Are We Pests? Microbial Genocide: The Effects of Abundant Use on the Environment

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Keywords: Pesticides, Eco-Friendly Pesticides, Microbes

Abstract

This research reviews a copious amount of agricultural studies in which the effects (pros & cons) of pesticide use on the environment are measured. A pesticide is any substance used to kill, repel, or control certain forms of plant or animal life that are considered to be pests. Pesticides affect the environment in numerous ways such as: contamination of soil, water, and vegetation. In addition, pesticides are toxic to many organisms including fish, birds, beneficial insects, and even humans. This paper focuses on the microbial mechanisms of pesticides and connects those biochemical properties (mechanisms) to deregulation of function within organisms, and how that, in turn, affects the environment overall. After reviewing a variety of studies, this paper suggests that pesticide application should be greatly reduced, and, instead, applied in concert with alternative, eco-friendly pesticides such as beneficial insects, biological methods, and transgenic crops to allow the environment to maintain a biogeochemical balance, and microbes to work efficiently.

Introduction

A microbe, or "microscopic organism," is a single-cell organism that is too small to be seen with the naked eye. Microbes surround the environment. They are present in forests, grasslands, deserts, oceans, and the air. In other words, they are everywhere. The most common examples of microbes include: bacteria, archaea, fungi, and viruses. Although microbes are practically invisible due to their size (1 μm -5 μm), there is an abundance of them present of which establishes their significance, and it is these organisms that maintain/balance the processes necessary to sustain life. Some of these microbial processes include photosynthesis, (de) nitrification, methanogenesis, and ammonia oxidation. Each microbial metabolic process plays a critical role in regulation of organisms present within an environment. Microbes perform these processes by metabolizing, or breaking down (redox) certain chemicals, and providing an output that maintains a balance within the environment in which they reside. However, with the prolific and rapidly increasing populous of life on Earth, microbes are beginning to have trouble keeping up with the mass influx of chemicals.

With the increase of the human population, it is of no surprise that necessary operations such as agricultural practices, in terms of food production, increase as well. The issue is not due to the increase of agricultural production, but the maintenance of agriculture; more specifically due to the escalating use of pesticides to allow crops to reach fruition. A pesticide is a substance used for the sole purpose of eliminating "pests", insects, or other organisms harmful to cultivated plants. The term pesticide is classified as several compounds including insecticides, fungicides, herbicides, plant growth regulators, and various others. Again, the problem is not the use of pesticides, but the abundance in which they are used. The amount of pesticides used today are affecting the environment by reducing oxygen levels, and increasing gaseous chemicals such as carbon dioxide, methane, and nitrous oxide. In terms of redox reactions, it is energetically favorable for microbes to metabolize oxidative reactions; therefore, a decrease in oxygen levels will force microbes to cycle over to the next most favorable reaction. These other non-oxidative (anaerobic) reactions produce chemicals that damage the atmosphere, and cause harm to the environment overall. It should be mentioned, however, that some microbes naturally metabolize elements other than oxygen. Such is the case with phosphorous-solubilizers and nitrifiers along with several others. Although aerobic and anaerobic microbes consume different chemicals and are involved in different cycles, both forms of microbes help maintain a stable and balanced environment.

Besides the large production of greenhouse gases from fossil fuels, livestock, and industrial manufacturing, it seems as though the only process that can be reduced or substituted is pesticidal fertilization. Pesticidal fertilization not only affects microorganisms, but also organisms on a macro-scale such as: contamination of soil, water, and vegetation. In addition, pesticides are toxic to many organisms including fish, birds, beneficial insects, and even humans. The contamination of soil, water, and vegetation affects regulatory cycles like the carbon, nitrogen, methane, and water cycle.

