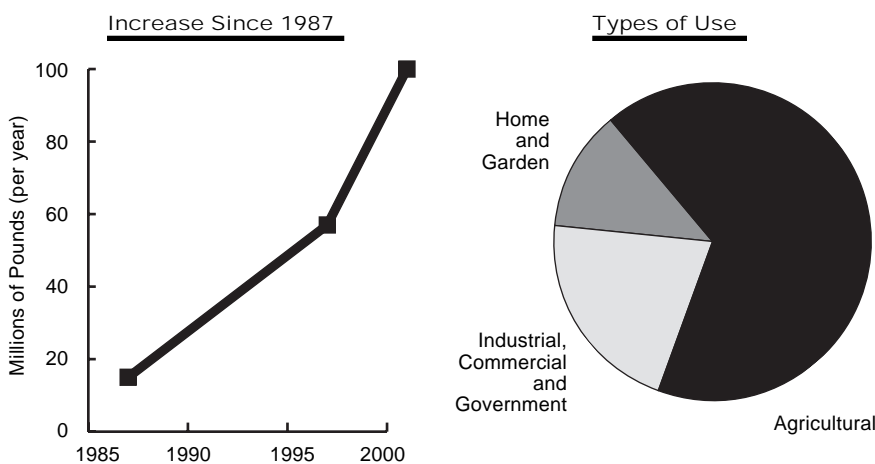


Figure 2
 Glyphosate Use in the U.S.



Aspelin, A.L. 1989. *Pesticide industry sales and usage: 1988 market estimates*. U.S. EPA. Office of Prevention, Pesticides and Toxic Substances. Office of Pesticide Programs. Biological and Economic Analysis Division. Washington, D.C.
 Aspelin, A.L. and A.H. Grube. 1999. *Pesticide industry sales and usage: 1996 and 1997 market estimates*. U.S. EPA. Office of Prevention, Pesticides and Toxic Substances. Office of Pesticide Programs. Biological and Economic Analysis Division. Washington, D.C.
 U.S. EPA. Office of Pesticide Programs. 2002. Details of the consultation for Department of State use of pesticide for coca eradication program in Columbia, Aug. www.state.gov/g/inrls/rpt/aeicc/.

Use of glyphosate has increased rapidly since the mid-1980s.

cide in non-agricultural applications (industrial land, commercial land, forest land, and homes and gardens).^{6a} The largest agricultural uses are in the production of soybeans, cotton, and corn.^{6a}

Glyphosate's use is rapidly increasing: estimated annual use according to EPA in 1995 was between 38 and 48 million pounds⁶; by 1999 was between 83 and 95 million pounds; and was over 100 million pounds in 2001.^{6a} (See Figure 2.) This increasing use is due, in large part, to the widespread use of crops which are genetically engineered to be tolerant of the herbicide.^{6a}

In the U.S., 25 million applications are made yearly on lawns and in yards.⁹

Mode of Action

Glyphosate's mode of action is "not known at this time,"⁴ according to EPA. However, considerable research has established that glyphosate inhibits an enzyme pathway, the shikimic acid pathway, preventing plants from synthesizing three aromatic amino acids. These amino acids

are essential for growth and survival of most plants. The key enzyme inhibited by glyphosate is called EPSP synthase.¹⁰ Glyphosate also "may inhibit or repress"⁴ two other enzymes, involved in the synthesis of the same amino acids.⁴ These enzymes are present in higher plants and microorganisms but not in animals.¹⁰

Two of the three aromatic amino acids are essential amino acids in the human diet because humans, like all higher animals, lack the shikimic acid pathway, cannot synthesize these amino acids, and rely on their foods to provide these compounds. One is synthesized in animals through another pathway.¹¹

Glyphosate can affect plant enzymes not connected with the shikimic acid pathway. In sugar cane, it reduces the activity of one of the enzymes involved in sugar metabolism.¹² It also inhibits a major detoxification enzyme in plants.¹³

Roundup affects enzymes found in mammals. In rats, Roundup decreased the activity of two detoxification enzymes in

the liver and an intestinal enzyme.¹⁴

"Inert" Ingredients in Glyphosate-containing Products

Virtually every pesticide product contains ingredients other than what is called the "active" ingredient(s), the one designed to provide killing action. These ingredients are misleadingly called "inert." The purpose of these "inerts" is to make the product easier to use or more efficient. In general, they are not identified on the labels of pesticide products.

In the case of glyphosate products, many "inerts" have been identified. See "Toxicology of 'Inert' Ingredients of Glyphosate-containing Products," p. 5, for basic information about these "inerts."

Many of the toxicology studies that will be summarized in this factsheet have been conducted using glyphosate, the active ingredient, alone. Some have been conducted with commercial products containing glyphosate and "inert" ingredients. When no testing is done with the product as it is actually used, it is impossible to accurately assess its hazards.

We will discuss both types of studies, and will identify insofar as is possible what material was used in each study.

Acute Toxicity to Laboratory Animals

Glyphosate's acute oral median lethal dose (the dose that causes death in 50 percent of a population of test animals; LD₅₀) in rats is greater than 4,320 milligrams per kilogram (mg/kg) of body weight. This places the herbicide in Toxicity Category III (Caution).⁴ Its acute dermal toxicity (dermal LD₅₀) in rabbits is greater than 2,000 mg/kg of body weight, also Toxicity Category III.⁴

Commercial glyphosate herbicides are more acutely toxic than glyphosate. The amount of Roundup (containing glyphosate and the surfactant POEA) required to kill rats is about 1/3 the amount of glyphosate alone.¹⁵ Roundup is also more acutely toxic than POEA.¹⁵

Glyphosate-containing products are more toxic via inhalation than orally. In-

halation of Roundup by rats caused "signs of toxicity in all test groups,"¹⁶ even at the lowest concentration tested. These signs included gasping, congested eyes, reduced activity,¹⁷ and body weight loss.¹⁶ Lungs were red or blood-congested.¹⁷ The dose required to cause lung damage and mortality following pulmonary administration of two Roundup products and POEA (when forced into the trachea, the tube carrying air into the lungs) was only 1/10 the dose causing damage orally.^{15,18}

Effects on the Circulatory System:

When dogs were given intravenous injections of glyphosate, POEA, or Roundup so that blood concentrations were approximately those found in humans who ingested glyphosate, glyphosate increased the ability of the heart muscle to contract. POEA reduced the output of the heart and the pressure in the arteries. Roundup caused cardiac depression.¹⁹

Eye Irritation: NCAP surveyed eye hazards listed on material safety data sheets for 25 glyphosate-containing products. One of the products is "severely ir-

ritating,"²⁰ 4 cause "substantial but temporary eye injury,"²¹⁻²⁴ 8 "cause eye irritation,"²⁵⁻³² 5 "may cause eye irritation,"³³⁻³⁷ 1 is "moderately irritating,"³⁸ and 3 are "slightly irritating."³⁹⁻⁴¹ The other three products require addition of a surfactant (wetting agent) before use,⁴²⁻⁴⁴ and the surfactant sold by glyphosate's manufacturer for this purpose "causes eye burns."⁴⁵

Skin Irritation: Glyphosate is classified as a slightly irritating to skin. Roundup is a "moderate skin irritant," and recovery can take over two weeks.¹⁶

Acute Toxicity to Humans

The acute toxicity of glyphosate products to humans was first publicized by physicians in Japan who studied 56 suicide attempts; nine cases were fatal. Symptoms included intestinal pain, vomiting, excess fluid in the lungs, pneumonia, clouding of consciousness, and destruction of red blood cells.⁶⁶ They calculated that the fatal cases ingested on average about 200 milliliters (3/4 of a cup). They

