PARAQUAT

Paraquat

A unique contributor to agriculture
and sustainable development

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Executive summary

Since 1961, agricultural output has outstripped global population growth by 20%, with a proportionate increase in per capita availability of food. This rapid growth in per capita production has reduced prices of agricultural produce, so that food is now cheaper than it was four decades ago. As a result:

- ◇ People are better fed now than at any time in the past century.
- ◇ Fewer people suffer starvation or malnutrition than 50 years ago in spite of a huge increase in population.
- ◇ Better nutrition has contributed to a significant reduction in infant mortality.

The majority of the increase in agricultural output (in excess of 60–70% for key food crops) is attributable to improved agricultural technologies, including herbicides such as paraquat. These technologies have resulted in huge increases in efficiency – using fewer resources to produce more food and other crops. By reducing the need to convert wild land to agricultural uses, modern agricultural technologies have conserved wildlife and biodiversity. Without these technologies, since 1961 farmers would have had to plough over an additional 14.1 billion acres – 44% of the land available on earth. The devastation – to humanity and our environment – that would have been wrought had modern technologies not been used to achieve greater food production is difficult to imagine.

Despite the use of such technology, an estimated one-third of global agricultural produce is still lost due to these pests, with weeds accounting for a significant proportion of such losses. The main reason for these losses is that many people are unable to utilise modern agricultural technologies.

Approximately 2.5 billion people in poor countries (about 40% of the world's population) still depend on agriculture for their livelihood. Many of these people still use agricultural technologies that would have been familiar to people living in medieval times. The obvious conclusion is that more of humanity needs to be able to benefit from crop protection and other modern agricultural technologies.

Restrictions on the use of modern agricultural technologies would limit access further, harm the poorest people most. The purpose of this study is to assess the costs and benefits of imposing restrictions on the use of such technologies in general and on one such technology, paraquat, in particular.

Herbicides such as paraquat are important because weeds compete vigorously with crops for water, light and other nutrients. As a result, if they are not suppressed they reduce crop yields by up to 80%. Until paraquat was developed, farmers in hot, wet climates had a limited range of options for dealing with weeds. Many relied on manual weeding, which is slow, tedious, and backbreaking. Some used basic chemical herbicides, which often damaged the crop and caused groundwater contamination.

Paraquat has several unique properties:

- ◊ It is fast acting, so it can be used even in wet conditions.
- ◊ Under most usage conditions, it does not damage or interfere with the crop or its roots (it is not 'systemic').
- ◊ It does not contaminate groundwater.
- ◊ In some cases – such as cover crop management – the roots are not killed. In these cases, paraquat helps maintain the structure of the soil, preventing soil erosion.

These properties have meant that, since its introduction in 1961, paraquat has become the herbicide of choice for millions of farmers around the world. Over 25 million farmers in over 120 countries currently use paraquat.

Paraquat has significantly enhanced agricultural productivity for many crops in many parts of the world. This report documents examples of the millions of farmers who have benefited, from banana growers in Costa Rica, to rice farmers in China and oil palm growers in Malaysia. Paraquat has enabled these farmers to increase output and reduce input costs. It has thereby increased farmers' profits, enabling them to save, to send their children to school, and to invest in other businesses.

Paraquat has also benefited the environment, by contributing to increases in agricultural productivity which means that more land may remain wild. Paraquat is also used in conservation tillage and no-till farming, agricultural methods which have been developed to eliminate some of the problems that result from conventional agriculture, such as soil erosion.

By replacing manual weeding, paraquat has saved millions of women from a life of drudgery, freeing them to do more productive and satisfying activities. By reducing the cost of food and other goods, paraquat has helped the poor and malnourished to feed themselves. Paraquat has been responsible, directly and indirectly, for improving the lives of hundreds of millions of people.

Contrary to claims made by opponents of pesticides, farmers and the agricultural community in countries where pesticides are used are aware that products such as paraquat must be handled with basic precautions relating to personal hygiene and protection. Recommended protection for safe use of paraquat includes basic apparel such as a full-sleeved shirt, trousers and boots, and personal hygiene, which primarily involves washing hands and body after usage or exposure to the product in the normal course. Farmers are understandably offended at being regarded as ignorant or incapable of making rational choices about what technologies to use just because they live in poor countries.

Like many other chemicals, paraquat has tragically been used as a suicide agent. This has contributed to a negative perception of the product, which has been exacerbated by groups and individuals who claim that its use adversely impacts human health and the environment. However, the evidence on paraquat clearly establishes the contrary.

Successive reviews of the product by the World Health Organization (WHO), the US Environmental Protection Agency (EPA), and other independent scientists over the past three decades have clearly established that paraquat is environmentally benign. It does not leach into ground water, cannot be absorbed into the plant and, in the unlikely event that it is present in minute quantities, is rapidly and safely expelled by the human body.

In terms of occupational health hazards, spray droplets of paraquat cannot be inhaled and paraquat is less readily absorbed through the skin than is water. The only serious concern relating to paraquat is the potential for oral ingestion, either intentional or unintentional (ingestion by accident or consumption by mistake). However, the number of such cases is extremely small.

Injury from oral ingestion of paraquat has been reduced considerably following the addition of an alerting agent (a stench), dye and emetic to nearly all formulations by responsible companies. The first two discourage consumption; the third reduces the chances that fatal amounts of paraquat will remain in the body.

There are many other products in daily use that cause a larger number of deaths every year and which are known to impact human health and the environment in specific circumstances. Cars and knives, for example. These products benefit society, and because they are harmless as long as basic precautions are taken, they continue to be used. The same enlightened thinking should be applied to paraquat and similar agrochemicals.

Severe restrictions on paraquat use in any major market would clearly undermine the incomes of farmers, who would have to switch to more expensive technologies and, in many cases, would be forced to resort to hand weeding, or suffer crop losses due to weeds. The people most affected would be the farmers and others in poor countries that benefit hugely from paraquat's unique properties.

Regulations that reduce the chances of mistaken ingestion of paraquat are encouraged. In particular, we recommend mandatory addition of an alerting agent, dye, and emetic, as well as clear communication to assist proper handling, storage and use. These regulations, which are reflected in the FAO guidelines, are supported by responsible companies in the crop protection industry. These companies also work in partnership with governments and farmer groups to train farmers on appropriate and safe use of pesticides.

The unsubstantiated fears of a vocal minority must not become a justification for undermining the right of the silent majority of farmers to choose technologies appropriate to their circumstances.

About the study

The author was commissioned to provide a balanced assessment of the benefits and drawbacks of pesticides in general and paraquat in particular. The study included a secondary survey of available literature as well as direct interaction with various stakeholders, including farmers, regulators, agricultural scientists, occupational health specialists and industry. The study was sponsored by the organisations listed on the cover of the report. Clearly, several of these organisations have an interest in ensuring that paraquat remains available. In order to ensure independence of the study, the author retained full editorial control over the published work. In addition, the study was independently reviewed and the comments of several anonymous reviewers have been included.

About the author

Prasanna Venkatesh Srinivasan has a post-graduate degree in management from the Indian Institute of Management, Ahmedabad and has over 16 years of industry experience in very diverse organizational and business settings.

Prasanna commenced his career in the shipping industry in 1987 with The Shipping Corporation of India, India's largest shipping company, where he worked in the department operating specialized ships on offshore oilfields. He subsequently joined The Shipping Credit and Investment Company of India (SCICI) in 1988, the leading provider of long term finance to the maritime industries in India. His responsibilities. included managing a loan portfolio of approximately US $ 150 million and a debt restructuring programme for the shipping industry another US $ 600 million.

In 1992, he took charge as head of Finance and Planning with CRY-Child Relief and You, an Indian not-for-profit working to help disadvantaged children. He subsequently co-promoted a telecom services project targeting retail financial services in 1994, a project abandoned as results were not forthcoming in the required time frames set by the promoters. From 1995–1997, he headed the consulting business of EIU-IMA India (the Indian associate of the Economist Intelligence Unit), where the work entailed working with transnational corporations on their India related business plans. Client companies included Rio Tinto Zinc, Eagle Star (BAT Financial Services), Mobil and United Distillers.

In 1998, he broke away to co-promote a consulting venture, Business Environment Assessments India Pvt Ltd, that has provided Business Planning and Advisory services and undertaken Policy and Regulatory Research, Industry research and project feasibility studies. Clients have included a cross section of corporates (Jardine Matheson, New Television (India), industry associations (The Indian Broadcasting Foundation), Indian entrepreneurs and not-for-profit organizations including policy think tanks and UNDP. Prasanna has done extensive work in policy, regulations and project evaluations in the areas of Information and Communications Technologies More recently, he has authored papers on the business and economic impact of global environmental treaties on developing countries like India.

Prasanna has been working as a freelance consultant from April 2003.

Prologue

Delhi, my home, has amongst the worst air quality of any city in the world – in no small part because of highly polluting vehicle emissions, though the continued reliance, by some 40 per cent of the population, on wood for heating their homes is also a significant cause. By the mid-1990s, the problem had become a constant source of discussion among Delhi's elite. A party at the author's house was typical. People were roughly divided into two groups: "ban diesel" and "ban two-stroke engines", with powerful arguments being made by proponents of each. Then, suddenly, a hitherto quiet participant said, "ban all automobile transport and let people cycle to work". This radical proposal set the cat amongst the pigeons for a while but at the end of the evening everyone got into their cars and drove home.

Banning all automotive transport would instantly transform air quality in most major cities – but it would also cause major problems. In a city like Delhi, where there is no realistic mass transit alternative to hydrocarbon-powered vehicles, the imposition of such a ban would bring the city to a halt, with devastating economic effects.

Introduction

Policymakers are charged with balancing the benefits and costs of technologies to society. Over the course of the past fifty years, techniques for assessing these costs and benefits have improved dramatically. However, policymaking continues to be dominated by lobbying from pressure groups and vested interests. In the past, the resultant policies often benefited industrial interests at the expense of consumers, workers and the environment. However, over the course of the past thirty years the balance has shifted. Indeed, it is no exaggeration to say that single-issue pressure groups are in most cases now far more powerful than industrial interests in influencing policymakers.

Whilst a shift away from the influence of industrial interests is to be desired, some of the pressure groups that have replaced them may be as bad or even worse. Certain extremist environmental groups, for example, seem to be more concerned with power than truth. They make poorly substantiated claims about the harms that technologies might impose on health and the environment, and demand that these technologies be severely regulated or restricted, regardless of the benefits the technologies provide or might provide.

Since the publication in 1962 of Rachel Carson's *Silent Spring*, many pressure groups have criticised the use of synthetic agricultural chemicals – especially pesticides. Whilst some early criticism was clearly justified – for example, the overuse of DDT at that time – many of the subsequent attacks have been based on poor science and a lack of appreciation of the benefits of these chemicals.

By contrast with these politically motivated pressure groups, many of the organisations working on the ground to promote sustainable agriculture base their analyses firmly on sound science, providing genuine solutions to genuine problems. Unfortunately, because of the nature of their work, these groups tend to be relatively less influential than the more vocal and often extreme pressure groups. We hope that this study will go some way to redressing the balance.

Chemicals in agriculture

Synthetic chemicals are one of several inputs used to enhance the productivity of land. Others include improved seed varieties, better water management and modern farm machinery. Synthetic chemicals perform broadly two functions in agriculture: they help crop growth (speed, yields, quality) and they protect crops from pests. Insecticides, herbicides, fungicides, and rodenticides protect crops from insects, weeds, fungi and rodents, respectively.

Weeds and herbicides

Weeds compete with crops for nutrients, provide a breeding ground for crop-eating insects, and interfere with the layout and infrastructure of the land. As a result they adversely impact yields and thereby reduce the income of farmers. In countries where climate and geology mean that the sowing and harvesting is limited to a short period of time, weeds can have a particularly serious affect on agricultural output and, hence, on farmers' incomes.

Historically, farmers removed weeds by plough or with handheld implements – a strenuous and time-consuming exercise. In the past century, these techniques have gradually given way to other methods, including the use of herbicides.

Herbicide use expanded after the 1940s because of the invention and marketing of chemicals of greater effectiveness and lower cost relative to alternatives. Herbicides are now in use in almost every country with significant agricultural activity.

Paraquat

In 1959, the government of recently-independent Malaya contacted the UK-based Imperial Chemicals Industry (ICI) to ask if it might develop an alternative herbicide for the nation's rubber and oil plantations. The government had concerns about the impact of sodium arsenite, the then-dominant pesticide used to control both grass and broad-leaf weeds. One concern was that although sodium arsenite was an effective herbicide, it damaged the bark of the rubber tree, from which latex was taken, reducing yields.[1] Moreover, there were concerns that sodium arsenite would leach into water supplies, with adverse consequences for the human population.

In May 1959, ICI sent one of their chemists, Roger Jeater, to Malaya to identify possible alternatives. Jeater identified paraquat, from among many chemicals that he had taken with him, as the most appropriate solution to Malaya's problems. Paraquat's herbicidal qualities had been discovered at ICI's Jealot's Hill laboratory in the early 1950s but it had not yet been developed it into a marketable product because, as Jeater puts it, "At that time, herbicides were sought for the selective control of weeds in arable crops and against that criteria there was no obvious use for the type of activity exhibited by paraquat."

Following extensive trials and tests in Malaysia, ICI developed and began to market paraquat, under the brand name Gramoxone, in 1962. Over the past 40 years, paraquat's unique properties have made it among the most popular agricultural chemicals in the world. It is currently used in over 120 countries, wealthy and poor alike. Jeater is today pleasantly surprised at the success and endurance of paraquat, pointing out that "Used properly, paraquat is a highly effective chemical. It wouldn't have been used during all of those 40 years, in so many countries, if it weren't so highly effective and useful."[2]

Perhaps because of its success, paraquat has from time to time been the subject of criticism. Recently there has been a concerted effort by a group of NGOs seeking to restrict paraquat use, as part of a more general effort to suppress the use of synthetic pesticides and other aspects of modern agriculture. Supporters of such restrictions have used manipulative language and poorly-reasoned, but emotive, arguments to support their case. The purpose of this study is to provide a corrective to this unjustified attack; to evaluate in a more dispassionate way the impact of paraquat both good and bad, and to put this into a broader context of modern agriculture in the global economy.

Overview of the study

The study proceeds as follows:

Section 1 considers the role of agriculture in the world economy and addresses the following issues:

- ◊ The role of agriculture in the world economy and its evolution over the past four decades.
- ◊ The contribution of technology to agricultural improvement.
- ◊ The people dependent on agriculture and thus likely to be affected due to regulations on inputs.
- ◊ The impact of such regulation on costs.

Section 2 traces the growth of the modern pesticides industry and the evolution of practices in national and international regulation of pesticides.

Section 3 focuses on the problem of weeds and weed management. Issues considered include:

◊ The economic cost of weeds on agriculture.
◊ The role of herbicides in weed management.
◊ The alternative techniques available to combat the adverse impact of weeds and their relative costs and benefits.

Section 4 looks at the role of paraquat, paying particular attention to the following issues:

◊ The benefits of using paraquat in weed management
◊ Why do farmers use paraquat?

Section 5 examines agriculture and paraquat use in three countries – Malaysia, China and Costa Rica.

