Pesticide reduction in agriculture - What action is needed?

Briefing paper

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- FAO (2011). *Save and Grow. A policy maker's guide to the sustainable intensification of smallholder crop production.* Rome: FAO.
- IAASTD (2009). *International assessment of agricultural knowledge, science and technology for development: global report.* Washington DC: Island Press.
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Contents

Executive Summary

Pesticides have a sensitive role in food systems: they are applied in order to protect crops, but they can have negative impacts on environment and human health. While global pesticide use has grown to 3.5 billion kg active ingredients per year, a significant portion of the chemicals applied has proved to be excessive, uneconomic or unnecessary both in industrialized and developing countries. For society as a whole it would be desirable that pesticides were only used when inevitable and with the least level of side effects.

Acute pesticide poisoning is a serious problem in developing countries, where many farmers use highly hazardous products, often without adequate protective measures. The widest exposure to pesticides, however, is through residues in food. Various studies found that pesticide exposure is a significant additional risk factor in many chronic diseases such as several types of cancer, Parkinson's disease and Alzheimer's disease. There is circumstantial evidence that exposure to pesticides is associated with disruption in the immune system and hormone imbalances which may increase the risk for obesity, diabetes, autoimmune diseases, reproductive problems and food allergies. Unborn and young children are in particular vulnerable to pesticide exposure. Pesticides are found in the cord blood of new born babies and in the urine of children. Numerous studies reported for children exposed to high levels of pesticides a delay in their cognitive development, behavioural effects and birth defects. Other studies indicate that even pesticide exposure from diet can be associated with poorer intellectual development or attention deficit/hyperactivity disorder (ADHD).

Pesticides are now found in every habitat on earth and are routinely detected in both marine and terrestrial animals. Pesticides in freshwater supplies have become a serious and increasingly costly concern, with detected levels often exceeding the set limits. There is substantial published literature on the effects of pesticides on wildlife and biodiversity. Studies have shown that systemic insecticides can trigger the collapse of bee colonies. Widespread pesticide application impacts on beneficial insects, spiders and birds, thus aggravating subsequent incidence of pest outbreak. Another growing concern is that pests and weeds increasingly develop resistance to pesticides.

While pesticide use may reduce crop loss and the costs of production, they also cause costs to society in terms of health and environmental costs. When health and environmental costs are factored in, pesticide application is only economical at a much lower threshold than what is commonly practiced. Moreover, evidence from introducing Integrated Pest Management (IPM) suggests that pesticides can be reduced through better management practices without substantially reducing yields or increasing costs. Ideally, agricultural systems should be designed in a way that pests, diseases and weeds do not build up to a level that they cause significant damage to the crop. Suitable agronomic practices like crop rotation and the use of resistant varieties are key preventive measures to manage pests, weeds and diseases. Agroecology and organic farming methods offer further options to substantially reduce the use of pesticides, but they require profound changes in farming system design.

Pesticide use is highly regulated by national legislation and international conventions and policies. Today it is widely accepted that a group of highly hazardous pesticides shall be phased out. Governments have a range of policy instruments to find a responsible balance between enabling judicious pesticide use where needed, and reducing the adverse health, environmental and agronomic risks. Pesticide legislation and registration, public health and environmental policies, but also budget allocations for enforcement, monitoring and research into alternatives are important tools to reduce pesticides. In addition there are financial instruments to trigger less use of pesticides and a switch to alternative methods. National pesticide action plans can set goals for pesticide reduction and define a set of measures to achieve them. Since pesticide reduction needs to be a shared responsibility of the overall society, private sector and civil society initiatives are essential to complement government efforts.

Introduction

In recent months pesticides received increased attention in the media: New research results indicate that pesticides increase the risk of severe health problems like cancer, Parkinson, dementia, diabetes and other diseases. The International Agency for Research on Cancer (IARC) of the World Health Organization classified the most commonly used herbicide glyphosate as “probably carcinogenic”, which initiated a heated discussion. Multiple pesticide residues are found in food, drinking water, surface water, breast milk and urine. Systemic pesticides (neonicotinoids) could be responsible for the collapse of bee colonies. Pesticides contribute to loss of biodiversity etc.

Debates around pesticides are usually highly polarized, with opponents demanding an immediate ban of pesticides because they are not safe, and proponents arguing that we cannot maintain food production without pesticides. As a consequence of this deadlock progress to address pesticide issues is slow and fragmented.