TOXICOLOGY OF "INERT" INGREDIENTS IN GLYPHOSATE-CONTAINING PRODUCTS

Three glyphosate products contain **ammonium sulfate**.^{29,30,32} It causes eye irritation, nausea and diarrhea, and may cause allergic respiratory reactions. Prolonged exposure can cause permanent eye damage.⁴⁶

One glyphosate product contains **benzisothiazolone**.⁴⁷ It causes eczema, skin irritation,⁴⁸ and a light-induced allergic reaction in sensitive people.^{49,50}

Four glyphosate products contain **3-iodo-2-propynyl butylcarbamate (IPBC)**.^{39-41,47} It is severely irritating to eyes and increases the incidence of miscarriages in laboratory tests.⁵¹ It also can cause allergic skin reactions.⁵²

One glyphosate product contains **isobutane**.³⁰ It causes nausea, nervous system depression, and difficulty breathing. It is a severe fire hazard.⁵³

One glyphosate product contains **methyl pyrrolidinone**.²⁰ It causes severe eye irritation.⁵⁴ It has caused fetal loss and reduced fetal weights in laboratory animals.⁵⁵

Three glyphosate products contain **pelargonic acid**.^{29,30,32} It causes severe eye and skin irritation and may cause respiratory tract irritation.⁵⁶

Nine glyphosate products contain **polyethoxylated tallowamine (POEA)**.^{21-24,31,35-38} It causes eye burns; skin redness, swelling, and blistering; nausea; and diarrhea.^{23,45}

Three glyphosate products contain **potassium hydroxide**.^{29,30,32} It causes irreversible eye injury, deep skin ulcers, severe digestive tract burns, and severe irritation of the respiratory tract.⁵⁷

One glyphosate product contains **sodium sulfite**.³⁴ It may cause eye and skin irritation with vomiting and diarrhea⁵⁸ as well as skin allergies.⁵⁹ Exposure to small amounts can cause severe allergic reactions.⁶⁰

Three glyphosate products contain **sorbic acid**.^{35,36,37} It may cause severe skin irritation, nausea, vomiting, chemical pneumonitis, and sore throat.⁶¹ It also causes allergic reactions.^{62,63}

Isopropylamine is used in some Roundup products.^{47,64} It is "extremely destructive to tissue of the mucous membranes and upper respiratory tract."⁶⁵ Symptoms of exposure are wheezing, laryngitis, headache, and nausea.⁶⁵

Table 1
Symptoms Following Unintentional Exposure to Glyphosate Herbicides

eye irritation
painful eyes
burning eyes
blurred vision
conjunctivitis
swollen eye, face
facial numbness
burning sensation on skin
itchy skin
tingling skin
blisters
skin rash
rapid heartbeat
chest pains
difficulty breathing
burning in chest and throat
dizziness
headache
nausea
diarrhea

Calif. EPA. Dept. of Pesticide Regulation. Worker Health and Safety Branch. 2002. Case reports received by the California Pesticide Illness Surveillance Program in which health effects were definitely, probably, or possibly attributed to exposure to glyphosate, alone or in combination. Unpublished report, Sept. 25.

believed that POEA was the cause of Roundup's toxicity.⁶⁶ More recent reviews of poisoning incidents have found similar symptoms, as well as lung dysfunction,⁶⁷⁻⁶⁹ erosion of the gastrointestinal tract,^{67,69} abnormal electrocardiograms,⁶⁹ low blood pressure,^{67,69} kidney damage,^{67,68,70} and damage to the larynx.⁷¹

Smaller amounts of Roundup cause adverse effects, usually skin or eye irritation as well as some of the symptoms listed above. (See Table 1.) For example, rubbing of Roundup in an eye caused eye and lid swelling, rapid heartbeat and elevated blood pressure. Wiping the face after touching leaky spray equipment caused swelling of the face. Accidental drenching with horticultural Roundup caused eczema of the hands and arms lasting two months.⁶⁸ A spill resulted in dizziness, fever, nausea, palpitations, and sore throat.⁷²

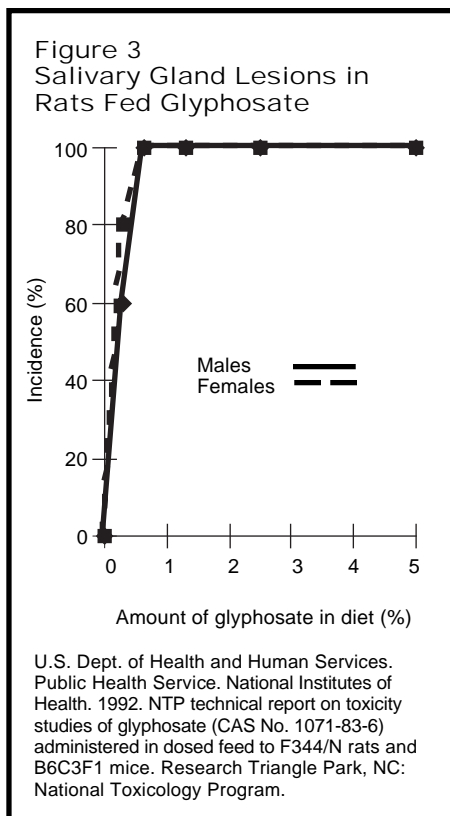
Toxicology Overview

Glyphosate is often portrayed as toxicologically benign: "extensive investigations strongly support the conclusion that glyphosate has a very low level of toxicity..."⁷³ NCAP's review of glyphosate's toxicology comes to a different conclusion. Adverse effects have been identified in each standard category of testing (subchronic, chronic, carcinogenicity, mutagenicity, and reproduction). NCAP's review has been challenged by the assertion that these effects were found because standard test protocols *require* finding adverse effects at the highest dose tested. However, the following five sections of this article summarize adverse effects that did *not* result from this requirement: they were all found at less than the highest dose tested. (The few exceptions are clearly identified.)

Subchronic Toxicity

In subchronic (medium term) studies of rats and mice done by the National Toxicology Program (NTP), microscopic salivary gland lesions were found in all doses tested in rats (200 - 3400 mg/kg per day) and in all but the lowest dose

tested in mice (1,000-12,000 mg/kg per day). (See Figure 3.) A follow-up study by NTP found that the mechanism by



Glyphosate causes salivary gland lesions in rats, mediated by the hormone adrenalin.

which glyphosate caused these lesions involved the hormone adrenalin.⁷⁴

The NTP study also found increases in two liver enzymes at all but the two lowest doses tested. Other effects found in at least two doses in this study were reduced weight gain in rats and mice; diarrhea in rats; and changes in kidney and liver weights in male rats and mice.⁷⁴

Another subchronic laboratory test found that blood levels of potassium and phosphorus in rats increased at all doses tested (60-1600 mg/kg/day).⁴

Glyphosate-containing products are more toxic than glyphosate in subchronic tests. In a 7 day study with calves, 790 mg/kg per day of Roundup caused pneumonia, and death of 1/3 of the animals tested. At lower doses decreased food in-

take and diarrhea were observed.²

Chronic Toxicity

Glyphosate is also toxic in long-term studies. At all but the lowest dose tested, excessive cell division in the urinary bladder occurred in male mice² and inflammation of the stomach lining occurred in both sexes of rats.²

