissolved solutes, suspended particles or adsorbed to particles of soil. Rainfall is a major factor contributing to runoff, especially on slopes. It may result in extensive removal of herbicide if it occurs shortly before or after herbicide application

---

[10] Water stored beneath the earth's surface and below the water table which saturates the pores, cracks, and crevices of sand, gravel and rock formations. It is often the source of water for wells and springs.

[11] Adsorption should not be confused with absorption which is defined as the uptake or surface penetration of ions or molecules by or into a substance or organ (e.g. the uptake or penetration of a herbicide by or into plant leaves or roots).

and also leads to leaching of herbicide in soil. Runoff from soil is more likely to occur if the soil is already saturated but may be reduced in soils with high organic content due to adsorption of herbicide to soil particles. The properties of a herbicide, including solubility and adsorption potential, and product formulation will also influence the extent of loss due to runoff.

Herbicides may be transported into and through the atmosphere either by spray drift or volatization. The former may be reduced by careful selection of formulation and by applying herbicide using appropriate equipment and under conditions less favourably for drift. Volatization is considered one of the primary processes by which herbicides are dissipated, with losses being as high as 90%. Volatization is strongly influenced by climatic conditions and will be much greater and more rapid from dry as opposed to wet surfaces, including oil.

At any one time a number of these processes may be acting simultaneously to transport, degrade and therefore remove the herbicide by various means.

Most herbicides are organic in nature and unstable in the environment. While this can be a drawback in that repeated applications may be necessary to attain a satisfactory level of weed management, inherent instability limits persistence and accumulation of the chemical and therefore reduces their risk to non-target organisms and the environment. Persistence will, however, depend on the physiochemical properties of the herbicide, transport and degradation processes acting on it and the rate at which these act. Transport can be a particular problem as it may result in herbicide contamination of areas beyond those in which it was applied. Persistence for longer periods in the environment will therefore increase the potential for a herbicide to be exposed to transport processes and moved or spread to previously uncontaminated sites.

The ecological fate of a chemical substance, as a potential environmental pollutant, is a fundamental aspect of ecotoxicology. It not only describes the processes and mechanisms by which organisms deal with chemicals, but also assesses the functionalities of chemicals within the organisms themselves. Prior knowledge of ecological fate enables predictions of the effects of chemicals’ not only on individual organisms but on the ecosystem as a whole.

Studies of chronic risk and bioaccumulation - or bioconcentration – are vital to understand the ecological fate of chemical substances present in pesticides. Bioaccumulation is a phenomenon often discussed in the context of ecological fate. An understanding of the processes of bioaccumulation is important for several reasons. Firstly, bioaccumulation in target or non target organisms may enhance the persistence of artificially constructed chemicals in the ecosystem as a whole, since they can become fixed in the tissues of organisms; secondly, chemicals stored in tissues are not exposed to direct degradation, As such, they may not only directly affect an individual's health but may also endanger higher trophic levels through predation and ingestion of the stored chemical. Modern theories on bioaccumulation take into account the integration of various environmental interactions, such as ecophysiology, general biology, molecular genetics and selection and the structure of communities (201).

An example of bioaccumulation was the build up of the agricultural insecticide DichloroDiphenylTrichloroethane, or DDT, the effects of which were brought to the attention of the world by the author Rachel Carson's book 'Silent Spring' in 1962 which concluded that pesticides such as DDT were poisoning wildlife, the environment and also endangering human health. As DDT, however, is an extremely lipophilic substance (i.e. able to dissolve in lipids, or fats, such as those in animal tissues), absorption of the chemical by organisms was extremely high, resulting in magnification of its effects as it progressed to higher trophic levels. The effects on thinning of raptors' eggshells and the sudden population explosion of rodents due to exposure of domestic cats to DDT are among the reported environmental impacts of the insecticide (199).

Although the extent of information available for herbicides may vary considerably and is not always comprehensive, the following provides a summary of information acquired on the environmental and ecological fate of each of the herbicides referred to in this report.

2, 4-D

Environmental fate

Drift resulting from spray application of 2,4-D has been highlighted as the main source of herbicide in the atmosphere and, unless proper procedures for application are adhered to, may result in toxic and detrimental effects on nearby non-target plants including crops (128, 179) and the broader ecosystem. Small amounts of 2,4-D that enter the air are largely subjected to photo-oxidation, with an estimated half life of just one day (128), or dissolve into water droplets and are transported back to the earth's surface via wet deposition. Low volatility ester and amine formulations are less prone to drift (144).

The fate of 2,4-D in or on soil is affected by several processes, including adsorption, runoff, photodecomposition, chemical and microbial degradation, and leaching. Residues of 2,4-D can enter ponds and streams by direct application, accidental drift, previously deposited herbicide in dry streambeds, irrigation channels, and by leaching into ponds and streams through the soil column (180). Leaching and runoff of 2,4-D are influenced by the herbicide's formulation, soil properties, slope and timing and the intensity of rainfall, with more runoff into the environment if a rain event occurred shortly after herbicide application and concentrations decreasing with time (182). Leaching of 2,4-D into groundwater reservoirs such as ponds and streams is dependent on soil type with coarse-grained, sandy soils of low organic content more liable to leach the herbicide (128). Losses from forest soils to water bodies are expected to be less than those from agricultural soils due to a number of factors, including reduced surface runoff, greater adsorption to forest litter and by plants, and higher levels of organic material and microbial activity (181).

The breakdown of 2,4-D in soil through photodecomposition is proportionately small and only occurs on the upper surface (128). Microbial degradation is, however, one of the most important mechanisms of 2,4-D breakdown in soil. Water potential, depth and temperature regulate the rate of microbial degradation in the soil and hence the rate of degradation. It has been reported that lowest degradation rate occurs in sandy loam soil containing herbicide degrading single-celled bacteria, filamentous bacteria and fungi (128, 184). Dry soil conditions inhibit 2,4-D mineralization through restriction of solute mobility, reducing the activity of organisms and reducing populations of microorganisms associated with degradation (144). Microbial degradation is also limited by the extent of adsorption-desorption of 2,4-D onto soil particles as the herbicide is rendered unavailable (183).

Ecological fate

In plants, penetration of 2,4-D formulations through foliage and roots is rapid and plant death results from abnormal metabolism of nucleic acids (181). Plants exhibiting resistance to 2,4-D are able to convert the herbicide into inactive, non-toxic carbohydrate conjugates as opposed to amino acid conjugates (which occurs in susceptible plants) (179, 181).

2,4-D may be taken up by mammals through inhalation, ingestion or via the skin and is not metabolized but rapidly eliminated via the kidneys and excreted in urine as the parent compound. As it is highly soluble, 2,4-D is carried in blood and interstitial tissues through the gut and kidneys without accumulation in tissues. It is not metabolized to reactive intermediates and does not cross lipid membranes into tissues without active ion transport systems (185).

Effects of 2,4-D on fish depend on the formulation and the age and species of fish, and bioconcentration can vary considerably (128). When applied in the acid form, 2,4-D shows little tendency to bio-concentrate in fish. If applied as the isooctyl ester, accumulation is expected in the absence of metabolization. Accumulated 2,4-D is, however, rapidly broken down into hydrocarbon fragments which will be utilized by fish for synthesis of normal body tissues and/or will be eliminated from the system (179). In trout, for example, approximately 72% of 2,4-D is excreted in the urine as the unchanged acid within 8 hours of exposure, with a half-life of only 2.4 hours (186).

Dicamba

Environmental fate

Dicamba is considered to be moderately persistent in soil, with a half-life of between 1-6 weeks (124) but, under favourable conditions, 14 days or less (53, 120) being reported. Greatest absorption onto soil particles, and hence slower dissipation, is expected in acidic soils that contain high organic matter content, such as hardwood forests and wetlands. As dicamba is degraded primarily through microbial action both in soil and aquatic ecosystems, it is also likely to be more rapidly degraded in soils with high microbial populations (124). Laboratory studies using sterile and non-sterile soil, for example, revealed large differences in degradation of the herbicide. In non-sterile soil, 50% of applied dicamba had degraded within two weeks while 90% remained in sterilized (heat treated) soil after four weeks, suggesting an important role of microbes. A similar situation has been observed in water, where 16% was found to be degraded after 133 days in non-sterile water as opposed to only 5% in sterile water (128). High moisture and temperature, and other conditions that favour microbial growth and activity, are therefore likely to increase the rate of degradation (122). A much longer half life of 141 days has been reported under anaerobic soil conditions (120).

As dicamba is very soluble (and hence mobile) in water, and is not considered to adsorb well to sediment, there is a risk of significant leaching of the herbicide into water bodies (120, 122, 128). The herbicide is relatively stable to hydrolysis and oxidation. Photochemical degradation does occur in soil and water but, as this is very slow it has little effect on persistence of the herbicide in soil (120, 128).

The principle soil and plant metabolite formed after degradation in soil is 3,6-dichlorosalicylic acid (3,6 DCSA), although 2, 5-dihydroxy-3, 6-dichlorobenzoic acid and 5-hydroxydicamba are also found in minor quantities (122). 3,6 DCSA is moderately toxic to rats, water flea, rainbow trout (76). It degrades in soil at a similar rate to dicamba, is therefore also reasonably persistent in aerobic and anaerobic conditions and would be expected to persist in groundwater (120). 3,6-DCSA is adsorbed to soil much more strongly than dicamba (124).

Ecological fate
Dicamba is not considered to bioaccumulate in terrestrial organisms as, following oral administration, the majority of the herbicide has been found to be excreted, unchanged, in the urine (1, 53). In a two generation reproduction study conducted on rats and rabbits, and following in utero and/or pre-/post-natal exposure to the herbicide, EPA reported no evidence of developmental anomalies or behavioural or neurological effects. Dicamba salts are considered to be practically non-toxic to avian species based on dietary studies, although oral gavage (force feeding) studies have dicamba acid to be moderately toxic to Bobwhite quail and slightly toxic to mallard ducks. However, no evidence was found of bioaccumulation of the herbicide in bird tissues (120).

Data on acute toxicity of dicamba to aquatic species indicate that the substance is slightly toxic to fish and invertebrates. However, and due to a lack of chronic studies to assess survival, growth and reproduction for example, uncertainty exists over the possible chronic effects on fish and aquatic invertebrates. Similarly, and again due to limited data, the risk to sediment-dwelling benthic organisms is unclear (120).

While dicamba is efficiently broken down in most vegetation, bioaccumulation may occur in the tips of leaves of certain plant species or may otherwise cause stunting, chlorosis, and plant death (198, 120). In the USA a number of crops, including soybean, corn and wheat, have been reported to be affected by accidental contamination with dicamba, the level of damage varying from browning of leaves to mortality (120).

Diuron

Environmental fate
Once in agricultural soil, a number of factors may affect the environmental fate of phenylurea herbicides such as diuron. Agricultural practice, soil profile and hydrological conditions, for example, will determine vertical and horizontal distribution of the substance. Based on these factors, diuron may be adsorbed onto the

soil, evaporate into the atmosphere, run off (into rivers and other waterways) or be leached to ground water. It may also accumulate in biota and/or degrade via abiotic and biotic processes. Microbial degradation (metabolism) is considered to be a primary mechanism in the transformation and mineralization of phenylurea herbicides such as diuron (104).

Diuron is not particularly volatile or, due to its relatively low solubility, mobile in water. However, it can be transported in soil where the soil is permeable and therefore has the potential to leach to, and has been found in, ground and surface water (98, 99). It is a strongly adsorbed and highly persistent substance that, once released into soil, can remain for prolonged periods. As such, diuron could potentially accumulate in soils and lead to environmental problems, particularly in agricultural situations where successive herbicide applications leaching to subsurface soil and ground water may occur (104). Reported levels of persistence do, however, vary. In terrestrial and aquatic field studies, EPA reported half lives of between 73-139 days and 115-177 days respectively (98). Variation in persistence of between 30 and 180 days has also been shown in other studies (104). The U.K. Environment Agency suggests a half life as long as 330 days in the upper 5-10 cm layer of soil (178) and that, once released into water, diuron will be adsorbed to sediment where it will slowly biodegrade. Adsorption of diuron into soil is correlated with organic matter content - the greater the organic matter content, the higher the level of adsorption (107).

As mentioned above, microbial degradation is the primary method of degradation of diuron, with microbial degradation in water being the major route of dissipation of the herbicide in the environment (98, 106). Indeed, diuron has been reported to be a substrate for the growth of bacteria (104). Temperature and moisture are also reported to have an effect (107), with warm, dry summer conditions potentially inhibiting microbial degradation of diuron in soil and resulting in an extended half life (106).

In an anaerobic environment the rate of degradation of diuron is much reduced, with a reported half life of 1000 days (99). Such conditions may develop or exist in stagnant ponds or waterways, for example. The herbicide may also be degraded through photolysis in water and soil, although at a slower rate than by microbial degradation (98, 108).

A number of products are metabolised through the breakdown of diuron, including dichlorophenyl-methylurea (DCPMU) and dichloroaniline (DCA). The metabolites are of some concern as their toxic effects are reported to be greater than those of the parent compound (104). EPA also reports the half life of DCPMU to be considerable longer than that of diuron at between 217 and 1733 days in terrestrial field dissipation studies (98). Tetrachloroazobenzene (TCAB), also a substance of concern for human health, was identified as a minor degradate of diuron in a soil photolysis study. Studies on farmland in Australia over a 38 week period following application of diuron showed that the majority of diuron, DCPMU, DCA and the metabolite 3,4-dichlorophenylurea (DCPU) was retained in the upper soil layer (topsoil), suggesting negligible potential for contamination of groundwater. Minimal amounts of diuron and DCMPU escaped in farm runoff. Levels of diuron and DCPMU in stream sediments indicated that they had potential for accumulation in sediments, while greater ecotoxicity of DCPMU to diuron and the presence of both compounds in stream sediments suggest they would collectively have a greater impact on sensitive aquatic species than assessments based on diuron alone (105).

Ecological fate

Diuron is excreted in the faeces and urine of test animals and lipophilic capacity of the herbicide is generally considered to be low, although bioaccumulation has been reported where cattle fed small amounts accumulated low levels of the herbicide in fat and muscle, liver, and kidney. Small amounts of residue have also been found in milk of cows fed on very low doses of diuron (1). Little storage of the herbicide in the tissues is expected. The chronic level of concern for mammals (as designated by EPA) has also been exceeded where small mammals have fed on grasses, broadleaf plants and insects in some crops (citrus, sugarcane and cotton) treated with multiple applications of diuron (98).

Information on the ecological fate and chronic risk to birds is limited and, as reported by the US EPA, cannot be calculated because no chronic avian toxicity data for diuron. An avian reproduction study is required in order to assess bioaccumulation of the herbicide diuron. The herbicide is considered to have potential to cause long-term effects on the aquatic environment, although chronic risk and bioaccumulation studies on fish and aquatic invertebrates are also yet to be reported (see below also). In non-target terrestrial and aquatic plants, the mechanism of chemical distribution is well known, the substance being translocated rapidly from roots to shoots via the xylem with little or no movement from the apex downward toward the base of a treated leaf via the phloem; however, chronic risk studies are yet to be done, and the risk remains unknown (1, 98, 178).

Of 29 known ecological incidents documented (in 2003) by EPA and involving exposure of non-target organisms to diuron, 16 involved fish, 12 involved plants and one birds (98). In the majority of cases where fish were killed this was due to (illegal) direct application of diuron to ponds. Of the few other cases two runoff into waterways from treated crops, although it was unknown whether the herbicide was applied at the rate recommended, and one through runoff from fence spraying. Unfortunately, of these cases, only one involved tissue analysis (for both fish and plants) for which data is not available, although the UK Environment Agency does consider bioconcentration in fish to be ‘not appreciable’ (178). The EPA has highlighted the fact that absence of documented incidents does not mean that they do not occur. Improved reporting and more detailed analysis of incidents such as those outlined above could help to elucidate some of the uncertainty regarding bioaccumulation of diuron and other chemicals in differing organisms.

Fluazifop-butyl

Environmental fate

If released into soil fluazifop-butyl is likely to bind strongly, and perhaps irreversibly, with the soil particles and is therefore likely to remain immobile. The herbicide is also insoluble in water. As a consequence, it is unlikely to contaminate ground water or surface water through surface or sub-surface runoff (1, 72, 92). Volatilization, from either wet or dry soil surfaces, is not expected to be an important process although the potential to volatilize may increase with increasing temperature or soil moisture and decreasing clay or organic matter content (92). Fluazifop-butyl does not readily degrade through photolysis, including under direct sunlight, or through other chemical processes (72, 92).

In soil and water both the ester (fluazifop-butyl) and acid (fluazifop) forms of the herbicide are broken down to herbicidally inactive compounds. Fluazifop-butyl is degraded primarily through hydrolysis and microbial activity (96), which is greater in warm, moist soils and under conditions otherwise favourable to microbial activity (72, 92) with persistence longer in cold and dry conditions (53). Biodegradation is considered to be an important fate process, especially in moist soils where a half-life of less than one week has been reported. Fluazifop, the major degradation product, is less toxic than fluazifop-butyl. It is further degraded by microbes but has a longer half life (of up to 3 weeks) than fluazifop-butyl and is considered to be highly mobile and leachable. In anaerobic soil and water conditions it has a long half lifes and is known to be persistent. Another metabolite, 5-trifluoromethyl-2-pyridone, is also mobile (1, 53, 72, 76, 92, 96).

In water, fluazifop-butyl is expected to bind to sediment and suspended solids and rapidly hydrolyses to fluazifop, the rate of hydrolysis increasing with increasing pH (92). As in soil, volatization from water is unlikely to be an important fate process. In the atmosphere, particulate-phase fluazifop-butyl may be physically removed by wet and dry deposition and in a vapour phase will be rapidly photochemically degraded, with an estimated half-life of 13 hours (72). In soil and water, both the ester and acid form are metabolized to herbicidally inactive forms (92).

In plants fluazifop-butyl is rapidly and completely hydrolysed to fluazifop, which is herbicidally active, within a few weeks of treatment. Degradation of the acid form takes longer, with residues known to remain in plants for more than 6 weeks after application (92). Fluazifop is not considered to be toxic to broadleaf plants or sedges with no injury observed on important macrophytes of wetland habitats three weeks after spray treatment with the active substance at rates equal to or exceeding recommended rates (197).

Ecological fate

When applied at recommended rates, fluazifop-butyl is not expected to present a hazard to wildlife, effects of the herbicide on wildlife habitat are expected to be minimal and adverse effects on fish and fish habitat are unlikely. Studies on the absorption, excretion and tissue retention of (labelled) fluazifop-butyl in mammals following oral and intravenous administration (1 mg/kg and 1000\mg/kg) have shown fluazifop to be the only metabolite detected in the blood. Clearance of the herbicide was independent of the route of administration, the major route of excretion being via the urine. However, clearance differed depending on the sex and dose, with half-lives of elimination at the lower concentration of 26-33 hours in males but only 2.7 hours in females. There is no indication that the enzymes involved in the biodegradation process become saturated through repeated exposure (197).

In birds, administration of (labelled) fluazifop-butyl over a 14 day period to domestic hens and at concentrations at least 10 times higher than those generally detected on treated crops showed that 97% of was recovered in the faeces. Metabolism and clearance was rapid, with very low levels detected in the eggs. Little fluazifop-butyl has been found to accumulate in the tissues of mallards and Bobwhite quail following daily oral administration (at 0.15 mg/kg and 0.20 mg/kg body weight respectively) for up to 28 days, suggesting low bioaccumulation potential of the herbicide. Reproduction was not affected in any way by diets containing 5 and 50 ppm of fluazifop-butyl, while spray application to fertile mallard duck eggs of the product Fusilade 250 EC at application rates equivalent to 0.5 and 2.5 kg a.i./ha during incubation produced no adverse affects on duckling hatchability, growth or survival to 14 days of age. The findings of these studies, as part of comprehensive assessments based on Fusilade, suggest that fluazifop-butyl poses no hazard to wild birds when applied at label rates and that no further avian testing is warranted (197).

In water, fluazifop-butyl is rapidly hydrolyzed to fluazifop acid which remains stable while in an aquatic environment. It has however been reported that there is moderate potential for bioconcentration of this herbicide in aquatic organisms (72). Fluazifop-butyl can pass readily into fish tissue and, as indicated in Section 5, is highly toxic to fish and other aquatic species including invertebrates. One study, conducted in 1990, suggested that bioconcentration in aquatic organisms is very high (76). In a continuous flow system, and based on whole body concentrations, the substance was found in bluegill (*Lepomis macrochirus*) tissues at 320 times the water concentration with the maximum body concentration reached in one day. The degradation product fluazifop has also been shown to bioconcentrate more than two-fold its water concentration in the channel catfish (*Ictalurus punctatus*). However, rates of depuration (removal from the body) were rapid, bluegill losing 97% of residues in three days and channel catfish 80% within a day. Hydrolysis of fluazifop-p-butyl to the much less toxic fluazifop was also very rapid. Given the rapid hydrolysis observed, it was concluded from these studies that there is little potential for bioaccumulation in fish or adverse effects on fish habitat, while the toxicity of the initial breakdown product, fluazifop, is low (197). Nevertheless, fluazifop-butyl is not normally registered for use in aquatic systems, with information on products containing the substance indicating that they may have a negative impact on aquatic ecosystems (90, 95).

Fluroxypyr

Environmental fate

Fluroxypyr is classed as being mobile in soil. However, dissipation by hydrolysis and microbial degradation have been shown to reduce persistence and also limit downward movement (leaching) in soil in field studies (73). Mobility of the substance also strongly decreases with increased residence time in soil (72). A study undertaken in 2005 showed that, one day after treatment, the herbicide had leached 50 cm into the soil while, after 14 days, it was no longer detectable, indicating that degradation occurs quickly and persistence is short (65). EC dossier laboratory and field studies have shown typical DT_{50} ranges for fluroxypyr of 3 - 55 days and 34 - 68 days respectively (76). Volatilisation of fluroxypyr from water or soil is not expected (72). It was considered unlikely that there would be any residues in the leaf or products of oil palm (65).

In soil, fluroxypyr is degraded to carbon dioxide and two main metabolites, 4-amino-3, 5-dichloro-6-fluoropyridin-2-ol and 4-amino-3, 5-dichloro-6-fluoro-2-

methoxypyridine (53). These metabolites are considered to be moderately toxic to aquatic life with, for example, acute LD_{50} values (rainbow trout) of 3.5 and 39 mg/l for the two metabolites in comparison with 14.3 mg/l (bluegill sunfish) for fluroxypyr. Acute EC_{50} of the three substances for aquatic plants (common duckweed) range from 8 to 15.5 mg/l (76). Persistence of 4-amino-3, 5-dichloro-6-fluoro-2-methoxypyridine may be considerably longer than that of fluroxypyr, EU dossier laboratory studies reporting a DT50 range of between 20 and 429 days (76).

Ecological fate

As fluroxypyr shows no tendency to bioaccumulate, the ecological risk it presents is considered to be low (66, 71). Mammalian studies have shown administered fluroxypyr (as fluroxypyr methylheptyl ester and methylheptanol) to be extensively absorbed (90%) but rapidly eliminated. The principal route of excretion of the herbicide is by expiration, with more than 50% being absorbed and expired within 12 hours of administration and a further 20% (approximately) excreted in the urine within the same period. Based on these studies a half-life of 6 hours was reported. Terrestrial mammals and invertebrates are generally not affected by fluroxypyr. In a one year chronic feeding study in dogs, no adverse effects were observed and no abnormalities observed through haematology, clinical chemistry or urinalysis. Furthermore, no abnormal findings were made at necropsy, nor were there any significant changes in food consumption or body weight (73).

Glufosinate-ammonium

Environmental fate

Glufosinate-ammonium shows moderate tendency to adsorb to soil. The major factor in determining the extent of adsorption appears to be clay content, for which there is a positive correlation (61). The herbicide has a relatively short half-life in soil of between 6 and 23 days although, in coarse textured soils, persistence may be extended (51). Adsorption may also be enhanced in soils rich in iron and aluminium oxides and hydroxides (101).

