THE EFFECTS OF PESTICIDES IN WATER RESOURCES
EFECTELE PESTICIDELOR ASUPRA RESURSELOR DE APĂ

Cumhur AYDINALP[1], M. Monica PORCA[2]

[1]Uludag University, Faculty of Agriculture, Department of Soil Science, Bursa 16059, Turkey, e-mail: cumhur@uludag.edu.tr
[2]University of Agricultural Sciences and Veterinary Medicine, Cluj – Napoca, Romania, e-mail: monicaporca@hotmail.com

Manuscript received: February 21, 2004; Reviewed: March 3, 2004; Accepted for publication: March 26, 2004

ABSTRACT
Environmental pollution is concerned problem all around world due to rapid increase of industrialization and urbanization. Especially, the intensive pesticide use has caused some environmental problems in many countries. The major problem occurred in water resources. Therefore, these resources need to be protected from the contamination of pesticides for future sustainable use.

KEY WORDS: water, pesticides, pollution

REZUMAT
Poluarea mediului este o problemă care produce îngrijorarea în întreaga lume, datorită creşterii rapide a ritmului industrializării şi urbanizării. Mai ales, utilizarea pesticidelor produce probleme legate de protecția mediului în multe țări. Problema majoră ese legată de resursele de apă. De aceea, aceste resurse trebuie să fie protejate împotriva contaminării cu pesticide, în vedere utilizării lor durabile.

CUVINTE CHEIE: apă, pesticide, poluare

DETAILED ABSTRACT
Water pollution is an important factor for concerning the quality of environment. Water has been used for many purposes, especially for agriculture, industry, recreation, and household. Nowadays, the quality of surface and ground water is declining due to several reasons. The pesticide in water has become an important problem in many developed countries. The use of pesticides was increased to obtain enough crops in many countries. This intensive use caused surface and ground water pollution. The proper pesticide use is extremely important to protect water resources for future use. In this paper, the causes and effects of pesticide pollution have been discussed and management practices explained briefly.

INTRODUCTION

Water is one of our most precious natural resources in the world. All living organisms depend on water during their life. In addition, people use water for agriculture, industry, recreation, and household. Concerns exist in many countries about the quality of surface and ground water. In recent years, there have been concerns about pesticides entering both surface and ground water in many countries all around the world. It is extremely important that pesticide users understand the processes involved in pesticide contamination of ground and surface water. Those who apply pesticides have a responsibility to use practices that minimize off-site movement of pesticides. Both surface water and ground water need to be protected from the introduction of pesticides. Groundwater is much more serious problem because pesticides do not degrade there as rapidly as in other environments, dilution of the contaminant concentration does not occur as rapidly, and ground-water is commonly used for irrigation and for drinking by man and domestic animals.

A fundamental contributor to the Green Revolution has been the development and application of pesticides for the control of a wide variety of insectivorous and herbaceous pests that would otherwise diminish the quantity and quality of food produced. The use of pesticides coincides with the 'chemical age', which has transformed society since the 1950s. In areas where intensive monoculture is practiced, pesticides were used as a standard method for pest control. Unfortunately, with the benefits of chemistry there are also disbenefits, some so serious that they now threaten the long-term survival of major ecosystems by disruption of predator-prey relationships and loss of biodiversity. Also, pesticides can have significant consequences on human health. While agricultural use of chemicals is restricted to a limited number of compounds, agriculture is one of the few activities where chemicals are intentionally released into the environment because they kill things. The term 'pesticide' is a composite term that includes all chemicals that are used to kill or control pests. In agriculture, this includes herbicides (weeds), insecticides (insects), fungicides (fungi), nematocides (nematodes), and rodenticides (vertebrate poisons). The modern era of pest control with synthetic organic pesticides began in the early 1940's with the introduction of the insecticide DDT and the herbicide 2,4-D. Since that time, many other pesticides have been developed for a variety of crop protection purposes, and their volume of use has increased tremendously. Pesticides have been found frequently in surface water; in the last several years, they have also been found in groundwater [1].