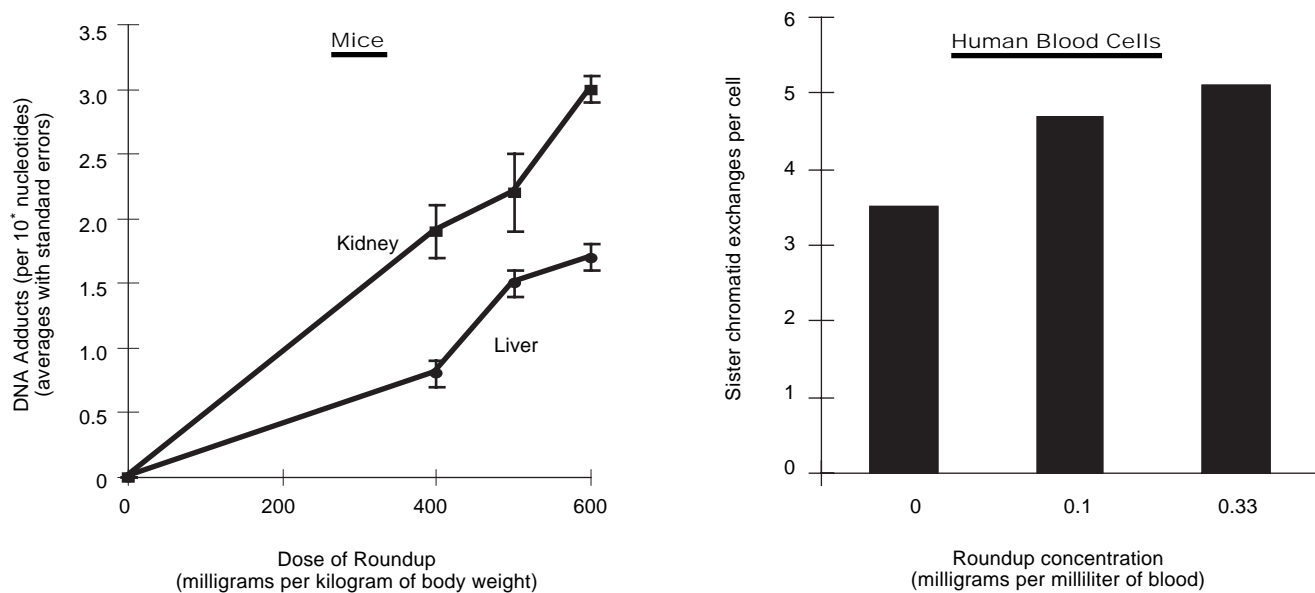
Carcinogenicity

A recent Swedish study of hairy cell leukemia (HCL), a form of the cancer non-Hodgkin's lymphoma, found that people who were occupationally exposed to glyphosate herbicides had a threefold higher risk of HCL. A similar study of people with non-Hodgkin's lymphoma found exposure to glyphosate herbicides was associated with an increase in risk of about the same size.^{74ab}

The publicly available laboratory studies of glyphosate's ability to cause cancer were all conducted by or for its manufacturer.² The first carcinogenicity study submitted to EPA (1981) found an increase in testicular tumors in male rats at the highest dose tested as well as an increase in the frequency of a thyroid cancer in females. Both results occurred at the highest dose tested (30 mg/kg of body weight per day).^{75,76} The second study (1983) found an increasing trend in the frequency of a rare kidney tumor in male mice.⁷⁷ The most recent study (1990) found an increase in pancreas and liver tumors in male rats together with an increase of the same thyroid cancer found in the 1983 study in females.⁷⁸

All of these increases in tumor or cancer incidence are "not considered compound-related"⁷⁸ according to EPA (This means that EPA did not consider glyphosate the cause of the tumors.) For the testicular tumors, EPA accepted the interpretation of an industry pathologist who said that the incidence in treated groups (12 percent) was similar to those observed (4.5 percent) in other rats *not* fed glyphosate.⁷⁸ For the thyroid cancer, EPA stated that it was not possible to distinguish between cancers and tumors of this type, so that the two should be

Figure 4
 Genetic Damage Caused by Roundup



Peluso, M. et al. 1998. ³²P-Postlabeling detection of DNA adducts in mice treated with the herbicide Roundup. *Environ. Molec. Mutag.* 31:55-59.

Bolognesi, C. et al. 1997. Genotoxic activity of glyphosate and its technical formulation Roundup. *J. Agric. Food Chem.* 45:1957-1962.

Roundup causes genetic damage in laboratory animals and in human blood cells.

considered together. The combined data are not statistically significant.⁷⁶ For the kidney tumors, the manufacturer reexamined the tissue and found an additional tumor in untreated mice so that statistical significance was lost. This was despite the opinion of EPA's pathologist that the lesion in question was not really a tumor.⁷⁷ For the pancreatic tumors, EPA stated that there was no dose-related trend. For the liver and thyroid tumors, EPA stated that pairwise comparisons between treated and untreated animals were not statistically significant.⁷⁸

EPA concluded that glyphosate should be classified as Group E, "evidence of non-carcinogenicity for humans."⁷⁸ They added that this classification "should not be interpreted as a definitive conclusion."⁷⁸ The cancer tests leave many questions unanswered. Concerning one of the carcinogenicity studies, an EPA statistician wrote, "Viewpoint is a key issue. Our viewpoint is one of protecting the public health when we see suspicious data."⁷⁹ Unfortunately, EPA has not taken that

viewpoint in its assessment of glyphosate's cancer-causing potential.

There are no publicly available laboratory studies of the carcinogenicity of Roundup or other glyphosate-containing products.

Mutagenicity

Although glyphosate's manufacturer describes "a large battery of assays"⁸⁰ showing that glyphosate does not cause genetic damage,⁸⁰ other studies have shown that both glyphosate and glyphosate products are mutagenic. Glyphosate-containing products are more potent mutagens than glyphosate.⁸¹ The studies include the following:

- In fruit flies, Roundup and Pondmaster (an aquatic herbicide consisting of glyphosate and a trade secret surfactant⁸²) both increased the frequency of sex-linked, recessive lethal mutations. (These are mutations that are usually visible only in males.) Only a single concentration was tested in this study.⁸³

- A study of human lymphocytes (a

type of white blood cell) showed an increase in the frequency of sister chromatid exchanges following exposure to the lowest dose tested of Roundup.⁸⁴ (Sister chromatid exchanges are exchanges of genetic material during cell division between members of a chromosome pair. They result from point mutations.) A 1997 study of human lymphocytes (see Figure 4) found similar results with Roundup (at both doses tested) and with glyphosate (at all but the lowest dose tested).⁸¹

- In *Salmonella* bacteria, Roundup was weakly mutagenic at two concentrations. In onion root cells, Roundup caused an increase in chromosome aberrations, also at two concentrations.⁸⁵

- In mice injected with Roundup, the frequency of DNA adducts (the binding to genetic material of reactive molecules that lead to mutations) in the liver and kidney increased at all three doses tested.⁸⁶ (See Figure 4.)