Section 6 considers the key concerns relating to paraquat raised by those who oppose its use:

◊ Impact on soil, plant life and ground water.
◊ Impact on humans, when ingested through air, food or direct exposure.
◊ Deliberate ingestion.

These concerns are then evaluated.

Section 7 draws conclusions on paraquat vis-à-vis policy and regulation.

1 Agriculture in the world economy

Archaeological records indicate that agriculture began about 12,000 years ago. Early agricultural practices were simple, involving merely the planting of seed and harvesting of the resultant crop. Over time, farmers developed ways of increasing crop output. Among the first innovations was irrigation, which enabled farmers to plant crops even in areas where rainfall was uncertain. By the time of the Romans, farmers were already using pesticides and fertilizer.

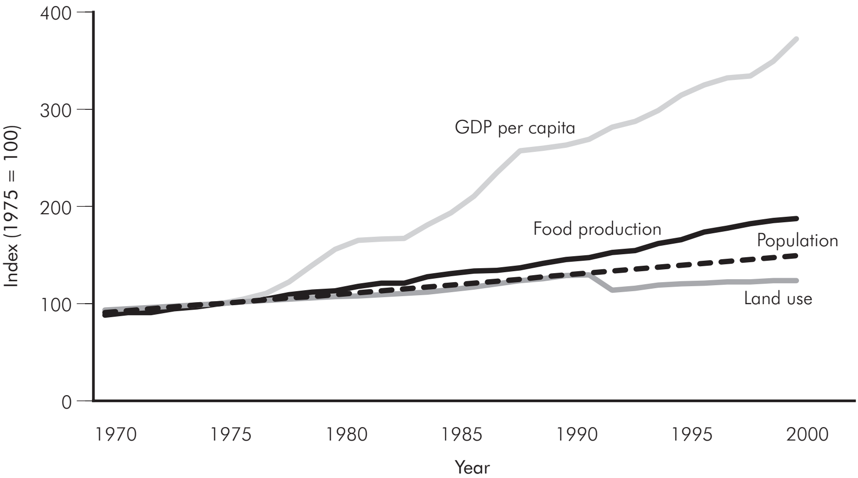
As economic development progresses, manufacturing and other activities become increasingly important, but food production remains necessary. The search for more effective and efficient ways of feeding humanity continues apace.

Agriculture and the world economy

Since 1960, total world economic output has increased over four-fold, from about US$8 trillion in 1960 to US$34 trillion in 2000. Between 1961 and 2000, agricultural production grew at an average compound rate of approximately 2.4 % per annum.

This improvement in food production is a function of two factors: an increase in land used for agriculture and better agricultural technologies. Agricultural land area increased from about 4.5 billion hectares in 1961 to 5 billion hectares in 2001 – a total increase of only 11%. With such a small increase in land use, most of the increase in agricultural output of the past 40 years has clearly been driven by improvements in agricultural technology. Indeed, two-thirds of the increase in rice production can be attributed to technological improvements and for wheat and cereals the figure is three-quarters. Consumption of agricultural chemicals during the period shows a similar growth pattern, suggesting an important role for these technologies in enhancing agricultural output. Consumption of fertilizers has increased four

Figure 1.1 **Agriculture and development 1970–2000**



fold from about 31 million tones in 1961 to about 136 million tones in 2000. Most of the growth occurred during the period up to 1981 when fertilizer consumption grew at 6.75% per year.[3]

Pesticide consumption and production has likewise increased globally and especially in low- and middle-income countries. Global consumption of crop protection chemicals was estimated at about US$25.76 billion in 2001. [4]

Although the world's population has grown 90% since 1950, per capita availability of key food crops has increased by between 20% and 40% since 1961. Not only is there is more food available per person today, but it is available at a lower cost than forty years ago.[5] "A century-long trend of falling real food prices continued during the period 1950 to 1992 as international food commodity prices dropped 78 percent in constant 1990 prices."[6]

The proportion of people engaged in agriculture has been declining steadily since 1960, from 58% to about 41% in 2001. However, as with the relative share of agriculture in GDP, there are stark differences between rich and poor countries. In low-income countries, more than half the adult population is still engaged in agriculture – though even there the trend is falling (from nearly 80% in 1961). By contrast, in high-income countries only a small percentage of the adult population works in agriculture.

However, because of population growth, the absolute number of people in agriculture has risen over the past four decades. Today, approximately 2.6 billion people depend on agriculture for their livelihoods, compared with about 1.8 billion 40 years ago. Of these 2.6 billion, about 2.5 billion live in poor countries. Meanwhile, the number of people in rich countries dependent on agriculture has actually declined from around 250 million to around 90 million during this same period.

Rural women and agriculture

According to the Food and Agriculture Organisation of the United Nations (FAO), women are responsible for half the world's food production and produce 60 to 80 percent of the food in developing countries. In India, "the proportion of women employed in agriculture is 80.7%, compared to 62.7% for men. In rural areas 89.5% of the total females employed are engaged in the agricultural and allied industrial sector."[7]

Lacking modern agricultural technologies, women carry out agricultural tasks with manual, physical labour, working long hours to grow food. These tasks include sowing, hoeing, weeding, fertilizing, harvesting and threshing staple crops such as wheat and rice, and collecting food and caring for livestock and poultry. After crops are harvested, women carry out much of the processing of crops with menial technologies.

Women farmers work long hours: The FAO estimates that while a bullock cart in India works 1064 hours in a year on a one-hectare farm, and a man works 1212 hours, a woman works 3485 hours – an average of about 9.5 hours a day. In Pakistan, "Surveys have revealed that a woman works 12 to 15 hours a day on various economic activities and household chores."[8] In addition to agricultural tasks, women may spend five hours a day collecting fuel wood and water, and up to four hours preparing food.

Women also spend time collecting manure, shaping and drying it into dung cakes which are burned for cooking and heating. Making dung-cakes can take up to two hours a day, depending on how much dung a woman has access to and the amount of cooking fuel required.[9] The burning of dung or low quality coal in poorly ventilated huts is associated with chronic bronchitis, respiratory diseases, congestive heart failure, and early onset of *cor pulmonale*.[10]

Women and children are most exposed to smoke because they spend the most time indoors, cooking and tending the fire. According to a study by the World Health Organisation, "the public health problem of indoor air pollution is severe, accounting for nearly two million deaths and 53 million 'disability adjusted life years' lost, which represents about 4.3% of the global total of DALYs lost in developing countries."[11]

Poor women experience many other health problems as a result of poverty. They often lack even basic sanitation facilities such as indoor toilets and latrines. This causes rural women to suffer kidney problems from not relieving themselves for long periods of time. There are many problems associated with being a poor female farmer, including legal systems and social biases which do not allow women to own land. It is because of these problems that women would benefit enormously from modern agricultural technologies. These technologies would immensely enhance the value of women's time (an important resource often not included in economic calculations), and would spare them difficult physical labour.

Limits on the availability of labour mean that improvements in crop yields and quality can only realistically be achieved by using better technologies. The use of such technologies would have the considerable side benefit of enabling more women to escape the drudgery of subsistence agriculture.

Inferences on the state of agriculture and humanity

Based on the above analysis, the following inferences can be made:

- ◇ Agriculture is an essential component of human existence.
- ◇ Agriculture is a small and declining contributor to global GDP, but remains a significant component of the GDP of middle- and low-income countries.
- ◇ Agricultural output has outstripped global population growth since 1961 by 20%.
- ◇ Per capita availability of food has increased by a similar amount.
- ◇ As a result, nutrition has improved dramatically – by over 50 per cent in India and China – with a consequent increase in life expectancy and fall in infant mortality.
- ◇ A significant proportion of the increase in agricultural output (in excess of 60–70% for key food crops) is attributable to improved agricultural technologies.
- ◇ Of these technological improvements, synthetic fertilizers and pesticides have been very important.
- ◇ The rapid growth in production has reduced prices of agricultural produce, so that food is now cheaper in real terms than it was four decades ago.
- ◇ Agricultural production has become significantly more efficient – using fewer resources to produce the same amount.
- ◇ Over 90% of people dependent on agriculture for their livelihoods live in poor countries. This represents 40% of the people on the planet. By contrast, only about 7% of the population of rich countries depends on agriculture.

- ◇ Because of this reliance on agriculture, regulations restricting the use of important agricultural technologies will have a disproportionate economic effect on poor countries.
- ◇ Because of this disproportionate impact on poor countries, it is absolutely imperative that the effects of such regulations be evaluated in a balanced and dispassionate way.
- ◇ Where a regulation would prevent farmers in poor countries from engaging in more efficient production methods, this cost must be accounted for in evaluating the pros and cons of imposing the regulation.
- ◇ Restrictions on the use of agricultural technologies may also specifically harm women, who make up the larger part of the agricultural labour force in poor countries. This gender-specific effect must be taken into consideration when evaluating the costs and benefits of imposing a specific regulation.

2 Pests, pesticides and regulations

History of pests and pesticides

Pests, in the context of this report, refer to those unwanted species which interfere with the production, processing, storage, transport or marketing of plants, animals, fish, and related products.

Pests and pest control have been an inherent part of agriculture since its inception 12,000 years ago. In most cases, before a crop can be sown, existing indigenous species must be removed. Early on this was done by burning, later by ploughing and most recently through the application of chemicals. But removing an indigenous species prior to sowing is no guarantee that it will not return. Wild plants tend to be better adapted to the local environment than the cultivars sown by man, and they compete effectively with crops for light, water and other nutrients. In addition, fungi, viruses, bacteria, insects, rodents and other species damage crops in various ways. The net result is that pests reduce yields, so man has searched long and hard for cost-effective ways of controlling them.

Forms of chemical-based pest management date back at least to ancient Egypt (see Box 1 below). Until very recently, however, most such chemicals were made from naturally occurring substances.

The impact of pests varies with several factors including the type of land, climatic conditions and soil conditions. Pests, which include insects, fungi, microbes, weeds and rodents, can and do destroy entire crops (the most devastating pests are perhaps locusts, which can consume vast fields in no time at all). The Food and Agriculture Organisation (FAO) of the United Nations has estimated that pest losses account for about one-third of the world's food crops.[13] Pests can impact a crop at any stage of its life cycle, from early growth to harvesting. The following table provides an indicative range of crop losses due to pests, even when various crop protection technologies are employed.

Elsewhere, the authors of *Crop Production and Crop Protection* estimate

Box 2.1 A brief history of pesticides[12]

1500 BC	Egyptians produce insecticides against lice, fleas and wasps
1000 BC	The Greek poet Homer refers to pest-averting sulphur
200 BC	Roman writer Cato advises farmers to burn bitumen to remove insects
Early 1700s	John Parkinson, author of "Paradisus, The Ordering of the Orchard" recommends concoction of cow dung, vinegar and urine to be put on trees with canker
1711	In England, rue, a foul smelling herb, was boiled and sprayed on trees to remove cantharid flies
1763	In Marseilles, a mixture of water, slaked lime and bad tobacco was a remedy for plant lice
1821	London Horticultural Society advised that sulphur is the remedy for mildew on peaches
1867	The beginning of modern pesticide use. Colorado beetle invaded US potato crops and arsenic is applied.
1885	Professor Millardet, a French professor, discovers a copper mixture to destroy mildew
1892	The first synthetic pesticide, potassium dinitro-2-cresylate, marketed in Germany

that for eight major crops, global losses are currently 42.1% of attainable production: "Despite the cultural, manual, biological and chemical methods currently being used to protect these eight crops, about 42% of attainable production is lost as a result of attack by pests. Animal pests account for 15.6% loss of production, pathogens for 13.3% and weeds for 13.2%."[15]

Without such interventionist measures against pests, crop losses worldwide would be nearly 70 percent. The same book notes: "Globally, the measures taken to protect crops prevent production losses to the value of US $160,000 million; this is equivalent to 27.6% of attainable production and 47.7% of actual production." [16]

Modern pesticides and regulation

In the late nineteenth and early twentieth century, innovations in chemistry and biology led to the synthesis of many new pesticides (including insecticides, herbicides and fungicides), which were employed for a variety of uses, including disease prevention and agriculture.

As we have seen, these substances contributed to massive increases in agricultural productivity and improvements in human wellbeing. And during

Table 2.1 **Percentage losses for the period 1988–90[14]**

Region	*Insects*	*Pathogens*	*Weeds*	*Total*
Africa	16.9	15.7	16.5	49.0
North America	10.1	9.7	11.4	31.2
Latin America	14.5	13.6	13.4	41.4
Asia	18.7	14.2	14.2	47.1
Europe	10.3	9.8	8.3	28.3
Former Soviet Union	12.8	15.2	13.0	40.9
Oceania	11.5	15.4	9.6	36.5
Average	15.7	13.3	13.1	42.1

the 20th century, many original pesticides were replaced with substances that are more environmentally benign and safer for users. At the same time, governments, especially in rich countries, have developed regulations to encourage sound pesticide management.

At an international level, the FAO has recognized both the importance of crop protection for attaining food security and the importance of science-based regulations to encourage good pesticide management.

Thus, the FAO has developed codes and reference materials for use by countries when they are developing pesticide regulations, enabling regulators in many different countries to share best practices with each other.

These guidelines, given in box 2.2, include: measurements of toxicity,

Box 2.2 **FAO Guidelines for the Registration and Control of Pesticides (excerpts):[17]**

"The purpose of registration is to ensure that pesticides, when used according to registered label directions, will be effective and efficient for the purposes claimed, and safe. Misused, pesticides can certainly be harmful. Properly handled, they form an essential management tool in the production of food and fibre."

"The balance between risk and benefit will differ greatly under different socio-economic conditions and it is important for each country to study its own priorities when deciding which compounds may be used. It should not be influenced too much by decisions made elsewhere. For example, in a country with a highly developed system of agriculture and adequate resources the threat of harm to a rare bird species may be sufficient reason to avoid the use of a particular compound, whereas in situations where vector-borne human diseases, starvation and malnutrition are regularly encountered, the risk/benefit analysis is likely to result in a different decision".

health and environmental impacts; packaging and labelling; storage and transportation; guidelines for safe use and eventual disposal of equipment and surplus stocks. The FAO codes for the most part represent guidelines and reference materials to be used by national regulators.

Alternatives to pesticides

Synthetic chemical pesticides are one of several technologies used to combat pests in the practice of sustainable farming. Other technologies include biotechnology, biological control, habitat manipulation, modification of cultural practices, and the use of resistant varieties. Integrated pest management (IPM) is a method firmly grounded in science, which uses a combination of these technologies, with the aim of ensuring effective long-term pest control, whilst at the same time limiting its environmental impact.[18]

Organic agriculture is a farming practice that uses a limited range of technologies, including some (mostly inorganic)[19] chemical pesticides. In Europe and the US, most organic farmers use some chemicals, such as sulphur, zinc, copper, sulfites, antibiotics, and microbacterial sprays. Such modern, rich-world 'organic' farming may under certain circumstances be relatively sustainable.

While organic farming may have lower environmental impacts in some respects, it is by no means automatically the most sustainable form of agriculture. There are trade-offs that must be considered when choosing which technology to adopt. For example, it tends to result in lower yields, which mean that more land must be used to produce the same amount of food, and it also relies on tillage for weed control.

