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Agriculture's Impact on Groundwater in South Dakota

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QUESTIONS & ANSWERS

Concerning

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In the last 10 years, American agriculture has been increasingly accused of polluting the nation's groundwater resources.

Groundwater pollution is a highly visible public issue. This publication uses current, research-based information to answer selected, commonly asked questions about agriculture's impact on groundwater. To tell us what the scientific community understands about this impact, the most frequently asked questions are divided into four categories:

1) Agricultural management practices.
2) Movement of agricultural chemicals through soil.
3) Impacts of agricultural chemicals on groundwater.
4) Impacts of agricultural chemicals on health.

Agricultural Management Practices

QUESTION: **Is there anything farmers can do to minimize our nation's groundwater contamination problem?**

ANSWER: *Yes, every farmer's management decisions impact our nation's water resources.* Implied in this question voiced by many farmers is the perception that our nation's groundwater problem is so large that anything a single farmer does is futile. The solution to the large national problem rests with solutions to problems on every individual farm and in each individual field. The more prudently farmers apply fertilizers and pesticides, the less potential there is for contamination by these applications.

QUESTION: **Will more prudent use of agricultural chemicals have an impact on our nation's food and fiber supplies?**

ANSWER: *If prudent use just means reducing fertilizer and pesticide use, there is likely to be a parallel reduction in the nation's total agricultural production capacity.* As long as global population growth continues, the world and our nation will experience an ever-increasing demand for agricultural produce. This demand has resulted (at least within the 19th and 20th centuries) in an increase in farming intensity across the U.S., including South Dakota.

Prudent use can mean increasing management intensity (and actively considering environmental impact within the framework of the decision-making process). In this way farmers may be able to maintain and increase food and fiber production while minimizing the potential impact of agricultural chemicals on our groundwater.

QUESTION: **Is the timing of the application of fertilizer and pesticide important or are we concerned only about total amount applied? There has been considerable indictment of fall-applied fertilizer in particular.**

ANSWER: *One of the most effective management practices is to synchronize the timing of agricultural chemical application with the period of greatest nutrient need (fertilizers) or the period of greatest efficacy for controlling the target pest (pesticides).*

Application of nitrogen fertilizer close to, but prior to, the time of greatest need increases the potential for efficient fertilizer use. Since a greater percentage of fertilizer ends

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up in the plant, less is available to be lost to leaching and/or runoff. Similarly, pesticides usually are most effective when applied during the most vulnerable periods of the pests' growth cycles. This effectiveness reduces the need for subsequent applications. Pesticides applied shortly before a rainfall can be washed off and not affect the targeted pest. It is shortly after application (before attachment to plants and soil) that pesticides have the greatest potential to be leached into and through the soil profile.

Movement of Agricultural Chemicals through the Soil

QUESTION: Are all agricultural chemicals dangerous and, once applied, will they eventually end up in our water resources?

ANSWER: *There is danger associated with almost any concentrated chemical compound. Most agricultural chemicals are not stable and break down into inert compounds within a relatively short time.*

Every pesticide or fertilizer formulation has physical and chemical properties that contribute to its uniqueness as a compound and determine its ability to volatilize, to move, or to break down into inert substances. Knowledge of these properties allows scientists to predict the behavior and fate of a compound after it has been applied to a soil. Some agricultural chemicals have a high probability of leaching to ground water resources, while other compounds have a very low probability of moving.

These physical and chemical properties of chemical compounds are important:

- solubility
- sorbtivity
- half life
- concentration

The solubility of a compound partially determines the ability of the compound to move with water. Solubility can be explained best by using an example of two common compounds -- table salt, NaCl, and gypsum, $CaSO_4$, the basic material in wall board. Both are water soluble salts. If you place about a tablespoon of each into a glass of water, the table salt will totally dissolve while the gypsum will only partially dissolve. If a tablespoon of table salt and a tablespoon of gypsum were placed on the soil surface before a 2-inch rain, the table salt would all wash down into the soil while most of the gypsum would be left behind.

This same type of response occurs with different pesticides and fertilizers. Highly soluble chemicals will wash into and through the soil profile more readily than less soluble compounds.

