CENTER FOR
FOOD SAFETY

October 17, 2022

OPP Docket
Environmental Protection Agency
Docket Center (EPA/DC), (28221T)
1200 Pennsylvania Ave., NW
Washington, DC 20460-0001

RE: Docket EPA-HQ-OPP-2016-0223

Center for Food Safety appreciates the opportunity to comment on EPA's draft ecological and human health risk assessments of dicamba for registration review. Center for Food Safety (CFS) is a public interest, nonprofit membership organization with offices in Washington, D.C., San Francisco, California, and Portland, Oregon. CFS's mission is to empower people, support farmers, and protect the earth from the harmful impacts of industrial agriculture. Through groundbreaking legal, scientific, and grassroots action, CFS protects and promotes the public's right to safe food and the environment. CFS has consistently supported comprehensive EPA review of registered pesticides and individual inert ingredients.

EPA's draft ecological risk assessment contradicted by real-world harms

CFS is disappointed by the Agency's draft ecological risk assessment (EPA 8/9/22). As in past treatments, EPA has strictly segregated the formal risk assessment from its description of real-world damage caused by off-target movement of this herbicide. Even though the numerous "incidents" of dicamba damage described by the Agency here and elsewhere (e.g. EPA 12/15/21) decisively contradict many of the assumptions and conclusions of the formal risk assessment (this one and EPA 10/26/20), EPA has apparently made no attempt to determine where its assessments have gone awry, much less correct them. Later in these comments, we point to several flaws in EPA's risk assessment tools that have doubtlessly or likely resulted in failure to predict off-target damage from OTT dicamba.

Because risk assessment conclusions are at such variance with real-world outcomes, EPA must base its assessments and registration review decision on the considerable knowledge accumulated in the course of six years' commercial use of OTT dicamba and the dicamba-resistant crop system,[1] for instance the learnings discussed in EPA (12/15/21). Based on that

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[1] EPA persists in using the incorrect term "dicamba-tolerant" ("DT") when referring to dicamba-resistant crops. The Weed Science Society of America defines "herbicide-resistance" as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or ***induced by such techniques as genetic engineering*** or selection of variants produced by tissue culture or mutagenesis" (WSSA 1998). Thus, we use "dicamba-resistant" or "DR" in these comments, and we urge EPA to do so as well.

knowledge base, there is no question that OTT dicamba uses do not meet FIFRA standards, and must be cancelled as soon as possible.

One egregious example of the mismatch between risk assessment prediction and real-world outcome is EPA's risk quotient (RQ) calculations for the risk posed by dicamba to terrestrial plants in various use scenarios. EPA's TerrPlant model predicts that OTT use of dicamba on DR cotton and soybean is far less risky to non-target plants than the majority of non-OTT uses with other crops (EPA 8/9/22, Table 11-2, p. 96). This modeling prediction couldn't diverge farther from reality than if the model had been deliberately programmed to deliver false results, since as EPA elsewhere acknowledges, most of the thousands of dicamba drift damage episodes result from OTT uses on DR crops (EPA 12/15/21), and far fewer damage episodes were recorded prior to approval of OTT uses (EPA 8/9/22).

Similarly, EPA modeling predicts that some non-OTT dicamba uses pose off-field risks to birds (acute) and mammals (chronic) via dicamba residues on off-field plants these animals consume, as well as to terrestrial invertebrates (chronic), but that OTT uses pose essentially no off-field risks[2] to the same taxa "due to label restrictions that reduce off-field movement of dicamba below toxicity thresholds" (EPA 8/9/22, pp. 6-7). Here again, EPA's modeling is worthless. We know OTT uses have caused immeasurable off-field damage to plants near and as far as 20 miles from dicamba treatment sites via incident reports (EPA 12/15/21, p. 21), and that such off-field drift cannot fail to leave residues on plants that birds and mammals use for forage. In contrast, we know from the relative paucity of non-OTT dicamba incidents that such uses have far less potential to drift and end up as residues consumed by birds and mammals.

When risk assessment delivers the wrong answers, it must be rejected, period. After all, risk assessments are based on myriad assumptions, limited data from small-scale tests, and modeling, and their outputs, properly speaking, have the sole purpose of predicting real-world harms. When they fail to do this, they lose all value, unless or until they can be fixed sufficiently to provide a reasonable representation of reality. This assumes, of course, that the purpose of the risk assessment is not the perverse one of creating a pseudoscientific virtual reality where dicamba can continue to be safely used, whatever havoc it might in fact cause.

Risk assessment flaws

In a fully-documented report that is appended to these comments as Attachment 1, CFS explains some of the risk assessment flaws that doubtlessly (in some cases) and likely (in others) have led to such disastrously wrong predictions of OTT dicamba's potential for off-target movement.

Use of faulty, inappropriate, and unvalidated model

Registrants and EPA have made extensive use of an inappropriate and unvalidated model – the **P**robabilistic **E**xposure and **R**isk **M**odel for **FUM**igants, PERFUM for short – to assess

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[2] OTT uses supposedly only pose off-field chronic risks to mammals 2 feet beyond the edge of the treated field, with respect to dicamba, and potentially vis mammalian exposure to a dicamba metabolite, DCSA, formed only in DR plants.

dicamba's vapor drift potential (e.g. EPA 10/26/20; see Attachment 1, Section 3.1 and specified subsections for the following discussion). First, as the name implies PERFUM was developed to assess the volatile drift of soil fumigants, which have vastly different properties than conventional pesticides like dicamba (Section 3.1.1). Second, PERFUM has never been validated for conventional pesticides in general, or dicamba in particular, despite explicit recommendations from EPA's scientific advisers that such validation is critical (Section 3.1.4). Third, the model itself was developed by consultants for a pesticide company to help it win approval of the soil fumigant methyl iodide, with the aim of reducing buffer distances needed to prevent hazardous inhalation of the fumigant by bystanders, relative to buffer zones calculated by California pesticide regulators (Section 3.1.2). PERFUM is now maintained by Exponent, Inc., a product defense firm notorious for corporate-funded junk science, and is not, as EPA sometimes suggests, an EPA model. Fourth, PERFUM does not predict the impact of multiple application events in localized areas, and thus cannot address the "atmospheric loading" scenario that many experts blame for the long-distance, area-wide, damage episodes caused by OTT dicamba (Section 3.1.5).

Perhaps most significantly, PERFUM does not predict vapor concentration under temperature inversion conditions. The underlying dispersion model, ISCST3, estimates vapor concentrations in part based on wind speed, and is programmed to exclude concentrations calculated for wind speeds below 1 meter per second (2.24 mph). Because dicamba vapor concentrations are highest when it is windless, the PERFUM model underestimates vapor concentrations during these frequent, and in practical terms unavoidable (whatever the label may prescribe) conditions (Attachment 1, Section 3.1.6). Even if it were reasonable to expect farmers to consistently avoid application during temperature inversion conditions (it isn't), they have no control over inversions that begin one or several days after application, which can trap dicamba volatilizing from treated plant surfaces. It should be noted that use of the AERMOD rather than the ISCST3 dispersion model (whether embedded in PERFUM or not) does not help here, because AERMOD also excludes the high vapor concentrations outputted in calm periods in the same manner as ISCST3 (Attachment 1, Section 3.1.6).

All models of pesticide drift have serious flaws, with outputs often deviating dramatically from empirical results, where the latter are even available. However, modeling is especially unreliable where it is most needed in the OTT dicamba context: to predict volatilization from plant surfaces, which occurs at greater rates than from soil (Attachment 1, Section 2.3 and p. 27). For instance, Mueller and Steckel (2021) found that dicamba emissions were over 300% greater when the herbicide was applied to green plants vs. other surfaces. Yet EPA's two sets of test guidelines for lab and field volatility both prescribe application of the pesticide to soil, because they were designed to test the volatility of soil fumigants and perhaps other soil-applied pesticides, and neither makes any reference to vapor drift injury to plants (Attachment 1, Section 5.1.2). It has been a quarter-century since the first GE herbicide-resistant crop system was released, and yet EPA still has not adapted its regulatory system to account for them.

Modeling parameters bias vapor concentration estimates downward

Even to the extent that one might consider PERFUM modeling appropriate in theory (it isn't), several factors specific to dicamba assessments have biased the estimates of volatilization and vapor drift downward. These include aspects of the field trials used to derive dicamba flux estimates used as inputs to PERFUM (discussed in Attachment 1, Section 2) as well as other parameters of the modeling effort (Ibid., Section 3.2).

No scale-up from small field trial to commercial production acreage

A major source of error in EPA's various risk assessments is its failure to scale up estimates of the distance dicamba drift travels off-field, in the form of either spray or vapor, from field-trial to commercial production scale (see Attachment 1, Sections 2.1, 3.2.3 and Appendix for the following discussion). XtendiMax volatility was originally assessed based primarily on flux data gleaned from two tiny field trials of 3.4 and 9.6 acres. Academic studies that came in subsequent years were still quite small, mostly a dozen or two dozen acres, despite EPA's designation of them as "large-scale" (EPA 10/26/20, p. 215). EPA has applied the results of such studies directly, or as inputs to modeling, without scaling up as needed to predict the distance that damaging drift would travel when commercial fields orders of magnitude larger than the field trials are sprayed.

This is entirely illegitimate, as the distance air pollutants disperse scales up with the amount being emitted, which in this case is equivalent to the area treated with dicamba. The need for scale-up is well-known to modelers, and in fact is baked into the PERFUM model that EPA used to project dicamba vapor drift distance. Yet EPA does not discuss the appropriate scale-up factor, or discuss the scale issue at all, as it has explicitly done when using PERFUM to assess the off-field movement of volatile drift for other pesticides, such as methyl iodide and chlorpyrifos (Attachment 1, Section 3.2.3).

How to handle upper-bound exposure estimates

Models of pesticide volatilization like PERFUM can deliver a wide range of vapor concentration outputs at any given distance from a treated field, depending on locale-specific flux rates and historical weather data-sets (see Attachment 1, Section 3.2.5 for the following discussion). The range of concentration values for any given distance off-field can be interpreted as a probability distribution, and poses the question of which percentile of exposure is appropriate for the risk assessment process. The 95th percentile of such a distribution (at a given distance) would be the concentration of dicamba that is exceeded by 5% of modeled values at that distance. One would anticipate that if dicamba were sprayed 20 times under the given set of conditions, one of the 20 applications would result in dicamba vapor concentration exceeding the 95th percentile. If it were applied 200,000 times, then a safety threshold based on the 95th percentile would be exceeded 10,000 times. Clearly, the percentile of exposure must be chosen with consideration of the number of applications.

Shockingly, EPA has entirely ignored this matter in its dicamba assessments, but instead arbitrarily chosen the 90th or 95th percentile values for risk assessment purposes without regard to their protectiveness, or lack thereof.

Plant sensitivity to dicamba

EPA derived the vapor phase plant harm threshold for dicamba from tests of the susceptibility of soybeans conducted in laboratory-based humidomes – primitive plastic chambers in which soybean seedlings are exposed to various concentrations of dicamba vapor (see Attachment 1, Sections 4.1 to 4.3 and p. 70) for the following discussion, with citations). Among several problems with this scheme is the fact that the humidomes are not "humid," but rather operate at 40% relative humidity, ostensibly due to the technical limitations of these jerry-rigged devices. Plant susceptibility to herbicidal injury increases with humidity, for instance by softening the plant cuticle, prolonging the life of herbicide droplets on leaves, and opening plant stomata, and is regarded as a more important factor than temperature for herbicidal plant damage. Egan and Mortensen (2012) found dicamba injury to soybeans at greater distances from a treated field when conditions were humid, and hypothesized that humidity "increases the residence time of dicamba near plant surfaces or facilitates the uptake of dicamba" by plants. Illinois pesticide applicators also noted that not only heat, but humidity, correlated with dicamba injury (IFCA 2017), and weed scientists have often observed more dicamba injury in humid areas along waterways. EPA tried for years to obtain high humidity tests of plants' susceptibility to dicamba from registrant Monsanto, but the company never complied.

The seedlings were also tested under just one humidome temperature regime: 85°/70° (16 h/8 h). Temperatures exceeding 85° are of course common in OTT dicamba country, and higher temperatures generally increase the absorption, translocation and activity of foliar-applied herbicides. In addition, the humidome seedlings were well-watered (bottom watering), while dry conditions that stress plants have been observed to exacerbate dicamba injury. Finally, only seedlings at the V2 stage were tested, leaving susceptibility at other growth stages uncertain.

With regard to temperature and humidity, it is interesting to note that in 2017 Monsanto advised farmers using the company's plant-growth regulators (a group to which dicamba belongs) as follows: "Do not spray when air temperatures and/or humidity is high or is expected to be high" (see Attachment 2, under Best Management Practices). However, dicamba is not explicitly mentioned, nor is this instruction to be found on the XtendiMax label or other OTT dicamba-specific materials. This indicates that Monsanto is aware of the volatility hazards of its dicamba product under conditions of both high temperature ***and*** high humidity, but is unwilling to put such a hazard warning where it is needed, on the label.

New terrestrial plant endpoint needed

EPA established the plant harm threshold on soybeans, the most sensitive to dicamba of plants tested in registrant studies. However, there is evidence that snap beans are over 3 times as sensitive as soybeans, based on 50% leaf deformation values (I_{50}) measured via an imaging technique, as EPA noted nearly a year ago (EPA 12/15/21, p. 19, citing Wasacz et al. 2021). EPA stated then it was evaluating this study to determine if it would impact the terrestrial plant endpoint for dicamba, but does not mention the matter in this draft ecological risk assessment.

The I_{50} values for snap bean and soybean, based on a leaf imaging technique that is more reliable than visual estimates, are 0.11 g/ha (0.000098 lb/acre) and 0.35 g/ha (0.00031 lbs/acre), respectively. At present, EPA's soybean endpoint for dicamba's vegetative vigor effects is an IC_{25} value of 0.000513 lbs/acre, roughly equivalent to Wasacz and colleagues' I_{50} value. Since the IC_{25} and I_{50} values for soybeans are so close, closely related snap beans are quite likely to be 3-fold more sensitive than soybeans as gauged by EPA's IC_{25} metric as they are based on the leaf deformation metric. EPA should modify its terrestrial plant risk assessment, using snap beans in place of soybeans for the endpoint.

Wide-area vs. near-field dicamba drift damage

In EPA (10/26/20), EPA sharply distinguishes "near-field" from "wide area" dicamba drift and volatility damage. Only near-field impacts are projected by EPA's formal risk assessment, based on available field studies and available modeling tools. In contrast, wide area impacts represent EPA's bin for the thousands of incidents of off-target plant damage that have occurred in the real world, but that are not predicted by modeling based on field trials, humidome studies and other risk assessment tools. Indeed, EPA concedes that vapor drift on large landscape scales beyond the 10 to 20-acre field scale used for distance to effects field studies simply cannot be modelled with existing tools (EPA 10/26/20, pp. 19, 310).

EPA is extremely vague as to what constitutes wide area damage, but suggests such episodes occur "hundreds of feet from a known dicamba use site," are likely caused by vapor phase exposure (EPA 10/26/20, p. 19), and impact tens to hundreds of acres per incident (EPA 8/9/22, p. 8). The vagueness does not matter to EPA, because wide area impacts are safely excluded from the formal risk assessment, and the mitigations based on it.

However, wide area incidents occur at far greater distances from treated fields than suggested by "hundreds of feet." According to Larry Steckel of University of Tennessee, dicamba drift often damages plants at distances of ½ to ¾ miles from the nearest treated field, and all too frequently beyond that (Steckel 2018). Similarly, based on a survey of its membership, comprised of ag retail companies and commercial pesticide applicators, the Illinois Fertilizer and Chemical Association reported that nearly 60% of dicamba damage incidents occurred at distances of ¼ to ½ mile from treated fields, even when labels were followed; additionally, 85% of survey respondents reported that they saw dicamba damage to soybeans ***upwind*** of the DR soybeans they treated, and attributed this damage to volatility and vapor drift (IFCA 2017). EPA also now admits that wide area impacts occur 1-2 miles from the nearest treated field (South Dakota) and even 20 miles from the nearest dicamba applications (Arkansas) (EPA 12/15/21, p. 21).

That dicamba regularly drifts to cause damage from ¼ to ¾ mile – 1,320 to 3,960 feet – from a treated field, and often much farther, and can do so in any direction, makes a mockery of EPA's spray drift buffer (maximum 240/310 feet downwind for counties without and with endangered dicots), and still more the entirely laughable 57-foot omnidirectional volatility buffer – which in any case only applies in ESA counties (a small fraction of counties where OTT dicamba is registered). The paltriness of the volatility buffer is particularly puzzling in light of the fact that volatility episodes are literally defined as those episodes occurring at the largest distances from treated fields, with EPA acknowledging that vapor can travel in any direction from a treated field. These real-world demonstrations of how thoroughly EPA's mitigations have failed underscore once again the flaws in EPA's risk assessment tools, as described above.

Volatility control measures

Despite the plethora of wide area incidents, EPA touts the efficacy of three volatility control measures. Two are applicable to all OTT dicamba applications, and the third is only required in counties with threatened or endangered species of non-monocot plants, or listed species that depend on non-monocot plants. The Agency calculates success rates for each measure, which it expresses as percent "certainty"[3] the measure will prevent volatility-related adverse effects at the edge of a treated field. Adverse effect (aka "discernable effect" [4]) is defined as greater than 10% visual signs of injury (on a scale of 100, in which 0 = no effect and 100 = plant death) or 5% reduction in height to soybean, the plant assumed to be most sensitive to dicamba. Thus, dicamba injury below these thresholds is dismissed as not adverse. The corresponding failure rate is 100% minus the success rate.

The three volatility reduction measures and their success and failure rates are as follows (see EPA 10/26/20, Appendix J, pp. 324-326):

	Success rate	Failure rate
Volatility reduction agent (VRA)	89%	11%
Calendar date cut-off soybeans (varies by state):	3 to 72%	28 to 97%
Calendar date cut-off cotton (varies by state):	0.3 to 36%	64 to 99.7%
57-foot omnidirectional buffer (only counties with listed species):	78%	22%

The evidentiary base for each of these measures is extremely poor. For instance, EPA concedes that very few studies assess the efficacy of the volatility reduction agents (VRAs): apparently just four, two by BASF, one by Bayer and one by academics (EPA 10/26/20, pp. 269-270). The 89% success/11% failure rate of VRAs was based on just 45 volatile exposure transects from these studies, in which five of 45 (11%) exhibited damage greater than EPA's threshold of 10% visual signs of injury beyond the 57 feet of the omnidirectional volatility buffer. These field trials ranged in size from just 7 to 23 acres, miniscule plots relative to commercial-scale production, yet EPA applied no scaling factor (see discussion above), but rather proceeded on the ridiculous pretense that dicamba vapor travels precisely the same distance whether the source is a 10, 1,000 or 10,000 acre field or locality sprayed with dicamba.

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[3] The proper mathematical term here is "probability," which admits of degree, whereas "certainty" does not. EPA likely chose "certainty" instead of probability to deceive laymen into thinking these inadequate measures are more effective than they really are.

[4] EPA seems to use these terms interchangeably, even though "discernable" suggests any effect that can be seen, which would include visual signs of injury less than the "adverse" cutoff of 10%.

The calendar date cutoffs (no OTT applications after June 30th for soybeans, or after July 30th for cotton) are designed to prohibit OTT dicamba applications in the hottest parts of summer, since heat enhances volatility. The success/failure rates of these calendar date mitigations vary so widely because they are calculated for each relevant state, and states differ dramatically in summer temperatures.

That said, EPA's calculation of their efficacy is based on flux rates measured in small-scale field trials, humidome data, modeling, and data in registrant incident reports (EPA 10/26/20, Appendix I, pp. 309-323), each of which data source is suspect for reasons discussed above and in Attachment 1. Two examples suffice. First, three field trials of roughly 20 acres in size were used as a critical input to determine the distance to effects, or distance dicamba vapor travels off-field at sufficient concentrations to cause injury. Yet EPA makes no attempt to scale-up the modeled off-field dicamba air concentrations to account for the orders of magnitude larger commercial production fields that are sprayed in the real world; thus, this entire exercise is limited to assessment of "near-field exposure" and has no relevance to the wide area impacts observed in thousands of real-world incidents (Ibid. pp. 311, 313, 317). Second, EPA utilized several registrant humidome studies in this temperature cutoff exercise (EPA 10/26/20, pp. 124-127) – studies conducted at higher temperatures and marginally higher relative humidity (up to 60%) than those discussed above. However, the most interesting outcome of these studies is ignored by EPA: namely, that volatilization rates increase exponentially above approximately 35°C (95°F), and EPA's regression coefficients (represented by the curves in the cited figures) substantially understate volatility (i.e. flux) in this temperature range (EPA 10/26/20, Figures I.1, I.2, pp. 311-312). This in turn means that the volatility and vapor drift outputs in EPA's modeling exercise are understated at the high temperatures that do often occur in June and July, particularly in southern states.

Setting aside these reservations, and taking EPA's assessment on its own terms, the cumulative probability of failure to stop off-field volatility damage beyond the effects threshold of 10% visual signs of injury is the product of the applicable individual failure rates: VRA and calendar cutoffs for counties without listed species, and those measures plus the omnidirectional buffer for counties with listed species:

	Cumulative success rate	Cumulative failure rate
Counties without listed species		
Soybeans:	89% to 97%	3% to 11%
Cotton:	89% to 93%	7% to 11%
Counties with listed species (ESA counties):		
Soybeans:	97.7% to 99.3%	0.7% to 2.3%
Cotton:	97.6% to 98.5%	1.5% to 2.4%

EPA chose 95% probability of no discernable effects as the threshold it must achieve to ensure protection of listed species, though without giving any rational basis for this choice. However, EPA set no threshold for acceptable volatility damage in the 90% of counties where omnidirectional buffer is not required due to lack of listed dicot species, and in fact neglected to even report the probabilities that we give above. Neither does EPA explain what these cumulative failure rates mean in terms of number or severity of volatile drift episodes.

To calculate the predicted number of volatile drift episodes that cause off-field plant damage that exceed EPA's harm thresholds (10% VSI or 5% height reduction) requires an estimate of the number of OTT dicamba applications farmers make. Our very conservative estimate is that 245,000 OTT dicamba applications are made annually, based on the following:

- USDA 2017 Census figures for number of soybean (303,191) and cotton (16,149) farms;
- The percent of soybean (67%) and cotton (75%) acreage planted to Xtend crops in 2019/2020 (EPA 12/15/21);
- The assumption that the percent Xtend soybean and cotton acreage is equivalent to the percent of soybean and cotton farms growing Xtend crops;
- The latest USDA NASS figures for the weighted average number of annual applications of dicamba salts permitted for OTT use (diglycolamine and BAPMA salt) on soybeans (1.1 in 2020) and cotton (1.8 in 2021); and
- The conservative assumption that each Xtend soybean and cotton farmer sprays dicamba OTT on all Xtend acres on his/her farm in one spray operation.[5]

Because the 287 ESA counties represent only roughly 10% of all counties in the 34 states where OTT dicamba is registered, a small share of Xtend soybean and cotton acreage where dicamba is sprayed OTT, our calculations below focus on those counties where dicamba-susceptible listed species are not present, and the only volatility-specific mitigations are volatility reduction agents and cutoff dates. Please recall that the volatile mitigation failure rates are given as a range because the efficacy of the cut-off date mitigation factor varies widely by state. Thus, the minimum and maximum volatile drift damage episodes reported below represent the potential range of episodes for one year on a national basis, with the minimum number based on the state where the cutoff is most successful (i.e. a northern state with cooler temperatures), while the maximum number is based on the state where the cutoff date most frequently fails to prevent applications above the threshold temperature.

	Volatile Mitigation Failure Rate	No. of Applications	Volatile Drift Damage Episodes Minimum	Volatile Drift Damage Episodes Maximum
Soybeans:	3% to 11%	223,452	6,704	24,580
Cotton:	7% to 11%	21,820	1,572	2,400
TOTALS:		245,272	8,276	26,980

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[5] With average soybean and cotton farm size of 297 and 788 acres, respectively, it is certain that many larger farmers will spray dicamba on portions of their Xtend crop acreage in two or more separate spray operations. This conservatism is likely to be roughly offset by the number of farms with dicamba-resistant crops grown for defensive reasons, and thus not sprayed with dicamba OTT>

Thus, even if one takes seriously EPA's volatility mitigation package and the data underlying it (CFS does not), by EPA's own reckoning these measures would still permit somewhere between 8,200 and 27,000 volatile drift damage episodes each year in the majority of counties with no listed species.

Data Needs

Before EPA acquires any more data on dicamba, the Agency needs to ensure that it is not soliciting the same sorts of regulatory studies that have failed so miserably to predict dicamba's harms. EPA must develop reliable protocols that provide reasonably accurate predictions of dicamba's behavior in the environment. Thus, requiring field volatility studies for dicamba applied OTT to corn of the same type that have failed to predict volatility with respect to DR crops is an exercise in futility, and can only mislead (EPA 8/9/22, pp. 10-11). See Attachment 1, Section 5 for recommendations on reform of EPA's volatility assessment process.

Human Health

Dicamba is a likely carcinogen, as demonstrated in two rodent feeding trials submitted to the Agency in the 1980s, and discussed in CFS objections to EPA in 2017 (CFS 2017), and supported by suggestive evidence of carcinogenicity in epidemiology studies (e.g. McDuffie et al. 2001)

EPA needs to revisit it cancer evaluation of dicamba and assess it in accordance with its 2005 Guidelines or Carcinogen Risk Assessment (https://www.epa.gov/sites/default/files/2013-09/documents/cancer_guidelines_final_3-25-05.pdf).