- In another study of mice injected with glyphosate and Roundup, the frequency of chromosome damage and DNA

damage increased in bone marrow, liver, and kidney. (Only a single concentration was tested in this study.)⁸¹

Reproductive Effects

Glyphosate exposure has been linked to reproductive problems in humans. A study in Ontario, Canada, found that farmers' use of glyphosate was associated with an increase in miscarriages^{86b,87} and premature births in farm families.⁸⁷ (See Figure 5.) In Minnesota's Red River Valley, farm children with attention deficit disorder were over three times more likely to have fathers who used glyphosate herbicides than children without this disorder.^{87a} In addition, a case report from the University of California discussed a student athlete who suffered abnormally frequent menstruation when she competed at tracks where glyphosate had been used.⁸⁸

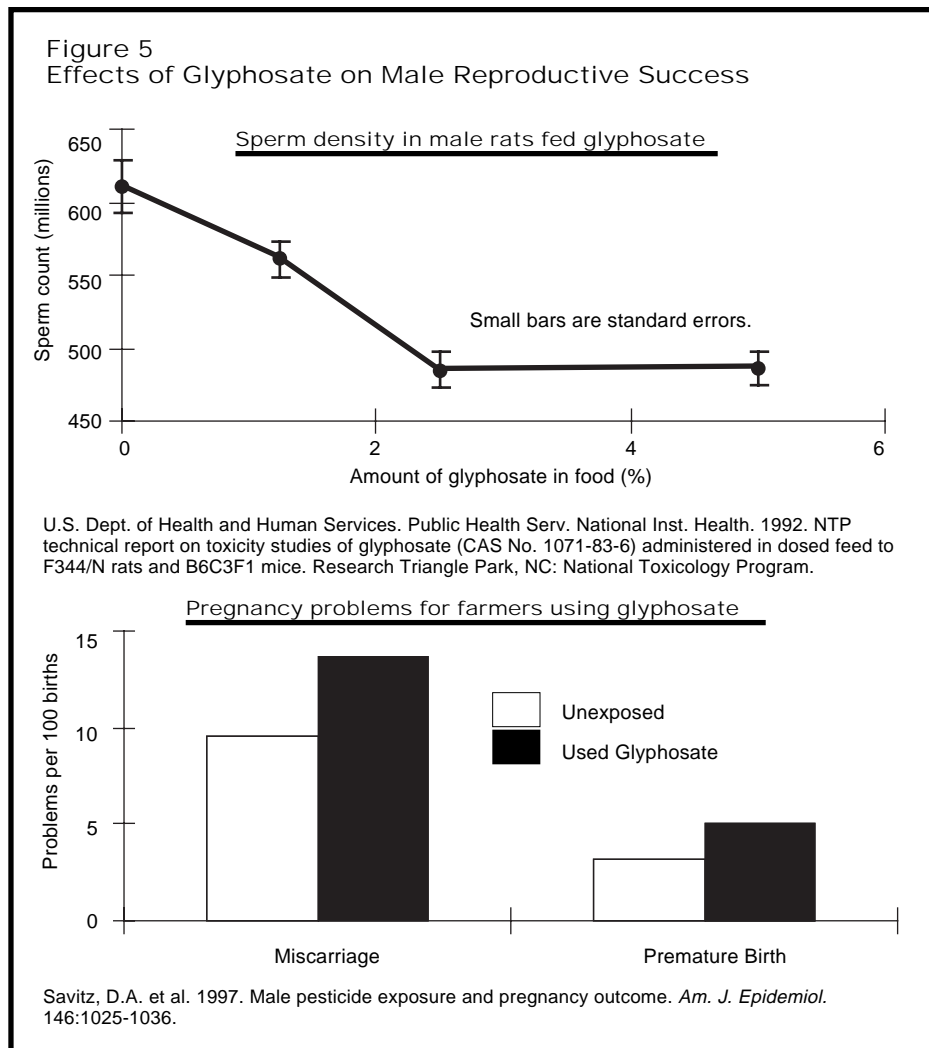
Laboratory studies have also demonstrated a number of effects of glyphosate on reproduction.

In rats, glyphosate reduced sperm counts at the two highest doses tested. (See Figure 5.) In male rabbits, glyphosate at doses of 1/10 and 1/100 of the LD₅₀ increased the frequency of abnormal and dead sperm.⁸⁹

Using cells taken from Leydig cell testicular tumors in mice, researchers from Texas Tech University showed that exposure to Roundup (but not glyphosate alone) caused a decrease in the production of sex hormones. Specifically, Roundup inhibited the expression of a protein that carries cholesterol (the molecule from which sex hormones are made) to the site where these hormones are synthesized. Lacking necessary amounts of cholesterol, the testicle cells' production of sex hormones decreased about 90 percent.^{89a}

A study of pregnant rats given glyphosate in their drinking water showed that this exposure caused changes in the activity of three enzymes in their fetuses. Enzymes related to energy production were affected in the liver, heart, and brain.^{89b}

In a study of female rabbits given



Glyphosate exposure is associated with reproductive problems in both laboratory animals and farmers.

glyphosate orally during their pregnancies, glyphosate caused a "slight" decrease in fetal weight in all treated groups.⁹⁰

Roundup can also disrupt embryo development. Scientists from the National Center for Scientific Research (France) found that Roundup delayed the first cell division in sea urchin embryos, often used as a model system for studying development. The delay was not caused by glyphosate alone; further experiments indicated it was caused by a synergistic interaction between glyphosate and the inert ingredients in Roundup. The researchers also described the molecular mechanism that causes this delay. Roundup inhibits the activity of an enzyme involved

in the cell division process and also inhibits overall protein synthesis in the embryo.^{90b}

Toxicology of Glyphosate's Major Metabolite

In general, studies of the breakdown of glyphosate find only one metabolite, aminomethylphosphonic acid (AMPA).² Although AMPA has low acute toxicity (its LD₅₀ is 8,300 mg/kg of body weight in rats),¹⁶ it causes a variety of toxicological problems. In subchronic tests on rats, AMPA caused an increase in the activity of an enzyme, lactic dehydrogenase, in both sexes; a decrease in liver weights in males at all doses tested; and excessive

cell division in the lining of the urinary bladder in both sexes.¹⁶ AMPA is more persistent than glyphosate; studies in eight states found that the half-life in soil (the time required for half of the original concentration of a compound to break down or dissipate) was between 119 and 958 days.² AMPA has been found in lettuce and barley planted a year after glyphosate treatment.^{90a}

Quality of Laboratory Testing

Tests done on glyphosate to meet registration requirements have been associated with fraudulent practices.

Laboratory fraud first made headlines in 1983 when EPA publicly announced that a 1976 audit had discovered “serious deficiencies and improprieties” in studies conducted by Industrial Biotest Laboratories (IBT).⁹¹ Problems included “countless deaths of rats and mice” and “routine falsification of data.”⁹¹

IBT was one of the largest laboratories performing tests in support of pesticide registrations.⁹¹ About 30 tests on glyphosate and glyphosate-containing products were performed by IBT, including 11 of the 19 chronic toxicology studies.⁹² A compelling example of the poor quality of IBT data comes from an EPA toxicologist who wrote, “It is also somewhat difficult not to doubt the scientific integrity of a study when the IBT stated that it took specimens from the *uteri* (of *male* rabbits) for histopathological examination.”⁹³ (Emphasis added.)

In 1991, EPA alleged that Craven Laboratories, a company that performed studies for 262 pesticide companies including Monsanto, had falsified tests.⁹⁴ “Tricks” employed by Craven Labs included “falsifying laboratory notebook entries” and “manually manipulating scientific equipment to produce false reports.”⁹⁵ Roundup residue studies on plums, potatoes, grapes, and sugarbeets were among the tests in question.⁹⁶

The following year, the owner of Craven Labs and three employees were indicted on 20 felony counts.⁹⁷ The owner was sentenced to five years in prison and fined \$50,000; Craven Labs was fined

15.5 million dollars, and ordered to pay 3.7 million dollars in restitution.⁹⁵

Although the tests of glyphosate identified as fraudulent have been replaced, this fraud casts shadows on the entire pesticide registration process.