All in all, this cycling and system of feedbacks between micro and macro organisms is destabilized. At the moment, this issue poses a minimal threat, but as time progresses this will affect environmental habitats by making them inhabitable to various organisms. The aim of this paper is then to review numerous studies addressing the topic of abundant pesticide use in agriculture, its effect on microbes, and, in turn, the environment. This research review will also examine, analyze, and propose future directions for pesticidal fertilization techniques in agricultural practices.

Microbial Processes & Pesticide Introduction

Microbes can include bacteria, fungi, and viruses. In agriculture, these are unjustly perceived as detrimental organisms. Despite this perception, recent studies suggest that microbes such as these are in fact beneficial to farmlands and their surrounding environment. According to a recent study, microbes present in soil (bacteria & fungi) form relationships with crops by introducing a nutrient trade-off where plants provide microbes with nutrients, and these microbes return these nutrients in a form that is beneficial to those plants (Roossinck 2008). Soil microbes are essential for decomposing organic matter and recycling old plant material. For instance, fungi can provide many benefits, including drought/heat tolerance, resistance to insects, and resistance to plant diseases all while maintaining an even balance in the environment. Before the introduction of pesticides to agriculture, the terrestrial (carbon, nitrogen, methane, etc.) and marine cycles were at equilibrium with neither side gaining or losing (Altman 1997). The introduction of pesticides destabilized this even balance and introduced foreign chemicals to plants such as: ammonia, arsenic, benzene, chlorine, dioxins, ethylene oxide, formaldehyde, and methanol to name a few. The majority of pesticides include chemicals such as these, and this makes pesticides recalcitrant, or incompatible with the terrestrial carbon cycle. During the early years of pesticidal fertilization, it appeared as though soil microbes adapted to this change in their environment, but with the increase in use of pesticides due to the increasing demand for agricultural practices, microbes began to have a difficult time keeping up.

Microbes are pivotal players in regulation of biogeochemical systems in all environments. These include: the carbon, nitrogen, methane, and water cycle. The carbon cycle is the circulation and transformation of carbon (CO_2) back and forth between organisms and the environment. Plants and animals utilize carbon to produce carbohydrates, fats, and proteins, which can then be used to build their internal structures or to obtain energy. Carbon dioxide is readily obtained from the atmosphere, but before it can be incorporated into living organisms it must be transformed into a usable organic form. This is process of carbon fixation is also known as photosynthesis. In simple terms, photosynthesizing bacteria absorb CO_2 from the atmosphere, convert it to a usable form for plants, and plants feedback oxygen into the atmosphere. Based on recent findings, however, this process is no longer occurring efficiently due to the mass amount of pesticidal fertilization (Chen 2007). A number of pesticides inhibit photosynthetic activities. If this inhibition continues, and microbes cannot adapt to current conditions, then they will adapt to other non-carbon dependent processes. For photosynthesizing bacteria, it was found that about half of all nitrogen-containing pesticides, such as the popular herbicide atrazine, inhibit the photosynthetic process by disrupting the transfer of electrons of particular quinones (Stenersen 2004). Disrupting the photosynthetic process leads to an accumulation of carbon emissions in the atmosphere, soils, and water because plants no longer acquire the ability to produce oxygen.