It has been estimated that the yields on organic farms are typically 20% or more below that of farms using modern synthetic pesticides even where soils and other conditions are excellent.[20] Where soils are poor and pests more prevalent, yield differences are higher and the overall costs far higher than conventionally grown foods.[21]

Some consumers believe that organic food is more nutritious and safer than conventional foods, but there is little evidence to support these beliefs.[22] While organic agriculture no doubt has a place, for the foreseeable future sustainable agriculture will continue to utilise synthetic chemical inputs if it is to produce enough food and fibre to satisfy demand from the world's population.[23]

Another form of organic agriculture is involuntarily practiced by millions of subsistence farmers around the world who lack the financial means to afford chemical pesticides and fertilisers. Ironically, these 'organic' farmers cannot even afford the technologies used by rich-world organic farmers, so their agriculture is less sustainable.

Biodiversity and agriculture

According to policy analyst Indur M. Goklany, "Worldwide, agriculture accounts for 38 percent of land use, 66 percent of water withdrawals, and 85 percent of water consumption. It is responsible for most of the habitat loss and fragmentation that threaten the world's forests, biodiversity, and terrestrial carbon stores and sinks." [24]

Goklany argues that if agricultural technology was frozen at 1961 levels, production of the world's food output in 1998 would have required the amount of land devoted to agriculture to have more than doubled. "Such land would have increased from 12.2 billion acres to at least 26.3 billion acres, that is, from 38 to 82 percent of global land area. This optimistically assumes that productivity in the added acreage would be as high as in the other areas. Cropland alone would have had to more than double, from 3.7 to 7.9 billion acres. An additional area the size of South America minus Chile would have to be ploughed under."[26]

In addition, Goklany says that in the absence of pesticides, an estimated 70 percent of the world's crops might still be lost, instead of 42 percent or less. Thus, "without pesticides and other pest controls, at least 90 percent more cropland would be required to offset the loss in production."[27]

"Applying agrochemicals, so that land most suited to agriculture is utilized, helps to avoid land conversion, especially of land that is covered with vegetation and with steep slopes."

Jose Guillermo Pacheco, Agronomist Engineer, who in 1974 founded the Asociacion Guatemalteca Pro Defensa del Medio Ambiente [Guatemalan Association for Defense of the Environment].[25]

In its 2001 *Rural Poverty Report*, the International Fund for Agricultural Development says: "Without the Green Revolution, the continuation of the near-stagnant yield trends of 1955–65 would have induced massive intensification of production and expansion into previously forested areas and other environmentally fragile lands, encroaching upon their use by marginalized rural people who were often ethnic minorities."[28]

Goklany concludes that by reducing hunger, agricultural technology "has not only improved human welfare and reduced habitat loss but has made it easier to view the rest of nature as a source of wonder and not merely as one's next meal or the fire to cook it with. It also decreased the socioeconomic cost of conservation."[29]

Consumer health and pesticides

In most poor countries, the poorest people have meagre diets, based on staple foods. This is in stark contrast to consumers in wealthy countries, who have a large variety of inexpensive foods, especially fruits, vegetables and grains. Often the diets of poor people do not include sufficient protein or micronutrients, and because of this, many women and children are anaemic, and even go blind or suffer other physical ailments because of malnourishment.[30]

Dr. Bruce Ames, Professor of Biochemistry and Molecular Biology and Director of the National Institute of Environmental Health Sciences at the University of California, Berkeley, is emphatic about the role of fruits and vegetables in fighting disease: "Low dietary intake of fruits and vegetables doubles the risk of most types of cancer as compared to high intake and also markedly increases the risk of heart disease and cataracts."[31]

Nevertheless, improved agricultural technologies have contributed to a significant reduction in malnutrition in the past fifty years. Analyst Indur Goklany observes:

> *Since 1950, the global population has increased by 90%, increasing the demand for food, but at the same time the real price of food commodities has declined 75%. Greater agricultural productivity and international trade have made this possible. As a result, average daily food supplies per person increased 24% globally from 1961–98. The increase for developing countries was even larger, at 38% … Between 1969–71 and 1995–7 such increases in food supplies reduced the number of chronically undernourished people in developing countries from 920 million to less than 800 million (or from 35% to 19% of their population), despite a 70% growth in population.*[32]

However, malnutrition remains a very serious problem. The FAO's 1999 *Report of the State of Food Insecurity in the World* estimated that, globally, 790 million people in the developing world do not have enough to eat.[33] "Almost two-thirds of the undernourished people in the world live in Asia and the Pacific. India alone has more (204 million) than all of sub-Saharan Africa combined [180 million]."[34]

Unlike their counterparts in rich countries, subsistence farmers continue to suffer substantial crop losses from weeds, insects and pathogens. In general, a lack of food in poor countries is due to policies that frustrate more efficient agricultural production. One major problem is that people do not have access to capital to purchase modern agricultural technologies such as pesticides. This and other deficiencies, such as poor infrastructure and lack of refrigeration, mean that food is more expensive. With little money to spend on relatively more expensive fruits and vegetables, poor people mostly eat staple foods such as millet, which lack many vital nutrients.

Agricultural chemicals have improved both the quality and quantity of food available to consumers. These technologies decrease the cost of food production, and ensure that crops do not have to compete for soil nutrients. To improve the nutrition of the poor will require more affordable and nutritious food, which is most likely to result from the appropriate use of modern agrochemicals and other agricultural technologies.

Dr. David Pimental, an agricultural ecologist at Cornell University, says that natural toxins are found widely in plants, and in staple foods such as grains and legumes.[35] He notes, though, that the presence of natural toxins, and potential risks of consumption, does not mean that consumers should eliminate such products from their diets. Rather, consumers need access to information to make informed decisions:

> *Risk from naturally occurring toxins in foods – as well as from pesticide residues – depends on the dosage of the chemical, the time of exposure, and the susceptibility of the individual human. These data, along with the sound experimental investigation of particular pesticides or natural toxins, are essential in estimating the potential risks to humans of various toxic chemical exposures in human foods.*[36]

In summary

Synthetic chemical pesticides remain the key weapon against pests of all forms in the practice of sustainable agriculture. But pests still account for a substantial loss in agricultural yields – up to one-third of global food production according to the FAO's estimates. So the search for more effective pesticides and other forms of pest management must continue.

Pesticides have helped increase agricultural productivity, contributing to an unprecedented increase in food production which has seen rates of malnutrition and deaths from starvation plummet over the past fifty years, even as the world's population has multiplied. By increasing yields and thereby reducing the amount of land needed for agriculture, pesticides have also helped to conserve biodiversity.

However, "The critics [of pesticides] overlook the fact that in the less affluent parts of the world, where the population is still increasing year by year, without the use of agrochemicals to protect the crops more catastrophic famines would be inevitable. It is unrealistic to assume that the risks for world agriculture and for the world population are the same, and that food supplies are equally secure, the world over." [37]

Although regulatory controls on pesticides have been demanded by wealthier societies, these regulations have rendered the process of bringing new pesticides to market extremely expensive. This does not mean that the resultant regulations are necessarily undesirable; rather it means that the increasing cost of the product must be borne in mind as an adverse consequence.

There are many different agricultural methods for pest management and for sustainable farming. Each farmer should be free to choose the methods and technologies that best suit his or her purposes. The task of national regulators should be to ensure that this choice is preserved – free of influence of pressure groups (whether industry, NGOs, or foreign governments).

3 Weeds and weed management

What's wrong with weeds?

Weeds are typically part of the natural flora of the environment in which crops are grown. As such, they compete for water, nutrients and light with other plant life. They prevent crops from reaching their full growth potential and thereby reduce yields – sometimes by up to 80 percent, though 10–15% is considered a very conservative estimate of average impact of weeds on yields.[38]

Weeds proliferate with availability of nutrients, light and water. They also inhibit farming activity by obstructing farm workers and hindering the use of specialized machinery (e.g. a combined harvester will be slowed down). Weeds also act as a breeding ground for pests and crop diseases, often acting as a carrier between successive crops. Managing weeds has thus always been an integral part of farm activity.

Early weed management

Historically, weeds have been managed through manual weeding (literally pulling the weeds out and destroying them), ploughing and other mechanical techniques (which have the same effect) and through use of chemical herbicides, including salt.

Hand weeding is backbreaking, tedious work that is time consuming and energy sapping. It can occupy several hours of a farmer's day. Added to this is a peculiar problem facing farmers with small land holdings: they cannot afford to hire labour for weeding, so they and their families must do it themselves. In many countries, such as Malaysia, manual labour is either in short supply or expensive.

Mechanical weeding is quicker but lays bare the soil to erosion from wind and rain because the weeds are uprooted. Mechanical weeding is also inappropriate for many steep and rocky terrains, and also causes soil damage by compaction, which can cause excessive damage.

Chemical weeding attempts to address the drawbacks of both the above, saving time and protecting the soil from erosion. Though several inorganic chemicals have been used in weeding since the early twentieth century, it was not until the 1940s that specialized herbicides came into wide use.

Studies assessing a variety OF crop growth circumstances in different countries around the world have established that hand weeding consumes four to five times as many man-hours as chemical weeding. It takes roughly 24 man-hours to weed one hectare of rice fields in Japan by hand compared with about 4–5 hours using herbicides.[39] According to a study of agriculture in Cote d' Ivoire in Africa, "manual weed control takes 60 working days per hectare, per year. This can be reduced 80% if herbicides are used. The yields are higher in these trials than those achieved on plantations, indicating that commercial production can be improved."[40]

Total costs are reduced by up to 50% when herbicides are used. In a competitive market, some of these cost savings are passed on to consumers, so using herbicides reduces the cost of agricultural products (food, oil, cotton, wool, wood, paper, and so on) and frees up resources to be used for other activities.

Some peculiar characteristics of weeds

Weeds, in addition to being predatory plants that compete with crops, have presented several additional challenges, even as weed management techniques have advanced.

- The nature and growth of weeds adapt differently to different land preparation and cropping techniques. For example, ploughing the land could remove the weeds on the top layer but could cause dormant weed seeds that have been lying too deep in the soil to germinate and grow.
- Over a period of time, weeds build resistance to treatment, including from chemicals. This is not dissimilar to well known experiences in insect pest control. For example, mosquitoes develop resistance to specific chemicals and render some insecticides ineffective. This has proven to be the case even with highly effective herbicides.
- Weeds can vary in how they affect crops at different stages of the individual crop's life cycle. Various methods of weed management including drowning of weeds, land preparation, transplanting of saplings (rather than planting seeds) have been and continue to be used in the constantly evolving battle against weeds.

The economic impact of weeds

The authors of *Crop Production and Crop Protection* show that:

> *At present, globally, [in agriculture] the overall loss [from pests] is 42.1% of attainable production. However, if no physical, biological or chemical measures were used to protect crops, this figure would be 69.8%. So globally, the measures taken to protect crops prevent production losses to the value of US $160,000 million; this is equivalent to 27.6% of attainable production and 47.7% of actual production.*[41]

If current global agricultural output was to be achieved with no weed management, "an estimated 70 percent of the world's crops might be lost, instead of the current 42%. Thus, without [pest control systems], at least 90 percent more cropland would be required to offset the loss in production." [42]

The increased costs of production would significantly reduce profits for farmers. For low-income countries – where 25% of GDP comes from agriculture – a 10% yield loss in output would seriously impact economic development. In addition, the use of such additional land would come at the expense of forests, wetlands and wilderness areas.

The human costs would also be large. A decline in food production means more hunger, and its consequences: "Hunger and undernourishment retard education and the development of human capital, slowing down technological change and economic growth."[43]

Techniques in weed management

Since the early manual and plough techniques, weed management has witnessed several significant technological developments, each of which has involved herbicides and farming practices based on use of these herbicides.

Historically, weed management has revolved around the several different techniques, often used in combination. The following list (based on techniques used in wet seeded rice farms in Japan) is illustrative:

- ◇ Land preparation – field drainage and water control can be critical for weed management.
- ◇ Seeding rate – low plant density and the presence of gaps encourage the growth of weeds. Appropriate density of seeds can counter the impact of weeds to some extent.
- ◇ Water management – in rice paddies, deep water can kill some weeds but this must be used in combination with other techniques.
- ◇ Hand weeding – this is time consuming, expensive, and inappropriate in

circumstances where the window for sowing and/or harvesting is very narrow due to climatic conditions.

◊ Inter-row cultivation – in rice cultivation, saplings are planted in very high density and then mechanical weeding is used to suppress weeds under water. The rice saplings survive but the weeds die. This gives the visual impression of rice being cultivated in rows when the saplings eventually emerge.
◊ Herbicides – several types of herbicides exist, each with different characteristics and each functioning at different crop stages. Some herbicides are systemic (e.g. glyphosate), while others only act on the foliage (e.g. paraquat).

A recent study illustrated the benefits of paraquat use in lowland rice plantations in Lombok, an island which is part of the Indonesian Archipelago.[44] Erratic rainfall in Lombok causes high weed density for rice farmers. Without weeding, rice yields may be reduced by 40 to 100%.[45]

To prevent such losses, rice requires a long period of weeding, which entails high costs because labour is scarce. An experimental study in Ketare and Kaw Villages showed that when paraquat was used, it required less time than traditional weeding (without herbicides), reduced farm labour costs by 28%, and gave farmers additional income compared with traditional rice fields. It also meant that farmers had extra time for productive agriculture or non-agriculture activities.

Paraquat is also beneficial in no-till and low-till (conservation tillage) farming, an integral part of sustainable agricultural practices. Conventional tilling of the land has come under criticism for the following reasons:

◊ It removes all plant life by the roots, leaving the soil bare to erosion by wind and or water.
◊ It upsets the natural structure of the soil and can affect the availability of nutrients and the condition of the soil.
◊ It affects natural organisms in the soil. For example, it kills earthworms that function as a natural nutrient developer.

Conservation tillage has been developed as a way to eliminate some of these problems. Some benefits of conservation tillage are that:

◊ It reduces erosion, to 5% of the ploughed field, and improves soil nutrition, structure, and drainage.
◊ It prevents sediment losses from erosion, which greatly sustains or improves local aquatic habitat.

Box 3.1 **Conservation tillage in Ghana**[46]

Ghana's traditional agriculture, still widely practiced today, relies on slash-and-burn methods and, in some areas, tillage of soil. This leads to a loss of soil mulch, requires long fallow periods for soil regeneration, and results in heavy soil erosion.

Conservation tillage has been adopted by some of Ghana's agricultural organizations as a way to increase yields, decrease costs, and reduce soil erosion and nutrient depletion. Particularly for maize, "no-tillage optimizes production and productivity under the existing soil, climatic, and agro-economic circumstances in which the maize crop is produced."

> *Since 1991, the Ghana Grains Development Project adopted the tillage/mulching/no-burning system in five main research stations for planting maize and grain legumes. The most common weed control program used has been the application of glyphosate two weeks before planting, atrazine plus alachlor after planting, and paraquat (band or spot application) or hand weeding during the first 45 days, when required.*

As a result of no-tillage, "equal or higher yields, reduction of tractor operations, savings of time and money and drastic reduction in soil erosion have been achieved." Specifically, no-tillage has reduced the number of work days: to produce 1 hectare of maize, work days are reduced from 100–120 (with solely mechanical control of weeds) with yields of 1–2 tons/hectare, to 15–20 days with no-tillage and herbicide use, and yields of 5–6 tons/hectare.