Despite a moderately low level of adsorption to soil, the likelihood of this substance leaching is not considered to be high due to rapid and efficient degradation by microorganisms (61). Lysimeter and field leaching studies and computer simulations have therefore shown minimal risk of glufosinate-ammonium leaching into groundwater (101). Microbial activity is the major method of degradation and leads to production of two major metabolites; 3-methylphosphinico-propionic acid (MPP) and 2-methylphosphinico-acetic acid (MPA) (61, 101). These metabolites, which are less toxic than the parent compound (64), are further degraded into carbon dioxide and bound residues (53, 101). Neither metabolite is considered to be persistent, with half lives ranging of between 6 and 38 days (MPP) and 1 and 19 days (MPA). Both metabolites adsorb to the soil to some extent, MPA showing greater adsorption properties, particularly in clay soils and with increasing pH (64).

In (sterile) water glufosinate-ammonium is hydrolytically stable, is not degraded by photolysis and is not readily biodegradable (64, 101). Degradation occurs in a similar way to that in soil, but producing an additional major metabolite - ethylphosphinicoformic acid (MPF) - which is further degraded (64, 101). Photodegradation of glufosinate-ammonium in water or in soil does not appear to occur (64).

Ecological fate

The majority of glufosinate-ammonium ingested by animals is rapidly excreted, mainly via the faeces, with little movement of the herbicide to organs or tissues other than those involved with elimination. MPP is the principal faecal metabolite produced, along with N-acetylglufosinate formed by intestinal micro-organisms. Repeated ingestion (administration) has been shown not to have an influence on excretion or metabolism of the herbicide. The herbicide is reported not to accumulate in the fatty tissues of fish or other animals (53, 56, 101). In contact with soil glufosinate-ammonium is usually rapidly degraded with only the breakdown product MPP considered to be taken up by plants, and in very small quantities (53, 101). The risk of glufosinate-ammonium to birds, bees, earthworms, other soil non-target macro-organisms, soil micro-organisms and biological methods for sewage treatment is considered to be low (64).

Glyphosate

Environmental fate

The risks of contamination of ground and surface water by glyphosate are considered to be limited. It is strongly adsorbed in most soils, perhaps more so than most other herbicides due to the polarity of the molecule, and despite its high solubility in water generally does not show tendency for movement or leaching and has low potential for runoff. As it also exhibits low volatility there is usually little or no movement into, and hence contamination of, the atmosphere. However, and while the mechanisms are not clearly understood, the extent of adsorption may be influenced by a number of factors, including pH, mineral composition, phosphate content and organic matter. Glyphosate is, for example, strongly adsorbed by minerals in soil at pH 4-8, particularly soils that contain variable-charge minerals such as iron and aluminium. In contrast, adsorption is reduced in soils containing permanent-charge minerals such as illite and smectite. As phosphate behaves in soil with respect to adsorption in a similar manner to glyphosate, the presence of both substances may reduce glyphosate adsorption due to competition for sorption sites. As a consequence, problems with leaching, for example, may occur where the soil has become saturated with phosphate due to fertilisation. (1, 28, 103).

Although glyphosate exhibits moderate persistence in soil, studies of persistence have shown variable results and initial breakdown has been observed to be more rapid than subsequent degradation of the remaining metabolites (1, 42). It has also been reported that the herbicide does not move more than six inches below the surface layer of soil and remains relatively immobile due to adsorption to different soil and clay minerals (42, 43). It is therefore not likely to contaminate ground water, but may contaminate surface waters due to its aquatic use patterns. Where erosion occurs, the herbicide will be carried in runoff water and has been reported to be found in ground and surface waters (42, 43).

Degradation of glyphosate is primarily through microbial activity (1, 40). In soil glyphosate is degraded mainly into aminomethyl-phosphonic acid (AMPA) by microbes, with no adverse effects on microbial activity being noted (29). AMPA is subsequently converted to carbon dioxide and ammonia and, like glyphosate, is not considered likely to contaminate groundwater due to its strong adsorption and has been shown to be retained in the upper soil layers (28, 40, 43). Although it is considered to have low acute toxicity, trials on rats have reportedly shown effects such as reduced body weight and changes within the urinary system (42).

In water, glyphosate is less durable than in soil but is strongly adsorbed to suspended soil particles and is again degraded mainly through microbial action (1). In water it would not be readily degraded by chemical (e.g. hydrolysis) or photochemical activity (40, 43).

Ecological fate

Glyphosate exhibits low toxicity to animals due to its mode of action being based on prevention of the production of aromatic amino acids, essential to plants but not produced by animals. Furthermore, orally ingested glyphosate is poorly absorbed by the digestive system, is rapidly excreted unchanged and has shown little or no tendency to bioaccumulate in animal tissues. Although glyphosate, through possible contamination of waterways, may present a risk to aquatic organisms, it is not expected to bioaccumulate in view of its high water solubility and ionic properties, as confirmed in studies on fish, crustaceans and molluscs. It also shows very low potential to accumulate in the tissues of aquatic invertebrates (1, 40, 53). Only traces of the substance were found in the tissues of farm animals and their products after feeding with glyphosate (1). Studies have however shown AMPA to cause a variety of toxicological problems, including in the liver, bladder and kidney (42). In plants glyphosate is translocated, including to the roots, but may be metabolized rapidly by some species while remaining intact in others (1).

Metsulfuron-methyl

Environmental fate

Metsulfuron-methyl is considered to be moderately persistent but highly mobile with the potential to enter surface water from runoff. However, due to low rates at which it is usually applied and microbial degradation, it is considered to have little potential for contaminating ground water (82, 202). Adsorption of the herbicide to soil is affected by many factors, including pH, temperature, soil moisture and organic matter content. Studies on different soil types commonly found in Malaysian oil palm plantations have, as for other herbicides, indicated that soils of high organic matter content had a high affinity for adsorption of the herbicide. However, pH was observed to have a greater effect on adsorption, with soils of low pH exhibiting greater adsorption capacity (81). Adsorption to clay soils is reported to be poor (80).

The estimated half life of metsulfuron-methyl in soil is reported to range from one week to 180 days, with degradation occurring more rapidly in soils of lower pH, higher moisture content and at higher temperatures (53, 79, 80, 202). Metsulfuron-methyl is degraded in soil mainly by two processes, chemical hydrolysis and microbial degradation, to produce non toxic, non herbicidal products. In neutral to alkaline soils microbial degradation is the major pathway of herbicide breakdown. In acidic conditions occurs to produce 2-(aminosulfonyl) benzoate, 2-(aminosulfonyl) benzoic acid, phenylurea and saccharin as products (76, 84). Both pathways of degradation have been shown to occur primarily in surface soil where there is greater organic matter content, more abundant microbial populations and higher pH (84).

Metsulfuron-methyl does not evaporate easily but is readily soluble in water. As such, it may be highly mobile (especially in alkaline soils) and may cause contamination in surface waters if applied directly to water bodies or wetlands. Nevertheless, the half life of the herbicide in water, when exposed to artificial sunlight, has been found to be may be as short as one day. Metsulfuron-methyl may also contaminate ground water at very low concentration, especially by leaching through sandy and silt-loam soils of lower organic matter (80). As an acidic compound, and in alkaline soils, it has been shown to leach more deeply into soil with field trials revealing leaching to a depth 120 cm following rainfall and irrigation (83, 84). Conditions conducive to leaching may therefore result in the herbicide moving to zones of low organic matter and low microbial activity. In such zones, and with microbial activity being the major degradative pathway in alkaline soils, it is likely that the herbicide will persist for longer (83, 84) and may also have a more damaging effect on non-target plants, including crops.

Ecological fate

Like glyphosate, metsulfuron-methyl is excreted from mammals largely unchanged, with the methoxycarbonyl and sulfonylurea groups only partially degraded by demethylation and hydroxylation (53). The herbicide is considered to have either no potential or low potential for bioaccumulation (79, 82) and, although it exhibits toxicity to fish and aquatic invertebrates, has been reported not to bioaccumulate in the former (80).

Metsulfuron-methyl is reported to rapidly break down in animals and to be eliminated from the body. In rats treated with the herbicide, for example, half lives of 23 - 29 hours were observed for elimination of high doses and 9 - 16 hours for lower doses. The substance is recognised as being practically non-toxic to aquatic organisms and has been shown not to bioaccumulate in fish (1, 85, 200, 202).

Metsulfuron-methyl is rapidly taken through plants roots but will degrade completely to non-herbicidal products within a few days through hydrolysis and conjugation. Breakdown occurs rapidly in cereal plants (1, 53, 202). In oil palm specifically, herbicide residues in soils planted with oil palm have been shown to cause leaf chlorosis in plants after three weeks (87).

Paraquat

Environmental fate

After application, free paraquat is rapidly degraded or becomes irreversibly deactivated by soil (6). In contact with soil, including soil particles and sediment present in water, the herbicide is rapidly and strongly adsorbed (6, 53, 77, 166), becoming immobile and inactivated (17, 53, 166). As a consequence, contamination of surface and ground water due to runoff, drainage and leaching groundwater is not considered to be a problem (53, 77, 166). The extent of adsorption depends on soil type and, as binding to organic and clay particles is particularly rapid and strong, increases with increasing clay and organic matter content (4, 77). The herbicide has been found to be slightly mobile in sandy soils while addition of fertiliser, such as ammonium, may also increase mobility (4). While adsorption limits availability of the herbicide for uptake by plants and other organisms it also greatly reduces availability to, and therefore degradation by, soilborne organisms such as earthworms and microbes – leading to greater, and perhaps indefinite, persistence (4, 77, 53, 166, 187, 188). Half lives of 1000 days and 13 years have been reported, for example, raising concern as to the extent to which paraquat may gradually bioaccumulate in soil (166).

In water, paraquat also adsorbs rapidly and strongly to suspended matter, including soil particles, sediment and plants where it is subsequently degraded and, while in aqueous solution, is not subject to hydrolysis nor to photodegradation (4, 6, 17). While it could be found in surface water associated with soil particles carried by erosion, it is not considered to be a groundwater concern under normal patterns of use (17). Indeed it has been reported that more than 99% of paraquat applied in accordance with GAP is strongly adsorbed with the remainder, held in soil solution, being rapidly and completely degraded by soil microorganisms. As a consequence, continued use of paraquat according to GAP is not considered to have detrimental effects on soil flora or fauna (20). A half life (DT_{50}) of less than 7 days has been reported for non-adsorbed herbicide in soil (53) while, in water, variable half lives of between 1.5 and 23 weeks have been observed, depending on the nature of the study (166).

It has been estimated that the strong adsorptive capacity in soil is several hundred times greater than the amount of paraquat normally applied in a year (4). FAO does not consider potential phytotoxicity to crops from paraquat residues in soil a problem (4). It is also considered that residue levels in food and drinking water resulting from normal use are unlikely to present a health hazard (109).

As paraquat is considered to be non-volatile, spray drift, especially following aerial application, is likely to be the primary cause for concern in terms of atmospheric distribution and fate (6, 17, 35, 76).

Ecological fate

Paraquat is not considered to bioaccumulate in animals, including mammals, birds, fish or other aquatic organisms, but may do so in aquatic vegetation with levels of abnormalities and mortality in tadpoles being attributed to high levels of paraquat present in aquatic plants on which they were feeding. (6, 53, 166). The herbicide has also been found to be toxic to blue-green algae and cyanobacteria (166). Studies in mammals (rat) have shown the herbicide to be rapidly excreted, with the majority (>90%) of orally administered herbicide being excreted in the faeces and urine within 3 days (53). Although exposure of mammals, birds and other non-target terrestrial and semi-aquatic plants may occur due to spray drift, acute toxicity is considered to exist only for a short period after application and risks to greatly decrease due to bound and dried herbicide being less hazardous (17).

Paraquat is rapidly photochemically degraded on surfaces exposed to light, including plants, with methyl-carboxypyridium chloride and methylamine hydrochloride as breakdown products (20, 53). In terrestrial plants, and as paraquat is broken down by the sun on the surface of plant leaves, it should rarely be found in food unless the herbicide was applied shortly before harvest. In a long term study of the fate of paraquat and its uptake in cereal crops, uptake and concentration of the herbicide were initially high but soon fell to undetectable levels. On the basis of field trials it has been concluded that repeated applications of paraquat at rates corresponding to GAP will not affect earthworm populations. Similar results were obtained for microarthropods. (20).

7. Summary and concluding points

As mentioned in the Introduction, the primary objective in preparing this report was to collate and present information on the toxicology and fate of herbicidal substances commonly used in oil palm production. In preparing the report almost 200 literature sources of relevance were examined and referenced. These include scientific journals, electronic databases (including the extensive agricultural databases held at CABI), internet websites, herbicide material safety data sheets and a range of grey literature. A significant proportion of the information was obtained from European and USA sources and/or did not refer specifically to herbicides for oil palm, the information is nevertheless of considerable value.

Extensive and detailed information has been included in the report with regard to the physical and chemical properties of each of nine herbicide active substances, the mechanisms by which they exert their herbicidal effects and the purposes for which they are suitable and why. Although a complex and much debated subject for which considerable detailed information is available from diverse sources, the toxicology of each herbicide is presented in relation to effects on humans, animals, plants and other organisms, both terrestrial and aquatic. Much of this information is based on numerous scientific studies for which the findings and conclusions, for various reasons, are not always consistent. The manner in which the herbicides are known, or expected, to behave in the environment following release is also presented and is increasingly a cause for concern and debate for pesticides generally. From a more practical and applied perspective, and based on the various characteristics including toxicology, the hazards and risks associated with each substance are presented along with recommended measures – including the use of protective equipment – that will help to reduce the level of risk. Importantly in this context, consideration is also given to herbicide products as these constitute formulations that can vary markedly in terms of the type and concentration of ingredients (including the active ingredient(s)) they contain. As such, and as the marketed package available to growers, they also differ considerably in terms of toxicity and the level of hazard they present and must therefore be treated accordingly. In the report a broad range of products known to contain each of the active ingredients, or a combination of active ingredients, has been listed along with their manufacturer, thus facilitating selection and acquisition of suitable products from recognised manufactures and retailers.

The intention was to present this information in a comparative but unbiased manner to provide a resource on which palm producers and other stakeholders within the oil palm industry could base future decisions regarding weed management practices. The authors are of the opinion that the information provided in the report will be of major benefit for decision-makers, from selection of appropriate herbicides by individual growers to development of broader, improved weed management policies by RSPO as an international association representing the industry as a whole. It was not the intention, nor within the remit, of the authors to make recommendations as to which herbicide(s) should be utilised for a particular purpose or to suggest that any herbicide(s) should be avoided. These are decisions that can only be made by those within the industry based on their respective objectives and needs and how they perceive the attributes and benefits of herbicides and of any proposed modification in approach to weed management. As such, every effort has been made to ensure that a particular substance or product was not promoted in the report to the disadvantage of others.

The manner in which the information is presented does however enable comparison of the herbicides on the basis of specific characteristics. For example, the nine active ingredients referred to have been grouped according to their mode of action, on which herbicide selectivity, plant resistance/tolerance to herbicides and many other properties are based. Where weed resistance to herbicides is to be avoided, or has already been encountered, the use (e.g. by rotation) of substances exerting their effect through alternative modes of action may be very beneficial. Herbicides that are more suitable for, and in some cases already known to be effective against, particular weed types have been highlighted.

In order to make informed management or policy decisions concerning use of herbicidal substances in oil palm production, or simply decide whether herbicides should constitute a management component, many factors must be taken into account. These include the attributes, be they perceived as advantageous or disadvantageous, of the herbicide substances and products available. Although many of these attributes have been highlighted and discussed in this report, reaching a conclusion on more appropriate or preferred substances and products is not an easy task. They must be considered in context of the reasoning behind weed management needs and objectives and also the circumstances or environment (e.g. agroecosystem) in which weed control is to be implemented. These are key factors that may vary considerably and of which those responsible for deciding on and implementing weed management strategies must have good understanding.

Importantly, and in reflection of their toxicological properties, the hazards and risks of the active substances are highlighted in the report, as are hazard classifications as defined by internationally recognised organisation and authorities. Hazard classifications are authoritative, derived following extensive reviews by pesticide specialists across the world and form the basis for national regulations and legislation in many countries. They may also provide a baseline for the development of agreements on the movement (import and export) of herbicides between countries and regions such as Europe and the USA, where regional agreements are already established. The report highlights countries in which the use of each of the herbicides is known to be - or has previously been - prohibited or restricted. Related to toxicology, hazards and risks the report provides information on recommended PPE and other precautions that should be taken if a particular substance or product is to be handled or used. Such information should be taken into account with other factors when herbicides are being considered for use, particularly in circumstances where the recommendations cannot be fully adhered to due for example to excessive costs of purchase, unfavourable climatic conditions for use or inability to adequately maintain the PPE.

Where a preference or necessity exists for a substance or product with particular attributes to be substituted, due to its withdrawal from the market for example, the information in this report will assist in the identification of substances (and associated products) possessing similar and possibly more beneficial characteristics. Of the nine substances 2,4-D and paraquat are classified by WHO as being more hazardous (Class II - moderately hazardous) than dicamba, fluazifop-butyl and glufosinate-ammonium

(Class III - slightly hazardous). These, in turn, are more hazardous than diuron, fluroxypyr, glyphosate and metsulfuron-methyl (Class U - unlikely to present acute hazard in normal use). Of significance some of the substances, while of differing class designations, exert their effect through a similar mode of action. This may offer possibilities for substitution. 2,4-D, dicamba and fluroxypyr, for example, are selective, systemic, auxin-type growth regulators effective for the control of broad leaf weeds. 2,4-D and fluroxypyr have both been reported as used for control of the broadleaf creeper *Mikania micrantha*.

During the preparation of this report, and as another component of the RSPO funded Integrated Weed Management project, a survey of weed management practices employed by oil palm growers was initiated in Colombia, Indonesia, Malaysia and PNG. Preliminary findings from this study, which reflect feedback from organisations in the latter three countries, show that growers employ a broad range of weed management practices, both chemical and non-chemical. However, all growers indicated that they include herbicides as part of their overall strategy and most consider them to be very cost effective in relation to the perceived benefits. The survey data confirmed the use of one or more of the nine substances referred to in this report by each of the growers. Glyphosate and metsulfuron-methyl were used by all or virtually all of the growers and 2,4-D and paraquat by about half. The other five substances were less commonly used. More comprehensive information will become available from this study as further feedback is received from participating growers.

.

Appendix 1

World Health Organization (WHO) classification for estimating the acute toxicity of pesticides

Class		LD$_{50}$ for the rat (mg/kg body weight)			
		Oral		Dermal	
		Solids[1]	Liquids[1]	Solids[1]	Liquids[1]
Ia	Extremely hazardous	≤5	≤20	≤10	≤40
Ib	Highly hazardous	5-50	20-200	10-100	40-400
II	Moderately hazardous	50-500	200-2000	100-1000	400-4000
III	Slightly hazardous	501	≥2001	≥1001	≥4001
U	Product unlikely to present acute hazard in normal use	≥2000	≥3000	-	-
O	Not classified; believed obsolete				
FM	Fumigants, not classified under WHO				

1 - Solids and liquids refer to the physical state of the active ingredient being classified
- = indicates data not available

Appendix 2

Environmental Protection Agency (EPA) categories and signal words derived from the acute toxicity of pesticides

Category	Signal word	Acute toxicity to rat			Eye effects	Skin effects
		Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)	Inhalation LC_{50} (mg/l)		
I	Danger[1]	≤50	≤200	≤0.2	Corrosive; corneal opacity not reversible within 7 days.	Corrosive
II	Warning	50-500	200-2000	0.2-2.0	Corneal opacity reversible within 7 days; irritation persisting for 7 days.	Severe irritation at 72 hours.
III	Caution	500-5000	2000-20000	>2.0-20	No corneal opacity; irritation reversible within 7 days.	Moderate irritation at 72 hours.
IV	Caution	>5000	>20000	>20	No irritation.	Mild or slight irritation at 72 hours.

1 - In addition, if the product was assigned to Toxicity Category I on the basis of its oral inhalation or dermal toxicity the word 'Poison' also applies.

Appendix 3.

Glossary (as related to herbicides/pesticides)

Active ingredient	The chemical in a pesticide formulation that kills or otherwise controls a pest or a weed. The remainder of a formulated pesticide is one or more inert ingredients.
Brand name	A name used by a pesticide manufacturer or supplier for a formulation, and the most prominent name on product labels and in advertisements.
Common name	A relatively short name for a pesticide, approved by either an international body such as ISO (International Organization for Standardization) or by a national body such as ANSI (American National Standards Institute) or BSI (British Standards Institution).
Defoliant	A plant growth regulator that causes the leaves or other foliage to drop from a plant, usually to facilitate harvest.
Desiccant herbicide	A herbicide that promotes the drying of living plant tissues, such as unwanted foliage.
Formulation	A pesticide as sold to personal and professional end users, usually a mixture of an active ingredient and several inert ingredients, and with a prominently-displayed brand name on its label.
Herbicide	A pesticide that is used to kill plants, or to inhibit their growth or development. Also known as weedkillers.
Herbicide safener	A chemical that protects crops from injury by herbicides, but does not prevent the herbicide from killing weeds.
Inert ingredient	A substance that is not an active ingredient and that is included in a formulation for reasons other than pesticidal activity. Functions of inert ingredients include diluting the pesticide, making it safer, making it more effective, making it easier to measure and mix, making it easier to apply, and making it more convenient to handle. Despite being called ‘inert’ and not being toxic to pests, these substances can be biologically or chemically active, and can cause environmental and health problems. In some countries, they are listed on the label.
Label	The printed information on the packaging of a pesticide formulation that displays the brand name, provides information about the active ingredient, gives instructions for using the product, and lists additional information as required by the registration authority.
Natural pesticide	A pesticide in which the active ingredient is a biochemical or some other naturally-occurring substance, as opposed to a synthetic pesticide in which the active ingredient has been manufactured. It must not be assumed that natural pesticides are safe or environmentally friendly.
Non-target organism	Any organism that a pesticide is not intended to control.
Organic pesticide	A pesticide that is an organic chemical, meaning that the molecule consists mainly of a carbon skeleton plus other elements such as hydrogen, oxygen, nitrogen, sulfur, phosphorus or chlorine. By this definition, nearly all pesticides are organic, while only a few are inorganic, such as copper sulfate, cryolite, lead arsenate, mercurous chloride and phosphine. **or** A pesticide that is claimed to be environmentally friendly. By this definition, very few pesticides are organic. Claims that a pesticide

	is environmentally friendly should be viewed with scepticism.
Organism	Any living thing, including humans, mammals, birds, fishes, insects, snails, plants, fungi, bacteria and viruses.
Pesticide	A substance that is intended to kill, repel or otherwise control any organism that is designated a ‘pest’, including weeds, insects, snails, rodents, fungi and bacteria.
Plant growth regulator	A substance that alters the expected growth, flowering or reproduction rate of plants. Fertilizers and other plant nutrients are excluded from this definition.
Registration	Formal licensing with a government-approved body of a new pesticide formulation that allows it to be distributed and sold. Registration normally requires data that demonstrates no unreasonable adverse health or environmental effects when applied according to the directions on the label.
Safener	A chemical that when used in combination with a pesticide reduces its effects on non-target organisms. Only herbicide safeners have so far been produced, and these protect crops from injury by herbicides but do not prevent the herbicide from killing weeds.
Synergism	A phenomenon in which a mixture of two chemicals exhibits higher toxicity to a pest than would be expected from their individual toxicities. It can involve either two pesticides, or one pesticide plus a substance that is not by itself toxic to the pest (termed a synergist).
Synergist	A chemical that enhances the toxicity of a pesticide to a pest, but that is not by itself toxic to the pest.
Synthetic pesticide	A pesticide in which the active ingredient has been manufactured, as opposed to a natural pesticide in which the active ingredient occurs naturally.
Systematic name	A name that fully defines a chemical compound and is derived using a set of rules. The main rules are those produced by IUPAC (International Union of Pure and Applied Chemistry) and CAS (Chemical Abstracts Service).
Toxicity	The capacity of a pesticide to harm an organism by other than mechanical means. A measure of the ability of a pesticide to cause acute, delayed or allergic effects in an organism.

Source: Compendium of Pesticide Common Names. Alan Wood website, http://www.alanwood.net/pesticides/index.html) (134).

Appendix 4.