(De)Nitrifiers, Plants, & Pesticides

Another issue is the effect pesticide use has on nitrogen-fixing bacteria in soils. Plants produce an array of chemicals that attract nitrogen-fixating (N-fixing) bacteria (Nitrifiers) into their root systems. In agriculture, plants produce these chemicals in order to attract *Rhizobium* soil bacteria. These *Rhizobium* soil bacteria digest atmospheric nitrogen and spit out ammonia (natural fertilizer). Plants can then use this fertilizer to proliferate and grow. Once these plants wither away (decompose), their remains are decomposed by the same nitrogen-fixating bacteria that provided them with the fertilizer in the first place. A relationship such as this is beneficial for both parties; however, with the introduction of pesticides this relationship is now compromised. Commonly used pesticides today contain substances such chlorine, phosphorous, and nitrogen; popular products containing these elements include glyphosate, atrazine, and metachlor ("PCP" based substance). In a recent study, it was found that organo-chlorine, phosphate, and nitrogen based pesticides inhibited root nodule receptors by 50-90% (Potera 2007). In other words, this inhibition means that nitrogen-fixating bacteria were no longer attracted to plants. What does this mean? Without nitrogen-fixation, crop yield will surely decrease because they will not have the proper nutrients needed to grow and survive. At first, it appears beneficial for the bacteria because they no longer have to fixate nitrogen; they can just eat the dead plants, and continue on. However, in the long run, if crop yield decreases, then there will be less "food" for these bacteria to consume leading to a decrease in the number of N-fixating bacteria. With a decreasing presence of N-fixing bacteria, the environment will accumulate a greater amount of harmful nitrogen. Without the N-fixing bacteria incorporated into a plant's root-nodule system, plants will be more susceptible to harmful pathogens and "pests," which calls for a larger use of pesticides. This, in turn, adds to the growing pollution issue.

In addition, the reduction in function of denitrifiers also occurs. Denitrifying bacteria are responsible for supplying atmospheric nitrogen (N_2) back into the atmosphere by reducing nitrate through a series of biochemical reactions. Two of the intermediate biochemical reactions are nitrite (NO_2^-) and nitrous oxide (N_2O). Whereas atmospheric nitrogen is an inert gas and a necessary environmental component, nitrites, however, have the ability to form toxic compounds when reacted with certain chemicals. Nitrites, in general, are mainly toxic to all organisms. The threat imposed by the greenhouse gas carbon dioxide is of no surprise, but nitrous oxide poses an even greater threat to all organisms and the atmosphere's ozone layer. Such as nitrifying bacteria, denitrifiers are also affected when introduced to organo-chlorine, phosphate, and nitrogen based pesticides. In fact, in one study, it was found that pesticides containing these chemicals inhibited, or disrupted the denitrification process when applied in abundance (Bollag & Kurek 1980). The process was interrupted intermediately, meaning that the intermediate chemicals were released causing denitrification to never reach fruition. The chemicals released were nitrite and nitrous oxide.

The issue with interrupting the denitrification process is that chemicals such as nitrite and nitrous oxide reside in the soil inducing toxic properties into plants, and polluting the atmosphere with nitrous oxide once they perish. The remaining residue that runs-off contains not only nitrite, but pesticides as well, which, in turn, is transferred into the water system that humans, animals, and plants consume. Therefore, the increase in use of pesticides affects not only both nitrifying and denitrifying microbial bacteria by destabilizing their natural, eco-friendly processes, but also the other organisms that surround their environment.

Phosphorous-Solubilizing Bacteria (PSB), Pesticides, & Metals

Phosphorus (P) is an essential element classified as a macronutrient because of the relatively large amounts of phosphorous required by plants. Organic compounds that contain phosphorous are used to transfer energy to drive reactions within cells (ATP). Adequate phosphorous availability for plants stimulates early plant growth and hastens maturity (Sharma et al. 2013). The phosphorous cycle is similar to other mineral nutrient cycles in that phosphorous exists in soils and minerals, living organisms, and water. In natural systems like soil and water, phosphorous will exist as phosphate (PO_4^{-3}). Phosphate is taken up by plants from soils, utilized by animals that consume plants, and returned to soils as organic residues decay in soils. Much of the phosphate used by living organisms becomes incorporated into organic compounds. When plant materials are returned to the soil, this organic phosphate will slowly be released as inorganic phosphate or be incorporated into more stable organic materials and become part of the soil organic matter. Phosphorus is a somewhat unique pollutant in that it is an essential element, has low solubility, and is not toxic itself, but may have detrimental effects on water quality at quite low concentrations. There is considerable concern about phosphorous being lost from soils and transported to nearby streams and lakes. Several chemical properties of soil phosphorous have important implications for the potential loss of phosphorous to surface water.