◇ It prevents run-off of herbicides, because rainwater drains through the soil, and chemicals are broken down by microbial action.[47]

◇ It balances soil moisture during drought. A lack of ploughing enables the survival of capillaries which connect the surface layers with water tables at much deeper levels.[48]

◇ It improves soil drainage, because pest predators – carabids, staphlinids – and large earthworms increase about 6-fold. In ploughed soils, smaller worms are dominant. Earthworms, which are larger, leave open channels in the soil, and pest predators hide under vegetation at the surface.[49]

◇ It benefits wildlife, such as birds, whose territories and nests increase anywhere from 3- to 100-fold. Time requirements for young bird feeding are reduced five-fold.[50]

Present developments in weed management cover two main areas:

1. Integrated weed management, which includes crop rotation and rotation of chemical herbicides, in order to discourage the development of resistance to specific chemical formulations.
2. Agricultural biotechnology, which focuses on altering the plant's genetic characteristics, either by enabling the more efficient use of broad-based herbicides, or by enhancing the plant's own resistance to weeds.

Other methods, such as integrated pest management, require concerted efforts from large numbers of farmers and have been difficult to implement in countries with small farm holdings.

4 Paraquat – history and performance

The chemical paraquat was discovered in the late 19th century by two German scientists. However, it was not until 1955 that its herbicidal properties were discovered by ICI. This eventually resulted in the launch of a commercial product, Gramoxone, in 1962. Since then, Gramoxone and other paraquat formulations have been used for weed management in over 120 countries around the world.

How does paraquat work?

Paraquat is a non-selective, non-systemic contact herbicide. "Non-selective" implies that it attacks and kills all the green parts of plants with which it comes into contact. "Non-systemic" means that it does not attack the roots or move freely in the plant. "Contact" means that it must physically contact the surface area of the foliage that it destroys. It acts by interfering with the photosynthetic process and is fast-acting.

What makes paraquat unique?

Paraquat has some unique properties which have resulted in its widespread adoption by farmers:

- ◊ It is adsorbed rapidly and strongly to clay particles in the soil. This property ensures that it is not taken up into crops through the roots – i.e. it is non-systemic. It also facilitates planting of crops soon after spraying since adsorbed paraquat is not biologically active.
- ◊ Rapid adsorption means that it is rainfast within a few minutes of application. This makes it ideal for use in climatic conditions where there is frequent rainfall.

Box 4.1 **De-activation of paraquat in soil**

Most paraquat (some 99.99%) is strongly adsorbed to soil where it is relatively stable and biologically unavailable, leaving vanishingly small concentrations in soil solution, the biologically active part of soil.

A key laboratory methodology for testing the potential impact pesticide residues in soil is through bio-assays. For paraquat, a bio-assay has been developed that essentially tests the impact of short-term adsorption on exposure via soil solution for wheat roots, since wheat is one of the most sensitive crops. In the bioassay, the dose that inhibits the growth of wheat roots by 50% is determined as a test level Strong Adsorption Capacity-Wheat Bioassay (SAC-WB). Soils are then treated at various fractions of the SAC-WB level to establish potential impact on soil organisms and life under actual field conditions.

Long-term trials conducted at Fensham, UK, (up to 20 years) indicated no adverse effects on soil micro-organisms and micro-arthropods at levels up to the SAC-WB values, equivalent to several hundred times the amount of paraquat normally recommended for application. For earthworms, an impact was only observed at more than nearly 720 times normal application amount but none at 100 times the amount. The amount that can be in the soil without effects varies depending on the type of soil due to different adsorption capacities. Similar long-term trials in the USA, Australia, Malaysia and elsewhere on different soil types and climates gave similar results. Such trails also introduced fertiliser minerals such as potassium at high rates, and verified that even such changes in the soils composition could not affect the stability of paraquat's adsorption to soil.

These experiments clearly establish the enormous capacity of all soils to adsorb paraquat and the lack of effects of adsorbed paraquat on soil life during long-term use.

Because it works so rapidly and is rainfast, paraquat may be used in wet conditions with negligible risk to farm workers and without any adverse effects to the soil and groundwater. In practice, it not a risk to aquatic life including green foliage given normal spraying conditions and quantities.

Also, because it works on sprayed green foliage, the root systems of weeds remain intact. This is helpful in areas where agricultural crops are grown on steep slopes, where physical removal of weeds might lead to erosion.

Box 4.2 **Pesticides and paraquat**

Dr Richard H Bromilow, Rothamsted Research, UK

Modern pesticides have been used extensively in agriculture for over 50 years. Though crops vary in their susceptibility to pests, diseases and weed competition, it is thought that controlling these problems with pesticides increases crop yields by about 30% on average. Not only yield but also crop quality may be greatly improved, giving for example vegetable crops without insect damage and cereals free of the fungi-produced mycotoxins. Losing all these benefits to agriculture would substantially reduce world food supplies, bringing hardship to many people and increasing the pressure to bring more virgin land into cultivation to the detriment of biodiversity and wildlife.

Though many other techniques are usually used in conjunction with pesticides in order to reduce crop losses (such techniques including agronomic practices, resistant varieties and biological control), much of world agriculture is still highly dependent on pesticide use. For weed control, the only practicable alternatives to herbicides are mechanical or hand weeding, the former often not being very efficient and the latter being very labour intensive.

Paraquat is a contact herbicide which rapidly kills the green parts of plants under the action of sunlight. The paraquat molecule has the unusual feature of being a planar dication (i.e. with two positive charges), and so it is tightly bound by clay particles in soil, especially those derived from expanding-lattice clays such as montmorillonite. This strong binding in soil so reduces paraquat concentrations in soil water that it is immediately deactivated due to a lack of availability to plants; paraquat thus differs in its behaviour from most other herbicides, which remain active via uptake from soil for some time after application and so cannot be used immediately prior to planting.

The degradation of paraquat is rapid in soil-free culture systems, but the low availability of most paraquat residues in soil to microbes in soil pore water slows down its rate of degradation in field soils. Nevertheless, in long- term field trials, paraquat has been shown to be degraded in soil and is not continually accumulated, and no phytotoxic effects have been observed or would be expected even with continual use at agronomic rates over the long-term.

The strong sorption of paraquat to soil also prevents leaching and losses to surface water via drainage or surface run-off during heavy rainfall. Such sorption also limits paraquat availability both to soil microorganisms and to larger soil organisms such as earthworms, and so paraquat has no deleterious effects on these organisms in soil.

Paraquat in its formulated form is moderately toxic to mammals if ingested, and so stench agents are added to deter accidental or deliberate ingestion. Once diluted and sprayed, given its use pattern and environmental behaviour then paraquat residues would not be expected on the edible parts of crops.

The unusual properties of paraquat, first recognised in 1954, have allowed agronomic systems to be devised to exploit these opportunities. Paraquat can be used in no-till agriculture or minimum-cultivation systems, in short-rotation production systems for vegetables, in vegetation management in oil-palm plantations, and in the establishment of tidal rice. Weed seedlings are killed within a day or two, and the ground can be immediately sown with the next crop without risk of phytotoxicity. As paraquat is rainfast and acts rapidly on weeds, it is an especially valuable herbicide in tropical regions, both in developed and in subsistence agriculture. Indeed, paraquat has been used commercially for over 40 years and there is no evidence of such use causing any environmental problems. The benefits of paraquat have been manifest in many agricultural systems and, given its unique properties, will continue to offer such benefits in the future.

◊ It does not penetrate woody tissue and cannot accidentally kill a tree during spraying, or destroy its bark. It is therefore the first choice of herbicide for most tree and bush crops.

Environmental characteristics

Because of its adsorption qualities, paraquat does not leach into groundwater. The adsorbed paraquat degrades into substances that are not a risk to the soil or plant life. One scientific study suggests that

> *The major part (some 99.99%) of a paraquat application that reaches the soil within the typical Good Agricultural Practice is strongly adsorbed to soils of a wide variety of textures. However, the paraquat in soil solution is intrinsically biodegradable, being rapidly and completely mineralized by soil microorganisms.*[51]

Its degradation rate at 5–10% per annum is sufficient to ensure that paraquat is always strongly adsorbed to soil given normal use practices. Thus, while its degradation rate is slow relative to some other chemicals, it is environmentally benign. Paraquat is not a risk to soil organisms, nor during its breakdown does it release substances that are a risk to soil or soil organisms.[52] Because it works so rapidly and is rainfast, paraquat may be used in wet conditions without risk to farm workers or any adverse effects to the soil and groundwater. It is not harmful to aquatic life other than green foliage given normal spraying conditions and quantities.

> *It is important to consider whether there is evidence to show that paraquat has affected soil quality in the 40 years of its widespread use. There appears to be no such evidence. In fact, since the first use of paraquat in the early 1960s, its use has played a major role in the way many crops are grown throughout the world. It is relevant to note that in all this time paraquat has been shown not to contaminate either ground water or surface water and so meets the water quality criteria established by the European Union.*[53]

Human safety characteristics

The following properties of paraquat have been validated by the World Health Organization through its International Programme on Chemical Safety[54] and independently validated by the US Environmental Protection Agency):

◇ Paraquat is non-volatile and its droplet size in a typical spray application cannot be inhaled by the lungs.
◇ Paraquat's absorption rate on intact skin is lower than that of water. This means that with normal precautions of use and personal hygiene habits, the herbicide is not dangerous to human beings through the skin.
◇ It is not carcinogenic.
◇ It is not harmful to foetuses in pregnant mothers.

5 Paraquat case studies

Paraquat has been in wide use for a variety of crops in different countries. These include:

- ◊ Plantation crops (banana, cocoa-palm, coffee, oil-palm, rubber, etc.), citrus fruits, apples, plums, vines, and tea.
- ◊ As a desiccant on certain crops (potato, pineapple, sugarcane, sunflower).
- ◊ As a cotton defoliant.
- ◊ As a foundation treatment to kill weeds before crop emergence in no-tillage production of corn, soybeans, cotton, wheat, oil seed rape and other crops.

In addition, uncropped land on industrial sites, railways, roadsides, etc. can be cleared of weeds by applying paraquat.

Paraquat's non-systemic killing of foliage has a significant environmental benefit in preventing soil erosion by wind and rain, because the roots of the dead weeds remain intact and bind the soil.

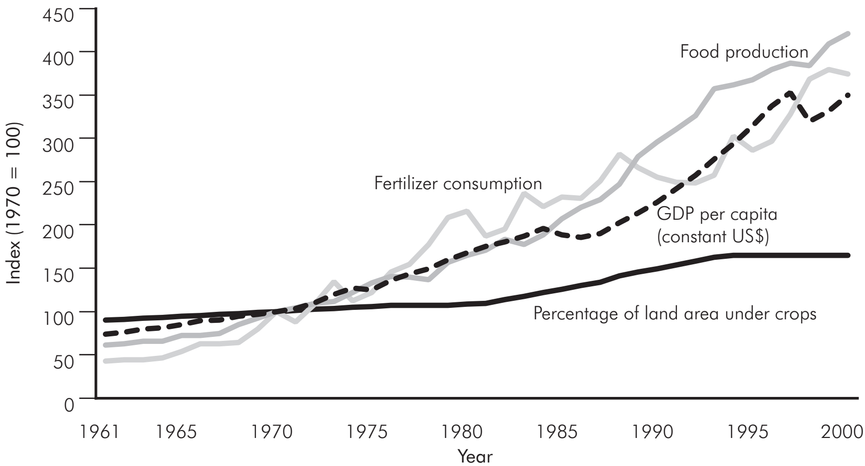
Perhaps the best way to illustrate the role of paraquat in agricultural crops is to study the impact of its use in specific crops in different countries. In this section, we evaluate three different geographical areas:

- ◊ Malaysia
- ◊ China
- ◊ Costa Rica

5.1 MALAYSIA

Malaysia has been one of the most dramatic economic success stories of the past four decades. In 1960, the country had a population of 8.1 million and

Figure 5.1 **Food, agriculture and development in Malaysia 1961–2000**



Source: World Bank

an average per capita income of around US$1000 (in constant 1995 US$). By 2000, its population had risen to 23 million people and per capita income had risen nearly five-fold to US$4,800. (In purchasing power parity terms, per capita income has risen nine-fold, from less than $1300 in 1975 to nearly $9000 today.) During the same period (1960 to 2000), life expectancy rose from 54 to 72 years and infant mortality fell from 73 per 1000 lives births to 8. Meanwhile, the proportion of children aged 10–14 who are working has fallen from over 10 per cent to around 2 per cent. Nearly all children now receive at least primary school education and the rate of illiteracy among adults has fallen from over 40% in 1970 to around 12%.[55]

Agriculture in Malaysia's economy

The productivity of Malaysian agriculture has increased continuously over the past four decades. As figure 5.1 shows, the area of land used for crop production has barely doubled, whilst output has risen more than five-fold. The increase in productivity is directly attributable to the use of modern technologies, including fertiliser and pesticides.

Technology has increased the efficiency of Malaysia's agriculture, making it more competitive internationally. It has also liberated people from servile, backbreaking jobs such as weeding, so that they may engage in more rewarding, higher-value jobs. This is reflected in the proportion of women working in agriculture, which fell from 44% as recently as 1980 to 13.4% in 1999.

If the use of such technology were to be limited by, for example, restricting certain products that are in common use, these trends would be reversed.

One of the proponents of imposing stronger restrictions on the use of modern agricultural technologies is the Pesticide Action Network. The PAN Asia-Pacific website declares, "We believe in people-centred, pro-women development through sustainable agriculture."[56] So, one presumes that PAN would support wider adoption of technologies that enable women to escape the servile, demeaning life of hand weeding, especially if these technologies also enable more efficient use of land and lead to better lives for people.

Oil palm cultivation

Over the past thirty years, oil palm has become the dominant crop in Malaysian agriculture, with cultivation increasing five-fold from 640,000 hectares in 1970 to 3.37 million hectares in 2000. Meanwhile, productivity increased significantly: whereas the area of land under cultivation increased by about 6.8% per year between 1975 and 2000, production of crude palm oil and palm kernel increased by 9% and 11% respectively over the same period.[57] Oil palm has also become a major source of foreign-exchange revenue: in 1999, exports of oil palm and its products contributed RM 17.70 billion (about US $4.66 billion).

Herbicide use

One of the reasons oil palm has become such an important and successful crop in Malaysia is the effectiveness of modern herbicides – and specifically paraquat – in combating weeds that would otherwise dramatically reduce oil palm productivity.

As a result, palm plantations are the most significant consumers of herbicides, representing approximately 84% of land area under herbicidal treatment. (Rubber and other crops/plantations account for the balance of the 4.2 million hectares treated with herbicides in Malaysia.)

Paraquat was originally developed by ICI in 1959 for use in Malaysia and remains the preferred herbicide of oil palm plantation owners because its fast action and rainfast properties make it particularly suitable to Malaysia's wet climate. Plantation owners also benefit from the fact that paraquat, being non-systemic, does not destroy the roots of weeds. This enables the weed roots to prevent soil erosion, which is very important in a country that receives high rainfall.

