The Use of Pesticides: Beneficial or Detrimental?

The Uses of Pesticides and the Effects on Non-Target Plants and Animals

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It is clear that pest protection is key to agricultural sustainability globally, which is now more important than ever, as with a rapidly growing human population the demand for food is only becoming greater. It is estimated that between 26% and 40% of the world's crop yield is lost each year due to pests, and this could rise up to 52% to 80% without the use of crop protection (1)**.** Pesticides are chemical compounds used to kill pests, which can include any destructive organism that is a vector of disease or attacks crops or livestock. Not only are pesticides effective, at least in some circumstances, at directly eliminating the threat of pests, but they can also have secondary benefits such as preserving soil quality (1). However, although pesticides may be effective in some circumstances, their true long-term effectiveness and the consequences that they impose on non-target plants and animals pose an important question about their suitability for continued usage. Pesticides can have devastating consequences on non-target organisms and biodiversity, especially on fish where upon entering water sources can kill many fish through acute poisoning or oxygen depletion (2). Considering these effects, alongside increasing resistance to pesticides due to their great usage, are pesticides an effective long-term solution? Are they beneficial or detrimental to us, humans, and non-target plants and animals?

Benefits of Pesticides

It is important to fully understand the background to the use of pesticides and the full extent of the benefits and advantages that they provide both in local and global circumstances. Firstly, pesticides have proved vital to the rapid increase in major crop yield; global rice yield – the major source of food for over half the global population – has increased by more than 150% since 1960 and wheat production has increased by 160% in the same time (3). These major crops have to be grown while in competition with tens of thousands of species of pests – including 30,000 species of weeds, 3,000 species of worms, and 10,000 species of plant eating insects – as well as having to withstand many other pests while in storage which can limit the life of crops (4). These can all cause major harvest losses and in some areas with specific dependencies cause famine. In 2019 it was estimated that more than 820 million people were suffering undernourishment with 2 billion suffering moderate or severe food insecurity (5). It is crucial that global supply can be maintained and increased to be able to reduce global famine and hunger, and extra care must be taken in the future to ensure that those countries involved in conflicts do not have these food supply routes cut-off. For many small and large-scale farmers, pesticides are vital in the fight against pests and in many circumstances are cheaper, easier to use, and more effective than other alternatives. Since the late 20th century around 2.5 million tonnes of pesticide have been used globally every year (although in gradual decline) with up to $56 billion being used on pesticides globally in 2012 (6) with the figure remaining relatively high since. The economic effectiveness

though perhaps justifies this cost, as it was estimated that every $1 spent on pesticides returned $4 of saved crop yield (7). A joint report between the Organisation for Economic Co-Operation and Development and the Food and Agricultural Organisation of the United Nations (OECD and FAO) indicated that without the use of pesticides up to 80% of global crop yield could be lost (1). It cannot be understated what a detrimental effect this would have on the global population, with the potential for billions to suffer hunger. The use of pesticides, with nearly 50% of global pesticide usage being used as herbicides (6), provides farmers with a key way to control and limit invasive species and hence improve crop yield and crop and livestock quality. As things stand, the UN 'Zero Hunger' aim for 2030 already provides a formidable challenge and currently pesticides play a crucial role in global food production on our way to eliminating hunger.

Secondly, protecting and increasing crop yield is not only important for maintaining and increasing food production, but also for the production of biofuels. As global supplies of non-renewable energy sources slowly shrink and there is a greater global focus on renewable sources with lower carbon emissions, the demand for biofuels is only going to grow. Crop protection will be crucial for being able to produce the volume of crops needed, and pesticides can offer effective, large scale, and easy to use crop protection that will play a significant role in the turn towards renewable biofuel, at least in the short term. It has been estimated that by 2021/2022 29.6 Mt of biofuels will be produced from global vegetable oil supplies accounting for 16% of total vegetable oil consumption (1). Biofuels are any renewable fuel made from organic biomass with the main two global biofuels being bioethanol and biodiesel (8). Currently, most biofuels are produced from agricultural crops – vegetable oils for biodiesel and crops with high sugar or starch levels, such as sugarcane, for bioethanol produced through fermentation (8). ln 2012 it was estimated by the OECD and FAO that biodiesel production would be the cause of 73% of the growth in total consumption of vegetable oils over the period 2012-2021 in developed nations (1). As crops take in CO_2 from the atmosphere during growth and then release it when used as fuels, they are theoretically carbon neutral – although some emissions are produced while growing, transporting, and using them – and hence are much more environmentally sustainable than conventional fossil fuels. The biofuel industry will play a pivotal part in the global transition to environmental sustainability with renewable fuels and decreased carbon emissions, especially as more varieties of biofuels start being produced and utilised. However, to utilise this opportunity it seems a necessity that at least in the near-future, pesticides will have to play a large role in being able to protect crops and increase crop yield needed for biofuels as well as food.