These managers of Phosphorous are coined "Phosphorous-solubilizing bacteria" (PSB). PSBs are essential rhizosphere microorganisms that promote a higher uptake of phosphorous in plants. The introduction of pesticides, however, has affected the solubilization capability of the majority of PSBs by reducing their tolerance to pesticides, and, plant-promoting activities. In fact, in one study it was found that five of the six most common PSBs were incapable of tolerating such high levels of pesticides and demonstrated reduced intake levels of phosphorous (Rajasankar 2013). The purpose of this experiment was to identify an effective phosphate solubilizing bacteria from pesticide polluted field soil, but in doing so, the researchers proved that PSBs cannot withstand the current pesticidal conditions in which they reside. Without the efficient intake of phosphorus by PSBs, phosphorous along with pesticides will be lost from soils and run into water systems and atmosphere, which poses a threat to the environment because most organisms cannot drink water with phosphorous let alone pesticides.

As stated previously, PSBs cannot adapt or withstand the amount of pesticides applied today, but how much is too much? The answer to this question was the objective of one particular study. Kumar et al. (2015) examined the dosage toxicity of four common pesticides (chlorpyrifos, mancozeb, endosulfan, and phorate) at five dosage levels (1X, 1.5X, 2X, 2.5X, and 3.0X). The researchers found that at the recommended dose (1X), level of toxicity of all the pesticides to phosphate solubilization activity was not detrimental; however, as dosage levels increased the percentage of phosphate solubilization decreased. The pesticides they used also contained the same compounds (organo-chlorine, phosphate, and nitrogen) that affected the nitrifying bacteria. This study provides additional data supporting the notion that abundant pesticide use poses a threat to microbes responsible for providing plants with the two most important elements they require: nitrogen and phosphorous. It should be noted that there exist numerous studies suggesting that pesticides actually promote the functioning of both nitrifiers and PSBs, but there also exist countless studies that suggest otherwise.

In addition to pesticides, the introduction of toxic heavy metals released from industrial manufacturing and into the environment has occurred. Toxic metals include: Hg, Cr, Pb, Zn, Cu, Ni, Cd, As, Co, Sn, etc. When soil is contaminated with metals such as these it is rendered useless and deemed unfit for agricultural use (Ahemad 2013). Usually, toxic metal containing soils are cleaned using chemicals that relieve microbial stress and aid them in breaking these metals down, but the use of chemicals presents another problem. The chemicals used remain in the soil even after the metals are broken down, and some, not all, of these chemicals threaten the life of the microbes present (Ahemad 2014). However, a natural alternative does exist. PSBs acquire the potential to enhance phosphate-induced immobilization of metals to remediate contaminated soil (Martinez 2014). According to Martinez et al. (2014), PSBs are a promising and less costly remediation method because they are capable of cleaning metal contaminated soils even at very toxic levels.

Yet, another issue presents itself. If pesticides inhibit PSBs, then would they be capable of breaking down such heavy metals? The short answer is no. In a recent study, researchers tested this exact hypothesis. In summary, Park et al. (2010) tested PSBs in various soils containing lead with pesticides (stressful) and non-leaded, non-pesticide soils. The researchers discovered that PSBs were unable to solubilize phosphorous and breakdown lead under stressful conditions, but performed normally under natural, environmental conditions. Without the proper, efficient functioning of PSBs, not only will water, air, land, and food be polluted by pesticides, but harsh metals as well. Therefore, it is essential that measures such as pesticidal reduction or alternatives are implemented in order to preserve PSBs.

