And While We Wait:
Perspectives on Chlorpyrifos Toxicity and Use in California Agriculture

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ABSTRACT

Reliance on Chlorpyrifos, an organophosphate pesticide, has diminished in recent years. However, new data sets are demonstrating that it is still used prolifically throughout California despite increased tolerance in pest populations to Chlorpyrifos. Chlorpyrifos is a neurotoxicant and can have long-lasting adverse neurodevelopmental effects, especially for children exposed to the pesticide during key developmental periods. The Environmental Protection Agency (EPA) banned Chlorpyrifos from home use in 2001, but has yet to come to a decision about Chlorpyrifos use in agriculture. In this paper, I synthesize the most recently published peer-reviewed literature on Chlorpyrifos toxicity, analyzing which risk factors the EPA is taking into consideration. I also present thematic findings from interviews with five key informants to present strategies that different individuals and organizations are employing while the EPA debates prohibiting Chlorpyrifos from agricultural use.

KEYWORDS

Pesticide regulation, revoked tolerances, child development, buffer zones, organic

INTRODUCTION

Although the U.S. Environmental Protection Agency (U.S. EPA) banned Chlorpyrifos (CPF), a widely used organophosphate pesticide, from household use fifteen years ago, it is still frequently used nationwide as an agricultural application to enhance crop yields (U.S. EPA 2014). CPF is primarily used on almond, citrus, cotton, and alfalfa crops in California (UCIPM 2014). California accounted for 90 percent of global almonds production in 2014, and many growers are switching from cotton production to almond production due to increasing national and global demand (UCIPM 2014; Pierson 2014). CPF was also designated a Restricted Material in California, effective July 2015 (California Department of Pesticide Regulation 2015). However, this is not the end goal for those advocating for a conclusive CPF ban in California and the greater United States **(**PANNA 2016). In January 2016, the U.S. Environmental Protection Agency proposed restricting all CPF use in agriculture. This would effectively be a nation-wide ban, but the wording of the EPA's potential legislation may be too focused on a limited number of CPF's multiple toxic modes of action, which may prevent the EPA from considering and minimalizing exposure risks facing people in agricultural communities (Eaten et al. 2008; U.S. EPA 2015). The proposed ruling references CPF's toxicity as dangerous when ingested from two specific pathways: food residues and water contamination (U.S. EPA 2015). However, certain groups of people are more frequently exposed to dangerous levels of the pesticide. In California, children living in agricultural areas are at heightened risk of consistently high exposure levels.

Restricting CPF from home use reflects the EPA's concern about its adverse health effects. Its resistance to degradation in soil and water contributes to continuing concern about the pesticide by community members, public health advocates, regulators and policy makers. CPF is a persistent pollutant, so even if it is prohibited from agricultural use in January, it will still exist in the environment – for a longer period of time in soil and water than in air (National Pesticide Information Center 2011). It also has the ability cross the placental barrier, facilitating mother to child transmission (Condette et al. 2015). Organophosphate pesticides have been proven to alter neurological

development, disrupt hormone processes, and are linked to increased incidence of reduced lung function (Lu et al. 2015; PANNA 2016). The varying modes of CPF exposure have therefore caused regulators, policy makers, researchers and community members to shift focus away from its acute effects and toward its long-term effects instead, especially when exposure occurs during critical periods of neurodevelopment.

Most studies, including the most recent EPA review (U.S. EPA 2014), have focused on CPF's inhibitive effect on acetylcholinesterase (AChE). AChE inhibition leads to accumulation of acetylcholine in brain synapses, which is toxic to the brain, disrupting neurological processes that are necessary for healthy functioning (U.S. EPA 2014). Although the EPA's proposed revoked tolerance ruling focuses on AChE inhibition, CPF metabolites inhibit more than one enzyme involved in neurotransmission (Eaton et al. 2008). A recent animal study also showed the potential for CPF to cross over to other systems in the body (Condette et al. 2015). Many peer-reviewed studies show the dangers of in-vitro and in-vivo exposure to CPF. Public awareness about CPF toxicity is on the rise, and the number of studies published on CPF has grown steadily since 2001 (NRDC 2016). Americans submitted over 80,000 comments advocating to ban CPF from agricultural use before the public comment period closed in December 2015 (EarthJustice 2016). This reaction happened even considering that studies on CPF published in the previous year were not included in the EPA's latest CPF review (U.S. EPA 2014). Discussing newly discovered toxic effects alongside popularly referenced effects could provide insight into the potential that CPF has to affect the neurological development of children in farming communities.

