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I. INTRODUCTION

Consumers shopping for produce consider the produce's freshness (usually by looking for bruising or rot) and sometimes its "organic" or "non-GMO" certification.[1] And while more environmentally conscious consumers may be concerned about single-use plastic packaging their produce comes in, they likely do not think of the excess of plastics farmers use just to grow that produce.[2]

The agricultural industry uses an extraordinarily high amount of plastic, notably through"[a]gricultural films[, which are] thin plastic membranes" used for mulching.[3] In fact, "[t]he use of these films has become so predominant in recent years that there is now a name for it: plasticulture."[4] Plasticulture has become a multi-billion-dollar industry[5] that produces dumpsites "so large, they can be seen from the Space Station."[6]

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[1] Julie Taylor, *10 to Keep Your Diet GMO-Free*, CNN HEALTH (Mar. 31, 2014, 10:32 AM), https://www.cnn.com/2014/03/25/health/upwave-gmo-free-diet/index.html.
GMOs, or genetically modified organisms, are "the result of a laboratory process that inserts genes from one species into the genes of another to obtain a desired trait or characteristic." *Id.*

[2] *See* John Geddie, *75% of People Want Single-Use Plastics Banned, Global Survey Finds*, REUTERS (Feb. 21, 2022, 4:56 PM), https://www.reuters.com/business/environment/75-people-want-single-use-plastics-banned-global-survey-finds-2022-02-22/ (stating that "[t]hree in four people worldwide want single-use plastics to be banned as soon as possible," and that 82% of people across 28 countries favor products that use less plastic packaging).

[3] Brian Barth, *3 Ways Farmers Are Kicking the Plastic Habit*, MOD. FARMER (Sept. 10, 2015), https://modernfarmer.com/2015/09/agriculture-plastic-waste/.

[4] *Id.*

[5] *Id.*

[6] Erik Kobayashi-Solomon, *Feeding the World with Plastic*, FORBES (May 24, 2019, 8:55 AM), https://www.forbes.com/sites/erikkobayashisolomon/2019/05/24/feeding-the-world-with-plastic/.

Although plastic mulch has many benefits (including water conservation, pest and weed suppression, increased crop quality, and soil temperature control),[7] its ubiquitous use creates substantial waste that, when broken down into microplastics, eventually enter the human body.[8] While the full effects of ingested microplastics on the human body is still uncertain,[9] research indicates that "exposure to airborne nano-particles may cause asthma, cardiac disease, allergies[,] and autoimmune diseases," and that "microplastics contain monomers and additives that are endocrine disruptors."[10]

Organic farming is not exempt from the plastic problem; a farm and its produce can maintain organic status while still using plastic mulch[11] as long as the mulch is created without polyvinyl chloride (PVC) and is replaced annually.[12]

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[7] *Id.*

[8] *See* Consumer Reports, *You're Literally Eating Microplastics. How You Can Cut Down Exposure to Them*, WASH. POST (Oct. 7, 2019), https://www.washingtonpost.com/health/youre-literally-eating-microplastics-how-you-can-cut-down-exposure-to-them/2019/10/04/22ebdfb6-e17a-11e9-8dc8-498eabc129a0_story.html; *see also* GREENPEACE, *3 Everyday Foods That Contain Microplastics* (July 21, 2020), https://www.greenpeace.org/eastasia/blog/6016/3-everyday-foods-that-contain-microplastics (citing studies that "found that microplastics are penetrating the roots of lettuce and wheat plants, and nanoplastics were absorbed by plant roots. Fruits and vegetables can accumulate microplastics through uptake from microplastic-contaminated water or soil"); Kieran D. Cox, *Human Consumption of Microplastics*, 53 ENV'T. SCI. & TECH. 7068 (2019), https://pubs.acs.org/doi/10.1021/acs.est.9b01517 (estimating that Americans consume or inhale 74,000-121,000 microplastic particles yearly).

[9] *See* Claudia Campanale, Carmine Massarelli, Ilaria Savino, Vito Locaputo, & Vito Felice Uricchio, *A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health*, 17 INT'L J. OF ENV'T. RES.& PUB. HEALTH 1, 1, 18 (2020), https://doi.org/10.3390/ijerph17041212; Evan Bush, *Microplastics in the Human Body: What We Know and Don't Know*, NBC NEWS (Apr. 11, 2022), https://www.nbcnews.com/science/science-news/microplastics-human-body-know-dont-know-rcna23331.

[10] Joana Coreia Prata, *Airborne Microplastics: Consequences to Human Health?*, 234 ENV'T. POLLUTION 115, 122 (2018), https://doi.org/10.1016/j.envpol.2017.11.043.

[11] *Allowed Mulches on Organic Farms and the Future of Biodegradable Mulch*, U.S. DEP'T OF AGRIC., https://www.ams.usda.gov/sites/default/files/media/5%20Mulches%20incl%20biodegradable%20FINAL%20RGK%20V2.pdf (last visited Apr. 1, 2021).

[12] *See* Sreejata Bandopadhyay, Lluis Martin-Closas, Ana M. Pelacho, & Jennifer M. DeBruyn, *Biodegradable Plastic Mulch Films: Impacts on Soil Microbial Communities and Ecosystem Functions*, 9

To examine some of these problems, this article first discusses the benefits of plastic mulch.[13] Then, it looks at the problems plastic mulch use causes,[14] currently available alternatives to plastic mulch, and drawbacks to alternatives to plastic mulch.[15] This article will then conclude by offering possible solutions to the plastic mulch situation.[16] While immediate banning of plastic mulch use is not a feasible option, the USDA should use its administrative powers to encourage farmers in the United States to decrease their plastic mulch use until it can permanently ban plastic mulch without causing severe repercussions to the agricultural industry.

II. PLASTIC MULCH AND ITS USES

Mulch is material that prevents plants from drying in heat by "reduc[ing] weed growth and enhanc[ing] storage of soil moisture."[17] Some common materials include "wood chips, paper, or other shredded material."[18] However, "[s]ince its introduction in the 1950s, plastic mulch," mulching using plastic sheeting, "has become a standard practice used by many

FRONTIERS IN MICROBIOLOGY 1, 1 (2018), https://doi.org/10.3389/fmicb.2018.00819. Conventional plastic mulch is made with polyethylene, so PVC-created mulch is not generally an issue. *Id.*

[13] *See infra* Part II.

[14] *See infra* Part III.

[15] *See infra* Part IV.

[16] *See infra* Part V.

[17] Sharon Durham, *Plastic Mulch: Harmful or Helpful?*, 51 AGRIC. RES.. 14, 14 (2003), https://agresearchmag.ars.usda.gov/ar/archive/2003/jul/mulch0703.pdf.

[18] *Id.*

farmers."[19] In fact, "[i]t's estimated that in the US alone, farmers use around 1 billion pounds of plastic annually."[20]

Plastic mulch is popular for multiple reasons: "It controls weeds, conserves soil moisture, increases soil temperature, improves crop yield and quality, has a relatively low cost, and is readily available."[21] Although most people might not think plastic is "organic," the National Organic Program (NOP) defines mulch as "non-synthetic material, such as wood chips, leaves, or straw, or any *allowed* synthetic material such as newspaper or plastic that serves to suppress weed growth, moderate soil temperature, or conserve soil moisture."[22] The list of allowed synthetic materials includes conventional plastic mulches as long as "[1] they are removed from the field at the end of the growing season, and [2] they are petroleum-based, but not [made of] polyvinyl chloride (PVC)."[23]

In fact, plastic mulching may be more important to organic farming than conventional farming; because organic farmers cannot use chemical weed killers, plastic mulch is invaluable in helping them with weed control.[24]

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[19] Carol Miles, Erin Klingler, Liz Nelson, Tracy Smith, & Cheri Cross, *Alternatives to Plastic Mulch in Vegetable Production Systems,* WASH. ST. UNIV. 1 (2006), http://agsyst.wsu.edu/MulchReport07.pdf.

[20] Natalie Hoidal, *Exploring Alternatives to Plastic Mulch,* UNIV. OF MINN. EXTENSION (Jan. 8, 2021), https://blog-fruit-vegetable-ipm.extension.umn.edu/2021/01/exploring-alternatives-to-plastic-mulch.html.

[21] *Allowed Mulches on Organic Farms and the Future of Biodegradable*, *supra* note 11.

[22] *Id.*

[23] *Id.*; *see also supra* note 12 and accompanying text.

[24] Lisa Elaine Held, *Organic Farming Has a Plastic Problem. One Solution Is Controversial*, NPR (June 7, 2019, 7:00 PM), https://www.npr.org/sections/thesalt/2019/06/07/729783773/organic-farming-has-a-plastic-problem-one-solution-is-controversial.