The sorbtivity of a compound can best be understood by using an example. What happens when dust is poured over a highly waxed auto? Over an auto covered with double-sided scotch tape? We would say the dust sorbed to the Scotch tape, but it did not readily sorb to the waxed auto. The same phenomena occurs when water laced with different chemicals flows through the soil profile. Some chemical will sorb to the soil as the solution flows through, and some will not.

The length of time a compound will maintain its identity as a pesticide -- its longevity after being applied to soil or leaves -- varies greatly from one compound to another. Scientists describe this longevity of a compound in terms of its half life. Half life is the time it takes for one half of the compound to break down. The actual, field half life of a compound varies greatly with the management practices of the farmer. For example, a farmer can soil-apply or foliar-apply the same compound. Under each circumstance, the life expectancy will be different.

Rates of application of active ingredient vary greatly from one compound to another. Lowering the total amount of a compound that is applied (assuming the toxicity of the compounds to nontargeted life forms remains constant) reduces the pollutant risk associated with that compound.

How can the average farmer use this information in the management of pesticide applications to minimize the impact of agriculture on the environment? With computers to help us, we can understand how the physical and chemical considerations described here can be integrated into farm management decisions. USDA scientists have used this information to develop the Goss index (available in SDSU Farm*A*Syst material) which categorizes chemicals into high-, medium-, and low-leaching compounds. A Goss index categorization is available to help us predict the relative leaching and/or runoff hazard associated with the use of most labeled compounds.

QUESTION: Do no-till farming systems greatly increase the likelihood of ground water contamination?

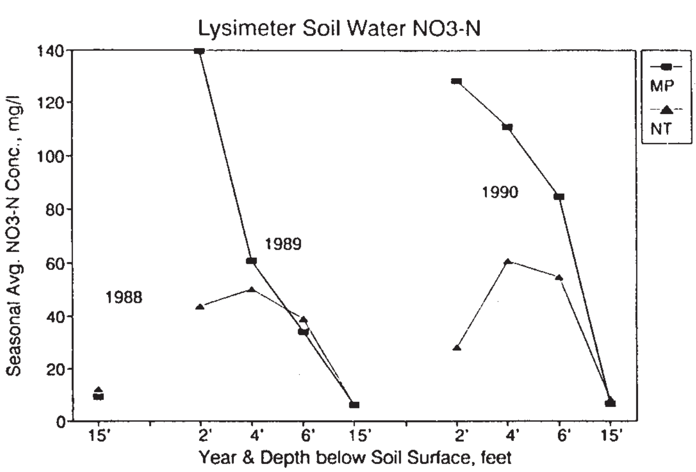
ANSWER: Research conducted in South Dakota and other states over the last several years has provided information about how tillage systems affect the way agricultural chemicals move to ground and surface water systems. *There are circumstances under which no-till increases the likelihood for movement of pollutants to the groundwater, and there are circumstances under which the potential is decreased.*

Generally, the tillage system used by a farmer determines the soil structure of his cropped land. Under native prairie conditions, extensive surface water holding capacity develops because of the accumulation of previous years' growth. Along with increased surface holding capacity, there are extensive macropores (big pores or holes in the soil profile). The increased surface holding capacity and the extensive macropore system result in rapid and relatively deep movement of rain water below the soil surface. Compounds dissolved in the water that flows over surface trash or the soil surface are moved deep into the soil profile and perhaps into the groundwater system. No-till farming results in a hydrologic system that is somewhat similar to native prairie.

Recently a study indicated (Bischoff, et al 1992) that the nitrate-nitrogen loading to the groundwater is higher under no-till than moldboard plow tillage when high amounts (200 lbs N/Ac) of broadcast fertilizer are applied to corn (Figure 1). Under a higher rainfall year (1990 compared to 1989), the average seasonal concentration of NO_3 - N from samples of water taken from the soil profile during leaching events was higher deeper in the soil profile for both NT and MP. The MP treatments still had higher NO_3 - N concentrations than NT. This may have greater impact to groundwater resources in areas of shallow soils over shallow aquifers than in areas of no aquifers.

Conventional tillage systems that utilize the plow and disk or field cultivator remove much of the natural surface water holding system and most of the the macropore system. Water flowing vertically through the conventionally tilled soil profile moves much slower and has the capability to dissolve more soil-mixed compounds. More water is held higher in the soil profile with this type of system.