Thirdly, pesticides play a vital role in limiting the spread of disease among livestock and humans. Millions of human lives have been saved from diseases such as malaria (9) by using insecticides (a form of pesticide). In particular, dichlorodiphenyltrichloroethane (DDT) has been shown to reduce malaria transmission by female anopheles mosquitos by 90% (10) and since the reintroduction of DDT in South Africa in 2000, malaria has been kept at an all-time low and possibly en route to elimination (10). It is also important to mention that disinfectants used to kill bacteria and viruses are also a form of pesticide that are vital for daily sanitation and medical usage. Not only do pesticides benefit humans by helping limit the spread of human pathogens, they also help protect livestock from other disease spreading

vectors and thus also help in producing food and reinforces their benefits in providing food locally and globally and combatting global hunger.

Lastly, pesticides also have several secondary effects that provide key benefits to farmers. They can indirectly lead to greater crop yield and secondary economic benefits as well as serve social, non-agricultural, uses to preserve infrastructure. Herbicides can help preserve soil quality on agricultural farmland by maintaining moisture in the soil and can thus maintain topsoil quality with much less need for cultivation processes, such as tilling, which is a major cause of soil erosion. It is estimated that in the US the use of herbicides reduces soil erosion by 161Mt every year (1) and thus allows for increased crop yield as well as economic efficiency by not having to pay for tilling and other cultivating processes. Pesticides also have important non-agricultural uses such as maintaining public areas and social infrastructure, such as roads and motorways, by controlling the spread of plants and weeds through the use of herbicides such as glyphosate (11). Although the necessity of the use of pesticides for aesthetic purposes can be questioned, it must also be noted that herbicides are widely used for aesthetic purposes such as on golf courses to prevent unwanted growth of plants.

The Consequences

It is clear that pesticides have many vital and wide ranging uses that contribute to many different aspects of human welfare and infrastructural regulation and maintenance. However, what are the consequences of using pesticides for these benefits? Are pesticides a long-term effective solution? Are they safe for continued usage? Or do they greatly harm many non-targeted organisms and eco-systems? These are important questions that must be answered.

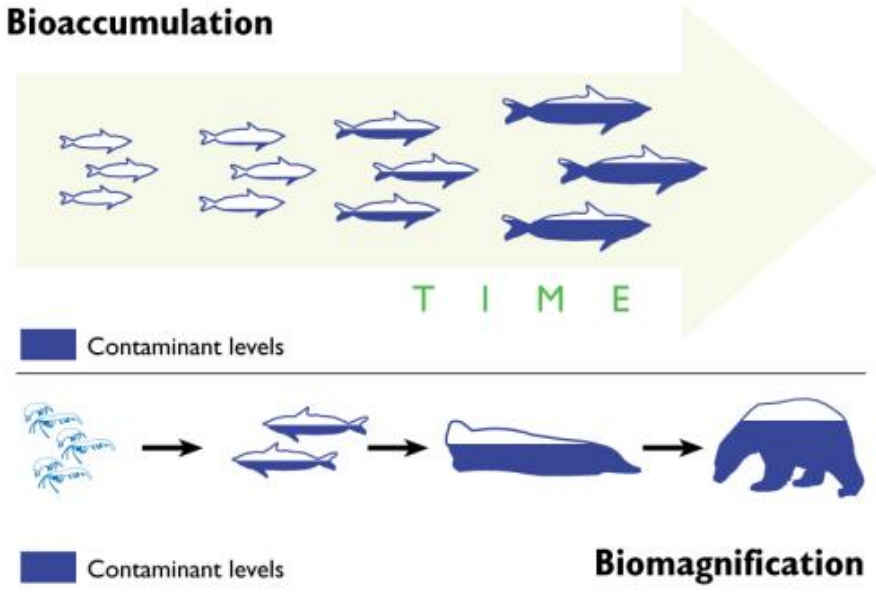

***Figure 1**: Bioaccumulation and Biomagnification – WWF [Accessed: 21 July 2020] http://sustainable-nano.com/2013/12/17/the-cautionary-tale-of-ddt-biomagnification-bioaccumulation-and-research-motivation/*