Sincerely,

Bill Freese, Science Director
Center for Food Safety

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Attachment 1 - The Dicamba Debacle

How Regulators Enabled Historic Herbicidal Crop Injury and Failed American Farmers

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May 2019, revised August 2020

EXECUTIVE SUMMARY

Over the past two years, rural America has been ravaged by an unlikely assailant – a weed-killer called dicamba. This volatile herbicide – sprayed on millions of acres of genetically engineered (GE) soybeans and cotton designed to withstand its deadly effects – has drifted rampantly, leaving vast fields of damaged crops in its wake, as well as injured trees, ruined gardens, and honeybee colonies deprived of a sufficient supply of the flowering plants they need. No herbicide used outside of wartime has ever devastated so many plants. The physical damage is matched by the human costs. Economic losses from ruined crops have torn at the fabric of rural America, by pitting the victims of drift against those who sprayed, making enemies of once friendly neighbors. Some find their very livelihoods threatened, leading to resentment, recriminations, lawsuits, and, in one case, a gunshot death.

The dicamba debacle has two major culprits: unethical corporations and weak government regulators. The Monsanto Company (recently acquired by Bayer) developed the dicamba-resistant crops, and manufactures XtendiMax, the major dicamba formulation used with them. Dicamba has long been notorious as a volatile drift-prone herbicide, and it was widely understood that spraying it on resistant crops to kill the weeds among them would make things much worse. To quell these concerns, Monsanto claimed it had fixed dicamba; that its new formulation, XtendiMax, would not drift like older forms of the herbicide; and that its new crop system could be used safely. However, the company did not allow independent scientists to test XtendiMax for drift.

It was the government's responsibility to vet Monsanto's claims and otherwise ensure its crops and herbicide could be used safely. Yet the disjointed nature of the regulatory review process set it up for failure. Even though industry views its GE seed-herbicide packages as "systems," and their drift threats can only be understood as such, regulators pretend the components are unrelated. Thus, USDA deregulated Monsanto's GE crops in 2015, without meaningful consideration of drift. Two years later, EPA then approved XtendiMax together with two other dicamba formulations (Engenia and FeXaPan), virtually blind to the drift-promoting implications of their use on those resistant crops.

Following the massive crop injury caused by dicamba in 2017, EPA imposed minor usage restrictions recommended by Monsanto. Yet they proved to be ineffective, since dicamba continued to drift rampantly and injure crops in 2018. Rather than allow the XtendiMax registration to automatically expire because of the excessive drift damage, EPA approved it for two more years through 2020, with additional minor usage restrictions of the sort that proved ineffective in 2018 (Section 1.1, Appendix 1).

EPA had ample reason to fear XtendiMax, particularly its potential to volatilize and drift in vapor form (INSET: Different Forms of Herbicide Drift). Scientists, farmers and civil society groups warned the Agency of the severe drift injury threats posed by the Xtend system as early as 2010. EPA's own 2013 screening assessment suggested that dicamba vapor could cause substantial injury to plants nearly a mile from a sprayed field. Likewise, the Agency received field reports of dicamba drifting to damage soybeans ½ to over 2 miles from sites of application. In the end, however, EPA simply dismissed this evidence, and based its assessment entirely on studies by Monsanto and its contractors. These studies purportedly showed that the concentration of dicamba vapor in the air at the edge of a sprayed field would be below the concentration that causes injury to dicamba-sensitive plants. On this basis, EPA concluded that there was no need for buffer zones to protect neighboring crops and plants from dicamba vapor drift injury (Section 1.2).

In this report, we show the many ways in which these studies, and EPA's interpretation of them, dramatically underestimated the vapor drift threat posed by XtendiMax. Sections 2 and 3 address the field volatility and modeling studies, respectively, that were used to estimate the dicamba vapor concentrations at the edge of a field sprayed with XtendiMax. In Section 4, we critique the laboratory study conducted to determine plant sensitivity to dicamba vapor. Section 5 presents recommendations for improving the quality of volatility studies and EPA's assessment methods for herbicides applied to resistant crops. In Appendix 1, we assess the evidence upon which EPA based its two-year extension of new dicamba registrations through 2020.

Field Volatility Assessment

Monsanto conducted two field volatility studies in Georgia and Texas that were fundamentally flawed in both design and execution, in ways that vastly underestimated vapor drift (Section 2).

As for design, the tiny plots (3.4 and 9.6 acres) sprayed with XtendiMax in the two field trials were far too small to simulate the substantially longer-distance vapor drift that occurs when the herbicide is applied to real-world fields many times their size; and were still less adequate for estimation of vapor drift from thousands of acres sprayed in a localized area (Section 2.1). Because volatilization is influenced by many different environmental factors that differ by region (e.g. temperature, soil properties), and because the influence of some factors is context-dependent (INSET: XtendiMax Drift Injury and Relative Humidity), numerous field volatility studies must be conducted in areas of major use. Monsanto's Georgia and Texas field studies did not begin to meet this requirement, because practically no soybeans are grown in these states, and the majority of XtendiMax is applied in soybean-growing regions (Section 2.2). In addition, the field studies, conducted early in the season, did not simulate the greater volatilization that occurs when XtendiMax is applied to larger dicamba-resistant plants in the higher temperatures of early summer (Section 2.3). Finally, nothing in EPA's registration of XtendiMax requires testing to determine whether XtendiMax's volatility is increased when it is applied together with other pesticides and additives in so-called tank mixes, a very common practice among farmers. EPA's failure here comes despite the Agency's recognition that tank mixing could increase volatility, and its initial proposal to require such testing (Section 2.4).

The field volatility studies were also flawed in execution. For one, Monsanto intentionally conducted the spraying operations in ways that minimized both spray and vapor drift: the sprayer pressure, boom height and sprayer travel speed were all lower than permitted on the XtendiMax label (Section 2.5, INSET: Sprayer Pressure and Droplet Size for XtendiMax-Approved

Nozzles). Neither field volatility study incorporated a plant effects evaluation – sentinel plants placed just beyond the edge of the treated plot, to assess potential vapor drift injury – despite such an evaluation being included in the protocol of one of the studies. This would have permitted correlation of dicamba vapor concentrations and soybean injury under more realistic conditions than those in the "humidome" study (Section 2.6).

Finally, additional flaws in the field volatility trials described by EPA scientists were ignored in the decision by higher-ups to register XtendiMax (Section 2.7, INSET: Pesticide Volatilization Rates and Vapor Concentrations). These included failure to consider the high rate of volatilization that occurred during application, and weather conditions that did not optimize volatilization at the time of day when spraying took place. These scientists' requests for additional data to resolve "uncertainties" went unanswered. Another deficiency is EPA's failure to assess the combined effects of vapor drift, spray drift, and movement of dicamba-bearing dust particles.

Ideally, a volatilization assessment would be based on a full and robust set of field studies designed and executed in ways that answered the foregoing criticisms. Instead, Monsanto relied on deficient computer modeling in an attempt to fill the huge data gaps.

Faulty Modeling Fails to Compensate for Field Trial Deficiencies

Pesticide dispersion models are designed to take the particularized volatilization (aka flux) data from field studies as the basis for predicting how the same pesticide would behave when sprayed on fields of different size, under a wide range of weather conditions. While sound in theory, in practice models often do not predict pesticide vapor drift very well, especially when the pesticide is sprayed on plants rather than the soil (INSET: Models to Estimate Pesticide Drift in Need of Much Improvement). Monsanto commissioned the consulting firm Exponent, Inc. to model dicamba vapor drift from XtendiMax applications (Section 3.0).

The model Exponent used – the **P**robabilistic **E**xposure and **R**isk Model for **FUM**igants (PERFUM) – was entirely unsuitable for this task in numerous respects (Section 3.1). Even assuming it were appropriate, the modeling was executed in ways that substantially understated vapor drift (Section 3.2).

As its name suggests, PERFUM was developed to assess soil fumigants, specialty biocides with far different properties than conventional pesticides like dicamba. It has previously been used to set no-spray buffer zones that purportedly protect bystanders from inhaling hazardous levels of fumigant vapor, not to prevent herbicide vapor from injuring off-field plants (Section 3.1.1). PERFUM was developed by scientists now with Exponent, Inc. to facilitate introduction of a hazardous fumigant by setting buffer zones far smaller than those calculated by government scientists using other methods. Exponent, Inc., which maintains PERFUM, is frequently hired to forestall regulation of toxic chemicals (Section 3.1.2). The core of PERFUM is an obsolete air pollutant dispersion model that EPA retired nearly 15 years ago, and it has never been retooled to incorporate the Agency's much-improved AERMOD model, as recommended by its scientific advisors (Section 3.1.3).

Critically, scientific advisors to the EPA confirm that PERFUM has not been validated for assessing the volatilization of conventional pesticides like dicamba, casting further doubt on its predictions of vapor drift with respect to XtendiMax (Section 3.1.4). PERFUM modeling of XtendiMax drift was also based on the assumption of just one application to a single field, and so could not account for the much greater volatilization arising from intensive, local use on many fields (Section 3.1.5). Finally, PERFUM has not been modified to predict vapor concentrations of pesticides under "worse-case" temperature inversion conditions, another capability that EPA's scientific advisors regard as critical (Section 3.1.6).

Even if PERFUM were an appropriate model in this context, it was misused in several important ways to understate XtendiMax vapor drift. Three key inputs to PERFUM – volatilization rates, weather data and field size – were biased to obtain artificially low and unrepresentative estimates of off-field dicamba air concentrations. The volatilization rates derived from the field volatility studies were underestimated for the many reasons already discussed (Section 3.2.1). The historical weather data fed into PERFUM – used to simulate dicamba air concentrations in four modeling locations – were 30 years old, and hence missed the hotter, volatility-enhancing years of the 21st century. Moreover, the four locations were unrepresentative of soybean-growing regions where XtendiMax is most used, and where crop injury has been most severe (Section 3.2.2).

Perhaps the most transparent modeling error involved field size. The distance that vapor drifts at plant-damaging concentrations increases substantially with the extent of the sprayed cropland (Section 2.1), and the same holds true for fields simulated by modeling. By using PERFUM to model XtendiMax vapor drift from a tiny 80-acre simulated field, far smaller than the thousands of acres sprayed in many regions of intensive XtendiMax use, off-field dicamba air concentrations were correspondingly underestimated (Section 3.2.3). In addition, PERFUM modeled dicamba air concentrations at a height of 1.5 meters, likely underestimating the concentrations experienced by soybeans and other short-stature plants (Section 3.2.4). Finally, the supposedly "peak" dicamba air concentrations derived from modeling and used by EPA for regulatory purposes are actually 95th percentile values, meaning they are exceeded 5% of the time under the given conditions. The frequency and scope of XtendiMax use, together with the paucity of field volatility studies, require that much higher upperbound percentile estimates be used for regulatory decision-making purposes (Section 3.2.5).

Even if use of this inappropriate model is somehow judged acceptable, the many biases and deficiencies in the field volatility studies and associated modeling understated XtendiMax volatilization substantially, likely by several orders of magnitude (Section 3.3).

Laboratory Study Conditions Underestimate Plant Sensitivity to Dicamba

EPA's assessment of the plant harm threshold – the highest vapor concentration of dicamba known to be safe to a sensitive plant – was based on a single study in which soybean seedlings were exposed to different vapor concentrations of dicamba in small plastic chambers known as "humidomes." Because the "peak" dicamba air concentration from PERFUM modeling studies exceeded this harm threshold – despite the many downward biasing factors discussed in Section 3 – EPA should have established protective vapor drift buffer zones, but did not (Section 4.1). Moreover, the humidome study was conducted under just one set of conditions that understated soybean susceptibility to dicamba relative to real-world conditions of high temperature and humidity as well as dry soil. This is particularly true of the humidome's low 40% relative humidity, since many studies show plant susceptibility to herbicides increases with rising humidity (Section 4.2). EPA scientists regarded these highly unrealistic humidome conditions as one reason Monsanto's data did not begin to explain two incidents in which dicamba vapor drift injured soybeans 2,800 feet and 2.2 miles from the sites of application. Neither did Monsanto provide any data on the harm threshold for reproductive-stage soybean plants, which are both more threatened by and more sensitive to XtendiMax vapor injury than seedlings (Section 4.3).

Recommendations

To avert future drift debacles with both dicamba-resistant and the many future herbicide-resistant (HR) crops being introduced and developed, USDA and EPA must coordinate their assessments of and decisions on the HR crop and herbicide components of these systems (Section 5.0).

EPA regulations prescribe tests intended to identify and protect against the harms of pesticides. However, current volatility testing regulations are either not being enforced or they are inapplicable to the unique challenges posed by herbicide use on HR crops (Section 5.1). Monsanto's volatility tests violated a number of existing test directives, such as determining volatility under real-world use conditions (Section 5.1.1). However, many existing guidelines are inappropriate or lacking. For instance, volatility is to be tested following application to soil rather than after the volatility-enhancing application to plant foliage typical of herbicide use with HR crops; and EPA has not developed any test procedures to assess vapor drift injury to non-target plants (Section 5.1.2).

A new testing regime is urgently needed. Laboratory studies must measure volatilization rates under the most volatility-enhancing conditions (e.g. temperature, humidity, soil moisture) representative of regions where the herbicide will be used, which will require chambers permitting full control of such conditions, unlike Monsanto's primitive humidomes. Field volatility studies must simulate the most volatility-enhancing farmer production practices. Applications should be made to multiple commercial-size fields in a localized area, at the latest permissible crop growth stage in a weedy field, and under temperature inversion conditions. Sentinel plants of different species and ages placed outside the treated fields should be assessed for injury, and grown out to measure potential yield and transgenerational fertility impacts on 2nd generation seed. Any modeling study to estimate off-field vapor drift must await development and validation of an appropriate model with the capability to simulate worse-case scenarios (Section 5.1.3).

EPA must do a better job of incorporating input from independent stakeholders, knowledge derived from experience, and qualitative information in its assessment process. EPA received a tremendous amount of such input from scientists, farmers, public interest groups and others, many warning of severe drift injury from XtendiMax. When information of this sort suggests serious risks that registrant studies entirely deny, it should move the Agency to reject registrant studies, or at least to undertake an extremely rigorous and conservative assessment, which it clearly did not do in the case of XtendiMax (Section 5.2).

The many deficiencies of modeling described in Section 3 suggest that EPA should demand much more empirical air monitoring data under a broad range of conditions. Interestingly, this is the path EPA ended up taking with its volatilization assessment of the insecticide chlorpyrifos, after initially relying on PERFUM modeling estimates (Section 5.3).

Even plentiful air monitoring data may easily miss volatilization under "worse-case" scenarios, which might include intensive localized use and/or temperature inversion conditions (Section 5.4.1). Scientific advisors to EPA proposed a formula to calculate the high-end probability distribution of pesticide vapor concentrations to account for such scenarios. Critically, this approach recognizes that limiting the probability of a worse-case exposure at any one of many sites requires a much lower probability of occurrence at each individual site. With XtendiMax being applied on over 100,000 farms, only buffer zones based on extremely high upper-bound percentiles of modeled exposure at individual sites would have a chance of keeping overall injury within "acceptable" bounds (Section 5.4.2).

Another approach to worse-case exposures has already been implemented by EPA. One of its screening-level assessments of XtendiMax volatilization (which it instantly dismissed) predicted excessive injury to plants up to 1,500 meters from a sprayed field, which proved to be far more accurate than estimates derived from registrant studies and PERFUM modeling. The screening tool – based essentially on a pesticide's vapor pressure – has provided estimates of flux or air concentrations of 17 pesticides applied to plant foliage that agree remarkably well with empirical measurements. EPA should put this tool front and center in its volatilization assessments, unless or until more refined registrant studies and modeling prove themselves to be much more reliable than they were in the case of XtendiMax (Section 5.4.3).

Conclusion

The USDA and EPA have entirely failed to meet the unique challenges posed by genetically-engineered, herbicide-resistant crop systems. Whether it's the epidemic of resistant weeds stemming from first-generation glyphosate-resistant crops or the dicamba debacle, they have ignored warnings and rubber-stamped enormous harm to rural communities and the environment.

Still worse than the physical damage and monetary losses, as bad as they have been, are the human costs of Monsanto's biased studies and EPA mis-regulation. John Seward of South Dakota has seen his vegetable farm devastated several times over the past two seasons; unable to obtain compensation, he is considering giving up his dream of farming. An elderly Illinois homeowner has fallen into depression, watching dicamba severely damage her trees, shrubs and garden. Feeling betrayed by indifferent neighbors, she spoke only on condition of anonymity "to protect her from reprisals in her community." Mike Hayes' Tennessee resort has been hit with dicamba drift at least eight times, killing off young trees he planted as well as the vegetable garden that supplies his restaurant. An Arkansas beekeeper has closed his retail honey operation due to huge declines in honey production where dicamba damage is severe, likely the result of dicamba's suppression of flowering plants, and is moving his hives out of state to escape the devastation (Steed 2019).

HR crop systems are the most intensive R&D priorities of the seed-pesticide industry. DowDuPont is introducing crops resistant to dicamba-like 2,4-D, and many more are sure to come as escalating weed resistance creates new markets for "new tools." Without fundamental regulatory reforms, more herbicidal crop debacles and environmental harm are inevitable.

Appendix 1: EPA Extends Registration of XtendiMax Through 2020

On Halloween of 2018, EPA extended the registrations of XtendiMax, Engenia and FeXaPan through 2020. EPA has added a few minor additional usage restrictions that weed scientists predict will be ineffective. The Agency is also requiring registrants to conduct new studies in 2019 to supply fundamental information on XtendiMax's volatility, phytotoxicity and other properties – clear evidence that the Agency had no legitimate scientific basis on which to approve XtendiMax in 2016, much less to grant a two-year extension. Several additional Monsanto volatility studies were also assessed, but they provided no useful information as most were conducted with dicamba formulations other than XtendiMax, and they share the flaws of those conducted for the original 2016 registration.

EPA for the first time assessed several field studies by independent scientists, which despite their small size and various deficiencies demonstrated that XtendiMax and Engenia drift to damage plants much farther than industry studies suggested they could. Based on an assessment of these data, EPA scientists recommended a 135-meter (443-foot) no-spray buffer zone on all sides of treated fields to protect susceptible plants listed under the Endangered Species Act (ESA). EPA higher-ups rejected this recommendation by ignoring the majority of available data, and instead established a 57-foot buffer zone – nearly eight times smaller – that in any case only applies in 8% of the counties where XtendiMax is registered – that is, in those counties with ESA-listed dicot plants.

If EPA had honestly accounted for the massive economic, social and environmental costs of dicamba use in 2017 and 2018, it would have been constrained by federal pesticide law to ban the spraying of XtendiMax, Engenia and FeXaPan on Xtend crops rather than approve their use for another two years. In order to avoid this outcome, EPA's "benefits and impacts" assessment entirely failed to ascribe any costs to the dicamba debacle – in terms of reduced yield from drift damage, forced expenditures on Xtend seeds for self-protection, harm to pollinators and businesses (honey production) that depend on them, or social strife in rural communities. Conversely, EPA found no evidence of real benefits. In extending the registrations for two years, EPA sided with new dicamba manufacturers over farmers, rural communities and the laws it is pledged to uphold.

The Dicamba Debacle

INTRODUCTION

The past two years are unlike anything rural Americans have ever seen before. Vast fields of soybeans, entire peach orchards, conventional and organic vegetable farms, stately bald cypress trees in parks along with many thousands of other trees, and home gardens in small towns across the country – all damaged to one degree or another by the same blight. Not a disease or natural disaster, the agent of this devastation is an herbicide – dicamba – that has drifted rampantly to wreak this injury across millions of acres. The physical damage is bad enough; still worse is the dissension it has caused, tearing at the fabric of rural America. Some farmers, their crops ruined, find their livelihoods threatened; once friendly neighbors are at each other's throats. Resentment is rife, and farmers with no recourse find themselves entangled in lawsuits in attempts to recoup their losses. Dissension over a dicamba drift episode even led to a gunshot death in Arkansas (Koon 2017).

If the agent of this debacle is the herbicide dicamba, the vehicle is the crops developed to survive its deadly effects: dicamba-resistant soybeans and cotton. Like other weed-killers, dicamba injures crops as well as weeds. Long notorious for its volatility, dicamba's propensity to drift onto neighbor's crops once strictly limited its use. Genetically engineered resistance has lifted that constraint – fear of crop injury – but only for those who grow the dicamba-immune soybeans or cotton. The majority without this protection have suffered. To add insult to injury, many farmers whose crops suffered injury one year have found themselves constrained to purchase dicamba-resistant seeds the next, purely for self-protection, an insidious form of extortion.

The culprit in this dicamba debacle is the Monsanto Company (recently acquired by Bayer), the developers of dicamba-resistant soybeans and cotton. Monsanto also manufactures the XtendiMax formulation of dicamba that it claimed would solve the volatility problem. Two seasons of use have decisively refuted that claim. XtendiMax and two other supposedly "low-volatility" dicamba formulations are indisputably causing much of the conservatively estimated 5 million acres of crop damage that has occurred thus far (Bradley 2018, 2017a). And it's not only crops: in areas hard hit by dicamba drift, injury to flowering plants has deprived honeybees of sufficient nectar and pollen, resulting in steeply declining honey production (Steed 2019, Gross 2019).[6]

Monsanto is guilty twice over. In the 1990s, the company introduced Roundup Ready crops, resistant to its Roundup (glyphosate) herbicide, and unethically sold farmers on the self-serving notion that they could rely on entirely on glyphosate for weed control without risk of weeds

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[6] This report rests on the overwhelming scientific consensus that XtendiMax and other new dicamba formulations have caused much of the extensive dicamba crop damage observed over the past two years, and has caused such damage even when used in accordance with the label. Monsanto's continuing denials on this front have been decisively refuted by scientists and farmers, and will not be addressed here (for a review, see e.g. CFS 2017, 2018).

evolving resistance to it (Hartzler 2004; Hartzler et al. 2004). Now, with glyphosate-resistant weeds legion, Monsanto has sold many farmers on the supposed need for its dicamba-resistant crops and XtendiMax to control the resistant progeny of its Roundup Ready system.

If Monsanto is the culprit, government regulators are the accessories in this unprecedented devastation. After all, many genetically engineered (GE) crops and all herbicides are regulated by the U.S. Department of Agriculture (USDA) and the Environmental Protection Agency (EPA), respectively. How is it that both the GE crops and the herbicide formulations sprayed on them passed muster with these agencies? Why didn't they foresee the devastation and either keep them off the market, or enact necessary restrictions? That is the subject of this report.

Center for Food Safety is uniquely qualified to tell this story. We engaged both USDA and EPA throughout the nearly decade-long review and approval process for both dicamba-resistant crops and XtendiMax herbicide.[7] We warned both agencies – in extensive and scientifically documented comments – of the serious volatility-related drift threats posed by dicamba application to these crops (see e.g. CFS 2010, 2012, 2013, 2014). The government ignored our warnings, and those of thousands of others, including other public interest groups, scientists, and farmers with long experience of dicamba's propensity to drift (e.g. Mortensen et al. 2012, SOCC 2016).

INSET:

Different Forms of Herbicide Drift

Herbicides drift beyond the site of application in three basic ways.

All herbicides are subject to spray drift, which is the wind-blown movement of fine spray droplets emitted by spray nozzles. This occurs only during the application process.

Some herbicides like dicamba are volatile, enabling them to drift in a second way as well. Volatile herbicides readily transition (volatilize) from liquid or solid form to vapor phase. Volatilization occurs during, but also after, application. Wet or dried residues of the herbicide that have landed on plant and soil surfaces can re-volatilize into the air, leading to substantial vapor drift from hours to many days after application.

Finally, herbicide residues can attach to soil particles and be carried on the wind in dry conditions.

The type of drift determines how far herbicides travel. Droplets carried on the wind during the spraying process normally moves short distances. In contrast, herbicide vapor can travel much farther, sometimes a mile or more, depending on weather conditions. High temperatures increase volatilization. And while high winds exacerbate spray drift, vapor drift is paradoxically worse in still conditions. Lack of wind allows vapor to accumulate to hazardous concentrations. Then gentle breezes move this vapor mass to injure susceptible crops and plants, sometimes in swaths hundreds to thousands of acres in extent. Herbicides attached to particles of soil can also move great distances in high winds.

In this report, we pay particular attention to EPA's decision-making process with respect to

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[7] As noted above, Monsanto's XtendiMax is one of three dicamba formulations approved by EPA for use on dicamba-resistant crops. The others are DowDuPont's FeXaPan (a "me-too" formulation identical to XtendiMax) and BASF's Engenia. XtendiMax/FeXaPan are diglycolamine salts of dicamba; Engenia the N,N-Bis-(3-aminopropyl)methylamine (BAPMA) salt of dicamba. This report focuses on XtendiMax as the formulation for which the most information is publically available, and which was the focus of EPA's regulatory assessment. The volatility of Engenia is similar to that of XtendiMax/FeXaPan. We use the term "new dicamba" to refer to these three formulations, to distinguish them from older versions of the herbicide that are not approved for use on dicamba-resistant crops.

XtendiMax registration. Our critique frequently references work by a Pennsylvania State University team, led by Dr. David Mortensen, that has conducted extensive research on dicamba's drift threats (e.g. Egan et. al. 2014; Egan and Mortensen 2012). Other major sources are two Scientific Advisory Panels[8] that advised the Agency on pesticide drift modeling issues that bear directly on EPA's failed assessment of XtendiMax (SAP 2009, 2004).

1.0 THE REGULATORY PROCESS FOR DICAMBA-RESISTANT CROPS AND XTENDIMAX

The U.S. Dept. of Agriculture regulates field trials of most genetically engineered crops, which can only be grown commercially without regulation following USDA assessment and approval (technically, a determination of "nonregulated status"). The Environmental Protection Agency regulates pesticides (a category that includes herbicides), and following an assessment of pesticide company data approves (registers) a given pesticide formulation for particular uses, subject to usage directions detailed on the pesticide label.

1.1 Failure to Assess the Dicamba-Resistant Crop System

Even though industry conceives of and markets their products as seed-herbicide systems,[9] regulators pretend they are entirely unrelated. USDA assessed dicamba-resistant soybeans and cotton[10] without any meaningful consideration of dicamba's use on them, deferring to EPA. EPA assessed XtendiMax like any other herbicide, virtually blind to the drift-promoting implications of its use on resistant crops. This disjointed process had serious consequences.