Additionally, plastic mulch, in combination with "drip irrigation, a system that conserves water by delivering it directly to plant roots through a network of thin plastic tubes snaking beneath the mulch," helps conserve about sixty percent of water usage when compared with sprinklers.[25]

Lastly, plastic mulch "increase[s] yield and season length for farmers" because it warms the soil.[26] This allows "heat-loving crops—like tomatoes, peppers and eggplants" to "mature weeks earlier on plastic versus bare ground."[27]

III. PROBLEMS WITH PLASTIC MULCH

However, despite plastic mulch's bountiful benefits, it creates many problems: it contributes to runoff pollution of environmentally harmful pesticides,[28] adds to general waste and disposal problems,[29] and increases the presence of microplastics in the soil, which in turn increases the microplastics consumers ingest through fruits, vegetables, and dairy products.[30]

A. RUNOFF POLLUTION FROM PESTICIDES

"[T]o combat weeds and insect pests," many commercial growers use pesticides with plastic mulch.[31] "Unfortunately, plastic mulch, which can cover between 50 percent and 70

[25] *Id.*

[26] *Id.*

[27] *Id.*

[28] *See infra* Part III Section A.

[29] *See infra* Part III Section B.

[30] *See infra* Part III Section C.

[31] Durham, *supra* note 17.

percent of a field, increases surface water runoff from both rainfall and irrigation. That means more of the pesticides applied on plastic-mulched fields" pollute runoff water.[32]

This pollution takes place in both conventional and organic farming.[33] While some may believe organic produce is grown without pesticides, this is not the case: "There are over 20 chemicals commonly used in the growing and processing of organic crops that are approved by the US Organic Standard."[34] As long as the organic farms only use approved pesticides,[35] they are growing organic crops.[36] However, "[w]hile organic pesticides are typically viewed as safer alternatives to synthetic pesticides," this is not always true.[37] Organic pesticides can be "dangerously toxic in certain doses" while synthetic pesticides can be nontoxic or just slightly toxic; whether a pesticide is synthetic or organic does not determine how toxic or dangerous it is.[38]

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[32] *Id.*

[33] *See* Christie Wilcox, *Mythbusting 101: Organic Farming > Conventional Agriculture*, SCI. AM. (July 18, 2011), https://blogs.scientificamerican.com/science-sushi/httpblogsscientificamericancomscience-sushi20110718mythbusting-101-organic-farming-conventional-agriculture/.

[34] *Id.*

[35] "Organic pesticides are generally considered to be pesticides derived from naturally occurring sources such as minerals, plants, or animals," and usually "are broken down relatively quickly by weather or soil microbes." Tim McCoy & Daniel Frank, *Organic vs. Conventional (Synthetic) Pesticides: Advantages and Disadvantages*, VA. STATE UNIV. 1, 1 (June 25, 2020), https://resources.ext.vt.edu/contentdetail?contentid=2386. In contrast, synthetic pesticides, also known as conventional pesticides, are "formulated or manufactured by a chemical process or by a process that chemically changes a substance extracted from naturally occurring plant, animal, or mineral sources." *Id.* However, some synthetically produced pesticides, such as copper sulfate, "meet the criteria for use in organic agriculture." *Id.*

[36] Wilcox, *supra* note 33.

[37] McCoy & Frank, *supra* note 35, at 1–2.

[38] *Id.*

Pesticide runoff can also create serious problems.[39] For example, copper, "the most widely used fungicide-bactericide for control of tomato diseases . . . has been found in runoff from fields that have plastic mulch. Unfortunately, elevated levels of copper can harm shellfish, finfish, and other aquatic organisms."[40] Other insecticides, herbicides, and fungicides similarly harm the environment when they contaminate water sources by "poison[ing] fish and wildlife, contaminat[ing] food sources, and destroy[ing] the habitat that animals use for protective cover."[41]

In addition, states have reported that agricultural nonpoint source (NPS) pollution[42] is "a major contributor to contamination" of water in rivers, lakes, wetlands, estuaries, and ground water.[43] This contamination can cause algae blooms, which not only affect the taste and smell of drinking water, but also "kill fish by removing oxygen from the water."[44] Furthermore, "[h]igh concentrations of nitrate in drinking water can cause methemoglobinemia, a potentially fatal disease in infants."[45]

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[39] Durham, *supra* note 17.

[40] *Id.*

[41] *Protecting Water Quality from Agricultural Runoff*, ENVTL. PROTECTION AGENCY, https://www.epa.gov/sites/production/files/2015-09/documents/ag_runoff_fact_sheet.pdf (last updated Mar. 2005).

[42] NPS pollution is pollution that does not originate from any specific source (in comparison to pollution that originates from "industrial and sewage treatment plants"). *Id.* at 1. Agricultural NPS pollution can originate from "poorly located or managed animal feeding operations; overgrazing; plowing too often or at the wrong time; and improper, excessive, or poorly timed application of pesticides, irrigation water, and fertilizer." *Id.*

[43] *Id.*

[44] *Id.*

[45] *Id.* Nitrates are "the final breakdown product of nitrogen fertilizers and can accumulate "in groundwater under agricultural land." Mary H. Ward, *Too Much of a Good Thing? Nitrate from Nitrogen Fertilizers*

Unfortunately, using plastic mulch exacerbates normal pesticide run off because it increases "the runoff of water after rainfall or irrigation."[46] This "means that more of the pesticides and other chemicals applied over the plastic mulch films run off the field to surface waters, such as nearby river or lake, or ground water."[47]

B. DISPOSAL, WASTE, AND RECYCLE ISSUES

Most plastic mulches are made from polyethylene, which is a petroleum-based plastic.[48] Similar to the environmental harm caused by plastic packaging, plastic mulch is difficult to recycle, and farmers struggle to appropriately dispose of the millions of plastic sheets used in commercial agriculture.[49] Even worse, not only is conventional plastic mulch not biodegradable, not all of it can be removed by machines; some of it must be removed by hand before being discarded.[50] After removal, disposal can pose a problem as well; although the mulch is technically recyclable, the process is far too difficult because the mulch is "contaminated with too much dirt and debris to be recycled directly from the field."[51] Also, many recycling centers refuse to accept "[p]lastic films with more than 5% contaminants by weight."[52] Considering

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and Cancer, NAT'L INST. OF HEALTH (Oct. 21, 2008), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3068045/.

[46] Subrahmaniyan Kasirajan & Mathieu Ngouajio, *Polyethylene and Biodegradable Mulches for Agricultural Applications: A Review*, 32 AGRONOMY FOR SUSTAINABLE DEV. 501, 507 (Jan. 16, 2013), https://doi.org/10.1007/s13593-011-0068-3.

[47] *Id.*

[48] *Id.* at 505.

[49] *Id.*

[50] *Id.*

[51] *Id.* at 506.

[52] *Id.*

"contaminants in agricultural plastics can be up to 40–50% by weight from pesticides, fertilizers, soil and debris, moist vegetation, silage juice water, and UV additives," [53] it is not surprising that very little plastic mulch is recycled.[54] In most cases, it is not economically feasible to recycle due to the high level of contamination.[55] In fact, "[b]etween 1992 and 2008, 95 million lb of high-density polyethylene pesticide containers were recycled in the USA, while only 1% of agricultural plastic film and nursery container was recycled . . . due to the high level of contamination."[56]

Although some organizations, such as the Recycling Agricultural Plastics Program (RAPP) at Cornell University and the Florida Agricultural Plastic Recyclers (FLAG), "have developed ways to clean used mulch film efficiently . . . recycling options are very limited in many states and regions around the country."[57]

In addition, it can be both difficult and expensive for farmers to properly dispose of plastic mulch.[58] First, it must be removed from the fields, and "[n]ot all farmers will make the

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[53] *Id.*

[54] *Id.*

[55] *Frequently Asked Questions: Plastics Recycling*, CALRECYCLE, https://www.calrecycle.ca.gov/plastics/faq (last updated Aug. 17, 2020).

[56] Kasirajan & Ngouajio, *supra* note 46, at 506.

[57] Jenny Moore & Annette Wszelaki, *Plastic Mulch in Fruit and Vegetable Production: Challenges for Disposal*, UNIV. OF TENN. INST.OF AGRIC. 1, 2 (Dec. 2016), https://ag.tennessee.edu/biodegradablemulch/Documents/Plastic%20Mulch%20in%20Fruit%20and%20Vegetable%20Production_12_20factsheet.pdf.