Pesticides can have detrimental effects on non-target plants surrounding the area of application, and thus cause unintended phytotoxicity: the devastating effects on physiological processes of plants, such as seed germination and growth, by toxic chemicals like pesticides. Not only are these consequences detrimental to plants, but also have much wider reaching consequences throughout ecosystems, and it is estimated that for every plant species that becomes extinct another 10-30 animal species also become extinct (12). Pesticides contaminate the soil of the areas in which they

have been used and can be absorbed by future plants growing in the same soil. Plants can also be contaminated through pesticide drift, either as spray drift from sprayed pesticides, or through water run off carrying the pesticides and then being absorbed by the plants. This means that vegetation surrounding agricultural fields where pesticides may be used are those most at risk of facing unintended consequences. Many plants have developed metabolic processes to be able to transfer the pesticide toxins into less harmful states, however, rarely can they transfer all the toxins and some plants do not even have the capability to do so. In particular DDT and hexachlorocyclohexane (HCH) can be absorbed in high enough quantities by most plant species that they pose a risk to consumers of the plants and bioaccumulate strongly in animal species (12). Bioaccumulation and biomagnification can have devastating consequences within an ecosystem, especially for the apex predator. Despite DDT's efficacy in tackling malaria, DDT becomes easily embedded in the fat stores of animals and cannot be broken down easily and has a half-life of 6.3 years in humans (13). DDT has a half-life of 2 to 15 years in soil (14) and around 150 years in water (14) and hence provides a long period in which it can be bioaccumulated by organisms in the area. When organisms in higher trophic levels consume large numbers of the smaller organisms in which DDT and other pesticides have bioaccumulated within, they suffer from biomagnification and experience a higher concentration of DDT that can have more pronounced and extreme effects (15). The effects of bioaccumulation and biomagnification can be seen in humans where DDT has been linked to cancer, diabetes, miscarriage, and infertility (16), as well as in the USA where in 1963, prior to the DDT ban of 1972, less than 500 pairs of bald eagles were found in the conterminous United States, yet in 1996 more than 5000 were found (17). This has largely been linked to the ban of DDT in 1972, as it had been suspected that DDT had caused shell thinning of the eggs of many birds and hence prevented the egg hatching or caused the shell to break during incubation and subsequently resulted in reduced populations (17). In addition, the residue of herbicides in soil, and those spread by pesticide drift, can frequently accumulate to phytotoxic levels in plants and result in stunted growth and even plant death. It is clear that the effects of pesticides on non-target plants and animals is a cause of concern for both the organisms within the ecosystems, but for us as well.

Not only can animals be affected by consuming plants containing toxins from pesticides, in many situations pesticides alone can kill hundreds of non-target animals. Aquatic species are especially vulnerable to acute poisoning (poisoning caused by single contact) due to the many different ways that they can be threatened by the use of pesticides. Pesticides can accumulate in ponds at a concentration high enough to cause mortality. This is an extreme case that usually only

***Figure 2**: Fish killed due to oxygen depletion caused by herbicide phytotoxicity of phytoplankton; University of Florida/IFAS Pesticide Information Office; [Accessed 10 October 2019] https://edis.ifas.ufl.edu/pdffiles/PI/PI12200.pdf*