List of abbreviations

.e.	acid equivalent (active ingredient expressed in terms of parent acid)
a.i.	active ingredient
aRfD	acute reference dose; see the Guide to Using the Main Entries, under ADI
BCPC	British Crop Production Council
b.p.	boiling point at stated pressure
b.w.	body weight
d	day(s)
DT_{50}	time for 50% loss; half-life
EC	European Community; European Commission
EC_{50}	median effective concentration
ED_{50}	median effective dose
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency (USA)
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
h	hour(s)
ha	hectare(s) (10^4 m^2)
IARC	International Agency for Research on Cancer
IPM	integrated pest management
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
K_{oc}	soil sorption coefficient, adjusted for proportion of organic carbon in soil
K_{om}	soil organic matter sorption coefficient
LC_{50}	concentration required to kill 50% of test organisms
LD_{50}	dose required to kill 50% of test organisms
m^2	square meter
m^3	cubic meter
Min	minute(s)
mo	month(s)
mol	mole
m.p.	melting point
NOEL	no observed effect level
o.m.	organic matter
pH	$-\log_{10}$ hydrogen ion concentration
PIC	Prior Informed Consent (see Tab 7, Background - Guide)
pK_a	$-\log_{10}$ acid dissociation constant
ppb	parts per billion
ppm	parts per million
RED	Reregistration Eligibility Decision (of US EPA)
RfD	Reference Dose; see the Guide to Using the Main Entries, under ADI
r.h.	relative humidity
USDA	United States Department of Agriculture
v.p.	vapour pressure
WHO	World Health Organization
>	greater than
<	less than

Literature cited

1. Extension Toxicology Network, Pesticide Information Profiles. (http://extoxnet.orst.edu/pips/ghindex.html)

2. Paraquat Information Centre website. Produced on behalf of Syngenta Crop Protection AG 2009 (http://www.paraquat.com/)

3. European Commission Health and Consumer Protection Directorate-General (2003). Review Report for the Active Substance Paraquat. October 2003. http://ec.europa.eu/food/plant/protection/evaluation/existactive/list_paraquat.pdf

4. Isenring, R. (2006). Paraquat. Unacceptable health risks for users. J. Madeley (ed). Berne Declaration (Zurich, Switzerland), Pesticide Action Network UK (London, UK) and PAN Asia and the Pacific (Penang, Malaysia).

5. Dinham, B. (2007). Pesticide users at risk. Survey of availability of personal protective clothing when purchasing paraquat in China, Indonesia and Pakistan and failures to meet the standards of the Code of Conduct. Berne Declaration (Zurich, Switzerland). Produced for Pesticide Action Network Asia and the Pacific Pesticide Eco-Alternatives Centre.

6. Brown, R., Clapp, M., Dyson, J., Scott, D., Wheals, I. and Wilks, M. (2004). Paraquat in Perspective. *Outlooks on Pest Management*, **15**: 259-267. (http://www.pestoutlook.com)

7. Wesseling C., Van Wendel de Joode B., Ruepert C., Leon C., Monge P., Hermosillo H. and Partanen T. J. (2001). Paraquat in developing countries. *International Journal of Occupational and Environmental Health* **7**: 275–86.

8. Paraquat poisoning. A practical guide to diagnosis, first aid and hospital treatment. Health Assessment and Environmental Safety Department of Syngenta and the Medical Toxicology Unit, Guy's and St Thomas' Hospital NHS Trust, London, UK. http://www.syngenta.com/pqmedguide/Index.aspx

9. World Health Organization (2004). *The Who Recommended Classification of Pesticides by Hazard and Guidelines to Classification*. http://www.who.int/ipcs/publications/pesticides_hazard_rev_3.pdf

10. The Swedish statement on Paraquat. Swedish Statement to Berne Declaration Press Conference, Bern, 17 October 2006. Swedish Chemicals Inspectorate, Sweden.

11. Kuntom, A., Ai, T. Y., Kamaruddin, N. and Beng, Y. C (2007). Pesticide application in the oil palm plantation. *Oil Palm Bulletin* **54**: 52-67

12. Information on chemicals subject to the PIC procedure (as amended in 2004) http://www.pic.int/en/Table7.htm

13. Wibawa, W., Mohamad, R., Omar, D. and Juraimi, A. S. (2007). Less hazardous alternative herbicides to control weeds in immature oil palm. *Weed Biology and Management* **7:** 242–247

14. Gochez, A. (Ed.) (2009). Goodbye paraquat. Palm oil, banana and tea producers saying no to hazardous pesticide. International Union of Food, Agricultural, Hotel, Restaurant,

Catering, Tobacco and Allied Workers' Associations (IUF) and the Berne Declaration (February 2009).

15. Cheah U. B., Kirkwood, R. C. and Lum K. Y. (1998). Degradation of four commonly used pesticides in Malaysian agricultural soils. *Journal of Agricultural and Food Chemistry* **46** (3): 1217-1223

16. Jayakumar, R. and Sankaran, S. (1994). Dynamics of paraquat in different soils. *Pesticide Research Journal* **6** (2): 127-130

17. Pesticides: Registration. Reregistration Eligibility Decision (RED), Paraquat Dichloride. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (August 1997).
http://www.epa.gov/oppsrrd1/REDs/0262red.pdf

18. Environmental Handbook – Documentation on Monitoring and Evaluating Environmental Impacts. German Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung [BMZ**]**).
http://ces.iisc.ernet.in/energy/HC270799/HDL/ENV/enven/vol355.htm#paraquat

19. Material Safety Data Sheet. Gramoxone 250. Syngenta Crop Protection Pty Ltd, North Ryde, NSW, Australia (May 2007).

20. Roberts, T. R., Dyson, J. S., Lane and M. C. G. (2002). Deactivation of the biological activity of paraquat in the soil environment: a review of long-term environmental fate. *Journal of Agricultural and Food Chemistry,* **50** (13): 3623-3631

21. Bromilow, R.H. (2003). Paraquat and sustainable agriculture. *Pest Management Science* **60**: 340–349

22. Kuntom, A; Kifli, H. and Tan, Y. A. (1999). Method for the determination of paraquat residue in oil matrix. *Journal of Oil Palm Research* **11** (2): 57-62.

23. Ngim , J., Lee LimJung and Vijai Deb (1995). Control of volunteer oil palm seedlings with herbicides in Malaysia. *Planter* **71 (**833): 353-356, 359-360

24. Bradberry, S. M., Proudfoot, A. T. and Vale, J A. (2004). Glyphosate poisoning. *Toxicological Reviews* **23** (3):159-167

25. Material Safety Data Sheet. Glyphosate 450. Syngenta Crop Protection Pty Ltd, Macquarie Park, NSW, Australia (May 2008)

26. Review Report for the Active Substance Glyphosate. European Commission Health and Consumer Protection Directorate-General (January 2002).

27. Lee, H. L., Chen K. W., Chi C. H., Huang J. J. and Tsai L. M. (2000). Clinical presentations and prognostic factors of a glyphosate-surfactant herbicide intoxication. A review of 131 cases. *Academic Emergency Medicine* **7** (8): 906–10.

28. Borggaard, O. K. and Gimsing, A.L. (2008). Fate of glyphosate in soil and the possibility of leaching to ground and surface waters: a review. *Pest Management Science* **64** (4): 441-456

29. Haney, R. L., Senseman, S. A., Hons, F. M. and Zuberer D. A. (2000). Effect of glyphosate on soil microbial activity and biomass. *Weed Science* **48** (1): 89-93

30. Jacobsen, O. S. (2003). Degradation, sorption and persistence of glyphosate and the metabolite AMPA in a fractured clay soil profile. *Pesticide in air, plant, soil & water system. Proceedings of the XII Symposium Pesticide Chemistry, Piacenza, Italy, 137-144*

31. Schuette J. (1998). Environmental fate of glyphosate. Environmental Monitoring and Pest Management, Department of Pesticide Regulation, Sacramento.

32. Buffin, D. and Jewell, T. (2001). Health and environmental impacts of glyphosate: the implications of increased use of glyphosate in association with genetically modified crops. P. Riley, M. Taylor, E. Diamand & H. Barron (eds). Pesticide Action Network, UK.

33. Naylor, R. E. L. and Lutman, P. J. (2002). What is a weed? pp. 1-150 in: R. E. L. Naylor (ed.) *Weed Management Handbook, 9th edition.* 432 pp. Oxford, Blackwell Science Ltd. ISBN 9780632057320

34. Dinis-Oliveira, R. J., Remião, F., Carmo, H., Duarte, J. A., Sánchez Navarro, A., Bastos, M. L. and Carvalho, F. (2006). Paraquat exposure as an etiological factor of Parkinson's disease. *Neurotoxicology* **27** (6): 1110-1122

35. Madeley J. (2002). Paraquat – Syngenta’s controversial herbicide. Report written for Berne Declaration, Swedish Society for Nature Conservation, Pesticide Action Network United Kingdom, Pesticide Action Network Asia Pacific and Foro Emaús.

36. Fates of herbicides in the environment, including degradation and transport processes. http://courses.cropsci.ncsu.edu/cs414/cs414_web/CH_5_2005.htm

37. Wibawa, W. Mohamad, R. Juraimi, A. S. Omar, D. Mohayidin, M. G. and Begum, M. (2009). Weed control efficacy and short term weed dynamic impact of three non-selective herbicides in immature oil palm plantation. *International Journal of Agriculture and Biology* **11** (2): 145-150

38. Wibawa, W., Mohamad, R. Puteh, A. Omar, D. Juraimi, A. S. and Abdullah, S. A. (2009). Residual phytotoxicity effects of paraquat, glyphosate and glufosinate-ammonium herbicides in soils from field-treated plots. *International Journal of Agriculture and Biology* **11** (2): 214-216

39. *The UK Pesticide Guide* (2009). M. A. Lainsbury (ed.). CAB International and British Crop Protection Council. ISBN: 978-1-845935-62-7

40. Chemical Safety Information from Intergovernmental Organizations. Environmental Health Criteria 159; Glyphosate. International Programme on Chemical Safety (IPCS) website.
http://www.inchem.org/documents/ehc/ehc/ehc159.htm

41. Brust, G. E. (1990). Direct and indirect effects of four herbicides on the activity of carabid beetles (Coleoptera: Carabidae). *Pesticide Science* **30** (3): 309-320.

42. Cox, C. (1995). Glyphosate. Fact sheets, Parts 1 and 2. *Journal of Pesticide Reform* **15** (4): 27 pp. Northwest Coalition for Alternatives to Pesticides (NCAP), Eugene, USA.

43. Pesticides: Registration. Reregistration Eligibility Decision (RED). Glyphosate. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (September 1993).

44. Material Safety Data Sheet. Quali-Pro Glyphosate T&O. Farmsaver, Raleigh, NC, USA. (2009).

45. Woodburn A. T. (2000). Glyphosate: production, pricing and use worldwide. *Pest Management Science* **56** (4): 309-312

46. Backrounder; Aquatic Use of Glyphosate Herbicides in Australia. Monsanto company (May 2003).

47. Monsanto Company (2002). Backgrounder: Glyphosate and Drift. September 2002. http://www.monsanto.com/monsanto/content/products/productivity/roundup/gly_drift_bkg.pdf

48. Santos A. and Flores M. (1995). Effects of glyphosate on nitrogen fixation of free-living heterotrophic bacteria. *Letters in Applied Microbiology* **20**: 349-352

49. Netto, A. (2009). Malaysia: Return of Paraquat - Activists Aghast. News Release, IPS-Inter Press Service International Association, Rome, Italy (23 October 2009). http://ipsnews.net/news.asp?idnews=35148

50. Bhanusri, A., Reddy, V. M. and Rethinam, P. (2001). Weed management in oil palm plantations. *International Journal of Oil Palm Research* **2** (1): 45-46

51. You, W. and Barker, A. V. (2002). Herbicidal actions of root-applied glufosinate ammonium on tomato plants. *Journal of the American Society for Horticultural Science* **127** (2): 200-204

52. Calas, A. G., Richard, O., Même, S., Beloeil, J. C., Bich Thuy Doan, Gefflaut, T., Même, W., Crusio, W. E., Pichon, J. and Montécot, C. (2008). Chronic exposure to glufosinate-ammonium induces spatial memory impairments, hippocampal MRI modifications and glutamine synthetase activation in mice. *NeuroToxicology* **29** (4): 740-747

53. *The Pesticide Manual* 14th edition, 2008-9. British Crop Production Council. Alton, United Kingdom. 683 pp. ISBN: 978-1-84593-562-7

54. FAO statistics database (FAOSTAT). Food and Agriculture Organization of the United Nations. Accessed December 15 2009. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

55. Topsy J., (1998). Glufosinate ammonium fact sheet. *Pesticides News* **42:** 20-21 (December 1998).

56. Material Safety Data Sheet. Basta Non-Selective Herbicide. Bayer CropScience Victoria, Australia. (September, 2007).

57. Dinehart, S. K. **,** Smith, L. M. **,** McMurry, S. T. **,** Anderson, T. A. **,** Smith, P. N. and Haukos, D. A. (2009). Toxicity of a glufosinate- and several glyphosate-based herbicides to juvenile amphibians from the Southern High Plains, USA. *Science of the Total Environment* **407** (3): 1065-1071

58. Watanabe, T. and Sano, T. (1998). Neurological effects of glufosinate poisoning with a brief review. *Human and Experimental Toxicology***.** **17** (1): 35-39.

59. Pampulha, M. E.**,** Ferreira, M. A. S. S. and Oliveira, A. (2007). Effects of a phosphinothricin based herbicide on selected groups of soil microorganisms. *Journal of Basic Microbiology* **47** (4): 325-33.

60. Withdrawal or non-authorisation of paraquat. Berne declaration website. Accessed December 2009. http://www.evb.ch/en/p25008931.html

61. Herbicide Technical Guide. Liberty 200. Bayer CropScience. Victoria, Australia.

62. Fee, C.G., Cheong, S. S. and Wah, P. K. (1994). Crop protection practices in oil palm plantations. p.27 in 'International Planter's Conference', Kuala Lumpur.

63. Backgrounder: No Restriction on Autumn Use of Glyphosate in Denmark. Monsanto Company. April 2005.

64. European Food Safety Authority (EFSA) (2005). Conclusion on the peer review of glufosinate. *EFSA Scientific Report* **27**: 1-81. http://www.efsa.europa.eu/cs/BlobServer/Praper_Conclusion/praper_ej27_conclusion_glufosinate_en1.pdf?ssbinary=true

65. Muhamad Halimah, Tan, Y. A. and Ismail, B. S. (2005). The fate of fluroxypyr in the soil in an oil palm agroecosystem. *Weed Biology and Management*. **5** (4): 184-189

66. Review Report for the Active Substance Fluroxypyr. European Commission Directorate-General Health and Consumer Protection (December 1999).

67. Material Safety Data Sheet. Finale Herbicide. Bayer CropScience (April 2008). www.Bayercropscience.com.au

68. Kuan, C. Y. Recent Development of Integrated Weed Management in Plantation Crops (Oil Palm and Rubber). Paper presented at Student Excellence Award 200 Prize Presentation Ceremony and Public Lecture organised by CCMB Agrochemicals Sdn Bhd, Kuala Lumpur, Malaysia.

69. *Fluroxypyr. Roadside Vegetation Management Herbicide Fact Sheet* (2006). Washington, Washington State Department of Transportation.

70. *Innova Fluroxypyr 200 Herbicide, Safety Data Sheet* (2007). Syngenta Crop Protection Pty Limited.

71. Kegley, S.E., Hill, B.R., Orme S. and Choi A.H. (2009). Paraquat dichloride: identification, toxicity, use, water pollution potential, ecological toxicity and regulatory information. PAN Pesticide Database, Pesticide Action Network, San Francisco, USA. http://www.pesticideinfo.org

72. Lehmann, R., Miller, J. and Laskowski, D**.** (1990). Fate of fluroxypyr in soil: II. Desorption as a function of incubation time. *Weed Research* **30** (6): 383-388.

73. Fluroxypyr; Pesticide Fact Sheet. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (September, 1998)

74. Fluroxypyr; Pesticide Tolerance. United States Environmental Protection Agency Federal Register **72** (No. 248): 73631-73635 (December 2007).

75. California Department of Pesticide Regulation Public Report 2005-01: Fluroxypyr.

76. International Union of Pure and Applied Chemistry Pesticide Properties Database. Hatfield, University of Hertfordshire. http://sitem.herts.ac.uk/aeru/iupac/

77. Dinham, B (2004). Why paraquat should be banned. *Outlooks in Pest Management* **15**: 268–271.

78. European Union (EU) Pesticides Database. Directorate General for Health and Consumer Protection (DG SANCO), European Commission 2008. http://ec.europa.eu/sanco_pesticides/public/index.cfm

79. Material Safety Data Sheet. Innova Metsulfuron 600 Herbicide. Syngenta Crop Protection Pty Limited, North Ryde, Australia. (November 2006).

80. Metsulfuron Methyl Pesticide Fact sheet. Prepared for U.S. Department of Agriculture (USDA) Forest Service by Information Ventures, Inc., Philadelphia, U.S.A (November 1995).

81. Mohd Tahir, N. and Yeow Jee Sing, N. (2007). Adsorption of metsulfuron-methyl on soils under oil palm plantation: a case study. *Jurnal Teknologi* **47**: 35–43

82. Metsulfuron-methyl herbicide factsheet. U.S. Department of Energy, Bonneville, Power Administration. March 2000.

83. Sarmah, A. K.**,** Kookana, R. S. and Alston, A. M. (2000). Leaching and degradation of triasulfuron, metsulfuron-methyl, and chlorsulfuron in alkaline soil profiles under field conditions**.** *Australian Journal of Soil Research* **38** (3): 617-631

84. Sarmah, A. K., Kookana, R. S. and Alston, A. M. (1998). Fate and behaviour of triasulfuron, metsulfuron-methyl and chlorsulfuron in the Australian soil environment: a review. *Australian Journal of Agricultural Research* **49** (5): 775-790

85. Buchwalter, D., Jenkins, J., Kerkvliet, P. and Thompson, P. (1996). Metsulfuron-methyl. Pesticide Fact Sheet: Forestry Use. Environmental Toxicology and Chemistry Program & Community outreach program, Oregon State University (updated by W. Trevathan, November 2002).

86. Cedergreen, N., Streibig, J. C. and Spliid, N. H. (2004). Sensitivity of aquatic plants to the herbicide metsulfuron-methyl. *Ecotoxicology and Environmental Safety, Environmental Research, Section B.* **57** (2): 153-161

87. Ismail, B. S. and Chong TetVun (2001). Effects of metsulfuron-methyl on ALS activity and its metabolism in immature oil palm. *Journal of Oil Palm Research* **13** (1): 1-10

88. Chung, G.F. and Balasubramaniam, R. (1991). Chemical control on *Asystasia intrusa* (Bl.) in immature oil palm. *Proceedings of the Third Tropical Weed Science Conference* (edited by S. A. Lee and K. F. Kon). Malaysian Plant Protection Society, Kuala Lumpur, Malaysia.

89. Material Safety Data Sheet. Associate Herbicide. Nufarm Limited, Victoria, Australia. (October 2005). http://search.nufarm.com.au/msds/nufarm/associate_24107527.pdf

90. Material Safety Data Sheet. Fusilade II Turf and Ornamental Syngenta. Syngenta Crop Protection Inc., Greensboro (2005).

91. Overview of the Fluazifop-P-Butyl Risk Assessments. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (September 2005).
(see http://www.epa.gov/pesticides/reregistration/status.htm)

92. Tu, I. M., Hurd, C. C. and Randall, J. M. (2001). Fluazifop-P-Butyl. pp. 7c.1-7c.6 in: *Weed Control Methods Handbook: Tools and Techniques for Use in Natural Areas*. 195 pp. Arlington, VA, USA, The Nature Conservancy.

93. Factsheet; Fluazifop-P-Butyl, Systemic Grass Herbicide. Ishihara Sangyo Kaisha Ltd, Osaka, Japan.

94. Rokich, D. P., Harma, J., Turner, S. R., Sadler, R. J. and Tan, B. H. (2009). Fluazifop-p-butyl herbicide: implications for germination, emergence and growth of Australian plant species. *Biological Conservation* **142** (4): 850-869

95. Safety Data Sheet. Fusilade Forte 150 EC. Syngenta Crop Protection (revised January, 2007)

96. Fluazifop-P-Butyl: Revised HED Chapter of the Tolerance Reassessment Eligibility Document (TRED). Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (December, 2004).

97. The List of lists: a catalogue of lists of pesticides identifying those associated with particularly harmful health or environmental impacts. Briefing Paper, 3rd edition 2009. Pesticide Action Network, London, U.K.
http://www.pan-uk.org/List%20of%20Lists.html

98. Pesticides: Registration. Reregistration Eligibility Decision (RED). Diuron. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (September, 2003).
http://www.epa.gov/oppsrrd1/REDs/diuron_red.pdf

99. Environmental Risk Assessment for the Reregistration of Diuron. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C.

100. Material Safety Data Sheet. Diuron 80 WDG Weedkiller. Loveland Products, Inc., Greely, USA. (July 2004)

101. Glufosinate Ammonium. Technical Information. Bayer CropScience, Monheim, Germany. 2004. www.bayercropscience.com

102. Fact Sheet (2003); Paraquat exposure and Parkinson's Disease. Pestizid Aktions-Netzwerk e.V. (Pesticide Action Network), Hamburg, Germany.

103. Duke, S. O. and Powles, S. B. (2008). Glyphosate: a once-in-a-century herbicide. *Pest Management Science* **64**: 319-325.

104. Guzzella, L., Capri, E., Corcia, A. di, Caracciolo, A. B. and Giuliano, G. (2006). Fate of diuron and linuron in a field lysimeter experiment. *Journal of Environmental Quality* **35** (1): 312-323

105. Stork, P. R., Bennett, F. R. and Bell, M. J. (2008). The environmental fate of diuron under a conventional production regime in a sugarcane farm during the plant cane phase. *Pest Management Science*. **64** (9): 954-963.

106. Field, J. A., Reed, R. L., Sawyer, T. E., Griffith, S. M. and Wigington, P. J. Jr . (2003). Diuron occurrence and distribution in soil and surface and ground water associated with grass seed production. *Journal of Environmental Quality* **32**: 171–179

107. Lin, L. C., Cibes-Viade, H. and Koo, F. K. S. (1970). Adsorption of ametryne and diuron by soils. *Weed Science* **18** (No.4): 470-474

108. Moncada, A. Environmental fate of diuron. Environmental Monitoring Branch, Department of Pesticide Regulation, CA, U.S.A.

109. *Specifications for Agricultural Pesticides, New Specifications*. Food and Agriculture Organization of the United Nations. http://www.fao.org/agriculture/crops/core-themes/theme/pests/pm/jmps/ps/ps-new/en/

110. Ikuenobe, C. E. and Ayeni, A. O. (1998). Herbicidal control of *Chromolaena odorata* in oil palm. *Weed Research* **38**: 397-404.

111. Tu, M., Hurd, C., Robison, R. and Randall, J. M. (2001). Triclopyr. pp. 7k.1-7k.8 in: *Weed Control Methods Handbook: Tools and Techniques for Use in Natural Areas*. 195 pp. Arlington, VA, USA, The Nature Conservancy.

112. Harrington, T. B. and Reichard, S. H. (tech. eds.) (2007). Meeting the challenge: invasive plants in Pacific Northwest ecosystems. General Technical Report PNW-GTR-694. . Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Portland, U.S.A. 166 pp.

113. Holmes, S. B., Thompson, D. G., Wainio-Keizer, K. L., Capell, S. S. and Staznik, B, (1994). Effects of lethal and sublethal concentrations of the herbicide, triclopyr butoxyethyl ester, in the diet of zebra finches. **Journal of Wildlife Diseases 30** (3): 319-327.

114. Ameena, M. and George, S. (2004). Control of purple nutsedge (*Cyperus rotundus* L.) using glyphosate and 2,4-D sodium salt. *Journal of Tropical Agriculture* **42** (1-2): 49-51.

115. Kreutzweiser, D. P**.,** Thompson, D. G**.,** Staznik, B. and Shepherd, J. A. (1998). Accumulation dynamics of triclopyr ester in aquatic leaf packs and effects on detritivorous insects. *Journal of Environmental Quality* **27** (5): 1138-1147

116. Von Uexkull, H. R., East and South-East Asia Program of the Potash and Phosphate Institute. International Potash Institute, Singapore.

