Glyphosate, Part 2:
Human Exposure and Ecological Effects
by Caroline Cox.

Journal of Pesticide Reform
Volume 15, Number 4, Winter 1995.
Northwest Coalition for Alternatives to Pesticides
Eugene, OR.

Index

Overview

Residues of the commonly-used herbicide glyphosate have been found in a variety of fruits and vegetables. Residues can be detected long after glyphosate treatments have been made. Lettuce, carrots, and barley planted a year after glyphosate treatment contained residues at harvest.

In California, where reporting of pesticide-caused illnesses is more comprehensive than in other states, glyphosate exposure was the third most commonly-reported cause of pesticide illness among agricultural workers. For landscape maintenance workers, glyphosate ranked highest.

Glyphosate can drift away from the site of its application. Maximum drift distance of 400 to 800 meters (1300-2600 feet) have been measured.

Glyphosate residues in soil have persisted over a year.

Although not expected for an herbicide, glyphosate exposure damages or reduces the population of many animals, including beneficial insects, fish, birds, and earthworms. In some cases glyphosate is directly toxic; for

example, concentrations as low as 10 parts per million can kill fish and 1/20 of typical application rates caused delayed development in earthworms. In other cases, (small mammals and birds, for example) glyphosate reduces populations by damaging the vegetation that provides food and shelter for the animals.

Glyphosate reduces the activity of nitrogen-fixing bacteria. These bacteria transform nitrogen, an essential plant nutrient, into a form that plants can use. Glyphosate reduces the growth of mycorrhizal fungi, beneficial fungi that help plants absorb water and nutrients. Glyphosate also increases the susceptibility of plants to diseases, including Rhizoctonia root rot, take-all disease, and anthracnose.

Glyphosate is a widely-used, broad-spectrum herbicide that is used to kill unwanted plants in a wide variety of agricultural, lawn and garden, aquatic, and forestry situations. It ranks among the top ten herbicides used in the U.S., both in agricultural and nonagricultural situations. Common brand names are Roundup, Rodeo, Accord, and Vision. This is the second part of a summary of glyphosate's hazards Part 1 (JPR 15(3):14-20) discussed the toxicology of glyphosate, its breakdown products, and the other ingredients in glyphosate-containing products. This part discusses human exposure to glyphosate and its ecological effects.

Human Exposure

The most important ways that people are exposed to glyphosate are 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." (1) For this reason, it is not included in government monitoring of pesticide residues in food. (1) The only information available about contamination of food comes from research situations. Such studies demonstrate several

important points:

* First, glyphosate can be taken up by plants and moved to parts of the plant that are used for food. For example, glyphosate has been found in strawberries, (2) wild blueberries and raspberries, (3) lettuce, carrots, barley,(4) and fish (8,6) following treatment.

* Second, pre-harvest use of glyphosate on wheat (to dry out the grain prior to harvest) results in "significant residues in the grain,"(1) according to the World Health Organization. Bran contains between 2 and 4 times the amount on whole grains. Residues are not lost during baking.(1)

* Third, glyphosate residues can be found in food long after treatments have been made. For example, lettuce, carrots, and barley contained glyphosate residues at harvest when planted a year after treatment.(4)

Occupational Exposure

Workers in a variety of occupations are exposed to glyphosate. Researchers have documented exposure for forestry workers in Finland7 and the southeastern U.S., palm plantation workers in Malaysia1 and conifer nursery workers in Mississippi and Oregon.(8) All of these studies generally found low, but consistent, exposure rates.

Physicians, however, paint a different picture. In California, the state with the most comprehensive program for reporting of pesticide-caused illness, glyphosate was the third most commonly-reported cause of pesticide illness among agricultural workers.(9) Among landscape maintenance workers, glyphosate was the most commonly reported cause.(10) (Both these statistics come from reviews of illness reports collected between 1984 and 1990.) Even when glyphosate's extensive use in California is considered, and the illness statistics presented as "number of acute illnesses reported per million pounds used in California," glyphosate ranked twelfth.(9)