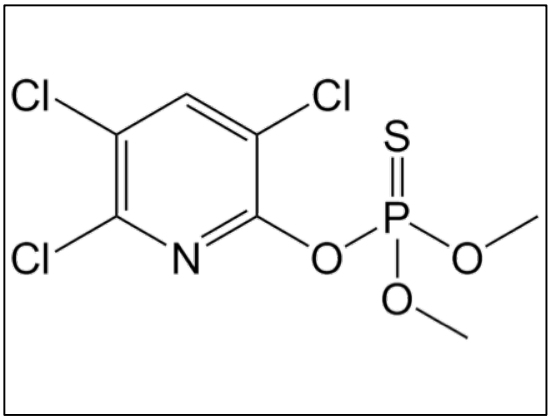
Furthermore, while specialists in pest management, toxicology, public health, and regulation have published blogs and contributed to government and agency documents about CPF, the opinions of these key informants have not yet been synthesized in a cross-discipline analysis. These two gaps in current research inform my central research question:. What strategies are people with roles in research organizations, pest management, and community education using given uncertainty about regulatory change, their understanding of existing and future policy options, and their understanding of the science behind CPF toxicity?

I begin this paper by synthesizing scientific information about the toxicology and health effects of CPF exposure in-vitro and during early childhood, focusing specifically on risks faced by children living in agricultural areas. I also present current regulatory strategies in California focusing on limiting CPF use in agriculture.

Background

Chlorpyifos Use and Toxicology

Integrated Pest Management emerged in the 1940s, when pesticide use was relatively unquestioned (Guedes et al. 2016). Since then, research on how pesticides can cause acute and chronic toxicity has risen drastically; research on CPF itself has risen steadily in the past 15 years (Singla 2016). However, pesticides are still used heavily on a global scale (Guedes et al. 2016). In California, some pest managers want to include CPF as an option on a case-by-case basis, boosting worker protection by incorporating more accountability into the current monitoring and worker education plan (UCIPM 2014). Pest managers in California also cite CPF's dwindling use statewide as an argument to limit regulation, citing research that shows that CPF is the only pest management option for certain pests in specific situations (UCIPM 2014).



However, toxicology researchers and public health professionals are concerned about CPF's biochemical toxicity and the long-term effects that exposure has on child development. CPF is classified as a chlorinated organophosphate insecticide that kills insects upon contact by affecting their nervous systems (National Pesticide Information Center 2011*)*. This mode of action also causes harmful neurological effects in humans (Aldridge et al. 2005; Rauh et al. 2006; Eaton et al. 2008; Shelton et al. 2014; Condette et al. 2015; Rauh et al. 2015). CPF inhibits the breakdown of the neurotransmitter acetylcholine (ACh), which leads to accumulation of ACh in brain synapses

Figure 1. Chlorpyrifos molecular structure. When oxygen replaces the sulfur atom (S) in the liver, the molecule inhibits acetylcholinesterase activity in the brain.

(U.S. EPA 2014). This toxic effect is toxic prohibits normal brain function. Chlorpyrifos' chemical structure includes a phosphorus-sulfur double bond (Figure 1). In the liver, the S in this S=P bond is replaced by oxygen. This desulfurated form – called the CPF oxon – can inhibit acetylcholinesterase (AChE), the enzyme that breaks down ACh, at 2-3 orders of magnitude greater than the CPF parent molecule, and can also interfere in-vitro (Iyer et al. 2008; Flaskos 2012).

Inhibition of AChE is the most recognizable and classified metabolic effect of CPF (Eaton et al. 2008). It is also the only mode of action mentioned in the EPA's most recent CPF Review (U.S. EPA 2014)**.** This mechanism is one of numerous ways that CPF affects body processes. In the brain, butylcholinesterase (BuChE), another enzyme, is more sensitive to inhibition by CPF than AChE (Eaton et al. 2008). AChE is used as a primary marker for CPF, but higher levels may be necessary to see effects in AChE inhibition even if lower levels could affect BuChE. Other enzymes can also have an effect on CPF metabolism, especially when considering mother-child transmission. In one study, a CPF exposure level that was slightly above the minimum detection level in a mother was correlated with lower levels of the enzyme paraoxonase.. Mothers with higher CPF exposure levels had babies with smaller head circumferences and lighter brain weights, which are predictors of cognitive ability (Timofeeva and Levin 2010). The metabolic altering effects of CPF in the mother can therefore be predictors of startling health effects in her child.