USDA approved Xtend crops in 2015, but EPA did not register the new, putatively "low volatility" dicamba formulations for use on them until the 2017 crop season (USDA APHIS 2015, EPA 2016a). Thus, there was a two-year period when farmers growing dicamba-resistant crops crops could not legally apply any dicamba to them.[11] Limited plantings of Xtend crops in 2015 and 2016 were accompanied by extensive dicamba drift injury – the result of some farmers illegally applying older versions of dicamba to them (Laws 2016).

The two-year gap between approval of Xtend crops by USDA and "new dicamba" by EPA had three unfortunate consequences. First, it gave Monsanto a government stamp of approval to unethically sell Xtend crops to weed-challenged farmers before they could legally exploit the crops' signature feature – the ability to apply dicamba "over-the-top." Second, it also gave Monsanto a pretext for continuing to blame illegal use of old dicamba for the unprecedented dicamba crop injury that occurred in the 2017 and 2018 crop seasons, despite abundant

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[8] A Scientific Advisory Panel is an *ad hoc* group of experts appointed by EPA to meet and advise it on specific scientific and regulatory questions before the Agency. Each Panel produces a report that answers specific questions put to it by EPA staff.

[9] Monsanto refers to its seed-herbicide package as the Roundup Ready Xtend Crop System. See https://www.roundupreadyxtend.com/About/Traits/Pages/default.aspx, last visited 2/2/19.

[10] Monsanto has incorporated additional resistance to glyphosate in its soybeans and to both glyphosate and a third herbicide, glufosinate, in its cotton. They are sold under the brand names Roundup Ready 2 Xtend soybeans and XtendFlex cotton. For simplicity, we henceforth refer to both as "Xtend" or "dicamba-resistant" crops.

[11] Dicamba was originally introduced in the 1960s, and older versions (chiefly the dimethylamine salt of dicamba) have never been approved for use on dicamba-resistant crops.

evidence that XtendiMax was a big part of the problem.[12] Most critically, the 2015 and 2016 drift injury, coupled with expectations of much more damage in 2017 with widespread planting of Xtend soybeans, put enormous pressure on EPA to approve new dicamba formulations. This pressure may help explain the EPA's acceptance of Monsanto studies that EPA scientists found to be clearly deficient, setting up the debacle of the past two crop seasons.

The hazards of the piecemeal approach are well illustrated by USDA's assessment. Incredibly, USDA actually predicted that that there would be ***less*** dicamba drift damage if it granted rather than denied Monsanto's petition to "deregulate" Xtend crops (USDA APHIS 2014, p. 22). This conclusion was based on uncritical acceptance of Monsanto's claims that its new, ***yet-to-developed*** dicamba would be "low volatility," coupled with speculation about marginally increased use of old dicamba in the absence of Xtend crops. Officially, however, USDA did not own this ludicrous appraisal. Instead, it passed the buck to EPA to assess the drift and other impacts that would result from its own premature decision.[13]

In the wake of the disastrous crop injury caused by dicamba in 2017, several restrictions were imposed on how new dicamba could be used.[14] But these Monsanto-drafted changes proved to be ineffective, since new dicamba continued to drift rampantly in 2018; among weed scientists, there was "near unanimous agreement that the level of off-target injury observed in 2018 is unacceptable" (Swoboda 2018). EPA had provided for just this eventuality by including a provision that the new dicamba registrations would automatically expire on November 9, 2018, "unless the U.S. EPA determines before that date that off-site incidents are not occurring at unacceptable frequencies or levels" (XtendiMax Label 2017). Although EPA could not and did not make such a determination, it nevertheless chose to extend the registrations of XtendiMax, FeXaPan and Engenia for two more years (until December 20, 2020) a week before they would have otherwise expired (EPA 2018a). The additional usage restrictions that accompanied the extension are unlikely to ameliorate dicamba drift going forward, in part because EPA failed to include a single measure recommended by weed scientists the Agency consulted (Ibid., Swoboda 2018, Chen 2018). The revised XtendiMax label for 2019 and accompanying information and EPA analysis are discussed in Appendix 1.

1.2 Overview of EPA's Volatility Assessment

Monsanto has given the impression that its XtendiMax formulation was exhaustively tested and

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[12] Monsanto also invented other pretexts to falsely exculpate XtendiMax (see CFS 2017).

[13] Our call for integrated assessment of and regulatory action on these crop systems should not be confused with USDA's belated concession that it would be desirable to have "synchronous decisions" by USDA and EPA on herbicide-resistant crops and their companion herbicide(s), respectively (USDA APHIS 2017, pp. ES-33 to ES-35). USDA's assumption that this would prevent "significant problems" is unfounded, disproven in the case of Xtend crops by massive drift injury from use of new dicamba approved by EPA.

[14] These restrictions – which included limiting use of new dicamba to specially trained applicators (i.e. restricted use status), reducing the maximum permissible wind speed during application from 15 mph to 10 mph, prohibiting application from dusk to dawn, as well as new record-keeping requirements – were proposed by Monsanto and accepted by EPA, and reflected Monsanto's viewpoint that farmers were to blame for crop injury episodes rather than the views of independent agronomists that new dicamba's volatility was largely responsible (NFFC et al. vs. EPA 2018a).

shown not to pose a vapor drift threat. Nothing could be further from the truth. First, the company prohibited any independent research on XtendiMax drift prior to the herbicide's commercialization in 2017. Its only explanation for this extraordinary prohibition is that such testing would have delayed registration – an implicit admission that independent scientists would have found evidence of vapor drift harm that Monsanto's own testing did not reveal. This in fact turned out to be the case (CFS 2017). Second, the company has vastly exaggerated the scope of its own in-house testing – the great majority of which was conducted on already approved dicamba formulations or experimental precursors to XtendiMax (Ibid).

EPA had ample reason to fear dicamba vapor drift. As early as 2010, scientists who published extensive research on dicamba drift warned the EPA that the Xtend system would lead to serious crop and nontarget plant injury (e.g. see EPA 2011, p. 20), as did farmers with extensive practical experience with the herbicide, and civil society groups (Smith 2010; CFS 2010). The EPA conducted a screening assessment in 2013 that predicted dicamba vapor could cause substantial damage to plants up to 1,500 meters from a sprayed field (EPA 2013a, p. 11). This is discussed further in Section 5.4.3. In 2016, the Agency discussed dozens of dicamba drift injury episodes from 2012 to 2015, most in the context of dicamba-resistant crop field trials. Particularly alarming were two incidents involving vapor drift injury to soybeans 2,800 feet and 2.2 miles from fields sprayed with dicamba[15] (EPA 2016b, pp. 6-10).

In the end, however, EPA entirely dismissed these findings and warnings, and instead based its XtendiMax approval decision entirely on volatility studies conducted by Monsanto, and modeling studies by Exponent, Inc., a Monsanto contractor.

These studies were supposed to determine two values: how much dicamba vapor is present in the air beyond a field treated with XtendiMax, and how much dicamba vapor sensitive plants can withstand without being injured, with both quantities expressed as concentration of dicamba in the air. EPA's assessment concluded that dicamba vapor concentrations at the edge of a sprayed field would not exceed the amount that harms plants, and thus that there was no need for measures such as no-spray buffer zones around the field to prevent damage to neighboring plants.

In this report, we show the many ways in which these studies, and EPA's interpretation of them, dramatically underestimated the volatility threat posed by XtendiMax. However, even with their flaws, they did provide credible evidence that XtendiMax could pose a vapor drift threat, evidence that EPA glossed over (see NFFC et al. vs. EPA 2018a, 2018b).

In Section 2, we critically evaluate Monsanto's field volatility studies, which were used to establish the putative rates at which dicamba volatilizes following an XtendiMax application. In Section 3, we address the modeling conducted by Exponent, Inc. to transform these volatilization (aka flux) rates into estimates of off-field dicamba vapor concentrations under

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[15] Both episodes involved Clarity, the formulation of dicamba that Monsanto originally intended to register for use on Xtend crops.

various weather conditions. In Section 4, we critique the laboratory study Monsanto conducted to determine plant sensitivity to dicamba vapor. Section 5 presents recommendations for improving the quality of volatility studies and EPA's assessment methods. In Appendix 1, we assess the evidence upon which EPA based its two-year extension of new dicamba registrations.

2.0 FIELD VOLATILITY ASSESSMENT

2.1 Small Trials Understate Volatility Threat

EPA's assessment of XtendiMax volatilization was based on two small field volatility studies designed and conducted by Monsanto: one in Georgia of 3.4 acres and a second 9.6-acre trial in Texas (Monsanto 2016a, 2016b). One application of XtendiMax was made to bare soil in Georgia, and to small Xtend cotton plants in Texas. Sensors set up on and just off the fields measured dicamba air concentrations, which were used to calculate flux (volatilization) rates over the three days following the single applications.

In an *amicus* brief submitted in support of our lawsuit against EPA, eminent weed scientist Dr. David Mortensen found these field studies to be "shockingly insufficient," and EPA's failure to demand more extensive field testing "a fatal flaw in the Agency's review process," for several reasons (for this section, see Mortensen 2018). First, the studies were far too small in scale to project real-world effects – for the simple reason that vapor drift increases dramatically with the size of the sprayed field. As the land area that is sprayed rises, the "volume of the dicamba plume" over the dicamba-sprayed field increases, and "[t]he probability of the plume moving much further and at phytotoxically damaging concentrations is a function of the plume size." Since a typical Midwest soybean field is 160 acres in size, Monsanto's field studies were 17 to nearly 50 times too small to assess real-world vapor drift from even an average-sized field.

Even a 160-acre field study, however, would be insufficient, because of "the reality [] that many hundreds to thousands of acres on one farm will be sprayed in a compressed window of time, and many neighboring farmers are doing the same." The plume of dicamba vapor is then formed by volatilization from "the aggregate of many, many [sprayed] fields," a phenomenon known as atmospheric loading. In other words, one cannot rely on results from a test plot a few acres in size, or even one as large as a single farm field. One must consider the aggregate use of the herbicide by farmers in a given locale.

Dr. Mortensen is not alone here. Many scientists have referred to atmospheric loading of dicamba vapor from intensive local use to explain the unprecedented extent of crop damage they witnessed in 2017 (e.g. ARK DTF 2017, Appendix B, slide 29). Canadian scientists who studied the atmospheric behavior of dicamba and other pesticides for many years have even arrived at estimates of the amount of dicamba suspended in the atmosphere over the Canadian prairies, where dicamba is used on cereal crops like wheat, but not nearly as intensively as in the U.S., on dicamba-resistant crops (e.g. Waite et al. 2005; for overview, see CFS 2017, pp. 20-21).

2.2 Too Few Volatility Trials, Inappropriately Sited

Vapor drift is influenced not only by the intensity of spraying in a given locale, but by weather and other environmental factors, including temperature, relative humidity and soil properties. Because there is still much to learn about how various sets of factors interact to influence pesticide volatilization and the injury it causes, it is extremely important to conduct multiple field tests in all regions of the country where the pesticide is to be used. In fact, this is precisely what EPA regulations demand: "Field volatility studies should be conducted in areas considered representative of major areas where the pesticide is intended to be used" (EPA 2008a; see also Section 5.1 of this report).

Monsanto did not comply. Its field studies were conducted in two southern states (Texas and Georgia) where there is cotton, but extremely little soybean production. Those two states together had only 0.4% of the 91.1 million acres of soybeans planted in 31 states in 2017 (USDA NASS 2018). There were no field trials in the Corn Belt, Northern Plains, Lake or Delta States, where the great majority of soybeans are grown. And the studies were conducted earlier in the season, when it is cooler and less humid, than when most farmers would typically spray XtendiMax (see next section).

To account for regional variability, Dr. Mortensen advises that 60 to 100 field trials – on "experimental fields the size of real farm fields" – are needed to assess real-world vapor drift "over a broad range of temperature, soil moisture and relative humidity conditions" (Mortensen 2018).

2.3 Volatilization From Realistic Post-Emergence Application Never Tested

Besides being too small, too few, and misplaced, Monsanto's field volatility studies also failed to simulate the volatility-enhancing conditions of most farmers' real-world use patterns.

The chief attraction of the Xtend system to farmers is to enable "post-emergence" application of dicamba; that is, application directly to growing crops to kill weeds weeks to more than a month after the resistant crop has "emerged" or sprouted. While XtendiMax can also be applied pre-emergence, at planting time, this use is much less favored.

Unfortunately, volatilization and its adverse effects increase dramatically with post-emergence versus pre-emergence applications. First, neighboring plants have leafed out and are thus susceptible to injury. Second, the higher temperatures of later season applications tend to increase volatilization relative to earlier-season use, both for pesticides generally and dicamba in particular (Bedos et al. 2002, van den Berg et al. 1995, Breeze et al. 1992, Behrens and Lueschen 1979, Monsanto 2017a). The effect of humidity is complex, and varies by circumstance (see inset: XtendiMax Drift Injury and Relative Humidity). Finally, much of a typical post-emergence application lands on the growing crop and weeds, whereas a planting-time application encounters mostly soil. This is important because many studies have shown significantly greater volatilization from plant surfaces than from soil, with rates up to three times as high by one estimate (FOCUS 2008, p. 25 and references therein; Bedos et al. 2002). That this is true of dicamba in particular was established 40 years ago in the seminal experiments on dicamba volatility (Behrens and Lueschen 1979).

INSET

XtendiMax Drift Injury and Relative Humidity

Monsanto gives conflicting advice on how humidity affects XtendiMax volatility and spray drift. On its XtendiMax label, Monsanto directs farmers to set up their equipment to produce larger droplets under ***low humidity conditions***, or when temperatures exceed 91˚ F., to reduce spray drift (XtendiMax Label 2017, Section 9.1.2). Applicators are referred to www.xtendimaxapplicationrequirements.com for directions on how to do this, but that Monsanto website contains no special instructions on equipment adjustments to reduce drift under conditions of low humidity or temperatures > 91˚ F. (last visited 1/7/19).

In an obscure informational sheet on drift injury caused by plant growth regulator herbicides (which includes dicamba), Monsanto directly advises farmers: "Do not spray when air temperature and/or humidity is high or is expected to be high" (Monsanto 2017a). The publication provides no explanation as to why ***high humidity conditions*** pose a greater threat of drift injury, nor any instructions about measures to take when humidity is low, as the label does.

Thus, it appears that ***both low and high relative humidity can exacerbate drift in different ways***. Low humidity exacerbates herbicide drift ***during*** the spray operation by speeding up the evaporation of fine droplets to vapor phase, or at least to still finer droplets that can travel long distances much like vapor, soon after being emitted from the spray nozzle (Jordan et al. 2009, Wolf 1997). However, high humidity appears to promote volatilization ***after*** application. Volatilization increases when dried pesticide residues on the soil or plant (leaf) surfaces are re-moistened under conditions of high humidity (FOCUS 2008). EPA also recognizes that high humidity increases volatilization of pesticides like chlorpyrifos (EPA 2013b, p. 54), and a majority of pesticide applicators in Illinois found that "heat and humidity correlated with symptoms and complaints" of dicamba injury in 2017 (IFCA 2017, p. 3).

It is unclear why Monsanto failed to include any instructions to farmers to avoid spraying under high humidity conditions on the XtendiMax label, which contains the only instructions applicators are obligated to read and follow, when it elsewhere warned against this practice as increasing the risks of drift injury. EPA, which is ultimately responsible for and must approve label language, is also at fault. The likely explanation is that high humidity conditions are so frequent in soybean and cotton-growing regions that such a label prohibition would have made it nearly impossible to use XtendiMax in many areas, and that Monsanto was not willing to accept the associated loss in sales revenue.

Neither field study provided a good test of XtendiMax volatilization. In Georgia, XtendiMax was applied early in the season (May 5, 2015) to simulate a pre-emergence application, while typical Georgia cotton and soybean farmers would spray up to one or two months later, respectively, when conditions are considerably hotter and more humid (Monsanto 2016a, p. 18).[16] The temperature at the time of application (between 8 and 9 am) was just 15.62° C (= 60.1° F), while the maximum temperature that day was only 30.2° C (86.4° F) (Ibid., Appendix 1, p. 55). Temperatures in the 90's and 100's are of course common in cotton and soybean production regions throughout the U.S. In addition, the application was made to bare soil, rather than farmers' preferred post-emergence use pattern, in which crop foliage is sprayed (Ibid., p. 14).

Neither was the Texas trial a good test of XtendiMax volatilization. Although XtendiMax was applied post-emergence to Xtend cotton, the application was made just 34 days after planting when the seedlings were quite small: at the 6-8-leaf growth stage, and on average just 11" tall

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[16] Pre-emergence applications take place around planting time, and in Georgia cotton and soybeans are planted as late as June 11th and July 5th, respectively (USDA NASS 2010, p. 37). Post-emergence applications typically take place a month or more after planting.

(Monsanto 2016b, pp. 18-19). Thus, they likely intercepted only 15% of the spray.[17] This estimate is consistent with Figure 1, which shows cotton at this same growth stage. Moreover, there were likely few weeds to intercept spray, given the intensive treatment of this field with five herbicides prior to the XtendiMax application in 2015, as well as a history of heavy herbicide use in the three preceding years (Monsanto 2016b, Table 2, p. 36).

Figure 1. Low angle view of a field of early growth, 6-8 leaf stage cotton in a conventional tillage field, Tennessee. Photographer: Bill Barksdale. Design Pics Inc / Alamy Stock Photo.

Farmers often apply XtendiMax substantially later in the season, when both crop and weed foliage is more extensive and so would intercept more spray than was the case in this trial.[18]

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[17] Monsanto failed to report the parameter – percent crop coverage – that would have told what proportion of the spray was intercepted by cotton plant foliage versus soil (Monsanto 2016b, Table 5, p. 39). Our estimate that only 15% landed on the cotton plant is derived from a study that determined the relationship between cotton plant height and field coverage, which shows that cotton plants assessed 35 days after planting were 32 cm (13") in height and covered between 15% and 20% of the ground (Muharam et al. 2017, Figures 6d and 6f (blue, no fertilizer)). Assuming a similar relationship holds for Monsanto's 11" tall plants, their foliage would cover roughly 15% of the ground.

[18] We know this based on several lines of evidence. First, the XtendiMax label operative in 2017 and 2018 permitted spraying throughout the growing season on Xtend cotton, until seven days before harvest (XtendiMax Label 2017, 12.1). Second, USDA data show that cotton farmers sprayed XtendiMax and Engenia an average of 1.5 and 1.6 times, respectively, in the 2017 season (USDA NASS 2017). This means roughly half of growers made two applications rather than just one. Even if the first application were early (as in both the Texas and Georgia trials),

As discussed above, volatilization increases with temperature and when the herbicide lands on plant foliage rather than soil. Thus, both field studies understated volatilization relative to farmer use patterns, due to temperatures that were lower, and plant foliage that was either absent (Georgia) or far less extensive (Texas) than is usually encountered in real-world farmer practice.

2.4 Tank Mix Partners Can Increase Dicamba Volatility

Like other herbicides, XtendiMax is often used in mixtures with other pesticides and additives called tank mixes. As EPA acknowledged in its XtendiMax risk assessments, interactions between the components of a tank mix can result in "chemistry changes in the applicator's tank [that] may alter the risk associated with the pesticide application," including increased spray drift or volatility (EPA 2016c, pp. 14-15).

EPA scientists accordingly recommended a prohibition on tank-mixing XtendiMax, unless specific tests were conducted that showed the tank mix products in question would not "increase the likelihood of drift/volatility" (EPA 2016d, p. 5). However, EPA subsequently registered XtendiMax without the volatility testing requirement, and authorized tank mixes after testing only for "spray drift properties" (EPA 2016a, Appendix A, p. 4). This is important because detection of increased volatility requires different tests than those used to assess the potential for increased spray drift. EPA thus permitted XtendiMax to be used in mixtures that may increase the herbicide's volatility, despite explicitly acknowledging this to be a risk.

Still worse, EPA has learned since the original registration in 2016 that tank mix partners that lower the pH of tank mixtures increase the volatility of XtendiMax (Monsanto 2018b, label section 8.0). Instead of acting on this knowledge, EPA extended the XtendiMax registration for two years without demanding pH testing of tank mixtures; the tank mix testing protocol continues to require tests only for "spray drift properties," and not pH or volatility (Ibid., Appendix A, p. 8).

The criticisms in the preceding sections relate to failings in how Monsanto designed its field volatility testing process, as well as EPA's flawed assessment and regulation. Even on their own terms, however, Monsanto's two volatility studies were improperly conducted in ways that understated drift.

2.5 Spray Settings Understate Real-World Spray and Vapor Drift

Monsanto conducted the spray operations in its two field studies in ways that minimized spray and vapor drift. It is commonly supposed that any drift during application is spray drift, while

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the second would be made substantially later than the 6-8 leaf growth stage, only after a new flush of weeds had had the time to emerge. Third, we know from long experience with Roundup Ready crops that many growers delay post-emergence herbicide applications until weeds are rather large, in hopes of making do with a single application for the entire year (Hager 2004).

vapor drift occurs only afterwards. In fact, the two cannot be distinguished so cleanly. As EPA states: “Volatilization can occur during the application process or thereafter. It can result from aerosols evaporating during application, while deposited sprays are still drying (possibly via co-distillation), or after as dried deposited residues volatilize” (EPA 2016e, p. 12).

Vapor and spray drift are influenced by how the spray equipment is set up and operated. The herbicide spray solution is forced through a nozzle under pressure. High sprayer pressures exacerbate drift by reducing the size of droplets exiting the spray nozzle. Smaller, lighter droplets drift farther than larger, heavier ones. Depending on their initial size, fine droplets can evaporate rapidly, transitioning to still finer droplets or to vapor phase, soon after leaving the spray nozzle (Wolf 1997). The finest droplets (smaller than roughly 150 microns in diameter) are difficult to distinguish from vapor in terms of their behavior: both stay aloft for extended periods and can drift long distances (Jordan et al. 2009). Drift also increases with the height of the boom-mounted nozzles above the crop canopy or soil surface (so-called boom height), and with the operating speed of the sprayer, because in these situations spray is more exposed to higher velocity and/or more turbulent winds (TeeJet Technical undated, p. 150; University of KY 2016).

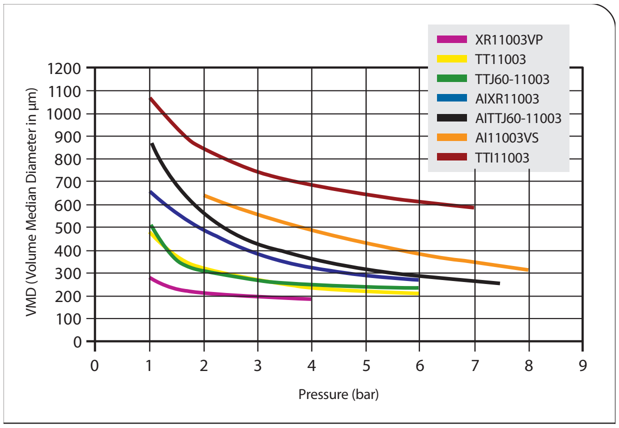
The XtendiMax label prescribes how farmers must use the herbicide. It specifies maximum sprayer pressure, boom height and equipment ground speed in order to mitigate drift. The label also mandates use of drift-reducing nozzles, which achieve their effect by increasing the average spray droplet size (see inset: Sprayer Pressure and Droplet Size for XtendiMax-Approved Nozzles). In order to provide a reasonably accurate assessment of drift, field volatility studies have to be conducted with the most drift-promoting sprayer parameters that farmers can legally use, as specified on the label.

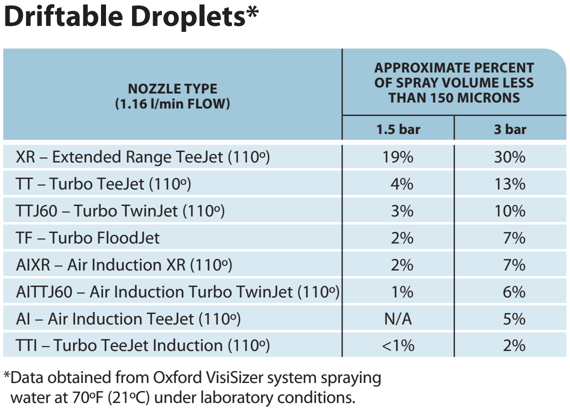
INSET:

Sprayer Pressure and Droplet Size for XtendiMax-Approved Nozzles

The nozzles approved for use with XtendiMax are said to emit “ultra-coarse” (big) droplets. This is an over-simplification. All nozzles produce a range of droplet sizes called the droplet size spectrum. Droplet size labels (eight categories from “extremely fine” to “ultra-coarse”) are based on the volume median diameter (VMD), the droplet size at which half of the spray volume is composed of larger, and half of smaller, droplets (Wilson undated). Thus, even “ultra-coarse” nozzles emit many droplets much smaller in size than the VMD.

Figure 2 below shows how droplet size (VMD) declines with increasing sprayer pressure for several TeeJet Technologies’ nozzles, including two approved for XtendiMax (TTI11003 and AI11003VS). Figure 3 shows how the percent of driftable droplets (< 150 microns in size) likewise increases with sprayer pressure. For the TTI Turbo TeeJet Induction line of nozzles approved for XtendiMax, the proportion of driftable droplets more than doubles from <1% to 2% of the spray volume as pressure increases from 1.5 bar to 3 bar (21.8 to 43.5 psi). At the maximum permitted sprayer pressure of 63 psi (4.34 bar) for the TII11004 nozzle, one would expect perhaps 3% of the spray volume to be comprised of driftable droplets directly after emission from the nozzle. Evaporation of marginally larger droplets would result in a still higher proportion of driftable (< 150 um) droplets within one to several minutes after emission (Wolf 1997). These results were obtained under laboratory conditions based on water; XtendiMax may give different results.