happens when ponds or water sources are located very near to treated land where insecticides have been used, and due to surface run off or leaching are present in high concentration to be lethal (2). However, many causes of death for aquatic animal species due to pesticides is indirectly through the use of herbicides that can kill large amounts of phytoplankton and other aquatic plants. When these plants die, decomposers, such as species of bacteria, decompose the phytoplankton and plants and to do this require oxygen for respiration. The increased usage of oxygen by the decomposers and the reduced supply of oxygen, as there are fewer plants to supply oxygen into the pond via photosynthesis, causes severe and rapid oxygen depletion in the water and hence makes it inhabitable and cause many fish to die (18). Fish are, however, not the only animals very susceptible to pesticide caused acute poisoning; birds are also very susceptible to poisoning. Like fish, birds can be affected either directly or indirectly by pesticides. Birds can be killed by direct contact with pesticides through spray drift or, more commonly, by birds misinterpreting pesticide pellets or granules as food and dying through consumption of the pesticide (2). This can also be a problem for terrestrial animal species. Indirectly, birds can be impacted by eating crops contaminated with pesticides, drinking contaminated water, and eating prey that are contaminated with pesticides leading to bioaccumulation (2).

Crops and flowers treated with pesticides are also a great cause of danger for bees and insect pollinators because, like birds, when they come into contact with pesticides on plants they can die due to indirect causes. Pesticides can cause impaired ability to navigate and collect food and hence cause pollinators to find it hard to survive over an extended period of time, especially during the winter. However, perhaps the most significant found effect of pesticides – especially neonicotinoids which are a set of systemic insecticides which are also the largest used type of pesticides accounting for 25% of global pesticide use (19) – is that they compromise the immune systems of pollinators. As seen in Figure 3, honey production from 1986-2012 has decreased by about 25% and this is largely due to the decreasing population of honeybees. A study found that when honey bees were exposed to clothianidin (a neonicotinoid pesticide used for seed treatment and on a variety of plants) and then exposed to a virus, their immune system was less effective and had reduced signalling of the protein complex NF-κB, which is needed for the immune system to function properly (20). They also found that neonicotinoids promoted

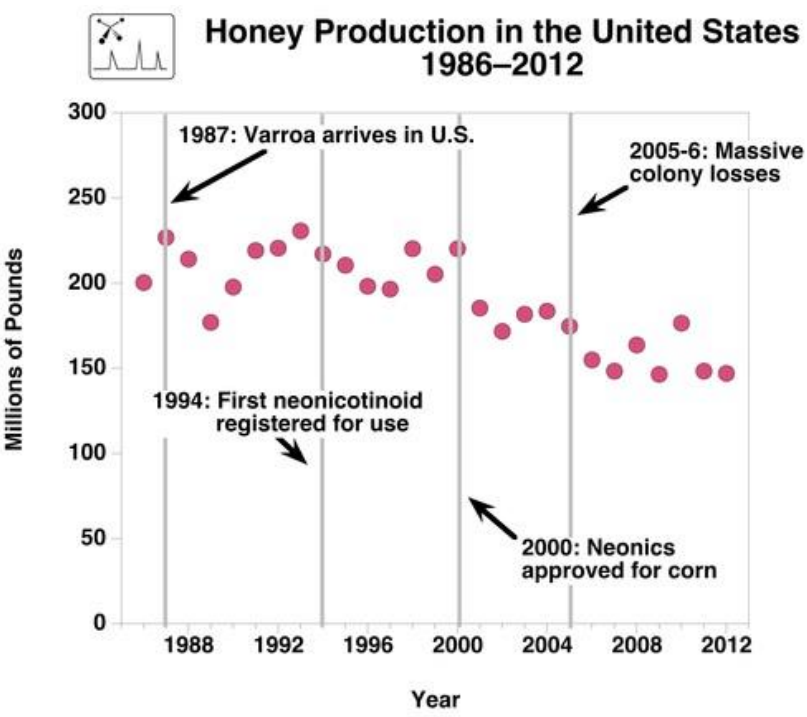

***Figure 3**: Honey Production in the United States 1986-2012; Dr Susan Kegley, Pesticide Research Institute ; [Accessed 7 October 2019] https://www.pesticideresearch.com/site/*

replication of viral pathogens in these bees (20). These findings would back up and explain the findings in Figure 3 and explain a cause of the decreased honeybee population. The neonicotinoids first registered in 1994 and then approved for corn in 2000 would have compromised the honeybees' immune systems and made them more susceptible to varroa, a parasitic mite that attacks certain species of honeybee, and the varroosis disease caused by varroa. As shown in Figure 3, these effects have caused devastating losses of honeybees and thus honey production that can be largely blamed on pesticides. Not only does this add to the great consequences of pesticides on ecosystems and nature, but also has large economic consequences as well. The production of honey is reduced, and there are insufficient pollinators that are needed to pollinate the crops. Surely pesticides cannot be deemed suitable for continued long-term usage if they cause such devastating effects on nature and our environment like this.