Adverse Health Effects on Child Development: Human Studies

In-vitro and Early childhood exposure to CPF can adversely effect neurodevelopment. In one study of prenatal exposures in an inner city population, higher quantities of umbilical cord concentrations of CPF were 5 times more likely to have delayed psychomotor development and 2.4 times more likely to have delayed mental development (Rauh et al. 2006). The children in that study were followed for 11 years, and those with higher umbilical cord CPF levels showed mild to moderate tremor in one or both arms when tested in middle school (Rauh et al. 2015). Early exposures had significant persistent neurological effects, since neurological processes were manifested by motor control.

Keeping in mind that this study referred to inner-city residents, and that children in agricultural areas are generally exposed to higher pesticide levels, it is possible that these numbers are conservative estimates for children in agricultural communities.

Close proximity to agricultural land where CPF is administered can also increase the risk of neurodevelopmental disorders. A study that traced mother residential locations during CPF applications found that there was a greater than 60 percent increased risk of autism spectrum disorders with second-trimester CPF applications. Per 100-lb increase of pesticide applied over the course of pregnancy, women living within 1.5 km of the application site were associated with a higher incidence of autism spectrum disorder and developmental delays, signifying endocrine disruption (Shelton et al. 2014).

The long-lasting effects of early CPF exposure are not limited to neurological development. A Chinese research team recently correlated in-utero CPF exposure to lesser viability and proliferation of fetal liver cells, and DNA damage in the fetal liver, suggesting CPF's contribution to the development of infant leukemia (Lu et al. 2015). Exposures later in the adolescent period may correlate with reduced lung function, similarly to how adult agricultural workers experience lung health problems (Callahan et al. 2014).

Adverse Health Effects on Child Development: Animal Studies

Recent animal studies have expanded on the demonstrated adverse health effects in humans. Animal studies provide a controlled environment to test CPF exposure effects via distinct exposure routes (Reif 2011). Animal toxicology studies show adverse effects on endocrine targets, including a link between in-utero CPF exposure and delay in psychomotor and cognitive maturation in mice (Venerosi et al. 2015). In guinea pigs, offspring with prenatal exposure to CPF had significantly decreased body weight and brain volume, and spatial learning deficits that corresponded with reduced brain matter (Mullins et al. 2015). Rats that were exposed to CPF via oral uptake had smaller body length and weight, smaller microbial intestinal imbalance, and increased bacterial invasion into the spleen and liver (Condette et al. 2015). These results suggest further

systemic impacts of CPF exposure, ones that could affect the digestive and detoxifying systems in the body.

Regulatory Strategies and Limitations: CPF Designated a Restricted Use Material

CPF was designated a Restricted Use Material in California in 2015 (California Department of Pesticide Regulation 2015). As such, CPF use is limited to trained individuals, and farmers that want to spray CPF on their fields need to first obtain a one year permit from their County Agricultural Commissioner. The Commissioner evaluates each application and determines "if it will cause substantial harm to people or the surrounding environment (DPR 2008)."

California is the only state that has a CPF permitting system (UCIPM 2014), which is indeed a better alternative to having none. However, the regulatory power of the Restricted Use Material listing is limited for three reasons:

1. The language of the Restricted Use designation does not place any restrictions on where or how a pesticide is used, meaning that CPF can be continually used close to schools and homes, further endangering children (Singla 2014).
2. If anyone living or working near the application site does not agree with the approval of a permit or, more importantly, how a pesticide is used, they have to go through a formal appeal process. To file an appeal, one must include the details about the application of the restricted material, including where the pesticide is to be used, its name, the name and address of the owner of the property, who or what would be affected by the application, and what actions the Commissioner should take next. Appeal are submitted to the Commissioner and reviewed within 10 days (DPR 2008), and the commissioner has the authority to authorize CPF use "if a delay would mean damage to a crop (DPR 2008)."
3. Other pesticides labeled as Restricted Use Materials in California have initially decreased in use statewide, but then increased again over time. The National Resource Defense Council calculated the use frequency of other organophosphate pesticides, finding for example that sulfuryl fluoride, an oranophosphate pesticide,

was restricted in 2005, but by 2012 its use was approaching 2005 levels (Singla 2016).