DESCRIPTION OF THE PROBLEM

Water contamination is directly related to the degree of pollution in our environment. As a result, the hydrologic cycle may be affected on many levels. After airborne pollution is flushed from the sky by rainwater, it is washed over land before running into rivers, underground aquifers, and lakes. Since drinking and irrigation water come from surface and ground water, any chemical used may pollute water supplies (Figure 1) [2].

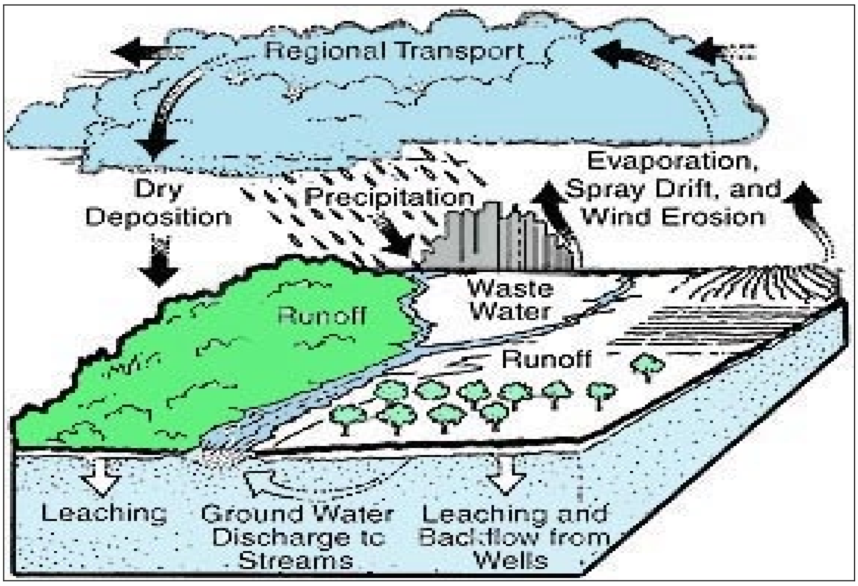

Figure 1: Pathways of pesticide movement in the hydrologic cycle [2]
Figura 1: Căile circulației pesticidelor în ciclul hidrologic [2]

All pesticides are toxic to some degree. For some of them, only a very small amount is needed to cause acute or chronic effects; others are no more toxic than many materials in everyday use. To be prudent, inadvertent water contamination with any pesticide should be avoided. About 800 million pounds of pesticides are used annually in the United States [1]. The major classes of pesticides used in agriculture are herbicides, insecticides, and fungicides. Herbicide use has increased most rapidly during the last 15 years. Today herbicides account for about 85 percent of the pesticides used in agriculture, insecticides 13 percent, and fungicides the remaining 2 percent in the United States [1].

Contamination of surface water is less serious than is the case for ground water. Most surface waters (except deep lakes) have a rapid turnover rate, which means that fresh water dilutes the concentration of the contaminant quickly. In addition, most surface waters contain free oxygen, which enhances the rate at which pesticides are broken down by microorganisms. Contamination of surface waters should not be treated casually, however. An extremely toxic pesticide can cause the death of fish and other aquatic organisms even at low concentrations.

Pesticides in groundwater are an extremely serious problem. The turnover rate for groundwater may be as short as a few months, but more commonly years and decades are needed to replace the water in an underground aquifer. Oxygen is absent in ground water, and the microorganisms that live in an oxygen-free environment are much less effective in breaking down pesticide chemicals. Extremely slow dilution and breakdown means that the contaminant will be present for a long time.

The most critical hazard of contaminated groundwater is the potential for toxic effects in man and domestic animals that drink the water. In addition, because herbicides account for about 85 percent of the pesticide used in agriculture [1], there is the possibility that ground water contaminated with a herbicide may be used for irrigation and cause damage to crops.

Contamination of an underground aquifer cannot be easily corrected. Doing so requires drilling purge wells and pumping the water to the surface. Pumping may have to be continued for a long time to remove all the contaminated water. The process is extremely expensive. Preventing groundwater contamination is the best solution to what could be a hazardous situation.

