



# Pesticides and Soil Health



## Acknowledgements

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## Why Reducing Pesticide Use is Central to Regenerative Agriculture

Regenerative agriculture shows us that building healthy soil can be a part of the solution to the climate crisis. By farming and ranching in ways that draw carbon down from the atmosphere — where it drives climate change — into the soil beneath our feet, regenerative agriculture can sequester carbon and build healthy soils that save precious water resources, increase soil biodiversity, improve crop yields and bolster resilience to drought and extreme weather associated with climate change.

Regenerative agriculture achieves these goals by keeping the soil covered and maximizing crop diversity through practices like cover cropping, crop rotation, reducing tillage, using compost to maintain soil fertility and rotational grazing for animals.

This brief summarizes the science on a third critical principle of regenerative agriculture that receives comparatively little attention: minimizing use of

pesticides. The science is clear that pesticides disrupt soil biotic communities — the very life that drives soil carbon sequestration and, therefore, the heart of regenerative agriculture.

### How pesticides harm soil life

A single teaspoon of healthy soil holds billions of soil microorganisms, including bacteria, fungi and other tiny life forms. These organisms have been sequestering carbon for hundreds of millions of years. They form symbiotic relationships with plant roots through mycorrhizal fungi. These networks help plants access nutrients like nitrogen and phosphorus from the soil in exchange for a steady flow of carbon in the form of carbohydrates the plant photosynthesizes from the air.

The flow of carbon to the soil depends on this partnership between plant roots and soil

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*We know more about the movement of celestial bodies than about the soil underfoot.*

**- Leonardo da Vinci**

”

microorganisms. But toxic pesticides can damage this microbial bridge.

Pesticides — a term that encompasses herbicides, insecticides and fungicides — are chemical compounds designed to kill, each with their own targets and mechanisms of action. As little as 0.1 percent of an applied pesticide interacts with its targeted weed or pest.<sup>1</sup> The remainder contaminates the soil, air and water and can have significant nontarget effects throughout the ecosystem.

Pesticides can undercut regenerative agriculture goals by harming soil communities and altering critical biochemical processes in the soil.

## Disrupting soil communities

Pesticides can cause significant changes in the composition, diversity and basic functioning of important soil microflora.<sup>2,3,4</sup> This soil life is critical both to carbon sequestration and to a thriving, sustainable agriculture system. Some studies have found that pesticides decrease soil microbial biomass;<sup>5</sup> others indicate that while total microbial biomass may not change, pesticides can reduce the abundance and diversity of soil organisms, damaging and altering important dynamics in the soil community.<sup>6,7,8</sup> Some organisms can be suppressed while others may proliferate in the resulting vacant ecological niches, so organisms that were rare become abundant and vice versa.<sup>9</sup> Research also shows that pesticides can impact larger fauna that help maintain the structure and fertility of the soil. For example, by impairing the reproductive capacity and survival of earthworms and springtails.<sup>10,11</sup>

## Increasing bacterial populations over fungal populations

Maintaining the right balance between bacterial and fungal populations in the soil is important for capturing more

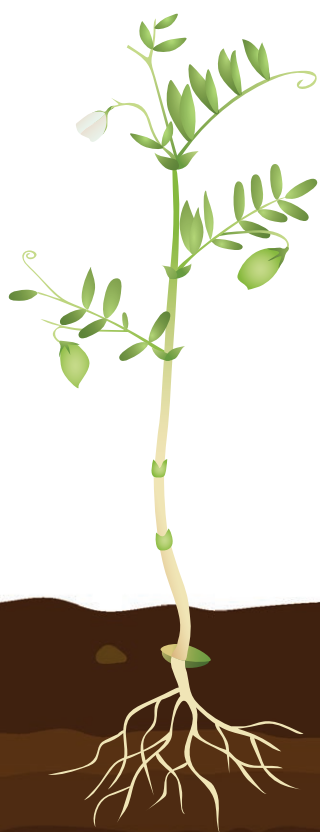
carbon. As the work of Dr. David Johnson shows, building fungal-dominant soil improves crop productivity and carbon sequestration.<sup>12</sup> Pesticides can produce the opposite, increasing the proportion of bacterial to fungal populations in soil, according to several studies.<sup>13,14,15</sup>

## Altering biochemical processes

Soil microbes and plants make enzymes that catalyze biochemical transformation; these enzymes are the drivers of carbon and nutrient cycling. Research shows that some pesticides can interfere with enzyme production, inhibiting some while stimulating others, thus altering soil fertility, nutrient cycling and metabolism.<sup>16</sup>