What pesticide use would be desirable for society?

For society as a whole, the ultimate goal should be to manage pests in a way that allows sustainable crop production, without negative impacts on environment and human health. It would be desirable that pesticides were only used when inevitable and with the least level of side effects. In economic terms, the negative externalities (i.e. the impact on health and environment and the costs to avoid them) should at least not be higher than the value generated by using pesticides (i.e. yield increase and net cost reduction). Current pesticide use is often far higher than what this equation suggests. It is therefore reasonable to combine all available know-how and forces in order to identify pathways for gradual reduction of pesticide use.

Purpose of this paper

This paper shall provide orientation and guidance to a broad range of stakeholders including policy makers on how pesticide use can be reduced at a global level. Part I of this paper provides a brief overview on current facts and issues related to pesticides and on available strategies and policy instruments to reduce and regulate their use. It largely builds on recent publications that elaborate on this topic in much detail based on comprehensive literature reviews (see References). Part II of this paper will summarize the conclusions of a symposium on pesticide reduction held on 3 September 2015 in Zurich, Switzerland. In this symposium a broad range of stakeholders from science, civil society, private sector and government discuss the need and feasibility of pesticide reduction and concrete action to get there.

PART I: OVERVIEW ON ISSUES, APPROACHES AND POLICIES RELATED TO PESTICIDE REDUCTION

1. Pesticide use in agriculture – What are the issues?

1.1. Current use of pesticides in agriculture

Pesticides are used to protect crops and livestock from various pests, diseases, competition from weeds and parasites, thus contributing to increased agricultural production. They help farmers to reduce production costs and risks, and to survive in a highly competitive market. Global pesticide use has grown over the past 20 years to 3.5 billion kg active ingredients per year, amounting to a global market worth $45 billion (1). A significant portion of the chemicals applied has proved to be excessive, uneconomic or unnecessary both in industrialized and developing countries (2). While some countries reduced pesticide use over the past two decades (particularly UK, France, Denmark and Japan), in most regions it considerably increased (1). In Switzerland, pesticide sales are more or less stable at 2’120 tons of active ingredients in 2013 (3). The volume alone, however, does not necessarily reflect the impact of pesticides used, as older products are often replaced by substances that have more effect at lower doses.

What type of pesticides are used

Herbicides account for 42%, insecticides 27%, fungicides 22% and disinfectants and other agrochemicals 9% of global pesticide sales. In Switzerland, fungicides have the highest share (47%), followed by herbicides (35%) and insecticides (17%) (3). Herbicides dominate the North American and European domestic markets where they are also used to synchronize ripening of crops, but insecticides are more commonly used elsewhere in the world (1). Pesticide use intensity is highest in vegetable, fruit and cotton production.

Today's most used herbicide glyphosate was introduced in combination with genetically modified herbicide-tolerant (HT) crops in the late 1990s. Presently, glyphosate (e.g. *Roundup)* accounts for more than 50% of total herbicide use (4) and is applied on more than 80% of the genetically modified crops (5). The use of herbicides allows for methods like low- and zero-tillage that reduce soil erosion. However, serious concerns are increasingly raised due to the development of herbicide-resistant weeds.

1.2. Pesticides and health

Pesticides can have adverse effects to human health - acute but also chronic. While there are no accurate data available on acute pesticide poisoning due to occupational and accidental exposure most estimates are in the range of several million cases per year (6). Acute pesticide poisoning is a serious problem in developing countries, where many farmers use highly hazardous products, often without adequate protective measures. The harms in actual conditions of use are experienced disproportionately by the poor and disadvantaged (2). Replacing highly hazardous pesticides such as endosulfan and paraquat with less toxic ones, and training farmers on proper handling of pesticides are expected to reduce acute poisoning. However, despite official adoption of the FAO/WHO International Code of Conduct on the Distribution & Use of Pesticides in 1985, there is evidence from the field that, especially in developing countries, pesticides still pose a serious threat to human health and the environment. Sadly enough, pesticide poisoning also plays today an important role as a mean of suicide (7).