117. Middendorf, P**.,** Timchalk, C**.,** Kropscott, B. and Rick, D (1992). Forest worker exposures to triclopyr butoxyethyl ester during directed foliar applications of Garlon 4 herbicide. *Proceedings 45th Annual Meeting of the Southern Weed Science Society.* pp 177-185

118. Group Standard Operating Procedure (StOP) for Weeding, (2007). IOI Group. September 2007.

119. Stephenson, G. R**.,** Solomon, K. R**.,** Bowhey, C. S. and Liber, K. (1990). Persistence, leachability, and lateral movement of triclopyr (Garlon) in selected Canadian forestry soils. *Journal of Agricultural and Food Chemistry* **38** (2): 584-588.

120. Reregistration Eligibility Decision for dicamba and associated salts. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (June 2006).

121. Bakar, B. H. (2004). Invasive weed species in Malaysian agro-ecosystems: species, impacts and management. *Malaysian Journal of Science* **23:** 1-42.

122. Caux, P. Y., Kent, R. A., Taché, M., Grande, C., Fan, G. T. and MacDonald, D. D. (1993). Environmental fate and effects of dicamba: a Canadian perspective. *Reviews of Environmental Contamination and Toxicology* **133:** 1-58.

123. YuTai L. **,** Zimmerman W. T.**,** Gorman M. K.**,** Reiser R. W.**,** Fogiel A. J. and Haney, P. E. (1999). Aerobic soil metabolism of metsulfuron-methyl. *Pesticide Science* **55:** 434-445

124. Dicamba Herbicide Information Profile. United States Department of Agriculture Forest Service, Pacific Northwest Region. February 1999.

125. Material Safety Data Sheet. Vanquish herbicide. Syngenta Crop Protection Inc., Greensboro, NC, USA. (April 2004).

126. Cox, C. (1994). Dicamba. Herbicide factsheet. *Journal of Pesticide Reform* **14** (1): 30-35.

127. Garnier, R., Bazire, A. and Chataigner, D. (2003). Risks of occupational paraquat exposure: a review. *Archives des Maladies Professionnelles et de Médecine du Travail*, **64 (5)**: 310-324

128. Howard, P. H. (1991). *Handbook of Environmental Fate and Exposure Data for Organic Chemicals: Volume III, Pesticides*. CRC Press, Florida, USA. ISBN-10: 0-87371-328-1 http://books.google.co.uk/books?id=0yPaA9yiKYwC&dq=Handbook+of+Environmental+Fate+and+Exposure+Data+For+Organic+Chemicals%3B+Pesticides&printsec=frontcover&source=bl&ots=b4XXQ0cNoS&sig=gR6alOFs51ykPRzkoZ-ayd9MMXc&hl=en&ei=Ap5pSvPmFMeZjAetpvi2Cw&sa=X&oi=book_result&ct=result&resnum=1

129. Ecobichon, D. J. (2001). Pesticide use in developing countries. *Toxicology* **160:** 27–33.

130. Cantor, K. P. (1992). Pesticides and other agricultural risk factors for non-Hodgkin’s lymphoma among men in Iowa and Minnesota. *Cancer Research* **52**: 2447-2455.

131. Samanic, C., Rusiecki, J., Dosemeci, M., Hou, L., Hoppin J. A., Sandler, D. P., Lubin, J., Blair, A. and Alavanja, M. C. R. (2006). Cancer incidence among pesticide applicators exposed to dicamba in the agricultural health study. *Environmental Health Perspectives* **114** (10): 1521-1526

132. Pesticide Residues in Food – 2004: Toxicology Evaluations. Joint FAO/WHO Meeting on Pesticide Residues. Food and Agriculture Organization, World Health Organization and the International Programme on Chemical Safety (1992). 466 pp. ISBN 9241665203.

133. Cox, C. (1996). Glufosinate. Herbicide factsheet. *Journal of Pesticide Reform* **16** (4): 15-19. Northwest Coalition for Alternatives to Pesticides (NCAP), Eugene, USA.

134. Compendium of Pesticide Common Names.
(see Alan Wood website - http://www.alanwood.net/pesticides/index.html)

135. Harker, K. N. and O'Sullivan, P. A. (1991). Synergistic mixtures of sethoxydim and fluazifop on annual grass weeds. *Weed Technology* **5** (2): 310-316.

136. Bukowska, B. (2003). Effects of 2,4-D and its metabolite 2,4-dichlorophenol on antioxidant enzymes and level of glutathione in human erythrocytes. *Comparative Biochemistry and Physiology. C, Toxicology & Pharmacology,* **135** (4): 435-441

137. Watt, B. E., Proudfoot, A. T. , Vale, J. A. and Bradberry, S. M. (2000). Mechanisms of toxicity, clinical features and management of acute chlorophenoxy herbicide poisoning: a review. National Poisons Information Service, Birmingham Centre, City Hospital, Birmingham, U.K. *Journal of Toxicology, Clinical Toxicology,* **38** (2): 111-122

138. Garabrant, D. H. and Philbert, M. A. (2002). Review of 2,4-Dichlorophenoxyacetic acid (2,4-D) epidemiology and toxicology. *CRC Critical Reviews in Toxicology* **32** (4): 233-257

139. Reregistration Eligibility Decision for 2,4-D, Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (June 2005). http://www.epa.gov/oppsrrd1/REDs/24d_red.pdf

140. Technology Transfer Network, Air Toxics Web Site. 2,4-D. United States Environment Protection Agency (last updated November 2007). http://www.epa.gov/ttnatw01/hlthef/di-oxyac.html#ref1

141. Pesticides: Reregistration. 2,4-D RED Facts. Office of Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C. (June 2005). http://www.epa.gov/oppsrrd1/REDs/factsheets/24d_fs.htm

142. Review report for the active substance 2,4-D. European Commission Health and Consumer Protection Directorate-General (October 2001).

143. French, K., and Buckley, S., (2008). The effects of the herbicide metsulfuron-methyl on litter invertebrate communities in a coastal dune invaded with *Chrysanthemoides monilifera* spp. *rotundata*. *Weed Research* **48**: 266–272.

144. Walters, J. Environmental fate of 2,4-Dichlorophenoxyacetic acid. Environmental Monitoring and Pest Management Department of Pesticide Regulation, Sacramento, U.S.A..

145. Ghassemi, M., L., Fargo, P., Painter, S., Quinlivan, R., Scofield and Takata, A. (1981). Environmental fates and impacts of major forest use pesticides. P.A-101-148. U. S. EPA Office of Pesticides and Toxic Substances. Washington DC, USA.

146. Hermosin, M. C. and Cornejo, J. (1991). Soil adsorption of 2,4-D as affected by the clay minerology. *Toxicology and Environmental Chemistry*. **31-32**: 69-77.

147. Material Safety Data Sheet. Diuron 4L. Consult Makhteshim Agan of North America, Inc. Raleigh, NC, U.S.A. (2006).

148. Mathews, J., Ng, S., Lee, N. and Hanaffee, H. (2007). IOI Group’s Experience and Approach in Testing the Principles and Criteria (P&C) of Roundtable on Sustainable Palm Oil. Paper presented at Roundtable 5 (RT5), Kuala Lumpur, 20-22 November 2007.

149. Material Safety Data Sheet. Cadence WG Herbicide. Syngenta Crop Protection, NSW, Australia (June 2005)

150. Pesticide Fact Sheet: Dicamba. U.S. EPA. Office of Pesticides and Toxic Substances (1984). Washington D.C., USA. (October, 1983)..

151. Dicamba (General Fact Sheet). National Pesticide Information Centre. Oregon State University and United States Environmental Protection Agency. (2002)

152. Palmer, J. S. and Radeleff, R. D. (1964). The toxicological effects of certain fungicides and herbicides on sheep and cattle. *Ann . NY Acad. Sci.* **111**: 729-736.

153. Summary of results of studies submitted in support of the registration of dicamba. U.S. EPA. Office of Pesticides and Toxic Substances, Washington D.C., U.S.A. (1984).

154. Potter W. T., Garry V. F., Kelly J. T., Tarone R., Griffith J. and Nelson R. L. (1993). Radiometric assay of red cell and plasma cholinesterase in pesticide appliers from Minesota. *Toxicology and Applied Pharmacology* **119**: 150-155.

155. Beasley, V. R. (1991). 2,4-D toxicosis I: A pilot study of 2,4- Dichlorophenoxyacetic acid and dicamba-induced myotonia in experimental dogs. *Vet. Hum. Toxicology* **33** (5): 435-440.

156. Cox, C. (2005). 2,4-D. Herbicide fact sheet.. *Journal of Pesticide Reform* **25** (4): 10-15.

157. Occupational Safety and Health Guideline for 2,4-D (Dichlorophenoxyacetic Acid). Occupational Safety and Health Administration, United States Department of Labor, Washington, DC, U.S.A. (http://www.osha.gov/SLTC/healthguidelines/2_4d-dichlorophenoxyaceticacid/)

158. Soo S. H., Mathews, J. and Clarence P. J. (2003). Control of *Costus speciosus* Sm in IOI Sabah Oil Palm Plantation. *The Planter, Kuala Lumpur* **79** (927): 387- 396.

159. Material Safety Data Sheet. Amine 4 2,4 D Weed Killer. Loveland Products Inc., Greeley, CO, U.S.A. (February 2009).

160. Dost, F. N. (2003). Toxicology and potential health risk of chemicals that may be encountered by workers using forest vegetation management options. Part III. Risk to workers using 2,4-D formulations. Title No 5. Victoria, BC, Ministry of Forests, Forest Practices Branch. http://www.for.gov.bc.ca/hfp/PubsVegMngt.htm

161. Bus, J. S. and Hammond, L. E. (2007). Regulatory process, toxicology, and public concerns with 2,4-D: where do we stand after two decades? *Crop Protection* **26:** 266-269.

162. Kohli, J. D., Khanna, R. N., Gupta, B. N., Dhar, M. M., Tandon, J. S. and Sircar, K. P. (1974). Absorption and excretion of 2,4-Dichlorophenoxyacetic. *Xenobiotica* **4** (2): 97-100.

163. Reigart, R. and Roberts, J. (eds) (1999). *Recognition and Management of Pesticide Poisonings* (5th edition). Office of Prevention, Pesticides and Toxic Substances, United States Environmental Protection Agency.

164. Bukowska, B. (2006). Toxicity of 2,4-Dichlorophenoxyacetic acid – molecular mechanisms. *Polish Journal of Environmental Studies* **15** (3): 365-374.

165. Occupational Fatalities Associated With 2,4-Dichlorophenol (2,4-DCP) Exposure, 1980—1998. *Morbidity and Mortality Weekly Report* **49** (23): 516-518 (June 16, 2000). Centers for Disease Control and Prevention, Atlanta, U.S.A http://www.cdc.gov/

166. Watts, M. (2003). Paraquat. Pesticide Action Network Asia and the Pacific, Penang, Malaysia.
http://www.panap.net/uploads/media/paraquat_monograph_PAN_AP.pdf

167. Kegley, S.E., Hill, B.R., Orme S. and Choi A.H. (2009). Paraquat dichloride: identification, toxicity, use, water pollution potential, ecological toxicity and regulatory information. PAN Pesticide Database, Pesticide Action Network, San Francisco, USA.
http://www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PC33358

168. Mishra, A. K and Pandey, A. B. (1989). Toxicity of three herbicides to some nitrogen-fixing cyanobacteria. *Ecotoxicology and Environmental Safety* **17** (2): 236- 246.

169. Ahn YoungJoon, Kim YoungJoon, Yoo JaiKi (2001). Toxicity of the herbicide glufosinate-ammonium to predatory insects and mites of *Tetranychus urticae* (Acari: Tetranychidae) under laboratory conditions. *Journal of Economic Entomology* **94** (1): 157-161

170. Glyphosate Fact Sheet. pp. 28-29 in: *Pesticides News* No.33 (September 1996). London, Pesticide Action Network.
http://www.pan-uk.org/pestnews/Actives/glyphosa.htm

171. Page, B. and Lord, S. (2006). The oil palm industry's approach to the use of pesticides in Papua New Guinea. *The Planter* **82** (958): 13-21.
http://www.nbpol.com.pg/downloads/Pesticides_in_Papua_New_Guinea.pdf

172. Syngenta (2009). Paraquat – A unique tool in weed management and safety in use. (presentation – can we use?)

173. International Code of Conduct on the Distribution and Use of Pesticides (2003). Food and Agriculture Organization of the United Nations. Rome, Italy. ISBN 92-5-104914-9.
http://www.fao.org/DOCREP/005/Y4544E/y4544e00.htm

174. Reade, J. P.H. and Cobb, A. H. (2002). Herbicides: modes of action and metabolism. pp. 134-170 in: R. E. L. Naylor (ed.) *Weed Management Handbook, 9th edition.* 432 pp. Oxford, Blackwell Science Ltd. ISBN 9780632057320

175. Copping, L. G. (2002). Herbicide discovery. pp. 93-113 in: R. E. L. Naylor (ed.) *Weed Management Handbook, 9th edition.* 432 pp. Oxford, Blackwell Science Ltd. ISBN 9780632057320

176. Taiz, L. and Zeiger, E. (1998). Mode of action of some herbicides. Chapter 7, Section 7.10 in: *Plant Physiology Online (4th Edition).* Sinauer Associates Incorporated, Sunderland USA.
http://4e.plantphys.net/article.php?ch=7&id=75&search=herbicide

177. Howard, P. H. and Meylan, W. M. (1996). Handbook of Physical Properties of Organic Chemicals. Florida, CRC Press Inc. pp. 2112. ISBN-13: 978-1566702270

178. Diuron. The Environment Agency, Rotherham, United Kingdom (September, 2009).
http://www.environment-agency.gov.uk/business/topics/pollution/39125.aspx

179. Ghassemi, M., L., Fargo, P., Painter, S., Quinlivan, R., Scofield and Takata, A. (1981). Environmental fates and impacts of major forest use pesticides. pp. 101-148. Office of

Prevention, Pesticides and Toxic Substances, United States Environment Protection Agency, Washington D.C.

180. Norris, L.A. (1981). The movement, persistence, and fate of the phenoxy herbicides and TCDD in the forest. *Residue Reviews* **80**: 65-135.

181. Pesticide Background Statements pp.1-181 in: *Agricultural Handbook No. 633. Vol. 1. Herbicides*. United States Department of Agriculture Forest Service, 1984.

182. Stearman, G. K. and Wells, M. J. M. (1997). Leaching and runoff of simazine, 2,4-D, and bromide from nursery plots. *Journal of Soil and Water Conservation* **52**: 137-144.

183. Bolan, N. S. and Baskaran, S. (1996). Biodegradation of 2,4-D herbicide as affected by its adsorption-desorption behavior and microbial activity of soils. *Australian Journal of Soil Research*. **34:** 1041-1053.

184. Han, S. O., and New, P. B. (1994). Effect of water availability on degradation of 2,4-Dichlorophenoxyacetic acid (2,4-D) by soil microorganisms. *Soil Biology and Biochemistry* **26**(12): 1689-1697.

185. Munro, I. C., Carlo, G. L., Orr, J. C., Sund, K. G., Wilson, R. M., Kennepohl, E., Lynch, B. S., Jablinske, M. and Lee, N. L. (1992). A comprehensive, integrated review and evaluation of the scientific evidence relating to the safety of the herbicide 2,4-D. *Journal of the American College of Toxicology* **11**(5):560-664.

186. Carpenter, L. A. and Eaton, D. L. (1983). The disposition of 2,4-Dichlorophenoxyacetic acid in rainbow trout. *Archives of Environmental Contamination and Toxicology* **12:** 169-173.

187. Lee, S.J., Katayama, A. and Kimura, M. (1995). Microbial degradation of paraquat sorbed to plant residues. *Journal of Agricultural and Food Chemistry* **43**: 1343-1347.

188. Arnold, D. J. and Briggs, G. G. (1990). Fate of pesticides in soil, predictive and practical aspects. *Progress In Pesticide Biochemistry And Toxicology* **7:** 101-122. John Wiley and Sons

189. Ross, M. A. and Childs, D. J. (1996). Herbicide mode-of-action summary. Cooperative Extension Service, Purdue University, West Lafayette, USA. www.extension.purdue.edu/extmedia/ws/ws-23-w.html

190. Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. Rotterdam Convention Secretariat, Rome, Italy (Revised 2008) http://www.pic.int/home.php?type=s&id=77 or http://www.pic.int/home.php?type=t&id=34&sid=32#

191. Baumann, P. A., Dotray, P. A. and Prostko, E. P. (2008). Herbicides; how they work and the symptoms they cause. AgriLife Communications, Texas A&M System. 10 pp. https://agrilifebookstore.org/publications_details.cfm?whichpublication=1063&orderby=pubnumber&simplesearch=herbicides&criteriastring=simplesearch%3Dherbicides

192. Australian/New Zealand Weed Risk Assessment adapted for Hawai‘i. Research directed by C. Daehler (UH Botany) with funding from the Kaulunani Urban Forestry Program and US Forest Service.

193. Thiruchelvam, M., McCormack, A., Richfield, E. K., Baggs, R. B, Tank, A. W., Di Monte, D. A. and Cory-Slechta, D. A. (2003). Age-related irreversible progressive

nigrostriatal dopaminergic neurotoxicity in the paraquat and maneb model of the Parkinson's disease phenotype. *European Journal of Neuroscience* **18** (3): 589-600.

194. Logroscino, G. (2005). The role of early life environmental risk factors in Parkinson disease: what is the evidence? *Environmental Health Perspective* **113** (9): 1234-1238.

195. Oeser, J. (2006). Product information: advantages of glufosinate-ammonium. Monheim, Bayer CropScience, 18 July 2006. 6 pp.

196. Muhamed Ramdhan Ab Latiff, Mohd Ahdly Arbain and Tey, C. C. (2009). Efficacy of generic herbicides of glyphosate, glufosinate ammonium and metsulfuron methyl for weed control in palm oil. Proceedings MPOB International Palm Oil Congress 2009 (PIPOC), Kuala Lumpur, 9-12 November 2009. **Vol. 2:** 25-38.

197. Consumer Product Safety Decision Document: Fluazifop-butyl. Health Canada website, June 2008 (accessed 25 January 2010). http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_decisions/e88-01/index-eng.php#longtox

198. Chang, F. Y. and Vanden Born, W. H. (1968). Translocation of dicamba in Canada Thistle. *Weed Science* **16,** No. 2: 176-181

199. Toxicological Profile for DDT, DDE, and DDD. Report by Agency for Toxic Substances and Disease Registry, Public Health Service, U.S. Department of Health and Human Services, Atlanta, Georgia. September 2002.

200. Pesticide Fact Sheet Number 71: Metsulfuron-methyl. U.S. Environmental Protection Agency Office of Pesticide Programs, Washington, DC. 1986.

201. Streit, B. (1992). Bioaccumulation processes in ecosystems. *Experientia* **48**, No.10: 955-970.

202. Metsulfuron-methyl. Roadside Vegetation Management Herbicide Fact Sheet. Washington State Department of Transport. February 2006.

Part 2. Survey of Ground Cover Management Practice and the Use of Chemical Herbicides by Oil Palm Producers in Malaysia, Indonesia and Papua New Guinea

Roundtable for Sustainable Palm Oil (RSPO):
Research project on Integrated Weed Management Strategies for Oil Palm

Survey of ground cover management practice and the use of chemical herbicides by oil palm producers in Malaysia, Indonesia and Papua New Guinea

Compiled by:

M. Rutherford & S. S. Sastroutomo
(CAB International, UK and Malaysia)

February 2010

www.cabi.org

Introduction

In January 2009 a research project was initiated by the Roundtable on Sustainable Palm Oil (RSPO) to obtain important information on weed management practices employed by oil palm producers. This information is intended to provide an up to date overview of weed management and also help RSPO and the oil palm industry to identify, recommend and introduce improved, integrated management practices that are sustainable and effective but less reliant on the use of chemical herbicides that may be hazardous and damaging to the user, the crop and the environment.

As one component of this project, and between July 2009 and January 2010, a survey was undertaken in Malaysia, Indonesia and Papua New Guinea (PNG)[12] to investigate the approaches used by oil palm producers to manage ground cover vegetation on their plantations and to better understand the role and use of chemical herbicides. The survey was undertaken on behalf of the Roundtable for Sustainable Oil Palm (RSPO) by CABI Europe-UK Centre (Egham, UK), supported by the CABI South East & East Asia Regional Centre (Kuala Lumpur, Malaysia). It formed part of a broader research initiative to investigate weed management as a basis for reducing/improving herbicide use and to help seek and promote to producers a more integrated approach to weed management.

Survey Methodology

As it had previously been agreed (under the Terms of Reference of the project) that direct consultation with producers would not be possible, information was obtained by completion and return of structured questionnaires. The information requested from producers using this approach related primarily to the following:

- The producer organisation and scale of operation
- RSPO membership and knowledge/application of RSPO Principles & Criteria (P&C)
- Ground cover vegetation, its management and the perceived benefits of management approaches
- The use of herbicides for ground cover management and other purposes
- Awareness of the hazards associated with herbicides
- Procedures in place to ensure herbicides are used appropriately and safely.

Information was also requested from producers on specific herbicidal products that they used and the active ingredients that they contained.

The questionnaires (and supporting documents, see below) were prepared by CABI in consultation with RSPO and a range of producers. This was to help ensure that the information being requested was appropriate and accessible to producers and also to increase the likelihood of producers providing feedback as requested without having queries or concerns as to how or why the information was being requested, how it was to be used and how it would be of benefit to them. The questionnaires were also designed to facilitate straightforward and rapid completion plus transfer and analysis of data through provision of multiple choice responses, numeric coding of responses and drop-down numeric lists for data transfer. The questionnaires, along with guidelines for completion and information on the aims of the IWM project, were prepared in English, Indonesian and Spanish and provided by

---

[12] Colombia was originally included as a fourth country in the grower survey. However, and although survey questionnaires (in Spanish) and supporting documents were provided to the NIWG, no completed questionnaires were received from grower organisations.

CABI to the RSPO National Interest Working Groups (NIWG) in each of the countries for dissemination to selected producer organisations. The NIWG, having extensive knowledge of oil palm production in their respective countries, were responsible for final selection of producers to participate in the survey. To help ensure that the producers were representative of national production the NIWG were requested, as appropriate and practical, to take account of variation in agro-ecological conditions and diversity of producer type. Key criteria in this regard included scale of operation, organisation ownership (e.g. government, private), approach to chemical use (e.g. organic/non-organic) and level of RSPO P&C certification.

While the survey would ideally seek information from large and small scale producers it was recognised that obtaining information from smallholders, particularly through distribution and completion of a questionnaire, presents great difficulties. As a consequence, information on smallholders was sought through consultation with smallholder parent organisations or associations.

Questionnaires were distributed to a total of 66 producers; 43, 18 and 5 in Indonesia, Malaysia and PNG respectively. On completion, questionnaires were returned directly to CABI for collation and analysis. The information was collated on an electronic database based on Microsoft Windows *Excel* software (Microsoft Corporation, Washington, USA) and analysed using *Excel* spreadsheet software and also SSC-STAT V2.0 *Excel* add-in statistical software developed by University of Reading Statistical Services Centre (URSSC, Reading, UK). Summary data tables depicting key producer characteristics were produced as described below.

Information provided by producers on the identity and quantity of active ingredients in herbicide products used on their plantings was verified against details of registered products produced by national registration authorities in the respective countries.

Results

Of the questionnaires distributed, and eight months after distribution to NIWG, 25 had been completed and returned. Nine of the respondents were located in Indonesia, eleven in Malaysia[13] and five in PNG[14] (for details see Appendix 1). Due to the limited number of producers on which information was received, no comparison of findings between individual countries is made in this report.

The area of oil palm production of the organisations ranged from 1,000 to 525,000 hectares. Eighteen respondents stated that they were private companies, six were government owned or government linked companies and one a private company/consortium. All producers were members of RSPO, were aware of and practicing RSPO Principles and Criteria and either already held or were seeking RSPO certification.