Regulatory Strategies and Limitations: Buffer Zones

The Restricted Use Material jurisdiction does not specify where and how CPF can be sprayed. Since CPF is sprayed through the air on alfalfa, cotton, citrus, and almonds, pesticide drift is a concern that directly relates to CPF use in California. Drift involves pesticides landing in a non-target area, and can happen when the application misses its target or evaporates after application, leaching into soil, water and air (CERCH 2012; PANNA n.d.). This can disrupt ecological processes, harming flora and fauna near farms where pesticides are sprayed (Syversen and Bechmann 2004). Buffer zones can filter out pesticides, especially sediment-bound pesticides (Ibid.; Reichenberger et al. 2007; Zhang et al. 2010).

Implementing buffer zones around schools and homes, where pesticide application and drift would not be allowed, is an alternative regulatory option (Singla 2016). Logistically, width of buffers contribute to their effectiveness in removing pesticides up to a certain width of 30 meters, beyond which increasing width becomes negligible (Zhang et al. 2010). Location also matters; buffer strips located at the edge of farm fields could be more effective in reducing risk of pesticide runoff and drift (Reichenberger et al. 2007). Microbial communities could also grow in soil to help decompose pesticides. It is possible to biodegrade CPF using microbial communities and/or biochar, a carbon-rich byproduct of plant and animal biomass (Ahmad et. al 2012; Ahmad et al. 2014).

METHODS

To access this information, I conducted a literature review of recently published peer-reviewed and grey literature. Published research and agency-sponsored documents presented reasoning that supported and questioned the necessity of a revoked tolerances

ruling for CPF. Alternatives to CPF and, more generally, pesticide use in agriculture are also published in the peer review literature. I explored this literature to ground my questions in research papers and policy documents that are publicly available. However, experience and opinions of key informants are frequently anecdotal. It is also possible that individuals hold views that they've gained from their personal experience, details of which are not necessarily published online. I chose to interview five people with professional experience in pest management, biological research, and community advocacy to gain insight into the intricacies behind the debate on CPF regulation.

To understand the historical use and regulation of CPF, I interviewed five people with insight into pesticide regulation and public health in California during March and April, 2016. I conducted two interviews in person, and completed three interviews by phone (Table 1). Interview subjects included the following:

1. Daniel Madrigal, MPH, California Department of Public Health
2. Dr. Veena Singla, Ph.D., National Resource Defense Council
3. Caroline Cox, MS, Center for Environmental Health
4. Dr. Peter Goodell, Ph.D., UC Statewide Integrative Pest Management Program
5. Joe Vasquez, Pest Manager, Farmer and the Dale Organic Farm

To identify each respondent's role and goals are while the EPA's decision remains in limbo, I chose to begin each interview by asking an open-ended question about each individual's experience. I researched each individual and designed distinct interview questions tailored to explore the reasoning behind each person's perspective. I tailored my questions to focus on the role each individual has in the regulatory system according to the position they hold, what goals they have for the immediate and long-term future for themselves, and what opportunities they see for collaboration across disciplines and ages.

These questions acted as a guide, focusing my attention on each person's background and expertise during interviews. I conducted interviews in a conversationalist style to create room for expansion on topics that each interviewee felt passionate and knowledgeable about. The differences in interviewees' experiences contributed to a variety of perspectives on the CPF debate and supported the idea that there is not necessarily one silver bullet solution. To further understand the distinct perspective of each interviewee, I looked for verbalizations of knowledge and uncertainty about

pesticide regulatory processes in California and the mechanism of the CPF oxon. To do so, I transcribed these interviews, then organized information garnered by theme. The secondary literature research I conducted initially informed my decisions on the thematic groupings. I finalized the themes by deciding which ideas, expressed by the five key informants, seemed most relevant and applicable to answering my central research question.

Table 1. Interview Respondent information.