Illegal Advertising

In 1996, Monsanto Co. negotiated an agreement with the New York attorney-general that required Monsanto to stop making certain health and environmental claims in ads for glyphosate products and pay the attorney general \$50,000 in costs.⁹⁸ Claims that glyphosate products are “safer than table salt,”⁹⁸ safe for people, pets, and the environment, and degrade “soon after application”⁹⁸ were challenged by the attorney-general because they are in violation of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the national pesticide law.⁹⁸ According to the attorney-general, Monsanto had engaged in “false and misleading” advertising.⁹⁸

In 1998, Monsanto Co. negotiated a similar agreement with the New York attorney-general about a different advertisement. The attorney-general found that the advertisement featuring a horticulturist from the San Diego Zoo also was “false and misleading” because it implied to consumers that Roundup could be used (contrary to label directions) in and around water.^{98a} Monsanto paid \$75,000 in costs.^{98a}

EPA made a similar determination about Roundup ads in 1998, finding that they contained “false and misleading”⁹⁹ claims and were in violation of FIFRA. However, EPA took no action and did not even notify Monsanto Co. about the determination because two years had elapsed between the time that the ads were submitted to EPA and the time that EPA made the determination.⁹⁹

Human Exposure

People are exposed to glyphosate through workplace exposure (for people who use glyphosate products on the job), eating of contaminated food, exposure caused by off-target movement following

application (drift), contact with contaminated soil, and drinking or bathing in contaminated water. The next five sections of this factsheet summarize information about these five routes of exposure. The third section, discussing drift, also covers impacts on plants.

Contamination of Food

Analysis of glyphosate residues is “in general laborious, complex, and costly.”² For this reason, it is not included in government monitoring of pesticide residues in food.² The only information available about contamination of food comes from research studies.

Monsanto’s studies of residues in food crops found glyphosate in lettuce over five months after treatment (the lettuce was planted four months after treatment). Monsanto also found glyphosate in barley over four months after treatment (the barley was planted one month after treatment).^{90a}

“Significant residues,”² according to the World Health Organization, have been identified from pre-harvest use of glyphosate on wheat (to dry out the grain). Bran contains between 2 and 4 times the amount on whole grains. Residues are not lost during baking.²

Occupational Exposure

In California, the state with the most comprehensive program for reporting of pesticide-caused illness, glyphosate-containing herbicides are a common cause of pesticide illness caused by occupational exposure. For example, in incidents reported to the California Department of Pesticide Regulation from 1998 to 2000, glyphosate herbicides were the eighth most common cause of pesticide illness for agricultural workers.^{100a}

While many of the California reports involve “irritant effects,”¹⁰² mostly to the eyes and skin, NCAP’s survey of about 100 reports made between 1996 and 2000 found that over half of them involved more serious effects: burning of eyes or skin, skin or eye lesions, blurred vision, headache, vomiting, diarrhea, dizziness, numbness, swelling and blistering of the

genitals, and difficulty breathing.^{103a}

Other occupational symptoms were observed in a flax milling operation in Great Britain. A study compared the effects of breathing dust from flax treated with Roundup with the effects of dust from untreated flax. Treated dust caused a decrease in lung function and an increase in coughing, and breathlessness.¹⁰⁴

Drift

In general, movement of a pesticide through unwanted drift is "unavoidable."¹⁰⁵ Drift of glyphosate is no exception. Glyphosate drift, however, is particularly significant because drift "damage is likely to be much more extensive and more persistent than with many other herbicides."¹⁰⁶ This is because glyphosate moves readily within plants so that even unexposed parts of a plant can be damaged. Damage to perennial plants (when not exposed to enough glyphosate to kill them) is persistent, with some symptoms lasting several years.¹⁰⁶ In addition, plant susceptibility varies widely. Some wildflowers are almost a hundred times more sensitive than others; drift in amounts equal to 1/1000 of typical application rates will damage these species.¹⁰⁷

A simple answer to the question, "How far can I expect glyphosate to travel off-site?" is difficult, since drift is "notoriously variable."¹⁰⁸ However, extensive drift of glyphosate has been measured since the 1970s when a California study found glyphosate 800 m (2600 feet) from aerial and ground applications. Similar drift distances were found for the 8 different spray systems tested in this study.¹⁰⁹

Drift distances that have been measured more recently for the major application techniques include the following:

- **Ground Applications:** A study of 15 noncrop plants found seedling mortality (killing about 10 percent of seedlings) for most of the species tested at 20 meters (66 feet) downwind when using a tractor-mounted sprayer. Seedlings of some sensitive species were killed at 40 meters (131 feet).¹¹⁰ A drift model predicted some native species would be damaged at

distances of 80 meters (262 feet).¹⁰⁷ Glyphosate's manufacturer reported that drift from a ground application in Minnesota damaged 25 acres of corn,¹¹¹ and the Washington Department of Agriculture reported damage to 30 acres of onions from a ground application of a glyphosate herbicide.¹¹²

- **Helicopter applications:** A study done in Canada¹¹³ measured glyphosate residues 200 meters (656 feet) from target areas following helicopter applications to forest sites. In this study, 200

"Glyphosate's manufacturer reported that drift from a ground application in Minnesota damaged 25 acres of corn, and the Washington Department of Agriculture reported damage to 30 acres of onions from a ground application of a glyphosate herbicide."

meters was the farthest distance at which samples were taken, so the longest distance glyphosate travelled is not known.

- **Fixed-wing aircraft:** Long drift distances occur following applications of glyphosate made from airplanes. Two studies on forested sites conducted by Agriculture Canada (the Canadian agricultural ministry) showed that glyphosate was found at the farthest distance from the target areas that measurements were made (300 and 400 meters, or 984 and 1312 feet).^{114,115} One of these studies¹¹⁵ calculated that buffer zones of between 75 and 1200 meters (246 feet - 0.75 miles) would be required to protect non-

target vegetation. According to Monsanto, drift from single aerial applications of glyphosate has been extensive enough to damage 1000 trees in one case,¹¹⁶ 250 acres of corn in another,¹¹⁷ and 155 acres of tomatoes in a third incident.¹¹⁸