## Hindering nitrogen fixation

Scientific evidence demonstrates that some pesticides can also hinder nitrogen fixation — another key regenerative agriculture aim — by inhibiting molecular communication between plants and rhizobia, the bacteria that fix nitrogen inside legume roots, and by diminishing root growth and reducing the number of root sites available for essential rhizobia.<sup>17</sup>







## No-till farming and glyphosate

Reducing soil tillage is an important principal of regenerative agriculture. However, advocates should be aware of the connection between no-till farming and glyphosate use as well as the latest science examining whether or not no-till agriculture increases overall soil carbon stocks.

While some farmers are succeeding at no-till farming with few chemical inputs, data indicates that the majority of no-till farmers rely on herbicides such as glyphosate, the active ingredient in Roundup. In fact, 86 percent of *No-Till Farmer* readers said they planned to plant Roundup Ready corn in 2017, while 80 percent planned to plant Roundup Ready soybeans, and some 92 percent planned to use glyphosate for weed control.<sup>18</sup>

Although the effects of glyphosate on soil are not fully understood, mounting evidence shows cause for concern.<sup>19,20,21</sup> Studies have found that glyphosate damages the ecology of mycorrhizal fungi that enable the flow of carbon

to the soil.<sup>22,23,24</sup> Earthworms, so central to a healthy soil ecosystem, are also at risk from glyphosate exposure. One study found that the casting activity of earthworms at the soil surface nearly disappeared after three weeks of glyphosate application and that reproduction of earthworms dropped by half after three months.<sup>25</sup>

Other potential negative effects of glyphosate on soil health include an increase in pathogenic microorganisms in the soil, impairment of respiration of soil-dwelling organisms and nutrient immobilization for plants and microorganisms.<sup>26</sup>

The science is clear that routine use of glyphosate results in the development of resistant weeds.<sup>27</sup> “Superweeds” now plague more than 60 million acres of U.S. farmland,<sup>28</sup> driving an intensification of herbicide use with new crops genetically engineered to withstand hazardous herbicides dicamba and 2,4-D. A 2018 survey

conducted by *No-Till Farmer* found that 43 percent of growers surveyed planned to plant dicamba-resistant soybeans that season.<sup>29</sup> The pesticide treadmill that often results from routine use of agricultural pesticides increases the toxic burden on soil life.

Meanwhile, the science on the benefits of no-till for soil carbon sequestration is not settled. Early studies found an increase in soil carbon in no-till systems, but that research focused only on the top foot of soil. Probing deeper into the soil profile, research suggests that no-till farming may redistribute soil carbon from deeper to shallower zones rather than increase the overall stock of soil carbon.<sup>30,31,32</sup> This effect could cause more carbon releases from soil, rather than storing it deep in the ground where it is more stable — particularly as intermittent tillage may be important in no-till systems in some regions.<sup>33</sup>



