Thinking Holistically When Making Land Management Decisions

Regulatory analyses that support pesticide use ignore complex ecological impacts

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This article focuses on ecological impacts of chemical-intensive practices when they are adopted on a wide scale as the dominant land management system. These impacts are not easily captured in an ecological risk assessment because they may result from interactions among stressors and cumulative impacts of single or multiple stressors. In order to get a better idea of the impacts of chemical-intensive agriculture and land management, it is necessary to see the entire system in contrast with organic management systems. Organic agriculture and land management demand not just the avoidance of toxic chemicals, but also the promotion of healthy soil and biodiversity in crop and non-crop areas.

Ecological changes occur on a broad scale—such as shifts in plant and animal populations—in response to widespread low or high levels of chemicals in the environment, as well as physical and biological impacts of practices such as monoculture, short rotations, and intensive tillage. Examples include the impacts of glyphosate on milkweed and monarch butterflies, effects of nitrogen deposited from the atmosphere on forests, poisoning caused by low levels of phenoxy herbicides vaporizing and moving to natural areas, and the dead zone in the Gulf of Mexico.

MICROBIAL AND SOIL INVERTEBRATE COMMUNITIES

Microbial communities in the soil and on plants contribute to plant growth and health. Soil communities include bacteria, fungi, earthworms, and other invertebrates that break down organic matter and make nutrients available to plants. Bacteria and fungi engage in reciprocal exchanges of nutrients with plants –providing soluble forms of plant nutrients in return for sugars produced through photosynthesis. Some —perhaps most—of the minerals needed by plants and soil organisms are abundant in the soil and are available under favorable conditions. Synthetic nitrogen can be replaced by legumes and their symbiotic microbes. Phosphorus, though plentiful, can be locked up in the soil unless freed by bacteria or mycorrhizal fungi. Iron and other micronutrients are made more available by microbial action. The task of the organic farmer, landscaper, or gardener, then, is to feed and create a favorable environment for the soil organisms who make nutrients available to plants.

Chemical-intensive farming and land management, on the other hand, destroys these essential communities. Soil fumigants are highly toxic gases—including methyl bromide, chloropicrin, dazomet, 1,3-dichloropropene, metam sodium (methyl isothiocyanate), and dimethyl disulfide—that are injected into the soil to sterilize it. They are used on a wide range of high-

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value crops to control nematodes, fungi, bacteria, insects, and weeds.[1] Soil fumigants wipe out entire soil communities, thus necessitating the use of other chemicals to provide the fertility and pest control services that soil organisms provide.

In addition to fumigating soil, which intentionally kills all living things in the soil, other practices also threaten soil life. Glyphosate, the most widely used herbicide, is also an antibiotic.[2] Glyphosate varies in its impacts on microbes—some species are inhibited by glyphosate, some tolerate it, and still others may use glyphosate or its metabolite aminomethylphosphonic acid (AMPA) as a food source.[3] The impacts of glyphosate's interactions with the microbiota of the root zone are various. For example, soybeans are legumes and hence harbor nitrogen-fixing bacteria in root nodules. Glyphosate interferes with nitrogen fixation in glyphosate-tolerant soybeans.[4] Glyphosate-tolerant plants release glyphosate into the soil, where it has a continued impact. Glyphosate is also released to the soil by dead treated plants. "Once in soil, glyphosate may be adsorbed [adhere to the surface] onto soil particles, degraded by microbes, or transferred to deeper soil horizons, migrating via soil pores or root canals. However, some agricultural practices, such as adding a phosphorous amendment, may re-solubilize glyphosate in soils, making it available for leaching and to the rhizosphere of non-target plants."[5] Other herbicides, diminish or shift microbial populations.[6]

Seeds of corn, soybeans, canola and others are widely coated with pesticides, such as neonicotinoid insecticides, before they are planted –in an effort to poison soil pests, including insects and fungus, before and after germination. The pesticides are also applied to vegetable and flower seedlings and plants, including turf, as a soil drench, spray, granules, or dust. Whether applied as a seed coating or to the plant, these systemic pesticides translocate throughout the plant, essentially making the entire plant a pesticidal agent. Pesticides applied to seeds and seedlings also seep into the soil and kill insect and other invertebrate decomposers, such as earthworms.[7] Since neonicotinoids have long half-lives and are mobile, these impacts affect invertebrates in surrounding soil, as well as the crop site. The biological insecticide bacillus thuringiensis (Bt), when genetically engineered into crops, lets loose its toxin in exudates or in decomposition.[8] Other insecticides and fungicides sprayed on crops affect the life of the soil as well.[9] And while these impacts occur mostly on cultivated fields, the chemicals and genes drift to surrounding areas.[10] Intensive tillage, with soil left bare over the winter, allows all of these threats to be carried away in dust and runoff.[11]