Numerous instances of groundwater contaminated with pesticides have been identified. In some cases, small communities have had to use bottled water until other sources of drinking water were developed. At this time, the full extent of groundwater contamination is not known. Pesticides have been found in groundwater in numerous instances, however, and it seems apparent that more instances will be discovered as more and more underground aquifers are sampled and tested for the presence of pesticides [3].

The history of pesticide development and use is the key to understanding how and why pesticides have been an environmental threat to aquatic systems, and why this threat is diminishing in developed countries and remains a problem in many developing countries. Stephenson and Solomon [4] outlined the chronology presented in Table 1.

Table 1: Chronology of pesticide development [4]

Tabelul 1: Cronologia dezvoltării industriei pesticidelor [4]

Period	Example	Source	Characteristics
1800-1920s	Early organics, nitro-phenols, chlorophenols, creosote, naphthalene, petroleum oils.	Organic chemistry, by-products of coal gas production, etc.	Often lack specificity and were toxic to user or non-target organisms.
1945-1955	Chlorinated organics, DDT, HCH, chlorinated cyclodienes.	Organic synthesis	Persistent, good selectivity, good agricultural properties, good public health performance, resistance, harmful ecological effects.
1945-1970	Cholinesterase inhibitors, organophosphorus compounds, carbamates.	Organic synthesis, good use of structure-activity relationships.	Lower persistence, some user toxicity, some environmental problems.
1970-1985	Synthetic pyrethroids, avermectins, juvenile hormone mimics, biological pesticides.	Refinement of structure activity relationships, new target systems.	Some lack of selectivity, resistance, costs and variable persistence.

Table 2: The ecological impacts of pesticides in water [1]
Tabelul 2: Impactul ecologic al pesticidelor asupra apei [1]

Toxicity:	Mammalian and non-mammalian toxicity usually expressed as LD_{50} ("Lethal Dose": concentration of the pesticide, which will kill half the test organisms over a specified test period). The lower the LD_{50}, the greater the toxicity; values of 0-10 are extremely toxic [5]. Drinking water and food guidelines are determined using a risk-based assessment. Generally, Risk = Exposure (amount and/or duration) × Toxicity. Toxic response (effect) can be acute (death) or chronic (an effect that does not cause death over the test period but which causes observable effects in the test organism such as cancers and tumors, reproductive failure, growth inhibition, teratogenic effects, etc.).
Persistence:	Measured as half-life (time required for the ambient concentration to decrease by 50%). Persistence is determined by biotic and abiotic degradational processes. Biotic processes are biodegradation and metabolism; abiotic processes are mainly hydrolysis, photolysis, and oxidation [6]. Modern pesticides tend to have short half-lives that reflect the period over which the pest needs to be controlled.
Degradates:	The degradational process may lead to formation of "degradates" which may have greater, equal or lesser toxicity than the parent compound. As an example, DDT degrades to DDD and DDE.
Fate (Environmental):	The environmental fate (behavior) of a pesticide is affected by the natural affinity of the chemical for one of four environmental compartments [6]: solid matter (mineral matter and particulate organic carbon), liquid (solubility in surface and soil water), gaseous form (volatilization), and biota. This behavior is often referred to as "partitioning" and involves, respectively, the determination of the soil sorption coefficient (K_{OC}); solubility; Henry's Constant (H); and the n-octanol/water partition coefficient (K_{OW}). These parameters are well known for pesticides and are used to predict the environmental fate of the pesticide.

The ecological impacts of pesticides in water are determined by the following criteria in Table 2.

An additional factor can be the presence of impurities in the pesticide formulation but that are not part of the active ingredient. A recent example is the case of TFM (3-trifluorometthy-l-4-nitrophenol), a lampricide used in tributaries of the Great Lakes for many years for the control of the sea lamprey. Although the environmental fate of TFM has been well known for many years, recent research by Munkittrick et al. [7] has found that TFM formulation includes one or more highly potent impurities that impact on the hormonal system of fish and cause liver disease.