Drift

In general, movement of a pesticide through unwanted drift is "unavoidable."(11) Drift of glyphosate is no exception. Glyphosate drift, however, is a particularly significant problem. Its wide use means that there is a correspondingly large potential for drift.(12) When drift does occur, "damage is likely to be much more extensive and more persistent than with many other herbicides."(13) This is because glyphosate translocates (moves) within plants readily 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.(13) In addition, plant susceptibility varies widely. Some wildflowers are almost a hundred times more sensitive than others; small amounts of drift will damage these species.(14)

A fundamental question about drift is "How far can I expect glyphosate to travel off-site?" Unfortunately, the question is difficult to answer, since drift is "notoriously variable."(18) Factors that increase drift are aerial application techniques, high wind speeds (over 10 kilometers, or 6 miles, per hour), spray nozzles that produce a high proportion of fine droplets, and calm conditions (without enough turbulence to drive the glyphosate droplets onto plant foliage).(18) Drift distances that have been measured for the major application techniques include the following:

* Ground Applications: Between 14 and 78 percent of glyphosate applied as ground sprays moves off-site.(18) Seedling mortality has been demonstrated 20 meters (66 feet) downwind when using a tractor-mounted sprayer. Sensitive species were killed at 40 meters (131 feet).(16) Models indicate that even more sensitive species would be killed at distances approaching 100 meters (328 feet).(14) Glyphosate residues have been measured 400 meters (1312 feet) downwind from ground applications.(17)

* Helicopter applications: Between 41 and 82 percent of glyphosate applied from helicopters moves off the target site.15 Two studies done in Canada(18),(19) measured glyphosate residues 200 meters (656 feet) from target areas following helicopter applications to forest sites. In both studies, 200 meters was the farthest distance at which samples were taken, so the longest distance glyphosate traveled is not known.(18,(19) A third study (from California) found glyphosate 800 meters (2624 feet) downwind following a helicopter application. Again, this was the farthest distance at which measurements were made. Plant injury was recorded 400 meters (1312 feet) downwind.(17)

*Fixed-wing aircraft: Long drift distances occur following applications of glyphosate made from fixed-wing airplanes. Three studies on forested sites conducted by Agriculture Canada (the Canadian agricultural ministry) showed that glyphosate was consistently found at the farthest distance from the target areas that measurements were made (200, 300, and 400 meters, or 656, 984, and 1312 feet).20-22 A California study found glyphosate 800 meters downwind of an airplane application. Again, this was the farthest distance at which measurements were made. Plant injury was observed at 100 meters (328 feet). Unlike the first three studies, this study used a grass field as the test site.(17)

One of the Canadian studies(22) calculated that buffer zones of between 75 and 1200 meters (246 feet - 0.75 miles) would be required to protect nontarget vegetation.

Soil Contamination

Persistence: 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 and as long as 141 days have been measured by glyphosate's manufacturer.(4) Initial degradation (breakdown) is faster than the subsequent degradation of what remains, resulting in long persistence.(23) Long persistence has been measured in the following studies:

55 days on an Oregon Coast Range forestry site(24); 249 days on Finnish agricultural soils(28); between 259 and 296 days on eight Finnish forestry sites(23); 335 days on an Ontario (Canada) forestry site(26); 360 days on 3 British Columbia forestry sites(27); and, from 1 to 3 years on eleven Swedish forestry sites.(27) These are minimum estimates because, in all but two of these studies, glyphosate was detected on the last date samples were analyzed.

Glyphosate is thought to be "readily bound to many soils and clay minerals"1 and therefore "immobile or slightly immobile in many soils."1 This means that the glyphosate will be unlikely to move away from the application site and contaminate water or soil elsewhere. However, a new study(29) paints a different picture. The researchers found that glyphosate bound readily to the four soils studied. 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 concludes that "this herbicide can be extensively mobile in the soil environment.."(29)

Water Contamination

Based on the prevailing view that glyphosate binds readily to soil particles, it does not have the chemical characteristics of a pesticide that is likely to leach into either ground or surface water.(1) (If it readily desorbs, as described above, this picture would change.) In either case, 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.(1)

However, glyphosate has been found in both ground and surface water. Examples include two farm ponds in Ontario, Canada, contaminated by run-off from an agricultural treatment (one pond) and a spill (the other pond)(30); the run-off from a watersheds treated with Roundup during production of no-till corn and fescue (31); contaminated surface water in the Netherlands1; and seven U.S. wells (one in Texas, six in Virginia) contaminated with glyphosate.(32)

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 following direct application.(33)(34) Glyphosate persists longer in sediments. For example, a study of Accord applied to forest ponds found glyphosate residues in sediment 400 days after application.1 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 effects, through destruction of food or shelter.