Discussion

In this section, the discussion of pesticide application effects on macro-organisms such as humans and animals is explained. Alternatives to pesticides and future aims of research are presented as well. Humans, animals, and perhaps every living organism comes into contact with pesticides (Aktar 2009). Interactions with pesticides commonly occur, for example, when pesticides are used around homes, pets/livestock, environmental communities, and on crops. The risk of health problems depends on the toxicity of pesticide ingredients and the amount of exposure. Although minimal exposure is considered negligible, it is still quite safe to state that consuming a toxic substance in any measure is not ideal. In fact, one study suggests that acute inhalation of pesticides may cause headaches, blurred vision, vomiting, abdominal pain, suppress the immune system, lead to blood and liver diseases, depression, asthma, and nerve damage (Hicks 2012). This study concluded that even those exposed to pesticides for a brief moment a day were affected and displayed signs of toxicity. The issue with these effects is that they are latent meaning that symptoms are not immediately identifiable. The symptoms of pesticide exposure are quite similar to those of the flu, which is why pesticide toxicity is mistaken for the flu, and, therefore, left untreated. Ingredients found in common pesticides such as chloroform, phosphates, and nitrogenous bases are known to cause serious risks to the liver and nervous system. These effects are synonymous in animals living around water systems where pesticides runoff and accumulate. The consumed pesticides bio-accumulate within the animals; the pesticides bio-magnify up the food chain as one animal eats another meaning their concentrations increase as they move from one animal to the next (Hicks 2012).

Neither the benefits of pesticides, nor the use of pesticides is being denied in this paper. They are necessary for crop protection and food production. This research review is calling for an effective and eco-friendly alternative to pesticides. The application of pesticides is not the problem; it is the amount that is applied on a yearly basis. The USDA produced a census detailing the amount of pesticides used in pounds/year (Table 1).

Year	*Pounds of Herbicide Applied*	*Herbicide*	*Pounds of Insecticide Applied*	*Insecticide*	*Pounds of Fungicide Applied*	*Fungicide*	*her Pesticides*	*Other*	*Total lbs. Applied*
	Millions	Share	Millions	Share	Millions	Share	Millions	Share	Millions
1960	35.18	0.18	113.83	0.58	25.15	0.13	22.31	0.11	196.47
1961	40.45	0.19	124.79	0.59	24.76	0.12	22.87	0.11	212.87
1962	42.60	0.20	121.14	0.57	24.38	0.12	23.42	0.11	211.54
1963	47.20	0.21	125.86	0.57	24.05	0.11	23.98	0.11	221.09
1964	58.62	0.26	118.64	0.53	23.77	0.11	24.53	0.11	225.56
1965	82.55	0.33	116.36	0.47	23.49	0.09	25.14	0.10	247.53
1966	97.44	0.37	120.04	0.45	23.20	0.09	25.74	0.10	266.43
1967	115.75	0.37	146.29	0.47	24.17	0.08	26.78	0.09	312.99
1968	127.07	0.41	131.36	0.42	25.13	0.08	27.83	0.09	311.39
1969	142.01	0.46	109.50	0.36	26.09	0.09	28.87	0.09	306.48
1970	169.28	0.48	124.11	0.35	27.06	0.08	29.92	0.09	350.37
1971	214.13	0.52	141.09	0.34	28.02	0.07	30.96	0.07	414.20
1972	210.68	0.49	158.14	0.37	27.93	0.07	30.91	0.07	427.66
1973	257.39	0.60	115.06	0.27	27.84	0.06	30.85	0.07	431.15
1974	273.59	0.60	125.38	0.27	27.76	0.06	30.80	0.07	457.52
1975	280.63	0.63	109.83	0.24	27.67	0.06	30.74	0.07	448.88
1976	365.67	0.64	147.94	0.26	27.58	0.05	30.69	0.05	571.88
1977	396.28	0.66	145.67	0.24	27.36	0.05	30.57	0.05	599.88
1978	403.14	0.71	103.25	0.18	27.15	0.05	30.45	0.05	563.98
1979	442.59	0.74	101.22	0.17	26.93	0.04	30.33	0.05	601.06
1980	468.06	0.74	105.05	0.17	26.71	0.04	30.21	0.05	630.03
1981	477.89	0.76	97.38	0.15	26.50	0.04	30.09	0.05	631.85
1982	477.86	0.78	78.80	0.13	26.28	0.04	29.97	0.05	612.90