[58] *See* Margarita Velandia, Aaron Smith, & Annette Wszelaki, *The Economics of Adopting Biodegradable Plastic Mulch Films*, UNIV. OF TENN. INST. OF AGRIC. 1 (Feb. 2020), https://www.researchgate.net/publication/339032488_The_Economics_of_Adopting_Biodegradable_Plastic_Mulch_Films.

effort to remove [the smaller] mulch fragments."[59] While transportation costs and disposal fees can vary depending on location, "[s]ome landfills may not even accept [plastic] mulch for disposal."[60]

Although burning the mulch may sound like a potential solution since "[p]olyethlene mulches contain nearly as much potential energy per unit weight as oil (20,000 Btu/lb) and could be incinerated to produce heat or electricity," there are some problems with this solution as well.[61] First, "most power plants and incinerators are not designed to burn dirt- and debris-covered plastic, and operators are reluctant to make attempts to do so."[62] Second, the incinerators must be "capable of burning at 1,000–1,200°C [1832°F–2196°F] or higher . . . to ensure complete combustion and less pollutant emission."[63] For such incinerators to efficiently produce energy, they must be equipped with "steam turbines, generators, and a scrubber system, which reduces pollutant emissions."[64] Properly equipped incinerators can cost several million dollars and therefore are not regularly available.[65] Though creating more incinerators to increase availability may initially sound like an appealing solution, plastic mulch—due to its seasonal nature and decentralized use—cannot provide a "predictable fuel supply," something that is crucial to sustaining these expensive facilities."[66]

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[59] *Id.* at 2.

[60] *Id.* at 3.

[61] Kasirajan & Ngouajio, *supra* note 46, at 506 (citations omitted).

[62] *Id.* (citation omitted).

[63] *Id.* at 507 (citation omitted).

[64] *Id.*

[65] *Id.*

[66] Moore & Wszelaki, *supra* note 57.

Many growers, however, have turned to burning their agricultural plastic waste on-site due to the "high transportation cost and landfill tipping fees."[67] In fact, in 2003, experts estimated "that more than 50% of agricultural plastics in New York and Pennsylvania were burned on-site."[68] However, understandably, these growers do not have incinerators capable of burning plastic waste at 1832°F and do not properly rid their plastics of contaminants before burning.[69] Unfortunately, burning "mulch films contaminated with fertilizers and pesticides" at temperatures of 600°F or lower "usually generates air pollutants" such as dioxins, compounds related to dioxins, and fine air particles.[70] Because dioxins are known "endocrine disruptors and carcinogens," and "exposure to fine particles (diameter<2.5 mm) from open burning has been associated with many health effects, such as increased risk of stroke, asthmatic attacks, decreased lung function, respiratory diseases, and premature death," this method of self-disposal is not a viable long-term solution.[71] In fact, several states, "including Arizona, California, Colorado, Connecticut, Hawaii, Idaho, Kentucky, Massachusetts, New York, Ohio, Tennessee, Vermont and Wisconsin," have made it illegal "to dispose of PE [polyethylene] mulch by open burning on the farm."[72]

To get around the expensive disposal problem, some growers have turned to storing or burying their plastic waste.[73] However, this leads to the plastic mulch breaking down and further

[67] Kasirajan & Ngouajio, *supra* note 46 (citation omitted).

[68] *Id.* (citation omitted).

[69] *Id.*

[70] *Id.*

[71] *Id.*

[72] Moore & Wszelaki, *supra* note 57 (citation omitted).

[73] Kasirajan & Ngouajio, *supra* note 46.

contaminating the soil with microplastics.[74] Based on a 2004 "survey of Pennsylvania vegetable growers, 66% of participating growers said they disposed of used agricultural plastics by on-site burning, 27% by landfilling, and 25% by burying, dumping, or piling on-site," indicating that this is widespread problem.[75]

C. PRESENCE AND EFFECTS OF MICROPLASTICS

The term microplastics generally refers to small plastic particles that are less than five millimeters in length.[76] Increasing levels of microplastics are a global environmental concern due to their near-permanent nature.[77] Microplastics have been found in the "ocean, seashores, estuaries, inland rivers, lakes, and even deep-sea sediment," and in "more than 160 marine and 39 freshwater species."[78] In addition, numerous studies suggest microplastics may cause "feeding disruption, reproductive reduction, intestinal damage, and metabolic disturbances."[79] For example, a 2012 study found that "high density polythene with sizes of 0–80 μm can be taken up into the cells of blue mussels, *Mytilus edulis L.*, and induce a strong inflammatory response."[80] Another study published in 2016 found that exposure to polystyrene microbeads caused "a reduced growth rate, reduced fecundity, decreased lifespan, and longer reproduction

[74] *See infra* Part III Section C.

[75] Kasirajan & Ngouajio, *supra* note 46 (citation omitted).

[76] Yi Huang, Weiqian Jia, Qin Liu, Jie Wang, & Changrong Yan, *Agricultural Plastic Mulching as a Source of Microplastics in the Terrestrial Environment*, 260 ENVTL. POLLUTION 1 (2020), https://doi.org/10.1016/j.envpol.2020.114096 (citation omitted).

[77] *Id.* (citations omitted).

[78] *Id.* (citations omitted).

[79] *Id.* at 1–2 (citations omitted).

[80] *Id.* at 2 (citation omitted).

times" in the monogonont rotifer *Brachionus koreanus*,[81] which are a species of "microscopic, aquatic invertebrates"[82] that are "commonly used as ecological and evolutionary models to address questions related to aquatic ecology."[83]

However, microplastics are no longer just a topic of concern for aquatic environments.[84] Although less research has been done regarding microplastics on land, several studies have found microplastics not just on "the surface soil in an industrial zone" but also in "soils from natural reserve areas that are almost devoid of human activities."[85] Research also indicates that various practices including plastic mulching "may contribute to terrestrial microplastic contamination."[86] In fact, though many people were initially only concerned about microplastics in the ocean, "researchers say that most microplastics are actually accumulating on land, including agricultural areas."[87] A 2016 article estimates that 44,000 to 300,000 tons of microplastics yearly accumulate

[81] *Id.*

[82] *Rotifer*, ENCYCLOPÆDIA BRITANNICA, INC., https://www.britannica.com/animal/rotifer (last visited Apr. 1, 2021).

[83] Hui-Su Kim, Bo-Young Lee, Jeonghoon Han, Chang-Bum Jeong, Dae-Sik Hwang, Min-Chul Lee, Hye-Min Kang, Duck-Hyun Kim, Hee-Jin Kim, Spiros Papakostas, Steven A. J. Declerck, Ik-Young Choi, Astushi Hagiwara, Heum Gi Park, Jae-Seong Lee, *The Genome of the Freshwater Monogonont Rotifer Brachionus Calyciflorus*, 18 MOLECULAR ECOLOGY RES. 646, 646 (2018), https://doi.org/10.1111/1755-0998.12768.

[84] Huang et al., *supra* note 76, at 2.

[85] *Id.* (citations omitted).

[86] *Id.* (citations omitted).

[87] Kate S. Petersen, Microplastics in Farm Soils; A Growing Concern, ENV'T HEALTH NEWS (Aug. 31, 2020), https://www.ehn.org/plastic-in-farm-soil-and-food-2647384684.html.

in North American farmlands.[88] In comparison, the article estimated that a total of 93,000 to 236,000 tons of microplastics were "present in surface water in the global oceans" in 2016.[89]

In 2019, researchers conducted a study in China to determine the impact plastic mulching has on agricultural soils.[90] After gathering various samples across China, with sampling sites based on plastic mulching consumption, the researchers found a significant linear correlation between plastic mulch use microplastic residues in soil, indicating that plastic mulching "was the major source of macroplastics in farmlands in China."[91] They then theorized that the macroplastics accumulated in the soil and contributed "to the formation of microplastics."[92]

The researchers also studied the "cotton fields in the Xinjiang Uygur Autonomous Region, . . . a potential 'hotspot' of microplastic contamination due to its long-history of plastic mulching."[93] By analyzing the soil, the researchers determined that "the amount of microplastics in arable lands increased significantly [] with the number of years of plastic mulching."[94] The soil samples also showed signs indicating that the plastic mulch used degraded and broke down

[88] Luca Nizzetto, Martyn Futter, & Sindre Langaas, *Are Agricultural Soils Dumps for Microplastics of Urban Origin?*, 50 ENVTL. SCI. & TECH. 10777, 10777 (2016), https://doi.org/10.1021/acs.est.6b04140.

[89] *Id.*

[90] Huang et al., *supra* note 76.

[91] *Id.* at 3–4.

[92] *Id.* at 4.