Effects on Nontarget Animals

Beneficial insects: Glyphosate-containing products pose hazards to insects that are economically beneficial because they kill pest insects. **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.35 Over 80 percent of a fourth species, a predatory beetle, was killed.**

Similar impacts on beneficial insects have been shown in field studies. In North Carolina winter wheat fields, populations of large carabid beetles declined after treatment with a commercial glyphosate product and did not recover for 28 days.(36) A study of Roundup treatment of pasture hedgerows in the United Kingdom showed a similar decline in carabid beetles.(37)

Roundup treatment of a Maine clear-cut caused an 89 percent decline in the number of herbivorous (plant-eating) insects. While these are not usually considered beneficial insects, they serve as an important food resource for birds and insect-eating small mammals.(38)

Aquatic insects can also be affected by glyphosate. Midge larvae (important food for breeding waterfowl(39)) are killed by glyphosate in amounts that vary widely. For example, one study found that 55 parts per million (ppm) of glyphosate killed midge larvae(6)while other studies found that 65040 - 560039 ppm of Rodeo (containing glyphosate and water) were required to kill the larvae. Part of the variability is related to water hardness.(39)

The U.S. Fish and Wildlife Service has identified one endangered species of insect, a longhorn beetle, that would be jeopardized by use of glyphosate.(41)

Other arthropods: Glyphosate and glyphosate-containing products kill a variety of other arthropods. For example, over 50 percent of test populations of a predatory mite that is an important predator of pest mites was killed by exposure to Roundup.(38) 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.(42) Roundup treatment of pasture hedgerows reduced the number of spiders, probably by killing the plants they preferred for web-spinning.(37) The water flea Daphnia pulex is killed by concentrations of Roundup between 3 and 25 ppm.(6),(34),(44) Young Daphnia are more susceptible than mature individuals, and suspended sediments in the water increased the toxicity.(43) The red swamp crawfish, a commercial species, was killed by 47 ppm of Roundup.(48)

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 in toxicity to fish can be explained by the toxicity of the surfactant (detergent-like ingredient) in Roundup. It is about 30 times more toxic to fish than glyphosate itself.(44)

Acute toxicities of glyphosate vary widely: median lethal concentrations (LC50s; the concentrations killing 50 percent of a population of test animals) from 10 ppm to over 1000 ppm have been reported depending on the species of fish and test conditions.1 In soft water there is little difference between the toxicities of glyphosate and Roundup.

Acute toxicities of Roundup to fish range from an LC50 of 3.2 ppm to an LC50 of 52 ppm.1 Acute toxicities of Rodeo (used with the surfactant X-77 per label recommendations) vary from 120 to 290 ppm.(46)

Factors important in determining the toxicity of glyphosate or glyphosate-containing products to fish include the following:

* First, different species of fish have different susceptibilities. For example, coho and chinook salmon are more tolerant of glyphosate than pink or chum salmon.(47)

* Water quality is important: glyphosate in soft water was 20 times more toxic to rainbow trout than was glyphosate in hard water. For Roundup, the reverse is true: it is more toxic in hard water than in soft.(47),(48)

* Age affects the susceptibility of fish because juveniles are often more susceptible than adults. For example, Roundup was four times more toxic to rainbow trout fry and fingerlings than it was to larger fish.(6)

* Nutrition also can determine toxicity. Hungry fish are more susceptible to glyphosate than fed fish. For example, fed flagfish were 10 times more tolerant of glyphosate than unfed fish.(49)

* Finally, glyphosate toxicity increases with increased water temperature. In both rainbow trout and bluegills, toxicity about doubled between 7 and 17!C (45 and 63!F).(6) Treatment of riparian areas with glyphosate causes water temperatures to increase for several years following treatment(80) because the herbicide kills shading vegetation. This means that repeated use of glyphosate in a watershed could favor its increased toxicity to fish. In addition, the temperature increase itself could be critical for fish, like juvenile salmon, that are sensitive to water temperature.

