ECONOMIC IMPORTANCE AND ENVIRONMENTAL IMPACT OF PESTICIDES; A REVIEW OF THE LITERATURE

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Abstract
The purpose of this paper is to present and discuss: pesticide environmental effects, eliminating pesticides, pesticide classification, pest resistance, persistent organic pollutants human effects. The pesticides are used to destroy the crop pests, in order to increase the yield and quality of the products. However, many pesticides can pose a risk to human health. Human exposure to pesticides can occur by eating contaminated food and drinking water, in people handling and working with pesticides. Pesticides also have negative effects on the environment (water, soil, air). There are intense concerns about the dosing of pesticides in the environment and food, in order to assess their risk to human health. This tendency is accentuated by the uncertainty of agricultural and industrial production methods, as well as by the control of pesticides. The probability of reducing the environmental risk associated with pesticide use is very low because many manufacturers consider that by avoiding pesticides or reducing doses, the yield on agriculture decreases and increases production costs. Current policies on pesticides, their role and their various implications, advocate the selection of the most effective pesticides that are specific to crop classes, corroborated with research and innovation on how to increase the quality of pesticides and their costs.

Keywords: pesticides, soil contaminants, ecotoxicology, human exposure

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1. INTRODUCTION

Of great importance in increasing the risks reserved for ecotoxicity and its maintenance are the continuous advances of science and the continuous development of new chemicals, intended to obtain the growing industrial and agricultural productions. These trends lead to the continuous and aggressive release of ecotoxic residues from different industries, but also to the use of chemicals to limit or destroy certain pests of agricultural ecosystems. These processes, generically covered under the term pollution, lead to the continuous dissimulation and accumulation of ecotoxicological chemicals.

Thus, the action of chemical substances can lead to harmful effects, characterized by damage to the environmental balance, reflected in the soil, water and air, by exceeding the maximum allowable tolerance limits (CMA) and ADI-acceptable daily intake of Animal species, aspects that affect the productive performances and the health of some environmental bio utilizers (plants, animals, humans). The impact of pesticides consists of the effects of pesticides on non-target species. Pesticides are chemical preparations used to kill fungal or animal pests. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, because they are sprayed or spread across entire agricultural fields (Miller, 2004). Runoff can carry pesticides into aquatic environments while wind can carry them to other fields, grazing areas, human settlements and undeveloped areas, potentially affecting other species. Other problems emerge from poor production, transport and storage practices. Over time, repeated application increases pest resistance, while its effects on other species can facilitate the pest's resurgence (Damalas and Eleftherohorinos, 2011).

Pesticides can be classified by the nature of pest control in:

- insecticides (to control insect pests, transmitters of human or domestic animal diseases);
- herbicides (for the destruction of crop weeds);

• fungicides (to combat fungi that cause plant diseases);
• acaricides;
• nematocides (for combating pests of crops);
• algicides (for algae destruction);
• rodenticides (used against rodents).

The properties of the DDT insecticide, the first pesticide used scientifically, were discovered by Paul Herbert Műller, a researcher at Ciba-Geiby in 1939. Because of low water solubility (<1 mg / l) DDT was produced as an emulsifiable concentrate to be applied by spraying (emulsifiable concentrates = pesticide solutions introduced into organic liquids which, in admixture with water, form creamy-like emulsions). Each pesticide or pesticide class comes with a specific set of environmental concerns. Such undesirable effects have led many pesticides to be banned, while regulations have limited and/or reduced the use of others. Over time, pesticides have generally become less persistent and more species-specific, reducing their environmental footprint. In addition the amounts of pesticides applied per hectare have declined, in some cases by 99%. However, the global spread of pesticide use, including the use of older/obsolete pesticides that have been banned in some jurisdictions, has increased overall.

Agriculture and the environment

The arrival of humans in an area, to live or to conduct agriculture, necessarily has environmental impacts. These range from simple crowding out of wild plants in favor of more desirable cultivars to larger scale impacts such as reducing biodiversity by reducing food availability of native species, which can propagate across food chains. The use of agricultural chemicals such as fertilizer and pesticides magnify those impacts. While advances in agro chemistry have reduced those impacts, for example by the replacement of long-lived chemicals with those that reliably degrade, even in the best case they remain substantial. These effects are magnified by the use of older chemistries and poor management practices (Table 1).