Ground cover vegetation and its management

---

[13] One Malaysian organisation, FELDA, provided three completed questionnaires, one for each of three plantations. For the purposes of this report these have been treated and are referred to as individual producers, the data for each being analysed and presented in its own right.

[14] In PNG plantation production systems account for 58% of the total area planted with oil palm, while smallholders account for 42% (data for 2008). As the entire area of plantation production is managed by the five companies that completed and returned survey questionnaires, the information provided reflects weed management measures as used in large scale plantation systems across PNG.

With regard to ground cover vegetation and its management, all producers indicated that a layer of ground cover vegetation, as either natural plant (including weed) growth or a leguminous cover crop, was present under the oil palm. For the majority (96% of producers) this was present between the rows of oil palm although, in some cases, also present on paths (40%) and around the 'tree circle'[15] (12%). One or a few producers also indicated other areas where ground cover vegetation was present and/or reasons for the presence of groundcover. These included terrain areas, around the perimeter of the plantation, on steep slopes (to prevent soil erosion and landslides) and as ground cover crops in river/stream riparian reserve and hilly areas. Efforts were also made to encourage full coverage of soft grasses, fern and cover crops - with the exception of palm circles and harvesting paths - and to plant cover crops to cover exposed areas and following land clearing. In one case a box layout system of frond stacking was used to increase the area of ground cover and prevent erosion.

The majority (84%) of producers stated that they regularly monitored ground cover growth and all producers managed growth through both the use of chemical herbicides and cultivation of one or a combination of cover crops (Table 1). Most producers (92%) also applied an organic mulch to help control ground cover, while between 68% and 72% relied on hand weeding, weeding with a hoe and/or slashing. Between 24% and 40% producers managed ground cover through mechanical means, allowing livestock to graze on the plantation, the use of biological approaches, increasing palm planting density and/or covering the ground with sheeting (to reduce ground cover growth primarily by restricting the availability of sunlight and rainfall). *Mucuna*, *Pueraria*, *Calopogonium* and *Centrosema* were the most commonly planted cover crops (48-80% of producers). *Desmodium*, ‘soft grasses’ and a combination of *Paspalum conjugatum* and *Nephrolepis biserrata*, although also used, were each planted by only one producer (Table 2).

With the exception of grazing by livestock, adjustment of planting density and the use of sheeting, all of the ground cover management measures specified by producers were used in the nursery, during the immature and mature stages of crop growth and in replantings (Table 1). Hand weeding, planting of a cover crop, herbicide application and, again, use of a cover crop were, respectively, the most common approaches used in each of these areas of the plantation. Application of herbicides and mulch, introduction of biological measures and removal of weeds with a hoe, by slashing and by mechanical means were all used predominantly during the immature and mature stages of oil palm growth. With the exception of hand weeding, practiced by nearly half the producers, none of the measures were used in the nursery by more seven (in the case of herbicide application) of the 25 producers consulted. Indeed, none of the producers permitted livestock to graze in the nursery, immature crop and replanting in an attempt to reduce ground cover growth, nor did they cover areas of the immature crop with sheeting. None of the producers managed ground cover vegetation by burning or flooding.

---

[15] The area around the base of palms where ground cover growth is controlled to facilitate crop management practices such as addition of fertiliser and harvesting of bunches and to reduce competition by other plants for water and soil nutrients) and/or around the perimeter of the planting.

Table 1. Methods employed by oil palm producers in Malaysia, Indonesia and Papua New Guinea for ground cover management in oil palm and the stages of palm cultivation at which they are used.

Ground cover management method	% producers using method for:				No. producers using method
	Nursery	Immature crop	Mature crop	Replanting	
Chemical treatment (herbicide application)	28	72	96	48	25
Cover crop planted	12	80	40	64	25
Organic mulch applied	24	72	88	52	23
Uprooting plants - by hand	44	32	32	20	18
Slashing	4	44	56	28	17
Uprooting plants - with a hoe	8	48	56	24	17
Mechanical (e.g. mower, tractor)	4	28	36	16	10
Biological control (predators, parasites, fungi, pheromones)	12	28	32	16	9
Grazing by livestock	0	0	28	0	7
Area covered with sheeting (e.g. plastic)	8	0	4	12	6
Increasing palm planting density	0	12	4	20	6

Table 2. Cover crops planted by oil palm producers in Malaysia, Indonesia and Papua New Guinea.

Cover crop	% producers
Mucuna	80
Pueraria	72
Calopogonium	64
Centrosema	48
Desmodium	4
Paspalum conjugatum and *Nephrolepis biserrata*	4
‘Soft grasses’	4

Cost-effectiveness of ground cover management approaches

Of the various ground cover management measures specified, the use of herbicides was perceived to be the most effective in relation to the costs involved (cost-effectiveness) (Table 3). With the exception of slashing and uprooting plants by hand or with a hoe, all of the approaches were considered to be moderately to very cost-effective. This may be due, at least in part, to the associated time and costs of labour and, in the case of slashing, to renewed growth of vegetation. The scores provided by producers were based on an overall score for all plantings on which it was used (i.e. nursery, immature, mature and/or replanting).

Table 3. Cost-effectiveness of ground cover management methods as perceived by oil palm producers in Malaysia, Indonesia and Papua New Guinea.

Ground cover management method	**Perceived cost-effectiveness of method**[1]	**No. producers using method**	**No. producers responding**[2]
Chemical treatment (herbicides)	2.55	25	22
Organic mulch applied	2.52	23	21
Increasing palm planting density	2.50	6	6
Mechanical (e.g. mower, tractor)	2.44	10	9
Cover crop planted	2.43	25	23
Grazing by livestock	2.25	7	4
Area covered with sheeting (e.g. plastic)	2.20	6	5
Biological control (predators, parasites, fungi, pheromones)	2.00	9	8
Slashing	1.94	17	16
Uprooting plants - by hand	1.86	18	14
Uprooting plants - with a hoe	1.81	17	16

1. Mean of cost-effectiveness scores provided by all producers where: 3= very cost effective; 2 = moderately cost effective; 1 = not very cost effective.
2. Total number of producers that provided information on cost-effectiveness and on which the effectiveness rankings are based. Note that, in some case, not all producers using a particular approach provided a ranking of its cost-effectiveness.

Knowledge and application of herbicides

Although all producers used herbicides for ground cover vegetation management, all except two (i.e. 92%) stated that they also had a policy for, and/or made efforts to, reduce or avoid the risks associated with their use by using less toxic substances (of the two producers, one was unable to confirm either way) (Table 4). The majority (72%) also confirmed that they had a policy for and/or made efforts to use alternative, non-chemical management measures. All producers maintained records of herbicide use while more than half also monitored herbicide residues levels, although the substrate(s) analysed is not known. All except one applied specific herbicides for particular weed types while 72% routinely changed or rotated herbicidal substances to reduce or prevent build-up of resistance in the plants.

Table 4. Management measures employed by oil palm producers in Malaysia, Indonesia and Papua New Guinea to monitor and improve on the use of herbicides

Herbicide policy/management	% producers
Using less toxic herbicides	92
Using alternative non-chemical methods	72
Herbicide records kept	100
Herbicide residues assessed or monitored	64
Weed specific herbicides selected for use	96
Herbicides changed/rotated to prevent herbicide resistance	72

All producers stated that plantation/estate management staff received information - other than the instructions provided with the individual products - on how herbicides should be handled and applied properly and all except one stated that plantation staff had also received formal training (Table 5). In all cases the herbicides were being used as specified on the labels/instructions provided with products, the products were prepared at the correct dose before being taken to the field for application and specially trained personnel (e.g. spray gangs) were responsible for their preparation and application.

Table 5. Information and training on proper herbicide handling and use received by staff [1], premixing of herbicides[2] and preparation/application of herbicides by appropriately trained personnel in oil palm plantations in Malaysia, Indonesia and Papua New Guinea.

Herbicide knowledge/practice	% producers
Information received	100
Training received	96
Trained personnel responsible for herbicide preparation/application	100
Herbicides handled/applied as specified in instructions	100
Herbicides premixed before taken to field for application	100

1. Other than instructions provided with products.
2. Before transferring to the field for application.

The majority of producers (92%) applied herbicides around the base of oil palm plants while approximately half applied them on paths and/or between the rows of oil palm. Two producers indicated that they used herbicides on roadsides, at net points, in housing areas, in sports fields and/or for clearing drains.

In terms of purposes for which herbicides were used other than for ground cover management, 64% of producers highlighted specific reasons. Foremost amongst these were: poisoning palms (36% of all producers) in order to thin the crop, destroy sterile palms and clear land for replanting; destroy woodies/woody growth (24%) and epiphytes (20%); and, in a few cases, to control broadleaved weeds, volunteer oil palms (VOP), bamboo, yam, wild bananas and taro as well as particularly noxious weeds such as lalang (*Imperata cylindrica*), Siam weed (*Chromolaena odorata*) and species of *Mikania*, *Hedyotis* and *Asytasia*. In some cases the latter was achieved through selective spraying (e.g. spot spraying).

All producers used knapsack sprayers to apply herbicides (Table 6). Many also used controlled droplet applicators while approximately one third used equipment for injecting herbicide directly into the trunk of palms (a procedure used to thin or destroy diseased palms or other large woody plants for example). A small number used wiping wands, motorised mist blowers, boom sprayers, a ‘tractor mounted power sprayer’ and/or a paintbrush.

Table 6. Equipment used by oil palm producers in Malaysia, Indonesia and Papua New Guinea to apply herbicides on their plantations.

Herbicide application equipment	% producers
Knapsack sprayer	100
Controlled droplet applicator (CDA) machine	76
Trunk injection equipment	28
Wiping wand	16
Motorized mist blower	12
Boom sprayer	8
Paintbrush	8
Tractor mounted power sprayer	4

Health and safety procedures applied during herbicide handling and use

Information was requested from producers on personal protective equipment (PPE) used during handling, preparation and application of herbicides. It is important to note that this related to equipment and clothing that was worn specifically for protection during chemical use as opposed to normal, everyday wear. Furthermore, it was only possible to gain an overview of PPE used and not to determine precisely what PPE was used for individual herbicide substances or products.

All producers stated that some form of PPE was used but the type of equipment, including clothing, varied from producer to producer. All wore gloves as well as rubber boots while the majority also wore an apron, goggles to protect the eyes and/or a mask that was sufficient to cover the nose and mouth (Table 7). More than half wore overalls/over-trousers and/or a hat and approximately a third a full face mask (visor). The latter would afford greater protection from herbicide splash and drips than a nose and mouth mask but would not normally prevent inhalation or ingestion of spray, vapour or droplets. In this respect only three of the 25 growers indicated that a respirator was used, in one case by those preparing herbicides from stock concentrations. Four wore a coat for protection while one wore a cap or wrapped a towel around the head.

Table 7. Clothing or equipment worn by oil palm organisation staff in Malaysia, Indonesia and Papua New Guinea specifically for protection when handling or applying herbicides.

Clothing/equipment	% producers
Gloves	100
Rubber boots	100
Apron	84
Eye goggles	84
Mask to cover nose and mouth	84
Overalls or over-trousers	64
Hat	56
Full face mask (visor)	36
Coat	16
Respirator	12
Towel around head/cap	4

Storage and disposal of herbicides and product containers

All producers kept herbicides in a secure storeroom or storage area when not in use. Three producers indicated that at times there was a need to dispose of prepared (diluted) herbicide mixtures once application in the field was completed. Two producers achieved this by placing chemicals in a registered hazardous waste pit and two by sending them to an authorized waste disposal company.

All producers provided information on procedures used for disposal of empty or unwanted herbicide containers. Approximately half disposed of containers by sending them to an authorized chemical disposal company (Table 8), while approximately one third placed them in a registered hazardous waste pit. A small number buried containers in soil and/or burnt them. In some instances (data not shown) empty product containers were not disposed of but used for supplying water for spray application, for mixing chemicals or - in the case of large containers - to mix and despatch chemical spray mix to the field. Some producers also used them for to broadcasting fertilizer, as buckets for watering, for potting plants or as garbage containers. Unless the containers are thoroughly cleaned beforehand, the latter practices in particular may present a significant hazard to plantation staff and to the environment.

Table 8. Methods used by oil palm producers in Malaysia, Indonesia and Papua New Guinea to dispose of empty or unwanted herbicide containers.

Disposal method	% producers
Sent to authorized chemical disposal company	56
Disposed of in registered hazardous waste pit	28
Buried in soil	12
Burnt	4

Herbicide products and active substances applied

All producers provided information on the herbicidal products that they were using for ground cover management and the various other purposes highlighted above. In most cases they also provided information on the manufacturer of the products, the active ingredients contained in the products and also an indication of the amounts applied[16].

The range of herbicidal products and active ingredients and the extent to which these were used by producers is shown in Tables 9 and 10. Glyphosate was used by all and metsulfuron by 96% of producers, while 2,4-D, paraquat and triclopyr were also each used by more than half of the producers (Table 9). Ametryn, dicamba, diuron, fluazifop-butyl, imazethapyr, MSMA and sodium chlorate were each used by only one or two producers (equivalent to 4-8% of producers).

---

[16] Due to the format in which data on amounts applied was provided by producers, and the variation observed, no attempt has been made to present this information in the report.

Table 9. Herbicidal active ingredients used by oil palm producers in Malaysia, Indonesia and Papua New Guinea.

Active ingredient[1]	% producers using active ingredient
Glyphosate	100
Metsulfuron	96
Triclopyr	72
Paraquat	64
2,4-D	56
Glufosinate	44
Fluroxypyr	40
Imazapyr	12
Diuron	8
Fluazifop-butyl	8
Sodium chlorate	8
Ametryn	4
Dicamba	4
Imazethapyr	4
MSMA	4

1. Includes reference to derivative as well as parent forms (e.g. acid, ester, salt)

A similar trend was observed in terms of the extent, across all producers, to which products containing a particular active ingredient were chosen for use (Table 10). Of note, the frequency with which products containing glyphosate were reported was at least twice that of any other active ingredient with the exception of metsulfuron and triclopyr. Glyphosate products, reported as used on a total of 43 occasions, accounted for 25% of all reported cases of use.

As Table 10 also highlights, a broad range of products were specified by producers as used for vegetation management. It should be noted that the information presented is as provided by the producers and, as a consequence, a number of names are included that - while very similar - may or may not relate to the same product. This may simply be due to provision of inaccurate information by producers. Alternatively, herbicidal products with very similar trade names may exist that, in some cases, prove to be generics or perhaps unauthorised substances.

Table 10. Herbicide products and the extent to which products containing specific active ingredients were reported as used by oil palm producers in Malaysia, Indonesia and Papua New Guinea.

Active ingredient[1]	**No. cases of use**[2]	**Products used by producers**[3]
Glyphosate	43	Asset, Basmilang 480 AS, Bm Glyphosate, Contro-Up, Dewana Glyphosate, Dewana Glyphosate 41, Ecomax, Elang, Exert, Glyphosate, Glyphosate 450 SL, Glyphosate 480, Glyphosate CT, Glypho-Z, Ken-Glyphosate, Kill Up, Kleen UP, Kleen Up 480 A, Klen Up, Nufosat, Pelita 480 AS, Prima Up, Round Up, Round Up 486 AS, Roundup 486 SL, Sentry, Sidafos 480 AS, Smart, Smart 486 AS, Sun Up 480 AS, Supremo, Supremo 41, Supremo 480 AS, Supresate, Sweep 480 AS, Till Master 240/120 AS, Touch Up
Metsulfuron	32	Ally, Ally 20 DF, Ally 20 Up, Ally 20 WDG, Ally 200 DF, Bm Cergas, Canyon 20G, Farmet, Kenlly, Meta Prima, Metafuron, Metfuron, Metsulfuron, Metsulindo, Metsulindo 20 WP, Rapid, Trap 20 WP, Trendy 20 WG
Triclopyr	23	Comet, Foxil, Garlon, Garlon 250, Garlon 48 EC, Garlon 480 EC, Garlone 480 EC, Goal 240 AC, Treister 480 EC, Tricalon 250, Triclo, Tri-Ester 32
Paraquat	19	Action 13 SL, Capayam, Chemoxone Super, Gramoxone, Gramoxone 200, Gramoxon 276 SL, Hextar, Hextar Paraquat 13, Ken-Tec, Nuquat, Paranox 13, Paraquat, Paratop 276 SL, Primaxone, Supretox 276 AS
2,4-D	16	2,4-D Amine, 2,4-D Amine Salt, Abolisi 865 SL, Amine 720, CH Amine 60, DMA 6, Ken-Amine 600, Indamin 720 HC, Lindomin, Lindomin 865 AS, Rajmine 48, Rarity Amine 60, Rhodiamine
Fluroxypyr	12	Flurane 200, Kenrane 200, Starane, Starane 200, Starane 200 EC, Stanex 296
Glufosinate	11	Basta, Basta 15, Basta 150 WSC, Hallmark 15
Imazapyr	3	Chopper, Chopper 100
Diuron	2	Ancom Diuron F42, Monex HC
Fluazifop-butyl	2	Fusilade 125 EC, Fusilade 40
Sodium chlorate	2	Ancom Sodium Chlorate, Sodium chlorate
Ametryn	1	Symbol 45 SC
Dicamba	1	Kamba 500
Imazethapyr	1	Pursuit 50A
MSMA	1	Monex HC
Total	**169**	

1. Includes reference to derivative as well as parent forms (e.g. acid, ester, salt)
2. Denotes total number of cases across all producers where any product containing the active ingredient is used
3. Product names as specified by producers

As shown in Table 11, and in reflection of the diversity of products identified, the concentration of any one active ingredient in the various products used by producers could vary considerably.

Table 11. Concentration of herbicidal active ingredients present in various products used by oil palm producers in Malaysia, Indonesia and Papua New.

Active ingredient[1]	**Concentration (%)**[2]
2,4-D	48 - 86.5
Ametryn	45
Dicamba	50
Diuron	7.8 - 42
Fluazifop-butyl	12.5 – 13.2
Fluroxypyr	20 – 29.6
Glufosinate	13.5 – 15
Glyphosate[3]	24 – 48.1
Imazapyr	11.9
Imazethapyr	5.2
Metsulfuron[3]	20 – 35
MSMA	39.5
Paraquat	13 – 27.6
Sodium chlorate	99
Triclopyr[3]	32 - 48

1. Includes reference to derivative as well as parent forms (e.g. acid, ester, salt).
2. Indicates range in concentration found across all products containing the active ingredient.
3. A small number of concentrations provided by producers for glyphosate, metsulfuron and triclopyr were, in relation to recognised levels in known products, considered to be errors and have not been included in the respective ranges for these active ingredients.

A total of 69 manufacturers were identified for the various products used by producers across the three countries (Table 12), reflecting extensive diversity of product source. In a number of instances more than one manufacturer was identified for the same product.

Table 12. Manufacturers of herbicidal products used by oil palm producers in Malaysia, Indonesia and Papua New.

Manufacturer[1]
Agri-Bio Corporation Sdn Bhd
Agricorp
Agrokimia Bumi Makmur
Agrotech Pesticide Industry
Ancom
Ancom Crop Care Sdn Bhd
BASF
Bayer
Bayer Co (M) S/B
Bayer CropScience
Bayer Indonesia
Behn Meyer
Biotis
CBA
Crop Protection
Dow Agro
Dow Agroscience
Dow Agroscience (M) S/B
Dow Agroscience Indonesia (USA)
Dow Agrosciences
Dow Agrosciences Indonesia
Du Pont (M) S/B
Du Pont Agricultural Product Indonesia
Du Pont Inc
Du Pont Malaysia
Dupond Crop Protection
DuPont
Essence Agrochemicals
Farmcochem
Farmset Ltd
Farmset PNG
Hap Seng
Hextar
Hextar Chemical Sdn. Bhd
Hextar Chemicals
Hextar Chemicals S/B
Hextar Chemicals Sdn Bhd (Malaysia)
Imaspro Resources
Inti Everspring Indonesia
Kenso
Love land Products inc
Mitra Kreasi Darma
Monsagro Kimia
Monsanto
Monsanto (M) S/B
Mosanto
Mycrop Sdn. Bhd
Nanjing No.1 Pesticide Company
Nufarm
Nufarm Aust. Ltd.
PT Adil Makmur Fajar
PT CBA Chemical Industry
PT Centra Brasindo Abadi Intercon
PT Dupont Agricultural Produk Indonesia
PT Inti Everspring Indonesia
PT Kimika Usaha Prima
PT Nufindotama Makmur
PT Nufram Indonesia
PT Pasific Chemicals Indonesia
PT Pelita Agung
PT Syngenta Indonesia
PT Tribina Tanikarya
PT United Phosphorus – India
PT Yasida Makmur Abadi
PT. DOW Agrosience Indonesia
Serba Kimia
Sygenta
Tribina Tanikarya
Zeenex

1. Manufacturer name as provided by producers

Appendix 1

Oil palm producers in Malaysia, Indonesia and Papua New Guinea providing information on ground cover vegetation management and the role and use of chemical herbicides.

Country	Producer organisation
Malaysia	Boustead Estates Agency Sdn Bhd
	Estet Pekebun Kecil Sdn. Bhd (ESPEK)
	FELDA Agricultural Services Sdn. Bhd (FASSB)
	Genting Plantations Berhad (formerly Asiatic Development Berhad)
	Hap Seng Plantations Holdings Berhad
	IOI Group
	PPB Oil Palms Berhad
	Sime Darby Plantation Sdn. Bhd.
	United Plantations Berhad
Indonesia	BGA GROUP
	PT Agro Indomas
	PT Austindo Nusantara Jaya Agri
	PT Bakrie Sumatera Plantations, Tbk
	PT Musim Mas
	PT Perkebunan Nusantara IV (Persero)
	PT Perkebunan Nusantara V (Persero)
	PT Salim Ivomas Pratama
	PT Tasik Raja/PT United Kingdom Plantation Indonesia
PNG	CTP (PNG) Ltd
	CTP-CARGILL
	Hargy Oil Palms Ltd
	New Britain Palm Oil Ltd
	Poliamba Ltd

Part 3. Producer CASE Studies: Weed Management in Oil Palm and Measures to Reduce the Use of Herbicides

Roundtable for Sustainable Palm Oil (RSPO): Research project on Integrated Weed Management Strategies for Oil Palm

Producer CASE studies: weed management in oil palm and measures to reduce the use of herbicides

Compiled by:

M. Rutherford, J. Flood & S. S. Sastroutomo
(UK and Malaysia)

April 2011

www.cabi.org

Introduction

A research project undertaken by CAB International (CABI) on behalf of the Roundtable on Sustainable Palm Oil (RSPO) is seeking information on weed management practices employed by oil palm producers. This information is intended to provide an up to date overview of weed management. It will also be used to help RSPO and the oil palm industry to identify, recommend and introduce management practices that will help to reduce producer reliance on the use of hazardous and environmentally damaging chemical herbicides.

As part of this research, 25 producer organisations operating in Malaysia, Indonesia and Papua New Guinea (PNG) participated in a survey of weed management on their plantations. This survey identified, for example, a range of weed management measures employed by the producers and the extent to which these are used. It also revealed how each measure is perceived by producers and provided information on specific herbicides being used, why they are used and the manner in which they are used.

As a follow-up study, and based on the survey data, more detailed information was requested from six of the original survey participants (two operating in each of the three countries) on measures they were using. This study specifically sought to explore measures used to reduce or eliminate the use, and dangers associated with use, of chemical herbicides through their replacement or integration with other less hazardous substances or non-chemical measures. This information formed the basis for a number of producer CASE studies reported here.

