

II. Effects of Pesticides on Environmental Degradation

General Background on Pesticides

II.1. Definition

A pesticide is a chemical substance commonly used in agriculture to protect crops and control organisms considered harmful, such as insects (insecticides), fungal diseases (fungicides), and weeds (herbicides). In contrast, organic agriculture prioritizes natural pest-management methods, fostering natural predators, using pest-repellent plants, and crop rotation. Unlike synthetic chemical pesticides, which are often toxic to the environment and human health, organic farming emphasizes preventive strategies that enhance biodiversity and soil health, thereby reducing the need for artificial substances.

II.2. Historical Overview of Pesticides

Over the centuries, knowledge and practices for protecting crops from pests and diseases have evolved significantly. People have long relied on both botanical and inorganic chemicals to reduce pest- and disease-related damage to crops and livestock.

Two broad periods can be distinguished in the major development of pesticides:

- **Before 1950:** Arsenical compounds were widely used, particularly against insect pests of fruit trees and the notorious potato pest, the Colorado potato beetle. Alongside mineral insecticides, there was substantial growth in naturally derived and synthetic organic insecticides especially organochlorine compounds highly effective biocides. During this period, plant disease control still relied heavily on sulfur and copper.
- **After 1950:** Pesticide use expanded markedly in the second half of the twentieth century. Several factors contributed the pursuit of higher yields; protection of food quality; reduced agricultural labor; and the discovery of numerous active substances belonging to chemical families such as organophosphates, carbamates, and pyrethroids. From the early 1960s, pesticide use surged in Asia and South America. Although about 65% of global pesticide use historically occurred in developed countries, usage in developing countries has risen steadily.

II.3. Classification of Pesticides

Pesticides are classified according to their effects on health and the environment. Even when formulated differently, their inherent risks remain similar, and classification supports appropriate safety measures. Three principal categories are:

- **Fungicides:** control fungal pathogens.
- **Insecticides:** eliminate insect pests.
- **Herbicides:** destroy weeds.

Fungicides

Fungicides are used to treat fungal, bacterial, and viral plant diseases and to eliminate parasitic fungi. Among the oldest are **sulfur** and **copper** and its organic derivatives.

- **Contact fungicides** (e.g., *captan*) prevent pathogen penetration.
- **Systemic fungicides** (e.g., morpholine derivatives) exert curative action.

Two broad groups are distinguished:

1. Mineral fungicides

- **Copper-based:** the most common and frequently applied.
- **Sulfur-based:** treatment efficacy depends on sulfur quality.
- **Potassium permanganate-based:** act curatively on powdery mildews by contact.

2. Organic fungicides

These chemically diverse molecules protect plants from fungal infections and are characterized by complex structures that enable broad efficacy.

- **Carbamates:** inhibit fungal growth.
- **Phenol derivatives:** antifungal activity against key plant pathogens.
- **Dicarboximides:** widely used against rots of fruits and vegetables.
- **Amides and amines:** disrupt fungal development.
- **Inhibitors of sterol biosynthesis:** block production of essential fungal sterols.
- **Anilinopyrimidines:** hinder fungal development at multiple life-cycle stages.
- **Methoxyacrylates and related fungicides:** inhibit energy production in fungi.

Insecticides

Synthetic organic insecticides are commonly grouped into four major families:

- **Organochlorines (OC):** potent but largely banned/restricted due to environmental persistence and bioaccumulation.
- **Organophosphates (OP):** inhibit key enzymes of the insect nervous system; effective but also toxic to humans and animals.
- **Carbamates:** similar mode of action to OPs, generally less persistent in the environment.
- **Synthetic pyrethroids:** modeled on natural pyrethrins; broadly effective, often with lower mammalian toxicity.

Herbicides

Herbicides control competing vegetation (weeds) that impedes growth of cultivated plants.

3.1. Foliar-applied herbicides include:

- **Growth regulators:** affect plant growth by acting on protein synthesis and cell division.
- **Amino-acid synthesis inhibitors:** e.g., **glyphosate**, a post-emergence contact herbicide used against annual and biennial weeds.
- **Membrane disruptors:** bipyridiliums and diphenyl esters damage cell membranes.
- **Photosynthesis inhibitors:** triazines and phenylureas disrupt photosynthetic processes.

3.2. Soil-applied herbicides include:

- **Mitotic inhibitors:** interfere with cell division (chromosome separation and cell-wall formation) in roots.
- **Pigment destructors:** destroy chlorophyll, thereby preventing normal photosynthesis.