Figure 1. Seasonal average NO_3 - N concentrations of water samples collected from soil lysimeters on corn.



No-till farming practices, compared to conventional tillage, decrease the amount of runoff and increase the amount of water that percolates deep within the soil profile. (Bischoff, et al, 1990.)

QUESTION: Where does the rainfall or irrigation water that falls on a cultivated field end up?

ANSWER: *There are three possible destinations for this water. It could stay in the soil profile and be evaporated or used by plants, it could run off, or it could move below the effective plant root zone and into groundwater.*

We hope that most of the water that falls on a cultivated field will stay in the soil and be available for plant root uptake. Some of the water is needed to infiltrate into groundwater systems to recharge aquifers. Some is needed to replenish streams, rivers, potholes, and lakes.

Since many of our cultivated crops are short lived, they are vegetative and use water for less than 1/3 of the year. In South Dakota, it is early in the growing season when the probability of precipitation is the greatest and there are small, actively growing plants available to intercept the downward moving water.

Intense rainfall and excessive irrigation rates result in more runoff than low-intensity, steady rainfall or moisture application.

QUESTION: What nitrogen fertilizer application methods provide the least risk for groundwater contamination?

ANSWER: *There are two ways farmers can minimize the impact of fertilizer on the environment. The first is to use ammonia-based fertilizer with inhibitors that reduce the rate at which the ammonia converts to the nitrate form.* Ammonia attaches to soil and is not readily moved with water flow.

A second method, presently being researched, is to split the nitrogen applications (Kanwar et al, 1988). Since the highest rainfall months in South Dakota are usually May and June, dividing nitrogen fertilizer into three applications -- planting, June15, and July 15 -- will provide the plants with nutrient when they need it most. This reduces the amount of time the nitrogen is vulnerable to leach. Results of a 3-year study in Iowa on split application of N using 40% less nitrogen on no-till compared to moldboard plow for continuous corn showed no significant differences in corn yield but significantly lower NO_3 - N concentrations from subsurface drainage water.

Impact of Agricultural Chemicals on Groundwater

QUESTION: How has the American farmer's extensive use of fertilizer and pesticide impacted our environment? Have we created an environmental mess with ground water pollution being the greatest problem?

ANSWER: *The American farmer has not created an environmental mess. He has provided the consuming public with the safest and best quality food and fiber in the world. Surveys conducted for the South Dakota Rural Clean Water Program have concluded that South Dakota farmers are committed to using practices that allow them to produce food and fiber in an environmentally safe manner.*

The most comprehensive nationwide study of the impact of agriculture on groundwater resources was conducted by the U.S. Environmental Protection Agency in the late 1980's. The Phase I results of the "National Survey of Pesticides in Drinking Water Wells" were published in

Table 1. Community Water Systems

Nitrate	52%
DCPA	6.4%
Atrazine	1.7%
Simazine	1.1%

This is a partial list that includes only presently registered and used compounds

Table 2. Rural Domestic Wells

Nitrate	57%
DCPA	2.5%
Atrazine	0.7%
Prometon	0.2%
Simazine	0.2%
gamma - HCH	0.1%
Ethylene thiourea	0.1%
Bentazon	0.1%
Alachlor	0.1%

This is a partial list that includes only presently registered and used compounds

Table 3. How are these compounds, detected in the EPA study, used in South Dakota?

Nitrate	*Nitrogen is an essential plant nutrient that is applied extensively as fertilizer at rates as high as several hundred pounds per acre to crops such as corn, wheat, and other non legumes.*
DCPA	*Is the herbicide commonly called Dacthal and is used to control annual grasses in lawns, and to a lesser extent in the production of fruits, and vegetables.*
Atrazine	*Is the herbicide called Aatrex or atrazine and is used extensively in the production of corn and sorghum.*
Prometon	*Is the herbicide called Primatol and is used to control all vegetation around homes and farmsteads.*
Simazine	*A herbicide commonly referred to as Princep used extensively in shelterbelts and around farmsteads.*
gamma - HCH	*An insecticide commonly referred to as Lindane not used extensively in South Dakota.*
Ethylene thiourea	*A fungicide referred to as ETU used on flowers and vegetables but not used extensively in South Dakota.*
Bentazon	*The herbicide commonly known as Basagran used to control broadleaf weeds in soybeans.*
Alachlor	*The herbicide commonly known as Lasso used to control annual grasses and other weeds in corn and soybeans.*

November 1990. In this study, EPA collected samples from 540 community water systems (systems serving multiple household users) and 752 rural domestic wells (single-family farmsteads). The samples were analyzed for nitrates and an assortment of commonly used agricultural pesticides. Tables I and II show compounds currently used by South Dakota farmers that were found. Table III describes how those compounds are used in South Dakota.