Although not as common as the effects on plants and other animal species, humans can also experience poisoning due to pesticide usage, most frequently those with continued exposure to pesticides such as farmers. Pesticides can enter our bodies through our skin, lungs, or mouth (21). The most common way for pesticides to enter our bodies is through the skin, most often in the case of farmers when they are working where they may accidently come in contact with pesticides; the effects of pesticides entering through the skin are, however, the least dangerous compared to inhalation or ingestion. (21). It is also possible for pesticides, if they come in contact with our eyes, to cause damage to the eye and even blindness. Figure 4 shows the extent of the dangers of the 15 most used pesticides in the UK to humans. 13 out of the 15 are known or suspected carcinogens, with five being at least moderately acutely toxic as well as having several other toxic effects on humans. Most people who experience toxic effects of pesticides experience mild symptoms, such as skin irritation and mild headaches, but in some circumstances can experience severe effects like nausea. Organophosphates, a type of insecticides, can have especially severe effects on exposed humans if ingested and in extreme scenarios cause death (22). Surely if working with pesticides opens up farmers to such an array of possible dangers, we should seek safer, non-toxic alternatives to protecting crops and plants from pests.

TABLE 1 – Toxicity to humans of the 15 most frequently used pesticides in the UK

Active substance	Use	Acutely toxic	Carcinogen	Cholinesterase inhibitor	Developmental or reproductive toxin	Endocrine disruptor
Glyphosate	Herbicide		Probable			
MCPA	Herbicide	Yes	Possible			
2,4-D	Herbicide		Probable			
MCPP	Herbicide		Possible			
Carbendazim	Fungicide		Possible			Suspected
Dicamba	Herbicide				Yes	
2,4-DP	Herbicide		Possible			
Iprodione	Fungicide		Yes			Suspected
Chlopyrifos	Insecticide	Moderate		Yes		Suspected
Tebuconazole	Fungicide	Moderate	Possible			Suspected
Cypermethrin	Insecticide		Possible			Suspected
Chlorothalonil	Fungicide		Yes			
Dichlorprop	Herbicide		Yes			
Propiconazole	Fungicide	Moderate	Possible		Yes	Suspected
Metaldehyde	Molluscicide	Moderate	Possible			

***Figure 4**: Toxicity to humans of the 15 most frequently used pesticides in the UK; Environment Journal ; [Accessed 8 October 2019] https://environmentjournal.online/articles/notion-pesticides-best-practice-needs-radically-change/table-1-toxicity-to-humans-of-the*

Lastly, although, as previously mentioned, pesticides are cost effective at producing greater yield, new research has found that the medical costs associated with treatment for effects of chronic exposure has very large costs with the health cost of pesticides estimated

to be $15billion in 2005 (23). Alongside all damages associated with pesticide usage, the total damage caused by pesticides was worth $39.5 billion the late 20th century (23), and there is little to suggest that this would have improved significantly since. These damage costs caused by the use of pesticides would suggest that overall pesticides are not truly cost effective, and that with all the other dangers that they cause, they have no reason for continued long term usage.

Alternatives to Pesticides and Mitigating the Impacts of Pesticides

Although there are many consequences to pesticide usage, one cannot forget the crucial role they play in crop protection that serves benefits both for food and biofuel production, as well as in disease control and infrastructure maintenance. A full evaluation of how pesticide usage should change in the coming years must consider how their impacts can be mitigated as well as whether there are viable alternatives that can effectively protect crops on the scale needed.