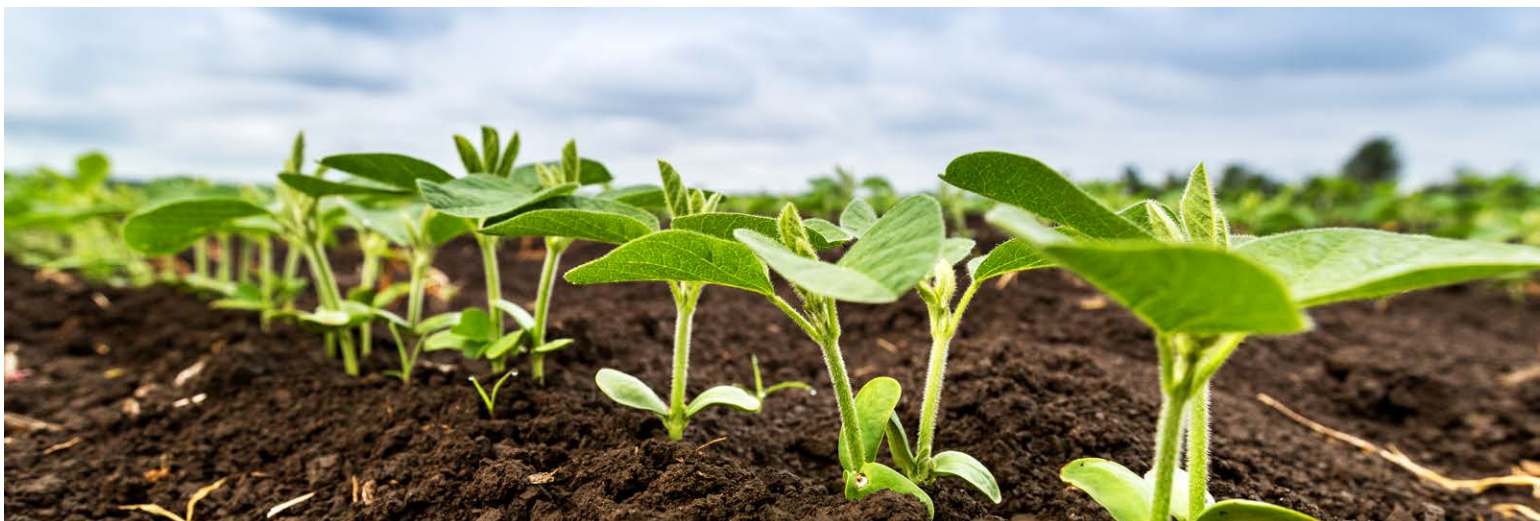


## From laboratory to living soil

The available scientific evidence likely underestimates pesticides' harm to soil health for a number of reasons. For one, we are just beginning to understand the factors that contribute to soil health and how the soil community functions. Additionally, research on pesticides and soil health is typically conducted in the laboratory rather than in the field, thus missing the complex, living nature of the soil biotic community. And most studies focus on acute impacts, failing to evaluate the chronic effects of pesticides on soil health.<sup>34</sup>

Another significant shortcoming of the available research is that most studies focus on individual pesticides, whereas typical field use includes multiple pesticides at a time and over the course of a season. Research shows that mixtures of pesticide residues in the soil are the rule rather than the exception.<sup>35</sup> The few studies that examine pesticide mixtures show that they can be more toxic than individual pesticides; mixtures can have synergistic or compounding effects. One study of two herbicides found that when each was applied alone,

they exerted minor effects on the soil microbial community, but when combined, the impact was *10 times* greater.<sup>36</sup> Another study found that a mixture of glyphosate and diflufenican (used on soybeans) increased the toxic effects of both herbicides on soil biological activity as well as the persistence of each herbicide in the soil.<sup>37</sup>





## Protecting the living soil and all life

Not only do pesticides pose a threat to the core aims of regenerative agriculture by harming the complex living community of the soil, mounting evidence shows that overuse of pesticides is decimating pollinators and other insects that are central to a sustainable food system. Scientists warn that we are in the midst of a “second silent spring” as populations of insects and birds suffer drastic declines.<sup>38</sup> A recent global meta-analysis points to agricultural pesticides as a key driver of plummeting insect numbers.<sup>39</sup> The researchers predict that over 40 percent of insect species may face extinction in coming decades, leading to widespread ecosystem collapse, if we don’t change the way we farm. And the most comprehensive scientific assessment to date warns that loss of biodiversity is a global challenge on par with climate change.<sup>40</sup>

Along with the environmental costs of agricultural pesticides, the human health costs are “catastrophic” according to a recent United Nations report.<sup>41</sup> Yet, over one billion pounds of pesticides are used in the U.S. every year<sup>42</sup> — and use of pesticides in the U.S. and globally is increasing.<sup>43</sup>

Phasing out toxic pesticides must be a core part of what it means to be “regenerative” for life below ground as well as above and to ensure that regenerative agriculture doesn’t become co-opted or used as a cover for maintaining chemical-intensive industrial agriculture.

The good news is that regenerative agriculture practices like cover cropping and crop rotations can reduce farmers’ need for toxic pesticides. A recent study in *Nature* reveals that most farmers could decrease pesticide

use while maintaining or even improving their productivity.<sup>44</sup> And decades of data debunk the myth that pesticides are necessary to feed a growing world population.<sup>45</sup>