Table 1. Comparative specific pesticide effects

Pesticide environmental effects	
Pesticide/class	**Effect(s)**
Organochlorine DDT/DDE	Egg shell thinning in raptorial birds[4]
	Endocrine disruptor[7]
	Thyroid disruption properties in rodents, birds, amphibians and fish[4]
	Acute mortality attributed to inhibition of acetylcholine esterase activity[6]
DDT	Carcinogen[5]
	Endocrine disruptor[5]
DDT/Diclofol, Dieldrin and Toxaphene	Juvenile population decline and adult mortality in wildlife reptiles
DDT/Toxaphene/Parathion	Susceptibility to fungal infection[7]
Triazine	Earthworms became infected with monocystid gregarines[3]
Chlordane	Interact with vertebrate immune systems[7]
Carbamates, the phenoxy herbicide 2,4-D, and atrazine	Interact with vertebrate immune systems[7]
Anticholinesterase	Bird poisoning[6]
	Animal infections, disease outbreaks and higher mortality.
Organophosphate	Thyroid disruption properties in rodents, birds, amphibians and fish[6]
	Acute mortality attributed to inhibition of acetylcholine esterase activity[6]

	Immunotoxicity, primarily caused by the inhibition of serine hydrolases or esterases[8]
	Oxidative damage[8]
	Modulation of signal transduction pathways[8]
	Impaired metabolic functions such as thermoregulation, water and/or food intake and behavior, impaired development, reduced reproduction and hatching success in vertebrates. [9]
Carbamate	Thyroid disruption properties in rodents, birds, amphibians and fish[4]
	Impaired metabolic functions such as thermoregulation, water and/or food intake and behavior, impaired development, reduced reproduction and hatching success in vertebrates. [9]
	Interact with vertebrate immune systems[7]
	Acute mortality attributed to inhibition of acetylcholine esterase activity[6]
Phenoxy herbicide 2,4-D	Interact with vertebrate immune systems[7]
Atrazine	Interact with vertebrate immune systems[7]
	Reduced northern leopard frog (Rana pipiens) populations because atrazine killed phytoplankton, thus allowing light to penetrate the water column and periphyton to assimilate nutrients released from the plankton. Periphyton growth provided more food to grazers, increasing snail populations, which provide intermediate hosts for trematode. [10]
Pyrethroid	Thyroid disruption properties in rodents, birds, amphibians and fish[4]
Thiocarbamate	Thyroid disruption properties in rodents, birds, amphibians and fish[4]
Triazine	Thyroid disruption properties in rodents, birds, amphibians and fish[4]
Triazole	Thyroid disruption properties in rodents, birds, amphibians and fish[4]
	Impaired metabolic functions such as thermoregulation, water and/or food intake and behavior, impaired development, reduced reproduction and hatching success in vertebrates.
Nicotinoid	respiratory, cardiovascular, neurological, and immunological toxicity in rats and humans[11]
	Disrupt biogenic amine signaling and cause subsequent olfactory dysfunction, as well as affecting foraging behavior, learning and memory.
Imidacloprid, Imidacloprid/pyrethroid λ-cyhalothrin	Impaired foraging, brood development, and colony success in terms of growth rate and new queen production. [12]
Thiamethoxam	High honey bee worker mortality due to homing failure (risks for colony collapse remain controversial)
Spinosyns	Affect various physiological and behavioral traits of beneficial arthropods, particularly hymenopterans[13]
Bt corn/Cry	Reduced abundance of some insect taxa, predominantly susceptible Lepidopteran herbivores as well as their predators and parasitoids. [3]
Herbicide	Reduced food availability and adverse secondary effects on soil invertebrates and butterflies[14]
	Decreased species abundance and diversity in small mammals.[20]
Benomyl	Altered the patch-level floral display and later a two-thirds reduction of the total number of bee visits and in a shift in the visitors from large-bodied bees to small-bodied bees and flies[15]
Herbicide and planting cycles	Reduced survival and reproductive rates in seed-eating or carnivorous birds [16]

Air

Pesticides can contribute to air pollution. Pesticide drift occurs when pesticides suspended in the air as particles are carried by wind to other areas, potentially contaminating them (Cornell University, 2007).

Pesticides that are applied to crops can volatilize and may be blown by winds into nearby areas, potentially posing a threat to wildlife (US Department, 2006). Weather conditions at the time of application as well as temperature and relative humidity change the spread of the pesticide in the air. As wind velocity increases so does the spray drift and exposure. Low relative humidity and high temperature result in more spray evaporating. The amount of inhalable pesticides in the outdoor environment is therefore often dependent on the season (Damalas and Eleftherohorinos, 2011).