For those involved daily in production agriculture, the most striking conclusion of this study was the fact that the mainline agriculture production pesticides (with the exception of atrazine) were absent or found in only one well out of the more than 500 wells sampled. Perhaps most important is the fact that, even when found, the concentrations of mainline agricultural pesticides were usually at levels far less than what is considered to be the safe concentration for use as drinking water.

Nitrate-nitrogen (NO_3 - N) is found in many aquifers and comes from the decomposition of organic matter and fertilizer. Many scientists consider nitrate-nitrogen contamination to be the most difficult problem in the immediate future. It is necessary to have adequate concentrations of nitrate-nitrogen in the soil for optimum crop production. There are only limited alternatives to nitrogen fertilization, and all have significant drawbacks.

From this study, it can be concluded that there's room for significant concern, but it should not revolutionize the way we farm. Rather, this concern should point us toward agricultural production practices which maintain our abundant supply of quality food stuffs while minimizing our negative impact on the environment. The most critical part of this process is educating farmers about how farming practices impact our environment and, most specifically, our water resources.

QUESTION: Are all aquifers and groundwater systems equally vulnerable to contamination by agricultural chemicals?

ANSWER: *There are considerable vulnerability differences from one field (soil and geological profile) to another.* To predict the vulnerability of a specific field, you must know the soils and geology of the area. There are fields in South Dakota highly vulnerable to aquifer contamination from farming practices. However, the majority of fields in the state carry little risk of aquifer contamination from farming practices.

The ability to conduct water through the soil profile varies from one soil to another. There is little question that the greater the ability to conduct water, the greater the potential for contamination to move deeper into the profile when compounds are present in the infiltrating water. Vulnerability increases as the soil profile's hydraulic conductivity increases (ability of water to move within the soil).

The makeup of the soil/geological profile between the land surface and an aquifer determines the specific vulnerability of an aquifer. Three typical profiles represent most soil/geological profiles in South Dakota. Figure 2 shows soil (usually less than 20 feet) over a sand and gravel aquifer.

Oxidized = medium permeability
Unoxidized = low permeability
Sand & gravel = high permeability

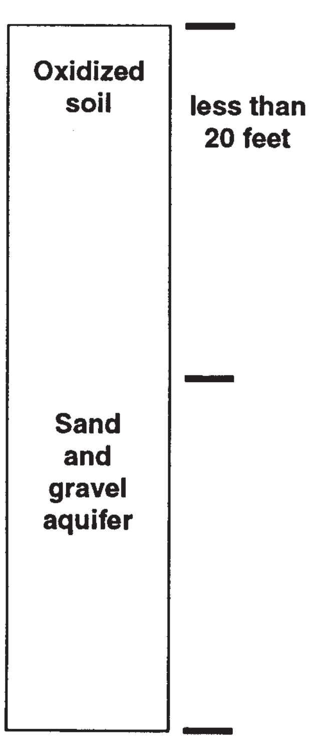


Figure 2.

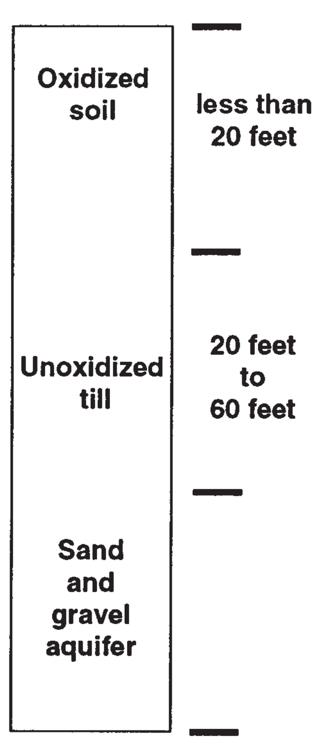


Figure 3.