Exposure to pesticides

In Europe and North America the focus of concern has generally shifted to chronic effects due to low-level exposures (8). Farmers and pesticide applicators are particularly prone to adverse effects due to their direct exposure to pesticides at work. In addition, in agricultural areas where pesticides are heavily used, the population nearby is also at risk. Pesticides drift in the air, pollute soil and water resources and can thus contaminate large areas. The widest exposure to pesticides, however, is through residues in food. Exposure is presented as multiple mixtures of chemicals, the toxic effect of which are unknown, particularly over longer time scales (9). In some cases these substances can interact such that mixtures may have unpredictable and higher toxicities than the individual components themselves (10). Most research on pesticides is done on the active ingredient. So-called inert ingredients in pesticide formulations that enhance the effect of the active ingredient, however, can also cause substantial health effects (11). In addition, metabolites of active and inert ingredients can be of even higher toxicity than the original substances (10).

Fruits and vegetables frequently have the highest levels of pesticide residues – food items that are generally eaten because they are deemed healthy. But also animal products contain pesticide residues that accumulate from feed or from treatment against parasites, or, in the case of fish and seafood, through bioaccumulation in the aquatic food web systems (12). Studies have shown that people consuming an organic diet may be expected to have consistently lower pesticide intakes than those who consume a conventional diet (13).

Health hazards due to low-level, long-term exposure to pesticides

The literature on health effects of pesticides at general exposure levels is inconclusive, and more research is definitely needed (14) (15). While most industry-financed research suggests that pesticides imply few health risks if they are properly used, there are hundreds of scientific studies published in renowned journals that point out serious health hazards (10) (16). Though there are inherent problems in conducting large-scale experiments and directly assessing causation of these human health problems, the statistical associations between exposure to certain pesticides and the incidence of some diseases are compelling and cannot be ignored (12). Moreover, some persons have an inherent genetic susceptibility to the health effects of pesticide exposure and are therefore likely to be more at risk than others.

Increased risk for cancer and damage to the nervous system

There is widespread evidence that exposure to certain pesticides is a significant additional risk factor in many chronic diseases, including different forms of cancer, neurodegenerative diseases and disruptions of the digestive system (10), (12). Various studies among farmers, farm workers and their families showed increased incidences of several types of cancer, such as lymphatic and blood system, lip, stomach, prostate, brain, testes, skin cancers and soft tissue sarcoma (17), (18), (14). The International Agency for Research on Cancer recently classified the widely used herbicide glyphosate as probably carcinogenic to humans (19). Several studies found that exposure to pesticides is statistically associated with an increased risk of developing Parkinson's disease (20) (21) and Alzheimer's disease (22). Whilst aging almost certainly represents the greatest risk factor, low-dose/long-term exposures to pesticides have been implicated as a further factor. Other studies found that chronic low-level exposure to certain pesticides may be related to adverse effects on brain functioning, including changes in attention, speech, sight, memory and emotional aspects (23), (24).

Effects on immune and hormone system

There is circumstantial evidence that pesticide exposure is associated with disruption in the immune system (25), and hormone imbalances (26), (27). These effects may increase the risk for diseases such as obesity and diabetes, autoimmune diseases or reproductive problems. Exposure to certain insecticides may also contribute to the increasing incidence of food allergies in westernized societies (28). Some studies showed that impacts may be extremely long-term as pesticides can disrupt gene expression and impact the following generations not directly exposed to pesticides (12).

Effects of prenatal and infant exposure

Unborn and young children are in particular vulnerable to pesticide exposure due to the high rate of growth and complex development processes, the higher dose per body weight and the lower level of detoxifying enzymes compared to adults. Children themselves employed in agricultural work, as often the case particularly in developing countries, are particularly vulnerable to the toxic effects of pesticides. Numerous studies reported for children exposed to high levels of pesticides a delay in their cognitive development, behavioural effects and birth defects (12), (10). A study in California, US, found that high levels of organophosphorus pesticides in mother's urine were statistically associated with poorer intellectual development and deficits in working memory in the children when they reached 7 years of age (29). These cognitive effects occurred in children whose mother's urine had levels of organophosphate pesticides that were near the upper end of the range typically found across the general US population. Another study reported that children with higher urinary pesticide levels, mainly from diet, were more likely to be diagnosed with attention deficit/hyperactivity disorder (ADHD) (30).

1.3. Pesticides and the environment

A large part of the pesticides applied to crops are either taken up by the plants and animals or are degraded by microbial or chemical pathways. A considerable fraction of the amount applied, however, is dispersed into the environment, by air drift, leaching and run-off so that they are found in soils, surface and ground water (31). Pesticides in freshwater supplies have become a serious and increasingly costly concern, with detected levels often exceeding the set limits (in the EU: 0.1 μg l^{-1} for any individual active ingredient, or 0.5 μg l^{-1} for total pesticides). In Switzerland, 70% of surface waters had pesticide levels above the official limit (32). Pesticides are now found in every habitat on earth and are routinely detected in both marine and terrestrial animals (33).