Also, droplets of sprayed pesticides or particles from pesticides applied as dusts may travel on the wind to other areas (US Environmental Protection Agency), or pesticides may adhere to particles that blow in the wind, such as dust particles (Environment Canada, 2007). Ground spraying produces less pesticide drift than aerial spraying does (Palmer et al., 2007). Farmers can employ a buffer zone around their crop, consisting of empty land or non-crop plants such as evergreen trees to serve as windbreaks and absorb the pesticides, preventing drift into other areas. Such windbreaks are legally required in the Netherlands.

Pesticides that are sprayed on to fields and used to fumigate soil can give off chemicals called volatile organic compounds, which can react with other chemicals and form a pollutant called tropospheric ozone. Pesticide use accounts for about 6 percent of total tropospheric ozone levels.

Water

In the United States, pesticides were found to pollute every stream and over 90% of wells sampled in a study by the US Geological Survey (Gillion et al., 2007). Pesticide residues have also been found in rain and groundwater (Kellogg et al., 2007).

Studies by the UK government showed that pesticide concentrations exceeded those allowable for drinking water in some samples of river water and groundwater (Bingham, 2007). Pesticide impacts on aquatic systems are often studied using a hydrology transport model to study movement and fate of chemicals in rivers and streams. As early as the 1970s quantitative analysis of pesticide runoff was conducted in order to predict amounts of pesticide that would reach surface waters (Kerbs et al., 1999).

There are four major routes through which pesticides reach the water: it may drift outside of the intended area when it is sprayed, it may percolate, or leach, through the soil, it may be carried to the water as runoff, or it may be spilled, for example accidentally or through neglect (States of Jersey, 2007). They may also be carried to water by eroding soil (Papendick et al., 1986). Factors that affect a pesticide's ability to contaminate water include its water solubility, the distance from an application site to a body of water, weather, soil type, presence of a growing crop, and the method used to apply the chemical.

Soil

Many of the chemicals used in pesticides are persistent soil contaminants, whose impact may endure for decades and adversely affect soil conservation.

The use of pesticides decreases the general biodiversity in the soil. Not using the chemicals results in higher soil quality, with the additional effect that more organic matter in the soil allows for higher water retention (Kellogg et al., 2007). This helps increase yields for farms in drought years, when organic farms have had yields 20-40% higher than their conventional counterparts. A smaller content of organic matter in the soil increases the amount of pesticide that will leave the area of application, because organic matter binds to and helps break down pesticides (Kellogg et al., 2007). Degradation and sorption are both factors which influence the persistence of pesticides in soil. Depending on the chemical nature of the pesticide, such processes control directly the transportation from soil to water, and in turn to air and our food. Breaking down organic substances, degradation, involves interactions among microorganisms in the soil. Sorption affects bioaccumulation of pesticides which are dependent on organic matter in the soil. Weak organic acids have been shown to be weakly sorbed by soil, because of pH and mostly acidic structure. Sorbed chemicals have been shown to be less accessible to microorganisms. Aging mechanisms are poorly understood but as residence times in soil increase, pesticide residues become more resistant to degradation and extraction as they lose biological activity.

Effect on plants

Nitrogen fixation, which is required for the growth of higher plants, is hindered by pesticides in soil. The insecticides DDT, methyl parathion, and especially pentachlorophenol have been shown to interfere with legume-rhizobium chemical signaling (Rockets, 2007). Reduction of this symbiotic chemical signaling results in reduced nitrogen fixation and thus reduced crop yields. Root nodule formation in these plants saves the world economy $10 billion in synthetic nitrogen fertilizer every year (Fox et al., 2007). Pesticides can kill bees and are strongly implicated in pollinator decline, the loss of species that pollinate plants, including through the mechanism of Colony Collapse Disorder, in which worker bees from a beehive or western honey bee colony abruptly disappear. Application of pesticides to crops that are in bloom can kill honeybees, which act as pollinators. The USDA and USFWS estimate that US farmers lose at least $200 million a year from reduced crop pollination because pesticides applied to fields eliminate about a fifth of honeybee colonies in the US and harm an additional 15% (Miller, 2004). On the other side, pesticides have some direct harmful effect on plant including poor root hair development, shoot yellowing and reduced plant growth (Walley et al., 2006).

Pesticides that are sprayed on to fields and used to fumigate soil can give off chemicals called volatile organic compounds, which can react with other chemicals and form a pollutant called tropospheric ozone. Pesticide use accounts for about 6 percent of total tropospheric ozone levels.

Effect on animals

Many kinds of animals are harmed by pesticides, leading many countries to regulate pesticide usage through Biodiversity Action Plans.