[93] *Id.*

[94] *Id.*

due to "photooxidation or soil particle mechanical abrasion."[95] Essentially, plastic mulch breaks down into macro- and microplastics, accumulating as the mulch is used year after year.[96]

Research indicates that microplastics in soil cause various problems.[97] First, while "[t]he full impact of microplastics contamination in agricultural soils, particularly as concentrations increase with time," is not yet fully known, researchers have discovered that exposure to nanoplastics, "plastic pieces that are less than 100 nanometers in size," stunts the growth of certain plants.[98] Second, microplastics can alter soil properties, including water holding capacity and microbial communities.[99] Third, microplastics ingestion causes "an 8 percent to 25 percent mortality rate in earthworms.[100] This is crucial because earthworms carry out various important ecological purposes: they improve soil quality by aiding decomposition, add organic nutrients to the soil through waste, and increase soil aeration.[101] Earthworms can also exacerbate the microplastics problem when they ingest microplastics because they "concentrat[e] the plastics in their castings[] and transport[] them through different layers of soil."[102] This means that when it rains, microplastics can contaminate groundwater systems, which implies that plastic mulch use eventually leads to groundwater contamination.[103]

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[95] *Id.*

[96] *Id.*

[97] Petersen, *supra* note 87.

[98] *Id.*

[99] *Id.*

[100] *Id.*

[101] *Id.*

[102] *Id.*

[103] *Id.*

Fourth, researchers found evidence that plants exposed to microplastics will absorb and accumulate the plastics.[104] Yongming Luo, a professor at the Yantai Institute of Coastal Zone Research and the Nanjing Institute of Soil Science in China, along with his colleagues, discovered "microplastics accumulation in wheat and lettuce plants exposed to microplastics in a laboratory setting."[105] They did this by growing the plants in mediums containing microplastics "laced with fluorescent dyes."[106] When "[t]he researchers analyzed cross sections of the plants under a microscope outfitted to detect the" fluorescent dyes, the "roots, stems, and leaves lit up," demonstrating the presence of the dyed microplastics in the plants.[107]

Luo and his colleagues' research is critical because prior to their research, scientists "believed that plastic particles [were] too large to pass through the physical barriers of intact plant tissue."[108] Luo's team also "reported that the microplastics seemed to be entering the plants through cracks in the roots where lateral branching occurs as well as diffusing through cells at the developing root tips."[109]

Another team of scientists independently found evidence supporting Luo's research when they discovered the presence of "microplastics in Italian supermarket produce including carrots, lettuce, broccoli, potatoes, apples, and pears."[110] The Italian researchers "found the most

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[104] *Id.*

[105] *Id.*

[106] *Id.*

[107] *Id.*

[108] *Id.*

[109] *Id.*

[110] *Id.*

microplastics contamination in apples and the least in lettuce[] and speculated that the perennial nature of a fruit tree allowed microplastics to accumulate more than in annual crops."[111]

With proof that plants not only can but actively are absorbing and accumulating microplastics, it is clear that consumers have been eating produce contaminated with microplastics.[112] Furthermore, Luo asserts that microplastics are "getting into everything that eats vegetables…which means [microplastics] are in our meat and dairy as well."[113] Considering "[m]icroplastics have previously been detected in honey, beer, and seafood . . . ingestion of microplastics by humans is practically unavoidable."[114]

While the exact consequences of microplastics ingestion are currently unknown, related research based on the effects of microplastics on the human body indicates that microplastics ingestion likely harms humans.[115] First, "[p]lastic microfibers have been found in malignant lung tissue biopsies of cancer patients."[116] While these plastic microfibers were likely "inhaled rather than swallowed," evidence exists "that microplastics can become lodged in tissue and cause dangerous inflammation" when ingested. [117] Second, studies indicate that microplastics, once ingested, "can pass through cell walls, move through the body, accumulate in organs, and impact the immune system."[118]

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[111] *Id.*

[112] *Id.*

[113] *Id.*

[114] *Id.*

[115] *Id.*

[116] *Id.*

[117] *Id.*

[118] *Id.*

Third, microplastics can "attract[] and bind[] to compounds known to harm human health," such as cadmium, lead, polychlorinated biphenyls (PCBs), and pesticides:[119] cadmium can cause lung damage, kidney disease, bone disease, lung disease, and cancer;[120] lead can cause anemia, kidney and brain damage, death, birth defects, miscarriage, stillbirths, infertility, and death;[121] PCBs "are highly toxic industrial compounds" that may cause developmental and neurological problems in babies and children;[122] and some pesticides may cause "cancers, birth defects, reproductive harm, neurological and developmental toxicity, immunotoxicity, . . . disruption of the endocrine system," and death.[123]

Furthermore, plastics can be "manufactured with their own suite of toxic compounds, which can include BPA, an endocrine disruptor."[124] These compounds can "leach out of degrading plastics into their environment, whether that be soil or human tissue."[125]

IV. ALTERNATIVES TO PLASTIC MULCH

The microplastics problem should immediately be tackled because it is a compounding problem: not only does strong evidence exist that microplastics can cause health and

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[119] *Id.*

[120] *Cadmium*, OCCUPATIONAL SAFETY & HEALTH ADMIN., https://www.osha.gov/cadmium (last visited Apr. 1, 2021).

[121] *Lead*, CTR. FOR DISEASE CONTROL & PREVENTION, https://www.cdc.gov/niosh/topics/lead/health.html (last visited Apr. 1, 2021).

[122] *PCBs in Fish and Shellfish*, ENV'T. DEF. FUND, https://seafood.edf.org/pcbs-fish-and-shellfish (last visited Apr. 1, 2021).

[123] *Pesticides and Human Health:*, CALIFORNIANS FOR PESTICIDES REFORM, http://www.pesticidereform.org/pesticides-human-health/ (last visited Apr. 1, 2021).

[124] Petersen, *supra* note 87.

[125] *Id.*

environmental problems,[126] but they are also difficult to remove from the environment.[127] For example, "most water treatment plants are not well-equipped to effectively remove microplastics from drinking water, resulting in another pathway for human microplastics consumption."[128] If the hypothesis that "there will be more waste plastic in the sea than fish by 2050"[129] is correct, combined with the fact that more plastics accumulate on European and North American farmlands per year than the total amount of microplastics "estimated to be present in surface water in the global oceans,[130] a catastrophe is imminent unless changes are immediately made to the status quo.

Even worse, there is compelling evidence that "microplastics are being transported through the air, making them a global problem, not a regional pollutant."[131] People have found microplastics in secluded areas of the world, such as "a remote, high-altitude lake in the Pyrenees mountains (southern France), . . . remote lakes in Italy and Mongolia, in floodplain soils in a Swiss nature reserve, and in melting Arctic sea ice," places that do not have any obvious sources of plastic pollution or microplastics.[132]

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[126] *See supra* Part III Section C.

[127] Rebecca Dzombak, *There's No Corner of the Globe Safe from Microplastic Pollution*, MASSIVE SCI. (June 19, 2019), https://massivesci.com/articles/microplastic-pollution-pyrenees-mountains-soil-air-environment-health/.

[128] *Id.*

[129] Graeme Wearden, *More Plastic Than Fish in the Sea by 2050, Says Ellen MacArthur*, THE GUARDIAN (Jan. 19, 2016, 9:23 AM), https://www.theguardian.com/business/2016/jan/19/more-plastic-than-fish-in-the-sea-by-2050-warns-ellen-macarthur.

[130] Nizzetto et al., *supra* note 88.

[131] Dzombak, *supra* note 127.

[132] *Id.*

However, many of the current alternatives to plastic mulch also come with their drawbacks: biodegradable mulches might pose similar drawbacks as plastic mulch,[133] many other mulches can only be used for certain types of crops,[134] and some other alternatives require refining their methods before they are used on a wider scale.[135]

A. BIODEGRADABLE MULCHES

Since conventional plastic mulch causes microplastics and disposal issues, biodegradable plastic mulches seem like the obvious solution.[136] In fact, they seem like they might even be a superior solution: not only do they provide nearly identical benefits to crops, they appear to be a more environmentally friendly, less labor inducing, solution at first glance since the biodegradable mulch can be "tilled into the soil where it decomposes" instead of manually removing the mulch "at the end of the season."[137]

However, problematically, biodegradable mulches include additives to improve elasticity, stability, and color of the mulch.[138] These additives "can migrate to soil during their use."[139] While these additives may only comprise of a small portion of the final mulch composition, "there is no requirement for proving their biodegradability" if the additives are less than 1% of

[133] *See infra* Part IV Section A.

[134] *See infra* Part IV Sections B–D, F.

[135] *See infra* Part IV Sections E, G–H.

[136] Hoidal, *supra* note 20.

[137] *Id.*

[138] Hadaly Serrano-Ruiz, Lluis Martin-Closas, & Ana M.Pelacho, *Biodegradable Plastic Mulches: Impact on the Agricultural Biotic Environment*, 750 SCI. OF THE TOTAL ENV'T 1, 4 (2021), https://doi.org/10.1016/j.scitotenv.2020.141228.