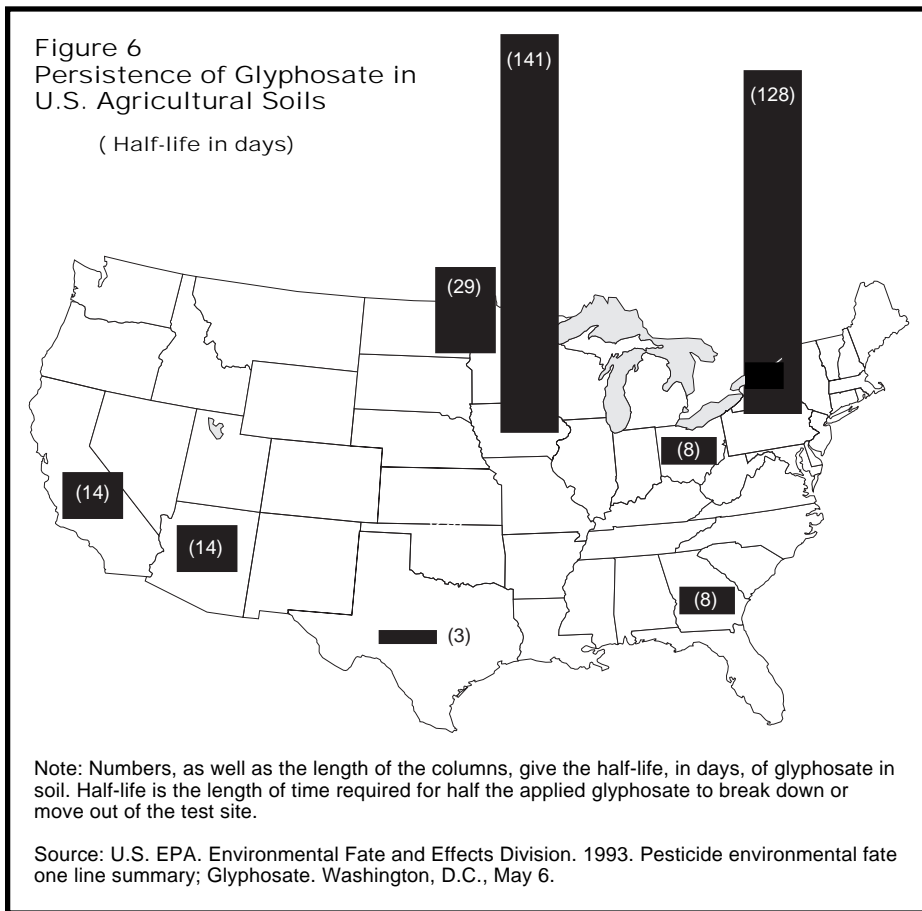
Persistence and Movement in Soil

Glyphosate's persistence in soil varies widely, so giving a simple answer to the question "How long does glyphosate persist in soil?" is not possible. Half-lives (the time required for half of the amount of glyphosate applied to break down or move away) as low as 3 days (in Texas) and as long as 141 days (in Iowa) have been measured by glyphosate's manufacturer.¹¹⁹ (See Figure 6.) Initial degradation (breakdown) is faster than the subsequent degradation of what remains.¹²⁰ Long persistence has been measured in the following studies: 55 days on an Oregon Coast Range forestry site¹²¹; 249 days on Finnish agricultural soils¹²²; between 259 and 296 days on eight Finnish forestry sites¹²⁰; 335 days on an Ontario (Canada) forestry site¹²³; 360 days on 3 British Columbia forestry sites¹²⁴; and, from 1 to 3 years on eleven Swedish forestry sites.¹²⁵ EPA's Ecological Effect's Branch wrote, "In summary, this herbicide is extremely persistent under typical application conditions."¹²⁶

Glyphosate is thought to be "tightly complexed [bound] by most soils"¹²⁷ and therefore "in most soils, glyphosate is essentially immobile."¹²⁷ This means that the glyphosate will be unlikely to contaminate water or soil away from the application site. However, this binding to soil is "reversible." For example, one study found that glyphosate bound readily to four different soils. However, desorption, when glyphosate unbinds from soil particles, also occurred readily. In one soil, 80 percent of the added glyphosate desorbed in a two hour period. The study concluded that "this herbicide can be extensively mobile in the soil..."¹²⁸

Water Contamination

When glyphosate binds readily to soil



Glyphosate's persistence in soil varies widely, but its half-life in agricultural soil can be over 4 months.

particles, it does not have the chemical characteristics of a pesticide that is likely to leach into water.² (When it readily desorbs, as described above, this changes.) However, glyphosate can move into surface water when the soil particles to which it is bound are washed into streams or rivers.⁴ How often this happens is not known, because routine monitoring for glyphosate in water is infrequent.²

Glyphosate has been found in both ground and surface water. Examples include farm ponds in Ontario, Canada, contaminated by runoff from an agricultural treatment and a spill¹²⁹; the runoff from a watersheds treated with Roundup during production of no-till corn and fescue¹³⁰; contaminated surface water in the Netherlands²; seven U.S. wells (one in Texas, six in Virginia) contaminated with glyphosate¹³¹; contaminated forest

streams in Oregon and Washington^{132,133}; contaminated streams near Puget Sound, Washington¹³⁴; and contaminated wells under electrical substations treated with glyphosate.¹³⁵

Glyphosate's persistence in water is shorter than its persistence in soils. Two Canadian studies found glyphosate persisted 12 to 60 days in pond water.^{136,137} Glyphosate persists longer in pond sediments (mud at the bottom of a pond). For example, the half-life in pond sediments in a Missouri study was 120 days; persistence was over a year in pond sediments in Michigan and Oregon.⁴

Ecological Effects

Glyphosate can impact many organisms not intended as targets of the herbicide. The next two sections describe both direct mortality and indirect ef-

fects, through destruction of food or shelter.

Effects on Nontarget Animals

Beneficial insects: Beneficial insects kill other species that are agricultural pests. The International Organization for Biological Control found that exposure to freshly dried Roundup killed over 50 percent of three species of beneficial insects: a parasitoid wasp, a lacewing, and a ladybug. Over 80 percent of a fourth species, a predatory beetle, was killed.¹³⁸

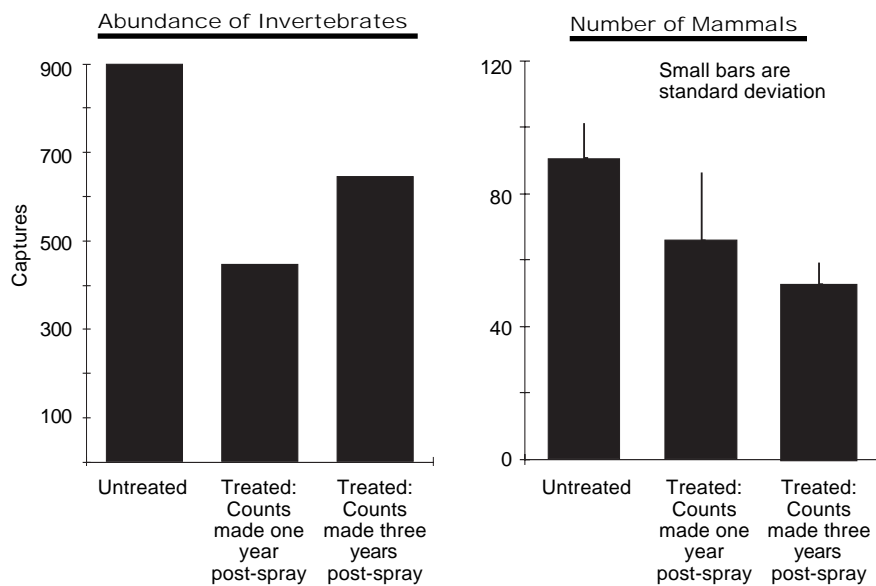
Impacts on beneficial insects have also been shown in field studies, probably due to destruction of their habitat by the herbicide. In North Carolina wheat fields, populations of large carabid beetles declined after treatment with a glyphosate product and did not recover for 28 days.¹³⁹ A study of Roundup treatment of hedgerows in the United Kingdom also showed a decline in carabid beetles.¹⁴⁰

Other insects: Roundup treatment of a Maine clear-cut caused an 89 percent decline in the number of herbivorous (plant-eating) insects because of the destruction of the vegetation on which they live and feed. (See Figure 7.) These insects serve as food resources for birds and insect-eating small mammals.¹⁴¹

The U.S. Fish and Wildlife Service has identified one endangered insect, a long-horn beetle, that would be jeopardized by use of glyphosate herbicides.¹⁴²

Other arthropods: Glyphosate and glyphosate-containing products kill a variety of other arthropods. For example, over 50 percent of test populations of a beneficial predatory mite were killed by exposure to Roundup.¹³⁸ In another laboratory study, Roundup exposure caused a decrease in survival and a decrease in body weight of woodlice. These arthropods are important in humus production and soil aeration.¹⁴³ Roundup treatment of hedgerows reduced the number of spiders, probably by killing the plants they preferred for web-spinning.¹⁴⁰ The water flea *Daphnia pulex* is killed by concentrations of Roundup between 3 and 25 ppm.¹⁴⁴⁻¹⁴⁶ Young *Daphnia* are more susceptible than mature individuals.¹⁴⁵ The

Figure 7
 Impacts of Glyphosate on Nontarget Animals on Maine Clear-cuts



Santillo, D.J., D.M. Leslie, and P.W. Brown. 1989. Responses of small mammals and habitat to glyphosate application on clearcuts. *J. Wildl. Manage.* 53(1):164-172.