Driftable Droplets*

NOZZLE TYPE (1.16 l/min FLOW)	APPROXIMATE PERCENT OF SPRAY VOLUME LESS THAN 150 MICRONS	
	1.5 bar	3 bar
XR – Extended Range TeeJet (110°)	19%	30%
TT – Turbo TeeJet (110°)	4%	13%
TTJ60 – Turbo TwinJet (110°)	3%	10%
TF – Turbo FloodJet	2%	7%
AIXR – Air Induction XR (110°)	2%	7%
AITTJ60 – Air Induction Turbo TwinJet (110°)	1%	6%
AI – Air Induction TeeJet (110°)	N/A	5%
TTI – Turbo TeeJet Induction (110°)	<1%	2%

*Data obtained from Oxford VisiSizer system spraying water at 70°F (21°C) under laboratory conditions.

Figures 2 and 3. Relationship between sprayer pressure and droplet size for Teejet Technologies TTI line of nozzles approved for use with XtendiMax. Source: TeeJet Technologies (undated), pp. 148, 151. For XtendiMax-approved nozzles, see http://www.xtendimaxapplicationrequirements.com/Pages/nozzles.aspx (last visited 10/23/18).

Instead, Monsanto chose settings that minimized drift. In both the Georgia and Texas trials, the sprayer pressure was less than half the maximum permitted. The boom was positioned closer to the soil surface (Georgia) or crop canopy (Texas) than the highest setting permitted by the label. And the sprayer was driven at less than half the label-specified limit (Table 1). In fact, Monsanto conducted the trials with the explicit intention of minimizing drift: "[B]oom [aka sprayer] pressure will be set near the low end of the pressure range specified by the nozzle manufacturer ***to minimize the potential for drift***" (emphasis added; identical language in Monsanto 2016a, p. 292; Monsanto 2016b, p. 289).

Table 1: Spray Parameters for TeeJet TII11004 Nozzle – Field Volatility Studies vs. Label

Parameter	Georgia	Texas	XtendiMax Label
Sprayer pressure (psi)	27-28	25	20 to 63
Boom height (inches)	18*	14-18**	24 (max. "above target pest or crop canopy")
Sprayer speed (mph)	6.8	7.23	15 (max.)

Sources: Monsanto (2016a), p. 19; Monsanto (2016b), p. 19; XtendiMax Label (2017), Section 9.1.1: Sprayer Setup. For permissible sprayer pressure with the TTI11004 nozzle used in both field studies, see http://www.xtendimaxapplicationrequirements.com/Pages/nozzles.aspx (last visited 10/3/18).

* Distance above soil

** Distance above crop canopy

Some might suggest that these spray parameters only minimize the potential for spray drift, and thus are irrelevant to the vapor drift being investigated by the field studies at issue here. This argument is based on the false premise that there is an absolute distinction between the two forms of drift. As explained above, fine spray ***behaves*** much like vapor in the air, and very fine droplets can rapidly ***transition to vapor*** once out of the nozzle. Raising sprayer pressure increases the proportion of driftable droplets that can transition to vapor with any nozzle, even one that emits mostly coarse droplets. Likewise, increases in boom height and sprayer operating speed increase the potential for longer-distance travel of droplets that can transition to vapor by exposing spray to higher velocity and/or more turbulent wind (see inset).

In view of these facts, Monsanto's drift-minimizing spray parameters in the Georgia and Texas field volatility studies clearly led to results that understated the distance that dicamba drifts relative to real-world farmer use patterns.[19]

2.6 Monsanto Fails to Conduct Plant Effects Evaluations

While the main purpose of Monsanto's field volatility studies was to calculate volatilization rates for use in modeling, one trial originally had a minor drift injury component as well. In the Georgia study, Monsanto's protocol called for placing potted soybean seedlings just beyond the boundaries of the treated plot ***after spraying was completed***, next to sensors that measure dicamba vapor concentration. The purpose of this "plant effects evaluation" was to detect ***post-application*** vapor drift, which would show up as visual injury and height reduction in the soybean plants relative to unexposed control plants. This evaluation could have provided data correlating any dicamba injury to dicamba vapor concentration under real-world conditions.

However, Monsanto cancelled this part of its Georgia study, ostensibly because the indicator soybean plants were sick, and "plants with poor plant health [sic] would not provide representative effects of a healthy plant response" (Monsanto 2016a: pp. 297-299, 313). That the world's largest seed company is seemingly incapable of growing a few dozen healthy soybean plants in pots is ironic, but also suspicious. If Monsanto really had sick plants in Georgia, and truly wanted the data this evaluation could have provided, the company would have repeated the experiment, or least have taken pains to ensure that it was carried out in the Texas field volatility study, conducted a month later. However, Monsanto did not even bother to write a plant effects evaluation into the protocol for its Texas study (Monsanto 2016b, Appendix 9, p. 278 ff.).

Had it been carried out, the experiment would only have captured the plant injury effects of ***post-application*** volatilization, not that which occurs ***during*** application. Even with this design bias against injury findings (see Section 2.7.1), Monsanto might have decided against this evaluation in both studies from fear that it would reveal unwelcome evidence of soybean injury at low dicamba vapor concentrations under field conditions. As discussed in Section 4, Monsanto instead relied entirely on a dubious laboratory study to estimate the amount of dicamba vapor that soybean plants can withstand without injury.

2.7 Other Deficiencies Give Rise to Uncertainties

EPA scientists with the Environmental Fate and Effects Division (EFED) who reviewed the volatility field studies found still other serious deficiencies that were essentially ignored in the decision to approve XtendiMax by the Agency's Registration Division (for following discussion, see EPA 2016f, pp. 9-12). Additional data needed to resolve uncertainties were not provided.

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[19] Farmers and custom applicators are incentivized to use the highest spray pressure and sprayer travel speed they can in order to save time, especially if they have much cropland to spray. The two factors are linked. Increased pressure means greater herbicide output, which allows for faster sprayer speeds and hence time savings.

See inset “Pesticide Volatilization Rates and Vapor Concentrations” for background on this section.

Pesticide Volatilization Rates and Vapor Concentrations

The volatilization rate, also known as the flux rate, is the amount of a substance that volatilizes to vapor from a given surface area per unit time. Thus, a flux rate of 1 ug/m^2-second means that every second, 1 microgram (ug) volatilizes from every square meter to which the substance has been applied. The flux rate is a function of the properties of the substance and the surface from which it volatilizes as well as application rate, atmospheric conditions, especially temperature, and other factors.

To calculate flux rates of pesticides in the context of a field volatility study, air samplers that are positioned on and off a treated field pull in air through a filter, which traps vapor. The weight of the trapped vapor divided by the volume of air pulled through the sampler gives the average air concentration for the sampling period (typically, 2 to 12 hours). The flux rate necessary to produce the vapor concentration for each sampling period is then calculated, taking account of weather conditions. Off-field samplers are typically used to calculate flux during pesticide application; on-site samplers for post-application flux rates. A flux profile comprises the time series of changing flux rates calculated over the course of the field volatility study, which is typically three days.

An air dispersion model then uses the flux profile, together with historical data on weather conditions at various locations where the pesticide is to be used, among other data, to estimate the pesticide’s vapor drift in terms of vapor concentrations at various distances off-field (see Section 3.2).

2.7.1 Highest flux rates ignored

As noted above, pesticides volatilize both during and after application. In both the Georgia and Texas field studies, however, Monsanto disregarded the higher volatilization rates that occurred during application (EPA 2016f, pp. 8, 12). This led to underestimates of dicamba vapor drift from XtendiMax applications in computer modeling, as discussed further in Section 3.2.

In Georgia, the flux rate during application was eight-fold higher than that in the highest post-application period: from 0 to 6 hours after spraying was completed.[20] The absolute amount of applied dicamba lost to volatilization during the 22 minutes (0.367 hour) it took to apply XtendiMax to the 3.4 acre plot amounted to over half (53%) of the volatilization loss over the first six hours after application.[21]

In the Texas field study, EPA states that Monsanto simply discarded the off-field sampler data needed to calculate flux during the XtendiMax application, and that “[s]ubmission of this discarded data would reduce some of the uncertainties discussed in this document” (EPA 2016f, p. 9). In fact, Monsanto calculated a flux rate, but decided not to report it (Monsanto 2016b, p. 13). The company’s report, however, contains off-field sample data (Table 2). It is not clear why EPA did not use these data to calculate the flux rate itself.

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[20] See Monsanto (2016a), Table 9, p. 44, showing flux rate during application = 0.008079 ug/m^2-second and flux rate 0-6 hours after application = 0.001017 ug/m^2-second.

[21] See Monsanto (2016a), Table 9, p. 44: “mass loss” during 0.367-hour application period of 0.000146 kg is 53% of the 0.000276 kg mass lost during the 0-6 hour post-application period.

Table 2: Off-Field Dicamba Air Concentrations During XtendiMax Application			
Time of Sample	**Location of Sample**	**Dicamba concentration (ug/m^3)**	
		Georgia	**Texas**
At Treatment	Corner NW	0.00000	0.00000
At Treatment	Corner NE	0.00000	0.03182
At Treatment	Corner SW	0.05189	0.00000
At Treatment	Corner SE	0.00000	0.00915
At Treatment	Edge N	0.00000	0.43418
At Treatment	Edge S	0.02370	0.00563
At Treatment	Edge E	0.00000	0.09232
At Treatment	Edge W	0.05846	0.00000

Legend: Eight air samplers in both trials were placed at equal distances from the corners and edges of the square fields. In Georgia, 15 m beyond the field perimeter at a height of 1.5 m; in Texas, 5 m from the field perimeter at a height of 0.43 m. Sources: Monsanto (2016a), p. 20 & Appendix 4, p. 78; Monsanto (2016b), p. 20 & Appendix 4, p. 77.

Flux during application was considerably greater in Texas for two reasons. First, the flux rate is directly proportional to air concentration in the indirect method used to calculate flux during application (Monsanto 2016a, pp. 23-24), and off-field concentrations were considerably higher in Texas than in Georgia. As shown in Table 2, for instance, the highest concentration in Texas (0.43418 ug/m^3) was over seven-fold greater than the highest Georgia value (0.05846 ug/m^3). Second, Texas values were so much higher despite the fact that only half as much XtendiMax was applied,[22] and flux rate also increases with rate of application (EPA 2013b, p. 49). This has implications for modeling, as discussed in Section 3.2.

2.7.2 Failure to aggregate different forms of drift

Monsanto's ostensible reason for not reporting the Texas flux rate is that the value might represent not only vapor, but also "spray droplets or dicamba-containing dust particles" (Monsanto 2016b, p. 13). As we have seen, however, it is almost impossible to cleanly differentiate spray and vapor drift during application, when both can and do occur. Fine droplets behave much like vapor in terms of off-target movement; and in any case can rapidly volatilize soon after leaving the spray nozzle.

While analytical effort and sophisticated testing to parse the contribution of different kinds of drift to off-field plant exposure and injury could be useful, it is even more important to ensure that the risk assessment aggregates exposure from all routes. After all, it is the total exposure experienced by off-field plants that ultimately determines injury levels and requires assessment. This was explicitly recommended to the EPA by its Scientific Advisory Panel a decade ago, in the context of assessing the human health risks of inhaling the vapor of conventional pesticides, and it applies equally to non-target plant risks:

> "the Panel was interested in how the MOE [margin of exposure] approach could be used to combine the three routes of exposure via volatilization, spray drift and respirable particles to assess cumulative or aggregate inhalation risk" (SAP 2009, p. 50-51).

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[22] 0.5 lb./acre in Texas, 1.0 lb./acre in Georgia (Monsanto 2016a, 2016b, p. 12).

Egan and Mortensen (2012) make the same point in their study of dicamba vapor drift:

> "Because our experimental design does not include assessment of particle drift or additional routes of exposure including residual herbicide in spray equipment or atmospheric deposition, total nontarget exposures to crops and wild plants could be substantially greater than our predictions for vapor drift."

Nowhere in its original risk assessment did EPA cumulatively assess the risk to plants from the three exposure routes identified by Monsanto, an EPA Scientific Advisory Panel and independent scientists.

2.7.3 Trials not conducted under weather conditions that optimize volatilization

The weather conditions that prevailed during and just after XtendiMax applications in the two trials were not optimal for volatilization or co-distillation, a related process.[23] In Georgia, EPA scientists found that "losses [of applied dicamba due to volatilization] could have been greater if applied earlier [in the day]." In Texas, XtendiMax was applied in the early afternoon, and morning application "could have provided a more vulnerable set of conditions for loss of dicamba [due to volatilization] from the field" (EPA 2016f, p. 9). The failure to test XtendiMax under conditions that optimize volatilization means the data underestimate real-world vapor drift potential. This deficiency is all the more egregious in light of the fact that volatilization data are derived from just two trials in two states, while real-world XtendiMax applications are made under a huge range of conditions, including those that most enhance volatilization, on many millions of acres of Xtend crops across the country.

2.7.4 Resolving "uncertainties" required data that were never provided

The term "uncertainty" or its plural form is used 15 times by EPA scientists in their most detailed volatility assessment of XtendiMax. Agency scientists found that the major deficiencies discussed above may have resulted in underestimation of vapor drift in both studies:

> The uncertainties associated with the flux data and deposition analysis, especially for the flux data from Texas, could result in underestimates of vapor drift under conditions more conducive to co-distillation than were tested in these studies. (EPA 2016f, pp. 6-7)

Thus, they repeatedly called for more data to resolve these uncertainties, including additional research on applications during the morning weather transition window, and incorporation of the flux during application into modeling of deposition (Ibid., p. 7). In the absence of these additional data (XtendiMax was registered just six days later), EPA scientists carefully hedged their conclusions:

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[23] While volatilization is the evaporation of herbicide molecules directly from water, soil or plant surfaces, co-distillation is evaporation of herbicide molecules together with water vapor (Fennimore 2005). Codistillation is favored when temperatures, moisture and pH are high, and the soil's organic matter contact is low (Hanson 2014).

> It is possible that volatilization could be greater under conditions outside the scope of the submitted studies. (Ibid., p. 3)
>
> As with all risk assessments, conclusions are made within the bounds of the stated uncertainties. In this case, these principally include whether the submitted field volatility studies adequately encompass the extremes of conditions that cause volatilization… (Ibid., p. 3)

Clearly concerned that their assessment was far from definitive, they recommended "post-marketing surveillance" for drift episodes under real-world use:

> If registration of M-1691 and/or M-1768 [XtendiMax] is granted, EFED recommends analysis of any post-registration incident reports associated with their usage to confirm the findings in this analysis concerning the volatilization route of exposure (Ibid., p. 4).

These numerous uncertainties regarding XtendiMax volatilization help explain why EPA took the unusual – and to our knowledge unprecedented – step of not only limiting the registration to two years, but including an explicit clause that it would expire absent an EPA determination that "off-site incidents are not occurring at unacceptable frequencies or levels" (XtendiMax Label 2017, p. 1 of label). As discussed in Appendix 1, EPA extended the registration of XtendiMax for two years despite continuing massive drift damage, without making such a determination.

2.8 Conclusion to Field Volatility Assessment

In conclusion, EPA had far too little field data – none of it realistic – on which to base its assessment of XtendiMax vapor drift. The Georgia and Texas trials were much too small to simulate real-world conditions. The two field studies did not begin to assess volatilization in the broad range of environments where XtendiMax is used; neither was even conducted in a soybean production region, where most XtendiMax is sprayed. The trials were conducted too early in the season, and thus failed to account for increased volatility from the high temperatures of summer, and from abundant crop and weed foliage. The potential volatility-increasing effects of tank mixes have gone untested.

Even on their own terms, the field studies were flawed. Spray parameters like sprayer pressure and boom height were intentionally chosen to minimize drift. Monsanto failed to assess off-field plant injury in either field volatility trial, meaning total reliance on an unrealistic "humidome" study for this key parameter (see Section 4). Monsanto excluded the far greater volatilization rate during application from its flux rate calculations, which were based only on lower post-application flux. There was no effort to aggregate different forms of drift (vapor, spray and particle), despite the fact that only total exposure matters to off-field plants. XtendiMax applications were timed so as to miss the most volatility-enhancing, early morning hours.

Despite numerous uncertainties in the volatility assessment, additional data requested by EPA scientists were not collected. EPA had so little confidence in its assessment that it imposed an unprecedented two-year sunset clause that could have been reversed only if EPA determined that drift was not occurring at “unacceptable frequencies” – clear evidence that the Agency anticipated precisely this outcome as at least a strong possibility.

The artificially low volatilization rates derived from the field studies served as key inputs for computer modeling of off-field dicamba air concentrations. In the next section, we discuss first the unsuitability of the model that was used; and how modeling based on the deficient field studies led to a vast underestimate of the dicamba drift threat.

3.0 FAULTY MODELING FAILS TO COMPENSATE FOR FIELD TRIAL DEFICIENCIES

Even if Monsanto’s field studies had been properly conducted, their results would only represent vapor drift of XtendiMax when sprayed on tiny plots of just 3.4 (Georgia) and 9.6 (Texas) acres, under the respective conditions prevailing at those sites during the trials. This is where modeling comes in. In general, pesticide air dispersion models take the particularized flux data from empirical studies, such as those on XtendiMax in Georgia and Texas, as the basis for predicting how the same pesticide would behave when sprayed on fields of different size, under a wide range of environmental conditions.

While modeling may in theory offer a means of generalizing the results of a few field studies, it is still in a primitive state of development with respect to predicting pesticide drift (see INSET). Modeling is also highly technical and hence exceedingly non-transparent; expertise in modeling opens up many opportunities to bias results in ways that easily escape detection.

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INSET

Models to Estimate Pesticide Drift in Need of Much Improvement

Despite decades of work on development of models to predict the volatilization and vapor drift of pesticides, even those most involved in the endeavor concede their weaknesses. In an exhaustive review of such models, a team of university, government and industry scientists in Europe recommended that empirical data from field and laboratory experiments, where available, be preferred to modeling estimates (FOCUS 2008, pp. 94-95). Modeling is especially unreliable for prediction of volatilization from plant surfaces, which occurs at greater rates than volatilization from soils, for pesticides in general and dicamba in particular (FOCUS 2008, Bedos et al. 2002, Behrens and Lueschen 1979):

> Currently, no models are available for reliable, physical based estimation of volatilization fluxes of pesticides from plant surfaces (Wolters 2003, p. 22).

While EPA has considerable expertise with air pollutant dispersion modeling, it is centered in the Agency’s Office of Air and Radiation, and nearly all focused on predicting the behavior of traditional pollutants from smokestacks and vehicles. The EPA’s Office of Pesticide Programs has historically focused on efforts to mitigate spray drift (defined to explicitly exclude volatility) through pesticide label statements (EPA 2001). Volatilization was first addressed in the context of the human health risks posed by the off-target movement of soil fumigants. EPA has essentially no guidelines or validated models for assessing the vapor drift risks to non-target plants of conventional pesticides like dicamba. Moreover, EPA has not adapted its regulatory framework to account for the increased drift threats posed by herbicides when used in the context of herbicide-resistant crop systems.

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Monsanto commissioned the consulting firm Exponent, Inc. to model dicamba vapor drift from a hypothetical field sprayed with XtendiMax. Exponent estimated the amount of dicamba that would settle on plants or the ground (deposition) and the amount that would remain airborne (air concentrations) at various distances from the edge of the simulated field. Here, we address only the modeling of off-field air concentrations, which was conducted with use of the PERFUM model (Exponent 2016).

3.1 EPA Allowed Monsanto to Use an Inappropriate Model

PERFUM – which stands for **P**robabilistic **E**xposure and **R**isk Model for **FUM**igants – is entirely unsuitable for assessing dicamba's volatilization threat. In this section, we discuss the many reasons this is so. Section 3.2 then shows that even if one assumes the model could provide useful estimates, it was badly misused to substantially understate dicamba volatilization.

3.1.1 Model developed for soil fumigants, not conventional pesticides

As its name suggests, PERFUM was developed to assess the human health risks posed by soil fumigants, a small class of specialty biocides that have very different properties, uses and application methods than conventional pesticides (see Froines et al. 2013 for this discussion).[24] These differences make PERFUM unsuitable for modeling the volatility of conventional pesticides.

Fumigants are injected into soil. Their extremely high volatility is essential to performing their function, which is to permeate the soil in gaseous form to kill pests such as nematodes and insects (and in the process destroy all soil life). In contrast, conventional pesticides are generally less volatile, and are sprayed into the air rather than the soil. The volatilization of most conventional pesticides depends more on environmental and spraying conditions than is the case with fumigants and other highly volatile pesticides (FOCUS 2008, p. 22). As noted in Section 2.3, greater volatilization occurs from plant surfaces than from soil.

Fumigants are used at much higher rates (50-400 lbs./acre), but at much smaller scale than conventional pesticides. This relates to their use on high-value fruit and vegetable crops, which are generally grown in beds of 1 to 40 acres (Reiss and Griffin 2004, p. 13) that are usually covered with tarps to impede vapor loss. Most conventional pesticides are applied at substantially lower rates, but much more extensively, to field crops planted on fields and farms many hundreds to thousands of acres in size.

Fumigant use is highly concentrated in the West and Southeast (especially California and Florida), regions with environmental conditions far different than those in the Midwest, where the majority of field crop production and conventional pesticide use take place. This is significant because volatility is greatly influenced by weather conditions, soil properties and other environmental factors.

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[24] In this context, EPA defines conventional pesticides as essentially any pesticide except fumigants and antimicrobials (EPA 2009a, p. 16).

PERFUM's ostensible purpose is to establish buffer zones to protect bystanders from inhaling hazardous levels of fumigant vapors. Until now, it has never been used for the very different task of evaluating vapor drift of herbicides to prevent off-target plant injury.

3.1.2 PERFUM introduced to win approval of hazardous fumigant

The Arvesta Corporation (now Arysta LifeScience) funded development of the PERFUM model in 2004 to gain EPA and state approval of its soil fumigant, methyl iodide, also known as iodomethane (Reiss and Griffin 2004, 2006). The problem Arysta faced was that methyl iodide is both highly volatile and extremely toxic. Fifty-four leading scientists were so alarmed by the prospect of its agricultural use that they jointly wrote a letter to EPA urging the Agency to deny its registration.[25] EPA nevertheless registered methyl iodide, based in large part on the assumption that PERFUM-calculated no-spray buffer zones would protect bystanders.

As its creators conceded, PERFUM was developed specifically to reduce the 1,000 to over 4,000-foot buffer zones that would have been required for methyl iodide using the approach then employed by the California Department of Pesticide Regulation (Reiss and Griffin 2004, p. 15). Thanks in part to PERFUM, the buffer zones EPA eventually mandated were just 25 to 500 feet (depending on field size) – one to two orders of magnitude smaller (EPA 2009b). They were also in line with the 300 feet that PERFUM's developers regarded as the largest that were "practical for agriculture," since larger buffer zones would "significantly limit[] the amount of agricultural land that a farmer can use for growing" (Reiss and Griffin 2004, p. 15). Note the unspoken assumption that buffers had to be reduced to facilitate methyl iodide's use, which glossed over the obvious alternative of simply not introducing a fumigant whose toxicity was such that safe use required "impractical" buffer zones. Though approved by EPA in 2007 and by California authorities in 2010, farmers made very little use of the fumigant due to its toxicity, and EPA cancelled its registration at the manufacturer's request in 2013 (Froines et al. 2013).

PERFUM is now maintained by Exponent, Inc., where its two developers are now employed. According to Dr. David Michaels – head of the Occupational Health and Safety Administration (OSHA) during Obama's tenure, and author of an expose of corporate junk science entitled *Doubt is Their Product* – Exponent is "one of the premier firms in the product defense business" (Michaels 2008). Exponent hires itself out to corporations to help them contest the hazards of their products, and thus reduce or eliminate regulation of them. Exponent's work has involved reports attacking the science showing the human health threats of asbestos, chromium, beryllium and perchlorate. Exponent worked for Syngenta to contest epidemiology showing associations between the company's atrazine herbicide and its own plant workers' prostate cancer; and for CropLife America (the pesticide industry's lobby group) to discount the substantial epidemiological evidence linking Parkinson's disease to pesticide exposure.

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[25] Their major concern was that "alkylating agents like methyl iodide are extraordinarily well-known cancer hazards in the chemical community because of their ability to modify the chemist's own DNA, as well as the target molecules in the flask, leading to mutations that are potentially very harmful." They also noted that animal studies showed methyl iodide causes neurological damage and fetal loss as well as thyroid gland toxicity (Bergman et al. 2007).

Exponent even wrote a study for the American Beverage Association defending school vending machines that dispensed soft drinks, claiming students' consumption was not excessive (Michaels 2008).

Thus, pesticide industry personnel and consultants were responsible for both generating the volatilization data for XtendiMax and developing the model used to interpret that data for regulatory decision-making.

3.1.3 PERFUM based on outdated dispersion model

PERFUM incorporates an obsolete dispersion model that EPA once used to estimate pollutant concentrations downwind of industrial smokestacks: the Industrial Source Complex Short Term Model, Version 3 (ISCST3). ISCST3 was first adapted for use in predicting soil fumigant exposure by the California Department of Pesticide Regulation in the 1990s (Johnson et al. 2010). EPA permitted Monsanto and its contractor Exponent, Inc. to utilize PERFUM despite the fact that its ISCST3 core has long been superseded; and despite numerous criticisms of its performance by two Scientific Advisory Panels.