Reduced biodiversity and ecosystem services

There is substantial published literature on the effects of pesticides on wildlife and biodiversity. Pesticide use has particularly contributed to the declines in the populations of birds, insects, amphibians and aquatic communities (34), (35), (36) (37). The effect is either direct through exposure, or indirect through a reduction in food availability. The widespread use of systemic pesticides that are absorbed by the crops is predicted to result in substantial impacts on biodiversity and ecosystem functioning (38). Studies have shown that systemic insecticides from the group of neonicotinoids can trigger the collapse of bee colonies, thus reducing their function as pollinators (39). Widespread and continued herbicide application eliminates plant species in fields and bordering areas that provide food and shelter to beneficial insects, spiders and birds. The effects of pesticides are enhanced by loss of habitat due to industrial farming methods.

Aggravated pest problems

Pesticide use reduces populations of insects, spiders and birds that naturally control pests. As pests usually recover faster than their predators, pesticide use can aggravate subsequent incidence of pest outbreak. In some cases reduced populations of beneficial insects due to overuse of pesticides contributed to the rise of pests that previously were of minor importance. Cotton and rice are two historical examples of induced pest problems by mismanagement and overuse of insecticides. Another growing concern is that pests and weeds increasingly develop resistance to pesticides. New pesticides are developed or combinations of pesticides are used in order to control them, resulting in additional costs and new side effects.

1.4. Economics of pesticide use

Pesticide application in agriculture has obvious short-term economic benefits – otherwise farmers would not use them. They may reduce the costs of production (e.g. by using herbicides instead of mechanical weeding) or reduce crop loss due to pest or disease infestation. However, pesticides also cause costs to society in terms of health and environmental costs. These external costs are not (yet) reflected in the market price of pesticides. They include health costs to humans (acute and long-term effects), costs of adverse effects on biodiversity (loss of beneficial insects, pollinators and wildlife), drinking water treatment costs, losses in aquaculture and fisheries, and costs of greenhouse gas emissions during pesticide manufacturing. Due to methodological difficulties and lack of data it is extremely difficult to quantify external costs of pesticide use. Estimates are in the range of US$4-19 per kg active ingredient, or $19-106 per ha cropland (1). With some 3.5 billion kg applied worldwide, this would suggest annual costs of $10-60 billion, for a market size of $45 billion.

However, these estimates do not account for the health effects of chronic exposure to pesticides described in chapter 1.2. If only a small fraction of the occurrence of certain diseases like cancer, dementia, diabetes and behavioural disorders can be attributed to pesticides, their external costs would be far higher. In addition, stockpiles of obsolete pesticides exist in many of the least developed countries and are a particularly high risk in situations of political instability. The root causes of the accumulation of these wastes are poor pesticide regulation and management; and over-reliance on chemical pesticides as a first option for pest control. Disposal of obsolete stocks is an extremely expensive undertaking which poses an economic burden on the governments and societies.

Factoring-in health and environmental costs

The question at hand is not to weigh the total benefits of pesticides against their total external costs in order to decide on whether or not to ban them completely – a rather theoretical scenario. More important is to assess to what extent pesticides can be reduced so that the costs of that change (in terms of lower yields or higher production costs) is compensated by an equal reduction in external costs. When health and environmental costs are factored in, pesticide application is only economical at a much lower threshold than what is commonly practiced. In addition, evidence from introducing Integrated Pest Management (IPM) suggests that in a majority of cases pesticides can be reduced through better management practices without substantially reducing yields or increasing costs. The concept of economic thresholds balances the value of crops lost to pests or diseases with the costs of pesticide treatments.

2. Strategies available for pesticide reduction

Ideally, agricultural systems should be designed in a way that pests, diseases and weeds do not build up to a level that they cause significant damage to the crop. Suitable agronomic practices, the use of resistant varieties, and Integrated Pest Management are key preventive measures. Bio control and the use of natural substances can complement these efforts. The safe application of minimal toxic synthetic pesticides should be used as a last resort. The following chapters provide an overview of applied approaches. In practice, they are overlapping and are often combined.