Glyphosate treatment reduced invertebrate and small mammal populations for up to 3 years.

red swamp crawfish, a commercial species, was killed by 47 ppm of Roundup.¹⁴⁷

Earthworms: A study of the most common earthworm found in agricultural soils in New Zealand showed that repeated applications of glyphosate significantly affect growth and survival of earthworms. Biweekly applications of low rates of glyphosate (1/20 of typical rates) caused a reduction in growth (see Figure 8), an increase in the time to maturity, and an increase in mortality.¹⁴⁸

Fish: Both glyphosate and the commercial products that contain glyphosate are acutely toxic to fish. In general, glyphosate alone is less toxic than the common glyphosate product, Roundup, and other glyphosate products have intermediate toxicity. Part of these differences can be explained by the toxicity of the surfactant (detergent-like ingredient) in Roundup. It is 20 to 70 times more toxic to fish than glyphosate itself.¹⁴⁴

Acute toxicities of glyphosate vary widely: median lethal concentrations (LC₅₀s; the concentrations killing 50 per-

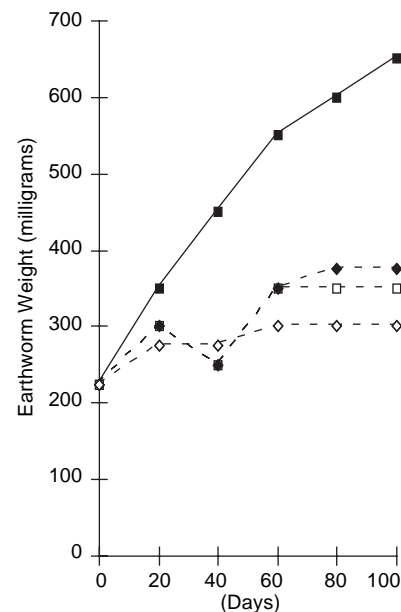
cent of a population of test animals) from 10 ppm to over 200 ppm have been reported depending on the species of fish and test conditions.²

Acute toxicities (LC₅₀) of Roundup to fish range from 2 ppm to 55 ppm.² Part of this variability is due to age: young fish are more sensitive to Roundup than are older fish.¹⁴⁴ (See Figure 9.) Acute toxicities of Rodeo (used with the surfactant X-77 per label recommendations) vary from 120 to 290 ppm.¹⁴⁹

In soft water there is little difference between the toxicities of glyphosate and Roundup.¹⁵⁰ Also, if fish have not recently eaten, the toxicity of glyphosate (LC₅₀ = 2.9 ppm) is similar to that of Roundup.¹⁵¹

Roundup toxicity increases with increased water temperature. In both rainbow trout and bluegills, toxicity about doubled between 7 and 17°C (45 and 63°F).¹⁴⁴ Treatment of riparian areas with glyphosate causes water temperatures to increase for several years following treatment¹⁵² because the herbicide kills shading vegetation. This means that use of

Figure 8
 Effect of Glyphosate on the Growth of Earthworms



Glyphosate concentration

- none
- 1/20 of agricultural rate
- ◆--- 1/10 of agricultural rate
- ◇--- 1/5 of agricultural rate

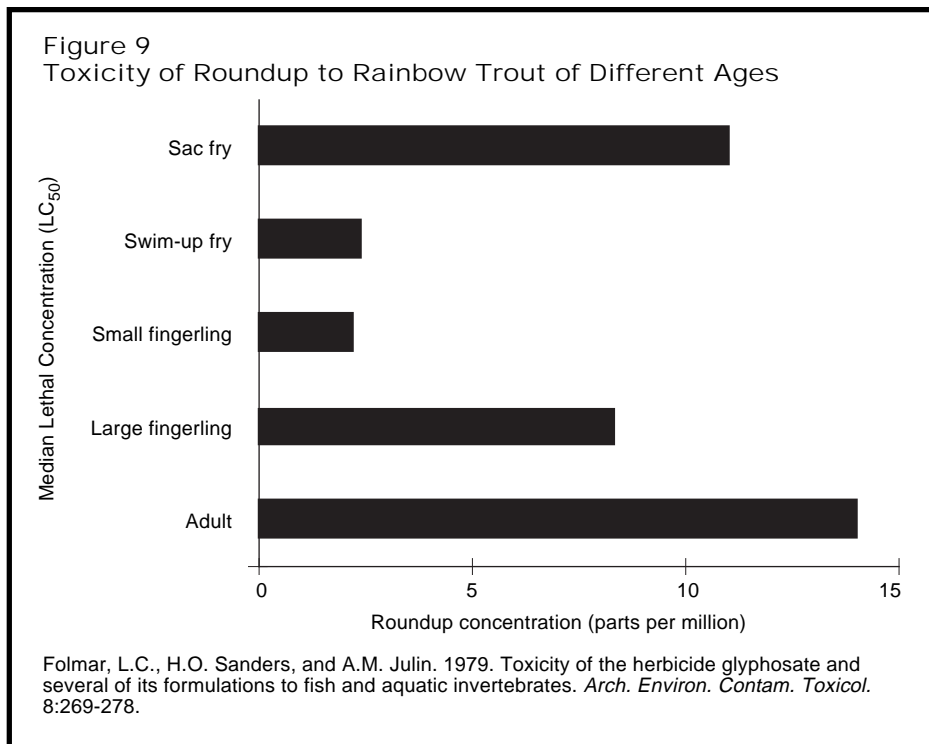
Springett, J.A. and R.A.J. Gray. 1992. Effect of repeated low doses of biocides on the earthworm *Aporrectodea caliginosa* in laboratory culture. *Soil Biol. Biochem.* 24(12):1739-1744.

Repeated applications of glyphosate reduce the growth of earthworms.

glyphosate could cause increased toxicity to fish. In addition, the temperature increase could be critical for fish, like juvenile salmon, that thrive in cold water.

Sublethal effects of glyphosate occur at low concentrations. In rainbow trout and *Tilapia* concentrations of about 1/2 and 1/3 of the LC₅₀ (respectively) caused erratic swimming.^{153,154} The trout also exhibited labored breathing.¹⁵³ These effects can increase the risk that the fish will be eaten, as well as affecting feeding, migration, and reproduction.¹⁵⁴ Less than 1 percent of the LC₅₀ caused gill damage in carp and less than 2 percent caused changes in liver structure.¹⁵⁵

Birds: Glyphosate has indirect impacts on birds. Because glyphosate kills plants,



Young rainbow trout (swim-up fry and small fingerlings) are more susceptible to Roundup than adult rainbow trout.

its use can create a dramatic change in the structure of the plant community. This affects bird populations, since the birds depend on the plants for food, shelter, and nest support.