Name of Interviewee	Work Experience	Date of Interview	Interview Method	Interview Length
Daniel Madrigal, M.S.	• Health Educator at the California Department of Public Health • Former director of the youth program for the CHAMACOS study in the Salinas Valley, CA	3/18/16	In person (Oakland, CA)	00:26:54
Dr. Veena Singla, Ph.D.	• Staff Scientist, Health & Environment, National Resource Defense Council • Former Senior Scientist at the Green Science Policy Institute	3/30/16	Phone	00:33:26
Caroline Cox, MS	• Research Director, Center for Environmental Health • Serves on Board of Directors of Beyond Pesticides • Former staff scientist at the Northwest Coalition for Alternatives to Pesticides	4/8/16	In person (Oakland, CA)	00:38:51
Dr. Peter Goodell, Ph.D.	• Cooperative Extension Advisor, Integrated Pest Management (IPM) with the UC Statewide IPM Program • Received Ph.D. in Entomology and Nematology from the University of California, Riverside in 1986	4/15/16	Phone	1:14:54
Joe Vasquez	• Pest Manager for organic farm • Worked as Pest Manager before, during, and after farm's transition from conventional to organic	4/20/16	Phone	00:28:12

RESULTS

Even though CPF is labeled a Restricted Use Material in California, new online tools are exposing the reality of its popularity as a pest-control method across the state. CPF regulation may come in the form of a national revoked tolerances ruling, but CPF could potentially be replaced with another neurotoxic pesticide. Key informants who conducted chemical toxicology research were most aware of this potential scenario. Pest managers were wary of cutting off CPF use in agriculture completely. Yet, regardless of whether or not CPF is banned, there are strategies – like implementing buffer zones – that could potentially appeal to those focusing on human health and crop production alike. However, there are gaps in research and a lack of knowledge dissemination that contribute to missed opportunities for collaboration across disciplines. The interviewees' contrasting and aligned positions were directly and/or indirectly connected to their individual experiences, which influenced their perspectives on CPF and pesticide use in general. Both pest managers seemed willing to shift their dependencies away from CPF if there was enough evidential proof of its toxicity. Herein lies an opportunity for collaboration between people who understand toxicology, people who communicate science well, and people who do not understand why pesticides like CPF are toxic. Clarifying the mechanism of CPF toxicity and its long-term effects could influence individual bias for or against pesticide use. Looking to history for guidance can also provide insight into grassroots strategies; since pesticides have been used prolifically since World War II, there are examples of successful legislation that curtailed pesticide use. Coupling historical evidence with the rise of organics insinuates the potential for the growth of agricultural system that can provide healthy food, without using pesticides that cause adverse health effects, in the United States.

Community-based education efforts have the potential to give agency to community members, exposing and explaining the intricacies of the California pesticide regulation process. It can also present opportunities to use new tools, like the Pesticide Mapping Tool, as data to back up arguments. This can return agency to agricultural community members advocating for stricter pesticide regulation in their neighborhoods.

Regardless of whether or not CPF is banned from agricultural use, these tools are still useful to communities; other pesticides will continue to be legally sprayed near homes and schools, potentially drifting through the air or leaching into water sources.

Education is also linked to transparency, a value that consumers are increasingly appreciating. Consumers are recognizing that consumption of pesticide residues is harmful to their health, and the health of their children, but they do not necessarily understand why. Communicating the science behind the toxicology of neurotoxic pesticides and providing the links between molecular toxicology and long-term neurological effects like low IQ and tremor can help consumers understand the severity of pesticide exposure. Biomonitoring studies have shown that eating organic foods drastically and rapidly lower the levels of pesticide metabolites in the body (Lu et al. 2006; Oates and Cohen 2011). If the results of these studies can be translated and made more public, consumers – who are able – may be more incentivized to buy produce that is grown organically. It also seems like a part of the tendency to buy conventionally grown fruits and vegetables comes from an aesthetic prejudice. Consumers have not been exposed to the reality of what food looks like when it is grown without pesticides. Understanding that some visual imperfections are natural and un-harmful could influence consumer preference.

There are historical anecdotes that can prove helpful in understanding the current politics around CPF regulation, and more generally pesticide dependencies, in California. The broad range of key informant opinions suggests that there are diverse ideas regarding feasible options for farmers, and alternatives to synthetic pesticides are rising in popularity across the United States. Interviewees who were deeply engaged in the CPF and pesticide debates questioned the feasibility of shifting the entire agricultural system of the U.S. to small-scale farms, especially in the short run. However, rising sales of organic foods show that consumers are paying attention to the organic label. It is possible that looking to methods that organic farmers are using could lead to further incorporation of alternative agriculture techniques on bigger farms.