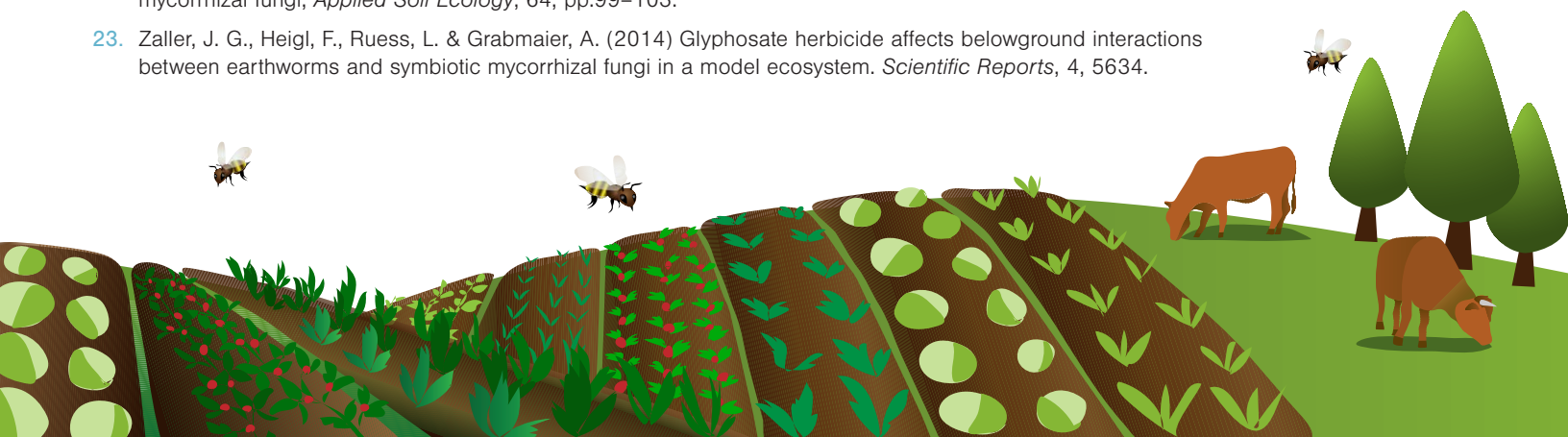
As our climate and biodiversity crises worsen, regenerative farming offers a crucial path to growing food in a way that nourishes both people and the planet. Innovative solutions should be guided by the best available science. And the science shows that eliminating or greatly reducing toxic pesticides is key to building healthy soils and ecosystems for a healthy planet.