For example, a study of four glyphosate-treated clear-cuts (and an unsprayed control plot) in Nova Scotia found that the densities of the two most common species of birds (white-throated sparrow and common yellowthroat) decreased for two years after treatment. By the fourth year post-spray, densities had returned to normal for these two species. By then the unsprayed plot had been colonized by new species of birds (warblers, vireos, and a hummingbird) which were not found on the sprayed plots.¹⁵⁶

An earlier three year study of songbird abundance following glyphosate treatment of clear-cuts in Maine forests showed similar results. Abundances of the total number of birds and three common species decreased. The decrease in bird abundance was correlated with decrease in the diversity of the habitat.¹⁵⁷

Black grouse avoided glyphosate-

treated clear-cuts in Norway for several years after treatment.¹⁵⁸ Researchers recommended that the herbicide not be used near grouse courtship areas.

Small mammals: In field studies, small mammals have been indirectly affected when glyphosate kills the vegetation they (or their prey) use for food or shelter. On clear-cuts in Maine,¹⁴¹ insect-eating shrews declined for three years post-treatment; plant-eating voles declined for two. (See Figure 7.) A second study in Maine after a Roundup treatment¹⁵⁹ found similar results for voles. In British Columbia, deer mice populations were 83 percent lower following glyphosate treatment.¹⁶⁰ Another study from British Columbia found declines in chipmunk populations after Roundup treatment.¹⁶¹ In Norway, there was a "strong reduction" in use of sprayed clear-cuts by mountain hare.¹⁶² Other studies have not found impacts on small mammals,¹⁶³ suggesting that the particular characteristics of the site and the herbicide application are significant.

Wildlife: Canadian research has documented that plants serving as important

food sources for wildlife are significantly damaged by glyphosate. "Severe" or "very severe damage" was recorded for 46 percent of the important food species eaten by moose, between 34 and 40 percent of the species eaten by elk, and 36 percent of the species eaten by mule deer.¹⁶⁴

Frogs: A biologist from Denison University found that the glyphosate-containing herbicide Kleeraway Grass and Weed Killer, at a concentration of less than 1 ppm of glyphosate, killed western chorus frog tadpoles. This concentration was the lowest tested in this experiment and caused 45 percent mortality. The herbicide was also toxic to plains leopard frog tadpoles.^{164a}

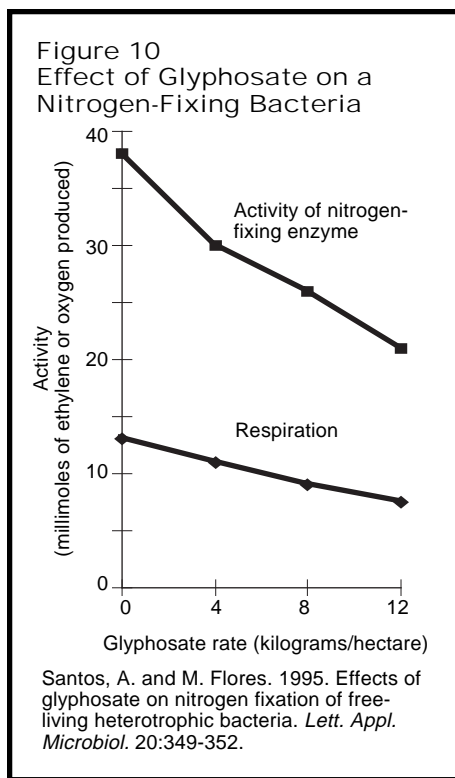
Effects on Nontarget Plants

As a broad-spectrum herbicide, glyphosate has potent acutely toxic effects on most plant species. There are also other kinds of serious effects. These include effects on endangered species, reduced seed quality, reduction in the ability to fix nitrogen, increased susceptibility to plant diseases, and reduction in the activity of mycorrhizal fungi.

Endangered species: Because many plants are susceptible to glyphosate, it can seriously impact endangered plant species. The U.S. Fish and Wildlife Service has identified 74 endangered plant species that it believes could be jeopardized by glyphosate. This list is based on the use of glyphosate on 9 crops, and does not include over 50 other uses.¹⁴²

Seed Quality: Sublethal treatment of cotton with Roundup "severely affects seed germination, vigor and stand establishment under field conditions." At the lowest glyphosate rate tested, seed germination was reduced between 24 and 85 percent and seedling weight was reduced between 19 and 83 percent.¹⁶⁵

Nitrogen fixation: Most living things cannot use nitrogen in its common form and instead use ammonia and nitrates, much rarer compounds. Ammonia and nitrates are created by processes called nitrogen fixation and nitrification. They are carried out by bacteria which can be found in soil and in nodules on roots of



legumes and certain other plants.¹⁶⁶

Studies showing effects of glyphosate on nitrogen fixation include the following: At a concentration corresponding to typical application rates, glyphosate reduced by 70 percent the number of nitrogen-fixing nodules on clover planted 120 days after treatment¹⁶⁷; a similar concentration of a glyphosate herbicide reduced by 27 percent the number of nodules on hydroponically grown clover¹⁶⁸; a similar concentration of glyphosate reduced by 20 percent nitrogen-fixation by a soil bacteria¹⁶⁹ (see Figure 10); a concentration of glyphosate approximately that expected in soybean roots following treatment inhibited the growth of soybean's nitrogen-fixing bacteria between 10 and 40 percent¹⁷⁰; and treatment with a glyphosate herbicide at the lowest concentration tested (10 times typical application rates) reduced the number of nodules on clover between 68 and 95 percent.¹⁷¹

All of the studies summarized above were done in the laboratory. In the field, such effects have been difficult to observe.

However, use of genetically-engineered glyphosate-tolerant crop plants means that nitrogen-fixing bacteria in field situations "could be affected by repeated applications of glyphosate."¹⁷⁰

Glyphosate also impacts other parts of the nitrogen cycle. A Canadian study found that treatment of a grass field with Roundup increased nitrate loss up to 7 weeks after treatment. The increase was probably caused by the nutrients released into the soil by dying vegetation.¹⁷²

Mycorrhizal fungi: Mycorrhizal fungi are beneficial fungi that live in and around plant roots. They help plants absorb nutrients and water and can protect them from cold and drought.¹⁷³ Roundup is toxic to mycorrhizal fungi in laboratory studies. Effects on some species associated with conifers have been observed at concentrations of 1 part per million (ppm), lower than those found in soil following typical applications.^{174,175} In orchids, treatment with glyphosate changed the mutually beneficial interaction between the orchid and its mycorrhizae into a parasitic interaction (one that does not benefit the plant).¹⁷⁶

Plant diseases: Glyphosate treatment increases the susceptibility of crop plants to a number of diseases. For example, glyphosate increased the susceptibility of tomatoes to crown and root disease¹⁷⁷; reduced the ability of bean plants to defend themselves against the disease anthracnose¹⁷⁸; increased the growth of take-all disease in soil from a wheat field and decreased the proportion of soil fungi which was antagonistic to the take-all fungus¹⁷⁹; and increased soil populations of two important root pathogens of peas.¹⁸⁰ In addition, Roundup injection of lodgepole pine inhibited the defensive response of the tree to blue stain fungus.¹⁸¹

Both the inhibition of mycorrhizae and the increased susceptibility to disease have been observed in laboratory, not field, studies. Given the serious consequences these kinds of effects could have, more research is crucial.

Plant Resistance

Plants that are resistant to glyphosate

are able to tolerate treatment without showing signs of toxicity. Although many weed scientists argue that "it is nearly impossible for glyphosate resistance to evolve in weeds,"¹⁸² others argue that "there are few constraints to weeds evolving resistance." The second group of scientists appears to be correct. In 1996 an Australian researcher reported that a population of annual ryegrass had developed resistance and tolerated five times the recommended field application rate.¹⁸³ ♣

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