Understanding of CPF Toxicity

Informants had varying levels of understanding about the biochemical mechanism of CPF toxicity. Singla and Cox, a cell biology researcher and research coordinator for the Center for Environmental Health, respectively, have scientific backgrounds grounded in molecular toxicity of chemicals like CPF. As an education coordinator for the CHAMACOS study, Madrigal experienced the adverse health effects of pesticide exposure on children in Salinas Valley agricultural communities. Madrigal could not explain the biochemical mechanism behind the toxicity of the CPF oxon, but he did state the link between CPF exposure and low IQ scores and low retention levels. By contrast, Goodell was skeptical of any causal relationship between CPF exposure and neurodevelopment effects. This divide reflects contrasting definitions of "sufficient" scientific proof. However, Goodell, who described himself as not advocating any particular side, emphasized that if CPF is indeed proven to be toxic, pest managers will not use it.

The pest managers that I interviewed seemed hesitant to accept existing published data on CPF. Vasquez emphasized that CPF is not used freel, saying that its use is preceded by testing and an attempt to incorporate as much organic pesticides as possible. He stated that precautionary measures are taken to assure that CPF is not sprayed directly on humans. However, according to toxicology studies, CPF is toxic even at low exposures. Goodell also stated that finding CPF residue in community drinking water sources would be unacceptable. Singla noted that there is little confusion about the mechanism and acute effects of CPF among the scientific community. Goodell mentioned that though acute toxicities are regulated through worker protection laws, there is not a comprehensive understanding of chronic effects. Madrigal and Cox also referenced the CHAMACOS study as evidence that the harmful health effects that children in agricultural communities are experiencing as reason enough for regulatory change. Cox articulated her opinion on the EPA's decision to continue researching CPF toxicity as follows:

> *I think that question of "how much research is enough?" it's kind of a complicated question, but my attitude is better safe than sorry. If we have these alternative practices that actually are working and giving farmers a farm that is economically viable and environmentally sound, then I think we can say look, we don't have to study CPF for another 40 years.*

> *Enough is enough. Maybe if there weren't alternatives or something, then there might be some sort of a different story.*

Cox clarified that when adverse health effects like low IQ are traced to pesticide exposure – as in the CHAMACOS study – but the molecular mechanism of why exposure causes a specific effect is unclear, the EPA calls for more research.

Market-based Strategies: Pesticide Use

Not all individuals were aware of the healthy alternatives that Cox seemed so sure of. Both pest managers emphasized market demand for California crops, and highlighted that consumers are reluctant to buy produce that appears imperfect. Vasquez related an anecdote to explain his rationale for pesticide use, suggesting that it is market driven:

> *"It's part of the markets' problem. [Markings on fruit are] superficial on the outside, [they don't] affect the fruit on the inside. but if people were to buy it, even organically…my brother in law is an environmental person who teaches up in the napa area, and he had me and a group up there one time, and he was telling everybody in the group, and these were teachers and professional people, and he was telling them that i sell pesticides. he kind of put me on the spot, and i said do you guys want to know why i use pesticides? i said let me show you something. they had a bowl of fruit on the table, and there was scale on 2-3 pieces of fruit, and i picked one out, and i said would you eat this piece of fruit with all these little peck marks on it. and they said, oh no! that's awful! and i said no it's not, that's a bug that's only on the outside, it doesn't affect the inside. all you have to do is peel it and eat it. yet you guys won't buy it because it has stuff on it on the outside…the consumer will not eat that or buy that."*

Cox also agreed that there is rationale for pesticide manufacturing, from the industry's perspective. If there is money to be made, a producer will not stop creating and selling the product. However, she cited the industry's reluctance to innovate; although new chemical products are increasingly coming to market, there has been no re-consideration of why old products continue to be marketed. Goodell said that alternatives might exist, but that they were not and would not be registered by the EPA. He also stated that if alternatives exist, but they are expensive, there is no excuse to resist switching materials. Goodell's comments show that some integrated pest managers are willing to shift away from CPF if presented with a viable alternative.

Market-based Strategies: Organic Agriculture

In recent years, organically grown foods have increased dramatically in popularity. Documents like the UCIPM's Chlorpyrifos Critical Use Document discount the potential of organic agriculture, suggesting that CPF is indispensable, despite the success of Californian organic farmers, which Cox and Singla both acknowledged. The Critical Use Document also did not reflect Goodell's view that integrated pest management fits well with organic agriculture. None of the interviewees referred to organic agriculture as a silver-bullet solution, but Cox emphasized the importance of organics because of consumers' familiarity with, and willingness to pay for, the label. Singla referred to growers who are profiting from organic farming as potential leaders in the field. She advocated for networking between growers to spread information about organic practices and methods to avoid using synthetic inputs, particularly CPF. Organic pest management aims to understand what processes are influencing negative pest growth, Cox explained.