1983	363.54	0.74	73.70	0.15	25.67	0.05	30.58	0.06	493.49
1984	465.57	0.78	74.10	0.12	25.05	0.04	31.19	0.05	595.91
1985	395.60	0.75	76.13	0.14	24.44	0.05	31.81	0.06	527.97
1986	387.31	0.75	75.75	0.15	23.82	0.05	32.42	0.06	519.29
1987	348.10	0.74	63.49	0.14	23.21	0.05	33.03	0.07	467.81
1988	356.83	0.74	68.17	0.14	22.59	0.05	33.64	0.07	481.23
1989	379.83	0.76	61.75	0.12	21.98	0.04	34.25	0.07	497.81
1990	405.64	0.77	63.10	0.12	21.36	0.04	34.86	0.07	524.96
1991	384.25	0.73	64.81	0.12	26.02	0.05	51.14	0.10	526.23
1992	388.87	0.73	64.59	0.12	22.09	0.04	55.16	0.10	530.71
1993	379.46	0.69	75.33	0.14	32.87	0.06	61.73	0.11	549.39
1994	404.76	0.71	69.11	0.12	24.02	0.04	70.61	0.12	568.50
1995	373.65	0.69	72.82	0.13	26.57	0.05	68.86	0.13	541.91
1996	409.34	0.69	67.94	0.11	32.46	0.05	87.58	0.15	597.32
1997	406.76	0.68	69.98	0.12	40.34	0.07	83.44	0.14	600.51
1998	388.94	0.71	49.66	0.09	34.40	0.06	76.20	0.14	549.20
1999	362.34	0.67	72.47	0.13	31.58	0.06	75.69	0.14	542.09
2000	354.58	0.67	71.00	0.13	28.97	0.05	76.62	0.14	531.18
2001	348.52	0.71	49.42	0.10	25.56	0.05	66.89	0.14	490.40
2002	336.19	0.71	29.67	0.06	26.83	0.06	79.76	0.17	472.45
2003	346.80	0.72	34.32	0.07	27.17	0.06	72.18	0.15	480.47
2004	357.78	0.71	31.45	0.06	30.45	0.06	81.76	0.16	501.44
2005	349.23	0.74	34.51	0.07	28.41	0.06	62.89	0.13	475.04
2006	366.87	0.76	28.17	0.06	27.50	0.06	63.38	0.13	485.92
2007	378.40	0.75	27.72	0.06	28.00	0.06	69.72	0.14	503.84
2008	393.88	0.76	28.55	0.06	28.87	0.06	64.81	0.13	516.11

Table 1 – USDA census measuring the amount of each type of pesticide, and their total amounts applied on U.S. field crops on a yearly basis. As depicted in the "total lbs. applied" data, the amount of pesticides applied is increasing gradually as time increases. In 1960, total lbs. applied was 196 million lbs., which increased to 516 million lbs. in 2008.