[139] *Id.*

the total mulch's composition.[140] This is especially problematic because "even substances listed as of 'Very High Concern' are allowed at 0.1% maximum as part of the biodegradable plastic mulch final weight."[141] This means growers using biodegradable mulches containing these very concerning substances will have their soil contaminated by concerning additives when the mulch degrades and the additives are released into the soil.[142]

Another problem, however minor, with "biodegradable mulch is that it can look quite messy when it begins to degrade, and pieces can stick to produce" an ugly sight for customers.[143]

In summary, further "[i]n-depth research on the effects . . . from using biodegradable plastic mulches is required to guarantee the environmental safety and sustainability of" biodegradable mulch.[144] If research can demonstrate that biodegradable mulches can not only completely break down without micro- or nanoplastics being left behind but also shows that whatever additives used also harmlessly break down, biodegradable mulches may ideally resolve the plastic mulch problem. However, if research concludes biodegradable mulches either leave behind plastics from not fully biodegrading or release harmful substances into the soil, then biodegradable mulches are not an ideal solution.[145]

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[140] *Id.*

[141] *Id.*

[142] *Id.*

[143] Hoidal, *supra* note 20.

[144] Serrano-Ruiz et al., *supra* note 138, at 12.

[145] *See supra* Part IV Section A.

B. PAPER MULCH

Unlike biodegradable plastic mulch, paper mulch biodegrades without any health concerns.[146] However, it has several drawbacks when compared with conventional plastic mulch.[147]

First, it is more difficult to apply since "the edges are more likely to tear during application if . . . not set up at the right angle."[148] Second, due to its more delicate nature, paper mulch requires more upkeep throughout the season; some researchers "recommend re-burying the edges at least once or twice during the season, as loose edges can catch in the wind or on equipment and tear," and even with this extra care taken, paper mulch still tends "to develop more tears and holes throughout the season than standard plastic mulch."[149] Third, paper mulch "keeps soil consistently cooler than plastic mulch."[150] While cooler-season crops do not experience temperature-related problems with plastic mulch, warm-weather crops may experience difficulty since they "require higher soil and air temperatures" to grow well and do very poorly in cooler temperatures.[151] In fact, a two-year study in 2006 determined that paper

[146] Viktorija Zenkova, *Is Paper Biodegradable And Is It As Eco Friendly As People Claim?*, ECOFRIENDLY PRINTER (Sept. 8, 2020), https://ecofriendlyprinter.eco/blog/2020/9/8/is-paper-biodegradable-and-is-it-as-eco-friendly-as-people-claim.

[147] Hoidal, *supra* note 20.

[148] *Id.*

[149] *Id.*

[150] *Id.*

[151] Cool-season crops are crops that need cool temperatures in order "to germinate, grow, set fruit, and mature." Lehigh County Master Gardeners, *Cool-season vs. Warm-season Vegetables*, PENNSTATE EXTENSION, https://extension.psu.edu/cool-season-vs-warm-season-vegetables (last updated Apr. 26, 2017).

mulch (compared to conventional plastic mulch) did not significantly impact yields of cooler-season crops but more greatly impacted warmer-season crop yields.[152]

In conclusion, while paper mulch offers a potentially viable alternative for cool-season crops, it fails to serve as a proper alternative mulch for warm-season crops.[153]

C. STRAW

"Straw is one of the most universally-used organic mulches" because "[i]t achieves many of the same benefits as plastic mulch: weed suppression, reducing fertilizer leaching, and moisture retention."[154] It can also help with "splash-dispersed pathogens,"[155] Alternaria leaf spot (ALS) on vegetables such as cabbage and kale,[156] and some pest control "for some pests including onion thrips and potato beetles."[157]

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[152] *See* Carol Miles, Erin Klingler, Liz Nelson, Tracy Smith, & Cheri Cross, *Alternatives to Plastic Mulch in Vegetable Production Systems*, WASH. STATE UNIV. 4 (July 2007), https://www.researchgate.net/publication/296111767_Alternatives_to_Plastic_Mulch_in_Vegetable_Production_Systems.

[153] *See id.*

[154] Hoidal, *supra* note 20.

[155] Splash-dispersed pathogens are plant pathogens (such as bacteria, viruses, or fungi) that are spread by water (and other liquid) splashes, such as rain. *See* Am. Physical Soc'y's Div. Fluid Dynamics, *Raindrops Splash Pathogens onto Crops*, SCIENCEDAILY (Nov. 20, 2017), https://www.sciencedaily.com/releases/2017/11/171120090041.htm.

[156] ALS is a fungal disease "of growing concern" to some "cabbage growers because of decreasing efficacy of chemical fungicides to control the disease." Susan B. Scheufele, Helene R. Dillard, & Joi-Anne Strauss, *Can Alternaria Leaf Spot Be Managed Organically?*, CORNELL UNIV. 1, http://www.hort.cornell.edu/expo/proceedings/2013/Cole%20Crops/Cole%20Crops%20Scheufele%20Alternaria.pdf (last visited Apr. 1, 2021).

[157] Hoidal, *supra* note 20. *See also* Laurent Penet, Sébastien Guyader, Dalila Pétro, Michèle Salles, & François Bussière, *Direct Splash Dispersal Prevails over Indirect and Subsequent Spread During Rains in Colletotrichum Gloeosporioides Infecting Yams*, NAT'L LIBR. MED. (Dec. 22, 2014), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4274098/.

However, straw has similar drawbacks to paper mulch for warm-weather crops since straw, like paper, does not keep the soil warm.[158] In addition, straw-mulched fields can cause additional problems to squash and pumpkins if a fall frost occurs; straw-mulched plots tend to cause further damage to both crops compared to when planted in bare soil.[159] Lastly, unlike paper mulch, lower-quality straw may contain weeds, which would defeat one of the main purposes of mulching.[160]

In summary, straw, like paper, works as an alternative mulch for cool-season crops but not for warm-season crops.[161]

D. STRIP TILLING

"[S]trip tilling, or direct planting into a field of rolled winter rye," is an alternative where "[r]ather than importing straw and spreading it," growers "essentially creat[e] straw in place with a cover crop" such as winter rye.[162] After farmers grow the cover crop, they roll and crimp[163] the cover crop and then directly plant their actual crops into the field of rolled rye.[164]

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[158] Hoidal, *supra* note 20.

[159] *Id.*

[160] *Id.*

[161] *Id.*

[162] *Id.*

[163] Rolling and crimping requires a roller/crimper tool that can flatten out actively growing crops. Dennis O'Brien, *Beginner's Guide to Rolling Down Cover Crops*, FARMPROGRESS (Nov. 30, 2015), https://www.farmprogress.com/management/beginner-s-guide-rolling-down-cover-crops. Most crimping tools "involve some type of rolling, paddle-wheel-like cylinder that attaches to a tractor and barrels over a field, tamping down and crimping the cover crop into a smooth mat to kill it." *Id.* After 3 weeks, a grower "can plant seeds directly into the ground without significantly disturbing the biomass mat" by planting parallel to the roller's path. *Id.*

[164] Hoidal, *supra* note 20.

Just like straw, the soil "does not get as warm as soil covered in plastic," making this a less-than-ideal alternative for warm-season crops.[165] Additionally, strip tilling presents another problem because the rolling and crimping does not always successfully kill the cover crop.[166] Growers have found solutions to this, fortunately: some growers "first terminate their cover crop with an herbicide,"[167] which is efficient but not the most environmentally friendly solution.[168] Others either choose to mow the winter rye right before planting (ideal for crops with larger seeds) or till only the strips they will plant in while leaving the rest of the field untilled (ideal for crops with smaller seeds).[169]

In conclusion, this can serve as a similar, and potentially more environmentally conscious, method to straw mulching if growers successfully terminate the cover crop in an eco-friendly manner.[170]

E. DEEP COMPOST MULCH

"Deep compost mulching is simply the practice of adding a thick layer [of] weed-free compost on top of [the] soil," which prevents weeds by burying their seeds.[171] While this is a very eco-friendly method—it prevents weeds while simultaneously organically fertilizing crops—it can get prohibitively expensive to use if growers cannot produce enough compost on

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[165] *Id.*

[166] *Id.*

[167] *Id.*

[168] *See supra* Part III Section A.

[169] Hoidal, *supra* note 20.