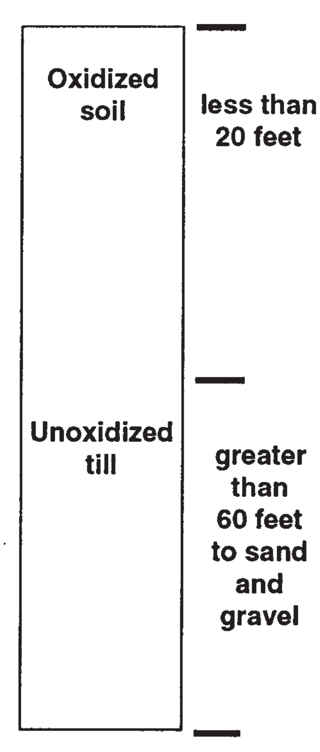


Figure 4.

Figure 3 shows oxidized soil over less than 20 to 60 feet of unoxidized glacial till over a sand and gravel aquifer. The profile in Figure 4 shows oxidized soil over unoxidized till; in this case, there is a limited, or perhaps even no, hydraulic connection between the soil profile and the unoxidized till.

South Dakota has good examples of all three soil profiles. The profile in Figure 2 is highly vulnerable and agricultural chemicals must be applied with great caution. Figure 4 illustrates a profile where farming will have little or no impact on the aquifer because of the limited hydraulic connection between the surface and the aquifer.

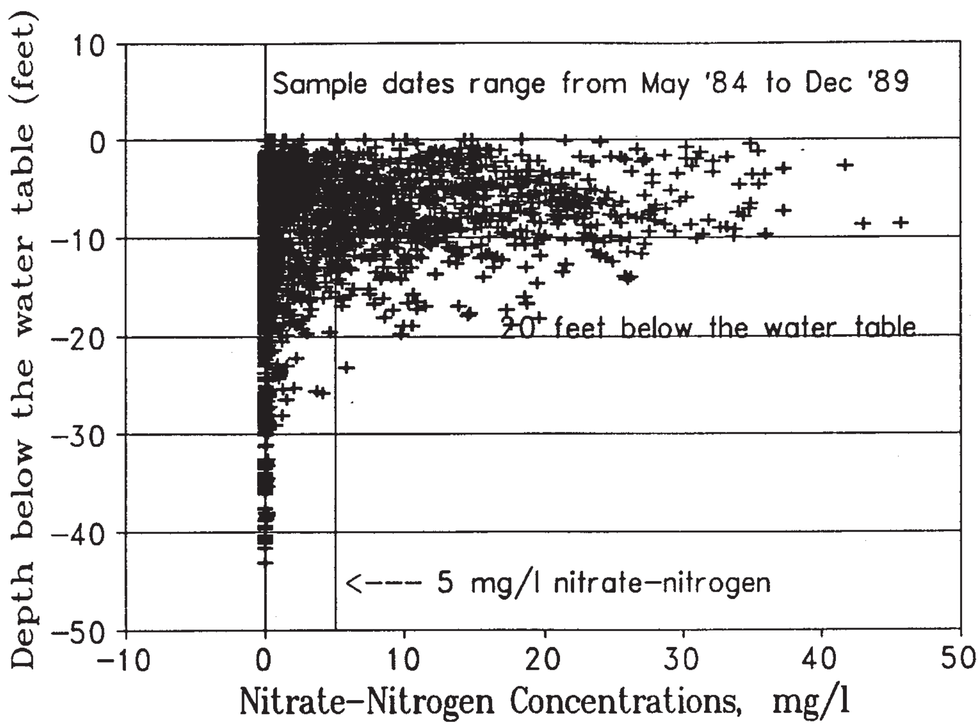


Figure 5. How the concentration of Nitrate-Nitrogen changes with depth within groundwater.

QUESTION: What happens to nitrates when they reach the groundwater?

ANSWER: *Unfortunately, scientists do not understand well the "fate" of nitrogen compounds that reach the groundwater.* Samples can be taken and chemically analyzed to determine the concentrations of nitrate-nitrogen in the aquifer's water at a point in time.