In selecting producers for the CASE studies, the information gathered through the weed management survey was reviewed. Using a number of criteria, two producers were selected for consultation in each of Malaysia, Indonesia and Papua New Guinea (PNG). The selection criteria, chosen to facilitate investigation of the application and merits of a range of management approaches, included:

- Use of herbicide substances of relatively low toxicity (based on internationally recognised World Health Organisation [WHO] Recommended Classifications17)
- Non-use of more hazardous substances (namely paraquat and/or 2,4-D, used by a number of the producers surveyed)
- Implementation of non-chemical weed management approaches

The process of producer selection also took RSPO Principles and Criteria (RSPO P&C) into consideration, specifically RSPO P&C Criterion 4.5 and 4.6. Criterion 4.5 refers to effective management of weeds, pests, diseases and invasive species using integrated pest management (IPM) techniques (incorporating cultural, biological, mechanical or physical methods to minimise chemical use). Criterion 4.6 refers to the use of agrochemicals in a way that will not endanger health or the environment, and includes specific reference to the need for safe and proper use of chemicals by trained personnel and a reduction in, or elimination of, use of the herbicide paraquat. All selected producers were members of RSPO and had indicated, through the previous

---

[17] World Health Organisation (2005). The WHO Recommended Classification of pesticides by Hazard and Guidelines to Classification, 2004. WHO Press, Geneva. ISBN 92 4 154663 8

survey, that they were aware of, and addressing, RSPO P&C. They also confirmed that they were attempting to, or had a policy for, reducing or avoiding the risks associated with herbicides by using less toxic herbicide substances and/or alternative, non-chemical management methods. This study sought further information from the producers on the manner in which this was being achieved and the RSPO P&C being fulfilled.

Information was obtained through completion, by the producers, of a Producer Response Form (PRF, see Appendix 1) and, as required and feasible, through follow-up consultation with individual organisations. The studies in Malaysia and Indonesia were led by scientists from the CABI South East Asia Regional Centre (CABI-SEA) in Malaysia. In PNG the participation of producers was facilitated by the Oil Palm Research Association Inc. (OPRA). The PRF, supporting information and guidelines for completion were distributed to the selected producers in July 2010.

Of the six producers approached, and by 31 March 2011, four had provided information for the study. The following is a summary of the information provided by each (in which interpretation of the original information provided has been kept to a minimum), followed by a summary of the key findings and concluding points. For the purpose of anonymity, the producers are referred to as Producers 1 to 4.

1. Procedures and precautions employed by producers when handling and using herbicides

1.1 RSPO Principles and Criteria 4.5 and 4.6

Producers were asked to briefly describe the main procedures or changes that they have introduced or are currently introducing to help ensure that RSPO P&C Criterion 4.5 and Criterion 4.6 are addressed specifically with respect to weed management and the use of herbicides.

Producer 1 introduced the practice of mechanical slashing of harvesting paths, using a tractor mounted slasher, primarily to reduce the use of chemical herbicides and, specifically, the costs associated with their use. The producer is also currently updating its procedures for training in pesticide use for all assistant managers, with revised procedures due to be rolled out to Field Supervisors by the end of 2010. All in-house plantation training programs undertaken by Producer 1 incorporated a component on procedures that should be used for the safe storage, preparation and application of herbicides, including standard spray concentrations that should be used.

Producer 2 advocates the use of a Pest Management System focused on more prudent use of pesticides in the context of well planned Integrate Pest Management (IPM). The protocol calls for sparing use of pesticides, application of pesticides as and when required rather than on a fixed schedule and the use of pesticides in combination with other pest control measures, namely mechanical, physical, cultural and biological.

Producer 3 procedures follow a standard controlled manual, ‘Plantation Quality Management System [PQMS]’), which comprises a Quality Management Manual (QMM), a Standard Operations Manual (SOM) and Standard Operating Procedure (SOP). The producer has specific SOPs in place with respect to the handling of chemicals, application of chemicals and storage of chemicals among other procedures for pesticide practice. In addition, the producer makes reference to its Agricultural Reference Manual (ARM) for implementation of pest management measures as part of Integrated Pest Management (IPM), which includes the establishment of barn owl (predator) boxes, cultivation of beneficial plants, cultivation of leguminous cover crops and more. These ‘best practices’ reduce the need for agrochemical application and promote more sustainable agricultural production.

Producer 4 implements weed management through both manual and chemical control measures. Herbicide application is introduced after a process of socialization and demonstration by its the companies, which include demonstrations on techniques used for application, safety measures, the disposal of herbicide containers and training on Pesticide Application Technique (PAT). Products used are evaluated and registered by the Pesticide Commission of the Ministry of Agriculture.

1.2 Information and training on the use of herbicides

Producers were asked whether they considered that the organisation and its staff received sufficient information and training on herbicide products and substances to enable them to understand levels of toxicity, the risks and dangers associated with individual herbicides and also how they should be properly stored, handled and applied. Reasons as to why the extent of information provision and training was perhaps inadequate, and how this could be improved upon, were also explored.

Producer 1 considered that the organisation and its staff did receive sufficient information and training on herbicide products and substances, certainly to enable them to understand the risks and dangers associated with each herbicide used and how they should be stored, handled and applied properly. All spray applicators were informed of the risks associated with spraying, with storage requirements considered to be well understood and generally well implemented. However, and while the organisation's in-house training covered the importance of LD50 ratings of herbicides, as a measure of herbicide toxicity, it was of the opinion that little practical use was made of this information in the field. Producer 1 considered that, for their training to be effective, an induction programme should be held for all new employees to ensure that they are brought up to the required standards. An ongoing program of re-training and monitoring should also be implemented to ensure that levels of employee knowledge are maintained and that procedures continue to be implemented appropriately.

Producer 2 continually strives to keep up to date with respect to those herbicides used for company operations. Staff complete an induction and training on pesticide toxicity and how they should be used properly to ensure personal safety and protect the environment. This is conducted internally and through the use of external consultants to meet specific training needs.

Producer 3 ensures that all employees who work with chemicals are trained and provided with adequate knowledge and information on herbicides. This involves training and provision of technical knowhow on the handling of chemicals and proper use of personal protective equipment (PPE). Supervisors are in attendance to guide employees during the storage, handling and application of chemicals. Employees are also provided with training on the use of Material Safety Data Sheets (MSDS) and Chemical Safety Data Sheets (CSDS) relating to all herbicides used by the producer, to help ensure that they understand differences in toxicity, the potential dangers of handling herbicides and also what action should be taken in the event of an accident or emergency.

Producer 4 considered that its organisation and staff received adequate information on the application of pesticides, which was communicated through the organisation's operating procedures, working instructions, circulars and internal training activities, among other channels. The producer did, however, consider that its working procedures could be supplemented though the use of pictorial guides and posters, for example.

1.3 Use and maintenance of health and safety equipment and equipment used for the application of herbicides

Producers were asked whether, with respect to those recommendations made by the manufacturer of individual herbicides, (i) the correct safety equipment and clothing was used by employees and staff and (ii) whether the correct equipment was used for preparation and application of the chemicals. Enquiries were also made as to whether the equipment for preparation and application was properly maintained to prevent spillage and leakage of herbicide and to ensure that the correct amount of herbicide is was. If this was not the case, they were asked the reasons why and how they considered that any failings in this regard could be addressed.

Producer 1 considered that its staff used appropriate safety equipment and clothing with respect to the handling and use of different herbicides. It provided all pesticide handlers (mixers and sprayers) with standard personal protective equipment (PPE) that complied with herbicide manufacturer recommendations. In addition, the organisation monitored the use of PPE by employees through a program of regular, documented audits and inspections undertaken in the field. Methods used for the preparation and application of each herbicide product were also standardised to comply with manufacturer recommendations.

To help prevent spillage and leakage of herbicide, and also ensure that the correct quantity was applied, Producer 1 suggested that its level of maintenance of herbicide application equipment, such as knapsack pumps, could be improved upon. The organisation viewed this as an aspect of herbicide use that required constant attention and considered it to be closely linked to its ongoing programmes for training and monitoring. The producer perceived standards of maintenance to have fallen due to a lack of attention by field managers and a general preference to replace items that could be serviced or repaired. Improved training on spray pump maintenance, coupled with greater accountability for the costs associated with equipment maintenance was suggested as a means by which maintenance standards could be improved.

Producer 2 had a mandatory requirement for all personnel involved in the handling, storage and application of pesticides and related tasks to be fully trained on the use of respective pesticides used in plantations and to be issued with the correct equipment, including appropriate PPE.

As indicated in Section 1.2, Producer 3 confirmed that it provided training and information on the handling and use of chemicals and also on proper use of PPE. For each individual herbicide, its employees used the recommended safety equipment and clothing. Recommended equipment was also used during the preparation and application of herbicides, and was considered to be adequately maintained by the organisation.

Producer 4 also considered that its staff used appropriate safety equipment and clothing, as recommended by herbicide manufacturers and with respect to the different herbicides being applied. All equipment used for herbicide preparation and application was prepared by the company according to International Organization for Standardization (ISO) standards, and was properly maintained and regularly calibrated.

1.4 Storage of herbicides

Producers were asked whether the herbicides it used were stored in a secure storage container or facility and, if so, what type of container or facility was used. Reasons as to why methods of storage were considered inadequate and could be improved upon were also sought.

Producer 1 ensures that all its plantations have a purpose built, standard design pesticide shed that contains a lockable pesticide store, a lockable equipment room, separate PPE storage facilities, a bunded mixing area and also emergency shower facilities.

Similarly, Producer 2 ensures that all herbicides are stored in secure, locked storage sheds equipped with shelving, a mixing bay and shower room.

Producer 3 reported that all herbicides they use are properly stored inside a locked chemical storage facility.

Producer 4 retained spent containers, especially those manufactured from plastic, aluminium and zinc, in specific lockers. Paper boxes and other paper containers were burnt.

2. Use of herbicide substances and non-chemical measures for weed management

2.1 Methods employed to reduce or eliminate the use of herbicides

Each of the producers consulted had, during the wider producer survey, confirmed that they were using a number of herbicides and also a variety of non-chemical measures for weed management. They were therefore asked whether they have been able to stop using, or reduce the use of, any particular herbicidal product or substance(s) used previously through adoption of new management approaches. Reasons as to why these herbicides were used and how their use was reduced or stopped were explored, as were the perceived benefits and drawbacks (including cost-effectiveness) of the new approach.

Producer 1 was able to reduce the use of the herbicidal active substance glyphosate. This was achieved through the introduction of a tractor mounted mechanical slasher to control weed growth on harvesting paths. Glyphosate was previously mainly used on paths to provide and maintain free access to the palm for crop for harvesting of bunches and routine maintenance, specifically during the immature and mature stages of palm growth. Where ground conditions permit, the slasher is used to cut all weed growth, without exposing the soil, to create an access pathway between 1.2 and 1.5 metres wide. The initial reasoning for introducing a non-chemical practice was to reduce herbicide usage and also to minimise the costs associated with chemical use, as no other herbicides or other non-chemical measures are now required. In overall terms, mechanical slashing of the paths has been found to be a more effective method for controlling weed growth, as it is less time consuming, requires less labour (hence increased output per man day) and is generally considered to be more cost effective. Performance of the new approach is now considered to be related to tractor availability, and can therefore be adversely affected if the machinery is not available. The producer believes, therefore, that performance could be enhanced by improving operator training to help avoid machinery malfunction for example.

Producer 2, also in line with the company’s IPM policy, actively pursues the adoption of non-chemical measures for weed control with the aim of reducing herbicide use as part of a reduction in overall pesticide use. The company's field standards or weed management policy stipulates the following requirements:

- Active establishment of leguminous cover plants (LCP) in new areas, replants and mature fields.
- Mowing of ground cover vegetation in harvesting areas with a rotary slasher,
- Control of pests using known and available biological control agents.

Currently the noxious weeds Siam Weed (*Chromolaena odorata*) and Water Lettuce (*Pistia stratiotes*), a problematic weed of waterways including irrigation systems, are managed using a combination of chemical and biological control measures. By-products of palm cultivation, such as empty fruit bunches (EFB) and cut fronds, are also used as mulch to suppress weed growth.

Like Producer 1, Producer 2 has managed to reduce the use of glyphosate as well as use of the herbicide 2,4-D. These herbicides were mainly used for the control of weed growth on paths and to maintain weed free circles around the bases of palm plants in the mature crop. The reason for reducing their use was to reduce costs, with a tractor and slasher now being used to manage weed growth on the harvesting path as opposed to herbicides. Producer 2 also considers this new approach to require less manpower and to be faster and more cost-effective. However, it does have concerns over safety when the tractor is used on slopes.

Producer 3 has been able to prohibit the use of the herbicidal substance paraquat. This was previously used in the mature crop to control a broad range of annual and perennial weeds that reduce palm yield and quality by competing for available water, nutrients and light. The herbicide was prohibited primarily on the basis of its toxicity to humans, and has been replaced by the less toxic herbicide glyphosate. Producer 3 estimates the cost per hectare of using glyphosate to be only about one third that of paraquat, and considers glyphosate to be a much safer herbicide in terms of the potential risks to human health and the environment. Overall, it views the replacement of paraquat by glyphosate as beneficial in terms of employee health and safety, causing less pollution to the environment and being more viable in terms of cost-effectiveness.

Producer 4 reported that it had been able to reduce the need for herbicides, including 2,4-D amine and paraquat, though the application of alternative herbicides as well as non-chemical measures. Alternative herbicides include glyphosate, fluroxypyr (the active ingredient of 'Ally', the product used by the producer) and metsulfuron-methyl (the active ingredient of 'Stearane'. Non-chemical measures involve manual weeding with sickles, hoes and cleavers as well as application of mulch to suppress weed growth. These approaches were adopted specifically to reduce or prevent competition for nutrients and erosion soil in young plantings and to facilitate harvesting and application of fertiliser in mature plantings. For the latter, where weed problems occur during fertiliser application, manual weeding is undertaken before fertiliser application commences. The Producer also wanted to reduce use of the herbicides, and introduce the new approach, to reduce soil compaction and promote the growth of beneficial soil microbes and worms (as manual weeding helps to loosen the surface soils). No indication was provided as to the effectiveness, cost or cost-effectiveness of the new measures in relation to the original approach, of any drawbacks of the new approach or any means by which it could perhaps be improved upon.

2.2 Herbicides of concern

Producers were asked whether they were using any other herbicides for which they would prefer to discontinue use, or reduce the amount used in the future, and how they considered this may be achieved through alternative herbicides and/or non-chemical measures.

Given the RSPO P&C requirement for producers to reduce or eliminate the use of paraquat, Producer 1 is concerned about its use of the product ‘Gramoxone’ which contains paraquat as the herbicidal active substance. The producer indicated, however, that it had experienced no practical problems with the use of Gramoxone and would prefer to continue using the herbicide until a viable alternative has been identified. It considered it unlikely that a non-chemical option would be successful. The producer is currently conducting trials to try to identify a suitable replacement, but no recommendations have yet been made.

Neither Producer 2 nor Producer 3 provided information on other herbicides that they considered to be of concern.

Producer 4 did not specify any herbicides of concern in terms of a desire to reduce or eliminate their future use, but simply stated that the Pesticide Commission was responsible for herbicide testing and the issue of regulations governing their production and distribution. It did, however, indicate that it would prefer to reduce or apply both chemical and non-chemical measures for weed control. The producer specified a ‘bio-based’ herbicidal product containing extracts of *Lantana camara* (‘Spanish Flag’ or ‘West Indian Lantana’) as a suitable alternative, citing less of a detrimental effect on soil microbes as the main advantage of using the product. When asked whether there was an intention to introduce any alternative measures, the Producer highlighted the research and development of ‘bio-based’ herbicides.

2.3 Future weed management and potential introduction of other, new weed management measures

Producers were asked as to whether there were any other herbicide substances or non-chemical weed management measures that they were not using but would like to introduce in the future. Reasons as to why these were desirable and why they had not already been introduced were also explored.

Producer 1 was not aware of any other herbicidal substances or other non-chemical measures that the organisation would like to introduce. However, it was expecting to be able to make more efficient use of chemicals through better management as well as continued or increased use of biological control measures for specific noxious weeds established on plantation boundaries and in reserve areas. A reduction in weed seed banks in areas outside the plantation was considered to be a specific benefit of the introduction of these new measures. Biological control of Siam weed and *Mikania* was ongoing on the producer’s properties.

Producer 4 indicated that it would like to introduce measures involving the use of ‘bio-based’ herbicides, mulching, manual weeding or mechanical control. Specific benefits of these were considered to be an increase in microbial diversity increased as well as a softer and more porous soil texture. Reasons as to why such measures had not already been introduced were a need for further development of mass-production methods of weed biocontrol and the testing and commercialisation of products.

Neither Producer 2 nor Producer 3 provided information on possible new measures for the future.

Summary and conclusions

The information provided by the four producers supports the findings of the previous, broader survey in terms of the range of chemical and non-chemical measures they use to attain effective weed management. It also highlights the fact that they are clearly aware of the of the RSPO P&C regarding the use of chemical herbicides, and all been proactive in seeking and introducing measures to reduce or eliminate their application of herbicides, including paraquat and 2,4-D. These two herbicides are considered to be Class II (‘moderately hazardous’) substances by the WHO and, based on the WHO classification system, were the two most hazardous substances used by oil palm producers that participated in the earlier survey. Indeed, each of the substances was found to be used by more than half the organisations consulted.

Reductions in herbicide have been achieved through a variety of non-chemical measures - including manual and mechanical weeding, application of mulch, cultivation of cover crops and the use biological approaches – and also more rational use of herbicide products and/or herbicide substitution with less toxic substances. Importantly, these measures have been adopted within an integrated approach to weed control as opposed to being used in isolation.

Specific examples of how producers have managed to reduce the use of chemical herbicides include use of a tractor mounted slasher in place of glyphosate to manage weed growth on paths used for harvesting palm bunches and facilitating general plantation maintenance in both immature and mature plantings. In this case no other weed management measures were deemed necessary and, significantly, the approach was considered to be quicker, more effective, less labour intensive and therefore more cost effective than the use of glyphosate. Furthermore, there is potential to improve upon this approach through better machinery maintenance. Similarly, the use of a tractor and slasher have enabled another producer to eliminate the need for application of not only glyphosate but also the more toxic 2,4-D during management of weed growth on harvesting paths and in palm circles. Again, this approach was considered to be faster and more cost effective than the original measures.

Elimination of the use of paraquat for control of a broad range of weed species in mature plantings has been achieved through substitution with the less toxic herbicide, glyphosate. As highlighted above, paraquat is a herbicidal substance for which RSPO is seeking, and encouraging its members to use, alternative and less hazardous weed management measures. The new approach was considered to be not only safer and less damaging to the environment but also much more cost-effective than the use of paraquat. The replacement of paraquat and 2,4-D, by the less hazardous herbicides glyphosate, fluroxypyr and metsulfuron, manual weeding and application of mulch, was also found to be an effective means of weed management in young and mature plantings. Significantly, products containing glyphosate, fluroxypyr and metsulfuron, as WHO Class ‘U‘ substances, are considered ‘unlikely to present an acute hazard in normal use’.

The cases highlighted above suggest that considerable potential may exist for broader adoption of the same approach by other producers and lead to similar benefits. One producer, for example, highlighted paraquat as a herbicide that they applied but for which it had concerns. Although this producer had already managed to replace the use of glyphosate with mechanical weed management, it considered it unlikely that a viable, non-chemical alternative would become available as an alternative to paraquat. Perhaps, however, substitution of paraquat by less hazardous herbicidal substances such as those identified and now used by Producer 4 (with or without the non-chemical measures also mentioned) may offer an alternative approach to this particular producer and indeed many others, including those identified as using paraquat in the survey.

It is clear that biological control of specific weed species is already being practiced by some producers and, as part of an integrated approach, can contribute to a reduction in the use of chemical herbicides - as highlighted in the control of Water Lettuce and Siam Weed. A desire, and indeed expectation, to continue to reduce chemical in weed control, partly through an expansion of biological approaches, was also expressed with, in the case of one producer, the effectiveness and benefits of a botanical-based herbicide being explored.

As referred to above, the producers highlighted a number of benefits that could be gained from the various alternative approaches, both chemical and non-chemical, that they had introduced to reduce on the use of pesticides. They included a reduction in health risks to operators (those handling and applying chemicals), possible exposure of other personnel and potentially detrimental effects on the environment - key factors in any decision making concerning the use of pesticides and agricultural inputs generally. A reduction in costs was also an important factor and may be due to reductions in associated costs of (for example) herbicide purchase, labour, application, PPE and indeed the storage and disposal of leftover herbicide and herbicide containers. Indeed, the producers did perceive their alternative measures to be more effective, less time consuming and labour intensive, and, overall, more cost effective. Realisation of benefits such as these is extremely important, as decision making involving a change in normal practice will rarely be based on effectiveness alone.

In terms of ensuring that chemical herbicides are handled and used in a safe and appropriate manner, the producers were generally of the opinion that staff were afforded adequate information and training on how they should be stored, handled and applied in line with manufacture recommendations and what PPE should be worn. This was provided through internal resources and/or external specialists and involved up-front (or induction) training, ongoing training programmes, monitoring (to determine how effectively procedures are put into practice) and modification of procedures as necessary. In some cases, staff were provided with fundamental knowledge on the chemical nature of herbicides, to enable them to better understand the risks they present, and were supervised during herbicide use. Despite the level of information and training provided, the producers did recognise some failings in their procedures and suggested a number of mechanisms for improvement in terms of, for example, maintaining employee knowledge and skill levels and enhancing the quality of information materials provided,.

The producers were also of the opinion that, for the most part, appropriate PPE was provided to, and worn by, personnel who handled and used herbicides. Recommended herbicide application equipment was also provided and used. Nevertheless, some issues were raised with regard to the extent to which application equipment was maintained, which could be resolved at least in part though better training and vigilance. With respect to storage of herbicides, three of the four producers confirmed that their products were kept in a secure (lockable) storage facility which, in some cases, also incorporated a herbicide preparation (mixing) area, shower room/area and other facilities. The fourth indicated that (spent) containers were kept securely in lockers.

It is unfortunate that, as with the producer survey, the level of feedback from producers in this study was more limited than anticipated in that only four of the six producers provided information. Furthermore, and while there may be a number of underlying reasons, producers who did participate in the study did not fully respond to applicable questions in the PRF. As a consequence, this may have prevented the realisation and promotion of other weed management approaches that may be of benefit to RSPO and its members, certainly in terms of achieving reductions in the use chemicals and implementing safer, cost-effective and more sustainable technologies.

Appendix 1.

Producer Response Form

RSPO Project on Integrated Weed Management for Oil Palm

PRODUCER RESPONSE FORM

Please complete Part 1 and Part 2 below by providing information of relevance to the questions above each box. Part 1 relates to procedures and precautions that are taken when herbicides are handled and applied. Part 2 relates to the use of herbicide substances and non-chemical measures for weed management as well as ways in which the use of herbicides may be reduced.

If possible, provide information on the each and every one of the questions specified above a particular box.

If you do have information or do not wish to provide information for a particular box, please enter NI (no information) in the box.

If you wish you may also provide relevant documents or parts of documents (such as Standard Operating Procedures) to provide more information in support of the responses you provide in the Form. If you do provide additional documents, please indicate in the relevant box(es) the document – or part of a document – that we should also refer to.

Please note that each box will expand as information is entered electronically.

It is advisable to read the questions above all of the boxes before filling any of the boxes.

***Note*:**
Where questions refer to the use of herbicides or herbicide substances, please provide information on chemical substances as opposed to chemical products. Examples of herbicide substances are:

2,4-D
Ametryn
Dicamba
Diuron
Fluazifop-butyl
Fluroxypyr
Glufosinate
Glyphosate
Imazapyr
Imazethapyr
Metsulfuron
Methylarsenic acid (MSMA)
Paraquat
Sodium chlorate
Triclopyr

Where questions refer to the use of non-chemical management measures, these include measures such as:

Planting a cover crop
Covering weeds with sheeting
Applying mulch
Altering palm planting density
Hand weeding
Slashing
Uprooting plants with a hoe
Mechanical weeding (with a mower, tractor etc)
Biological control (using predators, parasites, fungi, pheromones etc)
Grazing by livestock

PART 1

Procedures and precautions for handling and using herbicides

1.1 RSPO Principles and Criteria

Your completed survey questionnaire indicated that your organisation is a member of RSPO and is aware of, and practicing, RSPO Principles and Criteria (P&C). Criterion 4.5 and Criterion 4.6 of the RSPO P&C refer to the management of weeds, pests, diseases and invasive species and the use of agrochemicals.

Briefly describe the main procedures or changes that have been introduced, or are currently being introduced, by your organisation/plantation to help ensure that the Criterion 4.5 and Criterion 4.6 are addressed specifically with respect to weed management and the use of herbicides?

1.2 Information and training on herbicide use

Your completed survey questionnaire also indicated that your organisation/plantation is using a range of chemical herbicides and non-chemical measures for weed management.