## Endnotes

1. Pimentel, D. 1995. Amounts of pesticides reaching target pests: environmental impacts and ethics. *Journal of Agricultural and Environmental Ethics*, 8(1), pp.17-29.
2. Ahemad Munees, M. Khan. 2013. Pesticides as Antagonists of Rhizobia and the Legume-*Rhizobium* Symbiosis: A Paradigmatic and Mechanistic Outlook. *Biochemistry and Molecular Biology*. 1(4):63-75.
3. Yousaf, S., Khan, S. and Aslam, M.T. 2013. Effect of pesticides on the soil microbial activity. *Pakistan Journal of Zoology*, 45(4).
4. Riah, W., Laval, K., Laroche-Ajzenberg, E., Mougin, C., Latour, X. and Trinsoutrot-Gattin, I., 2014. Effects of pesticides on soil enzymes: a review. *Environmental Chemistry Letters*, 12(2), pp.257-273.
5. Merrington, G., Rogers, S.L. and Van Zwieten, L., 2002. The potential impact of long-term copper fungicide usage on soil microbial biomass and microbial activity in an avocado orchard. *Soil Research*, 40(5), pp.749-759.
6. Seghers, D., Verthé, K., Reheul, D., Bulcke, R., Siciliano, S.D., Verstraete, W. and Top, E.M., 2003. Effect of long-term herbicide applications on the bacterial community structure and function in an agricultural soil. *FEMS Microbiology Ecology*, 46(2), pp.139-146.
7. Nettles, R., Watkins, J., Ricks, K., Boyer, M., Licht, M., Atwood, L.W., Peoples, M., Smith, R.G., Mortensen, D.A. and Koide, R.T., 2016. Influence of pesticide seed treatments on rhizosphere fungal and bacterial communities and leaf fungal endophyte communities in maize and soybean. *Applied Soil Ecology*, 102, pp.61-69.
8. Atwood, L.W., Mortensen, D.A., Koide, R.T. and Smith, R.G., 2018. Evidence for multi-trophic effects of pesticide seed treatments on non-targeted soil fauna. *Soil Biology and Biochemistry*, 125, pp.144-155.
9. Lo, C.C., 2010. Effect of pesticides on soil microbial community. *Journal of Environmental Science and Health Part B*, 45(5), pp.348-359.
10. Santos, M.J.G., Ferreira, M.F.L., Cachada, A., Duarte, A.C. and Sousa, J.P., 2012. Pesticide application to agricultural fields: effects on the reproduction and avoidance behaviour of *Folsomia candida* and *Eisenia andrei*. *Ecotoxicology*, 21(8), pp.2113-2122.
11. Pelosi, C., Barot, S., Capowicz, Y., Hedde, M. and Vandenbulcke, F., 2014. Pesticides and earthworms. A review. *Agronomy for Sustainable Development*, 34(1), pp.199-228.
12. Kelley, Emily. 2014. NMSU researcher's carbon sequestration work highlighted in 'The Soil Will Save Us.' *New Mexico State University News Center*. July 8. Available online. <https://newscenter.nmsu.edu/Articles/view/10461/nmsu-researcher-s-carbon-sequestration-work-highlighted-in-the-soil-will-save-us>
13. Smith, M.D., Hartnett, D.C. and Rice, C.W., 2000. Effects of long-term fungicide applications on microbial properties in tallgrass prairie soil. *Soil Biology and Biochemistry*, 32(7), pp.935-946.
14. Pal, R., Chakrabarti, K., Chakraborty, A. and Chowdhury, A., 2006. Degradation and effects of pesticides on soil microbiological parameters-A review. *International Journal of Agricultural Research*, 1(33), pp.240-258.
15. Singh, S., Gupta, R., Kumari, M. and Sharma, S., 2015. Nontarget effects of chemical pesticides and biological pesticide on rhizospheric microbial community structure and function in *Vigna radiata*. *Environmental Science and Pollution Research*, 22(15), pp.11290-11300.
16. Riah, W., Laval, K., Laroche-Ajzenberg, E., Mougin, C., Latour, X. and Trinsoutrot-Gattin, I., 2014. Effects of pesticides on soil enzymes: a review. *Environmental Chemistry Letters*, 12(2), pp.257-273.
17. Ahemad Munees, M. Khan. 2013. Pesticides as Antagonists of Rhizobia and the Legume-*Rhizobium* Symbiosis: A Paradigmatic and Mechanistic Outlook. *Biochemistry and Molecular Biology*. 1(4):63-75.
18. Dobberstein, John. 2017. Is Glyphosate Harming Your No-Tilled Soil? *No-Till Farmer*. October 28. Available online. <https://www.no-tillfarmer.com/articles/7169-is-glyphosate-harming-your-no-tilled-soils?v=preview>
19. Strom, Stephanie. 2013. Misgivings About How a Weed Killer Affects the Soil. *The New York Times*. September 19. <https://www.nytimes.com/2013/09/20/business/misgivings-about-how-a-weed-killer-affects-the-soil.html>
20. The Soil Association. The impact of glyphosate on soil health: The evidence to date. Available online. <https://www.soilassociation.org/media/7202/glyphosate-and-soil-health-full-report.pdf>
21. Marks, Simon. 2019. Concerns over glyphosate pass from human health to the soil. *Politico*. April 9. Available online. <https://www.politico.eu/article/glyphosate-concerns-pass-from-human-health-to-soil/>
22. Druille, M., Cabello, M.N., Omacini, M., and Golluscio R.A (2013) Glyphosate reduces spore viability and root colonization of arbuscular mycorrhizal fungi, *Applied Soil Ecology*, 64, pp.99–103.
23. Zaller, J. G., Heigl, F., Ruess, L. & Grabmaier, A. (2014) Glyphosate herbicide affects belowground interactions between earthworms and symbiotic mycorrhizal fungi in a model ecosystem. *Scientific Reports*, 4, 5634.