2.1. Agronomic practices

Suitable agronomic practices are essential to achieve healthy crops and to prevent build-up of pest, disease and weed pressure (40). The following practices are of particular importance:

- Appropriate plant nutrition and soil fertility management based on organic matter forms the basis for healthy crops that are less susceptible to pests, diseases and weeds;
- Crop rotation prevents the carryover of pest, pathogen and weed populations to the following season;
- Intercropping and the use of variety mixtures limits the spread of pests and diseases and provides food and shelter for natural enemies of pests;
- Timely shallow tillage reduces weed populations and at the same time improves nutrient supply to the crop;
- Appropriate irrigation management avoids water stress (too little or too much water) that makes crops susceptible to pests and diseases and reduces proliferation of weeds;
- Appropriate timing of sowing or planting and of intercultural operations reduce pest pressure.

2.2. Resistant crops

Crops and crop varieties differ in their susceptibility to pests and diseases and in their ability to compete with weeds. Growing crops suitable for local conditions and selecting appropriate crop varieties is therefore fundamental to a preventive pest management system. The use of resistant varieties together with rotations of non-susceptible crops can substantially limit pest build-up within a field (8). While breeding for insect, disease and nematode pest resistance is well known, much less effort has been focused on breeding crops for greater weed suppressiveness. Resistance in crop varieties can be achieved by traditional breeding methods like crossing and selection as well as through genetic engineering. In both cases an identified resistance is incorporated into a plant with high yield potential and other favourable agronomic characteristics. Collections of traditional varieties and wild relatives are often a good source of useful resistance genes. Traditional plant breeding, however, takes time and results are only visible after years. Resistance may not be lasting as pests and diseases can adapt to the new crop. The wider the genetic base of resistance, the more likely is it to last.

Gene technology to breed resistant varieties

Marker assisted breeding and genetic engineering can speed up this process (41). The most important insect resistant crops produced by genetic engineering carry genes of the soil bacterium *Bacillus thuringiensis* (Bt). These genes induce the crop to produce a protein (Bt-toxin) that is toxic to specific insects that feed on the crop. However, the most widely used genetically engineered crops today are those resistant to herbicides like glyphosate (42). The herbicide is harmless to the modified crop and thus 'non-selective' herbicides can be used to remove all other plants in a field. It is currently not evident whether the use of genetically modified organisms (GMO) so far has reduced pesticide application (43). Critics point out to unwanted side effects on beneficial insects and other non-target organisms and to a narrowing of genetic crop diversity.

2.3. Bio-control and natural pesticides

Bio-control makes use of pathogens (bacteria, fungi, viruses), insect predators or parasitoids, pheromones and insect traps to keep pest populations low (2). The total eradication of a pest, which results from the use of synthetic pesticides, would reduce the food supply of the pest's natural enemies, undermining a key element in system resilience. The aim, therefore, should be to manage insect pest populations to the point where natural predation operates in a balanced way and crop losses to pests are kept to an acceptable minimum (40). The most widely used bio-control methods are:

- Conservation and augmentation of natural enemies of pests through flower strips, hedge rows and other natural habitats;
- Release of predators and parasitoids of pests such as *Trichogramma*, lady bird beetles, lacewings and predatory mites;
- Sprays with pathogens of pests such as *Bacillus thuringiensis*, *Beauvaria*, *Trichoderma* and nematode species;
- Pheromone dispensers to disrupt mating of pests;
- Traps like sticky coloured boards, pheromone traps and light traps to catch insect pests.

Natural pesticides

Various plant extracts and other natural materials are used that repel pests, reduce their feeding or reproductive activities, reduce proliferation of diseases or act as biopesticides. Some of them, however, also have unwanted side effects. Most commonly used natural pesticides are:

- Neem, the extract of the seeds of a tree common in tropical and sub-tropical areas, reduces proliferation of insect pests while having little impact on beneficial insects;
- Pyrethrum, the extract of a chrysanthemum species, decomposes rapidly in the environment, but affects beneficial insects and is toxic to aquatic life;
- Copper is widely used to control for fungal diseases, but it accumulates in the soil;
- Sulphur, soap and paraffinic oil preparations are used to control mites, aphids and other pests, but they also affect beneficial insects.

2.4. Integrated Pest Management

The FAO defines Integrated Pest Management (IPM) as the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment (44). IPM is an ecosystem approach that does not seek to eradicate pests - but rather to manage them. It is founded on the idea that the first and most fundamental line of defence against pests and diseases in agriculture is a healthy agro-ecosystem, in which the biological processes that underpin production are protected, encouraged and enhanced (40).