> *Many pesticides, including CPF, are really good at killing pests. However, what they're not good at is solving pest problems. And i think everybody knows this intuitively; if there's a weed growing in your garden and you just pull it up or kill it with a pesticide, you're just going to get more weeds. And the same thing with the ants in your kitchen, you can spray those ants all you want and there's going to be more ants coming back. The way that you actually solve the pest problem is by changing the conditions that allow the pest to thrive...That's the basic foundation of organic agriculture, saying "What does it take to grow a healthy plant, and what do we need to do to make that happen?" And then you don't need pesticides anymore. In the big picture, that's where we're headed.*

Cox expanded on the distinction between the goals of pesticide use and organic methods in agriculture, suggesting that pesticides target pests with more of a short-sighted approach, instead of taking time to discover and comprehend the root causes of pest infestations.

However, Madrigal and Goodell referenced an argument against completely banning pesticide use from California agriculture: that agriculture cannot feed the world if all farms completely abandon pesticide use. One means of achieving this is through

agricultural innovation zones, which allow only organic production is specified areas under California (AB/SB #?), could serve as means of keeping schools safe from pesticides without completely banning pesticide use.

Policy Engagement

Madrigal, Singla, and Cox, all of whom work for agencies advocating for environmental and public health, agreed on the need for the EPA to revoke all CPF food tolerances, and they saw opportunities for policy and regulation in addition to or instead of a ban. Literature and interviews also highlighted California's pivotal role with regards to CPF regulation and replacement options. Singla had experience as a researcher and science communicator, and continued to engage in the policy process as the EPA completes its evaluations on CPF toxicity. The National Resource Defense Council (NRDC) will submit technical comments on the EPA evaluations, and aims to ensure that the proposed revoked tolerances ruling is not impeded by industry pushback. As an entity focused on public health, this anticipated action aligns with the goals of the NRDC. As an individual who has been engaged at the California state and national policy levels, Singla expressed her belief in using California as a model state for agricultural innovation:

> *I think that California is very influential...in the regulatory sense, the economic sense, and showing leadership in different ways, and showing how policies can work and be implemented. One of the reasons that California is important is that, you know obviously I care about increasing protections for Californians and protecting communities here, but we can also serve as a model for the rest of the country and other countries about how policies can work...to actually make the California economy prosper while protecting our health and environment.*

Singla, Madrigal, and Goodell all mentioned the potential for buffer zones to be an effective state policy action. This is a notable finding; though Singla, Madrigal, and Goodell have different areas expertise (research/science communication, education, and integrated pest management, respectively), this regulatory option seemed to appeal to all three individuals.

Community Activism

Madrigal witnessed community organization strategies firsthand when implementing youth programs as part of the CHAMACOS study which were grounded in the opinions of youth in the community who are directly affected by CPF exposure. The youth council in Salinas submitted public comments to the EPA about findings of the CHAMACOS study and about regulatory decision-making. These comments included the youth's personal experience with pesticide exposure in Salinas, which Madrigal described as evidence of "piecemeal" regulatory legislation across the state.

> *It was interesting because they're talking about how as a cross country team they would just run through these fields and have this perspective of "yeah, that's just kind of what we do."...You don't know what's being applied in those fields, you just don't. And I think the assumption is [that] nothing hazardous is going to be applied there, but there's very little regulation...in terms of what can be applied near schools, for example.*

This suggests that although people working for regulatory agencies and pesticide application may assume that current safety guidelines protect human health, there are opportunities for pesticide exposure that are not accounted for by the law and monitoring processes.

Loopholes in pesticide regulation are not novel. Cox published a Human Exposure fact sheet on CPF in 1995, and has been aware of CPF toxicity and regulatory schemes specifically since then. Her prior experience with Northwest Coalition for Alternatives to Pesticides (NCAP) and long-term awareness of the potential for pesticides to harm human health informed her historical perspective on the forces supporting pesticide use. For example, NCAP was formed after one community noticed that their main water source, a river, was dirty. She explained that the Forest Service and the Bureau of Land Management – both federal agencies – were spraying pesticides on timber crops.