Sublethal effects of glyphosate on fish are also significant and occur at low concentrations. Studies of rainbow trout and Tilapia found that concentrations of about 1/2 and 1/3 of the LC50 (respectively) caused erratic swimming.(81),(82) The trout also exhibited labored breathing.(81) Behavioral effects can increase the risk that the fish will be eaten, as well as affecting feeding, migration, and reproduction.(82)

Birds: Glyphosate is acutely toxic to birds, but only in large amounts. The LC50, the amount in food that kills 50 percent of a population of test animals, is often above 4000 milligrams per kilogram of food.(1)

Glyphosate also has indirect impacts on birds. Because glyphosate kills plants, its use creates 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 glyphosate treatment. By the fourth year post-spray,

densities had returned to normal for these two species. However, the unsprayed plot had by then been colonized by new species of birds (warblers, vireos, and a hummingbird). These species did not appear on the sprayed plots.(83)

An earlier three year study of songbird abundance following glyphosate treatment of clear-cuts in Maine forests showed similar results. Abundance's of the total number of birds (Figure 2) and three common species decreased. The decrease in bird abundance was correlated with decrease in the diversity of the habitat.(84)

Black grouse avoided glyphosate-treated clear-cuts in Norway for several years after treatment.(88) Researchers recommended that the herbicide not be used near grouse courtship areas Small mammals: In field studies, small mammals have also been indirectly affected when glyphosate kills the vegetation they (or their prey) use for food or shelter. This was first shown in studies of clear-cuts in Maine.(38) Insect-eating shrews declined for three years post-treatment; plant-eating voles declined for two. A second study in Maine(86) found similar results for voles, but not shrews. A British Columbia study found that deer mice populations were dramatically (83 percent) lower following glyphosate treatment.(87) While some other studies have found no affect on mice, this may have occurred because treated areas were small.1 This suggests that effects are more severe when large areas are treated. In Norway, there was a "strong reduction" in use of sprayed clear-cuts by mountain hare.(88)

Earthworms: A study of the most common earthworm found in agricultural soils in New Zealand showed that glyphosate significantly affects growth and survival of earthworms. Repeated biweekly applications of low rates of glyphosate (1/20 of typical rates) caused a reduction in growth, an increase in the time to maturity, and an increase in mortality.(89)

Effects on Nontarget Plants

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

Endangered species: Because essentially all plants are susceptible to glyphosate-caused damage or mortality, glyphosate 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 use of

glyphosate. This list is based on the use of glyphosate on 9 crops, and does not include over 50 other uses.41Nitrogen fixation: Nitrogen is important because of its "near omnipresence" in membranes, proteins, and genetic material of living things. Most living things cannot use nitrogen in its common form and instead use ammonia and nitrates, much rarer compounds. The processes by which ammonia and nitrates are created are called nitrogen fixation and nitrification. They are carried out by certain bacteria.(60)

A number of studies (from Iowa,(61) Australia,(62) eastern Canada,(63) and Ontario (Canada)(64),(68)) have shown that commercial glyphosate products can reduce nitrogen-fixing or nitrification activity of soils. The amount of glyphosate that produces inhibitory effects varies from 262 to 200063 ppm. Effects can be persistent; the formation of nitrogen-fixing nodules on clover roots was inhibited 120 days after treatment. (62)

In addition, tests of cultured nitrogen-fixing bacteria have also shown that glyphosate inhibits nitrogen-fixation. These studies included the nitrogen-fixing species in roots of soybeans(66) and clover.(67),(68)

Given the importance of nitrogen-fixation to agriculture, more research is crucial. 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.(69) Glyphosate is toxic to many species of mycorrhizal fungi. Effects, mostly growth inhibition, have been observed at concentrations between 1 and 100 ppm.(70),(73)

Plant diseases: Glyphosate treatment increases the susceptibility of crop plants to a number of diseases. For example, glyphosate reduced the ability of bean plants to defend themselves against the disease anthracnose.(74)