The approach is knowledge-intensives and requires a broad understanding of the specific crop, its pests (including weeds) and their natural enemies. Strong focus is on pest prevention by applying good agronomic practices and using resistant varieties, pest identification and monitoring and biological pest control. As soon as the economic threshold is achieved - the point at which the cost of pesticide use pays off (cost of expected loss in harvest exceeds the cost of treatment) - chemical pest control becomes profitable. The last step includes learning and adapting from IPM for the next crop season.

Pesticide reduction without yield loss

In the global South IPM techniques are often promoted through Farmer Field Schools (FFS) in which a group of farmers frequently meets to share field observations and exchange experience. Through IPM-FFS rice farmers in the Philippines reduced pesticide application frequency and applications per hectare by 70%, increased yields by 12% and increased the inter-year stability of yields (1). Many examples across the world demonstrate that IPM can reduce pesticides while increasing the profitability for farmers. Integrated Production (IP), such as the label IP-Suisse, builds on IPM in their production guidelines.

2.5. Agroecology

Agroecology is a discipline that defines, classifies and studies agricultural systems from an ecological and socio-economic perspective, and applies ecological concepts and principles to the design and management of sustainable agroecosystems (45). It is an integrative way of farming that focuses on working with and understanding the interactions between plants, animals, humans and the environment. In Agroecology pest control seeks to reinforce interactions of pests and natural enemies with the aim to maintain a natural balance in the ecosystem (46). While there is no consent on what techniques and inputs are compatible with agroecology the common denominator is to make use of biodiversity-based ecological processes to optimize agricultural production systems.

Agroecology is gaining momentum

The increasingly high profile of agroecology is reflected in the growing body of evidence on high- performing agroecological management practices (47). A study examined 40 initiatives employing agroecological production methods in 20 countries, involving 10.4 million farmers (48). Analysis of project outcomes demonstrated not only an average crop yield increase of 113% compared to conventional systems, but also numerous environmental benefits, including carbon sequestration and reductions in pesticide use and soil erosion. Agroecological strategies like crop diversification, animal integration, soil organic management and water conservation are also expected to reduce vulnerabilities of farming systems and rural communities to climate change (49).

A particularly useful application of agroecology is the Push-Pull method introduced in Eastern Africa to control stem borer and striga weed in maize production (50). Farmers use Napier grass and desmodium legume as intercrops in their maize fields. Desmodium produces a smell that repels the maize stemborer - the push component, whereas Napier grass planted around the maize field acts as a trap plant for the stemborer - the pull component – and is also used as animal fodder. In addition, desmodium suppresses Striga weeds while fixing valuable nitrogen to the soil.

2.6. Organic agriculture

Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects (51). Organic standards strictly prohibit any use of synthetic pesticides. Crop protection in organic agriculture builds on good agronomic practices such as crop rotation and intercropping, the use of organic manures, resistant varieties and bio-control to prevent that pest, diseases and weeds cause significant damage. Organic farming makes use of techniques similar to Integrated Pest Management and agroecology, with the only difference that synthetic chemicals cannot be used as a last resort. Instead, organic farmers can use specific natural substances permitted by organic standards to control pests and diseases if preventive methods are not sufficient. Some of them, however, also have unwanted side effects on non-target organisms. Particularly the use of copper to control fungal diseases is problematic due to its accumulation in soils.

Limited yield reduction

Diversified organic systems can be more productive than monocropping, particularly in tropical regions where they often contribute to improved food security and livelihoods (52). At global level, however, yields in organic crops and systems tend to be 10-18% lower than in conventional agriculture (53). As the main reason for lower yields is probably related to nutrient management, the yield reduction effect of not using synthetic pesticides is likely to be in the range of maximum 5-8% on average. In specific crops like vegetables and fruits and for specific pests and diseases, however, organic farmers still face considerable challenges. More research is needed to identify suitable organic solutions for these cases.

2.7. Use of less hazardous pesticides

There are various systems to classify pesticides as per their toxicity for humans and the environment. Phasing out the use of highly hazardous pesticides and replacing them with less hazardous ones is therefore the most obvious way to reduce the negative side-effects of pesticides (54). This approach needs to be combined with safe handling of pesticides so that their impact on people and the environment is minimized. The use of protective gear and the observation of waiting periods before harvest are the most important measures in this regard. However, in many countries the availability of protective equipment and its impracticality in hot and humid climates result in low adoption rates (8).