In 2005, EPA formally replaced ISC3 with a more sophisticated model known as AERMOD (EPA 2005).[26] AERMOD is a joint development of EPA and the American Meteorological Society, and provides significantly more accurate pollutant dispersion estimates than ISCST3 because of improvements in 14 areas, summarized as follows:

> Relative to ISCST3, AERMOD as proposed contained new or improved algorithms for: 1) dispersion in both the convective and stable boundary layers; 2) plume rise and buoyancy; 3) plume penetration into elevated inversions; 4) treatment of elevated, near-surface, and surface level sources; 5) computation of vertical profiles of wind, turbulence, and temperature; and 6) the treatment of receptors on all types of terrain (from the surface up to and above the plume height) (EPA 2003, pp. 7-9, Table 1)

While some of the superior features in AERMOD are more relevant to the modeling of smokestack pollution, others result in more accurate predictions of fumigant vapor drift than is possible with ISCST3-based PERFUM. For instance, a Scientific Advisory Panel (henceforth, SAP) advising the EPA found that PERFUM's ISCST3 core does not do a good job of predicting fumigant drift in hilly, uneven terrain; and cannot account for variable wind speeds and directions at heights below 10 meters (SAP 2004, pp. 24, 27). This SAP "thought that many of the limitations in the ISCST3 model (the core of PERFUM) would be alleviated when the Agency adopts AERMOD," and that "approving the AERMOD model should be a high priority" for EPA so that it "could then be integrated into PERFUM" (SAP 2004, pp. 11, 24).

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[26] The rule establishing AERMOD as the preferred air dispersion model in place of ISC3 became effective December 9, 2005. After a one-year transition period, "the new model – AERMOD – should be used for appropriate application as replacement for ISC3." See https://www.epa.gov/scram/air-quality-dispersion-modeling-alternative-models#note, last visited 1/10/19. Note: ISCST3 is the **S**hort-**T**erm version of ISC3.

PERFUM's developers broached the idea of integrating AERMOD into PERFUM in 2006 (Reiss and Griffin 2006). Yet 10 years later, the Version 2.5 used to model XtendiMax vapor drift still had the outdated ISCST3 core (Exponent 2016, p. 11); and this version was last updated a full decade ago in 2008 (Reiss and Griffin 2008).[27] In contrast, EPA has updated AERMOD numerous times since it was introduced in 2005.[28] Updates are critical both to eliminate bugs and introduce improved modeling capabilities. PERFUM is stuck in the past with its obsolete ISCST3 dispersion model.

The SAP also noted that the method used by PERFUM to estimate uncertainty in fluxes is likely to "underestimate the frequency of high-end emissions and associated high-end buffer zone lengths" (SAP 2004, p. 18). This criticism may be moot, however, since in the latest 2008 version of PERFUM its developers have eliminated any treatment of uncertainty in fluxes (Reiss and Griffin 2008, p. 17). These and other deficiencies noted by this expert Panel cast doubt on Exponent's claim that the SAP found PERFUM to be "scientifically sound."[29]

Whether or not PERFUM is a reliable model for establishing buffer zones to protect human health from fumigant drift, it is clearly unsuited to assessment of off-target plant injury from the vapor drift of conventional pesticides like dicamba.

3.1.4 PERFUM not validated for conventional pesticides

In the 1990s and 2000s, public interest groups demonstrated that pesticides in the air in many rural areas put the health of residents, particularly children, at risk. The pesticides responsible were not only fumigants, but also conventional, semi-volatile pesticides like the insecticide chlorpyrifos and the herbicide molinate (Kegley 2003; EPA 2009a, pp. 10-11). EPA was slow to respond. As late as 2009, the Agency admitted it had essentially ignored the volatilization risks posed by most conventional pesticides: assessments were the exception rather than the rule, and flux studies were rare (EPA 2009a, pp. 15, 20).

In 2009, EPA appointed a second Scientific Advisory Panel to assess the suitability of several fate and transport models for estimating conventional pesticide flux rates, and PERFUM and one other dispersion model to predict off-field vapor concentrations. EPA presented several case studies for the SAP's consideration. The SAP's response was quite emphatic:

> "The Panel believed that the way the models were used in the Agency's case studies was inappropriate. For example, PERFUM is a model that was developed and field validated to estimate fumigant volatilization and downwind movement and concentrations under

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[27] "The current version of the model is version 2.5." https://www.exponent.com/experience/probablistic-exposure-and-risk-model-for-fumigants/?pageSize=NaN&pageNum=0&loadAllByPageSize=true (last visited 9/21/18). See hyperlink to "User's Guide" on this website, showing version 2.5 dates to 2008.

[28] See https://www3.epa.gov/ttn/scram/models/aermod/AERMOD_MCB11_v15181.pdf, last visited 1/9/19.

[29] See Reiss and Griffin (2006), repeated on the webpage in the next footnote, for Exponent's claim. What the SAP actually wrote was merely that: "The description of the model components was considered to be scientifically sound…." In fact, the SAP even noted that ISCST3 was developed for "industrial-source complexes," and questioned whether it was "appropriate to use ISCST3 to predict the movement of agricultural fumigants downwind from treated fields" (SAP 2004, pp. 13, 15).

> typical fumigation field conditions, i.e., flat, fallow fields, usually covered with plastic tarps. ***This model was not, as far as Panel members were aware of [sic], validated for any other class of pesticide or other field conditions.*** Not only was this model used to evaluate semi-volatile pesticides with very different physicochemical properties than fumigants, it was also applied to field environments that were radically different (orchard and cabbage fields) from the typical fumigation fields (fallow, flat). ***The only way this model, or any other for that matter, can be reliably used to predict source volatilization flux and downwind air concentrations is to field validate them under the typical field conditions the various pesticides in question will be used.***" (SAP 2009, p. 48, emphasis added).

There has been no field validation of PERFUM with respect to dicamba or any member of its synthetic auxin class of herbicides, making its use to assess the volatilization threat posed by XtendiMax illegitmate.

3.1.5 PERFUM not validated for multiple application events

Critically, both Scientific Advisory Panels that reviewed PERFUM and other models urged that they be configured to model "concurrent applications in high-use areas," the "fairly realistic scenario of emissions contributions from more than one field" (SAP 2004, pp. 15, 19, 30-31), and "multiple application events in the same region/air shed" (SAP 2009, p. 31) – all different words for the same point. This is precisely the real-world scenario discussed above that can lead to what Dr. Mortensen and other scientists refer to as "atmospheric loading," and which they believe is responsible for much of the extensive vapor drift damage caused by dicamba. Yet the PERFUM modeling of XtendiMax simulated just a single application to one field, and did not account for multiple application events and the increased dicamba vapor drift they would occasion.[30]

Xtend crops dominated soybean and cotton production in parts of the country in 2017, and it was in precisely those areas of intensive dicamba use that the most crop damage was recorded – precisely as one would expect if "multiple application events in the same region" exacerbated vapor drift. For example, Table 3 below shows that 80% of cotton and 65% of soybeans in the Missouri Bootheel were Xtend varieties in 2017, double and triple the national average, respectively. Some of the worst dicamba drift damage occurred in this area, and in the neighboring regions of northeast Arkansas and western Tennessee, where Xtend adoption rates were similarly high. According to Monsanto, 2018 acreage of Xtend crops was double that planted in 2017 (Smith 2018). Thus, the number of areas with locally intensive use of XtendiMax almost certainly increased as well.

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[30] While Version 2.5 of PERFUM does have two "multiple fields" scenarios (Reiss and Griffin 2008), the PERFUM modeling study of XtendiMax by Exponent did not make use of this option, since there is no mention of "multiple fields" in Exponent's report (Exponent 2016). It is also worth noting that Reiss and Griffin (2008) do not provide any empirical "ground-truthing" of their "multiple fields" options, so it is entirely unknown whether or not they accurately model air concentrations when multiple neighboring fields are sprayed in the same time frame.

Table 3: Adoption of Xtend Soybeans and Cotton in 2017

	National (millions of acre)				Arkansas (millions of acres)				MO Bootheel (millions of acres)		
	Total	Xtend	**% Xtend**		Total	Xtend	**% Xtend**		Total	Xtend	**% Xtend**
Soybeans	89.5	20	**22%**		3.55	1.5	**42%**		0.875	0.57	**65%**
Cotton	12.6	5	**40%**		0.45	0.3	**67%**		0.3	0.24	**80%**

Sources: Total planted acres nationally and in Arkansas from USDA NASS (2018). Xtend acres nationally and in Arkansas are Monsanto estimates (Monsanto 2017b). MO Bootheel estimates from Bradley (2017b).

3.1.6 PERFUM does not account for temperature inversions

A temperature inversion occurs in conditions of little or no wind, when cold surface air is trapped beneath a layer of warm air. If a pesticide is sprayed during an inversion, or an inversion develops after spraying, vapor and/or fine droplets can accumulate in the trapped air and then be transported by gentle breezes to cause considerable damage to crops and wild plants up to miles from the treated field(s). Temperature inversions are "common on evenings and nights with limited cloud cover and light to no wind," but "their presence can [also] be indicated by ground fog" (XtendiMax Label 2017). Inversions occur quite frequently in some areas: for instance, on one-third to one-half of the days in June and July in Missouri (Bradley 2017c). Inversions have been implicated in some episodes of plant injury caused by XtendiMax spraying.[31]

Both Scientific Advisory Panels (SAP 2004, p. 24) emphasized the need for dispersion models like PERFUM to explicitly account for pesticide volatilization under temperature inversion conditions:

> Volatilization dispersion prediction models should include scenarios with temperature inversions. Temperature inversions are common in some parts of the US whereby an air mass may be trapped and normal dissipation and dilution due to air mixing and ventilation are impeded. Inversions could create the potential for exposures to airborne pesticide concentrations that are higher and for a longer duration of exposure than expected (SAP 2009, p. 29 (pdf p. 46)).

Yet PERFUM's latest version 2.5 – used to estimate XtendiMax volatilization – has not been adapted to include temperature inversion scenarios (Reiss and Griffiin 2008).[32]

This issue is related to how PERFUM's core ISCST3 model is programmed to treat conditions of little or no wind, since stagnant conditions referred to as "calms" foster temperature inversions. To understand this, consider that PERFUM/ISCST3 generate vapor concentrations on an hourly basis, and averages those hourly values over time periods of interest to the user (e.g. 4, 8 and 24 hours). Concentrations decline in windy conditions, since winds disperse vapor

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[31] Although the XtendiMax label prohibits spraying during temperature inversion conditions, which most frequently develop from dusk to dawn, the difficulty of predicting their occurrence, and the frequency with which they occur, together make it practically impossible to avoid (see CFS 2017, Section 8).

[32] A search of the document for "inversion" yielded zero hits.

clouds. Conversely, the highest concentrations occur in still conditions that permit vapor to accumulate.

However, ISCST3 simply disregards hours in which wind speeds fall below 1 m/sec (= 2.24 mph) (Johnson 2001, pdf p. 21; Reiss and Griffin 2004, p. 98). By disregarding the "calms" periods, ISCST3 excludes the highest air concentrations from calculations of the model's output. According to EPA: "[o]ne of the main weaknesses of ISCST3 [and hence PERFUM] is in its treatment of calm periods" (EPA 2007, p. 106).

In a study of vapor drift of the soil fumigant methyl bromide, a senior research scientist and pesticide dispersion modeler with California's Department of Pesticide Regulation observes that calm conditions could "lead to high concentrations due to stagnation and/or low capping inversions," and "[t]hese conditions are not possible to simulate using ISCST3" (Johnson 2001). The same would be true of ISCST3-based PERFUM.

Unfortunately, the substitution of AERMOD for ISCST3 in PERFUM would likely not help matters. Although the latest version of AERMOD contains some limited capabilities "for dealing with low wind speed (near calm) conditions," in most circumstances it also excludes the high concentrations outputted in calm periods in the same manner as ISCST3 (EPA 2007, pp. 106-07). This means that an AERMOD-based PERFUM would also fail to model volatilization under temperature inversion conditions, especially in "extended periods of calms [that] often produce high concentrations over wide areas for relatively long averaging periods" (EPA 2017, section 8.4.6).[33] As EPA concedes, the root problem is a significant knowledge deficit: "our knowledge of wind patterns and plume behavior during these [calm] conditions does not, at present, permit the development of a better technique" than disregarding calms periods (Ibid., Section 8.4.6.1).

At least one model, CALPUFF, has "an enhanced treatment of calm conditions relative to ISCST3 or AERMOD because it can account for the plume being stable in calm conditions then moving again once winds pick up instead of skipping over such conditions" (EPA 2007, pp. 31-32). Thus, this does not appear to be an insoluble problem. Like PERFUM, however, this model was developed by pesticide industry consultants at Exponent, Inc.[34] It is also unclear whether it is appropriate for modeling the vapor drift of conventional pesticides; and as of 2008, European reviewers found that there was insufficient information available to assess it for this purpose (FOCUS 2008, p. 94).

That PERFUM is unable to simulate pesticide volatilization during weather conditions like temperature inversions that are both common and very conducive to extremely damaging drift episodes is still another strong argument against its continued use for this purpose. In Section 5, we recommend alternative assessment methods that are more protective.

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[33] The rationale for disregarding no/low wind periods is "to prevent the occurrence of overly conservative [high] concentration estimates during periods of calms" (EPA 2017, Section 8.4.6.1). In so doing, however, ISCST3 and AERMOD risk committing the opposite error of underestimating vapor concentrations.

[34] See http://src.com, last visited 1/14/19.

3.2 Monsanto and EPA Misuse Model to Underestimate Vapor Drift

The preceding section discusses several fundamental reasons why it is illegitimate to use PERFUM in this context. However, even if this model were deemed acceptable in principle, it has been blatantly misused in ways that substantially understate the threat of dicamba vapor drift.

As used to predict pesticide volatilization, the primary inputs to ISCST3/PERFUM are:

1) The flux profile of the pesticide as determined in field volatility studies;
2) Historical meteorological datasets – comprised of hourly temperature, wind speed, wind direction and atmospheric stability data over five years – from different locations in the country where the pesticide will be used;[35] and
3) Hypothetical field size (Reiss and Griffin 2006).

PERFUM uses these data to calculate estimated vapor concentrations at various distances in all directions from the edge of a hypothetical sprayed field for each day of the five-year period for which weather data are available. Concentrations are averaged over one or more user-selected exposure period(s), normally ranging from one to 24 hours. The simulated values of the model take the place of actual measurements of the pesticide's vapor concentration under the varying weather conditions at the modeling locations.

PERFUM is most often employed to produce buffer zone outputs: distances from the perimeter of a sprayed field to where the fumigant's vapor concentration falls below a threshold concentration (the highest concentration that can be inhaled without harm over a given exposure period) (Reiss and Griffin 2004, 2006; EPA 2007, pp. 40-44). However, Exponent used PERFUM in a different manner: to calculate dicamba vapor concentrations at selected distances in all directions from the perimeter of a field sprayed with XtendiMax, as discussed further in Section 3.2.5 (Exponent 2016, p. 10).

Below we discuss each of the inputs listed above and how they influenced PERFUM's outputs, and then address other problematic aspects of Exponent's modeling exercise.

3.2.1 Air concentrations underestimated due to artificially low flux rate inputs

The sole purpose of Monsanto's field volatility studies was to derive flux rates as inputs for PERFUM modeling of off-field air concentrations. Because those flux rates were substantially lower than the dicamba flux occurring in many real-world XtendiMax use scenarios, their use as inputs in PERFUM modeling led to correspondingly underestimated dicamba air concentrations. The flux rate-reducing factors in the field studies were discussed in Section 2, and include their small size, failure to capture higher flux rates from plant surfaces, drift-reducing spray equipment settings and operation, weather conditions that did not optimize volatilization, and exclusion of higher flux rates during application from flux profiles.

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[35] These data usually come from National Weather Service stations.

With regard to the latter point (see Section 2.7.1), EPA scientists found that "the highest levels of flux occurred at the time of application" for both studies (EPA 2016f, p. 8). Yet Monsanto failed to account for these higher flux rates in the flux profiles inputted into PERFUM:

> "[v]olatilization flux during the applications measured at the GA site was not considered in the flux profile constructed for the modeling inputs, and therefore not accounted for in the modeling inputs." (Ibid., pp. 6-7)

Because the highest flux rates were not accounted for in the modeling inputs, the modeling outputs (off-field dicamba air concentrations) were artificially low.

3.2.2 Modeling not representative of soybean-growing regions in 21st century

Exponent chose four locations in which to model off-field dicamba air concentrations following a single application of XtendiMax. Historical meterological data for each location (five years for three locations; three years for the fourth) served as inputs to PERFUM (Exponent 2016, Table 4). Because volatilization increases with temperature, one factor leading to underestimates of vapor drift was Exponent's use of 30-year old datasets (1987-1991; 1989-1991), dating to a time when temperatures were generally cooler than they are today thanks to climate change.

In addition, because soybeans are among the plants most sensitive to dicamba injury, and the majority of XtendiMax is applied in soybean-growing country, it was critical that volatilization modeling be conducted in such regions. Exponent seemed to understand the importance of this, stating that its choice of modeling locations was "based on the usage distribution of dicamba" (Exponent 2016, p. 14). This was not the case. The four locations it chose to model – Lubbock, TX; Peoria, IL; Raleigh, NC; and Phoenix, AZ – in no way represented the "usage distribution" of XtendiMax, which is heavily weighted to soybean-growing regions.

Essentially no soybeans are grown in Arizona; and only 0.2% and 1.9% of national acreage were planted in Texas and North Carolina, respectively, in 2017. The entire Corn Belt is represented by only one location (Peoria) in Illinois. The four states together comprise less than 14% of 2017 soybean acreage, and hence a similarly small proportion of national dicamba use (USDA NASS 2018). Entirely unrepresented in PERFUM modeling are the Northern Plains, the Great Lakes and Delta states – which together represent the majority of soybean cultivation outside the Corn Belt. States in these regions also had some of the most extensive dicamba drift injury in 2017 (Bradley 2017a).

In short, Exponent's modeling exercise was essentially useless for predicting dicamba's volatilization in the 21st century, in the majority of the country where the herbicide is most heavily used and threatens sensitive crops and wild plants.

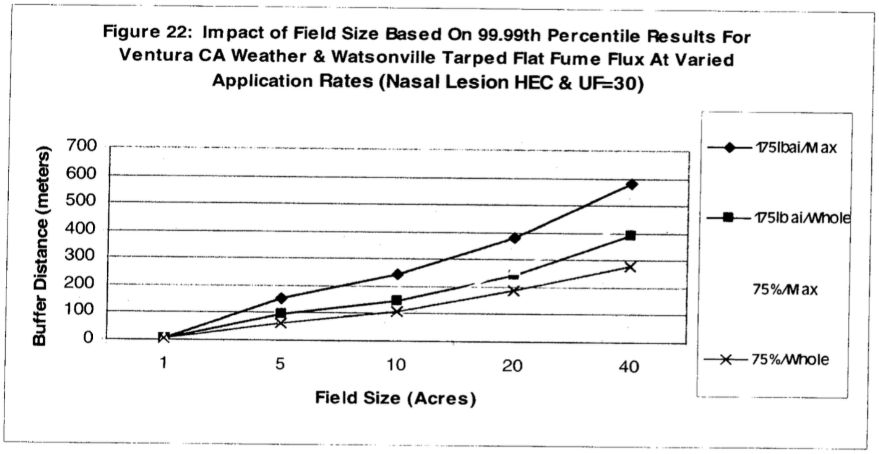
3.2.3 Small size of modeled field vastly understates vapor drift

A very significant and transparent way in which modeling was rigged to understate vapor drift from XtendiMax use relates to the scaling issue raised by Dr. Mortensen (Section 2.1): as the area of cropland that is sprayed increases, so does the volume of dicamba in the atmosphere and the distance it moves to damage wild plants and crops. Dr. Mortensen noted that "[t]he scaling issue is widely known to modelers…" (Mortensen 2017, p. 20). Indeed, the developers of PERFUM state that "[t]he field size … strongly influences the buffer zone…" and that the PERFUM user inputs the field size he/she wishes to model (Reiss & Griffin 2006).

Incredibly, Exponent and/or Monsanto chose to simulate off-field dicamba air concentrations arising from an 80-acre field treated with XtendiMax, which according to Exponent "is considered an upper-bound field size," and which EPA referred to as "a large area treated" (Exponent 2016, p. 11; EPA 2016f, p. 10).[36] Neither description is remotely true. As noted above, a typical Midwest soybean field is twice that size, 160 acres (a quarter of a 640-acre section of land). The typical size of a soybean farm is 490 acres (MacDonald et al. 2013), over six-fold larger than the PERFUM-modeled field.

Thus, the distance that plant-damaging dicamba vapor drifts under real-world conditions was substantially understated by the simple expedient of entering an artificially small field size into the PERFUM model. However, we do not know the precise magnitude of the underestimate, because we only have modeling data for the 80-acre field size.

An indication, however, can be gleaned from PERFUM modeling results for methyl iodide, portrayed in Figure 4 below. This graph is taken from EPA's 2007 human health assessment of the fumigant, and represents 99.99th percentile results. Data on methyl iodide that fit this very same pattern, but at the 90th and 95th percentiles, are reported by Reiss and Griffin (2004), Tables 5.1 and 5.2. (See Section 3.2.5 for a discussion of percentiles of exposure.)



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[36] 80 acres can only be considered "upper-bound" or "large" in the context of PERFUM's original use – to assess exposure arising from the fumigation of fruit and vegetable beds in California and Florida. In the first deployment of PERFUM with methyl iodide, the developers modeled field sizes of 1, 5, 10, 20 and 40 acres, which they stated "represents the range of potential field sizes in agricultural practice" in fruit and vegetable production (Reiss and Griffin 2004, p. 13). PERFUM Version 2.5 (used to model XtendiMax) has apparently been modified to enable simulation of fields up to 160 acres in size, still far too small to represent real-world use of XtendiMax on large-scale field crops like soybeans and cotton (Reiss and Griffin 2008).

Figure 4: PERFUM-calculated buffer zones as a function of size of field treated with methyl iodide (aka iodomethane) and application rate. Two lines represent results with maximum application rate of 175 lbs./acre with different buffer zone calculation methods (see ft. 32); one line 75% of the maximum rate (131 lbs./acre). Source: EPA (2007): see p. 62 for figure and Table 11, p. 57 for underlying data. With regard to this figure, EPA states: "Similar trends are observed regardless of the application rate or whether or not the results are based on maximum or whole field buffer results" (Ibid., p. 61).

Each line in the graph shows the PERFUM-calculated buffer distance for different field sizes, from 1 to 40 acres, with a given application rate and buffer zone calculation method. The buffer zone size is a proxy for vapor drift distance.[37] The size of the buffer zone increases by roughly 50% with each doubling of field size from 5 to 10, 10 to 20, and 20 to 40 acres. These results are not unique to the fumigant methyl iodide. As shown in Figure 7 below, PERFUM-estimated buffer zones increase still more (50-100%) with each doubling of acreage from 10 to 20 and 60 to 120 acres for the conventional, semi-volatile insecticide chlorpyrifos.

If dicamba behaves similarly to iodomethane and chlorpyrifos, the dicamba volatilizing from a typical 490-acre soybean farm sprayed with XtendiMax would drift three to over four times farther than calculated in Exponent's 80-acre PERFUM simulation. Dicamba vapor would drift even farther if the typical cotton farm of 1,090 acres (MacDonald et al. 2013, Table 2)[38] were all dicamba-resistant and sprayed with XtendiMax. Intensive use by many farmers in a given locale would increase vapor drift distance still more.

EPA is well aware that modeling a field size that is too small to represent real-world use understates exposure and hence risk, as it concludes in this same methyl iodide assessment:

> "As field size increases so do predicted buffer zones which is similar to what is noted based on increases in application rates."
>
> "The use of a maximum 40-acre field in the risk assessment may possibly understate potential exposure received by bystanders near treated fields that are larger" (EPA 2007, p. 68).

In a guidance document for EPA staff on volatilization modeling, the Agency warns against selecting inappropriate field sizes:

> "Users need appropriate justification for selecting field sizes, crop scenarios, and percent volatilized used in modeling runs. Any differences between what was modeled and what is expected to occur in the real-world should be characterized" (EPA 2014, p. 11).

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[37] As noted above in Section 3.2, PERFUM is usually employed to output buffer zone size, which represents the distance from the edge of a treated field at which air concentrations remain at or above a critical threshold value, and beyond which concentrations decline to below that value. The two buffer zone calculation methods referenced in the graph – "**max**imum distance" and "**whole** field" – are not relevant to this discussion, but are explained for those who are interested at EPA (2007), pp. 40-44.

[38] Figures for soybean (490 acres) and cotton (1,090 acres) farms refer to midpoint acreage (acreage at which half of farms are larger and half are smaller) in 2007.

Monsanto likewise understands this elementary principle. At a meeting of the Arkansas Dicamba Task Force in late August of 2017, Monsanto scientists made a presentation on the XtendiMax field volatility studies in Georgia and Texas discussed in Section 2, as well as the PERFUM modeling based on them. A Task Force member questioned the adequacy of Monsanto's analysis. The transcript of one exchange is particularly enlightening (TF = unidentified Task Force member; TM = Tom Moore, Monsanto regulatory field scientist; JH = John Hemminghaus, Monsanto formulations expert):

> TF: Can you show us, since you can model this, then surely you have modeled what effects you would see if you sprayed this [XtendiMax] over thousands of acres, instead of just a few acres. Can you show us that?
>
> TM: Yeah. So that's not… that's not something that we've modeled.
>
> JH: Yeah, **we have the capability to do that and we are actually looking into that now**. So we did scale… What is the acreage scaled up to Tom?
>
> TM: This represents an **80 acre application area**.
>
> JH: That's why flux is so important because it gives you the rate of dicamba and you can do these [field studies] on 10 acres and scale them up to 80. **We are going to take a look scaling them up even higher than that.** (ARK DTF 2017, p. 164, emphasis added)

There is no excuse for the failure of Monsanto/Exponent and EPA to model XtendiMax vapor drift to simulate the real-world scenario of thousands of sprayed acres.

3.2.4 Height at which dicamba concentrations modeled understates risks

During and following an application, vapor drift of a pesticide gives rise to air concentrations that vary considerably with height above the soil surface. EPA does not report the height at which off-field dicamba air concentrations were modeled, but it is almost certainly 1.5 meters. This is because PERFUM was developed to establish buffer zones that, ostensibly, protect human beings from inhalation of hazardous pesticide vapor. PERFUM's developers chose 1.5 meters as it "represents a typical breathing height for a person" (Reiss and Griffin 2006, p. 3551; Reiss and Griffin 2008, p. 13). This is also the height at which screening level air concentrations resulting from the volatilization of conventional pesticides are modeled (EPA 2014, p. 12).