PLANT COMMUNITIES

Plant communities are also affected by chemical drift and volatilization, dust, and runoff. Diminished populations of milkweed and their impact on monarch butterflies, have been documented, both within fields[12] and in all breeding areas.[13] The U.S. Geological Survey estimates that 1.8 billion more milkweed stems are necessary for a sustainable monarch population.[14]

Phenoxy herbicides, like 2,4-D, and similar herbicides in the benzoic acid family, like dicamba, are notorious for vaporizing and settling on susceptible plants, sometimes far from the application site.[15] Although the reduced use of 2,4-D had allowed crops like grapes to be grown in grain-producing states where their production was previously impossible, recent drift problems with dicamba and 2,4-D, reintroduced with new genetically engineered herbicide-tolerant plants, have brought back old problems.[16]

Hedgerows of plants and shrubs along fields that were widely planted in response to the Dust Bowl were torn out in the 1970s, with the official U.S. Department of Agriculture policy being to plant "fencerow to fencerow."[17] Organic farmers are required to devote space to conserving biodiversity, [18] and benefit from the habitat provided by hedgerows for pollinators, insect predators and parasitoids, and predators of rodents, as well as their value in protecting soil from erosion.[19] Hedgerows and woodlots adjoining fields that are managed in a chemical-intensive manner contain more grassy and weedy plants than those managed with fewer chemicals.[20] Because of the inclusion of those habitats and cropping systems with a complex structure (with intercropping, cover crops, diverse rotations, etc.), organic farms have greater plant diversity than chemical-intensive farms.[21]

ADVERSE EFFECTS FROM SYNTHETIC FERTILIZATION

Threats to forests and severe ecosystem changes are linked to the nitrogen from chemical fertilizers.[22] Nitrogen (as ammonia and oxides of nitrogen) moves in the air, and is deposited in forest soils. Of the 54 million tons of ammonia emitted to the air, 75 percent is of anthropogenic origin.[23] The impacts of the ammonia emitted by agriculture and deposited in forests has been summarized by Steingröver and Boxman: "Long-term increased atmospheric input of N may dramatically change forest ecosystems by acidification and/or eutrophication. Prominent changes to the non-tree part of the ecosystem are the increasing number of nitrophilous [i.e., early successional, "weedy"] species in forest undergrowth and the decline in the number of fruiting bodies of ectomycorrhizal fungi. In trees, nutritional imbalances may result from the loss of base cations from the soil, from preferential uptake of NH_4^+; by roots and from competition between NH_4^+ and the uptake of cations like K^+, Mg^{+2}, and Ca^{+2}. Next to these soil mediated effects, N may be taken up directly by the foliage, resulting in increased N concentrations and disturbing the N allocation in the tree."[24] Other impacts of excess nitrogen in forests include decline of mycorrhizae, changes in species composition and diversity, and overall decline resulting from increased susceptibility to insects, disease, freezing, and drought.[25]

Agricultural emissions of nitrogen fertilizers account for 80% of the growth in global air concentrations of nitrous oxide (NO_2), a greenhouse gas with global warming potential of 265-298 times that of carbon dioxide.[26] Synthetic nitrogen fertilizers applied to California cropland contribute 20 to 51% of the nitrous oxides emitted in the state, resulting air pollution, acid rain, and respiratory illness.[27] In addition to promoting the emission of greenhouse gases, chemical-intensive agriculture promotes climate change by reducing (in comparison to undisturbed land or organic production) the sequestration of carbon in the soil.[28]

Climate change causes wide-ranging shifts in plant communities. It causes changes in plant flowering times.[29] Those shifts in flowering times can lead to disruption of plant-pollinator interactions, with a predicted extinction of both pollinator and plant species.[30] Climate change and associated factors (such as increased nitrogen deposition and carbon dioxide (CO_2) concentrations) have been linked to "invasive species" problems, which are also connected to disturbances that cause openings in plant communities and provide opportunities for invaders.[31] While it is difficult to predict the impact of plant diseases in global climate change, it will at least add another layer of complexity and uncertainty to plant populations.[32]