Glyphosate increased the growth of take-all disease in soil from a wheat field. In addition, the proportion of soil fungi which was antagonistic to the take-all fungus decreased.(78) Bean seedlings also survived glyphosate treatment when grown on sterile soil, but not when grown on normal (not sterilized) soil.(76) Spraying of Roundup prior to planting barley increased the severity of Rhizoctonia root rot and decreased barley yield.(77) In addition, Roundup injection of lodgepole pine inhibited the defensive response of the tree to blue stain fungus.(78)

References

1. World Health Organization, United Nations Environment Program,

International Labor Organization. 1994. Glyphosate. Environmental Health Criteria #159. Geneva, Switzerland.
2. Cessna, A.J. and N.P. Cain. 1992. Residues of glyphosate and its metabolite AMPA in strawberry fruit following spot and wiper applications. Can. J. Plant Sci. 72: 1359-1365.
3. Roy, D.N. et al. 1989. Uptake and persistence of the herbicide glyphosate (Vision?) in fruit of wild blueberry and red raspberry. Can. J. For. Res. 19: 842-847.
4. U.S. EPA. Office of Pesticide Programs. Special Review and Reregistration Division. 1993. Reregistration eligibility decision (RED): Glyphosate. Washington, D.C. (September.)
5. Wang, Y., C. Jaw, and Y. Chen. 1994. Accumulation of 2,4-D and glyphosate in fish and water hyacinth. Water Air Soil Pollut. 74: 397-403.
6. Folmar, L.C., H.O. Sanders, and A.M. Julin. 1979. Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. Arch. Environ. Contam. Toxicol. 8:269-278.
7. Jauhiainen, A., et al. 1991. Occupational exposure of forest workers to glyphosate during brush saw spraying work. Am. Ind. Hyg. Assoc. J. 52(2):61-64.
8. Lavy, T.L. et al. 1993. Measurements of year-long exposure to tree nursery workers using multiple pesticides. Arch. Environ. Contam. Toxicol. 24:123-144.
9. Pease, W.S. et al. 1993. Preventing pesticide-related illness in California agriculture: Strategies and priorities. Environmental Health Policy Program Report. Berkeley, CA: University of California. School of Public Health. California Policy Seminar.
10. Robinson, J.C. et al. 1994. Pesticides in the home and community: Health risks and policy alternatives. Environmental Health Policy Program Report. Berkeley, CA: University of California. School of Public Health. California Policy Seminar.
11. Ware, G.W. et al. 1983. Reducing pesticide application drift-losses. Tucson, AZ: University of Arizona. College of Agriculture. Cooperative Extension Service.
12. Payne, N.J. 1992. Off-target glyphosate from aerial silvicultural applications and buffer zones required around sensitive areas. Pestic. Sci. 34:1-8.
13. Atkinson, D. 1985. Glyphosate damage symptoms and the effects of drift. Appendix I. In Grossbard, E. and D. Atkinson. The herbicide glyphosate. London: Butterworths.
14. Breeze, V., G. Thomas, and R. Butler. 1992. Use of a model and toxicity data to predict the risks to some wild plants from drift of four herbicides. Ann. Appl. Biol. 121:669-677.
15. Freedman, B. 1990-1991. Controversy over the use of herbicides in forestry, with particular reference to glyphosate usage. J. Envir. Sci. Hlth. C8(2):277-286.

16. Marrs, R.H. et al. 1993. Determination of buffer zones to protect seedlings of non-target plants from the effects of glyphosate spray drift. Agric. Ecosys. Environ. 45:283-293.