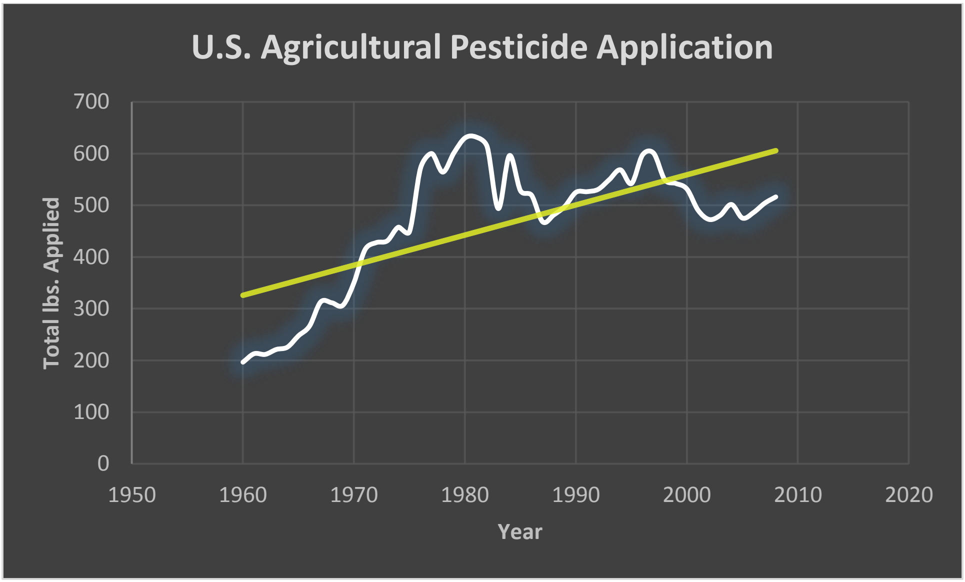

Figure 1 – U.S. Agricultural Pesticide Application graph. Over the last few decades, the yearly application of pesticide in the U.S. has fluctuated; however, as is seen in the graph's slope, the use of pesticide is steadily increasing. With the increasing demand for crops, the slope will continue to rise.

According to the Michael Alavanja (2009) and the USDA (2016), the total lbs. of pesticide applied has increased from 516 lbs. to 1.2 billion lbs. in the U.S., and 5.6 billion worldwide. It is evident that the amount of pesticides applied year-round is astonishing, and it is without a doubt that this number will increase. As this number increases, so will the toxicity of the environment for all organisms; therefore, pesticide application should be greatly reduced, but not halted. Halting the pesticidal application process completely will introduce another problem such as reduce in crop yield. Instead, pesticide application per year should be reduced to approximately 300 million lbs., and alternatives such as beneficial insects, biological methods, and transgenic crops should work in unison with pesticides to allow the environment to maintain a balance, and microbes to work efficiently.

Biological methods refer to the beneficial action of parasites, pathogens, and predators in managing pests and their damage. This also refers to pheromones. Pheromones are non-toxic and biodegradable chemicals; pests are lured into traps, using energy that they normally use to act as "pests" or mate. They work via semi-chemicals, or chemical signals that are produced by a plant or animal and are detected by a second plant or animal and cause a response in the second organism. Many species depend on these chemical signals for survival. Pheromones are species-specific chemicals that affect insect behavior, but non-toxic to insects. They are active in extremely low doses (one millionth of an ounce). Pheromones can play an important role in integrated pest management for structural, landscape, agricultural, or forest pest problems (Seybold 2006). As mention previously, bacteria and viruses can also be used to eliminate "pests" from environments that are harmful to them, but not to the organism into which they are introduced. Although this is difficult to manage in some circumstances; however, in these cases transgenic crops are pivotal players. Transgenic crops contain a gene or genes which have been artificially inserted for purposes such as pest control. These genes can then be passed naturally via pollination in the environment. Crop plants exhibit a wide diversity of defensive traits and strategies to protect themselves from damage by herbivorous pests and disease. For the most part, transgenic plant incorporated protectant (PIP) traits are compatible with biological control due to their selective toxicity to targeted pests and relatively low non-target impacts (Peterson 2016). In other words, transgenic crops are toxic to specified pests, but not to the host, or non-targeted organisms.

Conclusion

All in all, this research review presents evidence of the effects of abundant pesticide applications on microbial organisms, and, in turn, the environment. Pesticide use affects the microbial processes of microbes such as nitrifiers and PSBs by depressing their regulatory, beneficial functions due to biogeochemical manipulation. In addition to microbial threat, pesticides pose a threat to other organisms which interact with them. After reviewing a copious amount of studies, this paper suggests that pesticide application should be greatly reduced, and, instead, applied in concert with alternative, eco-friendly pesticides such as beneficial insects, biological methods, and transgenic crops to allow the environment to maintain a biogeochemical balance, and microbes to work efficiently.

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