ANIMAL COMMUNITIES

Frightening global reductions in biodiversity are occurring, and at least some of the reductions are due to pesticide use. European scientists document a decrease of over 75% in flying insect biomass in natural areas over a 27-year period.[33]

In addition to loss of species and numbers of animals, chemical-intensive agriculture shifts animal populations in ways that are detrimental to agriculture as well as the survival of natural communities. When the landscape is so dominated by crop fields without other habitat, native herbivore populations must shift to those species who feed on crop plants.[34] Without the hedgerows, cover crops, and diverse cropping systems provided by organic farms, chemical-intensive farms lack overwintering sites and food sources for insect predators and parasites outside of the time when their "pest" prey and hosts are available. As a result, natural controls are absent, leading to greater reliance on toxic chemicals.[35]

The impacts of pesticides on bees have been recognized as a problem since the 1870s, but intensification of insecticide and herbicide use after World War II, along with increasing monoculture and removal of hedgerows and other non-cropped areas, led to decreased populations of native pollinators and increased reliance on domesticated bees for pollination. Meanwhile, beekeepers were forced to pasture their bees on fields treated with insecticides.[36] In the time


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since pesticides were first recognized as a problem for bees and other pollinators, pest control technology has undergone several generations of change. With shifts from organochlorines to organophosphates to synthetic pyrethroids and neonicotinoids, the toxicological mechanisms may have changed, but there is abundant research demonstrating that insecticides, herbicides, and fungicides have significant lethal and non-lethal impacts on bees and other pollinators, which threaten pollinator-dependent crops.[37]

Organic farm management, on the other hand, nurtures pollinators and other insects considered beneficial to agriculture. Organic farms are required to support biodiversity, and providing nectar sources that have not been poisoned is one way that they meet that requirement.[38] Research shows that "ecological intensification,"[39] natural and semi-natural habitat surrounding fields,[40] and weedy areas[41] support populations of pollinators and other "beneficial" insects. The loss of these benefits due to the use of chemical-intensive approaches are necessary factors to consider in a valid assessment of pesticide risks.

All taxonomic groups benefit from organic, as opposed to chemical-intensive, production.[42] In chemical-intensive agriculture, birds lose nesting sites and perches from which to hunt. Larger mammals are affected by the loss of migration corridors, effectively reducing their available habitat. Deer foraging in pesticide-treated fields are subjected to pesticide residues that would not be allowed in domestic livestock feed, which ultimately affects the human consumers who may believe they are eating a less contaminated product.

AQUATIC/MARINE COMMUNITIES

Aquatic and marine communities are also affected by drift, runoff, and fallout from chemical-intensive agriculture.[43] The most notorious example is the Dead Zone in the Gulf of Mexico, caused mostly by runoff of fertilizer, which contributes 80% of the nitrogen and 60% of the phosphorous to the Gulf. Dead zones are areas of low oxygen (hypoxia) that have severe impacts on the biodiversity and functioning of marine ecosystems and the services they provide, including production of fisheries, nutrient cycling, and water column filtration.[44] On the way to the Gulf, the contaminants diminish the water quality of streams, compromising drinking water, posing risks from algal blooms, and threatening commercial fisheries.[45]

Herbicides from runoff, drift, or fallout cause shifts in populations of algae and aquatic plants. The loss of keystone species has been documented, and these impacts cascade up aquatic food chains.[46] Indirect effects of pesticides on aquatic and marine systems include changes in behavior, physiology, competitive or predator-prey interactions, which are generally not identified in toxicity testing.[47]

Higher rates of atmospheric carbon dioxide, which could be prevented or ameliorated by organic agriculture, contribute to acidification of oceans, reducing availability of carbonate ions that are needed by marine organisms, such as corals, marine plankton, and shellfish for formation of skeletons and shells.[48]

In addition to these broad impacts, residues of many individual pesticides in streams, lakes, and oceans have been documented, as well as their impacts on aquatic and marine species.[49] In all samples taken year-round, the U.S. Geological Survey (USGS) detected neonicotinoids in the Great Lakes and its tributaries, with increased detections during planting season. Michelle Hladik, PhD, lead author of the study and a research chemist at USGS, said the major risk of these chemicals is to aquatic insects—an effect that could ripple up the food chain. "If these pesticides are affecting aquatic insects, causing lower populations, it could affect the food chain by removing a food source" for fish, she said.[50]