Chemical herbicides are used on both small farms and large plantations. 750,000 farmers and 3000 estate owners annually use between 8 and 10 million litres of paraquat.[58]

Adverse effects

Various studies have been conducted on paraquat users and farm workers in plantations. Some problems relating to paraquat use were reported. However, these were cases of minor skin and eye irritation, which cleared up quickly with no long-term implications. The main causes of occupational exposure are leaky knapsack sprayers and accidental splashing on skin or body when spraying.

Concern has been raised over the fact that some workers do not use the protective clothing recommended for pesticide spraying. However, this is understandable in an environment where temperatures routinely exceed 27°C (80°F) and humidity can be close to 100%. Whilst few workers wear full protective clothing, studies have found that most workers use appropriate safety equipment and apparel.[59] Moreover, WHO studies confirm that despite this practice there is no evidence indicating long term health impacts of workers that are occupationally exposed to paraquat.[60] There are no recorded instances of fatalities resulting from occupational exposure to paraquat and no reason to believe that there ever will be any fatalities.

The Pesticide Action Network claims that workers do not know what chemicals the spraying container holds and generally do not follow safety measures.[61] But a recent survey of small-holders, full-time farm workers, and estate managers found that users were in general highly aware of both the benefits and the risks of paraquat (see Box 5.1). If anything, the mandatory warning labels on paraquat bottles may have exaggerated the dangers of misuse, in some cases creating unnecessary fears of the implications of long-term use.

One of the alternatives to paraquat in Malaysia's oil palm sector is manual weeding, pulling weeds by hand, or using a hoe or machete, with attendant risks of back and knee injuries. A severe back injury or knee injury can prevent a person from working for months or even permanently. By contrast, estimates put the total amount of time lost as a result of injuries from paraquat at 0.05% (or about one hour per worker per year).[62]

Although paraquat does not present any serious occupational hazards, it is highly toxic when drunk. Some alternatives, such as glyphosate, are less acutely toxic. However, they may be less rainfast, and because they are systemic, they are less useful for erosion-prone areas. We should also recall that before paraquat was developed for Malaysian agriculture, sodium arsenite

Box 5.1 **Malaysian farmers support paraquat use**[63]

A 2002 study by Asian Market Intelligence found that Malaysian farmers strongly support the use of pesticides and other agro-chemicals; they believe that they are a necessary part of farming. Moreover, they seem highly aware of the importance of taking precautions when using these chemicals in concentrated form and are highly cognizant of the possible dangers of misuse, information that was gleaned from mandatory warnings on the bottle labels.

Malaysian farmers place a very high value on paraquat is made clear and are clearly worried about the following statement by a possibility of a ban. Indeed, they argue that if the government wants to restrict or ban paraquat, it must first make available an alternative chemical that is just as efficient and cost-effective. They stress that no such chemical exists today. They feel that the government did not consult them when considering the restrictions, and the farmers do not have the power to oppose them. A representative of a group of estate managers: said:

> *"It is very unfair … as it is the most effective pesticide … and we are using it for many other things also … and we don't have other substitutes that can do the same job as effectively …" "*

was used extensively – and by several measures it is a more toxic, more environmentally harmful chemical.

The economic impact of restrictions on paraquat use[64]

Restrictions on the use of paraquat would affect the livelihoods and prosperity of the 150,000 smallholders in Malaysia's oil palm industry. Malaysian oil palm and oil palm products compete in the international market with products from Indonesia and Papua New Guinea (oil palm), Canada and Australia (Canola), and Brazil, the USA and Argentina (soybean). Production costs of oil from Malaysian oil palm are US $239.4 per ton, compared with Indonesia, whose costs are US $165 per ton. Restrictions on paraquat use could add up to US $8.60 per ton to the cost of Malaysia's product, rendering it the most expensive product in the international market.

Any restriction might reduce yields, increase soil erosion, and force farmers to use high-cost and debilitating manual weeding, resulting in an estimated 7% reduction in the farmers' income. The benefits, if any, of imposing restrictions on paraquat use must be carefully weighed against the costs.

Conclusion

Paraquat plays a very important role in Malaysian agriculture, especially in the oil palm sector. Restrictions on its use would harm Malaysia's economy and damage Malaysia's environment. Contrary to what their advocates suggest, such restrictions would also harm Malaysian farmers, small and large. By raising input costs, they would reduce the competitiveness of the oil palm sector. Many small farmers would go out of business. The farmers who remained in business would use alternative chemicals, some of which might be more hazardous and less environmentally benign, and they might also employ women and children to weed by hand, with attendant injuries and costs that such work entails. The diversion of workers from high value jobs to low value weeding, and the diversion of children from school to farm labour cannot be seen as a good thing. If the objective is to improve working conditions for poor farmers, restricting the use of paraquat is not the solution.

5.2 CHINA

China is the world's most populous country (1.26 billion people) with a GDP of US $1080 billion. Its per capita income at US$ 1,130 places it as a lower middle-income country by the World Bank's classification. The Chinese economy has grown rapidly over the past two decades (over 10% per annum) led by strong growth in industry and services.

In 1960, China had a population of 670 million and an average per capita income of less than US$100 (in constant 1995 US$). By 2000, its population had risen to 1.2 billion people and per capita income had risen more than eight-fold to US$800. During the same period, life expectancy rose from less than 40 to about 72 years and infant mortality fell from 132 per 1000 lives births to 31. Meanwhile, the proportion of children aged 10–14 who are working has fallen from over 40 per cent to around 7 per cent. Nearly all children now receive at least primary school education and the rate of illiteracy among adults has fallen from over 45% in 1970 to around 14%.

Agriculture in the economy

About two-thirds of China's workforce is employed in agriculture and a similar proportion of its population lives in rural areas[65]. Agricultures contribution to GDP declined from 30% in 1980 to less than 16% in 2000, but increased in absolute terms from about US$60 billion to about US$165 billion.[66]

Agricultural growth in China averaged 5.9% in the 1980s and 4.1% in the 1990s. This growth was aided by structural changes in Chinese agriculture in

Box 5.2.1 **A farming family in Sichuan**

Fan Huiqing is a farmer at Tongzi Village, Sichuan Province. Every year, Fan plants one season of rice and two seasons of vegetables. She also raises pigs, chicken and ducks. There is plenty of work to do and farming takes up 10 hours a day.

Fan takes a rational but cautious approach to new technologies. She says, "First, I listen to the introduction, watch other people's practice and try the experiment or demonstration myself, then I'll decide whether to accept it or not.

Paraquat is her preferred herbicide. "Without paraquat," she says, "I'll have to hire many more hands, which will increase the farming input, with other expenditures curtailed and regular life disturbed." Her husband, instead of earning money from other activities, would have to work on the farm and eventually she says, "the shortage of money will stress our life."

Fan believes that labour-saving technologies have improved living standards. Her family has already built a new house and owns a colour TV, video CD player and new furniture. She dreams of being a "boss" and having other people work for her.

the 1980s that encouraged private ownership, enterprise and market orientation in agriculture. But increased use of modern technologies, including chemical fertilizers and pesticides, has also contributed significantly to increased productivity, with commensurate benefits for farmers and their families (see Box 5.2.1).

Rice cultivation

China is the world's largest producer of rice, accounting for two-fifths of annual global production (about 500 million tons in 2002–03).[67] China exports only a small proportion of its rice (between 2 and 4 millions tons per year), but is still amongst the top five exporters in the world.[68]

According the Chinese Statistical Bureau, rice yields in China have increased from 2.11 t/ha in 1950 to 6.27 t/ha in 2001. Virtually all the productivity gains are the result of better technology and agricultural practices. The area under rice cultivation (currently 29.1 million hectares) has increased marginally (0.2% annually) since 1960 (when it stood at 27 million hectares), while overall production increased by 2.94% annually during the same period.[69]

Rice is grown both in northern and southern regions in China. However, the northern regions have a shorter growing season, due to cooler climates, and limited water resources.[70]

Box 5.2.2 **No-till farming in Dongpo District, Meishan City[73]**
Dongpo District, Meishan City, situated on the southwest border area of Chengdu Plain covers an area of 1330 square kilometers, has 3,997 United Agricultural & Economic Cooperatives under its jurisdiction in 500 administrative villages of 33 towns. There is an agricultural population of 686,000 and a cultured land of 744,000 mu [about 50,000 Ha], 600,000 mu of which are rice fields. The main crops sown in late autumn include wheat and rape, and the main crop sown in early spring is rice. This district is one of the commercial grain production base counties in the country.

The experiment and demonstration of no-till growth of wheat, rape and rice began in 1983, 1985 and 1988 respectively in this district and the project of application research for the comprehensive associated techniques for their non-tilling growth was accepted and registered with the Scientific & Technological Commission of Leshan City, a prefecture under the direct jurisdiction of Sichuan Province. The non-tilling growth of wheat, rape and rice has been formed into an integral system of techniques playing an exemplary role and widely spread in this district and successively awarded Science & Technology Progress Prizes respectively by the Agriculture Ministry of the People's Republic of China, the People's Government and the Agriculture Department of Sichuan Province, the People's Government of Leshan City and the People's Government of Meishan County.

Farming in China shifted from state-run co-operatives to private farms in the 1980s.[71] During this period, sales of pesticides for the rice farms alone grew from an estimated US$130 million in 1980 to US$715 million in 1996.[72] Herbicide use in rice cultivation increased from US$10 million to US$48 million during the same period. Paraquat is one of the products that has been adopted by farmers in China in general and in rice cultivation in particular.

China's geography entails unique problems for farmers in terms of floods, soil erosion, drought, and other problems. No-till farming is a technique that simultaneously addresses several of these problems. Departments of the Chinese government have been working with private sector and farmers to develop efficient no-till farming solutions. One such large-scale and successful project was undertaken at Dongpo District, one of the richer agricultural districts in China. (See Box 5.2.2).

The main advantages found by the project were:

◇ Timely sowing and the quality of the crop improved through proper access of the plantings to soil and nutrients;

◊ Drought endurance through maintenance of natural ground water systems;
◊ Better growing conditions and reduction of sheath blight in rice;
◊ Improvement of the soil structure;
◊ Significant increase in income through savings in labour and water.

A key component to the success of the no-till farming technique is the use of herbicides. Paraquat, with its environmentally-benign properties, speed of effect and rain endurance characteristics, coupled with its non-systemic effects, provides an effective solution.

"Chemical weeding is the key to the success of no-till growth."
Fang Shu-An and Wang Gen-Qi, Senior Agronomists, Agricultural Bureau, Dongpo District

75% of the rice growing areas in this region and 85% of the wheat and rape growing areas follow the no-till technique now. The savings to farmers in the region have been about 500 million RMB.

Other crops
Paraquat has proved highly effective in a variety of crops besides rice.

In Hebie province, corn is seeded in summer and wheat in winter. The corn-sowing season typically coincides with the rainy season. Lack of labour plus the short sowing seasons hinder weed management. A contact herbicide such as paraquat is an effective solution to the problem. In 2000, 1.5 million mu[74] of cornfields in Handan and Xingtai region of Hebei proving achieved an incremental output of 130 kg/mu. Cost savings included five to six labour days for each mu of cornfield. Further, there is no evidence of chemical injury to corn or wheat seeded this way.[75]

Vegetables and flowers are main crops in Hualong Town, Fanyu District of Guangzhou City (in southern China) and have been grown using Gramoxone for nearly 20 years. The herbicide is very popular among farmers, especially those who grow vegetables. Southern China is quite rainy and Gramoxone's rainfast properties combined with its environmentally benign effects has contributed to its widespread use in this region.[76]

Safety issues

The Chinese Ministry of Agriculture recognizes the role of pesticides in controlling pests and weeds. It has carried out pilot programmes relating to increasing safety in handling, usage and storage of pesticides. One such programme was a six-year, three-phase training programme with Zeneca (Syngenta's predecessor in China) with the National Agriculture Technical Extension Service Center (NATESC).

Conclusions

Paraquat and other herbicides have quickly become an important part of farming practices in much of China. Not only do they increase yields, but they reduce input costs, and save time. As a result, farmers such as Fan Huiqing and their families are able to be more productive: more time can be spent earning money from other jobs, enabling them to save, to educate their children, and to enjoy some of life's luxuries.

5.3 COSTA RICA

Costa Rica is a Central American country with a population of 3.8 million and GDP of US $15.9 billion. Costa Rica's per capita GDP rose from just over $1900 in 1960 to around $3900 in 2000.

Agriculture in Costa Rica's economy

About 20% of Costa Rica's workforce is employed in agriculture and roughly half its population (48%) lives in rural areas. Since 1970, the contribution of agriculture to Costa Rica's GDP has declined significantly (from about 30 percent in 1970 to 9 percent in 2001). In absolute terms, its value has tripled from about US $1 billion to US $3 billion during this period. Over the period 1980 to 2001, employment in agriculture decreased from 27.4% to 15.6%.

"Costa Rica is a country whose principle economic activity is agriculture – most people are farmers, and also there are many large export operations – this supports the country ... It is an important source of work, especially banana plantations."

Eduardo Madrigal, Toxic Substances Unit, Costa Rica's Ministry of Health

Costa Rica's commodity exports include coffee, bananas, and sugar cane. Other crops, including ornamentals and tropical fruits, are gaining an increasing share of Costa Rica's agricultural exports.

Banana cultivation

Banana cultivation has been a mainstay of the Costa Rican economy for most of the past three decades. It is the most important cash crop for Costa Rican farmers after coffee.

Costa Rica is the second largest exporter of bananas in the world. In 2001, Costa Rica exported 2.1 million tonnes out of 2.3 million tonnes of the bananas it produced.[77] In 2001, Costa Rica's banana exports were valued at US$509 million.[78] Bananas have contributed between 15% and 28%[79] of Costa Rica's exports through the 1990s, despite industry problems relating to a global oversupply and trade restrictions in its key markets in the EU.

A case study on Costa Rica's banana production was presented at the Food and Agriculture Organisation's "Committee on Commodity Problems", which is part of the Intergovernmental Group on Bananas and Tropical Fruits.

Banana cultivation provides employment for an estimated 100,000 people, or 8% of Costa Rica's workforce, including about 33,000 direct jobs.[80] Over 90% of banana production in Costa Rica takes place in the Caribbean region, on the eastern side of the country.

"Before, agriculture was only subsistence agriculture – for survival. During the past 40 years, agricultural technologies have allowed small farmers to escape this subsistence agriculture, and to produce more efficiently."

Basilio Rodriguez, farmer,
Union Nacional de Pequenos y Medianos Productores Agropecuario (UPA Nacional)

This report estimates that 31,000 banana workers are in the country's eastern/Atlantic region. According to household survey data collected by the Ministries of Labour and Social Security and of Economy, Industry and Commerce, "the share of households below the extreme poverty level, and the share of households not having satisfied their 'basic' necessities in the Atlantic Zone in 1996, were the lowest among all zones but the Central Region and the Pacific Central Zone (which are both more urbanized areas)."[81]

While most labour in banana plantations is "unskilled", the average wage is twice the minimum wage in Costa Rica. With little other economic activity in the banana growing region, this is clearly a key livelihood issue for this region in Costa Rica.