FACTORS OF CONTAMINATION

Point and Nonpoint Source Pollution

Pesticides can move into ground and surface water by both point and nonpoint source pollution (Figure 2).

Point source pollution occurs when pollutants originate from a single event or fixed site. Point source events include chemical runoff during improper storage, mixing/loading, disposal or misapplication to water bodies. One common type of point source pollution is called run-in, the direct movement of pesticides into ground water. Run-in occurs near wells as a result of pesticide spills, back-siphoning, careless or improper disposal of pesticide waste or faulty well construction or maintenance.

Nonpoint source pollution is the movement of pesticides from broad areas across watersheds over time into ground and surface water. The gradual leaching of nutrients into ground water is an example of nonpoint source pollution. Runoff (water flow) and erosion (soil particles) are common forms of nonpoint source pollution of surface water from agriculture. Most pesticides used in crop production in many agricultural lands are subject to loss in the first runoff event while dissolved in the water, not while attached to the sediment. Pesticides are most

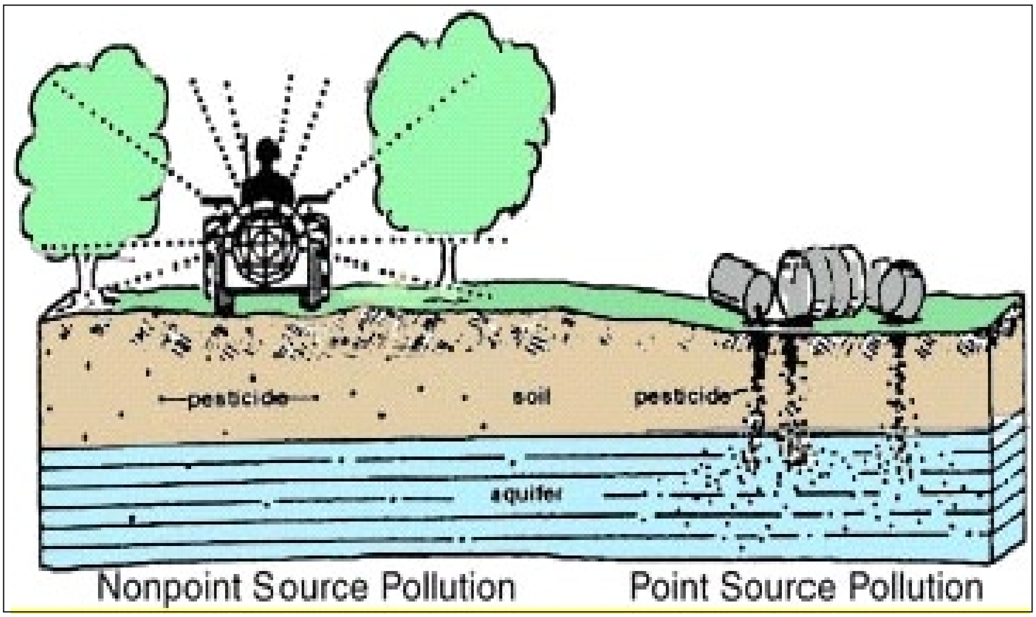

Figure 2: Pesticides can enter water supplies from point sources or from nonpoint sources [2]
Figura 2: Pesticidele pot pătrunde în rezervele de apă din sursele directe sau indirecte [2]

susceptible to runoff immediately after application when they are in the "mixing zone." The mixing zone is a thin layer (0.25 to 0.85 cm) at the soil surface. Once the chemical has leached or been placed below the mixing zone, it is much less susceptible to runoff.

FACTORS INVOLVED IN THE POLLUTION CONTROL

The movement of pesticides into water depends upon pesticide properties, climate, soil and geologic properties. These factors determine which strategies should be selected to reduce pesticide movement in any given situation. Some factors, which reduce the potential for ground water contamination, may increase the potential for surface water contamination.

a) Pesticide Properties

Four pesticide properties determine the tendency of pesticides to leach or runoff. These include adsorption, solubility, persistence, and volatilization. These processes determine the pesticide's tendency for movement to ground or surface water.