Animals including humans may be poisoned by pesticide residues that remain on food, for example when wild animals enter sprayed fields or nearby areas shortly after spraying (Palmer et al., 2007).

Pesticides can eliminate some animals' essential food sources, causing the animals to relocate, change their diet or starve. Residues can travel up the food chain; for example, birds can be harmed when they eat insects and worms that have consumed pesticides (Cornell University, 2007). Earthworms digest organic matter and increase nutrient content in the top layer of soil. They protect human health by ingesting decomposing litter and serving as bioindicators of soil activity. Pesticides have had harmful effects on growth and reproduction on earthworms. Some pesticides can bioaccumulate, or build up to toxic levels in the bodies of organisms that consume them over time, a phenomenon that impacts species high on the food chain especially hard.

Birds

The US Fish and Wildlife Service estimates that 72 million birds are killed by pesticides in the United States each year (Fimrite, 2011). Bald eagles are common examples of nontarget organisms that are impacted by pesticide use. Rachel Carson's book *Silent Spring* dealt with damage to bird species due to pesticide bioaccumulation. There is evidence that birds are continuing to be harmed by pesticide use. In the farmland of the United Kingdom, populations of ten different bird species declined by 10 million breeding individuals

between 1979 and 1999, allegedly from loss of plant and invertebrate species on which the birds feed. Throughout Europe, 116 species of birds were threatened as of 1999. Reductions in bird populations have been found to be associated with times and areas in which pesticides are used. DDE-induced egg shell thinning has especially affected European and North American bird populations (Vos et al, 2000). In another example, some types of fungicides used in peanut farming are only slightly toxic to birds and mammals, but may kill earthworms, which can in turn reduce populations of the birds and mammals that feed on them. Some pesticides come in granular form. Wildlife may eat the granules, mistaking them for grains of food. A few granules of a pesticide may be enough to kill a small bird.
The herbicide paraquat, when sprayed onto bird eggs, causes growth abnormalities in embryos and reduces the number of chicks that hatch successfully, but most herbicides do not directly cause much harm to birds. Herbicides may endanger bird populations by reducing their habitat (Palmer et al., 2007).

Aquatic life

Fish and other aquatic biota may be harmed by pesticide-contaminated water. Pesticide surface runoff into rivers and streams can be highly lethal to aquatic life, sometimes killing all the fish in a particular stream (Cone, 2000).
Application of herbicides to bodies of water can cause fish kills when the dead plants decay and consume the water's oxygen, suffocating the fish. Herbicides such as copper sulfite that are applied to water to kill plants are toxic to fish and other water animals at concentrations similar to those used to kill the plants. Repeated exposure to sublethal doses of some pesticides can cause physiological and behavioral changes that reduce fish populations, such as abandonment of nests and broods, decreased immunity to disease and decreased predator avoidance. Application of herbicides to bodies of water can kill plants on which fish depend for their habitat.
Pesticides can accumulate in bodies of water to levels that kill off zooplankton, the main source of food for young fish (Cone, 2000). Pesticides can also kill off insects on which some fish feed, causing the fish to travel farther in search of food and exposing them to greater risk from predators.
The faster a given pesticide breaks down in the environment, the less threat it poses to aquatic life. Insecticides are typically more toxic to aquatic life than herbicides and fungicides (Helfrich, 1996).

Amphibians

In the past several decades, amphibian populations have declined across the world, for unexplained reasons which are thought to be varied but of which pesticides may be a part (Cone, 2000). Pesticide mixtures appear to have a cumulative toxic effect on frogs. Tadpoles from ponds containing multiple pesticides take longer to metamorphose and are smaller when they do, decreasing their ability to catch prey and avoid predators (Science Daily, 2006). Exposing tadpoles to the organochloride endosulfan at levels likely to be found in habitats near fields sprayed with the chemical kills the tadpoles and causes behavioral and growth abnormalities (Raloff, 1998).
The herbicide atrazine can turn male frogs into hermaphrodites, decreasing their ability to reproduce (Science Daily, 2006). Both reproductive and nonreproductive effects in aquatic reptiles and amphibians have been reported. Crocodiles, many turtle species and some lizards lack sex-distinct chromosomes until after fertilization during organogenesis, depending on temperature. Embryonic exposure in turtles to various PCBs causes a sex reversal. Across the United States and Canada disorders such as decreased hatching success, feminization, skin lesions, and other developmental abnormalities have been reported (Vos et all., 2000).

Humans

Pesticides can enter the body through inhalation of aerosols, dust and vapor that contain pesticides; through oral exposure by consuming food/water; and through skin exposure by direct contact. Pesticides secrete into soils and groundwater which can end up in drinking water, and pesticide spray can drift and pollute the air.