With respect to the herbicides, do you consider that your organisation and its staff receive sufficient information and training on herbicide products and substances to enable them to understand (i) the differences between the level of toxicity of each herbicide (ii) the risks and dangers associated with each herbicide and (iii) how they should be stored, handled and applied properly?

If not, what are the reasons for insufficient information and training being provided?

How do you think this problem could be resolved to improve provision of information and training?

1.3 Health and safety equipment

For each of the different herbicides used by staff, is the correct safety equipment and clothing used as recommended by the herbicide manufacturer?

If not, what are the reasons for not using the correct equipment and clothing?

How could this problem be addressed to help ensure that the correct equipment and clothing is used?

1.4 Application of herbicides

For each of the different herbicides used by staff, is the correct equipment used for preparation and application of the chemical as recommended by the herbicide manufacturer?

Is the equipment properly maintained to prevent spillage and leakage of the herbicide and to ensure that the correct amount of herbicide is applied?

If not, what are the reasons for not using the correct application equipment or not maintaining it adequately?

What could be done to address these problems?

1.5 Storage of herbicides

Are the herbicides used by your organisation/plantation stored in a secure storage container or facility? What type of container or facility is used?

If the herbicides are not stored securely, why is this?

What steps could be taken to help ensure that herbicides are stored safely?

PART 2

Use of herbicide substances and non-chemical measures for weed management

2.1 Reducing herbicide use

Your completed survey questionnaire also indicated that your organisation/plantation is using a range of herbicides and non-chemical measures for weed management.

Have you already been able to stop using an herbicide substance(s) that was used previously for a particular weed problem, or to reduce the amount of the herbicide that is required?

If yes, please provide the name of the herbicide substance(s).

What were the main reasons for using the above herbicide(s) in terms of weed management?

Indicate any specific areas (e.g. nursery, mature crop etc) or conditions under which management of this weed problem is required.

Why did you want to stop using the herbicide(s) or reduce the amount that is required?

Describe how the original weed problem is now being managed without the herbicide(s) or with a reduced amount of the herbicide(s).

In doing so please indicate which other herbicide(s) and which non-chemical measures have been, or are being, introduced as alternatives to use of the original chemical.

Overall, do you consider the new approach to be as effective in controlling the weed problem as the old approach?

Is it more time consuming or less time consuming?
Is it more expensive of less expensive?
Overall, do you consider it to be more cost-effective?

What are the main benefits of using the new approach?
What are the main problems or drawbacks of using the new approach?
Could the new approach be improved and, if so, how?

2.2 Herbicides of concern

Are there other herbicide substances that you currently use but would prefer not to use or for which you would like to reduce the amount used use in the future?

If yes, please specify the herbicide substances of concern.

Why are you concerned about using each of these herbicides?

Would you prefer to reduce or replace these herbicides with other herbicides, with non-chemical measures or with both options?

Are you already aware of any other herbicides or non-chemical measures that would be suitable as alternatives?

What do you consider to be the main advantages of these alternative measures?

Do you intend to introduce any of the alternative measures? If so, which measures?

If you do not intend to introduce these alternative measures, or are unable to introduce them, what are the reasons?

2.3 Future weed management

Are there any other herbicide substances or other non-chemical weed management measures that you are not currently using but would like to introduce in the future?

For what weed management purpose would you like to introduce these measures?

What specific benefits would the use of these measures bring in terms of improving the way in which the weeds are managed?

Are there any specific reasons why these measures have not already been introduced (e.g. too expensive, lack of labour, lack of equipment etc.)?

THANK-YOU FOR YOUR ASSISTANCE

Part 4. Summary Report of Stakeholder Meeting ‘Communities and Chemicals: Sustainable Crop Production’, Kuala Lumpur

Roundtable for Sustainable Palm Oil (RSPO):
Research project on Integrated Weed Management Strategies for Oil Palm

Summary report of stakeholder meeting 'Communities and Chemicals: Sustainable Crop Production' held in Kuala Lumpur, Malaysia, 1 November 2009

Compiled by:

M. Rutherford, S. S. Sastroutomo & J. Flood
CAB International (UK and Malaysia)

February 2010

www.cabi.org

Introduction

In January 2009 a research project was initiated by the Roundtable on Sustainable Palm Oil (RSPO) to obtain important information on weed management practices employed by oil palm producers. This information is intended to provide an up to date overview of weed management, but also to help RSPO and the oil palm industry to identify, recommend and introduce management practices that are sustainable and equally effective but less reliant on the use of chemical herbicides that may be hazardous and damaging to the user, the crop and the environment.

To provide an opportunity to present the project and to highlight and discuss oil palm production, approaches taken in weed management and the role, benefits and concerns regarding herbicide use, an open stakeholder meeting was held in Malaysia in advance of the 7th Roundtable Meeting on Sustainable Oil Palm (2-4 November 2010). The meeting was held on the morning of Sunday 1 November 2009 in the Berlian Room, Hotel Istana, Kuala Lumpur. Participants included members of the project research team as well as representatives of oil palm producers, the pesticide industry, non-governmental organisations (NGOs), Government agricultural authorities and the RSPO Executive Board. Presentations were delivered by speakers from CAB International (CABI, UK), the Pesticides Board of Malaysia, CropLife Asia and Pesticide Action Network Asia and the Pacific (PANAP). Each was followed by open discussion. This was followed by a short question and answer session involving a panel of the presenters (for further information on speakers and topics, see meeting programme in Appendix 1).

The meeting was opened by Dato Mamat Salleh, Vice president III RSPO and chaired by Dr Lum Keng Yeang, CABI Southeast and East Asia Regional Centre. The following is a summary of the proceedings of the meeting and of comments and recommendations put forward by participants.

Oral Presentations

Opening address. Dato Mamat Salleh, Vice President III RSPO.

Dato Mamat Salleh welcoming all delegates and provided a short background and history of the RSPO and the RT annual conferences (from RT1-7). Delegates were informed that, during the establishment of RSPO the main objective was to achieve sustainable oil palm production with minimal or no negative effect on biodiversity. Currently there is a requirement to consider, and take steps to address, carbon balance and climate change. However, it is now considered to be very difficult for RSPO to achieve all of the various objectives.

The Executive Board of RSPO is managing several projects. The IWM project represents one of the larger projects (500,000 RM) and illustrates the RSPO's commitment to the topic.

‘RSPO Integrated Weed Management Strategies Project’. Mike Rutherford, CAB International, UK.

Dr Rutherford described the main objectives and activities of the Integrated Weed Management (IWM) project, the overall aim of which is to acquire and collate information on weed management practices in oil palm and the role and use, by producers, of chemical herbicides. This information may then be used by RSPO and the oil palm industry to help identify alternative, improved weed management approaches with potential for promotion to, and adoption by, RSPO members. The project commenced in January 2009, is funded by RSPO and focuses on IWM in a number of major oil palm producing nations including Malaysia and Indonesia.

Progress made to date with regard to surveys on producer IWM practice and compilation of a literature review on herbicides commonly used in oil palm, as key activities of the project, was presented and discussed. Survey activities had generally progress satisfactorily, in that a questionnaire had been prepared by CABI in consultation with RSPO and a number of producers. This requested information on a number of aspects of producer practice, including:

- Chemical and non-chemical methods used for ground cover management.
- Producer opinion on cost effectiveness of methods.
- Policy for/efforts made to reduce use of chemical herbicides.
- Specific chemicals used – quantities used, why used and how stored, prepared, applied and disposed of.
- Information and training provided to staff on proper herbicide use.
- The use of personal protective equipment (PPE).
- Equipment used for herbicide application.

The questionnaire had been provided to the NIWG in each country for dissemination to selected producer for completion and return. However, the level of response to date was low, only 11 producers (in PNG, Indonesia, Malaysia) having returned completed questionnaire. By the time of the workshop the information provided, which was clear and comprehensive, had been analysed by CABI. The findings, summarised by Dr Rutherford, revealed that:

All growers indicated that a layer of ground cover vegetation - either natural plant growth or a leguminous cover crop - was present under the oil palm. Most growers regularly monitored ground cover growth and all controlled growth through application of chemical herbicides and cultivation of cover crops belonging to the genus *Mucuna, Pueraria, Calopogonium* and/or *Centrosema.* All used herbicides for ground cover management around tree base, while some also applied the chemicals between rows, on paths, for poisoning palms (including palm thinning), other woody plants and epiphytes and for clearing drains. Most also removed ground cover growth by hand and/or with a hoe, by slashing or by mechanical means (e.g. mower, tractor). A number managed ground cover by increasing palm planting density and by using biological methods (e.g. predators, parasites, fungi or pheromones). One grower allowed cattle to graze in the mature planting while one covered the ground with sheeting (to restrict availability of sunlight, water and perhaps air to the vegetation). None of the growers controlled ground cover vegetation by burning or flooding.

All respondents kept records of herbicide use and the majority had a policy for, or made efforts to, reduce or eliminate their use. Of the herbicidal substances reported as used by growers, glyphosate was used by all and metsulfuron-methyl by ten of the eleven. 2,4-D, triclopyr and paraquat were used by more than half, while ametryn, dicamba, fluazifop-butyl, fluroxypyr, glufosinate-ammonium, imazapyr, imazethapyr and sodium chlorate were each used by one or two. Knapsacks and CDA sprayers were most commonly used for herbicide application, although a number of growers used using wiping wands, a mist-blower, boom applicator or trunk injection equipment. All indicated that they used at least some form of PPE. This was predominantly gloves, rubber boots, an apron, eye goggles and/or a mask to protect the nose and mouth. Spent herbicide containers were usually disposed of by burying in soil, placing in a registered waste pit or sent to an authorized waste disposal company.

Dr Rutherford indicated that efforts to obtain further feedback from growers would continue, and requested the assistance from delegates in this regard (Dr Rutherford made a similar request during a presentation provided at RT7 plenary).

Dr Rutherford indicated that good progress was also being made with regard to preparation of the literature review. Although this focused on a review of the human and environmental toxicities and the environmental and ecological fate of herbicides commonly used in oil palm production, it also made reference to their chemical and physical properties and mode of action – as characteristics that influence the toxicity, activity, potential targets (weed types, other organisms) and behaviour (movement, degradation, persistence in organisms and environment) of herbicidal substances. Products known to contain each active substance were being highlighted, as were the level of toxicity/hazard as defined by internationally recognised classification systems for pesticides (WHO, EU, EPA etc.). The review also cited examples of purposes for which each herbicide may be used in oil palm production, made reference to methods of application, the risks - from a health and safety perspective - associated with their handling and use, and highlighted recommended precautionary measures. Almost 200 sources of information had already been accessed to inform the review.

Dr Rutherford concluded his presentation by informing delegates that very important information of benefit to RSPO had already been collated through the surveys and literature review. This had already, for example, enabled comparisons to be drawn – from a variety of perspectives - between different weed management approaches and also between the various herbicides available for selection. However, he stressed that the project was very much ‘work in progress’ and that progress to date would be built upon to hopefully enable future planned activities, including producer CASR studies, to be undertaken.

Note. The Powerpoint of the full presentation delivered by Dr Rutherford is available in Appendix 1 to the main report.

Q&A session:
(C denotes comment)

Q1. *This is a sensitive subject. Is there any way to validate actual policy other than what producers say they are doing?*
Rutherford. *Agreed with the comments regarding sensitivity and indicated that verification really requires face to face interviews with producers to verify the details of what they are doing.*

Q2. *Have you looked at only certified companies or others?*
Rutherford. *We are trying to capture as much information as possible about what is being done, including from non-certified producers.*

Q3. *What is the deadline for the project and are you able to go to the field to check on IPM?*
Rutherford. *The project terminates in January 2010. There is no budget available to visit producers in the countries to see what the situation really is - for such information we have to rely on feedback provided from producers through the proposed CASE studies.*

Q4. *What is the best practice for each area of production – is a Standard Operating Procedure required for each?*
The project is about how RSPO can provide better advice about how things should be done and about alternative procedures or practices that may be available.

Q5. *Perhaps we require a follow-on project?*
Rutherford. *That could certainly be useful but would be a decision to be made by the RSPO.*

C1. *If there is going to be a requirement to reduce the use of paraquat, we must be able to say that we recommend alternative measures XYZ.*

'Control of Pesticides in Malaysia'. Ms. Nursiah Mohamad Tajol Aros, Director of Pesticide Regulatory Division, Department of Agriculture, Malaysia.

Ms. Nursiah informed delegates that The Pesticides Act of 1974, the principle legislation for the control of pesticides in Malaysia, is implemented by the Pesticides Board. The Board comprises various heads of government agencies and falls under the jurisdiction of the Department of Agriculture. Simultaneously, the role of implementation of the *Code of Conduct on the Distribution and Use of Pesticides* is also the responsibility of the Department of Agriculture.

The objective of the 1974 Act is to ensure that:

1. Pesticides that are sold and used in Malaysia are:

  - Effective for their intended uses.
  - Have no undesirable side effects on humans, non-target organisms and the environment.
  - Are of good quality as specified by the Board.
  - Do not cause residue problems to the resultant crops.

2. Manufacturing, storage and sale of pesticides adhere to the specified conditions in order to avoid adverse effects.

3. Advertisement of pesticides does not mislead the user or the public.

4. Pesticides are used safely and effectively.

5. Pesticides are controlled and managed in a proper manner.

Currently, seven subsidiary legislations are being enforced in relation to pesticide registration, importation for research and education purposes, labelling, licensing for sale and storage for sale, highly toxic pesticides, advertisement, and pest control operators. Some significant amendments recently made to the Pesticides Act include the imposing of: heavier penalties for all offences; control of importation of pesticides as a registration sample or an analytical standard; control of possession or use of unregistered pesticides and unapproved use of pesticides; and the mandatory requirement imposed on a pesticide offender to cover the costs of pesticide disposal.

Among other laws enacted to control other specific aspects of pesticides are:

1. The Poisons Act 1952 (Revised in 1989).
2. The Poisons and Deleterious Drugs Ordinance (Sabah).
3. The Poisons Ordinance (Sarawak).
4. The Hydrogen Cyanide (Fumigation) Act 1953 (Revised in 1981) - to control the fumigation of premises including ships using either hydrogen cyanide or methyl bromide.
5. The Poisons (Sodium Arsenite) Act 1969.

In addition the Pesticide Boards, through the DOA, also implement ‘post-registration monitoring’ covering the following activities:

- Check on market samples.
- Residue monitoring on crops.
- Poisoning incidents.
- Enforcement activities.
- Review of registration, if required.

Ms. Nursiah explained that Malaysia has a comprehensive pesticide risk reduction program implemented by various parties and using diverse approaches mainly based on the experience of other countries. Pesticide risk reduction has been actively on the Pesticide Board's agenda for a considerable number of years. These are administered by various means involving legislation, administration and cooperative efforts between agencies and other related parties. Activities that have been developing are:

- Banning of persistent pesticides.
- Registration of pesticides with safer formulations.
- Restrictions on quantities that are allowed to be stored in licensed premises.
- Prohibition of sale of Class Ia and Ib pesticides in sundry shops.
- Restrictions on the sale of *monocrotophos*, *methamidophos* and acephate.
- Improvements in the information provided on labels and its presentation.
- Improvements in pesticide application technology to ensure that pesticides are applied efficiently.
- Education and training on safe handling of pesticides.
- Implementation and promotion of Integrated Pest Management (IPM) as well as good agricultural practices (GAP).
- Awareness programs.

Finally, Ms. Nursiah has listed out several challenges faced by the Board/DOA, i.e. on:

- Legislative control.
- Monitoring of pesticide usage.
- Education of users.
- Involvement of stakeholders including plantation industry.
- Balancing all factors (science, social values, economics, public pressures, trade, etc.).

Q&A session:
(C denotes comment)

Q1. *Plantations are private so how can you monitor them?*
Nursiah. *To buy pesticides, plantation companies have to give details of how much they use, how they store etc. and generally there is good collaboration. There is more of a problem with smallholder farmers.*

'Chemical Management in Oil Palm Plantations'. Dr Martin Gibson, Stewardship Director, CropLife Asia.

Dr Gibson provided an introduction to CropLife, by indicating that the organisation represented the industry, had seven member countries, two associate companies and operated through 15 national associations. A primary aim of the organization is to develop and transfer technologies to farmers through training and other initiatives. Reference was then made to a number of topics relating to: challenges to agriculture; the importance of agriculture in Asia and of palm oil in Indonesia and Malaysia; crop protection products in managing palm oil; stewardship in palm oil; and, finally, lessons and benefits. Each of these is summarised below.

1. Challenges to agriculture include the following factors:

- Global population growth – increasing by 220,000 people per day - predicted that world population will reach 9.4 billion in 2050 (was 5.7 billion in 1995).
- Urbanisation.
- Increasing demand.
- Food security issues/minimizing losses.
- Rising input costs.
- Rising levels of malnutrition – 1 billion are hungry.
- Declining agricultural areas – more food must be produced on less land with less water. Arable land per person in 1960 was 4.3 ha and in 2020 will only be 1.8 ha.
- Water shortages – Relative sufficiency of 92% in 1995 and will only 58% in 2050.
- Climate change.
- Cost and timing of innovations –production of one good product/substance will cost the company approx. 215 million US$.

2. Importance of agriculture in Asia

The following table provides examples of total populations in Asia and the number and percentage of populations involved in agriculture.

Table 1. Projected populations in Asia in 2010 (millions)

Country	Total	In Agriculture	% in Agriculture
Indonesia	239.6	90.0	37.5
Malaysia	27.9	3.2	11.7
Philippines	93.1	31.1	33.45
Thailand	65.9	26.7	41.0
Vietnam	90.8	57.3	63.1

Tables 2 and 3 highlight agricultural commodities produced in Asia and the proportion of total global production that they represent. Asia is responsible, for example, for production of approximately 90% of the world's palm oil and rice. Palm oil is a major world agricultural commodity that plays a pivotal role in helping feed increasing numbers of people. It also yields a much higher level of oil in comparison with other oil crops. As Indonesia and Malaysia are responsible for 87% of global palm oil production, the crop is hugely important to the economies and social structure of both nations. Technology plays a vital role in maintaining and developing this industry.

Table 2. So what does Asia produce?

Crop	Asia Production – Million Tonnes	% of Global Production
Sugarcane	671	42
Rice	600	91
Wheat	281	46
Maize	217	27
Potatoes	116	37
Palm Oil	33	89
Cassava	72	33
Tomatoes	68	52
Bananas	48	56
Onions	42	64
Apples	39	60
Cabbages & other brassicas	52	75

3. The importance of palm-oil in Indonesia and Malaysia

Table 3. 2006 World Palm Oil Production:

Country	%	‘000 Tonnes
Indonesia	44	15900
Malaysia	43	15881
Others	7	2718
Thailand	2	820
Nigeria	2	815
Columbia	2	711

Source: Oil World, GAPKI

4. Crop protection products in managing palm oil

The oil palm industry is considered to be highly regulated, highly responsible and both research and science based. In terms of weed control in the palm oil industry, choice exists in terms of the use of cultural, mechanical, biological or chemical approaches and growers must be provided with options. Chemicals are the most effective and economical option. If used responsibly they can have many benefits, both direct and indirect. Currently the majority of herbicides used in palm oil are based on three active ingredients – glyphosate, paraquat and glufosinate - each of which has its strength and weaknesses and place. Selection is based on efficacy, crop phytotoxicity, the age of the crop and weed species and availability of options maximizes benefits from the science and also provides a profitable, sustainable industry. Correct management is the key to providing sustainable weed control solutions, where risks can be minimized and benefits maximized through Stewardship and Responsible Use.

5. Stewardship in palm-oil

Product stewardship is taken very seriously by the Crop Protection and the Palm Oil industry. Understanding and minimizing the risk and hazards of using a product is essential, with education and training being core elements. It has been estimated that 10% of all pesticide purchased globally is wasted through leakage for example. Access to quality information is possible, correct procedures are in place and monitoring performance-continuous improvement programs.

Stewardship in action in palm oil involves: sensible purchasing; secure storage; sprayer maintenance programs; a trained workforce; appropriate personal protection; use of IPM techniques; and waste disposal systems.

6. Lessons and benefits

There are a number of lessons for the palm oil industry in relation to the use of pesticides, in that:

- Weed resistance WILL occur with minimal diversity of products.
- Diversity of product use delays resistance.
- Resistance can be minimized and managed.
- It is better to avoid resistance than live with it.
- Banning or placing restriction of herbicides will lead to resistance.

In terms of the benefits of using naturally-safed herbicides in palm oil, these were summarised as:

- Herbicides eliminate the drudgery of back-breaking hand weeding – so leading to improved quality of life.
- Ineffective weed management will cost 20-22% yield loss.
- Herbicides minimize production costs (US$ 8-10/t).
- If herbicides are not used the farmer income will fall/decrease by 7%.
- Herbicides reduce soil erosion.
- Herbicides protect GDP and social infrastructure.
- Removing herbicide usage will result in annual losses of RM 2.73 billion (1.16 billion in yields and 1.57 billion in increased weed management costs).

Dr Gibson informed delegates that herbicides are very important and powerful fools for crop management, but that the industry must accept that they must be used responsibly.

'Integrated Pest Management in the Oil Palm Plantations'. Dr Sarojeni Rengam, PAN Asia Pacific.

Dr Rengam focused on three areas: use of pesticides in oil palm plantations, particularly herbicides, and the conditions of use; experiences with integrated weed management; and recommendations to RSPO on pesticide reduction and progressive elimination. She indicated that in Malaysia alone, one of the world's largest producers, the agrochemical market was worth (in 2004) approximately US$ 23 million and herbicides accounted for 64% of all pesticide use. Herbicides, including paraquat (still widely used), glyphosate, metsulfuron, 2,4-D and glufosinate ammonium, are also the main pesticides used in oil palm.

Dr Rengam pointed out that RSPO Principles and Criteria (P&C) (2007) state that agrochemicals should be used in a way that does not endanger health or the environment, that there is no prophylactic use of pesticides (with some specific exceptions) and that growers actively seek to identify alternatives to the use of World Health Organisation Type 1A or 1B and Stockholm or Rotterdam Conventions listed agrochemicals and that this is documented.

The reality of pesticide use in Malaysia is that there are many susceptible workers, such as pregnant women, very young/old workers, unhealthy workers and those with low literacy. Is there awareness of PPE and is it available, affordable and suitable to wear? There are no washing facilities in the field, limited household washing facilities and spray equipment is poor or non-existent with nozzles cleared by blowing. Many pesticide users are aware (through product stewardship) that pesticides are hazardous but there has been no major breakthrough in changing behavior and practices. Pesticides are also valuable, yet there are no lockable storage facilities with pesticides being stored in the house.

An overview of paraquat was provided with regard to marketing, regional use and its properties, including the fact that it is acutely toxic and a WHO Category II substance. Possible ingestion, inhalation and entry of paraquat through the skin were highlighted, as were the main health effects and symptoms, the estimated lethal dose for humans and the fact that there is no antidote for the herbicide. Mixing and loading of paraquat presents the greatest health risk to workers (in terms of serious and fatal accidents), although this may also occur with prolonged contact with diluted herbicide. Workers on estates in Malaysia frequently experience high levels of chemical exposure. Although the manufacturer Syngenta prioritises technical controls and also the use of an appropriate respirator, chemical resistant gloves and clothing, safety goggles and a face shield. However, conditions in developing countries may make it difficult to follow instructions and recommendations and apply protective measures due to expense and discomfort. Several studies in Asia have shown the lack of PPE or inadequacy of PPE use.

Paraquat is banned, withdrawn/non-authorised or has restrictions placed on its use in a number of countries around the world. It is also prohibited in certification schemes such as Forest Stewardship Council, Fairtrade Labelling Organisation and other organic and ecological certification schemes. Several major commodity producers have stopped using the substance, while others have moved away from reliance on it.

An alternative to paraquat use is the integration of different approaches and methods - preventative, cultural and mechanical - in a strategy based on the crop system and taking account of the ecology, health and economic gains of farmers. Examples are the use of cover crops (planting of leguminous crops), mulching with organic matter and mechanical weeding (including mowing) and animal grazing. Dr Rengam informed delegates that IPM and sustainable production is only possible if there is a plan for systematic pesticide reduction and elimination, and indicated that pesticide risk reduction is a priority area in FAO's pesticide management. The criteria used by PAN for designating highly hazardous pesticides (HHP) and the criteria for placing and categorizing pesticides on the PML were also explained.