The tropical climate favourable to banana growing also fosters the abundant growth of weeds, so weed management on banana plantations is unavoidable. Non-selective herbicides, such as paraquat, play an important role in ensuring that the crop can be produced economically, and with its full yield potential. Weed control also enhances the quality of the fruit, which is critical for bananas since they are a premium export crop in Costa Rica.

Paraquat's unique properties make it ideal for banana plantations. It is rainfast (which is ideal in wet, tropical climates like Costa Rica's), broad spectrum, and its results are observed within hours of its application.

The use of paraquat on banana plantations can also lead to better water and soil protection, and more sustainable production. Banana plantations contain extensive networks of creeks, streams and drainage canals, and since paraquat is rapidly immobilized in soil, it does not pose a significant risk to aquatic organisms or water quality. Soil erosion adversely affects banana cultivation, and paraquat helps to minimize the risk of erosion by maintaining weed roots intact in the soil.

Small agricultural producers in Costa Rica

Agriculture is also the livelihood of thousands of smallholder farmers in other regions of Costa Rica. These farmers grow crops for internal consumption and also for export, such as melons, beans, and tropical fruits. Many of these small producers grow ornamental plants and cut flowers for export.

There is a strong acceptance within Costa Rica that agricultural technologies (including use of pesticides) has been an important factor in helping small farmers transition from subsistence farming to commercial cultivation.

Basilio Rodriguez, who represents the UPA Nacional, an organization of small- to medium-sized farmers in Costa Rica, identified agricultural subsidies in wealthy countries as one of the primary reasons that Costa Rica's farmers must employ technologies that make them more competitive:

> *Costa Rica's government does not subsidize agriculture, and our farmers cannot compete with subsidized farmers. The government has ignored the need for farmers to acquire new agricultural technologies, which are especially important to improve their quality of life. Physical infrastructure – roads, bridges – is lacking, and education and healthcare in rural areas have also been neglected.*[82]

Costa Rica has been a growing market for pesticides, in general, and herbicides in particular. The banana industry is heavily reliant on fungicides, and it accounts for about 57 percent of pesticide use in Costa Rica. Coffee accounts for about 7 percent, rice for about 6 percent, and non-traditional

Box 5.3.1 **The worries of Costa Rican farmers**[84]

Basilio Rodriguez, a farmer, is with the Union Nacional de Pequenos y Medianos Productores Agropecuarios (UPA Nacional) in Costa Rica. He highlighted the concerns of farming families:

> *Small farmers have difficult lives. Their products don't have stable markets or prices, and they don't have sufficient time to enjoy life or to engage in social activities. They work long hours in the fields to produce more and to reduce their costs." The principle worries of a farmer, according to him, are getting better prices, controlling production costs, and having access to inputs such as herbicides and insecticides and other new technologies. He says the battle against insects and weeds is a key problem for farmers: "Without agricultural chemicals, their lives would be very difficult.85*

Jose Calvo, agronomist and producer for Costa Rica's UPA Nacional, concurs. He says the main problems faced by small farmers are volatile markets, imports, weather, weeds, insects and disease.

and other crops account for about 26 percent of pesticide use. In 1994, the value of pesticide imports to Costa Rica was about US$84 million, of which US$42.5 was fungicides.[83]

Agricultural technology and the environment

Farmers understand that agricultural technologies such as pesticides help to spare land from conversion to agriculture. Farmer Jose Calvo says that the intensive farming prevents land conversion thus preserving bio-diversity. This view is echoed by Primo Luis Chavarria, a weed expert at the University of Costa Rica: "Intensive agriculture means that land and biodiversity can be saved, because you need less land for agricultural production."

The data support this view. Banana production in Costa Rica has increased on average by over 4 percent per year since 1961. Approximately 60 percent of this increase can be attributed to yield increases.[87] At present, Costa Rica has an estimated 45,000 hectares of bananas under cultivation. Without these yield increases, a further 42,000 hectares of land would have been converted to banana cultivation to achieve the same production. Agricultural technologies, including paraquat, have contributed to land conservation, which is important because eco-tourism now contributes significantly to Costa Rica's economy.

"Agrochemicals are indispensable to obtain harvests, otherwise production volumes would be seriously affected. Agrochemicals help small producers to produce healthy and abundant crops."

Jose Guillermo Pacheco, an agronomist, Founder, Asociacion Guatemalteca Pro Defensa del Medio Ambiente [Guatemalan Association for Defense of the Environment][86]

Before the widespread use of herbicides, Costa Rican farmers battled weeds with their bare hands and tools such as machetes. Besides being less effective, manual weeding also resulted in occupational health problems (see box). The effectiveness of herbicides such as paraquat has enabled farmers to move away from these dangerous weeding methods.

H.G. Hernandez, a Costa Rican farmer says, "Today, you spray a complete hectare in one day. Formerly, you couldn't do this job, not even with 4 or 5 men hoeing." Hernandez cultivates corn on his 13 hectares and raises some cattle. For him, products such as paraquat have made a significant impact to his income.

Pesticide poisoning has been cited as a problem in Costa Rica, and paraquat has been singled out as one of the chief culprits by anti-pesticide activists. But people involved in Costa Rican agriculture have a very different perception of the problems involved with agriculture. The spectrum of opinion gathered suggests that much of the poisoning cases have to do with either intentional misuse or careless handling and application practices, and that restrictions on paraquat are not the appropriate solution to these problems.

[Before the introduction of chemical herbicides], "[One] frequently saw agricultural workers with serious injuries, such as hunchbacks, and people with torn muscles or permanent injuries to the hands – and hernia, of course."

Dr. Primo Luis Chavarria, weed expert

Dr. Primo Luis Chavarria, a weed expert in Costa Rica says, "There are problems associated with pesticide use – pollution and occupational health are two concerns – but these problems are the fault of poor usage, poor training, and of small agriculture itself, because people don't necessarily have the knowledge to use chemicals. Some farmers believe that 'if some is good, more must be better' so they use too much of it."[88]

Heriberto Arreaga, a retired Professor of Occupational Health in the

Faculty of Medicine at the Universidad de San Carlos in neighbouring Guatemala, says, “Farmers’ salaries are very low, less than three dollars a day, so farm workers intensify their work to try to earn more money, and as a consequence they suffer more accidents.” This view is echoed by many toxicologists who agree that the overall health of a farm worker and the tendency to work overtime to earn more income increases susceptibility to general health hazards including from pesticides.[89]

Eduardo Madrigal of the Toxic Substances Unit, at Costa Rica’s Ministry of Health, attributes poisonings and accidents to lack of awareness of the risks involved in handling pesticides, and to intentional misuse.[90]

With regard to those who suggest that paraquat should be replaced with alternatives, Basilio Rodriguez comments, “At the moment, there is no other product more useful than paraquat, and for that reason, farmers want to use it. There has been lots of attention in Costa Rica calling for its elimination, but that is a small group of people who are not farmers.”

O. Medrano, a farmer in neighbouring Guatemala and father of seven, uses paraquat under a stewardship programme run jointly with the Ministry of Agriculture. Through proper application, he has raised his crop yield from “1800 kg per unit to over 4,000 kg” and reduced risks to his personal safety and to those who work on his farm.

Paraquat is used widely in Costa Rica (as are other herbicides) because it is a cost-effective way for farmers to manage weeds. In an interview, Eduardo Madrigal suggested that Costa Rica and other Central American countries do not have the same capacity as developed countries to use fourth or fifth generation pesticides. So whilst farmers in developed countries can afford other alternatives, small producers in poor countries like Costa Rica cannot afford them. He recognized that products like paraquat are not harmful when used properly and that regulations don’t necessarily restrict access to a product in the way intended.

The Ministry of Agriculture in Costa Rica is working with corporations such as Syngenta in stewardship programmes that educate farmers on proper application and handling of the product, besides providing overall inputs on management of weeds. In several plantations such practices have been in vogue for some time. J J Arce, a farm worker at Finca Grosiva, says, “We use state-of-the-art equipment with gum boots, trousers, a shirt and an apron over our back, to protect ourselves in case the liquid spills down the back.”

Paraquat clearly benefits thousands of rural smallholder farmers and their families in Costa Rica, as well as thousands of people who are employed on banana plantations – it is contributing directly to improvements in their income from agricultural activities and indirectly to their wellbeing.

6 Paraquat: key concerns

As this paper has demonstrated, paraquat has become a critical tool in weed management throughout the world for the past 40 years. This success has drawn both positive and negative publicity. The latter has typically focused on adverse effects, especially its impact when orally ingested. If drunk in sufficient quantities, paraquat can be lethal. It has also given rise to legitimate concerns regarding accidental and mistaken consumption.

Unfortunately, the lethality of paraquat when ingested has led some individuals and groups to claim that paraquat must inevitably be harmful in many other contexts. For example, it is claimed that paraquat may result in groundwater contamination, human reproductive defects, endocrine disruption, and long-term effects of absorption through skin. But years of scientific investigation contradict these claims.

Paraquat is sprayed on specifically targeted weeds. Where spraying is done with backpack sprayers, the spray drops and leakages from defective backpacks may accidentally touch exposed skin. Where the spraying is done through tractors or other machinery on a large scale, there is a perceived danger of inhalation.

However, the WHO's toxicity studies conclude that: "When the recommended dilution rates were correctly used, systemic effects of oral, inhalation, or dermal exposure to paraquat have not been observed. Skin and eye irritation have occurred only when protective measures were disregarded."[91]

The evidence on paraquat

The 1991 World Health Organisation Health and Safety Guide on paraquat documents its findings the chemical based on eight reviews of the product made between 1970 and 1990.

Groundwater contamination

The WHO found that paraquat is strongly adsorbed to clay particles in the soil and thus will not be absorbed by plants and human beings. It is the same property that prevents paraquat from leaching into groundwater. In fact the study goes on to say that when paraquat is used for aquatic weeds:

> *Paraquat residues disappear rapidly from water by adsorption on aquatic weeds and by strong adsorption on the bottom mud. The toxicity of paraquat for fish is low, and the compound is not cumulative. Normal applications of paraquat for aquatic weed control are not harmful for aquatic organisms.*

It additionally states that

> *Treated water should not be used for overhead irrigation for 10 days following treatment.*

What this implies is that even water that has been deliberately treated with paraquat for aquatic weeds is safe for other uses including overhead irrigation after 10 days.

The US Environmental Protection Agency concluded, after a thorough review of paraquat in 1997 that:

> *Paraquat is not expected or considered to be a groundwater concern from normal paraquat dichloride use patterns.*[92]

Developmental or reproductive toxin?

This concern is with respect to effect on the foetus and on the growth of human beings after ingestion of paraquat.

The WHO (1984) and the US Environmental Protection Agency (1997) have independently conducted and evaluated research for the above effects. Both found no evidence that paraquat is associated with reproductive effects.

The WHO cites a study with rats treated with paraquat at a rate of 100mg/kg diet and found "no significant abnormalities in fertility, fecundity, neonatal morbidity or mortality, nor were there any signs of gonadotoxicity or structural or functional lesions."[93]

The US EPA states that "There is no evidence that paraquat is associated with reproductive effects. In a reproduction study using rats, paraquat had no effect on body weight gain, food consumption or utilization, fertility or length of gestation. Paraquat also shows no evidence of causing mutagenicity."[96]

This finding is supported by the Extension Toxicology Network

Box 6.1 **Acceptable daily Intake of paraquat – WHO studies**[94]
Most synthetic chemical pesticides can be absorbed into plant and animal tissue. Residues are commonly found in food that is consumed by humans. In order to ensure that such food is safe for human consumption, the WHO establishes limits of Acceptable Daily Intake (ADI) and Maximum Residue Limits (MRL). At these levels, which are pegged at a fraction of the concentrations likely to have health impacts, normal consumption of these foods over a lifetime of an individual will result in no adverse health effects.

Paraquat was evaluated for acceptable daily intake in 1970, 1972, 1976, 1982, and 1985. Unlike most pesticides, paraquat is non-systemic and does not bioaccumulate. If a minute quantity were to be ingested, it would be excreted by the human body and would not accumulate in tissue. The WHO has established an MRL for paraquat of 0.01 mg/kg – which is at the limits of detection as residues are not normally found.[95]

(Extoxnet), a science- and precaution-oriented collaboration between various US universities. Its Pesticide Information Profile states, "The weight of evidence suggests that paraquat does not cause birth defects at doses which might reasonably be encountered."[97]

Injection or ingestion of high doses of paraquat in pregnant mice killed the mothers, and foetuses weighed slightly less than normal. The WHO concludes that this "minimal embryotoxic effect" is because paraquat does not easily cross the placenta, reflected in low paraquat concentrations foetal tissue relative to the maternal tissue.

The weight of scientific evidence from two international authorities on health regulation unambiguously indicates that paraquat is not a significant developmental or reproductive toxin at likely levels of exposure.

Endocrine disruptor?

An "endocrine disruptor" is a substance that interferes with the endocrine system, which produces the hormones that affect growth and development in the human body.[98]

The toxicology studies referred to in the earlier section on reproductive systems form part of a larger study into the impact of paraquat on the human body (and indeed those of other animals).

There is no evidence to suggest that paraquat is an endocrine disrupter. Moreover, scientific studies suggest that paraquat, as it is normally likely to be encountered in the environment, soil and/or the food chain is likely to be excreted by the human body. The WHO confirms that the nature of paraquat does not allow it to stay for long in the human body and it is generally excreted. Paraquat does not bio-accumulate and is generally not found in food. Even deliberately ingested paraquat is for the most part excreted by the human body. Its adverse effects at high doses are mostly on the lungs, as lung tissue has a propensity for longer retention.

There are problems associated with pesticide use. Pollution and occupational health are two concerns. But these are the fault of poor use, poor training, and small agriculture, because people don't necessarily have the knowledge to use chemicals. Some farmers believe that "if some is good, more must be better" so they use too much of it.

"Farmers need to understand how to use the product in the correct way – that is, how to eliminate problems with use (not eliminating the product itself). They need to work in conjunction and in cooperation with companies."

Primo Luis Chavarria, Weed expert, University of Costa Rica[99]

None of the scientific reviews conducted on the product thus far, including those on occupational exposure, show any evidence of paraquat being an endocrine disruptor.

Accidental and occupational exposure

Paraquat is sprayed on specifically targeted weeds. Where spraying is done with backpack sprayers, the spray drops and leakages from defective backpacks may accidentally touch exposed skin. Where the spraying is done through tractors or other machinery on a large scale, there is a perceived danger of inhalation.

However, the WHO's toxicity studies conclude that: "When the recommended dilution rates were correctly used, systemic effects of oral, inhalation, or dermal exposure to paraquat have not been observed. Skin and eye irritation have occurred only when protective measures were disregarded."[100] The same study also notes that between 1956 and 1973, no paraquat related fatalities occurred in the USA.