[170] *Id.*

[171] *Id.*

their own and do not have any connections to "institutions who compost large quantities of food-waste."[172] In addition, this method may lead to over-fertilizing crops, especially if the compost is too high in phosphorous.[173]

F. WOODCHIPS

Woodchips serve as a great biodegradable mulch that enriches the soil by contributing organic matter.[174] "Over time, woodchips can add a substantial amount of organic matter and are excellent for absorbing and retaining moisture."[175] In addition, woodchips are also cost friendly, since "[m]any growers are able to obtain woodchips for free by working with local arborists."[176]

However, woodchips are ideal only in certain situations: "[T]hey should only be used in rows" and "are best suited to systems with fairly wide bed spacing to avoid ending up with woodchips under [the plant] beds."[177]

G. COVER CROPS BETWEEN ROWS

Some growers choose to plant cover crops as "[l]iving [m]ulches" in between rows of their main crops in lieu of plastic landscape fabric between rows.[178]

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[172] *Id.*

[173] *Id.*

[174] *Id.*

[175] *Id.*

[176] *Id.*

[177] *Id.*

[178] *Id.*

H. COVER CROPS WITHIN ROWS

Similar to planting cover crops in between rows, some growers choose to plant cover crops within the rows of their main crops.[179]

While this method has not yet been firmly established and works best for "upright crops with a fairly slim canopy such as peppers or staked tomatoes," this method works great in terms of sustainability and weed control when everything goes as planned.[180]

In conclusion, while there are many alternatives to plastic mulching currently available, the one most analogous to plastic mulch (biodegradable mulch) may have similar, if not worse, drawbacks[181] and others can only be used only for specific situations[182] or require further research and development to use on a commercial scale.[183]

V. POTENTIAL SOLUTIONS

Despite the multiple problems plastic mulch causes, no legislation in the United States exists to restrict its use.[184] In fact, the United States Department of Agriculture (USDA) currently seems to encourage its use by allowing growers using single-use conventional plastic mulch to classify their crops as organic.[185] However, other legislation enacted to ban or deter use of

[179] *Id.*

[180] *Id.*

[181] *See supra* Part IV Section A.

[182] *See supra* Part IV Sections B–D, F.

[183] *See supra* Part IV Sections E, G–H.

[184] *See Allowed Mulches on Organic Farms and the Future of Biodegradable Mulch*, *supra* note 11.

[185] *See id.*

various substances may serve as a framework for how the USDA may choose to deter or ban the use of plastic mulch.

A. MICROBEAD-FREE WATERS ACT OF 2015

Many skincare enthusiasts enjoy exfoliating, which "is the process of removing dead skin cells from the surface of your skin using a chemical, granular substance, or exfoliation tool."[186] One popular method of exfoliation[187] utilizes cleansing scrubs that contains plastic microbeads.[188]

However, "[o]n December 18, 2015, Congress amended the Federal Food, Drug and Cosmetic Act (FD&C Act) by passing the Microbead-Free Waters Act of 2015."[189] Unlike a majority of the eleven ingredients the Food and Drug Administration (FDA) prohibits or restricts by regulation,[190] microbeads were not banned due to human health concerns.[191] Congress passed the Microbead-Free Waters Act of 2015 (Microbead-Free Act), which "prohibits the

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[186] *What Does It Mean to Exfoliate? Why You Should and How to Start,* HEALTHLINE (Sept. 26, 2018), https://www.healthline.com/health/beauty-skin-care/meaning-of-exfoliating.

[187] *Id.*

[188] *The Microbead-Free Waters Act: FAQs,* FOOD & DRUG ADMIN. (Aug. 24, 2020), https://www.fda.gov/cosmetics/cosmetics-laws-regulations/microbead-free-waters-act-faqs. The Food and Drug Administration defines '"plastic microbead[s]' as any solid plastic particle that is [] 5 millimeters or less in size, and [i]ntended to be used to exfoliate or cleanse the body or any part of the body." *Id.*

[189] *Id.*

[190] *Prohibited & Restricted Ingredients in Cosmetics*, FOOD & DRUG ADMIN. (Aug. 24, 2020), https://www.fda.gov/cosmetics/cosmetics-laws-regulations/prohibited-restricted-ingredients-cosmetics. Of the eleven explicitly specified ingredients, nine of the ingredients are banned due to health concerns. *Id.* One of the ingredients—sunscreens in cosmetics—is banned because it overlaps with drug regulation. *Id. See also* Howard Thomas, *Some Non-Essential Aerosol Propellant Uses Finally Banned*, 19 NAT. RES. J. 217, 217–18 (1979). Chlorofluorocarbon (CFC) propellants are banned due to environmental concerns. *Id.*

[191] *The Microbead-Free Waters Act: FAQs*, *supra* note 188.

manufacturing, packaging, and distribution of rinse-off cosmetics containing plastic microbeads . . . to address concerns about microbeads in the water supply."[192] This also shows that Congress is already aware and concerned about the microplastics accumulating in the environment.[193]

For this particular scenario, Congress chose to regulate its concerns—microbeads polluting the water supply—by providing deadlines for when the law will start being enforced.[194] Essentially, the Microbead-Free Act gave cosmetic and drug firms a few years "to make any needed changes in formulations to eliminate plastic microbeads, and to give distributors and retailers time to sell their inventory of products containing plastic microbeads before the new law takes effect."[195] However, Congress likely passed this bill in part due to mounting concerns and pressures from various states: Illinois passed legislation in June 2014 banning the use of microbeads,[196] California passed legislation in 2015 to do so as well,[197] and at least fifteen states —including large states such as New York[198] and Texas[199]—had introduced legislation to ban microbeads.[200]

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[192] *Id.*
[193] *Id.*

[194] *Id.*

[195] *Id.*

[196] S.B. 2727, 98th Gen. Assemb. (Ill. 2014). *See also* 415 ILL. COMP. STAT. 5/52.5 (2015).

[197] Assemb. B. 888, Reg. Sess. (Cal. 2015). *See also* CAL. PUB. RES. CODE § 42360 (West 2019).

[198] Assemb. B. 4924, Reg. Sess. (N.Y. 2015); Assemb. B. 5896, Reg. Sess. (N.Y. 2015); S.B. 3932, Reg. Sess. (N.Y. 2015); S.B. 4403, Reg. Sess. (N.Y. 2015).

[199] H.B. 1501, 84th Leg., Reg. Sess. (Tex. 2015).

[200] *Microbeads*, NAT'L CAUCUS OF ENV'T LEGISLATORS (Nov. 26, 2016), https://www.ncel.net/microbeads/.

In summary, many states decided to introduce or pass legislation to ban plastic microbeads,[201] so Congress chose to make such regulation consistent nationwide by banning microbeads federally and giving affected parties time to adjust and comply.[202] This state-by-state prohibition, culminating into a nationwide ban, may serve as a potential framework to ban plastic mulch use.

B. PHASEOUT OF OZONE DEPLETING SUBSTANCES

The only ingredient the FDA has banned in cosmetics for environmental reasons is chlorofluorocarbons (CFCs).[203] However, unlike the Microbead-Free Act, the ban on CFCs was a coordinated effort by the FDA, Environmental Protection Agency (EPA), and Consumer Product Safety Commission (CPSC)—back in the 1970s and 1980s[204]—to comply with the Montreal Protocol[205] phaseout requirements. The Montreal Protocol requires not just a CFC ban but a phaseout of all hydrochlorofluorocarbons (HCFCs) by 2030.[206] Initially, the three agencies proposed a "three-step timetable for eliminating chlorofluorocarbons as propellants," where,

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[201] *Id.*

[202] *The Microbead-Free Waters Act: FAQs*, *supra* note 188.

[203] Thomas, *supra* note 190, at 217–18.

[204] *CPSC/FDA/EPA Announce Phase Out of Chlorofluorocarbons*, U.S. CONSUMER PROD. SAFETY COMM'N (May 11, 1977), https://cpsc.gov/zhT-CN/node/21136.

[205] *About Montreal Protocol*, U.N. ENV'T PROGRAMME, https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol (last visited Apr. 1, 2021). The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) is a "landmark multilateral environmental agreement that regulates the production and consumption of nearly 100 man-made chemicals referred to as ozone depleting substances (ODS)." *Id.* It is "the only UN treaty ever that has been ratified [by] every country on Earth - all 198 UN Member States." *Id.* Compliance with the Montreal Protocol reversed the depletion of the ozone layer, which is now "projected to recover by the middle of this century." *Id.* It "is considered to be one of the most successful environmental agreements of all time" due to the unprecedented level of cooperation among the United Nations' members. *Id.*

[206] *Id.*

similar to the Microbead-Free Act almost four decades after, the agencies would give time for the affected parties to eliminate CFCs in their products and find alternative solutions for their products.[207] The FDA chose to enact their part of the phaseout by simply banning the use of CFCs in cosmetic and drug products by 1996, with the exception of some "essential medical devices" such as inhalers.[208]

In comparison, the EPA chose to enact their portion of the phaseout in two main phases: the first portion phased out Class I[209] ozone depleting substances (ODS) in 1996.[210] The second portion aimed to comply with the Montreal Protocol by phasing out at least 99.5 percent of HFCFs by 2020, "culminating in a complete HCFC phaseout in 2030."[211] Essentially, the EPA chose to ban the "worst" of the ODS first and allowed for more leeway for the Class II substances with a lower ozone depletion potential.[212]

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[207] *CPSC/FDA/EPA Announce Phase Out of Chlorofluorocarbons*, *supra* note 204.