Adsorption: Pesticides that are sprayed and lands on the soil surface binds or 'sticks' to the soil particles and organic matter in varying degrees, in a process called adsorption. Some herbicides such as paraquat are strongly adsorbed while others such as atrazine are only weakly adsorbed. The degree of soil adsorption depends determines to a large degree how a pesticide is lost. A herbicide that is strongly adsorbed is lost mostly with sediment during runoff and are less apt to leach to ground water. Pesticides that are moderately or weakly adsorbed are lost mainly in surface runoff water and more likely to leach. Adsorption may be the most important chemical characteristic determining environmental fate.

Solubility: Solubility is the capacity of a chemical to dissolve in water. Solubility is often expressed in milligram per liter (mg/l) or part per million (ppm). Chemicals with a high solubility are generally easily detached in water and leaching is the primary concern. Chemicals with solubility of less than 1.0 ppm are normally strongly adsorbed or attached to sediment and loss to surface waters via soil erosion is the primary environmental concern.

Persistence: Persistence refers to how long it takes for a chemical to dissipate or disappear from the environment. Persistence will determine the length of time the pesticide is available for environmental loss as well as controlling pests. The rate of breakdown is influenced by microbial activity, chemicals reactions, and photo degradation (exposure to sunlight). Persistence can be expressed in terms of half-life, or the time required for one-half of the pesticide to discompose to products other than the original pesticide.

Volatilization: Volatilization occurs when a chemical changes from a liquid or solid to a gas. This gas is usually not a threat to water supplies, although pesticide volatilization may harm off-target plants or contribute to pesticide levels in rainwater. Volatilization can reduce the total amount of chemical available for movement to ground or surface water.

b) Climatic Factors

Several climatic factors are important in determining the amount of pesticide loss to surface or ground water.

Rainfall duration / amount: The amount and duration of rainfall influences the total volume of runoff and percolation and how much chemical is washed off from plant surfaces. The greater the rainfall amount and duration the greater the potential runoff of a pesticide.

Rainfall timing: The closer the rainfall event occurs following application, the greater the potential for leaching or runoff.

Rainfall intensity: As rainfall intensity increases, runoff rate is increased and more pesticide is detached from the soil surface into runoff. Lower intensity storms may move the pesticide into the soil below the soil surface before runoff begins.

Time to runoff after rainfall begins: The amount of soil water present prior to rainfall will affect the amount of pesticide runoff. The wetter the soil surface, the sooner runoff occurs after rainfall begins. The availability of pesticides for runoff losses is greatest early in the runoff event. Any precipitation that soaks into the soil prior to runoff may transport some of the pesticide down below the mixing zone. Any factor that increases the time between the start of the rainfall and the initiation of runoff will reduce runoff losses.

c) Soil and Geologic Properties

The characteristics of a site can have a major impact on pesticide movement to surface or ground water. These site characteristics include hydrologic soil group, soil permeability, organic matter, soil erodibility, soil texture, soil pH, flooding potential and geologic conditions and depth to ground water.

Hydrologic Soil Group: Soils are categorized into four hydrologic groups (A, B, C, and D). Hydrologic group D soils have the highest runoff potential, followed by C, B, and A soils. The reverse would be true for leaching potential.

Soil Permeability: Soil permeability is a measure of how fast water moves through a soil. Highly permeable soils, such as coarse sandy soils, have greater potential for pesticides to leach through than do clay soils, which are less permeable. Soils that are less permeable have greater potential runoff compared to highly permeable soils.

Organic Matter: A soil with higher organic matter will have more pesticide adsorbed to the soil, thus reducing detachment and leaching but may have a higher runoff potential because more of the chemical is retained in the surface zone of the soil.

Soil Erodibility: Practices that reduce soil erosion will reduce the amount of pesticide lost if the pesticides are those that are strongly adsorbed to soil particles.