24. Yamada, T., Kremer, R., Castro, P. and Wood, B., 2009. Introduction. Glyphosate Interactions with Physiology, Nutrition, and Diseases of Plants: Threat to Sustainability. *European Journal of Agronomy*, 31(3), pp.111-113
25. Gaupp-Berghausen, M., Hofer, M., Rewald, B. and Zaller, J.G., 2015. Glyphosate-based herbicides reduce the activity and reproduction of earthworms and lead to increased soil nutrient concentrations. *Scientific reports*, 5, p.12886.
26. Dobberstein, John. 2017. Is Glyphosate Harming Your No-Tilled Soils? *No-Till Farmer*. October 28. Available online. <https://www.no-tillfarmer.com/articles/7169-is-glyphosate-harming-your-no-tilled-soils?v=preview>
27. Powles, S.B., 2008. Evolved glyphosate resistant weeds around the world: lessons to be learnt. *Pest Management Science*, 64(4), pp.360-365.
28. Mortensen, D. A., Egan, J. F., Maxwell, B. D., Ryan, M. R., & Smith, R. G. (2012). Navigating a critical juncture for sustainable weed management. *BioScience*, 62(1), 75-84.
29. Lessiter, Frank. 2018. 24% of No-Tillers Seeding Dicamba-Tolerant Beans. *No-Till Farmer*. March 10. Available online. <https://www.no-tillfarmer.com/blogs/1-covering-no-till/post/8131-of-no-tillers-seeding-dicamba-tolerant-beans-to-combat-drift-fears-from-neighbors-fields-rather-than-for-better-weed-control-or-boosting-yields>
30. Fisher, Madeline. 2014. *No-till soil organic carbon sequestration rates questioned*. Soil Science Society of America. May 5. Available online. <https://www.soils.org/discover-soils/story/researchers-question-published-no-till-soil-organic-carbon-sequestration-rates>
31. Luo, Z., Wang, E. and Sun, O.J., 2010. Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. *Agriculture, Ecosystems & Environment*, 139(1-2), pp.224-231.
32. Corbeels, M., Marchão, R.L., Neto, M.S., Ferreira, E.G., Madari, B.E., Scopel, E. and Brito, O.R., 2016. Evidence of limited carbon sequestration in soils under no-tillage systems in the Cerrado of Brazil. *Scientific reports*, 6, p.21450.
33. Roger, Margaret and D. Stephens. New Initiative Investigates Non-wetting Solutions. *Ground Cover*, 118. Grains, Research and Development Corporation. Australian Government. Available online. <https://grdc.com.au/resources-and-publications/groundcover/ground-cover-supplements/ground-cover-issue-118-soil-constraints/new-initiative-investigates-non-wetting-solutions>
34. Lo, C.C., 2010. Effect of pesticides on soil microbial community. *Journal of Environmental Science and Health Part B*, 45(5), pp.348-359.
35. Silva, V., Mol, H.G., Zomer, P., Tienstra, M., Ritsema, C.J. and Geissen, V., 2019. Pesticide residues in European agricultural soils—A hidden reality unfolded. *Science of the Total Environment*, 653, pp.1532-1545.
36. Joly, P., Besse-Hoggan, P., Bonnemoy, F., Batisson, I., Bohatier, J. and Mallet, C., 2012. Impact of Maize Formulated Herbicides Mesotrione and S-Metolachlor, Applied Alone and in Mixture, on Soil Microbial Communities. *ISRN Ecology*.
37. Tejada, M., 2009. Evolution of soil biological properties after addition of glyphosate, diflufenican and glyphosate+ diflufenican herbicides. *Chemosphere*, 76(3), pp.365-373.
38. Bittel, Jason. 2014. Second silent spring? Bird declines linked to popular pesticides. *National Geographic*. July 9. Available online. <https://news.nationalgeographic.com/news/2014/07/140709-birds-insects-pesticides-insecticides-neonicotinoids-silent-spring/>
39. Sánchez-Bayo, F. and Wyckhuys, K.A., 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, 232, pp.8-27.
40. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2019. *IPBES Global Assessment*. May 6. Available online. Available online. <https://www.ipbes.net>
41. Elver, Hilal. 2017. Report of the Special Rapporteur on the right to food. United Nations Human Rights Council. January 24. Available online. <https://reliefweb.int/sites/reliefweb.int/files/resources/1701059.pdf>
42. Environmental Protection Agency. 2017. Pesticide Industry Sales and Usage 2008 – 2012. EPA Office of Pesticide Programs. Washington D.C. Available online. [https://www.epa.gov/sites/production/files/2017-01/documents/pesticides-industry-sales-usage-2016\\_0.pdf](https://www.epa.gov/sites/production/files/2017-01/documents/pesticides-industry-sales-usage-2016_0.pdf)
43. Marquez, Emily. 2018. In the U.S. and the world, pesticide use is up. Pesticide Action Network. August 2. Available online. <http://www.panna.org/blog/us-and-world-pesticide-use>
44. Lechenet, M., Dessaint, F., Py, G., Makowski, D. and Munier-Jolain, N., 2017. Reducing pesticide use while preserving crop productivity and profitability on arable farms. *Nature Plants*, 3(3), p.17008.
45. Cook, Christopher, Kari Hamerschlag, and Kendra Klein. 2016. Farming for the Future: Organic and agroecological solutions to feed the world. Friends of the Earth. Available online. <https://foe.org/resources/farming-for-the-future-organic-and-agroecological-solutions-to-feed-the-world/>