17. Yates, W.E., N.B. Akesson, and D.E. Bayer. 1978. Drift of glyphosate sprays applied with aerial and ground equipment. Weed Sci. 26(6):597-604.
18. Riley, C.M., C.J. Weisner, and W.A. Sexsmith. 1991. Estimating off-target spray deposition on the ground following the aerial application of glyphosate for conifer release in New Brunswick. J. Environ. Sci. Health B26(2):185-208.
19. Payne, N.J., J.C. Feng, and P.E. Reynolds. 1990. Off-target depositions and buffer zones required around water for aerial glyphosate applications. Pestic. Sci. 30:183-198.
20. Payne, N.J. and D.G. Thompson. 1992. Off-target glyphosate deposits form aerial silvicultural applications under various meteorological conditions. Pestic. Sci. 34:53-59.
21. Payne, N.J. 1993. Spray dispersal from aerial silvicultural applications. Crop Protec. 12(6):463-469.
22. Payne, N.J. 1992. Off-target glyphosate from aerial silvicultural applications, and buffer zones required around sensitive areas. Pestic. Sci. 34:1-8.
23. Torstensson, L. and Stark, J. 1979. Persistence of glyphosate in forest soils. In Weeds and weed control. 20th Swedish Weed Conference. Uppsala. 31 January - 2 February 1979. Uppsala, Sweden: Swedish University of Agricultural Sciences.
24. Newton, M. et al. 1984. Fate of glyphosate in an Oregon forest ecosystem. J. Agric. Food. Chem. 32:1144-1151.
25. Mller, M. et al. 1981. Fate of glyphosate and its influence on nitrogen-cycling in two Finnish agricultural soils. Bull. Environ.. Contam. Toxicol. 27:724-730.
26. Feng, J.C. and D.G. Thompson. 1990. Fate of glyphosate in a Canadian forest watershed. 2. Persistence in foliage and soils. J. Agric. Food. Chem. 38: 1118-1125.
27. Roy, D.N. et al. 1989. Persistence, movement, and degradation of glyphosate in selected Canadian boreal forest soils. J. Agric. Food. Chem. 37:437-440.
28. Torstensson, N.T.L., L.N. Lundgren, and J. Stenstrm. 1989. Influence of climate and edaphic factors on persistence of glyphosate and 2,4-D in forest soils. Ecotoxicol. Environ. Safety 18:230-239.
29. Piccolo, A. et al. 1994. Adsorption and desorption of glyphosate in some European soils. J. Environ. Sci. Health B29(6): 1105-1115.
30. Frank, R. et al. 1990. Contamination of rural ponds with pesticide, 1971-1985, Ontario, Canada. Bull. Environ. Contam. Toxicol. 44:401-409.
31. Edwards, W.M., G.B. Triplett, Jr., and R.M. Kramer. 1980. A watershed study of glyphosate transport in runoff. J. Environ. Qual. 9(4):661-665.

32. U.S. EPA. Prevention Pesticides and Toxic Substances. 1992. Pesticides in groundwater database. A compilation of monitoring studies: 1971-1991. National summary. Washington, D.C.
33. Goldsborough, L.G. and A.E. Beck. 1989. Rapid dissipation of glyphosate in small forest ponds. Arch. Environ. Contam. Toxicol. 18:537-544.
34. Goldsborough, L.G. and D.J. Brown. 1993. Dissipation of glyphosate and aminomethylphosphonic acid in water and sediments of boreal forest ponds. Environ. Toxicol. Chem. 12:1139-1147.
35. Hassan, S.A. et al. 1988. Results of the fourth joint pesticide testing programme carried out by the IOBC/WPRS-Working Group "Pesticides and Beneficial Organisms." J. Appl. Ent. 105:321-329.
36. Brust, G.E. 1990. Direct and indirect effects of four herbicides on the activity of carabid beetles (Coleoptera: Carabidae). Pestic. Sci. 30:309-320.
37. Asteraki, E.J., C.B. Hanks, and R.O. Clements. 1992. The impact of the chemical removal of the hedge-base flora on the community structure of carabid beetles (Col., Carabidae) and spiders (Araneae) of the field and hedge bottom. J. Appl. Ent. 113:398-406.
38. 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.
39. Buhl, K.J. and N.L. Faerber. 1989. Acute toxicities of selected herbicides and surfactants to larvae of the midge Chironomus riparius. Arch. Environ. Contam. Toxicol. 18:530-536.
40. Henry, C.J., K.F. Higgins, and K.J. Buhl. 1994. Acute toxicity and hazard assessment of Rodeo?, X-77 Spreader?, and Chem-Trol? to aquatic invertebrates. Arch. Environ. Contam. Toxicol. 27(3):392-399.
41. U.S. EPA. Office of Pesticides and Toxic Substances. 1986. Guidance for the reregistration of pesticide products containing glyphosate. Washington, D.C. (June.)
42. Mohamed, A.I. et al. 1992. Effects of pesticides on the survival, growth and oxygen consumption of Hemilepistus reaumuri (Audouin & Savigny 1826) (Isopoda Oniscidea). Trop. Zool. 5:145-153.
43. Hartman, W.A. and D.B. Martin. 1984. Effect of suspended bentonite clay on the acute toxicity of glyphosate to Daphnia pulex and Lemna minor. Bull. Environ. Contam. Toxicol. 33:355-361.
44. Servizi, J.A., R.W. Gordon, and D.W. Martens. 1987. Acute toxicity of Garlon 4 and Roundup herbicides to salmon, Daphnia, and trout. Bull. Environ. Contam. Toxicol. 39:15-22.
45. Holck, A.R. and C.L. Meek. 1987. Dose-mortality responses of crawfish and mosquitoes to selected pesticides. J. Am. Mosqu. Contr. Assoc. 3:407-411.