Firstly, it is important to note that in some cases the consequences of pesticide usage can largely be mitigated through more careful, and even more regulated, application of these chemicals in a way that is less impactful on the surrounding ecosystems and organisms as well as on those who apply them. Mitigations of the consequences of pesticide use can include simply reading and following labels more closely (24) , as well as using pesticides that do not leach and using more direct application rather than spray application to reduce pesticide drift and subsequently reducing the effects on surrounding ecosystems (24). Farmers can also be advised to leave a 'buffer zone' of crops around the edges of fields and agricultural land where pesticides have been used in order to reduce the chance of non-target plants and animals coming into contact with the pesticides (24). Responsible pesticide application can also include taking into consideration the surrounding geography as well as the weather; pesticides should be applied in dry conditions where rainfall is not forecasted because this prevents leaching and surface-run off water carrying the pesticide chemicals away and potentially affecting non target organisms (25). Similarly, pesticides should be avoided in windy weather where they can be diffused through the air and affect pollinators in particular, or where the temperatures are high and when plants are suffering drought as this will increase the rate of transpiration where pesticides can dissolve into water and be dispersed (25). Many other precautions can also be taken; however, it is important to realise that many of the damaging consequences of pesticides can be reduced by taking actions considerate of the surroundings and using them responsibly.

On the other hand, safer alternatives that can still effectively protect crops are always preferable. Many of these alternatives come under the branch of organic integrated pest management, which includes several methods to control pests in an environmentally sustainable manner (26). An important part of this is effectively preventing pest populations growing in large numbers through methods such as companion planting, where plants that repel certain insects are planted, and biological control, where natural predators are introduced to organically control pest populations (27). An example of introducing natural predators is that of utilising ladybird larvae which are effective at managing aphid populations (27) or other symbiotic relationships such as that of fish in rice fields where fish will eat the

pests attracted to the rice (28). In Bangladesh it was observed that pest infestation in rice fields containing only rice were 40-167% higher than those that also contained fish (28). Preventive measures can also be combined with increased monitoring of pests and mechanical pest control through means such as fences and nets to reduce access of pests to crops. Alternative chemical means to protect crops have been developed through genetic modification; for example, the genomes of maize and cotton have been altered to include genes that make the plant toxic to pests and hence protect themselves and the surrounding crops (29). All these methods can greatly reduce the impact that pesticides have on biodiversity, the recent Global Biodiversity Outlook 5 indicated that none of the 20 Aichi Biodiversity targets had been reached in the last decade (30) and the Living Planet Report 2020 has said that between 1970 and 2016 there has been a 68% decrease globally in populations of mammals, amphibians, birds and reptiles on average (31); this is up from 60% in 2018 when looking at the period 1970 to 2014 (32).

Figure 5 *Rice-Fish Culture in China, FAO, http://www.fao.org/giahs/giahsaroundtheworld/designated-sites/asia-and-the-pacific/rice-fish-culture/en/ [Accessed 18th September 2020]*

Considering these many alternatives to protect crops from damage from pests, and the need now more than ever to do everything we can to stop reducing global biodiversity, it seems clear that action should be taken to increase the usage of these alternatives that greatly reduce the impact on non-target organisms.

Conclusion

This report has explored both the benefits of using pesticides as well as the devastating and far reaching consequences. We must remember, however, the importance of crop protection and the even more devastating consequences of famine that we would experience if we had no way to protect crops from pests. Recently, more and more alternatives to pesticides have been brought into use under the form of integrated pest management, however, in reality many of these are yet able to be implemented on scales large enough needed for crop demand and in cost effective manners. Introducing more genetically modified crops into our ecosystem is another option, but this report is not the vehicle for this debate. Moreover, one must realise that with the extreme extensive use of agricultural pesticides, an increasing amount of pest species are evolving to become resistant to the used pesticide chemicals which hence limits the potential for pesticides as an effective long-term solution to crop protection.

Janek Czarnek 5H

Therefore, in conclusion, it is clear that pesticides used for agricultural crop protection and other uses with exposure to the environment (mostly in the form of insecticides and herbicides) are detrimental and have far reaching consequences throughout ecosystems, on both plants and animals, as well as for ourselves. Although pesticides also have important benefits, these will become less effective in the future and can be replaced by alternatives that pose significantly less danger to us and non-target organisms. On the other hand, moving forward we must ensure that the transition to these safer alternatives is carefully managed to ensure that more people do not suffer famine as a consequence – either due to limited effectiveness of these alternatives or by causing increased costs being passed onto the consumer and limiting access to food, especially in lower income countries. Although this transition may take time, it is clear that pesticides do not have a place in our long-term solution for crop protection from pests and are overall more detrimental than beneficial.

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