Through air

Paraquat formulations evaporate at a very low rate, so evaporation is not a relevant risk. Meanwhile, the droplet size when sprayed is too large to be inhaled. The WHO found that:

> *The amount of paraquat present in airborne dust was found to range from 0.0004 to 0.001 mg/m^3. The paraquat was so strongly bound to the dust particles that it did not exert any toxicological effect on rats that were exposed via inhalation.*

While paraquat ingested in the human body primarily attacks lung tissues, the danger of inhalation has in practice proved rare. The paraquat re-registration document from the EPA states with regard to inhalation toxicity:

> *In acute toxicity studies using laboratory animals, paraquat has been shown to be highly toxic by the inhalation route and has been placed in Toxicity Category I (the highest of four levels) for acute inhalation effects.*

However,

> *The Agency has determined that particles used in agricultural practices (400 to 800_m) are well beyond the respirable range and therefore inhalation toxicity is not a toxicological endpoint of concern.*[101]

There has been some concern that smoking marijuana contaminated with paraquat would have toxic effects. However, according to the US National Pesticide Information Center, "Most paraquat that contaminates marijuana is pyrolyzed during smoking to dipyridyl, which is a product of combustion of the leaf material itself (including marijuana) and presents little toxic hazard."[102] Indeed, by comparison with the toxic hazard of the marijuana and tobacco, the effect of paraquat is irrelevant. Worse, by focusing on the supposed effects of paraquat, people may be discouraged from paying sufficient attention to the dangers of smoking. It may even encourage the belief that tobacco produced without paraquat (and other synthetic pesticides) is somehow 'safe' or at least safer.

Through the skin

Paraquat's absorption rate through intact skin is very small – in fact, it is lower than that of water. Normal precautions and personal hygiene, wearing protective clothing and washing up after spraying, prevents any adverse effects from normal paraquat spraying.

If damaged skin is exposed to paraquat over long periods problems can result, such as irritation and rashes, but these quickly clear up when the exposure to paraquat ends. Following very simple safety procedures is sufficient to avoid such problems.

Through oral ingestion

Although difficult to determine precisely, the LD50 of paraquat in an adult human is approximately 3–5g. This means that ingestion by an adult of 10–15mls of the 20% formulation can be fatal.[103] This equates to 50–83mg/kg paraquat ion if one assumes a 60 kg human.

Syngenta's branded paraquat product, Gramoxone, is sold with a stenching agent, a dye and an emetic. These were added in order to discourage accidental ingestion and the practice is in line with FAO/WHO guidelines for such a product. The alerting agent gives the formulation a foul smell (a marketing negative in some markets); the dye distinguishes the product from other substances; and the emetic induces vomiting if consumed. Accidental ingestion of Gramoxone is therefore extremely unlikely. If a very small amount is accidentally ingested, most of it will be discharged through the kidneys.

Most accidental ingestion of paraquat is of generic copies that do not have a stench, emetic or dye added. Meanwhile, most consumption incidents with pesticides are intentional.

Suicides

The World Health Organisation estimates that about 1 million people die of suicides every year and between 20 and 40 times that number attempt suicide. It is the third leading cause of death in the 15–44 age group, for both sexes.[104]

90% of suicide cases relate to mental disorders including substance abuse. Countries of the East Asia and Russia are mapped by the WHO as high suicide rate zones (more than 13 per 100,000). Suicide rates have increased by more than 60% in the last 45 years.

In poor countries such as India and Pakistan, pesticides are a popular tool for suicide. In Pakistan, for example, out of 2,590 suicides in 2002, 306 were through consumption of pesticides, 490 were through intentional over-consumption of medicines, and 690 by consumption of other chemicals.[105]

Table 7.1 illustrates some of the primary causes of deaths in Thailand in 2000. "Suicide by liquid substance" was the cause of 338 deaths, but five highly preventable pathogenic diseases caused 1886 deaths, and other diseases, including meningitis and rabies led to at least 174 additional deaths.

The Ramathibodi Poison Centre in Bangkok serves the general public and health personnel all over Thailand. The Centre shows that in the period 2000–2001, intentional poisonings accounted for 63.3% of their poisoning cases, and of these, 98.4% were attempted suicides. 29.2% were unintentional, and of these 81.5% were accidental exposures.[106]

Suicide is tragic and regrettable. However, it must be seen as a social issue.

Table 7.1 **Comparison of causes of deaths in Thailand, 2000**

Cause	*Cases*	*Deaths*	*Mortality rate per 100,000*
Acute diarrhoea	954,109	193	0.32
Pyrexia (fever) of unknown origin	210,957	64	0.10
Pneumonia	140,459	1222	1.98
Malaria	51,848	102	0.17
Tuberculosis	32,012	305	0.49
Leptospirosis (disease obtained by exposure to animal urine, especially in tropical climates)	14,285	362	0.59
Suicide by liquid substance	6,288	338	0.55
Meningitis – total	3598	60	0.08
Rabies	50	50	0.07

There is no evidence that eliminating or greatly restricting pesticides would reduce suicide rates. Far more effective is the provision of social support networks to aid people who suffer from problems that drive them to suicide. The Samaritans and the Befrienders are examples of organisations which perform these functions.

Understanding and awareness in society are also critical to preventing these tragedies. According to a review of how the mass media treats suicide, Professor Keith Hawton and Kathryn Williams of the Centre for Suicide Research, Department of Psychiatry, Oxford University, most suicides are the result of psychiatric illness, but this is consistently under-reported by news media in many countries.[107] Moreover, the media often glamorize suicide or simply misrepresent it, and this does not help to prevent suicides.

Paraquat safety

According to Syngenta, safe handling and use of paraquat may be ensured by following five simple rules (these are promoted by Syngenta as the '5 golden rules'):

1. Be aware of risks.
2. Understand safety precautions – avoid exposure, avoid contact with skin and eyes, secure containers.
3. Personal hygiene – wash and change clothes at the end of spraying.
4. Knapsack sprayer maintenance.
5. Appropriate personal protective equipment – simple protection, provided by normal work clothes and boots, is sufficient.

"90 percent of labour-related pesticide poisonings have been eliminated in the past ten years … as a result of educational and training efforts. [These efforts were made] in conjunction with the Secretary of State for Agriculture, through the Department of Crop Protection and its Pesticides Registry Division, and with the participation of the pesticides manufacturers and importers in the Dominican Republic"

Executive Director of the National Commission on Pesticides, Dominican Republic

Training programs to reduce occupational poisonings

Because eliminating pesticide use is unrealistic, undesirable, and probably infeasible, training programs are perhaps the most important way to ensure safe handling and sustainable use of pesticides.

The pesticide industry has initiated training programmes in partnership with governments in several countries, to educate users on the appropriate and safe usage of pesticides. In some cases, these programmes are initiated by government and in many others by industry. Syngenta has initiated and participated actively in several such programmes in countries such as Costa Rica, China, and Mexico. Its LUPPA programme in Mexico, which began in 1987, trains small farmers in application and use. In China, Syngenta has partnered with the National Poison Center to train doctors. Meanwhile, Syngenta has received awards for the farmer training programmes that it carries out in collaboration with the Chinese Ministry of Agriculture.

These training programmes exist in various forms, focusing on small farmers, medical technicians and doctors, retailers of pesticides, and school children. The objective is to impart knowledge about appropriate use and safe storage of pesticides, as well as the importance of reading labels properly, disposing of bottles safely, using protective clothing, and maintaining equipment.

In the Dominican Republic, training programs have been enormously successful in reducing the number of occupational accidents resulting from poor use and management. Over a ten-year period, the number of occupational poisonings was reduced by 90 percent (see box).

In summary

The concerns about paraquat's impact on groundwater contamination, developmental or reproductive toxicity and as an endocrine disruptor do not have any scientific basis, as has been re-affirmed by numerous scientific studies, as well as by the WHO and the US EPA.

In terms of occupational and accidental exposure, the main risks relate to improper use of paraquat. Accidental ingestion does not appear to be a factor where a stenching agent, dye and emetic form part of the product. Deliberate ingestion, for the purposes of suicide, forms part of a separate discussion in terms of regulatory implications.

Training programs are a necessary part of pesticide use, and have shown to be enormously successful where they are offered. Regulators should be encouraged to work in partnership with companies and other stakeholders to ensure proper management and use of pesticides.

Given the lack of scientific evidence to support many of the claims made by opponents of paraquat, one wonders what motivates their concerns. Some insight is gleaned from the following statement on the PAN Asia-Pacific website: "The immediate development problem that PAN AP faces is the insurmountable dangers posed by pesticide use. The immediate and most logical solution is to stop its usage."[108] In other words, all pesticide use is assumed to pose 'insurmountable dangers'. It is unclear whether PAN would include biological pesticides, such as *bacillus Thuringiensis*, or indeed the many inorganic pesticides that are used by 'organic' farmers. It is also unclear whether PAN would include pesticides that are produced naturally by plants, many of which are highly toxic if ingested. Glycoalkaloids in potatoes, for example, can be deadly if the potato is not cooked.

The only serious danger posed by paraquat is that it will be drunk, either intentionally or mistakenly. But the same applies to bleach, ammonia, and many other common household items. Children are taught not to consume these dangerous products, and safety precautions (such as safety caps, or in the case of paraquat, an emetic, a dye, and a stench) must be taken to ensure that such products are not mistaken for food and drink. Farmers are aware of these dangers, and through education, training, and awareness, they can understand how to responsibly manage harmful substances.

Most mistaken ingestion of paraquat is of generic copies that do not have a stenching agent, emetic or dye added. There are virtually no reports of mistaken ingestion causing injury. Meanwhile, most ingestion is the result of intentional consumption. Most pesticide incidents are intentional self harm.

With awareness of the risk of pesticides now high, drinking of pesticides in mistake for a beverage has been virtually eliminated. This is especially the case for Gramoxone, where its smell and dye distinguish it as a non-consumable item.

It is utterly defeatist merely to presume that all pesticides pose insurmountable dangers, and then to conclude that they must all be banned. The important thing is to ensure, as far as possible, that the manufacture, distribution and use of pesticides occur in a way that provides net benefits to all concerned. The following section is written with this more reasonable approach in mind.

7 Implications for regulations

The massive improvements in agricultural technologies that have occurred in the past half-century have provided benefits to nearly everyone. The increased yields have led to dramatic increases in the availability of food per capita in spite of rapid increases in the number of people.

Improved technologies, such as fertilizers and pesticides, have enabled millions of smallholders to shift from subsistence farming to commercial agriculture. The Costa Rica case study provides a specific example. For the nearly 3 billion people on the planet who remain in the farming sector, such technological enhancements offer real hope of improved lives.

"Before, agriculture was only subsistence agriculture – for survival. During the past 40 years, agricultural technologies have allowed small farmers to escape this subsistence agriculture, and to produce more efficiently."

Basilio Rodriguez, Farmer, Union Nacional de Pequenos y Medianos Productores Agropecuario (UPA Nacional)

As trade becomes globalised and barriers to agricultural markets are reduced, farmers in poor countries will be able to benefit from the increased size of the market for their products. But with increased market size comes increased competition between farmers in different countries, which means that national regulations affecting agricultural technologies will have greater impacts on local farmers. It therefore becomes even more important to weigh the pros and cons of imposing regulations on such technologies.

General considerations

Herbicides such as paraquat have played a key role in improving agricultural efficiency. This is true of both rich and poor countries.[109] Improvements in productivity have meant that food has become more plentiful and cheaper for almost everyone, almost everywhere. They have also improved the lives of farmers, by increasing their incomes.

Herbicides such as paraquat and other modern agricultural technologies have also had a beneficial effect on biodiversity, through reduced pressure to convert wild land for agriculture. In spite of the widespread use of pesticides, pests still cause losses of up to one third of the world's food crop. In the absence of pesticides, however, these losses would be even higher and people would have to resort to extensive agriculture to make up for lost yields, with attendant losses of wild land.

The scientific evidence on paraquat clearly establishes the lack of any negative environmental implications as a result of long-term use, either on soil, on ground water, or the air. Nor is there any evidence of harms resulting from its presence in the food chain. Periodic assessments by credible agencies such as the WHO and EPA have reaffirmed this. Many of the studies cited in this report, spanning nearly three decades of paraquat use and assessment, show no evidence of negative environmental impacts.

Modern synthetic chemical herbicides such as paraquat comprise a significant technological advance in weed management over earlier technologies, such as mechanical weeding, manual weeding and arsenic-based herbicides. Mechanical and manual weeding are not only more time consuming but also more expensive. The use of hand-held implements and tedious work (usually done by women in poorer countries) causes injuries and other occupational health problems. In regions with short sowing seasons, manual weeding is simply ineffective.

The battle against weeds is constantly evolving, as weeds develop resistance to certain chemicals. However, in spite of more than 40 years continuous use, paraquat formulations are still known to be effective against weeds and have become part of integrated pest management practices.

Herbicides such as paraquat contribute to the lives of farming communities not just through cost efficiencies but by releasing people from the drudgery of manual weeding, freeing up time to do other, more economically rewarding activities (as we have heard from Chinese farmer Fan Huiging), as well as for more socially beneficial activities, such as greater participation in their communities and in political processes.

A risk-risk analysis

When evaluating the pros and cons of a specific technology it is valuable to compare the risks which that technology poses with the risks posed by other common technologies. The purpose of such an evaluation is to tell regulators and others involved in public policy decision-making whether or not it is worthwhile attempting to reduce any particular risk. If, for example, the risk is tiny relative to other risks, then the regulator knows that until those other, larger risks have been reduced, the risk in question should probably be left well alone. Such an evaluation is formally called 'risk-risk analysis' and is a well-established technique in regulatory circles.[110]

Risk-risk evaluations are a useful alternative to risk-benefit evaluations. In a risk-benefit analysis, the objective is to ensure that public resources are spent efficiently; that means not spending an excessive amount to eliminate any specific risk (to ensure that the benefits, in terms for example of the 'value' of lives saved, always exceed the costs). In an ideal world, risk-benefit calculations would enable us to perfectly identify the optimum amount of money to spend reducing each risk.

However, in the real world, it is often very difficult to calculate the cost of any risk-reduction expenditure. In such cases, risk-risk analysis offers a useful alternative. In the present case, for example, the costs of regulating paraquat would include (but are not limited to): the increased cost to the manufacturer of complying with the regulation; the increased cost to the farmer of more expensive product; any unintentional downstream increases (or decreases) in cost to the farmer associated with altered product attributes; the increase in cost to food processors who purchase the more expensive goods produced using the more expensive regulated product, and so on.

An interesting risk-risk evaluation was carried out by cancer experts Professors Lois Gold and Bruce Ames, who developed an index called HERP (for Human Exposure Rodent Potency) for ranking possible carcinogenic hazards from known rodent carcinogens. This appears as Table 7.1 below.