A more difficult question that is unanswered: How old is the nitrate-nitrogen found in groundwater samples and where did the nitrate-nitrogen come from? A recent study (Gillham et al, 1990) examined the degradation of nitrate-nitrogen while it was in shallow groundwater. The study found that approximately half of the nitrate-nitrogen present in a sample volatized off into nitrous oxide in less than 2 weeks while the concen-tration of a conservative tracer (bromide) did not change.

From the studies of the Rural Clean Water Program in South Dakota, it was found that for several different types of geological profiles, the concentration of nitrates found in the groundwater (taken from 118 shallow wells 8-50' deep) decreased with the depth below the water table from which the sample was taken (Figure 5). This means that if someone is using groundwater for drinking purposes, they should try to withdraw water far below the water level to reduce the possibility of nitrate-nitrogen contamination. (The system design must be such that the pumping rate does not introduce too much nitrate through the cone of depression.)

QUESTION: Do methods of pesticide and fertilizer application affect groundwater quality?

ANSWER: *Methods of applying pesticide and fertilizer have considerable impact upon the potential for compounds to move.*

Once we understand soil structure and geology, the importance of how fertilizer and pesticides are applied becomes more significant. Fertilizer and pesticides applied to a no-till field, and not afforded sufficient time to adsorb to the soil or organic matter before irrigation or precipitation, will undoubtedly move deeper into the profile in a shorter amount of time.

If ammonia-based fertilizer is banded into the soil and highly adsorbing pesticides are used, the water flowing through the soil profile of a no-till field usually will be of relatively good quality. It is important to note that some of the best quality water on the plains is found in shallow aquifers under native prairie conditions.

In a recent study of nitrate-nitrogen contamination of groundwater, grassed-soil profiles had nitrate-nitrogen concentrations of 2 ppm while the concentrations on an irrigated corn field ranged from 20 to 60 ppm. (Bischoff and Carlson, 1991.)

Conventional tillage is a process that mines organic matter by breaking it down into a less stable nitrogen form. Tillage by itself increases the nitrate-nitrogen content of a soil profile. Water flowing through shallow, tilled, farmed fields tends to be quite high in nutrients (with the implication that pesticides also may be moving with the water). (Bischoff and Carlson, 1991.)

QUESTION: Do scientists fully understand the movement and transport of agricultural chemicals through soils into the groundwater?

ANSWER: *While soil scientists, geologists, and engineers have a thorough understanding of their individual areas of interest, it has only been in the last 10 years that groups of scientists with different specialties have worked together to study chemistry, hydraulics, soils, microbiology, and groundwater and developed a more inclusive understanding of the mechanisms for flow, the fate of agricultural chemicals and fertilizers, and the recharge areas and flow within aquifers.*

The public has realized that surface and groundwater quality may be affected by the practices applied at the surface. How quickly specific pesticides break down and what is the toxicity to humans of these pesticides and their metabolites (broken down compounds) in the concentrations found is still being researched.

What is the best environment and what are the best micro-organisms to break down certain chemicals to inert compounds? These questions can not be answered with any degree of certainty until more research is completed.

Impacts of Agricultural Chemicals on Human Health

QUESTION: Are fertilizers harmful to humans if they ingest them?

ANSWER: *Consumption of drinking water containing nitrate-nitrogen at concentrations greater than 10 mg/l (the EPA drinking water standard) is dangerous to babies and small children.* Investigations of most of the situations where infants have become sick or even died from ingesting high-concentration nitrate water have traced the source of contamination to animal wastes rather than to the field application of fertilizer. That is not to imply that danger does not exist from non-point sources of contamination (such as fertilizer).

There are few conclusive studies linking long-term ingestion of higher nitrates to the health problems of adults. However, the EPA recently has labeled NO_3 - N as a substance that is under review as a health risk to humans (EPA 1991).

QUESTION: Are pesticides harmful to humans in the concentrations presently showing up in drinking water sources?

ANSWER: *The best scientific evidence indicates that the current health threat from pesticides in our water resources is minimum.* The EPA National Drinking Water Survey cited earlier has shown the existence of low concentrations of pesticides in drinking water from around the nation.

One of the ironies of water quality investigation is that while the presence of a contaminant in groundwater can be measured to the nearest parts per trillion, the toxicological effects on humans are poorly understood. Further work is being accomplished slowly because research is confined to existing cases of exposure. Investigating the toxological effects of agricultural chemicals also is complicated by the sensitivity of different people to different compounds.

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