[208] Tamar Nordenberg, *CFC-Free Medication for an Ailing Ozone Layer*, FOOD & DRUG ADMIN. (Dec. 7, 2015), https://www.fda.gov/drugs/resources-you-drugs/cfc-free-medication-ailing-ozone-layer. *See also Transition from CFC Propelled Albuterol Inhalers to HFA Propelled Albuterol Inhalers: Questions and Answers*, FOOD & DRUG ADMIN. (Feb. 28, 2018), https://www.fda.gov/drugs/questions-answers/transition-cfc-propelled-albuterol-inhalers-hfa-propelled-albuterol-inhalers-questions-and-answers. The FDA later chose to phase out CFCs in inhalers as well. *Id.*

[209] "Class I substances are primarily chlorofluorocarbons (CFCs)," and were phased out before Class II substances because the Class I substances "have a higher ozone depletion potential." *What Is the Phaseout of Ozone-Depleting Substances?*, ENV'T PROT. AGENCY, https://www.epa.gov/ods-phaseout/what-phaseout-ozone-depleting-substances (last updated Oct. 14, 2020).

[210] *Phaseout of Class I Ozone-Depleting Substances*, ENV'T PROT. AGENCY, https://www.epa.gov/ods-phaseout/phaseout-class-i-ozone-depleting-substances (last updated Oct. 14, 2020).

[211] *Phaseout of Class II Ozone-Depleting Substances*, ENV'T PROT. AGENCY, https://www.epa.gov/ods-phaseout/phaseout-class-ii-ozone-depleting-substances (last visited Apr. 1, 2021).

[212] *Phaseout of Ozone-Depleting Substances (ODS)*, ENV'T PROT. AGENCY, https://www.epa.gov/ods-phaseout (last updated Mar. 8, 2021).

Multiple agencies, and all 198 members of the United Nations,[213] decided to ban the use of ODS such as CFCs and HCFCs because the ozone layer depletion was a very serious and urgent environmental concern:[214] the widespread use of ODS prior to the Montreal protocol was reducing "the ozone shield, a gaseous belt extending 10 to 30 miles above the Earth that filters out harmful ultraviolet radiation from the sun."[215]

The United States quickly and significantly reduced its CFC emissions by using a few agency proposals.[216] Similarly to the microbeads ban, the United States banned CFCs on the federal level solely due to major environmental concerns by giving affected parties a deadline and time to adjust.[217] However, unlike the microbeads ban, CFCs were also banned on a worldwide level due to U.N. initiatives.[218]

C. PLASTIC BAG BAN IN CALIFORNIA

On September 30, 2014, California passed a law regarding single-use carry out bags.[219] The bill mandated that starting July 1, 2015, "stores that have a specified amount of sales in

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[213] *About Montreal Protocol*, *supra* note 205.

[214] A depleted ozone layer leads to increased chances of skin cancer; changes to "physiological and developmental processes of plants;" impaired production of marine creatures such as phytoplankton, fish, shrimp, crab, amphibians, and other marine animal, which impacts the whole marine food chain; and potential amplification of the negative effects of greenhouse gases. *Health and Environmental Effects of Ozone Layer Depletion*, ENV'T PROT. AGENCY, https://www.epa.gov/ozone-layer-protection/health-and-environmental-effects-ozone-layer-depletion (last updated Sept. 24, 2018).

[215] *CPSC/FDA/EPA Announce Phase Out of Chlorofluorocarbons*, *supra* note 204. *See also About Montreal Protocol*, supra note 205.

[216] *Phaseout of Class I Ozone-Depleting Substances*, *supra* note 210.

[217] *See CPSC/FDA/EPA Announce Phase Out of Chlorofluorocarbons*, *supra* note 204; *About Montreal Protocol*, *supra* note 205.

[218] *Compare supra* Part V Section A *with supra* Part V Section B.

[219] S.B. 270, 2013-2014 Reg. Sess. (Cal. 2014); Cal. Pub. Res. Code § 42280 (West 2016).

dollars or retail floor space" would be prohibited "from providing a single-use carryout bag to a customer, with specified exceptions."[220] This bill was ratified by California voters in 2016, when they approved Proposition 67 on the November 8, 2016 ballot.[221] The measure was passed to decrease the use of single-use plastic bags by banning them at many retail locations and requiring "stores to charge 10 cents for recycled, compostable, and reusable grocery bags."[222] The 10 cent revenue "was intended to cover the cost of non-plastic bags" by providing "$2 million to state plastic bag manufacturers for the purpose of helping them retain jobs and transition to making thicker, multi-use, recycled plastic bags," and using the remaining revenue to educate consumers.[223]

Essentially, similar to the microbeads ban and the CFC bans, California (along with other states that have banned single-use plastic bags)[224] set a deadline to ban the bags and provided some time for parties to adjust. However, what distinguishes California's single-use plastic bag prohibition from the former two prohibitions is that 1) it didn't fully ban the use of single-use plastic bags; it limited the prohibition to retailers of a certain size or revenue,[225] 2) it subsidized state plastic bag manufacturers so that it would be easier for them to transition from

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[220] *Id.*

[221] *California Proposition 67, Plastic Bag Ban Veto Referendum (2016)*, BALLOTPEDIA, https://ballotpedia.org/California_Proposition_67,_Plastic_Bag_Ban_Veto_Referendum_(2016) (last visited Apr. 1, 2021).

[222] *Id.*

[223] *Id.*

[224] Connecticut, Delaware, Hawaii, Maine, New York, Oregon and Vermont have also banned single-use plastic bags. *State Plastic Bag Legislation*, NAT'L CONF. OF ST. LEGISLATURES, https://www.ncsl.org/research/environment-and-natural-resources/plastic-bag-legislation.aspx (last updated Feb. 8, 2021).

[225] S.B. 270, 2013-2014 Reg. Sess. (Cal. 2014).

manufacturing single-use bags to "thicker, multi-use, recycled plastic bags," and 3) it incentivized people to reuse the bags (or other reusable bags) by charging them a 10-cent fee per bag.[226]

D. DISINCENTIVIZING TOBACCO USE THROUGH INCREASED TAXATION

"In the United States, tobacco is taxed by federal, state, and local governments."[227] The governments tax tobacco products in two ways: (1) with "the unit tax, which is based on a constant nominal rate per unit (that is, per pack of cigarettes)" and with (2) "the ad valorem tax, which is based on a constant fraction of either wholesale or retail price."[228] While the governments initially started taxing tobacco products to generate revenues, they have also started to use the taxes "as an effective strategy to discourage tobacco use and enhance public health" because research shows that "[t]he consumption of tobacco products is strongly related to their affordability."[229]

E. NATIONAL VACCINE INJURY COMPENSATION PROGRAM

The United States created the National Vaccine Injury Compensation Program (VICP) in the 1980s as a no-fault method to resolve vaccine injury petitions.[230] While most people who receive vaccines do not experience serious side effects, "[i]n very rare cases, a vaccine can cause

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[226] *California Proposition 67, Plastic Bag Ban Veto Referendum (2016)*, *supra* note 221.

[227] INSTITUTE OF MEDICINE, GROWING UP TOBACCO FREE: PREVENTING NICOTINE ADDICTION IN CHILDREN AND YOUTHS, 177 (Barbara S. Lynch & Richard J. Bonnie eds., 1994), https://www.ncbi.nlm.nih.gov/books/NBK236771/.

[228] *Id.*

[229] *Id.* at 177, 192.

[230] *National Vaccine Injury Compensation Program*, HEALTH RES. & SERV.'S ADMIN., https://www.hrsa.gov/vaccine-compensation/index.html (last visited Apr. 1, 2021).

a serious problem, such as a severe allergic reaction."[231] Previously, these cases led to "lawsuits against vaccine companies[,] and health care providers threatened to cause vaccine shortages and reduce U.S. vaccination rates, which could have caused a resurgence of vaccine preventable diseases."[232] Now, instead of always holding vaccine companies liable, the VICP, instead, "may provide financial compensation to individuals who file a petition and are found to have been injured by a VICP-covered vaccine."[233] Generally, claimants must first file their claim and have it processed "with the VICP before a civil lawsuit can be filed against the vaccine company or the person who gave [them] the vaccine."[234]

F. POSSIBLE SOLUTIONS

There are various ways that the plastic mulch problem can be addressed, with most of the approaches not being mutually exclusive. First, like the Microbead-Free Act and the CFC bans, the USDA could enact a complete ban of conventional plastic mulch, which includes a deadline that accounts for the time needed for affected parties to adjust.[235] Or alternatively, the UDSA could ban the use of plastic mulch state by state, like the plastic bag ban several states have enacted, based on the state's agricultural needs.[236] Second, the government could encourage and subsidize the transition from plastic mulch to other alternatives like they did for plastic bags

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[231] *Id.*

[232] *Id.*

[233] *Id.*

[234] *What You Need to Know About the National Vaccine Injury Compensation Program (VICP)*, HEALTH RES. & SERV.'S ADMIN. (May 2017), https://www.hrsa.gov/sites/default/files/vaccinecompensation/resources/vicpbooklet.pdf.