By mode of action:

- **Contact herbicides:** act at the point of impact.
- **Systemic herbicides:** absorbed through foliage or roots and translocated within the plant.

Additional Pesticide Types

Beyond the principal categories, intensive agriculture employs other agents:

- **Molluscicides:** control slugs and snails.
- **Rodenticides:** eliminate rodents (e.g., rats and mice), often via internal hemorrhage.
- **Corvicides:** target crows.
- **Fumigants:** disinfect soils.
- **Algicides:** remove algae.
- **Nematicides:** kill root-attacking nematodes, some of which are hazardous to humans.
- **Repellents:** deter pests (birds, insects) without killing them.

Environmental Effects of Pesticides

Pesticides have become essential tools for farmers to intensify agricultural production and meet market demand. Although they protect crops and can increase yields, their detrimental environmental impacts often outweigh their benefits. Pesticides contaminate nearly all components of the environment. While they eliminate certain harmful species, adverse effects include:

- Human health impacts
- Harm to fauna and flora
- Water contamination
- Soil degradation
- Air pollution

1. Soil Contamination

Soil composed of primary minerals from geological weathering and secondary minerals such as clays plays a crucial role in pesticide behavior after application. Excessive use can harm beneficial soil microorganisms, leading to soil degradation. The environmental fate of pesticides retention, transformation, and degradation is influenced by pesticide properties and by the characteristics of soil, water, and atmosphere.

- **Retention:** Pesticides can be retained by vegetation, soil microflora, or humic substances. They may also be taken up by plant roots and leaves, bioaccumulating along food webs and thus exposing humans and animals.
- **Transformation:** Microbial metabolism and photolysis alter pesticides, often reducing toxicity over time. Depending on solar energy and environmental conditions, transformations may lead to full degradation (aiding depollution) or, in some cases, to toxic intermediates.
- **Transport:** Leaching, washing, and runoff can carry pesticides to drainage waters, surface waters, and groundwater.

2. Water Contamination

Pesticides and residues occur in surface waters (streams, lakes) and in groundwater and marine systems. Groundwater pollution by toxic chemicals is a global concern, with detoxification often requiring years and significant expense and complexity. Surface waters intended for drinking generally show low pesticide concentrations, with limited evidence of major health risks at those levels; nevertheless, pesticide presence in drinking water raises concerns due to potential long-term health effects, including cancer and genetic diseases. Moreover, many insecticides, herbicides, and fungicides are toxic to aquatic organisms, thereby impairing ecosystems.

3. Air Contamination

Atmospheric dissemination occurs mainly during application (e.g., spray drift) and through volatilization from plants and soil. Detection of pesticides in rainwater indicates atmospheric contamination, albeit limited to water-soluble compounds. Airborne pesticides can be transported over long distances, with concentrations dependent on product properties, degradability, the nature of treated surfaces/organisms, agricultural practices, application equipment, and climatic and soil conditions.

4. Effects on Species

Many pesticides are harmful to beneficial insects, birds, mammals, amphibians, and fish. Intoxication may occur through direct contact during aerial treatments or ingestion (e.g., treated seeds pose acute risks to granivorous birds, sometimes causing significant mortality). Wildlife exposure pathways include contaminated food or water, inhalation of vapors, and dermal

absorption. Predators may be secondarily poisoned by consuming exposed prey. Numerous insecticides affect the nervous system of wildlife, compromising survival and reproduction.

Additional concerns include:

- **Residues on produce:** Pesticide residues can remain on fruits and vegetables, raising consumer-health concerns; public-health authorities regulate maximum residue levels.
- **Resistance development:** Repeated use can select for resistant pest populations, reducing efficacy and necessitating higher doses or new products.
- **Biodiversity impacts:** Non-target beneficial organisms such as pollinators (e.g., bees) and natural enemies may be adversely affected.

5. Effects on Agricultural Products

Pesticide use can influence crop quality and marketability via residues, resistance pressures, and impacts on post-harvest physiology and storage, necessitating careful residue management and adherence to regulatory standards.

6. Effects on Consumer Health

- **Exposure to residues:** Consumption of foods containing pesticide residues may pose health risks, including potential long-term effects such as endocrine disruption and cancers.
- **Shift to organic products:** In response to concerns about synthetic pesticides, many consumers opt for organically produced foods cultivated without synthetic pesticides.