Table 7.1 enables one to calculate the relative risk posed by certain common hazards and provides a potentially useful guide to policymakers. It is clear that the risk posed by ethylene dibromide prior to 1977 was very high and certainly worthy of regulatory control. By comparison, some of the other chemical hazards to which we are daily exposed may not be worthy of such concern. One striking observation from this table is that many natural products pose a greater carcinogenic risk than some of the synthetic chemicals about which certain interest groups have generated so much concern. Even the likely daily doses of DDT, dioxin (TCDD), and PCBs, three of the so-called 'dirty dozen' chemicals that are the subject of the Stockholm Convention on Persistent Organic Pollutants, are far less hazardous in the doses to

Table 7.1 **Ranking possible carcinogenic hazards from natural and synthetic chemicals**[111]

Relative hazard (HERP)	*Average daily US exposure*	*Human dose of rodent carcinogen*
140	EDB: workers (high exposure) (before 1977)	Ethylene dibromide, 150 mg
14	Phenobarbital, 1 sleeping pill	Phenobarbital, 60 mg
6.8	1,3-Butadiene: rubber workers (1978–86)	1,3-Butadiene, 66.0 mg
2.1	Beer, 257 g	Ethyl alcohol, 13.1 ml
0.5	Wine, 28.0 g	Ethyl alcohol, 3.36 ml
0.1	Coffee, 13.3 g	Caffeic acid, 23.9 mg
0.04	Lettuce, 14.9 g	Caffeic acid, 7.90 mg
0.03	Orange juice, 138 g	*d*-Limonene, 4.28 mg
0.02	Apple, 32.0 g	Caffeic acid, 3.40 mg
0.008	Aflatoxin: daily US avg (1984–89)	Aflatoxin, 18 ng
0.007	Cinnamon, 21.9 mg	Coumarin, 65.0 mg
0.005	Saccharin: daily US avg (1977)	Saccharin, 7 mg
0.005	Carrot, 12.1 g	Aniline, 624 mg
0.004	Potato, 54.9 g	Caffeic acid, 867 mg
0.003	Nutmeg, 27.4 mg	*d*-Limonene, 466 mg
0.003	Home air (14 hour/day)	Benzene, 155 mg
0.002	Carrot, 12.1 g	Caffeic acid, 374 mg
0.002	DDT: daily US avg (before 1972)	DDT, 13.8 mg
0.001	Plum, 2.00 g	Caffeic acid, 276 mg
0.0007	Dioxin: daily US avg (1994)	TCDD, 12.0 pg
0.0007	Bacon, 11.5 g	Diethylnitrosamine, 11.5 ng
0.0004	Tap water, 1 litre (1987–92)	Bromodichloromethane, 13 mg
0.00008	PCBs: daily US avg (1984–86)	PCBs, 98 ng
0.00008	DDE/DDT: daily US avg (1990)	DDE, 659 ng
0.000001	Lindane: daily US avg (1990)	Lindane, 32 ng
0.0000004	PCNB: daily US avg (1990)	PCNB (Quintozene), 19.2 ng
0.0000001	Chlorobenzilate: daily US avg (1989)	Chlorobenzilate, 6.4 ng
<0.00000001	Chlorothalonil: daily US avg (1990)	Chlorothalonil, <6.4 ng
0.000000008	Folpet: daily US avg (1990)	Folpet, 12.8 ng
0.000000006	Captan: daily US avg (1990)	Captan, 11.5 ng

a "." = no data in CPDB; (—) = negative in cancer test; (+) = positive cancer test(s) not suitable for calculating a TD_{50}.
b This is not an average, but a reasonably large sample (1027 workers).
c TD_{50} harmonic mean was estimated for the base chemical from the hydrochloride salt.
d Additional data from EPA that is not in the CPDB were used to calculate these TD_{50} harmonic means.

which we are likely to be exposed than are wine, beer, lettuce, apples and mushrooms.

How dangerous is paraquat compared with other things?
Applying this analysis, albeit informally, to paraquat, we can compare the risks this herbicide poses with risks posed by other everyday activities. About 850,000 people die every year in automobile accidents, about 60,000 of these in India.[112] Even more lethal than automobile emissions in India, is domestic cooking fuel. Most Indian homes still depend on cow-dung cakes and firewood to cook at home and a recent study suggested that fumes from this fuel accounts for 2.5 million premature deaths.[113] By comparison, paraquat results in no occupational deaths and very few unintentional deaths. Regulators who are seeking to prioritize the reduction in number of unintentional deaths, regulating the use of automobiles and cooking fuel would probably be a top priority, but paraquat would probably rank close to the bottom.

However, few people seriously advocate bans on automobiles or cooking fuel, whereas there have been vocal demands and campaigns for the elimination of paraquat and other pesticides. The reason is simple: these items are of direct benefit to hundreds of millions of people. The problem is that paraquat's benefits are opaque to most people. Only the few million users of the product, dispersed around the globe, know how important it is to them. This enables groups that oppose modern technologies such as paraquat to attack it virtually with impunity.

The dangers of restricting paraquat use

In the absence of environmental or food safety effects resulting from use of paraquat, proponents of restrictions on paraquat have focused on two main issues:

◇ Inappropriate use practices
◇ Deliberate ingestion for suicides

Even so, in terms of health costs and real risks to human life, paraquat is certainly less dangerous than automobiles or domestic cooking fuel in India. Moreover, millions of farmers *choose* paraquat over alternatives because it is the most cost-effective solution for their particular circumstances and increases their often-meagre incomes. In tropical countries with frequent rain, paraquat provides a unique dual benefit: it is effective even during wet weather and it helps prevent soil erosion. Meanwhile, farmers are generally aware of the acute toxicity of paraquat and take precautions to avoid drinking it. They believe that its benefits far outweigh the small risks to personal health and safety. Farmers such as Jose Calvo (see text box) are indignant that they are considered stupid and incapable of making choices simply because they live in poor countries.

"I find it offensive that, because of where I live, these people treat me like I do not have the intelligence to understand and make knowledgeable decisions on my own."

José Calvo, Costa Rican Farmer

Restrictions on paraquat use would impact the incomes and lifestyles of over 25 million farm-dependent families around the world.[114] Estimates suggest that these restrictions would increase input costs by 3 to 5% and reduce yields significantly, especially in areas that have high rainfall and/or are prone to soil erosion. Input costs would rise because more expensive alternatives would be used. Because most of these alternatives do not have paraquat's rapid, rainfast action, they are less effective. It is likely that farmers would thus use more of alternative products, with attendant increases in risks of exposure. Most alternatives are also less environmentally benign and few help to fight soil erosion in the way that paraquat does. Ultimately, these restrictions would achieve the opposite result that their proponents desire in terms of health and environment costs.

Some countries, including Denmark, have considered banning all pesticides, and converting to completely organic farming. The Bichel Committee concluded that the costs of an outright ban would be around €336 million. Field trials carried out by LandBoCentrum, a consultancy in Denmark, indicated that the economic costs of a complete ban would actually be about twice this figure – approaching €700 million. Moreover, these trials showed that a ban on pesticides would probably cause other undesirable environmental consequences, such as more energy use and greater nitrogen releases.[115]

Despite the enormous impact that eliminating pesticides would have at home, Denmark's Agency for International Development insists that pesticides should be replaced with alternatives, and it is spending huge amounts of Danish taxpayers' money to promote bans and restrictions on pesticides in poor countries.[116]

Regulators in poor countries have been pressured to greatly restrict or ban paraquat because its use was banned in European countries such as Denmark.

However, Eduardo Madrigal of the Toxic Substances Unit at the Costa Rica's Ministry of Health, observes:

> *Costa Rica and Central America do not have the same capacity as developed countries to use fourth or fifth generation pesticides. Farmers in developed countries can afford other alternatives, but small producers in poor countries like Costa Rica cannot afford them. Paraquat is widely used, but people don't have a correct perception of the risks associated with it. It is often used for things for which it was not intended. However, I do not believe that it should be banned, because it's okay when it's used correctly. Rules (like a ban) do not guarantee that access to a product is restricted."*

Restrictions on paraquat use would cause harm to many and disaster to some. The evidence regarding paraquat's impact on the environment and human health shows that it is less hazardous than many alternatives – including the alternative of using no pesticides at all. The benefits of paraquat products are obvious to its users, farmers, who should be free to continue to choose technologies and practices appropriate to their circumstances.

Appropriate regulation

Whilst eliminating paraquat is clearly an inappropriate response to the dangers posed by paraquat if used incorrectly, regulation based on sound science is desirable. In particular, the following would seem to be appropriate:

- ◇ Inclusion of a dye, alerting agent (the stench) and emetic in all formulations;
- ◇ Clear communication regarding appropriate handling, storage and use of the product, including guidelines on personal hygiene;
- ◇ Direct training programmes for users of the product.

These are not dissimilar to safety guidelines and precautions relating to any product that could be dangerous if used inappropriately. FAO Guidelines developed over the past two decades cover these aspects (see Box 7.2).

Syngenta, the world's largest producer of paraquat, states in its code of conduct, as well as in its health, safety and environment policy, that it adheres to these guidelines and higher safety standards. Its policy is to adopt such standards even in countries that may not have established regulations mandating high standards, and it welcomes regulations derived from sound

Box 7.2 **FAO guidelines on management of pesticides**

The FAO in conjunction with WHO and several other UN organizations has developed codes of "good practices" relating to the marketing, distribution, storage and safety of application of pesticides.

The codes are guidelines to assist national regulators in developing policies, laws and rules to deal with pesticides in their respective countries.

Such guidelines include:

- ◇ Good labelling practices – to communicate toxicity and hazard information, safety precautions to be observed in storage, formulation and use, safe disposal of empty containers and personal hygiene and safety measures.
- ◇ Packaging and Storage – to minimize risks to health and environment during storage and transportation between distribution points.
- ◇ Distribution of pesticides
- ◇ Application and use of pesticides – including training programmes for users

The FAO Codes also lay down guidelines for national regulation, where such regulatory structures are still evolving.

science. Syngenta is an active participant in stewardship programmes in several countries, the aim of which is to educate users and thereby promote sustainable, safe application and use amongst farmers and applicators of their crop protection products. In one intensive vegetable-growing area in China, farmers have reduced their pesticide use by 50% through the adoption of Syngenta's stewardship program.

Not all manufacturers of paraquat have followed Syngenta's example. In order to encourage better practices by these companies, it may be desirable to specify regulations that require certain steps to be taken by all manufacturers and retailers of paraquat. These regulations, like all pesticide regulations, should be based on sound science.

The mandatory inclusion of a dye, stenching agent, and emetic seems desirable. It would also seem desirable to require that the chemical be sold in appropriately labelled containers. These labels would contain, at a minimum, the name of the chemical and a clear visual symbol indicating that the contents should not be drunk. (The FAO guidelines on labelling are more comprehensive.)

Conclusion

For the majority of applications, there are currently no cost-effective alternatives to paraquat. In tropical countries with frequent rains, paraquat provides a unique dual benefit. It is effective in the rain and it helps prevent soil erosion. Restrictions on paraquat use could result in farmers using alternatives that are more toxic and less environmentally benign. A ban would thus be contrary to the objective of improving the environment and human health.

The proponents of a ban on paraquat are attempting to impose their unscientific, anti-technology views on others. They should not be permitted to do so. The losers would be poor farmers and their families, for whom paraquat has been a boon, enabling millions of people to escape the penury of subsistence agriculture and all of them to live better lives. To address genuine concerns about the health effects of paraquat, it would be appropriate to mandate the inclusion of a dye, alerting agent and emetic at relevant concentrations to all formulations, as well as mandatory labelling.

"At the moment, there is no other product more useful than paraquat, and for that reason, farmers want to use it. There has been lots of attention in Costa Rica calling for its elimination, but that is a small group of people who are not farmers. Farmers should utilize the best available technology. They want to produce. They want to compete – and they can't compete with subsidized farmers in other countries. "

Basilio Rodriguez, UPA Nacional, Costa Rica

Paraquat has benefited hundreds of millions of farmers in more than 120 countries during the past four decades. It has contributed to huge improvements in these farmers' lives by enabling them to generate income from crops, thus reducing their drudgery and providing better prospects for them and their children. Paraquat continues to be the herbicide of choice for over 25 million farmers in rich and poor countries. This report shows that the farmers' ability to continue to make that choice must be defended.

Paraquat has from time to time been subject to criticism from a small number of activists seeking to outlaw its use, without scientific or economic justification. To these critics we would simply assert that the unsubstantiated fears of a vocal minority must not become a justification for undermining the right of the silent majority of farmers to choose technologies appropriate to their circumstances.

Notes

1 R.S.L. Jeater. "Land of Hope and Hunger", agricultural scientist with ICI Crop Protection Division at http//www.uwe.ac.uk/fas/wavelength/wave16/jeater.html; and personal communication with Roger Jeater, March 2003.
2 Roger Jeater, personal communication, March 2003.
3 FAO Statistical Database
4 Phillips McDougall "AgriService – Countries Section 2001 Market", December 2002
5 The value of agricultural output grew at an average rate of about 1.9% per annum between 1972 and 2000, while the quantity of food produced grew by 2.4% per annum over the same period. The lower growth in the value of agricultural output compared with growth in quantity of food during this period indicates that prices were falling.
6 De Gregori, Thomas R. *Agriculture and Modern Technology*, citing Goklany, Indur M. "Meeting global food needs: The environmental trade-offs between increasing land conversion and land productivity". *Technology: Journal of Science Serving Legislative, Regulatory and Judicial Systems* 6(2–3): 107–30.
7 http://www.fao.org/sd/WPdirect/WPre0108.htm
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13 "Guidelines for the Registration and Control of Pesticides", FAO, Rome March 1985, Introduction, p1.
14 Presentation by Sathorn Sirisingh, Senior Expert in Plant Pests,

Department of Agriculture, Bangkok, Thailand, "Integrated Pest Management (IPM) and Green Farming in Rural Poverty Alleviation in Thailand".

15 *Crop Production and Crop Protectio*n: Estimated Losses in Major Food and Cash Crops, by E-C Oerke, H-W Dehne, F Schönbeck and A Weber, (Elsevier 1994), p. 748, hereinafter *Crop Production and Crop Protection*.

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18 See e.g. http://www.science.org.au/nova/041/041box01.htm

19 In chemistry, an 'organic' chemical is one that is based on carbon and is assumed to have derived from a living organism. By contrast an 'inorganic' chemical is one that does not derive from living organisms.

20 See e.g. "Soil Fertility and Biodiversity in Organic Farming," Paul Maeder, Andreas Fliessbach, David Dubois, Lucie Gunst, Padruot Fried, and Urs Niggli, *Science* 2002 May 31; 296: 1694–1697.

21 See for example the recommendations of the Scottish Agricultural College: http://www.sac.ac.uk/management/External/diversification/Novcrop/organiccrop.asp

22 A recent report by the House of Lords Select Committee concluded, "In the view of the British Nutrition Foundation 'the nutritional value of organic crops is likely to be the same as that of conventionally grown crops.'" Organic farming and the European Union", 16th Report, House of Lords Select Committee, 20 July 1999, http://www.parliament.the-stationery-office.co.uk/pa/ld199899/ldselect/ldeucom/93/9304.htm#a17. A recent Scottish Crop Research Institute report on organic food noted, "This attitude is, presumably, based on the perception that hazards in foods derive from agrochemical additives, whereas microbes, not chemicals, are the major source of food borne illnesses." The report quotes the Select Committee, saying, "The Committee found no evidence for or against the safety of organic products. Conventional and organic are equally safe." D.K.L. MacKerron, et al. "Organic Farming: science and belief", Scottish Crop Research Institute, 1999, http://www.scri.sari.ac.uk/Document/AnnReps/99Indiv/06OrgFar.pdf

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input use." E-C. Oerke, H-W.Dehne, F. Schonbeck A. Weber, *Crop Production and Crop Protection*, page 765.

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25 Personal communication.

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27 *Ibid*.

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37 *Crop Production and Crop Protection*, page 42.

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41 E-C. Oerke, H-W.Dehne, F. Schonbeck A. Weber, *Crop Production and Crop Protection*, 1994, Elsevier Science, Amsterdam, page 750.

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