3. Policies to reduce pesticide use and risks

3.1. International policies and instruments

International codes, treaties, conventions, commissions and advisory bodies play an important role in for plant protection and pesticide management. Through the ratification of international conventions, governments accept obligations to incorporate them into national policies. The following international policies and instruments are most relevant with regard to reducing the risk associated with pesticide use.

The Rotterdam Convention covers international trade in hazardous chemicals (most of them being pesticides) with the aim of protecting human health and the environment. If all parties agree that a specific pesticide constitutes severe health or environmental hazards it can be listed for prior informed consent procedures. They require exporting countries of these chemicals to notify importing authorities on data of known hazards. As any party can veto the listing of a pesticide the process is rather slow. Currently the convention lists 33 pesticides.

The Stockholm Convention aims to eliminate or restrict the production and use of persistent organic pollutants (POPs), some of which are pesticides. Based on a specified review process pesticides that fulfil the criteria for POPs can be listed for elimination or restriction.

The International Code of Conduct on Pesticide Management is a voluntary framework that has been endorsed by the FAO Members, and supported by key pesticide industry associations and civil society organizations (54). It became a role model to the development of pesticide legislation, and the major pesticide companies have agreed to abide by the Code of Conduct.

The Strategic Approach to International Chemicals Management (SAICM) is a voluntary policy framework and strategy facilitated by UNEP to promote chemical safety around the world. It brings together stakeholders and sectors that include agriculture, environment, health, industry, labour, economics, science and academia to catalyse achievement of the goal by 2020 "that chemicals are used and produced in ways that minimize adverse effects on human health and the environment."

The Joint Meeting on Pesticide Residues (JMPR) is an expert ad hoc body administered jointly by FAO and WHO with the purpose of harmonizing the requirement and the risk assessment on the pesticide residues. It recommends maximum residue levels in food and feed commodities and provides guidance on pesticide product quality parameters for regulatory and trade purposes.

3.2. National legislation and policies

The role of governments is to find a responsible balance between enabling judicious pesticide use where such use is necessary to achieve desirable crop production levels, and reducing the adverse health, environmental and agronomic risks (8). Governments have a range of policy instruments to influence this balance. Pesticide legislation and registration offers possibilities for regulating the availability and use of pesticides. The use of dangerous products can be banned or restricted to certain crops, users or circumstances. Governments have the opportunity and power to make budget allocations on the enforcement of pesticide legislation, for monitoring of pesticides residues in food and drinking water, and for research into the side-effects of pesticides use.

Various instruments are available

Public health policies may address pesticide residues in food and drinking water, and risks associated with the storage, transport and disposal of pesticides. Environmental policies on water quality, nature conservation and biodiversity can also influence the availability and use of pesticides. In addition there are financial instruments to provide incentives or disincentives for certain practices in crop production. This could be pesticide taxes or import tariffs, but also financial incentives for the development and use of alternative pest management approaches and products, and support for the local manufacture of such products. Pesticide-use fees or pesticide taxes may be used to finance the development of alternative pest management practices and subsidize their adoption. Equally important is to address factors that foster unnecessary pesticide use, such as pesticide subsidies, pesticide application recommendations by agricultural extension services or possible conflicts of interest affecting regulatory authorities, research and extension (55)**.**

Phasing out, phasing in

More and more countries, both industrialized and developing, are phasing out highly hazardous pesticides, while encouraging less hazardous pest management approaches and products (8). Integrated Pest Management (IPM) and biological control programmes are increasingly recognized and promoted as viable alternatives. Several countries have set IPM targets or declared IPM as the preferred approach to pest management. However, many developing countries are still facing various constraints to the effective enforcement of their regulatory systems. Available financing and human resources for the control of pesticides are very small.