The effects of pesticides on human health depend on the toxicity of the chemical and the length and magnitude of exposure (Lorenz, Eric S., 2009). Farm workers and their families experience the greatest exposure to agricultural pesticides through direct contact. Every human contains pesticides in their fat cells.

Children are more susceptible and sensitive to pesticides, because they are still developing and have a weaker immune system than adults. Children may be more exposed due to their closer proximity to the ground and tendency to put unfamiliar objects in their mouth. Hand to mouth contact depends on the child's age, much like lead exposure. Children under the age of six months are more apt to experience exposure from breast milk and inhalation of small particles. Pesticides tracked into the home from family members increase the risk of exposure. Toxic residue in food may contribute to a child's exposure (Hodgson and Levi, 1996). The chemicals can bioaccumulate in the body over time.

Exposure effects can range from mild skin irritation to birth defects, tumors, genetic changes, blood and nerve disorders, endocrine disruption, coma or death (Lorenz, Eric S., 2009). Developmental effects have been associated with pesticides. Recent increases in childhood cancers in throughout North America, such as leukemia, may be a result of somatic cell mutations (Crawford and Fiedler, 1992). Insecticides targeted to disrupt insects can have harmful effects on mammalian nervous systems. Both chronic and acute alterations have been observed in exposees. DDT and its breakdown product DDE disturb estrogenic activity and possibly lead to breast cancer. Fetal DDT exposure reduces male penis size in animals and can produce undescended testicles. Pesticide can affect fetuses in early stages of development, in utero and even if a parent was exposed before conception. Reproductive disruption has the potential to occur by chemical reactivity and through structural changes (Hodgson and Levi, 1996).

Persistent organic pollutants

Persistent organic pollutants (POPs) are compounds that resist degradation and thus remain in the environment for years. Some pesticides, including aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex and toxaphene, are considered POPs. Some POPs have the ability to volatilize and travel great distances through the atmosphere to become deposited in remote regions. Such chemicals may have the ability to bioaccumulate and biomagnify and can bioconcentrate (i.e. become more concentrated) up to 70,000 times their original concentrations (Ritter et al., 2007). POPs can affect non-target organisms in the environment and increase risk to humans (Centers for Disease Control and Prevention, 2007) by disruption in the endocrine, reproductive, and immune systems (Ritter et al., 2007).

Pest resistance

Pests may evolve to become resistant to pesticides. Many pests will initially be very susceptible to pesticides, but following mutations in their genetic makeup become resistant and survive to reproduce.

Resistance is commonly managed through pesticide rotation, which involves alternating among pesticide classes with different modes of action to delay the onset of or mitigate existing pest resistance.

- Presence of dominant genes responsible for transmitting resistance, which are spread more rapidly than non-dominant recessive populations.
- Shortening the interval between successive generations, makes the emergence of resistance more rapid (it is considered sufficient about 15 generations).
- Mobility of species, mobile ones, appearance of resistance - delayed due to migration of genes through migration, which diminishes the frequency of resistant genes in exposed populations, unlike sedentary species.

Eliminating pesticides

Many alternatives are available to reduce the effects pesticides have on the environment. Alternatives include manual removal, applying heat, covering weeds with plastic, placing traps and lures, removing pest breeding sites, maintaining healthy soils that breed healthy, more resistant plants, cropping native species that are naturally more resistant to native pests and supporting biocontrol agents such as birds and other pest predators (National Audubon Society, 2003). In the United States, conventional pesticide use peaked in 1979, and by 2007, had been reduced by 25 percent from the 1979 peak level (EPA, 2011), while US agricultural output increased by 43 percent over the same period (USDA ERS, 2013). Biological controls such as resistant plant varieties and the use of pheromones, have been successful and at times permanently resolve a pest problem (Lewis et al., 2007). Integrated Pest Management (IPM) employs chemical use only when other alternatives are ineffective. IPM causes less harm to humans and the environment. The focus is broader than on a specific pest, considering a range of pest control alternatives (Indoor Environmental Quality, 2000). Biotechnology can also be an innovative way to control pests. Strains can be genetically modified (GM) to increase their resistance to pests (Lewis et al., 2007). However the same techniques can be used to increase pesticide resistance and was employed by Monsanto to create glyphosate-resistant strains of major crops. In 2010, 70% of all the corn that was planted was resistant to glyphosate; 78% of cotton, and 93% of all soybeans (Acreage NASS National Agricultural Statistics Board annual report, 2012).

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