Plants are not people. For instance, soybean injury is a function of dicamba air concentrations from 0 to 0.5 meters, not 1.5 meters. This is the height range of Xtend soybeans when they are sprayed, and so also of most vulnerable soybeans in the vicinity.[39] This raises the question: How does dicamba vapor concentration vary with height? The trend for modeled values should

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[39] The 2017 XtendiMax label prohibits application of XtendiMax after the R1 (beginning bloom) stage, when they are typically 0.4-0.5 m tall. Neighboring susceptible soybeans will be at roughly the same growth stage. Soybean height maxes out at R5 stage, when they are approximately 1 m tall (University of WI 2015).

follow empirical measurements. The Georgia and Texas studies report vertical concentration data for five different heights, measured by sensors attached to a single mast in the center of the treated fields (Table 4).

Table 4: Variation in On-Field Dicamba Vapor Concentrations by Height in Field Volatility Studies

			Dicamba concentration (ug/m3 at given height (m))					Concentration Ratios	
Field Study	**Interval (h)**	**Duration (h)**	**0.15 m**	**0.33 m**	**0.55 m**	**0.90 m**	**1.5 m**	**0.15/1.5**	**0.55/1.5**
Georgia	0-6	5.50	0.02013	0.01042	0.00936	0.00457	0.00332	6.1	2.8
Texas	17.3-30.3	13.0	0.00797	0.00563	0.00533	0.00451	0.00362	2.2	1.5

Sources: Monsanto (2016a), Table 9, p. 44; Monsanto (2016b), Table 8, p. 42. The intervals chosen represent the post-application periods (0 = time XtendiMax application was completed) in which the highest post-application flux rates were observed in each field study.

Dicamba air concentrations at the soybean-relevant heights of 0.15 and 0.55 meters were 1.5 to 6 times higher than those measured at 1.5 meters. There is no corresponding vertical concentration data off-field, for which there are values for only one height: 1.5 m in Georgia and 0.43 m in Texas (Monsanto 2016a, 2016b, p. 20). However, this same relationship – increasing concentration closer to the ground – likely holds off-field as well.

Thus, it appears that by virtue of the height factor alone, concentrations of dicamba experienced by soybeans and many other plants with similar stature are likely several-fold higher than the PERFUM-modeled values at 1.5 meters. This is still another factor leading to understatement of the dicamba vapor drift threat.

Of course, the numerous reports of injury to thousands of trees shows that however much dicamba air concentrations might decline with increasing distance above the ground, the herbicide's vapor and aerosol all too frequently reach injurious levels even at heights well above 1.5 meters (Figure 5; Bradley 2018b, Unglesbee 2018a).

Figure 5. Dicamba drift damage to pecan tree at farm of Andrew Joyce of Malden, MO. Photo by Karen Pulfer Focht, for Food & Environment Reporting Network. Source: Gross (2018).

3.2.5 “Peak” modeled air concentrations are far from maximum values

Both Exponent and the EPA discuss what they refer to as the “peak” or “upperbound peak” off-field dicamba air concentrations produced in PERFUM modeling runs using flux rates from the Georgia and Texas field studies (Exponent 2016, p. 12; EPA 2016f, pp. 6, 8). Based on these values, EPA decided that there would be no damaging vapor drift with legal use of XtendiMax, and hence no need for buffer zones to protect against it.

In fact, these concentrations are vastly underestimated due to the many field trial and modeling deficiencies discussed in this report. Even on their own terms, however, irrespective of these deficiencies, they are by no means “peak,” but rather 95th percentile of exposure values. To understand what this means requires further background on PERFUM.

PERFUM calculates vapor concentrations at points on a grid defined by the intersection of radiating spokes and concentric rings around the hypothetical sprayed field (Figure 6). Concentrations are calculated at each grid point, for each day over the 5 years (1,825 days) of weather data in a given location. Modeled concentrations at a given grid point will differ from day to day of the simulation, depending on the specific set of weather conditions prevailing on a given day (e.g. wind direction and speed, temperature).

PERFUM is normally used to output buffer zones. In this case, Exponent programmed it to output four concentration arrays along four concentric rings at 5, 10, 25 and 50 meters from the perimeter of a simulated 80-acre field sprayed with XtendiMax (Exponent 2016, p. 10).

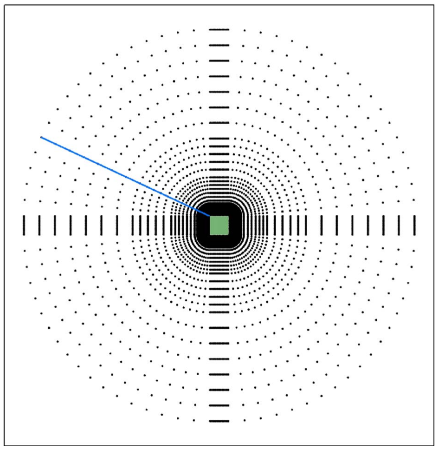

Figure 6: PERFUM simulation grid. Spokes and rings representing points at which PERFUM calculates vapor concentrations emanating from a treated field (in green). Reproduction of Figure 1 in Reiss and Griffin (2006).

The array of values for each ring represents the range of concentrations estimated to occur at that distance (e.g. 5 meters) on each day of the 5 years covered by the weather dataset. The 95th percentile concentration at 5 meters, for example, is the concentration that is greater than or equal to 95% of the values in the 5-meter array, and is exceeded by 5% of them. PERFUM treats the arrays as probability distributions. Hence, there is a 5% chance that dicamba concentrations will exceed the 95th percentile value at a given distance when XtendiMax is applied at the corresponding modeling location.

Exponent reported only 95th percentile concentration estimates, but the PERFUM user can select any whole number percentile from 1 to 99%, plus 99.9 and 99.99% (Reiss and Griffin 2008, pp. 9, 16). Higher percentile values are more conservative and hence protective: the 99th percentile of exposure is exceeded 1% of the time; the 99.9% value 0.1% of the time, etc.

Below we examine the variation in upperbound percentiles of exposure for other pesticides, and the factors that should guide the choice of percentile for regulatory decision-making.

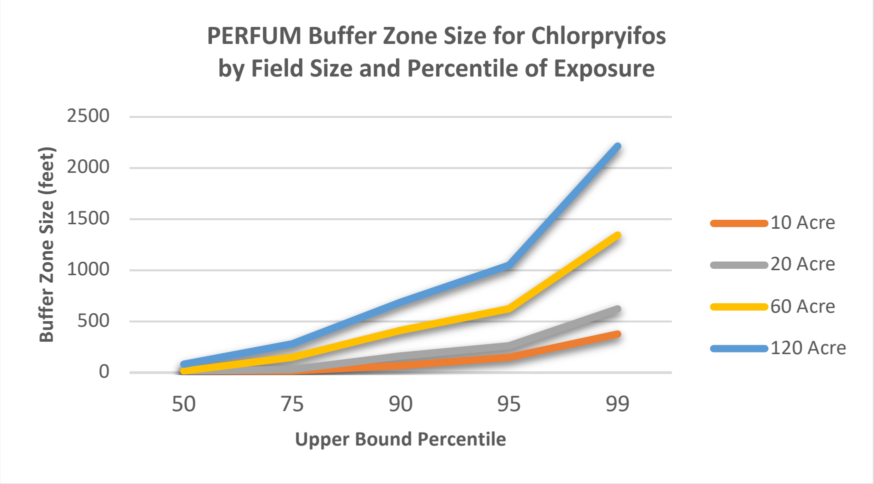

Figure 7. PERFUM-calculated buffer zone size (maximum buffer) as a function of upper bound percentile of exposure for differently-sized fields sprayed with a 1 lb./acre application of chlorpyrifos, modeled for Ventura, CA meteorological conditions. Based on data from EPA (2013b), Table 9, p. 32.

Figure 7 shows PERFUM-calculated buffer zone sizes as a function of upperbound percentile of exposure for differently-sized hypothetical fields sprayed with the insecticide chlorpyrifos. For each field size, the buffer zone size required to protect bystanders from inhalation of hazardous concentrations of chloryprifos increases by roughly 50% to 100% when 95th percentile values are used rather than 90th percentile figures, and more than doubles from the 95th to 99th percentile.

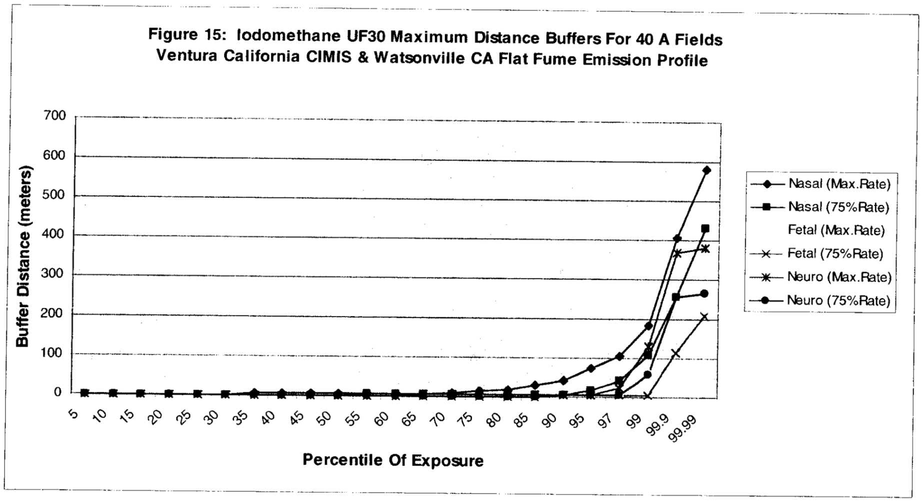

Figure 8. PERFUM-estimated buffer zone size as a function of upper bound percentile of exposure for application of methyl iodide (iodomethane) to a 40-acre field in California, showing results based for different rates of application and toxicological endpoints. Reproduced from EPA (2007), p. 54.

Figure 8 shows the same PERFUM-calculated relationship for a 40-acre field treated with methyl iodide. The buffer zone size increases dramatically with increasingly conservative exposure thresholds above the 95th percentile. The buffer zones (proxies for air concentrations) at this extreme end represent the most volatility-enhancing, but also infrequent, conditions at the modeled location.

There is no pat answer to the question of which percentile estimates to employ for regulatory purposes. One must consider at least two major factors. First, how well do the field studies and modeling projections represent the full range of possibilities in agricultural practice? If not well, then more conservatism (higher percentile) is called for in compensation. Second, how frequently is the pesticide used? Even a “low probability” vapor drift event may occur “too often” with frequent and widespread usage, which also argues for higher percentiles.

On the first point, as documented throughout this report, the dicamba vapor drift estimates derived from field volatility studies and modeling vastly understate the volatilization that occurs in real-world scenarios of XtendiMax application. This is due to both the many biasing factors in the assessment, and the paucity and inappropriateness of the locations chosen for the field studies and modeling, which are largely unrepresentative of the soybean-growing country where XtendiMax is most heavily used. Correcting the biases, and adding more and appropriately sited trials and modeling locations, would have yielded modeling runs with air concentrations far higher than those utilized by EPA in its risk assessment. On the second point, the roughly 25 and 50 million acres of dicamba-resistant crops sprayed one or more times in the 2017 and 2018 crop seasons means extremely widespread and frequent use of XtendiMax, and thus all too many occurrences of even "low probability" long-distance drift.

Thus, both factors argue for use of much more conservative (higher) exposure estimates than the 95th percentile figures upon which EPA based its risk assessment of XtendiMax vapor drift. We return to this topic in Section 5.4.2.

3.3 Conclusion to Faulty Modeling

As we have seen, there are many good reasons to simply reject PERFUM as an entirely inappropriate model for estimating XtendiMax vapor drift, particularly the lack of validation for use with conventional pesticides, and its inability to simulate intensive local use or volatility-enhancing temperature inversions. Even if one accepts PERFUM for this use in principle, however, the many biases and deficiencies in Exponent's modeling exercise clearly led to substantial underestimates of off-field dicamba air concentrations relative to those encountered in the real world when farmers spray XtendiMax. Multiple factors each biased "peak" air concentration results downward by several to many-fold: the small modeled field size, the artificially low flux rate inputs, the excessive height at which concentrations were modeled, and the relatively low upperbound percentile concentration estimates. Collectively, these biases and deficiencies in modeling likely understated off-field dicamba vapor concentrations by two or more orders of magnitude.

4.0 LABORATORY STUDY UNDERESTIMATES PLANT SENSITIVITY TO DICAMBA

The volatility assessment of XtendiMax involved two key bits of information: how much dicamba vapor is expected in the air beyond the treated field, which was discussed in Sections 2 and 3; and how much dicamba vapor sensitive plants can withstand without harm, the harm threshold, the subject of this section. If the former exceeds the latter, off-field crops are at risk and measures must be taken to protect them.

4.1 Off-Field Dicamba Vapor Concentrations Exceed Plant Harm Threshold

EPA's original assessment of the harm threshold was based on a single flawed Monsanto laboratory volatility study involving soybeans, which are among the plants most sensitive to dicamba injury (Monsanto 2016c).[40] Soybean seedlings were placed in closed plastic chambers called humidomes together with petri dishes containing various forms and mixtures of dicamba (see Figures 9 & 10). The dicamba formulations/mixtures in each of seven humidomes generated different vapor concentrations, and an eighth humidome without dicamba served as the control. After 24 hours in the humidomes, the seedlings were removed, placed in

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[40] Monsanto conducted one other laboratory volatility study (Monsanto 2015), but it contained no plant effects evaluation component, and played no substantive role in EPA's assessment.

greenhouses, and assessed for the effects of dicamba vapor after 14 and 21 days.[41]

The seedlings in all but one of the dicamba-containing humidomes were damaged by dicamba vapor. The only plants that did not show injury symptoms were those exposed to the lowest concentration – 17.7 ng/m^3 – the plant harm threshold, or in regulatory parlance the no observed adverse effect concentration or NOAEC (Monsanto 2016c, p. 9).[42]

Even with the many downward-biasing factors discussed in this report, the "peak" hourly dicamba vapor concentration modeled by PERFUM at 5 meters off-field – 20.8 ng/m^3 – exceeded the NOAEC (Exponent 2016, Table 5, p. 16; EPA 2016f, Table 1, p. 8).[43] This should have led EPA to conclude that vapor drift harm could occur and to impose a buffer zone to protect off-field plants (NFFC et al. vs. EPA 2018a, 2018b). Off-field dicamba vapor concentrations reach far higher levels than 20.8 ng/m^3, of course, as would have been clear if the field volatility studies and PERFUM modeling had been conducted with correction of the many biases and deficiencies identified in this report; this would have made the modest exceedance of the NOAEC (20.8 ng/m^3 > 17.7 ng/m^3) far larger and harder for EPA to dismiss.[44] Below, we discuss why Monsanto's assessment of the plant harm threshold is also unreliable.

4.2 Humidome Study Understates Soybean Susceptibility to Dicamba

There are many reasons to distrust Monsanto's humidome study as a means of determining the sensitivity of soybeans to dicamba vapor under real-world conditions. First of all, Monsanto set up a light vacuum in the humidome to pull air through it at a rate of 2 liters per minute, potentially creating advective transport that might have resulted in vapor measurement error (Monsanto 2016c, p. 11; van den Berg et al. 1999, p. 202). Thus, the reported vapor concentrations in the humidomes may not be accurate.

More importantly, the highly artificial conditions in this single humidome study cannot simulate the vast majority of real-world scenarios in which plants encounter dicamba vapor (Ibid.). Below we discuss three environmental factors known to influence plant sensitivity to herbicides generally and dicamba in particular – temperature, humidity and soil moisture – and how they differ in the humidome versus the real world. Note that the discussion in this section concerns how these factors affect plants' ***susceptibility to injury*** from a given concentration of dicamba; this is not to be confused with how they influence the ***extent to which dicamba volatilizes***, which was discussed in Sections 2.2 and 2.3.

The humidome study tested soybean susceptibility under only one set of conditions: 85°/70° F.

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[41] Symptoms of injury from exposure to dicamba and other synthetic auxins develop gradually from days to weeks after exposure. Thus, in studies meant to simulate herbicide drift damage, it is common to undertake injury assessments two to three weeks after application. See https://ag.tennessee.edu/herbicidestewardship/Pages/Herbicide-Damage-in-Tobacco.aspx.

[42] EPA identifies this dicamba concentration as the NOAEC, but using a different weight unit: 0.0177 ug/m^3 (EPA 2016f, p. 6).

[43] Note that 20.8 ng/m^3 is equivalent to the 2.08 x 10^{-2} ug/m^3 figure in the cited EPA document.

[44] This is not to endorse PERFUM as a valid means of estimating dicamba vapor drift.

(16 h/8 h) and a constant 40% relative humidity over the 24-hour exposure period; and presumably abundant soil moisture from bottom watering throughout the study (Monsanto 2016c, pp. 23-24).[45]

The humidome's simulated "daytime" temperature of 85° F. is frequently exceeded where XtendiMax is sprayed in the late spring and summer. Higher temperatures generally increase the absorption, translocation and activity of foliar-applied herbicides, although the effect on efficacy varies by herbicide (Varanasi et al. 2016; Roordink 1999, Appendix; Al-Khatib et al. 1992). Several studies of dicamba drift in particular suggest that higher air temperatures increase dicamba uptake by plant foliage and result in greater injury and yield loss in soybeans (Egan et al. 2014; Al-Khatib and Peterson 1999).

The humidome's constant 40% relative humidity is of course entirely uncharacteristic of U.S. soybean growing regions in the spring and summer, where humidity levels of 90% and above are not unusual. Plant absorption and efficacy of water-soluble herbicides like dicamba increase with humidity, and many agronomists regard humidity as a more important factor for efficacy (i.e. injury) than temperature (Varanasi et al. 2016; Stagnari 2007; Roordink 1999, Appendix). High humidity is thought to increase the injurious effects of herbicides by softening the leaf cuticle, prolonging the life of herbicide droplets on leaves, and opening plant stomata (Varanasi et al. 2016).[46]

Egan and Mortensen (2012) found that dicamba vapor injured off-field soybeans at greater distances from the application site under conditions of higher humidity, and hypothesized that humidity "increases the residence time of dicamba near plant surfaces or facilitates the uptake of dicamba by bioassay plants." An association of pesticide applicators in Illinois conducted a survey of their members' experiences with dicamba in 2017; the majority of applicator-respondents "stated that heat and humidity correlated with symptoms and complaints" of dicamba injury (IFCA 2017, p. 3). This evidence may explain why Monsanto, in an obscure publication on crop injury caused by growth regulator herbicides (which includes dicamba), advises farmers as follows: "Do not spray when air temperature and/or humidity is high or is expected to be high" (Monsanto 2017a). However, neither Monsanto nor EPA put any such restriction on the XtendiMax label, which contains the only usage instructions that applicators

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[45] Monsanto apparently recorded the temperature, humidity and light intensity in the greenhouse during the 21-day post-exposure period, but does not report these important data (Monsanto 2016c, p. 12).

[46] In a presentation to the Arkansas Dicamba Task Force, a Monsanto scientist responded to a task force member's astonishment that Monsanto's humidome study was conducted at 40% relative humidity, given that Arkansas has much higher humidity levels. The Monsanto scientist conceded that this and other differences in environmental conditions between the humidome and the field ***would render humidome results inapplicable to real-world conditions***. The scientist then emphasized that the humidome studies were only useful in ranking the relative volatility of different dicamba formulations and tank mixes. There is no discussion of using humidome results to establish the harm threshold for soybeans. The scientist also stated that 40% relative humidity was chosen not for any substantive reason, but only because higher humidity levels caused water to condense in the hoses attached to the humidome, which skewed results (ARK DTF 2017, pp. 156-157). Hence, the entirely unrealistic humidity levels were due to Monsanto's inability to engineer a proper volatilization chamber test design, although it is also possible that the company knowingly exploited the low humidity of its humidome system to suppress dicamba-induced soybean injury.

are likely to see and legally obligated to follow. This is no oversight. Such a label restriction would make it, practically speaking, impossible to legally apply XtendiMax in most areas where Xtend crops are grown.

The consistent soil moisture provided by bottom watering in the humidome does not reflect the dry conditions frequently encountered in most regions where soybeans are grown, particularly the Plains States. Several agronomists have found that dicamba drift damage to soybeans and/or consequent yield loss become more severe under conditions of low soil moisture (Egan et al. 2014, Andersen et al. 2004). In North Dakota in 2017, dicamba injury to soybeans was exacerbated by heat stress and drought conditions (ND DoA 2017), and made some unknown contribution to the 18% reduction in North Dakota soybean yield from 2016 to 2017 (USDA NASS 2018).

The conditions of the humidome study understated the sensitivity of soybeans to dicamba injury in many real-world settings where temperature and especially humidity are higher, and where dry conditions likely exacerbate dicamba injury.

4.3 EPA Fails to Demand Realistic Injury Data

In seeking an explanation for the long-distance dicamba vapor drift episodes of 2,800 feet and 2.2 miles discussed in Section 1.2, EPA scientists pointed to "conditions (temperature and humidity) in the days following the application ***which fall outside of the range of submitted laboratory data conditions***" (EPA 2016b, p. 9, emphasis added). EPA scientists called for "volatility experiments ***under varied conditions of temperature and relative humidity***, because these factors seem to be important in field conditions" (Ibid., p. 10, emphasis added). Despite these calls for additional data, EPA's registration decision relied entirely on this single flawed humidome study to establish the harm threshold for soybeans.

Not only was the harm threshold established under just one set of highly unrealistic conditions, it was determined only for soybeans at a single (V2) growth stage. Monsanto used V2 seedlings, which are only 6-8" tall and have very few leaves, for no better reason than that only small plants would fit into the humidome (Figures 9 & 10; Monsanto 2016c, p. 10). Yet the degree of visual injury from herbicide exposure and its ramifications (especially yield loss) differ widely for different growth stages. In spray drift simulation studies, soybeans exposed to dicamba at the reproductive growth stage suffer yield losses at far lower dicamba rates than those exposed as vegetative stage seedlings, even though they may display similar visual injury levels (Griffin et al. 2013). The same is likely true with exposure to dicamba vapor.

Figure 9. Soybean seedling at V2 growth stage (University of WI 2015).

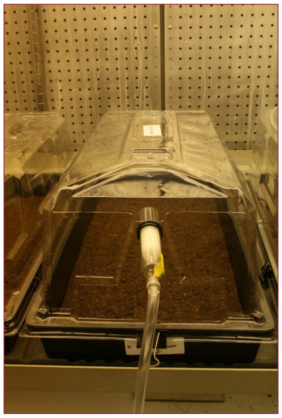

Figure 10. Monsanto's humidome (Monsanto 2015)

As discussed in Section 2.6, Monsanto failed to assess dicamba injury to sentinel soybean plants in either of its field volatility studies, which would have provided somewhat more realistic information. Even if this plant effects evaluation had been carried out as planned, however, it would have only provided visual injury data on seedlings, not reproductive stage plants, nor would it have assessed potential yield loss (Monsanto 2016a, pp. 297-299).

EPA recognized the need for data on XtendiMax volatility and the injury it causes under varied environmental conditions, yet failed to obtain these important data prior to its registration of XtendiMax.

5.0 RECOMMENDATIONS

Genetically engineered, herbicide-resistant (HR) crop systems are among the most impactful developments in field crop agriculture over the nearly quarter-century history of their commercial use. They remain the consolidated seed-pesticide industry's top research and development priority. More crops resistant to volatile herbicides are in the process of being introduced (e.g. DowDuPont's 2,4-D-resistant cotton, corn and soybeans) or in development. The dicamba experience highlights the urgent need for the federal government to devise an adequate regulatory regime for HR crop systems, to prevent future drift debacles.

The recommendations below relate to changes in EPA's assessment of herbicide use on HR crops. As discussed in Section 1.1, however, the dicamba debacle had much to do with dereliction on the part of USDA as well. The two agencies must devise means to coordinate their reviews and regulatory decisions on the HR crop and herbicide components of these systems.

5.1 EPA Should Write New Regulations and Enforce Compliance With Them

EPA regulations require a variety of tests intended to help protect people and the environment from the harmful effects of pesticides. The substance of these regulations – found in Title 40, Part 158 of the Code of Federal Regulations – is contained in regulatory guidelines that prescribe how various tests are to be designed and conducted, nearly always by registrants.

HR crop systems present unique challenges in terms of herbicidal drift injury, yet EPA has entirely failed to adapt its regulations and guidelines to address them.[47] This vacuum has emboldened registrants like Monsanto to develop novel and untested assessment methods that are both unsound and bias results in their favor, as discussed in this report.

The regulations and guidelines most relevant to herbicide volatilization and non-target plant injury are as follows:[48]

40 CFR 40, § 158.1300: Environmental fate data requirements.
* Test Guidelines 835.1410: Laboratory Volatility (EPA 2008a)
* Test Guidelines 835.8100: Field Volatility (EPA 2008b)

40 CFR 40, § 158.660: Nontarget plant protection data requirements:
* Test Guidelines 850.4150: Vegetative Vigor (EPA 2012)

While these regulatory guidelines are in many ways ill-suited to assess herbicide use on HR crops, Monsanto's tests deviated from them considerably even where they do apply. We first point out major deviations; then aspects of the current guidelines that are inappropriate. Finally, we present recommendations for the sort of regulatory tests that are needed in this area.