3.3. Pesticide action plans

In 2009 the European Union Commission passed a directive that requires all member countries to adopt National Action Plans (NAPs) to set up their quantitative objectives, targets, measures and timetables to reduce risks and impacts of pesticide use on human health and the environment and to encourage the development and introduction of Integrated Pest Management and of alternative approaches or techniques in order to reduce dependency on the use of pesticides (56). In 2013, the Pesticide Action Network (PAN) Europe has undertaken an analysis of all the NAPs that Member States have developed to comply with the EU Directive (57). They concluded that Member States' ambition to reduce pesticides use is extremely low due to:

- Lacking quantitative objectives, targets, and clear timetables for pesticide use reductions;
- Recycling what is already mandatory from other EU policies, without proposing new actions;
- Indicators for pesticide use reductions or conversion towards more use of non-chemical techniques are replaced by 'soft' targets (number of training hours, number of guidelines developed, number of certificates issued) unable to measure the effective change.

Two countries stand out as progressive examples with regard to pesticide reduction policies: Denmark and Sweden (57).

Denmark introduced its first pesticide reduction plan in 1986 to protect the ground water that is consumed directly without any purification treatment. Since that time, Denmark has banned specific pesticides when it was proved that they reached ground water. In 1999, an expert committee prepared a report on reduction of pesticide use. It recommended a reduction goal implemented through a three-pronged strategy: covering spraying-free zones, organic farming, and general use reduction through new technology and better farming practises. The recommendations, however, have only partly been implemented, and the goal has still not been reached. Nevertheless, the early introduction of a pesticide policy has led to the result that Danish products (especially fruit and vegetables) have residue levels of pesticides below the EU average today. In July 2013, Denmark introduced a pesticide tax on insecticides linked to environmental and health hazards.

Sweden has the overall objective of becoming a non-toxic environment. The Swedish National Action Plan contributes to this objective by further expanding on this goal through the following objectives:

▹ Concentrations of pesticides in surface and ground water should be close to zero;

▹ Pesticide residues in vegetables grown in Sweden should be low and not pose risks to the consumer;

▹ Development of sustainable farming systems, which includes alternative methods and techniques, will be developed and applied to a greater extent in order to reduce the dependence on chemical pesticides, as well as a specific target for organic agriculture.

The Swedish NAP defines detailed objectives, monitoring procedures and actions in a broad range of areas.

Swiss National Action Plan under development

The Swiss Federal Council mandated its administration to develop a National Action Plan on Pesticides by end of 2016. The Federal Office for Agriculture (BLW) initiated expert groups to formulate objectives and measures for pesticide risk reduction and organized workshops with interested stakeholder groups. A group of Swiss environmental organisations (WWF, Greenpeace, Pro Natura and BirdLife) demand that the government formulates concrete pesticide reduction targets in its National Action Plan. They elaborated a guidance document with nine demands addressed to the Swiss government (58).

3.4. Private sector and civil society initiatives

The growing consumer desire for safe and wholesome food and a similar demand from investors' side, motivated the food sector to proactively respond with more critical attention being paid to the crop production practices of their suppliers (8). Some of the largest players in the market now actively pursue internal policies to reduce safety risks through supply chain management. They often demand from their suppliers that certain production protocols are followed, including more sustainable pest management and more responsible pesticide management. The GLOBALGAP initiative of supermarket chains and their suppliers is an example of this approach (http://www.globalgap.org). A similar initiative is the Sustainable Agriculture Initiative (SAI) of a group of food processing companies, which promotes the sustainable use of production resources to safeguard their long-term economic availability (http://www.saiplatform.org). Another response to consumer demand for safe and sustainable products is the broad range and increasing market shares of products carrying sustainability labels (see http://www.isealalliance.org). Most of them address pesticide use to some extent, ranging from a total ban of synthetic pesticides in organic labels to rather vague formulations of objectives that are difficult to monitor or enforce.

Civil society initiatives

There are several civil society organisations and initiatives dedicated to the reduction of pesticide hazards. The most important one among them is the Pesticide Action Network (PAN) that involves over 600 participating nongovernmental organizations, institutions and individuals in over 90 countries working to replace the use of hazardous pesticides with ecologically sound and socially just alternatives. PAN was founded in 1982 and has five independent, collaborating Regional Centers that implement its projects and campaigns. Various environmental organisations worldwide lobby for using less pesticides and raise awareness among the public.

In Switzerland, the Berne Declaration (EvB) advocates for a global phasing-out of highly hazardous pesticides, with focus on paraquat. The four main environmental NGOs joined forces to lobby for concrete pesticide reduction targets in the Swiss National Action Plan. Consumer organisations and public health organisations also increasingly address the topic. In May 2015 the Swiss consumer organisation (SKS), Doctors for the environment (AEFU) and Greenpeace jointly launched a petition to ban the use of glyphosate.

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