> *I think underlying all that was sort of a pyramid scheme...By law, those agencies were supposed to be managing the forests on sustained yield, so you're not supposed to cut down more trees than you're growing...They came up with this scheme where they could claim that the trees would grow faster because they'd been sprayed...the other plants had been killed so the trees could grow faster and therefore they could up their timber harvest. It was all basically a house of cards. There was no data showing that, in fact – 'cause we are talking 60 to 100 years to grow a tree – so*

> *there was no data to show that in fact the spraying actually increased timber harvests.*

This lack of transparency continues today, as evidenced by Madrigal's experience in Salinas. Community members are aware that pesticides are being sprayed near their homes and schools, but they may not understand why the regulation process allows this to happen legally. Madrigal stated that "it can clearly be seen as an equity issue," but community members have additional poverty-induced stress factors. Many farmworkers "are living in poverty partly because a lot of them are undocumented," restricting their political authority. However, as explained by Cox, there are lessons from history that could be applied to community organizing strategies today. The communities in Cox's anecdotes understood that something was notably different about their immediate environment – apparent in the change in water quality and maternal miscarriages – and education provided transparency about the regulatory process to help them present a convincing argument to policy makers. As Cox described:

> *I think those concerned residents were being told by government agencies and the timber companies and the pesticide companies that there's no problem, but they could see it...ordinary people had to battle. It's not like that's changed. The government agencies and the pesticide companies would kind of put on this hat like "we have the good science and we can show you that there's no problem," and yet there was a lot of science that supported the residents in what they experienced and saw. and so somebody needed to translate that science to make it available and dig it out so that ordinary people had the tools to counter what they were hearing."*

Today, different technological tools can assist educational efforts, making them more affordable to community members exposed to pesticides, and citizens concerned about pesticide exposure in agricultural communities and urban food and water sources.

Agencies like the California Department of Public Health and the Office of Environmental Health and Hazard Assessment (OEHHA) have been using technology to spread awareness of environmental health issues. The Department of Public Health's Pesticide Mapping Tool allows users to look at data on pesticide use across time and space in California. The Department of Public Health also partners with the University of California, San Francisco in a program called Reach the Decision makers, which also

attempts to increase transparency about pesticide regulation in California. These initiatives are geared toward educating community members on their own health, and certain environmental and social determinants of health, like poverty, stress, and proximity to pesticide application sites. Madrigal described the field of health education as follows:

> *The goal in this field is to improve environmental health literacy, as some of us call this idea of the understanding between environment and health. I think as you become more informed, not just of the interaction between environment and health, but who makes these decisions in terms of environmental regulation, that's super important. It's just more awareness, that's a big part of it, more awareness of the interaction between environment and health, how regulation works, and then what [the community members'] role is to influence the process, or to have their opinions heard by those people who are making the decisions, is important.*

Increasing the transparency of regulatory agencies through education efforts, whether geared toward community members or consumers, can strengthen arguments for or against certain policies. Goodell referenced the American public's increasing demand for transparency in the production and distribution of products. Industry is responding to this. As data becomes more publicly digestible, the impacts of regulatory loopholes become more apparent. Platforms like the Pesticide Mapping Tool, which employ visual depictions to make sense of years of data, help clarify the reality of pesticide application.

CONCLUSION

California has a pivotal role in CPF regulation and substitution. Although the EPA may soon revoke food tolerances for CPF, phasing out all organophosphate pesticides seems unrealistic in the immediate future. The Department of Pesticide Regulation can have an influential role in reducing pesticide exposures by requiring implementation of permanent buffer zones around farms where pesticides are used. Respondents advocating for organic farming methods and pest managers cited the feasibility of incorporating organic growing practices into large farms. Considering consumers' affinity for organic products, especially given the current regulatory scheme, growing organically may be the most feasible way to avoid using CPF and any potential synthetic replacements it may have. Notably, there is room for collaboration across

disciplines with regards to environmental health education. Pesticide regulation in California is complex, but CPF exposure is affecting agricultural communities more drastically than urban consumers. Consumers are exposed to a specific amount of residual pesticides from ingested crops, but this amount is marginal when compared to the exposures that children of agricultural communities experience. Exploring the regulatory loopholes behind CPF's status as a Restricted Use Material can provide insight into social determinants of health and opportunities for regulatory change and incorporation of more sustainable agricultural practices.

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