5.1.1 Regulatory test guideline violations

The humidome study was not conducted under conditions that represent "an environment where the pesticide is intended for use," as discussed in Section 4.2; there was no sampling regime to determine air concentrations "continuously or at intervals which increase with time after the start of the experiment," but rather only a 24-hour average value was calculated (Monsanto 2016c, pp. 11-12); and Monsanto did not even determine a rate of volatilization, the express purpose of this study. Monsanto thus violated the following provisions of regulatory guidelines for laboratory volatility studies: (b), (d)(2)(ii) and (d)(2)(v) of EPA (2008a). More basically, EPA's regulations contain no provisions for using laboratory volatility studies to establish the plant harm threshold of herbicide vapor, the only purpose of Monsanto's humidome study.

As discussed in Section 2, the field volatility studies did not "provide[] realistic estimates of volatility when the pesticide is applied as it is intended to be used;" were not "conducted in areas considered representative major areas" of intended use; and the field study reports lacked key environmental data, such as soil moisture and cloud cover. These deficiencies

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[47] The same holds true of herbicide-resistant weed evolution, despite EPA's requirement that Monsanto implement an herbicide resistance management plan (EPA 2016a, Appendix D). For a critique of these plans in the context of dicamba, see CFS (2016), pp. 18-26.
[48] § 158.1100 contains spray drift data requirements, which relate to determining the droplet size spectrum of pesticides.

violated (b), (d)(2), (e)(7) and (e)(11) of EPA (2008b). For missing environmental data, see Monsanto 2016a & 2016b, Table 5 of each.

5.1.2 Regulations inappropriate for testing herbicide use on HR crops

Both the laboratory and field volatility regulatory guidelines were developed to test highly volatile pesticides such as soil fumigants, where the primary concern is human health harm from inhalational exposure. EPA has yet to update them for the volatilization risks posed by semi-volatile herbicides like dicamba.

This is evidenced by two key features. First, neither set of guidelines requires assessment of, or even mentions, vapor drift injury to sensitive plants. This is a major failing that permitted Monsanto to develop its own perverse testing regime out of whole cloth, in which flux rates were determined in the field, and plant harm assessed under artificial laboratory conditions, rather than *vice versa* (see next subsection). Second, both test guidelines prescribe application of the pesticide to soil. While this is appropriate for soil fumigants and other soil-applied pesticides, it misses entirely the increased volatilization rates that occur when herbicides are applied to crop and weed foliage – the defining feature of herbicide use with HR crops.

Another sign that the guidelines are outdated is the scientific papers they cite. Of the eight unique papers listed as references, seven were published in the 1970s and one in 1980 (EPA 2008a & 2008b). EPA apparently sees no need to incorporate anything learned about pesticide volatilization over the past 40+ years into its regulatory testing requirements.

5.1.3 Recommendations for new test regime

EPA should establish regulatory test requirements for herbicide use on HR crops in at least four areas: laboratory and field volatility, modeling and plant injury.

Volatilization chambers should be used to ascertain flux rates under different sets of environmental conditions representative of regions where the herbicide will be used. These volatility-relevant conditions include temperature, relative humidity and soil moisture. Tests should also be required to determine flux rates when the herbicide is applied to plant foliage as well as to soil and plant residue. These tests would require volatilization chambers capable of establishing and maintaining diverse sets of environmental conditions over time (e.g. see Wolters 2003, p. 27 ff.), and thus would have to be considerably more sophisticated than Monsanto's primitive and inaptly named "humidomes," which apparently were incapable of maintaining a relative humidity level over 40% without malfunctioning (see Section 4.2, ft. 41). Semi-field scale wind tunnels are another possible option for determining flux rates (Ibid., p. 33 ff.).

Field volatility studies should simulate farmer production practices as much as possible. They should be carried out under the more volatility-enhancing conditions determined in volatilization chamber tests, and in all major areas where the herbicide will be used. Several commercial-sized fields in a localized area should be treated at the same time to simulate vapor drift from multiple application events. Applications should be made at the latest crop growth stage permitted on the label, and in weedy fields, in order to simulate farmer practice and optimize volatilization from crop and weed foliage. Flux rate calculations must include flux during application.

Before EPA accepts the results of any modeling study to estimate off-field vapor drift, an appropriate model must first be developed (or identified) and validated for the herbicide being assessed. The model should permit simulation of multiple application events and temperature inversions, and provide estimates for all major areas where the herbicide will be used. Guidelines should prescribe proper use of the models, so as to prevent the many abuses described in this report.

Several of the most sensitive plant species should be tested for cumulative injury from all manner of drift – spray, vapor and particle-bound – in field studies. Sentinel plants at different ages (including reproductive stage) and various distances in all directions from the treated field should be assessed for visual injury, height/biomass reduction, and yield loss. Seeds of sentinel plants should be tested for germination rate, since plants injured by some herbicides, like dicamba, can produce seed with reduced fertility (Auch and Arnold 1978, Barber 2016). Tests on plants exposed at reproductive stage are particularly important, because the later-season use of herbicides on HR crops is more likely to result in drift onto flowering crops and non-crop plants, and because both yield loss and reduced fertility of offspring occur at lower levels when plants are exposed at this stage relative to seedling exposure (Boutin et al. 2014). Fertility reduction is a serious matter, since it can reduce viability of farm-saved seed, disrupt crop breeding efforts, and contribute to declining diversity of non-crop plants in agroecosystems (Ibid.). The existing vegetative vigor guidelines for assessing the effects of spray drift could perhaps serve as the basis for the more comprehensive drift injury assessment recommended here (EPA 2012).

5.2 Incorporate Input from Independent Stakeholders into Regulatory Decision-Making

Seldom has EPA received such so public comment opposing an herbicide use as it did for XtendiMax, beginning nearly a decade ago. Scientists, agronomists, farmers, sustainable agriculture groups and the general public repeatedly warned of precisely the impacts that have occurred. EPA must find ways to take account of the experience and expertise of independent stakeholders in its decision-making, rather than rely entirely on registrant studies.

EPA ignored or marginalized most criticism of the proposed new uses of XtendiMax. For instance, EPA met as early as 2010 with a team of Pennsylvania State University scientists who have done more research on dicamba drift than any other; their input was briefly described in EPA's first ecological risk assessment, but marginalized under a section entitled "Uncertainties" (EPA 2011, p. 20). The data in registrant studies, however poorly conducted, are not treated as "uncertainties;" they invariably become the basis for approval decisions.

In another instance, the EPA based a provisional, 100'/110' omnidirectional vapor drift buffer in part on the alarming episodes of long-distance (1/2 to over 2 mile) dicamba vapor drift discussed in Sections 1.2 and 4.3, and in part on a published scientific paper by members of the

Pennsylvania State team just mentioned (EPA 2016b, pp. 6-10; EPA 2016e, p. 17; EPA 2016f, pp. 2-3). But the Agency immediately dismissed the real-world field evidence and the independent study, and eliminated the proposed omnidirectional buffer, as inadequate as it was, upon receipt of registrant studies that purported to show no need for any buffer to protect off-field plants from vapor drift.

A group of farmers with decades-long experience of dicamba's notorious propensity to drift formed an organization – the Save Our Crops Coalition – specifically to oppose the introduction of this crop system. They shared with EPA their insights, along with scientific data, on the hazards of dicamba (e.g. SOCC 2016). The group's chairman, Steve Smith, warned emphatically that "[t]he widespread use of dicamba is incompatible with Midwestern agriculture" (Smith S 2010).

In addition, EPA was aware of surveys conducted by the Association of American Pesticide Control Officials which established that dicamba was the third-most frequently implicated pesticide in drift episodes in five of six years surveyed (1996-1998, 2003-2004), despite many-fold lesser usage than the top two culprits, 2,4-D and glyphosate (AAPCO 2005, 1999).

When information of this sort suggests serious risks that are not revealed in registrant studies, EPA should reject such studies and base decisions on the best available independent science, including conservative screening estimates. At the very least, stark conflicts between registrant and independent information should move the Agency to undertake an extremely rigorous and conservative assessment, which it clearly did not do in the case of XtendiMax.

5.3 Make Greater Use of Air Monitoring Data

The many deficiencies of modeling described in Section 3 suggest that EPA should rely more on empirical measurements of air concentrations of pesticides. This is the path the Agency took in what appears to be its most recent human health assessment of the insecticide chlorpyrifos (EPA 2016g).

EPA made extensive use of PERFUM to model the vapor drift of chlorpyrifos in its preliminary assessment of the insecticide (EPA 2013b). Figure 7 is based on that document. However, EPA correctly repudiated that approach when it finalized its risk assessment of chlorpyrifos in 2016. In that definitive assessment, EPA decided to rely upon "straight air monitoring data" – that is, empirical measurements of chlorpyrifos in the air at 13 sites – rather than the PERFUM-modeled air concentrations it had previously calculated (EPA 2016g, pp. 31-35).

EPA rejected the PERFUM modeling because of the criticisms of the 2009 Scientific Advisory Panel discussed above. Seven years later in 2016, EPA stated it was still "currently in the process of evaluating the SAP's comments," "including the recommendation to evaluate additional models," and that: "As appropriate, the agency will revise the modeling approach presented to the SAP for determining the rate of volatilization (flux) for semi-volatile pesticides and for estimating air concentrations of applied pesticides in the atmosphere under varying environmental conditions" (Ibid., pp. 34-35).

Dicamba is also a semi-volatile pesticide, so the reservations about PERFUM's use for chlorpyrifos apply to it as well. Yet EPA did not question the appropriateness of using PERFUM to assess dicamba's volatilization; did not "evaluate additional models" or respond to other recommendations of the 2009 SAP; and it failed to collect and utilize "straight air monitoring data" as it did for chlorpyrifos.[49] In short, EPA knew the modeling it relied upon for the conclusion of no off-field vapor drift harm from XtendiMax was unreliable, but proceeded to approve it on that basis anyway.

Air monitoring studies should be conducted in areas where and the seasons when the herbicide is intensively used – on multiple fields in a localized area. In the case of XtendiMax, monitors should be set up in areas with high dicamba injury report numbers in 2017 and 2018.

5.4 Worse-Case Scenarios

Even if numerous air monitoring studies are conducted, it is quite possible they would miss the most volatility-enhancing situations due to their infrequency. Thought should therefore be given to how best to account for worst-case, or better "worse-case"[50] scenarios. Both of the Scientific Advisory Panels referenced above addressed this issue. Their recommendations are discussed in the next two sections, followed by an approach based on EPA an screening tool.

5.4.1 No single "worst case"

SAP (2009) raised this matter in the context of multiple application events, and proposed "using the models to develop 'sentinel' worst-case scenarios" that, "[b]ecause worst cases can vary," would have to comprise "an array of exposure scenarios … stratified by chemical, crop and region" (SAP 2009, p. 48).

This advice usefully highlights that worse cases will likely involve multiple users in a concentrated area, as discussed in Section 3.1.5, and thus by extension the need to go beyond standard "single field, single application" modeling of the sort conducted by Exponent for XtendiMax to simulate them. The SAP also underscores that the multiplicity of interacting factors involved in pesticide volatilization means that there is unlikely to be some single set of conditions that can be designated worst case across the board. Rather, different scenarios are needed to accommodate different volatility-enhancing combinations of pesticide (with its unique physical properties), crop sprayed (and associated management practices), and regional

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[49] Ironically, the chlorpyrifos risk assessment based on straight air monitoring data rather than PERFUM modeling estimates bears exactly the same date as EPA's PERFUM-based evaluation of dicamba volatilization: November 3, 2016 (EPA 2016f). It should be noted that EPA's Health Effects Division conducted an entirely separate assessment of dicamba volatilization to evaluate the health risks to bystanders from inhaling dicamba vapor. The assessment was based on a different flux study than those discussed in Section 2, and PERFUM-modeled dicamba air concentrations assuming application to just a 40-acre field (EPA 2016h, p. 41-44). EPA nowhere explains why two separate volatilization assessments were conducted.

[50] "Worst" suggests the single most extremely damaging outcome, which by definition is both extremely rare and extremely difficult and perhaps infeasible to protect against (e.g. the 1 in a 1,000-year flood). "Worse-case" is used here to encompass seriously damaging outcomes that are infrequent but not extremely rare, and so both more necessary and feasible to forestall.

factors (climate, soil properties, vulnerable crops/plants, etc.). That said, the notion that these various worse cases can be modeled seems to presuppose greater knowledge of pesticide volatility and its promoting factors than we possess. No further details on how such worse-case modeling could be accomplished were provided.

5.4.2 Modeling with high upper-bound exposure estimates

According to SAP (2004), "the treatment of calm-wind periods in the simulation procedure"[51] made it difficult to estimate "the high-end probability distribution of ambient concentrations and exposures" – that is, worse-case scenarios (SAP 2004, p. 34). This implies that a buffer zone adequate for the range of more usual conditions fails to protect in certain "calm-wind periods" or stagnant air, which can give rise to temperature inversions. The same applies to intensive, localized use, and even more to situations where both conditions prevail.

The Panel recognized the important principle, ignored by EPA, that the infrequency of worse-case events must be considered together with frequency and scope of use. In other words, a soil fumigant intended for use on one or two crops, on limited acreage, in restricted areas, must be treated differently than a conventional pesticide intended for use on major field crops covering tens of millions of acres across the country. They proposed a mathematical approach to deal with this situation.

In the Panel's word: "reducing the probability of a serious exposure at any one of many sites, e.g. in a given year, will require a much lower probability of occurrence at each individual site" according to the following formula (Ibid., p. 34):

$$1 - P_N = (1 - P_1)^N$$

or, solved for P_1

$$P_1 = 1 - (1 - P_n)^{1/N}$$

Where:

* N is the number of sites where the pesticide is applied (assuming 1 application/site)

* P_N is the highest permissible probability of serious exposures at any one of N sites (per year)

* P_1 is the highest permissible probability of serious exposure at each individual site that is required to remain below P_N

For example, if one wishes to keep the probability of excessive exposures at 100 sites (N) below 5% ($P_N = 0.05$), then the probability of excessive exposure at each individual site (P_1) must be kept below 0.0513% ($P_1 = 0.000513$). This implies a buffer zone based on the model-predicted, 99.95th percentile of exposure (100 – 0.0513) – a buffer zone that would likely allow 5 excessive exposure incidents (5% of 100 sites).

What percentile values would be appropriate to prevent excessive injury episodes in the case of spraying on Xtend crops?

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[51] That is, disregarding the high concentration values at low wind speeds, as discussed in Section 3.1.6.

As a rough and conservative estimate, XtendiMax and other new dicamba formulations were sprayed one or more times on tens of thousands of farms in 2017, and over 100,000 farms in 2018.[52] Most farms comprise multiple fields where multiple spraying operations take place, but let us conservatively assume each farm is one site. If one were to set the modest goal of keeping the probability of one or more excessive exposures at these 100,000 sites (N) below 5% ($P_N = 0.05$), then the probability at each individual site (P_1) must be kept below 0.0000513% ($P_1 = 5.13 \times 10^{-7}$). This would require using a buffer zone based on the upper-bound 99.99995% percentile of exposure (100 – 0.0000513). Even a seemingly conservative, worse-case buffer zone calculated on this basis would likely permit 2,000 excessive off-field dicamba exposures per year (5% of 100,000).

PERFUM is apparently not programmed to output percentile-based buffer zones above 99.99%, but if dicamba behaves anything like methyl iodide, it is likely that one based on the 99.99995th percentile of exposure would be quite large (see Figure 8), especially if the biasing factors identified in the report were corrected. If this is so, it might be objected that such large buffer zones would be impractical for agriculture. Another view would be that this herbicide use is too hazardous for agriculture.

5.4.3 Screening estimates in absence of sound data

In 2013, EPA applied a screening tool to estimate off-field exposure from vapor drift of dicamba. Screening estimates represent approximations that are usually carried out early in a risk assessment. Their purpose is to estimate the worst case, based on limited data, to determine whether there is a potential risk that requires more detailed testing and assessment. One motivation for screening is to save resources. If a quick and easy method that delivers highly conservative, worst-case estimates indicates no risk, then both registrants and EPA are spared the time and money that would otherwise be spent on fuller studies and assessments.

To arrive at the screening estimate, EPA first estimated the rate of dicamba volatilization from plant surfaces using an equation based on dicamba's vapor pressure (for following discussion, see EPA 2013a, pp. 9-11). This volatilization rate was then fed into the screening version (AERSCREEN) of EPA's AERMOD[53] to predict the maximum 1-hour average dicamba air

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[52] This estimate is based on the acreage of dicamba-resistant crops and the number of total soybean and cotton farms. Monsanto reported 26 and 50 million acres of dicamba-resistant crops in 2017 and 2018, respectively, with the soybean/cotton breakdown 21/5 million acres in 2017 and 43/7 million acres in 2018 (Gray 2018). Sixty million Xtend acres are anticipated in 2019 (Unglesbee 2018e). These figures represent from 25-50% of national soybean plantings of 89-90 million acres, and 40-50% of national cotton plantings of 13-14 million acres in those years. The USDA reports 302,963 soybean and 18,155 cotton farms in 2012, year of the last Census of Agriculture (USDA 2014, Table 37). Assuming % acreage equates to % farms: 40% of 300K soybean farms (120K) + 50% of 18K cotton farms (9K) = 130,000 farms. This estimate is also conservative in that it assumes only one application per season, when in fact other other USDA data show that new dicamba was applied on average 1.1-1.2 times per season on soybeans and 1.5-1.6 times per season on cotton (USDA NASS 2017).

[53] AERMOD is discussed in Section 3.1.3. "AERSCREEN is the recommended screening model based on AERMOD. The model will produce estimates of "worst-case" 1-hour concentrations for a single source, without the need for hourly meteorological data…. AERSCREEN is intended to produce concentration estimates that are equal to or

concentration at the edge of a hypothetical 80-acre sprayed field, and the amount of dicamba deposited at various distances from it.

According to EPA's screening estimate, the dicamba vapor concentration at the edge of an 80-acre sprayed field is 283 ug/m^3; and enough dicamba vapor would be carried off-field to injure 25% or more of susceptible plants up to 1,500 meters (nearly 1 mile) from it[54] (Ibid., p. 11). However, EPA quickly dismissed this alarming result in favor of two other screening estimates using different methods (one by Monsanto) that found little or no dicamba vapor injury even to plants at the edge of a treated field. On this basis, the Agency concluded that "multiple lines of evidence" show that "the primary route of off-field exposure is more likely to be a result of spray drift and runoff" rather than vapor drift (Ibid., p. 11) – a conclusion that ignored the non-Monsanto screening estimate, long-distance drift episodes (Sections 1.2, 4.3), and the warnings of expert stakeholders (Section 5.2).

These screening level estimates were in any case superseded by the field studies and PERFUM modeling discussed in this report, which did in fact show potential for off-field plant injury (Section 4.1), but to nowhere near the extent of EPA's screening estimate.

The degree to which these various estimates differ is astonishing. To take just two examples. The flux rate used in the screening estimate is 0.566 ug/m^2-sec., over 550 times greater than the peak post-application flux rate in the Georgia field trial of 0.001017 ug/m^2-sec. (Monsanto 2016a, Table 9, p. 44). The screening estimate of 283 ug/m^3 dicamba vapor at field's edge is 13,600 times greater than the "peak" off-field concentration from PERFUM modeling based on the Georgia field study of 0.0208 ug/m^3 (EPA 2016f, Table 1, p. 8). These huge disparities naturally raise the question as to which estimate is more trustworthy.

We have detailed the numerous ways in which Monsanto and Exponent have biased their studies to substantially understate XtendiMax vapor drift. What can be said about EPA's screening estimate? It is superior to Monsanto's field studies and PERFUM modeling in at least four respects.

First, the screening estimate's flux equation, based on a much-cited paper by Woodrow et al. (1997), was specifically designed to account for the higher rate of volatilization from plant foliage versus soil, unlike Monsanto's studies (EPA 2013a, pp. 9-10). Second, Woodrow et al. (1997) validated their vapor pressure-based flux estimates for 12 pesticides, finding that they agreed quite well with empirical flux measurements (Woodrow et al. 1997, Fig. 2); and when flux estimates for five pesticides were entered into SCREEN-2 (a precursor to AERSCREEN), the

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greater than the estimates produced by AERMOD with a fully developed set of meteorological and terrain data, but the degree of conservatism will vary depending on the situation." See https://www.epa.gov/scram/air-quality-dispersion-modeling-screening-models.

[54] That is, in EPA's regulatory parlance, the dicamba deposition levels remained above the EC_{25} (the effect concentration (EC) that causes an observable adverse effect in 25% of plants) up to 1,500 meters from the edge of the sprayed field. For definition of EC, see https://www.epa.gov/sites/production/files/documents/ToxTrainingTool10Jan2010.pdf.

model's air concentration estimates agreed quite well with empirical measurements (Ibid., Table 5). In contrast, Monsanto and Exponent make no attempt to validate their PERFUM air concentration estimates for XtendiMax. Third, the tools used in the screening exercise – a university team's flux rate formula and the screening version of EPA's air pollution dispersion model (see Section 3.1.3) – were developed by independent scientists, EPA's Office of Air and Radiation, and the American Meteorological Society, in contrast to the pesticide industry assessment EPA relied upon. Most importantly, EPA's screening estimate comports much better with known episodes of dicamba drift discussed above (2,800 feet and 2.2 miles) as well as with numerous incidents reported by many agronomists and farmers in the 2017 and 2018 crop seasons, many of which involved vapor drifting a half-mile and more (see e.g. CFS 2017).

5.4.4 How to use worse-case scenarios

We have suggested three uses for worse-case scenarios. First, high-end percentile estimates can serve to compensate somewhat for deficiencies in the field volatility and modeling studies (Section 3.2.5). However, this use is questionable because it could be illegitimately used to "compensate" (perhaps insufficiently) for cutting corners or biasing the underlying studies. Second, worse-case screening estimates can replace a refined assessment when the latter is too flawed to rely upon (Section 5.4.3). Finally, worse case scenarios should be simulated even when the underlying studies are well-conducted – especially if there is need to account for "very low-probability" drift events that will nevertheless occur all-too-often when the herbicide is to be used on an extremely widespread basis (Section 5.4.2).

6.0 CONCLUSION

Thanks to Monsanto's malfeasance and EPA misregulation, the Xtend crop system has taken a tremendous toll on farmers, rural communities and the environment (for the following discussion, see Unglesbee 2018a).

John Seward, of Aurora, South Dakota, has seen his vegetable farm devastated several times by dicamba drift the past two years. As in many similar cases, his dicamba-spraying neighbor's insurance refuses to cover his losses.[55] While his CSA[56] members have supported him, some of his neighbors have turned hostile since he reported his damage to the state. John is barely hanging on, and seriously reconsidering his dream of farming.

An elderly Illinois homeowner has seen severe dicamba injury to many of her trees, including hundred-year-old oaks, ornamental plants, shrubs and a vegetable garden. She and her husband, themselves farmers, have already spent $10,000 for dicamba testing, tree removals, and rescue fertilizer treatments. Watching the devastation unfold has sunk her into

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[55] Ironically given EPA's approval decision, the insurance agent refused to pay up because it decided culpability lay not with the farmer (who sprayed according to the label), but rather the dicamba manufacturer and its defective product.

[56] CSA stands for Community Supported Agriculture, a system in which customers, at the start of the season, purchase from the farmer a share in the farm's harvest, usually delivered weekly. CSA's have become extremely popular across the country, and provide locally-produced fresh produce, agricultural diversity in a landscape often dominated by monocultures, and a means for small farmers to survive in an increasingly consolidated industry.

depression. She feels betrayed by once-friendly neighbors, who have offered no help, and refused to give her name to the reporter "to protect her from reprisals in her community."

In western Tennessee, Mike Hayes runs a resort that has been hit with dicamba drift at least eight times, killing young trees and wiping out the resort's garden (which once supplied his restaurant) so often he has given up on it. Century-old cypress trees in nearby Reelfoot Lake are suffering, and if lost cannot be replaced, creating concern for the fate of bald eagles and osprey that nest in them. State officials have given him the runaround, all too scared of the political clout of dicamba manufacturers to help him. Despite Tennessee state documentation of the dicamba damage, he has received no compensation, in part because the source(s) are impossible to identify with eight different farms applying dicamba in his area.

Dicamba cannot be causing such widespread damage to crops, gardens and trees without also impacting wild plants and the organisms that depend on them. Richard Coy, a large beekeeper based in Arkansas, has found up to 50% lower honey production in honeybee colonies situated in areas hard hit by dicamba drift (Charles 2017). Coy was forced to close his Arkansas retail honey outlet and relocate his hives to Mississippi as a result (Steed 2019). Beekeepers in other parts of the country have had similar experiences (Gross 2019).

The travails of beekeepers is entirely consistent with scientific research showing that dicamba drift reduces and delays the flowering of broadleaf plants, depriving pollinators of the nectar and pollen they require. Based on their study, the researchers predicted in 2015 that introduction of the Xtend system would result in dicamba drift injury to wild plants, and so "significantly decrease the pollinator and natural enemy communities that these plants can support" (Jeunesse 2015, Bohnenblust et al. 2016).

And these are just a few of the thousands of cases of dicamba injury to crops, trees, wild plants and pollinators that are occurring around the country.

This report details many deficiencies in EPA's assessment of XtendiMax, and the faulty science it was based on, in hopes that the Agency will enact urgently needed restrictions on XtendiMax and other new dicamba formulations. In the longer term, it is equally necessary that EPA reform its regulatory processes in this area. HR crop systems are the seed-pesticide industry's most active area of research and development. DowDuPont is now introducing field crops resistant to the dicamba-like 2,4-D; many other HR crops, some resistant to volatile herbicides, are certain as escalating weed resistance creates new markets for "new tools." Without fundamental regulatory reform, more herbicidal injury epidemics and environmental harm are inevitable.

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Appendix 1
A Critique of EPA's Two-Year Extension of XtendiMax Through 2020

On October 31, 2018, EPA approved XtendiMax, Engenia and FeXaPan for two more years of use on Xtend crops, despite a continuing high level of drift injury episodes in 2018.[57] The two-year extension came with label amendments, a requirement that a host of new studies be conducted in 2019, and assessment of new information collected since the original registration in 2016. EPA established a small endangered species buffer zone, and conducted an impacts and benefits assessment. We address each in turn below, concluding that EPA's two-year extension is not supported by science and violates federal law.