46. Mitchell, D.G., P.M. Chapman, and T.J. Long. 1987. Acute toxicity of Roundup? and Rodeo? herbicides to rainbow trout, chinook, and coho salmon. Bull. Environ. Contam. Toxicol. 39:1028-1035.

47. Wan, M.T., R.G. Watts, and D.J. Moul. 1989. Effects of different dilution water types on the acute toxicity to juvenile Pacific salmonids and rainbow trout of glyphosate and its formulated products. Bull. Environ. Contam. Toxicol. 43:378-385.
48. Wan, M.T., R.G. Watts, and D.J. Moul. 1991. Acute toxicity to juvenile Pacific Northwest salmonids of Basacid Blue NB755 and its mixture with formulated products of 2,4-D, glyphoste and triclopyr. Bull. Environ. Contam. Toxicol. 47:471-478.
49. Holdway, D.A. and D.G. Dixon. 1988. Acute toxicity of permethrin or glyphosate pulse exposure to larval white sucker (Catostomus commersoni) and juvenile flagfish (Jordanella floridae) as modified by age and ration level. Environ. Toxicol. Chem. 7:63-68.
50. Holtby, L.B. 1989. Changes in the temperature regime of a valley-bottom tributary of Carnation Creek, British Columbia, over-sprayed with the herbicide Roundup (glyphosate). In Reynolds, P.E. (ed.) Proceedings of the Carnation Creek Herbicide Workshop. Sault Ste. Marie, Ontario, Canada: Forest Pest Management Institute.
51. Morgan, J.D. et al. 1991. Acute avoidance reactions and behavioral responses of juvenile rainbow trout Oncorhynchus mykiss) to Garlon 4, Garlon 3A? and Vision? herbicides. Environ. Toxicol. Chem. 10:73-79.
52. Liong, P.C., W.P. Hamzah, and V. Murugan. 1988. Toxicity of some pesticides towards freshwater fishes. Malaysian Agric. J. 54(3):147-156.
53. MacKinnon, D.S. and B. Freedman. 1993. Effects of silvicultural use of the herbicide glyphosate on breeding birds of regenerating clearcuts in Nova Scotia, Canada. J. Appl. Ecol. 30(3):395-406.
54. Santillo, D., P. Brown, and D. Leslie. 1989. Responses of songbirds to glyphosate-induced habitat changes on clearcuts. J. Wildl. Manage. 53(1):64-71.
55. Eggestad, M. et al. 1988. Glyphosate application in forest--ecological aspects. VIII. The effect on black grouse (Tetrao tetrix) summer habitat. Scand. J. For. Res. 3:129-135.
56. D'Anieri, P., D.M. Leslie, and M.L. McCormack. 1987. Small mammals in glyphosate-treated clearcuts in northern Maine. Can. Field-Nat. 101(4):547-550.
57. Ritchie, C., A.S. Harestad, and R. Archibald. 1987. Glyphosate treatment and deer mice in clearcut and forest. Northw. Sci. 6(3):199-202.
58. Hjeljord, O. et al. 1988. Glyphosate application in forest--ecological aspects. VII. The effect on mountain hare (Lepus timidus) use of a forest plantation. Scand. J. For. Res. 3:123-127.
59. 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.
60. Hutchinson, G.L. 1995. Nitrogen cycle interactions with global change processes. In Nierenberg, W.L. (ed.) Encyclopedia of Environmental Biology. Volume 2. San Diego: Academic Press. Pp.563-557.