Some concerns exist regarding glyphosate and surfactants used with the herbicide, such as POEA (polyoxyethyleneamine), that are more toxic than the herbicide and widely used. A variety of health problems may result including skin and eye irritation, respiratory problems and effects on the heart. Glyphosate is also a concern for environmental reasons, particularly with regard to its effects on the aquatic environment. In the UK glyphosate is the most frequent cause of complaints and poisoning incidents and, in California, one of the most commonly reported causes of illness or injury to workers from pesticides.

Dr Rengam concluded her presentation by making a number of recommendations, as follows:

RSPO should be seen as a world leader in sustainable palm oil production and it must:

- Advocate chemical-free cultivation and stop allowing HHPs to be used on certified plantations.
- Amend P&C Criterion 4.6 on Agrochemicals to include an immediate ban on Class 1A and 1B chemicals and paraquat and a 5 year progressive ban on HHPs.
- It is imperative that activities to implement the progressive ban on HHPs are developed globally, as well as at national and local levels, by governments, standard setting organisations, food corporations, the pesticide industry, worker unions, and NGOs/CSOs.
- HHPs must be eliminated, not replaced with chemicals that are only marginally less toxic. As alternatives, RSPO should insist that plantations demonstrate that they are working towards strategies such as alternative weed management and organic cultivation, and that this will be achieved within a reasonable time frame.

Dialogue, Question and Answers

Mr Sim, a representative of the growers (from KLK Bhd), briefed delegates about his extensive experience in weed management in oil palm using herbicides, indicating that the task of spraying pesticides should be given to well-trained operators. He has had no problems (knowledge, health or physical) from doing spray treatments for many years and felt that pesticides (including paraquat) are useful tools for plantation management in oil palm as long as they are used properly with appropriate application techniques and an awareness of their dangers. Mr Sim suggested that findings from the survey should be distributed to the Smallholder Task Force.

During the panel discussion it was suggested that the RSPO IWM survey should also be done through face to face meetings with relevant respondents in the plantation industry. With this method it is possible to obtain more relevant information related to the questionnaire, as most of the relevant officers are very busy or suspicious about the objective of the questionnaire.

Growers were impressed by the CropLife presentation and many are already using personal protective equipment (PPE). Although there were reports that growers keep pesticides in their homes, as mentioned by Dr Rengam, this was considered unlikely to occur in present times. A discussion followed regarding the storage of pesticides in inappropriate places and the need for workers to use PPE. The need to highlight the hazardous nature of chemicals was pointed out, as was the requirement of workers for more training on the hazardous nature of chemicals in question and that this should be undertaken by a group not associated with chemical companies. In response, training was described as generic, covered the use of products in an appropriate and responsible manner and that all stakeholders would be able to obtain information on the code of conduct for using hazardous chemicals.

In response to a query as to how much is spent on training, given that 85 million RM is spent on products in Malaysia, it was stated that training was not solely about money but about effective training to improve long term behaviour.

Appendix 1

COMMUNITIES & CHEMICALS: SUSTAINABLE CROP PRODUCTION

Date: Sunday, 1st November 2009
Time: 0900 – 1315
Venue: Berlian Room, Hotel Istana, Kuala Lumpur

PROGRAMME

Time	Agenda	Speaker
0830 - 0900	Arrival and registration of participants	
	Chair: **Lum Keng Yeang** CAB International, Southeast & East Asia Office	
0900 – 0915	Opening Address	**Dato' Mamat Salleh** Vice President III RSPO
0915 - 0955	**SESSION 1:** RSPO Integrated Weed Management Strategies Project	**Mike Rutherford** CAB International, UK
0955 - 1035	**SESSION 2:** Pesticide Regulation and Registration in Malaysia	**Ms. Nursiah Mohamad Tajol Aros** Pesticides Board Malaysia
1035 - 1100	Coffee/Tea Break	
1100 - 1140	**SESSION 3:** Chemical Management in Palm Oil Plantations	**Martin Gibson** CropLife Asia
1140 - 1225	**SESSION 4:** Integrated Oil Palm Management	**Sarojeni Rengam** PAN AP
1225 - 1315	**SESSION 5: DIALOGUE and Q&A** **Panel Members:** • Growers (Kuala Lumpur Kepong Bhd) • Pesticides Board Malaysia • CAB International • Pesticide Action Network-Asia Pacific (PANAP) • CropLife (Asia/Malaysia)	**Lum Keng yeang** CABI SEA
1315 - 1430	Lunch	

Part 5. Other Engagement with Representatives of the Oil Palm Industry

Society of Chemical Industry meeting, Royal Society, London

In March 2009 Dr Rutherford and Dr Flood took the opportunity to participate in a two-day meeting held at The Royal Society, London entitled 'Palm oil – The Sustainable 21st Century Oil: Food, Fuels And Chemicals'. This meeting, which took place during the early stages of the IWM project, provided an excellent opportunity to become more familiar with oil palm production and trade and to meet representatives of the industry, including organisations that subsequently became involved in, or otherwise facilitated, project activities. During the course of the meeting leading experts from industry, NGOs, environmental groups and academia provided, through oral presentations and open discussion, a comprehensive and up to date overview of oil palm production, processing and trade, the use of oil palm products and future prospects for the commodity. This included reference to aspects of sustainable production, processing, nutrition and biofuels, as well as the role and importance of the RSPO, membership of the association and the importance of the newly established RSPO Principles and Criteria (P&C) for sustainable palm oil production. The latter was of particular relevance, given that RSPO will evaluate the findings of the herbicides project in relation to the requirements of the P&C and strategies for developing and implementing more sustainable and environmentally friendly weed management practices.

The meeting was organised by the Society of Chemical Industry (SCI) and sponsored by the Malaysian Palm Oil Board (MPOB) and the Malaysian Palm Oil Council (MPOC). Presentations and related discussion were very much focused on Malaysia and Indonesia as the world's largest producers. Drs Rutherford and Flood took the opportunity to meet with a number of participants to highlight the project and its objectives and to discuss particular aspects of oil palm production and weed management. They include: Mr Derom Bagun (Chairman, Indonesia Palm Oil Producers Association and Vice President, RSPO Executive Board); Dr Mohd. Basri Wahid (Director General, Malaysian Palm Oil Board); Dr Yusof Basiron, (Chief Executive Officer, Malaysian Palm Oil Council); and Mr Ian McIntosh (Aarhus Karlshamn, UK, and Treasurer of RSPO Executive Board). These individuals, and their organisations, are invaluable points of contact and potential sources of information and technical expertise. A number of producer organisations, including Pacific Rim/New Britain Oil Palm Limited (Andrew Worrall) and DAABON Organic, Colombia (Astrid Duque), provided information and assistance of considerable benefit to the project. The assistance of all concerned is appreciated and acknowledged.

Note. The participation of Drs Rutherford and Flood at the above mentioned meeting was funded from internal CABI funds.

Discussions with oil palm industry and associated organisations, Malaysia

While on other business in South East Asia in April 2009 Dr Rutherford, accompanied by Dr Sastroutomo, took the opportunity to spend several days in Kuala Lumpur in order to visit and discuss the project with representatives of a number of organisations involved in or associated with the oil palm industry. These included producers, chemical manufactures/retailers and NGO and were, specifically: Genting Plantations Bhd (formerly Asiatic Development Bhd), Sime Darby Plantation, IOI Group, FELDA Agricultural Services Sdn Bhd, Pesticide Board, Food Safety and Quality Division (Ministry of Health), Bayer CropScience, Monsanto, Syngenta Crop Protection Sdn Bhd and Tenaganita Sdn Bhd. Through these meetings the project team members gained a better understanding of oil palm management practice generally and were able to discuss and explore chemical and non-chemical measures being implemented or considered by producers. The discussions facilitated planning for the producer surveys, in particular the design of the survey questionnaire. A number of producers also kindly agreed to assist in evaluation (pilot testing) of draft survey questionnaires. Information of relevance to the literature review was obtained or information sources identified for later access. Issues of concern to the different stakeholder groups, including in relation to the use of pesticides, and mechanisms by which these may be addressed were also highlighted and discussed.

Though these meetings in particular it became very apparent that weed management and herbicide use in oil palm is a complex issue, and that the extent of information that could be realistically captured through completion of a questionnaire would be limited. Furthermore, concerns were raised as to why information was being requested, how it would be promoted and disseminated and what steps would be taken to ensure producer anonymity during presentation of the findings. Careful consideration was given by CABI to these concerns and, as a consequence and in consultation with RSPO Secretariat, specific measures incorporated within activities as the project progressed. These included: provision of a covering letter outlining the aims and benefits of the survey to the industry (and producers in particular) as well as specific channels by which information would be promoted; ensuring requests for information were structured appropriately to maximise feedback from producers; and establishing a system by which questionnaires were automatically routed to CABI for collation and analysis.

Note. The participation of Drs Rutherford and Sastroutomo at the above mentioned meetings was partially funded by the RSPO IWM project.

RSPO RT7 Annual Meeting, Kuala Lumpur

Drs Rutherford, Flood and Sastroutomo attended the RT7 Annual Conference in Kuala Lumpur (1–4 November 2009) where Dr Rutherford delivered an oral presentation entitled ‘Integrated Weed Management Strategies for Oil Palm‘ at a plenary session on Monday 2 November. In doing so, Dr Rutherford was able to provide an overview and progress report on the project research to a broad range of stakeholders. Dr Rutherford also participated in a Q&A panel comprising speakers from the Session during which responses were provided to questions and comments from the floor in relation to: the rate of progress of the project; acquiring feedback from producers on IWM practices; CASE studies; the project timeframe; poisoning by paraquat; violations of RSPO P&C and how complaints are addressed; and development of resistance to herbicides.

The presentation and participation of CABI personnel at RT7 facilitated further direct interaction and discussion with representatives of the oil palm industry, including those producers already participating in the survey. It also stimulated other producers to provide feedback through later completion of the survey questionnaire. Following RT7, Drs Rutherford and Sastroutomo met with Dr Rao, RSPO Secretary General, to discuss the project and agree on steps to progress the various activities.

Note. The Powerpoint of the full presentation delivered by Dr Rutherford is available in Appendix 2 to the main report.

Part 6. Overall Summary and Concluding Points

The objective of this research project was to obtain information on herbicides commonly used in the production of oil palm. This has been achieved from both a technical and an applied perspective and principally through the review of existing (and available) literature and the producer survey undertaken in Malaysia, Indonesia and PNG. Information of importance and of significant benefit to the project, including the manner in which project activities were undertaken, was also received through the Society of Chemical Industry (SCI) meeting in London (March, 2009), the project workshop (November, 2009) and RT7 (November, 2009), which provided the opportunity to engage with a broad range of oil palm stakeholders including many producers.

The project has provided comprehensive baseline information on nine herbicide active ingredients. Much of this is information is technical and describes specific properties, or characteristics, of each active ingredient. However, it is fundamental to the means by which the substances exert their herbicidal effect, their efficacy, the purpose for which they may be used and also the level of hazard they present - not only to humans but to other animals, plants, microorganisms and the environment. It is these characteristics that confer the suitability of a herbicide for a particular purpose and also the manner in which the herbicide should be used – certainly in relation to precautions that should be taken to ensure a chemical is used safely and will not cause undue harm. While technical in nature, considerable effort has been made to present the information in a user friendly way and, where possible, from an applied perspective to inform on-the-ground decision making and promote safe chemical use. Indeed, and based on the information provided, herbicide use may be deemed to be wholly inappropriate under certain circumstances with alternative management measures being a preferred option.

There are obviously numerous scenarios and circumstances under which herbicides may be considered for use, and the factors to be taken into account during decision making will vary markedly. The intention of this report is to present sufficient, comprehensive information to enable these decisions to be made irrespective of circumstances. It is impractical to attempt to summarise each and every property of even two active substances in this section, let alone all that have been referred to in this report. However, by way of compromise, a number of herbicidal characteristics of fundamental importance to decision making in crop production and for broader herbicide use will be outlined below.

Of the nine substances reviewed, and as shown in the table below, six exhibit selectivity and will therefore be suitable for treatment of specific weed types – broad leaved or grass weeds for example - and beneficial in terms of avoiding inadvertent damage to crops and plant species including ornamentals and recognised animal habitats. As these substances also differ with respect to plant groups or species that they affect (as indicated in Section 4 of the literature review), further consideration of their specificity in the context of intended use is warranted. Three herbicides, glufosinate, glyphosate and paraquat, are non-selective and will therefore harm all vegetation with which they come into contact but would be suitable for ground clearance prior to planting and maintenance of pathways for example. Similarly, seven are considered to be systemic and will therefore move from the point of treatment to damage or kill the whole plant. Two, glufosinate and paraquat, will affect only those plant parts that come into contact with the herbicides, although glufosinate does exhibit some systemic activity. The fact that the nine herbicides exert their effect through a number of modes of action is an important consideration in terms of avoiding build-up of weed resistance to a particular substance and avoidance of such a scenario through rotation of substances with differing modes of action.

The herbicides also differ markedly in the level of hazard that each presents. In terms of acute toxicity to humans, for example, two are internationally recognised (by the WHO) as being moderately hazardous, three as slightly hazardous and four as unlikely to present a hazard under normal use. For any chemical, consideration must be given to recommended procedures to ensure safe use and to ascertain whether these can be adhered to under the circumstances in which the herbicide is to be applied. It is pleasing to note that both the survey findings and the information acquired through the CASE studies have shown that producers do take precautions in terms of wearing protective clothing and equipment (PPE) during the preparation, storage and disposal of herbicides and indeed, of herbicide containers. Furthermore, those producers involved in the CASE studies indicated that, on the whole, their selection and use of PPE and herbicide application equipment was based on herbicide manufacturer recommendations for individual products and was adequately maintained. Unfortunately, the extent to which this is true for other producers is unclear and is an area that warrants further investigation.

Where procedures and equipment stipulated for a particular herbicide cannot be fully adhered to and used, or the risks of use (including to the environment) are deemed to be unacceptable, a less hazardous substance should be sought and/or an alternative, non-chemical management method employed. The properties of some herbicides, for example, show that they are highly toxic to aquatic organisms. If also water soluble, these are liable to move into, and perhaps persist in, soil water and ultimately waterways – including wells, ponds, rivers, fisheries and, in coastal areas, the marine environment - thereby presenting a serious risk to aquatic animal and plant life. Given that this study has highlighted the nature of a range of herbicides, including their toxicological properties, it provides a basis for initial selection of products of relatively low toxicity or substitution of products of concern with those deemed to present a lesser hazard. Furthermore, both the survey consultations and the CASE studies have highlighted a wide variety of non-chemical approaches to weed management already adopted by many producers as they are viewed as both appropriate and effective, at least for certain stages of palm growth. Such approaches can offer benefits other than alleviation of the risks associated with chemical use, which include reductions in costs and maximising use of other resources such as manpower. Clear examples of reductions and even elimination of herbicides were identified through the CASE studies, and include a move away from the use of the more hazardous substances 2,4-D and paraquat in favour of the markedly less toxic glyphosate, fluroxypyr and metsulfuron as well as manual and mechanical forms of weeding. As RSPO, through the RSPO P&C, advocate precisely this type of approach to help reduce the use of chemical-based pesticides, producers should be made aware of - and take into consideration - the various possibilities highlighted during the course of this study in the context of their respective needs and concerns. Of note, many producers consulted had already introduced a variety of chemical and/or non-chemical weed control measures for each stage of palm production, signifying the ease by which these may be used in parallel and the potential for overall adoption of a more sustainable and environmentally friendly management strategy. Where limitations were exposed in the CASE studies with respect to use of particular approaches, in terms of issues that limit the maintenance or use of equipment for example, consideration should also be given by producers and RSPO as to how these may be addressed to improve efficiency and increase potential for broader uptake.

Key characteristics of herbicides used in oil palm and their classification by toxicity hazard by the World Health Organisation (WHO), European Union (EU) and Environmental Protection Agency (EPA).

Active ingredient	Mode of action[1]	Contact/Systemic	Plant selectivity	Plants targeted	WHO[2]	EU[2,3]	EPA[4]
2,4-D	Auxin	S	Y	BLW	II	Yes	II
Dicamba	Auxin	S	Y	BLW,GR	III	Yes	III
Diuron	Photosynthesis	S	Y	BLW,GR	U	Yes	III
Fluazifop-butyl	Lipid	S	Y	GR	III	No	II (oral) III (dermal)
Fluroxypyr	Auxin	S	Y	BLW/GR	U	Yes	No consensus across products
Glufosinate-ammonium	Amino acid	C + some S	N	BLW/GR	III	Yes	III
Glyphosate[6]	Amino acid	S	N	BLW/GR	U	Yes	III
Metsulfuron-methyl	Amino acid	S	Y	BLW/GR	U	Yes	IV
Paraquat dichloride	Photosynthesis	C	N	BLW/GR	II	No[5]	II (oral) III (dermal)

1. Auxin - acts as auxin-type plant growth regulator; Photosynthesis - interacts with photosynthesis; Lipid - inhibits lipid biosynthesis; Amino acid - inhibits amino acid biosynthesis;
2. Relates to active ingredient. Ia - Extremely hazardous; Ib - Highly hazardous; II - Moderately hazardous; III - Slightly hazardous; U - Product unlikely to present acute hazard in normal use.
3. Included in Annex 1 of Directive 91/414/EEC
4. Relates to formulation. I - Danger; II - Warning; III - Caution; IV - Caution
5. Inclusion in Annex 1 (2003/112/EC) annulled by Judgement of the (EC) Court of First Instance, 11 July 2007
6. Unique mode of action amongst herbicides

This study has clearly yielded information which is of potential benefit for future decision making and for the development (and improvement) of recommendations relating to weed management and the use of herbicides. However it has also, through the producer consultations and discussion fora including the project workshop and RT7, identified a number of areas where further exploration would be of benefit and by which this may be improved. These include:

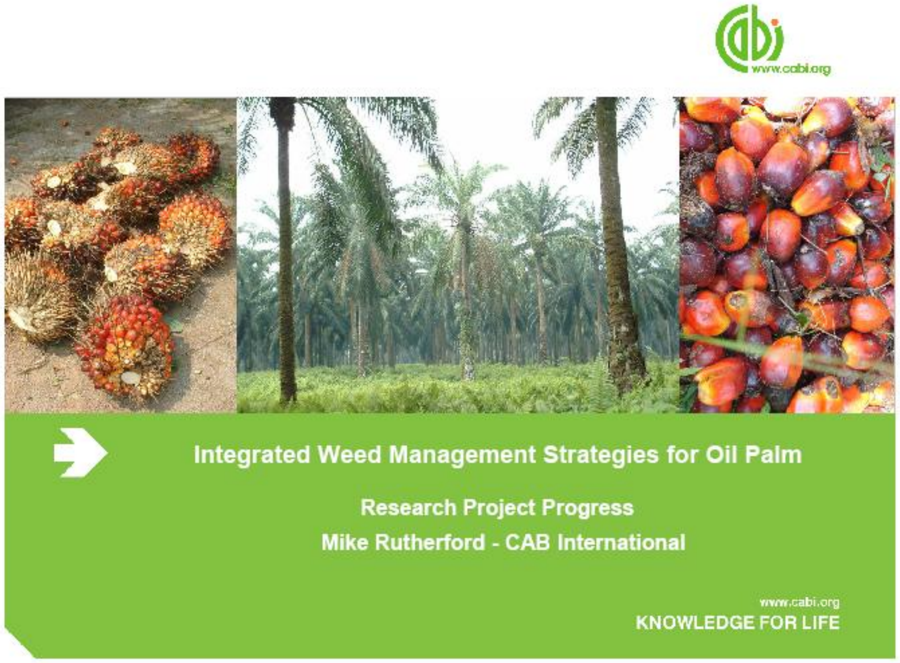
- Inclusion, in the consultation process, of organisations that are not members of RSPO. All participants in this study were RSPO members and were therefore perhaps better informed on progressive approaches to weed management, GAP and RSPO P&C.
- Assessment, through direct consultation, of smallholder producer weed management practices is needed; this study was confined to large estates.
- Further investigation of the purpose(s) for which each herbicidal active ingredient is used, how they are used and precisely what precautionary measures are adopted for each.
- Further investigation of approaches to weed management, including chemical products, currently being explored (by producers or commercial suppliers) or at a developmental stage.
- Determination of the status of authorisation (i.e. registered for use, recommended for oil palm) of herbicidal products identified as used by producers during this study.
- Identification of sources of information and training currently provided to producers, how effective this is perceived to be and mechanisms by which resources (i) may be further promoted and disseminated and (ii) training initiatives modified and implemented more widely.

Despite provision of survey materials to the NIWG and their onward dissemination to growers, it is unfortunate that the response from producers in Malaysia and Indonesia was limited and that no feedback was received from producers in Colombia. Similarly, considerable time was taken to obtain feedback from producers for the survey and the CASE studies, with lower than expected participation of producers in the latter. This had unfortunate and serious consequences in terms of the study team being unable to implement the key activities in a timely manner and as planned in the original proposal. On a more positive note, and with survey and CASE study methodologies now established and associated documentation prepared, the findings of this study could be readily built upon by RSPO not only in countries that participated here but through engagement with producers in other countries.

In undertaking the project research, and as also pointed out by a number of stakeholders, it was clear that the approach to part of the study (namely the producer survey) constituted a constraint to the depth of information that could be expected from producers. This was most apparent with regard to information on precisely how herbicidal products and active ingredients were being used. It is recommended that where further, in-depth investigation is to be considered this be undertaken (at least in part) through direct consultation with producers and preferably under field conditions where practice may be observed at first-hand.

Appendices

Appendix 1. Powerpoint presentation; 'Integrated Weed Management Strategies for Oil Palm'. M Rutherford, RT7 Pre-meeting, Kuala Lumpur, 1 November 2009



Integrated Weed Management Strategies for Oil Palm

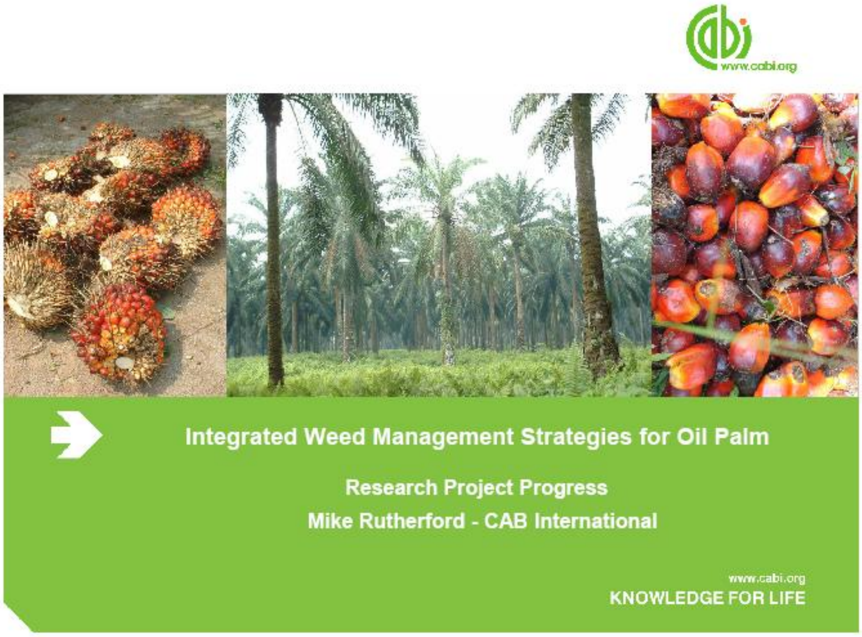
Research Project Progress

Mike Rutherford - CAB International

www.cabi.org

KNOWLEDGE FOR LIFE

Appendix 2. Powerpoint presentation; ‘Integrated Weed Management Strategies for Oil Palm. Progress Report’. M. Rutherford, RT7 Plenary, Kuala Lumpur, 2 November 2009



www.cabi.org

Integrated Weed Management Strategies for Oil Palm

Research Project Progress

Mike Rutherford - CAB International

www.cabi.org

KNOWLEDGE FOR LIFE