GLOBAL EFFECTS

Globally, the climate is affected by the loss of carbon sequestration in fields that lay bare half the year and contain minimal plant and microbial diversity during the growing season.[51]

Nitrate and ammonia from chemical fertilizers are deposited in aquatic and terrestrial ecosystems, shifting the balance of plants, algae, and seaweeds.[52] Chemical-intensive agriculture, with its lack of soil cover during most of the year, results in soil loss from wind and water erosion.[53] The siltation from erosion damages aquatic and marine ecosystems.[54]

For example, siltation affected the Willapa Bay and Grays Harbor, throwing the ecosystem out of balance, leading to the loss of some native predators, an increase in invasive species, and slumping oyster productivity. Over time, as impacts on streams impaired water quality and contributed to the decline of fish populations like salmon and sturgeon,[55] the native Washington oyster, Ostrea lurida, began to decline due to over-harvesting and declining environmental quality, and oystermen began importing the Pacific oyster from Japan and creating artificial oyster beds to help boost productivity.

By the early 1920s, numbers of the native burrowing shrimp grew, as the sediment layer increased[56] and predatory fish populations in the bay declined. Early efforts to prevent shrimp from burrowing –graveling, shelling— were not effective, and soon gave way to chemical control options. Several efforts are underway to restore salmon species in the Pacific Northwest, including Willapa Bay. Stream enhancement and restoration improves habitat for fish, amphibians, and invertebrates –species that help control bountiful populations of burrowing shrimp and aquatic plants.[57] The use of pesticides only serves to further threaten the long-term health of the sensitive ecosystem by adversely affecting other non-target species, and potentially throwing other communities out of balance.

> *Although efforts have been made to estimate the economic costs to the environment associated with pesticide use, these efforts have not focused on environmental services and do not include the costs of industrial agriculture as a system.*

ECOSYSTEM SERVICES—THE ECONOMIC VALUE OF ENVIRONMENTAL PROTECTION

The term "ecosystem services" refers to benefits that people receive from functioning ecosystems. The hydrological cycle provides clean water for agriculture and human consumption. The carbon cycle removes carbon from the atmosphere and incorporates it into plants. Microorganisms decompose waste and turn it into nutrients. Insects provide pollination and pest control services to agriculture.

A decrease in soil microbial diversity reduces the services that soil provides, from decomposition of organic matter to nutrient cycling and carbon fixing.[58] Chemical-intensive agriculture contributes to the loss of ecosystem services. When soil diversity is high, the soil functions more efficiently and provides a multitude of ecosystem services. The application of pesticides in industrialized agriculture reduces soil diversity and therefore reduces soil functionality. As mentioned above, glyphosate, the active ingredient in Roundup, is an antibiotic affecting soil organisms and interfering with nitrogen fixation. Along with other pesticides, glyphosate also harms earthworms, important for the decomposition of organic matter and aeration of soil.

Other ecosystem services are affected as well. Chemical-intensive agriculture reduces insect diversity that provides pollination and pest control services. By reducing vegetative cover during much of the year, it diminishes the ability of the land to mitigate flood events.

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PESTICIDE RISK-BENEFIT ANALYSES MUST INCLUDE COMMUNITY AND ECOSYSTEM IMPACTS

The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the nation's pesticide review law, requires that in registering a pesticide, the U.S. Environmental Protection Agency (EPA) consider risks "to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide." This requirement should not allow EPA to consider a single pesticide or single use of a pesticide in isolation from the system in which it is used. However, risk assessments of pesticides generally examine direct toxicological effects of acute or chronic exposures to single pesticide ingredients, but the impacts of chemical-intensive monoculture and non-target adverse effects are typically less direct and more serious than those considered in pesticide registration. Similarly, in considering whether to cancel the use of a pesticide, EPA compares its risks to those of the pesticide that it believes to be the most likely to be adopted by users. This practice not only gives an inaccurate picture of the risk of the pesticide, but it also creates a context for decision making that excludes options that are protective of human health and the environment.

The widespread availability of toxic pesticides makes possible the chemical-intensive system whose effects are broad and complex. The alternative is not the use of another product, but the implementation of another system –such as organic agriculture—that does not have these impacts. Organic agriculture and land management provide a standard against which pesticide impacts should be measured, both individually and in the aggregate. A broader assessment provides a more complete picture of the threats that pesticides pose and the importance of shifting to organic management systems.

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