Soil Texture: Soil texture plays an important part in whether leaching or runoffs of pesticides occur. A soil with high clay content will have higher potential for runoff and less potential for leaching compared to a coarse textured, sandy soil.

Soil pH: Soil pH will affect the electrical charge of certain pesticides. The electrical charge will determine the type and degree of adsorption. Soil pH can also affect the chemical and/or microbial degradation.

Flooding Potential: Flooding can have a large effect on the amount of pesticides lost to surface water.

Geologic Conditions and Depth to Ground Water: Geologic conditions and depth to ground-to-ground water also determine the likelihood of pesticides leaching to ground water.

STRATEGIES FOR REDUCING PESTICIDE LOSS TO SURFACE OR GROUND WATER

Adjusting pesticide management strategies can be effective in reducing the movement of pesticides to ground or surface water.

1. Reduce the amount of product available for loss. There is a direct correlation between the rate of pesticide applied and the amount that is lost to water. The higher the rate, the greater the potential loss. Practices that may allow lower field application rates - such as banding, using split applications, reducing the application rate, tank mixes, and foliar applications - may reduce leaching and runoff losses.

2. Reduce storage and handling losses. Losses can be minimized by preventing back siphoning accidents, assuring proper pesticide storage, mixing, handling, and disposal, and proper well construction and maintenance.

3. Reduce potential for detachment from the soil. Methods that reduce the potential for detachment from the soil surface will reduce the chances of contaminant from pesticides. For example, to reduce leaching losses, you could select a product or a formulation, which is more strongly bound to the soil surface and therefore less likely to move with percolating water. Where applicable, incorporation of pesticides into soil can reduce the potential for detachment.

4. Reduce potential for transport. Any practice that reduces the amount of water that leaves the root zone will reduce leaching losses. Transport to surface water occurs as a result of both runoff and sediment loss. For

pesticides dissolved in runoff water, any practice that delays the onset after rainfall begins, or reduces the total amount of runoff, will reduce the amount of pesticide loss in runoff.

5. Provide a mechanism for deposition. Filter strips, buffer zones, grass waterways, etc. can slow the velocity of runoff leaving a field and help increase water infiltration, adsorption onto soil or organic matter, or adsorption onto vegetative matter. This will reduce the amount of pesticide being lost from a field.

CONCLUSION

It is important that solutions for agrochemical waste management on farm are effective and safe to the environment, however it is equally important that they are practical, economic and do not over burden the farmer.

It is the industry's view that better disposal practice on farm will significantly reduce the risk of water contamination and that local on-farm disposal techniques such as biobeds and container incineration present the best available and most environmentally acceptable techniques without incurring excessive costs.

REFERENCES

[1] Ongley, E.D. 1996. Control of Water Pollution from Agriculture. FAO Irrigation and Drainage, Paper 55, FAO, Rome.

[2] Stevenson, D.E., Baumann, P. and Jackman, J.A. 1997. Pesticide Properties that Affect Water Quality. Texas A&M Agricultural Extension Service Pub. B-6050.

[3] Tschirley, F. 1990. Managing pesticides to avoid surface and groundwater contamination. Cooperative Extension Service, Michigan State University.

[4] Stephenson, G.A. and Solomon, K.R. 1993. Pesticides and the Environment. Department of Environmental Biology, University of Guelph, Guelph, Ontario, Canada.

[5] OMAF, 1991. Grower Pesticide Safety Course. Ontario Ministry of Agriculture and Food, Toronto, Ontario, Canada.

[6] Calamari, D. and Barg, U. 1993. Hazard assessment of agricultural chemicals by simple simulation models. In: Prevention of Water Pollution by Agriculture and Related Activities. Proceedings of the FAO Expert Consultation, Santiago, Chile, 20-23 Oct. 1992. Water Report 1. FAO, Rome. pp. 207-222.

[7] Munkittrick. K.R., Servos, M.R., Parrott, J.L., Martin, V., Carey, J.H., Flett, P.A. and Van Der Kraak, G.J. 1994. Identification of lampricide formulations as a potent inducer of MFO activity in fish. J. Great Lakes Research 20: 355-365.