[235] *See supra* Part V Sections A–B.

[236] *See State Plastic Bag Legislation*, *supra* note 224.

instead of enacting complete ban while disincentivizing plastic mulch use by charging growers a tax for the use of plastic mulch, like it did for tobacco products.[237] Lastly, like the National Vaccine Injury Compensation Program, a program can be instituted so consumers can pursue compensation for health issues that arise.[238]

1. COMPLETE BAN BY USDA

Following the example set through the Microbead-Free Act, CFC bans, and plastic bag bans, the USDA could enact a complete ban of conventional plastic mulch by setting a hard deadline while leaving enough time for affected parties to adjust.[239] The USDA has two options to carry out the ban. First, the USDA could ban plastic mulch state-by-state by either banning it through shorter deadlines in states not as dependent on it or staggering the ban similar to the EPA's two-part ODS phaseout plan—where the worst offenders were phased out first.[240] Second, the USDA could simply enact a nationwide ban and require parties to comply by a certain date. In preparation for an outright ban, the USDA could take plastic mulch off the list of allowed mulches on organic farms.[241]

Removing plastic mulch from the allowed mulches list is appealing because it would quickly solve many issues; if growers can no longer use plastic mulch, then they do not have to worry about its disposal. Additionally, removing plastic mulch from the allowed mulches list

[237] *See* INSTITUTE OF MEDICINE, *supra* note 227.

[238] *See supra* Part V Section E.

[239] *See supra* Part V Sections A–C.

[240] *See supra* text accompanying note 209.

[241] *See Allowed Mulches on Organic Farms and the Future of Biodegradable*, *supra* note 11.

would mean reduced burden to landfills, decreased pollution from improper disposal methods (i.e. burning or burying), and less plastic consumption and terrestrial microplastics.[242]

However, it may be difficult to enact a complete plastic mulch ban because current alternatives are inferior.[243] Although cool-season crops have viable alternatives such as straw mulching,[244] rolled crop mulching,[245] and wood chip mulching,[246] warm-season crops do not have any safe, comparable alternatives without further research;[247] plastic mulch remains superior because it can warm soil and increase crop yields.[248] Another glaring problem could arise if the USDA's compliance deadline is too close; growers might not be prepared to adjust to the new requirements, especially without a good alternative available.[249]

Regardless, as microplastics continue to accumulate in the environment at an alarming pace, a USDA ban may look more and more attractive.

2. SUBSIDIZE TRANSITION OF PLASTIC MULCH TO ALTERNATIVE SOLUTIONS

Another possible solution to the plastic mulch problem may be to subsidize alternative options and biodegradable plastic mulch research.[250] Just as the California legislature subsidized

[242] *See supra* Part III Section B.

[243] *See supra* Part IV.

[244] *See supra* Part IV Section C.

[245] *See supra* Part IV Section D.

[246] *See supra* Part IV Section F.

[247] *See supra* Part IV Sections A, E, G–H.

[248] *See Allowed Mulches on Organic Farms and the Future of Biodegradable*, *supra* note 11.

[249] *See supra* Part IV.

[250] *See supra* Part IV; Part V Section C.

multi-use, recyclable plastic bags, the USDA could also subsidize the transition to alternative mulches by charging growers a fee for using plastic mulch and use that money to subsize both growers who use alternatives and mulch alternatives research.[251]

One significant benefit to fees is that they deter use.[252] In addition, unlike tobacco users, growers are not addicted to plastic mulch; rather, they use it simply because it is cost-efficient and useful.[253] This means that plastic mulch use can more easily be controlled through price points; if it is more expensive for growers to use plastic mulch (not just because of initial cost but also because of reduction in total profits), then they will likely choose to switch from plastic mulch to less expensive alternative solutions.[254]

However, a potential drawback is that, depending on their situations, increasing costs may mean growers are unfairly penalized for plastic mulch use; if the "tax" on plastic mulch use and the price of the "subsidy" for alternate solutions is not balanced correctly, it could damage essential U.S. markets by backing growers into an untenable situation where continuing to use plastic mulch is not a feasible solution but switching over to an alternative solution is not cost-

[251] *See supra* Part V Section C.

[252] *See supra* Part V Section D.

[253] *See Allowed Mulches on Organic Farms and the Future of Biodegradable*, *supra* note 11.

[254] *See supra* Part V Section D.

effective.[255] However, if cost is the primary issue, the USDA can subsidize the transition while growers phase out plastic mulch use.[256]

3. REACTIONARY, NOT PREVENTATIVE, MEASURES

Like the National Vaccine Injury Compensation Program, one option is to wait and watch the full effects of microplastics on the human body.[257] Although microplastics may cause health concerns, it is also possible that either microplastics will have no observable effect on the population or will noticeably affect only a portion of the population.[258]

However, similar to how the Vaccine Injury Compensation Program operates, individuals should be able to file claims with an administrative agency for this solution to be successful.[259] This is especially necessary because, unlike vaccines, microplastics do not have an obvious source, so it is not clear who claimants should sue for compensation.[260]

However, a glaring problem with this solution is that even if only a small portion of the population is noticeably affected by microplastic pollution, microplastics will still have

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[255] *See* Velandia et al., *supra* note 58, at 2 ("In general, BDM (biodegradable mulches) cost more than PE (conventional) mulches."); *supra* Part IV Sections B–H; Robert A. Hoppe, *Profit Margin Increases with Farm Size*, U.S. DEP'T OF AGRIC. (Feb. 2, 2015), https://www.ers.usda.gov/amber-waves/2015/januaryfebruary/profit-margin-increases-with-farm-size/ ("Most U.S. farms are not profitable as ongoing businesses.").

[256] This would not be unprecedented action by USDA; in 2019, USDA sent farmers payment to compensate them for losses due to the trade war in China. Dan Charles, *Farmers Got Billions from Taxpayers in 2019, and Hardly Anyone Objected*, NPR (Dec. 31, 2019), https://www.npr.org/sections/thesalt/2019/12/31/790261705/farmers-got-billions-from-taxpayers-in-2019-and-hardly-anyone-objected.

[257] *See supra* Part V Section E.

[258] *See* Campanale et al., *supra* note 9; Bush, *supra* note 9.

[259] *See supra* Part V Section E.

[260] *See* Bush, *supra* note 9.

enormous and increasing environmental and health impacts.[261] Ignoring the microplastic problem will not make it go away, and without swift measures it may become an unsolvable dilemma.[262]

4. COMBINED APPROACH

While these approaches may not all individually be successful, a solution combining parts of each approach could be the most effective at eliminating the plastic mulch problem.[263]

First, the USDA should gather information about the market impact of a hard deadline ban on plastic mulch, since it is unclear how well growers will be able to adjust.[264] While researching for better alternatives, the USDA should emulate the tobacco tax and single-use plastic bag laws by taxing the use of plastic mulch, by amount used, and use the tax revenue to fund research and subsidize growers that choose to move away from plastic mulch.[265] This initial tax can start low, but as more growers transition, the USDA can slowly raise the tax to encourage more growers in opting out plastic mulch use due to the increasing costs.[266]

Next, once enough growers have chosen to stop using plastic mulch, the USDA can set a deadline for a plastic mulch ban, similar to the government banned microbeads and CFCs.[267]

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[261] *See supra* Part III Section C.

[262] *See* Wearden, *supra* note 129; Nizzetto et al., *supra* note 88; Dzombak, *supra* note 127.

[263] *See supra* Part V Section F Subsections 1–3.

[264] *See* Margarita Velandia, Karen L. DeLong, Annette Wszelaki, Susan Schexnayder, Christopher Clark, & Kimberly Jensen, Use of Polyethylene and Plastic Biodegradable Mulches Among Tennessee Fruit and Vegetable Growers, HORTTECHNOLOGY (Apr. 2020), https://journals.ashs.org/horttech/view/journals/horttech/30/2/article-p212.xml ("It is estimated that in vegetable production alone, U.S. farmers are using about 143,300 tons of PE mulch per year.").

[265] *See supra* Part V Sections C–D.

[266] *See supra* Part V Section D.

[267] *See supra* Part V Sections A–B.

This eventual ban will reduce the number of people severely affected by the microplastic dilemma.[268] Although this may not be a perfect solution, in the same way the United States had to tackle the ozone layer depletion problem in multiple phases,[269] banning plastic mulch can be a step forward in tackling part of the microplastics problem.[270]

[268] *See supra* Parts I, III Section C, IV.

[269] *See Phaseout of Ozone-Depleting Substances (ODS)*, *supra* note 212.

[270] *See supra* Parts I, III Section C, IV.