61. Martens, D.A. and J.M. Bremner. 1993. Influence of herbicides on transformations of urea nitrogen in soil. J. Environ. Sci. Health B28(40:377-395.
62. Eberbach, P.L. and L.A. Douglas. 1983. Persistence of glyphosate in a sandy loam. Soil Biol. Biochem. 15(4):485-487.
63. Stratton, G.W. 1990. Effects of the herbicide glyphosate on nitrification in four soils from Atlantic Canada. Water Air Soil Pollut. 51:373-383.
64. Tu, C.M. 1994. Effects of herbicides and fumigants on microbial activities in soil. Bull. Environ. Contam. Toxicol. 53:12-17.
65. Carlisle, S.M. and J.T. Trevors. 1986. Effect of the herbicide glyphosate on nitrification, denitrification, and acetylene reduction in soil. Water Air Soil Pollut. 29: 189-203.
66. Moorman, T.B. et al. 1992. Production of hydrobenzoic acids by Bradyrhizobium japonicum strains after treatment with glyphosate. J. Agric. Food Chem. 40:289-293.
67. Mortensson, A.M. 1992. Effects of agrochemicals and heavy metals on fast-growing Rhizobia and their symbiosis with small-seeded legumes. Soil Biol. Biochem. 24(5):435-445.
68. Eberbach, P.L. and L.A. Douglas. 1989. Herbicide effects on the growth and nodulation potential of Rhizobium trifolii with Trifolium subterraneum L. Plant and Soil 119:15-23.
69. Towle, A. 1989. Modern biology. Austin, TX: Holt, Rinehart and Winston. p.342.
70. Estok, D., B. Freedman, and D. Boyle. 1989. Effects of the herbicides 2,4-D, glyphosate, hexazinone, and triclopyr on the growth of three species of ectomycorrhizal fungi. Bull. Environ. Contam. Toxicol. 42:835-839.
71. Chakravarty, P. and L. Chatarpaul. 1990. Non-target effect of herbicides: I. Effect of glyphosate and hexazinone on soil microbial activity. Microbial population, and in-vitro growth of ectomycorrhizal fungi. Pestic. Sci. 28:233-241.
72. S.S. Sidhu and P. Chakravarty. 1990. Effect of selected forestry herbicides on ectomycorrhizal development and seedling growth of lodgepole pine and white spruce under controlled and field environment. Eur. J. For. Path. 20:77-94.

73. Chakravarty, P. and S.S. Sidhu. 1987. Effects of glyphosate, hexazinone and triclopyr on in vitro growth of five species of ectomycorrhizal fungi. Eur. J. For. Path. 17:204-210.
74. Johal, G.S. and J.E. Rahe. 1988. Glyphosate, hypersensitivity and phytoalexin accumulation in the incompatible bean anthracnose host-parasite interaction. Physiol. Molec. Plant Pathol. 32:267-281.
75. Mekwatanakarn, P. and K. Sivassithamparam. 1987. Effect of certain herbicides on soil microbial populations and their influence on saprophytic growth in soil and pathogenicity of take-all fungus. Biol. Fertil. Soils 5:175-

180.
76. Peerbolt, A. 1995. Does glyphosate block disease resistance in plants? The Digger (June):14,15,17.
77. Smiley, R.W. 1992. Influence of glyphosate on Rhizoctonia root rot, growth, and yield of barley. Plant Dis. 76:937-942.
78. Bergvinson, D.J. and J.H. Borden. 1992. Enhanced colonization by the blue stain fungus Ophiostoma claverum in glyphosate-treated sapwood of lodgepole pine. Can J. For. Res. 22:206-209.

==========

Northwest Coalition for Alternatives to Pesticides
P.O. Box 1393 Eugene, OR 97440
Phone: (541) 344-5044
email:
ncap@igc.org

==========

Pesticide Action Network North America (PANNA)
Phone: (415) 541-9140 | *For general information
Fax: (415) 541-9253 | about PANNA, send an
panna@panna.org
http://www.panna.org/panna/

==========