1.0 LABEL AMENDMENTS

The latest amendments to the XtendiMax label are similar to those established after the 2017 crop season, which failed to bring dicamba injury down to anywhere near acceptable levels (Swoboda 2018). They include a further minor restriction on who can make applications, a limit on the number of post-emergence applications to cotton, prohibition on spraying a certain number of days after planting (60 days cotton, 45 days soybeans), a revised time-of-day spray restriction, advisory language, and an additional buffer zone where certain threatened or endangered plant species are present (EPA 2018a, pp. 19-22).

According to weed scientists, the new usage restrictions will not have a significant impact on dicamba drift. The days after planting prohibition would still allow Xtend crops planted later in the season to be sprayed in the volatilization-enhancing heat of summer, when other crops are highly susceptible to injury. Barring application by those working under the supervision of certified applicators will be ineffective because there is no evidence of greater drift damage when such applicators spray dicamba. The main effect of the tighter time of day restriction will be to make it still more difficult to spray dicamba legally (Hartzler 2018).

Tellingly, although EPA solicited recommendations from academic weed scientists in two teleconferences, the Agency failed to adopt any of them for the new label (Chen 2018). The measures recommended by independent experts that EPA rejected included prohibiting applications above a certain temperature and after certain dates, as well as restricted use status for all dicamba-containing herbicides (Swoboda 2018). EPA officers admit they rushed their decision to avoid the automatic expiration of registrations on November 9th, and so failed to even vet their proposals with state officials (Unglesbee 2018c). Weed scientists have found

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[57] It is difficult to compare dicamba drift complaint numbers for 2017 and 2018 for several reasons. First, some states with dicamba episodes in both years chose not to respond to surveys in 2018, perhaps because their staffs are overwhelmed with a backlog of dicamba investigations (Unglesbee 2018b, 2018c). Illinois, Indiana and Nebraska are among those states with more dicamba complaints in 2018, while Arkansas, Missouri, and Minnesota are among those with fewer (Bradley 2018, 2017d; Unglesbee 2018b, 2018c). Iowa agronomists estimate similar levels of dicamba damage to soybeans in both years (Swoboda 2018). Second, fewer soybeans were vulnerable to injury due to increased plantings of Xtend soybeans, in part by farmers seeking only to protect themselves from dicamba drift damage (Steckel 2018). In any case, among weed scientists there is "near unanimous agreement that the level of off-target injury observed in 2018 is unacceptable" (Swoboda 2018).

some of the label amendments to be vague, confusing and impossible to enforce, and have not received satisfactory explanations of their precise meaning from EPA (Unglesbee 2018d).

2.0 NEW STUDIES AND INFORMATION REQUIRED IN 2019

As a condition of the two-year extension, EPA is requiring Monsanto to conduct an extraordinary range of studies pertaining to XtendiMax drift in 2019 (EPA 2018b):

1. Field studies to evaluate dicamba drift injury to non-target plants on all sides of the field, in varied geographical regions under a range of environmental conditions, particularly in areas with high incident numbers;
2. A study on the injury to soybeans and other plants from dicamba in irrigation water;
3. Controlled studies to ascertain how temperature, relative humidity and tank mix pH – in various combinations – affect dicamba's volatility;
4. Data on dicamba injury to sensitive trees, shrubs and woody perennial species;
5. A study on how pH affects dicamba volatilization when dicamba is mixed with other pesticides and additives and with water of different pH values.

EPA is also demanding that registrants report more information about dicamba drift complaints that they receive.

The fact that EPA is only now demanding fundamental information about dicamba drift and injury shows that it had no legitimate scientific basis upon which to approve XtendiMax in 2016, much less grant a two-year extension. If EPA wishes to collect new data from controlled experiments and enhanced reporting in 2019, it should have first ended the ongoing uncontrolled experiment that has had such disastrous consequences over the past two years.

This is the step demanded of EPA by federal pesticide law. EPA granted both the original registration and the two-year extension under a provision that requires "satisfactory data" demonstrating that the registered uses "will not significantly increase the risk of unreasonable adverse effects" on the environment (EPA 2018a, p. 16). The fact of substantial adverse impacts for two years, coupled with the requirement for new studies to supply fundamental information about dicamba's drift properties, indisputably demonstrates that the drift-related data EPA used to justify its original approvals and two-year extensions are very far from satisfactory, making the registration of XtendiMax, Engenia and FeXaPan illegal.

However, EPA has declined to take action to mitigate drift even when it already has the requisite scientific knowledge. For instance, the Agency now understands that dicamba's volatility increases as the pH of tank mixtures it is in declines. Yet despite this knowledge, EPA has still failed to mandate that tank mixtures be tested for pH or enhanced volatility as a condition for approving tank mix partners (see Section 2.4), instead adding useless advisory language to the XtendiMax label (EPA 2018b, label section 8.0).

3.0 ASSESSMENT OF INFORMATION SINCE ORIGINAL REGISTRATION IN 2016

EPA assessed a number of studies on dicamba by Monsanto and independent scientists since the original registration in late 2016. None of them provided data that justify the two-year extension, and in fact some study results argue against the extension.

3.1 Monsanto's Studies

Monsanto's five field volatility studies provide no useful information for several reasons (for the following, see EPA 2018c, pp. 14-18).

1. None of them even involved XtendiMax, but rather a premix formulation of dicamba and glyphosate, Roundup Xtend (two studies), or tank mixtures of glyphosate and a different form of dicamba (MON 76980) (three studies).[58]
2. Neither Roundup Xtend nor MON 76980 is registered for use in the U.S.
3. Because none of these studies were conducted in soybean-growing country, but rather in Georgia (1), Texas (2), Arizona (1) and Australia (1), they cannot represent dicamba volatility under environmental conditions where most XtendiMax is sprayed (see Section 2.2); this is particularly true of the trials in Arizona and Australia, where very low humidity prevailed (see inset: XtendiMax Drift Injury and Relative Humidity)
4. There is no explanation of how flux rates were derived, but they are presumably understated due to the same flaws as those discussed in Section 2.
5. Off-field dicamba air concentrations were also understated due to use of the inappropriate PERFUM model (see Section 3).

EPA reports on a second humidome study conducted by a registrant, presumably Monsanto, that sets a higher plant harm threshold than the first one discussed in Section 4.1 (EPA 2018c, p. 22). However, the conditions of this second study lead to an underestimate of soybean susceptibility to dicamba just as the first study did (Sections 4.2 & 4.3). These include a moderate temperature regime and extremely low relative humidity (40%) that are both greatly exceeded in many regions where XtendiMax is used. Comparison of the new plant harm threshold with the "peak" modeled dicamba air concentration is a pointless exercise because neither quantity bears any relationship to dicamba's behavior under real-world conditions of use.

3.2 Independent Studies

EPA also assessed 12 small field studies by university agronomists in Arkansas, Indiana, Missouri, Michigan, Nebraska, Tennessee and Wisconsin conducted from 2016 to 2018 (EPA 2018c, pp. 24-45, Appendix B). These studies comprised 17 trials of the spray and vapor drift injury caused by XtendiMax, Engenia and/or a mixture of XtendiMax and Roundup (and in one case a third herbicide) to susceptible (non-dicamba-resistant) soybeans surrounding small sprayed plots of Xtend soybeans. As discussed below, the results of these studies served as the basis for EPA's establishment of an endangered species buffer zone in those counties that harbor susceptible dicot plants listed as threatened or endangered under federal law.

EPA's belated decision to assess dicamba drift studies by independent scientists rather than rely entirely on registrant data is a positive development. However, the trials themselves were in some respects inappropriately designed for their purpose. More importantly, EPA's flawed and

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[58] EPA provides contradictory information on the dicamba formulation used in the Arizona trial. It is referred to as XtendiMax and as MON 76980 in different passages (EPA 2018c, pp. 14, 17). MON 76980 "is not registered in the United States but is similar to XtendiMax plus VaporGrip" (Ibid., p. 16).

blatantly biased interpretation – which directly contradicted the analysis presented by the Agency's working scientists – led to a buffer zone that was entirely too small to protect threatened or endangered species, and left other susceptible plants and neighboring crops with virtually no additional protection. Both study and interpretive deficiencies are discussed below.

3.2.1 Studies understate drift distance

While it appears these trials were generally well-conducted, they underestimate the full effects of spray and vapor drift injury for several reasons. First, the sprayed plots were too small to represent volatilization in real-world conditions: on average just 10.2 acres, ranging in size from 0.17 to 53 acres (EPA 2018c, Appendix B2[59]). As explained in Sections 2.1 and 3.2.3, vapor drift distance increases with size of the sprayed field, all other things being equal. While EPA does concede the important principle that field trial size matters – "Large field studies [are] more reflective of what occurs in the environment" (EPA 2018c, pp. 45, 82) – it errors in absurdly characterizing these small trials as "large" (EPA 2018c, pp. 45, 82). Trials should involve spraying a field at least 160 acres, the size of a typical Midwest soybean field (Section 2.1), which is 15-fold larger than the average "large" field study considered here. Further, to truly simulate real world conditions, multiple fields in close proximity would have to be sprayed at roughly the same time, as scientists advised the EPA in the context of modeling (Section 3.1.5).

Second, in all but two cases (Norsworthy 2018, Jones 2016) the researchers failed to assess plant injury in all directions from the treated field.[60] This is a significant deficiency because winds often shift in direction both during and especially in the several days after application.[61] As a result, the effects of both spray and vapor drift were often underestimated. To take just one example. In the Wisconsin trial, only plants to the north and south of the treated plot were assessed for injury; yet winds blew from southeast to north***west*** during the application, and thereafter in every direction ***except*** from north to south. The trial thus failed to properly assess injury from either application drift (which would likely have occurred at the greatest distance northwest rather than north of the field) or from vapor drift in any direction except the north (EPA 2018c, pp. 27-29, Figure 9). In contrast, Norsworthy (2018) assessed injury on four sides (N, S, E, W), and Jones (2016) in all eight cardinal and ordinal directions from the treated plot (N, NE, E, SE, S, SW, W, NW). In both trials, 10% or greater visual injury was observed at considerable distances from all sides of the treated plots, wherever assessment took place, with the exception of the southwest side of the Jones trial (Ibid., pp. 25-27; p. 86, Appendix B2).[62]

Third, in EPA's rush to extend the XtendiMax registration for two years, it assessed these studies before the full results were in. Namely, collectors set up to measure spray and vapor

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[59] The 10.2 acre average is based on the 16 independent field trial sizes listed in Appendix B2, plus the 0.36 acre Jones trial, the acreage of which was omitted in Appendix B2, but is cited on p. 41.

[60] Instead, plant injury was assessed primarily on the (presumed) downwind side of the treated field (three transects), with limited assessment of injury to plants on the (presumed) upwind side on the day of application only (one transect) (EPA 2018c, pp. 24, 84-85, Figure B.1).

[61] Vapor drift is especially likely to cause injury in multiple directions from the treated field, because wind shifts are almost inevitable over the several days after application when volatilization can occur, and even light breezes push vapor off the field.

[62] EPA should mandate that the drift studies being required of registrants for 2019 likewise include assessment of injury of plants in ordinal (NE, NW, SE, SW) as well the cardinal (N, S, E, W) directions from the treated plots (EPA 2018b, p. 6).

drift had not been processed by the time of EPA's extension decision (EPA 2018c, pp. 25, 84, Figure B.1).

3.2.2 EPA's flawed and biased interpretation

In spite of these issues (which all tended to underestimate drift distance), the independent studies supplied valuable data. Yet EPA ended up rejecting most of it. Researchers measured dicamba drift injury in one or both of two ways: Visual signs of injury or VSI (12 studies); and reduced plant height (4 studies).[63] EPA rejected the VSI studies for use in calculating a buffer zone despite its admission that they provide "a larger pool of data that encompasses more field trials, under more variable environmental conditions and [] in more geographic locations" [than the plant height studies] (EPA 2018c, p. 78). Instead, EPA based its assessment on studies that measured dicamba-induced reduction in plant height, despite its recognition of their many inadequacies, namely, that: 1) there were too few studies to represent different geographies and environmental conditions; 2) several provided insufficient data to cover "volatile dicamba deposition" after the initial application; 3) plant height says nothing about the more important yield parameter, and 4) there is "statistical uncertainty" arising from the extremely limited dataset represented by these four studies (EPA 2018c, pp. 47, 49).

Based solely on the inadequate plant height reduction data, EPA established an additional "omnidirectional" buffer zone of just 57 feet (17.4 meters) for the three non-downwind sides of an XtendiMax treated field.[64] As discussed below, even this small buffer zone applies only in those few counties that harbor dicot plants listed as threatened or endangered under federal law.

4.0 ENDANGERED SPECIES BUFFER ZONE OFFERS LITTLE OR NO PROTECTION

4.1 EPA Overrules its Scientists to Establish Entirely Inadequate Buffer Zone

In establishing this buffer zone, EPA rejected the analysis and recommendation of its working scientists with the Environmental Fate and Effects Division (EFED), which came to light when EPA was forced to release a confidential EFED memorandum in response a Freedom of Information Act request (EPA 2018d, Steed 2018). Using the more robust data from the visual injury (VSI) studies, the EFED scientists recommended an omnidirectional buffer zone of 135 meters (443 feet), nearly eight times larger than the 57-foot buffer EPA higher-ups eventually settled upon.

The EFED scientists based this recommendation on a 2018 study by Dr. Jason Norsworthy in Arkansas, in which application of an XtendiMax tank mix to a 38.5-acre plot of Xtend soybeans resulted in drift that caused 10% or more visual injury to surrounding soybeans up to 135 meters from the edge of the treated field. The memorandum summarizes a conference call between Dr. Norsworthy and EPA officers, which contained the following revelations (see EPA 2018d):

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[63] Agronomists overwhelmingly assess herbicidal drift injury on a "visual injury" scale ranging from 0% (no damage) to 100% (complete plant death). As EPA explains, the injury ratings are keyed to specific symptoms of plant injury (EPA 2018c, p. 85). A second, much less used method of assessing plant injury is measuring the reduction in plant height due to herbicide exposure (vs. unexposed control plants).

[64] The pre-existing downwind buffer zone of 110 feet (for 0.5 lb/acre applications) was retained.

1. Dr. Norsworthy answered specific questions about the study's methodology to the satisfaction of EFED scientists, who judged it to be acceptable for the purpose of establishing a 135-meter omnidirectional buffer zone;
2. Dr. Norsworthy responded to specific allegations intended to discredit the study results, unattributed allegations that were almost certainly made by the registrant, Monsanto;
3. Several allegations of putative flaws in the study involved design elements that were in fact determined by Monsanto, which sponsored the study: for instance, addition of a third herbicide, acetochlor (Warrant) to the XtendiMax + Roundup tank mix; and use of tarps to permit assessment of the effects of vapor drift as distinct from spray drift;[65]
4. In translating visual injury to yield loss, EPA higher-ups accepted Monsanto's recommendation over the determination of its own scientists, which led to understatement of the distance that damaging drift travelled.[66]

Norsworthy's 2018 study was not an outlier. Based on the proper 10% visual injury threshold, the majority of independent studies supported a buffer zone far greater than the 57 feet (17.4 meters) EPA higher-ups enacted. For instance, before EFED scientists had finished evaluating the 2018 Norsworthy study, they had preliminarily recommended a 60 meter (170 feet) buffer based on other studies (EPA 2018d). In the Michigan field trial, Dr. Sprague observed injury to soybeans (height reduction) in a low area situated 75 to 105 meters from the north edge of the field (EPA 2018c, p. 33), a result discounted by EPA.[67] In a 2017 Nebraska study in which separate plots of just 0.17 acres were sprayed with XtendiMax and Engenia, Dr. Kruger observed 10% or greater injury out to 69 and 67 meters, respectively, from plot's edge (EPA 2018c, Appendix B2, p. 86). Dr. Kruger's 2018 trial provided still more evidence of long-distance drift: extremely high 45-70% injury levels from field's edge out to 50 feet, and signs of injury (EPA does not specify the percent visual injury level) as far as 76 meters away (Ibid., Figure 19, p. 37).[68] In his 2016 trial in Arkansas involving Engenia, Jones found over 10% visual injury out to average distances of 6, 9, 11, 21, 37, 57 and 59 meters in different directions from his tiny, 0.36-acre plot (Ibid, p. 41; Appendix B2, p. 86). In most of these cases, the distance to injury also exceeded the pre-existing 110-foot (33.5 m) downwind buffer for spray drift.

Because volatile drift distance increases with size of the treated field, the true distance that it travels in commercial production is far greater than even these field trial results suggest. EPA should have either demanded trials with commercial-scale fields, or at least normalized the

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[65] This suggests the possibility that Monsanto's contributions to the study design were expressly intended to serve as grounds for Monsanto to then cast doubt on or discredit the Norsworthy study's results.

[66] EPA established 5% yield loss as the threshold of significant harm. Because yield loss was not determined in any of the studies, it was necessary to determine the level of visual injury that would lead to 5% yield loss. EPA higher-ups adopted the "registrant-suggested 20% visual signs of injury threshold" rather than the 10% visual injury threshold established by EFED scientists based on their "weight-of-evidence evaluation" (compare EPA 2018d and EPA 2018c, p. 79). Because 10% injury levels extend farther away from the treated field than 20% injury levels, EPA understated drift distance (Ibid., Appendix B2, pp. 86-87, compare figures in the average distance to 10% vs. 20% injury columns).

[67] In EPA's summary review, this Sprague study is listed as finding 5% height reduction at only 0 to 10 meters from field's edge (EPA 2018c, p. 87, Appendix B2, Sprague study).

[68] EPA suspiciously fails to report the average distance to 10%, 20% or 40% injury for this trial, for some reason denoting all three as ">15 meters" (Ibid, Appendix B2, p. 87).

study results to reflect the longer distance dicamba would drift when sprayed on a typical soybean field of at least 160 acres; and on multiple such fields totaling thousands of acres in localized areas.

4.2 Vapor Drift Buffer Zone Not Even Required in Most Areas

The EPA re-evaluated new dicamba due to the massive and unprecedented levels of drift injury it has caused to crops over the past two years. Yet paradoxically, the new buffer zone is required only in counties that harbor susceptible plants listed as threatened or endangered under the Endangered Species Act (EPA 2018c, pp. 9-10). XtendiMax, Engenia and FeXapan are registered in 34 states, which together comprise 2,696 counties.[69] The 57-foot buffer applies in only those 217 counties that have either listed dicot plants or critical habitats within the putative dicamba drift distance of soybean and cotton fields (EPA 2018c, pp. 51-57; Appendices D and E, pp. 111-128).[70] In other words, the additional buffer zone is required in only 8% of counties (217 of 2,696) where new dicamba is registered for use on Xtend crops; and it will provide next to no protection of any susceptible plants or crops even in those few counties.

5.0 REGISTRATIONS OF XTENDIMAX, ENGENIA AND FEXAPAN STILL ILLEGAL

Like its original registration of new dicamba, the extensions through the 2020 crop season violate federal pesticide law in that XtendiMax, Engenia and FeXaPan clearly have unreasonable adverse effects on the environment.

Under federal law, pesticide uses may only be registered if they do not cause unreasonable adverse effects on the environment, taking into account the pesticide's economic, social and environmental costs and benefits. Accordingly, part of EPA's latest assessment includes an evaluation of "benefits and impacts" of new dicamba applied to Xtend crops, which it describes as "over-the-top" (OTT) dicamba uses (EPA 2018e). Unlike the original 2016 registration, which EPA granted prior to any real-world experience with OTT dicamba on Xtend crops, the Agency's 2018 extension decision should have accounted for the massive crop injury that occurred in the 2017 and 2018 crop seasons as well as other costs, and weighed it against any benefits of OTT dicamba.[71]

5.1 Impacts

EPA's evaluation is heavily biased to discount the huge adverse impacts OTT dicamba use has had. This is accomplished through ignoring a wealth of critical information; lending credence to discredited, self-serving registrant views; and failure to provide even a rough estimate of the harms caused by OTT dicamba use.

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[69] For the 34 states, see EPA 2018c, p. 9; for number of counties in each of these states, see https://en.wikipedia.org/wiki/List_of_counties_by_U.S._state_and_territory. The total of 2,696 counties excludes two counties (Palm Beach County, FL and Wilson County, TN) in which use of new dicamba on Xtend crops had been prohibited in the original registration.

[70] See also https://www.regulations.gov/searchResults?rpp=25&po=0&s=epa-hq-opp-2016-0187-0974&fp=true&ns=true)

[71] As noted in Section 1.1, EPA had anticipated excessive drift injury from the start, and so had included in the original new dicamba registrations a clause that automatically terminated the registrations on November 9, 2018, absent an Agency determination that drift episodes were not occurring at unacceptable frequencies or levels. Nowhere in its decision documents does EPA make such a determination, which in itself is grounds for cancelling the registrations.

Dicamba drift episodes reported to EPA by registrants rose from no more than 40 per year in the 2010-2015 period to 2,622 in 2017, a more than 60-fold increase that EPA admits is “a record number of complaints” (EPA 2018e, pp. 3, 7). Despite the common knowledge of agronomists and EPA that farmers report only a small fraction of herbicide drift episodes to officials, with estimates of just 1 in 10 cases for OTT dicamba (Bamber 2017), EPA pretends that these official figures could be overestimates, citing Monsanto (EPA 2018e, pp. 6-7). Despite citing clear evidence from Indiana and Iowa officials that the great majority of dicamba complaints are both confirmed and attributable to OTT uses of new dicamba (Ibid., p. 9; OISC 2018), EPA also disingenuously suggests that “alleged” dicamba complaints could be due to old dicamba or other causes, again citing Monsanto (EPA 2018e, p. 8).

The more than 4,100 reported episodes over the past two years represent 4.7 million dicamba-damaged crop acres (Bradley 2017a, 2018; AAPCO 2018); including even modest estimates of unreported damage increases the total to over 10 million acres. As Andrew Thostenson, an an agronomist with the North Dakota State Extension Service put it: "We are in unprecedented, uncharted territory. We've never observed anything on this scale in this country since we've been using pesticides in the modern era" (as quoted in Unglesbee 2017a). Yet incredibly, EPA does not even give an estimate of crop acres injured by dicamba,[72] which is essential data for the cost accounting it is required to do under federal law.

EPA ignored extensive record evidence of yield and associated economic losses attributable to OTT dicamba drift injury. For instance, 200 Minnesota farmers suffered an estimated $7 million in losses collectively due to dicamba-induced yield deficits of 2 to 12 bushels per acre in 2017 (Steil 2017). A North Dakota farmer estimated 5-10 bushels/acre yield reduction on his dicamba-damaged acres (Pates 2017). Center for Food Safety provided EPA with numerous reports of dicamba-induced yield losses in these and other cases involving farmers in Tennessee, Missouri, Mississippi and Arkansas (Section 6.0; see also documented discussion in CFS 2017, Section 9.0, with relevant sources submitted to EPA). Dicamba damage is driving some unknown number of farmers out of business (Hall 2018, Steed 2019).

EPA has also entirely ignored the many social costs of its illegal registration of new dicamba (Section 6.0, see also CFS 2017). These costs include strife among once-friendly farmers due to dicamba drift damage; forced adoption of dicamba-resistant crops by farmers seeking only to avert dicamba drift damage, which annuls those farmers’ rights to buy the seed and plant the crops of their choice, and additionally imposes economic costs for the dicamba-resistance trait; and existential threats to farmers of “several hundred susceptible (e.g. sensitive) crops/crop groups,” including virtually all vegetables and fruit trees, for which no dicamba-resistant trait is available (EPA 2018e, p. 19). EPA’s failure to proscribe OTT dicamba uses is tearing apart the social fabric of rural America.

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[72] A critical table referenced in the text as reporting acres injured by dicamba drift was mysteriously omitted from the document (see EPA 2018e, page 19, for reference to a Table 2 that does not appear in the document).

Finally, EPA ascribes no environmental costs to the OTT dicamba registrations, despite credible evidence of harm to pollinators via impairment of flowering plants by dicamba drift in areas of heavy OTT dicamba use (Charles 2017, Jeunesse 2015, Bohnenblust et al. 2016, Steed 2019).

5.2 Benefits

EPA concedes that OTT uses of dicamba provide little if any benefit for those farmers who grow Xtend crops. EPA rejected registrants' claim that OTT dicamba is critical to conservation tillage programs, and thus dicamba cannot be credited with the benefits associated with conservative tillage, such as reduced soil erosion. EPA also finds that OTT dicamba use does not reduce yield loss from weeds any more effectively than other weed control programs, as registrants had claimed (EPA 2018e, p. 17). By properly rejecting these claimed benefits for lack of evidence, EPA has struck down Monsanto's two major justifications for its Xtend crop systems: they do not lead to increased yield or reduced soil erosion.

However, EPA accepted two other registrant-claimed benefits. OTT dicamba is supposed to offer: 1) Another herbicide for weed control; and 2) Resistance management benefits (for following discussion, see Ibid., pp. 13-17).

The first point borders on tautology. As a new use, OTT dicamba by definition provides an additional means to control weeds. But EPA itself finds that 14 and 9 other herbicides are used for OTT control of broadleaf weeds in soybeans and cotton, respectively; so the value of one additional option is dubious at best. These options include two non-glyphosate herbicides – glufosinate and 2,4-D – that like dicamba are used primarily OTT on crops engineered to withstand them.

The claim that OTT dicamba delays resistance to ***other*** herbicides fails on two counts: it is entirely unfounded, and distracts from the main issue of weeds evolving resistance to dicamba.

EPA presents no evidence that dicamba OTT will delay resistance to other herbicides. Instead, the Agency suggests that dicamba might control a few weed biotypes with multiple resistance to other herbicides. But controlling ***already resistant*** weeds is entirely different than ***preventing or delaying resistance*** in non-resistant weeds. The latter requires reduced reliance on herbicides and greater use of non-chemical weed management tactics, not OTT use on an herbicide-resistant crop (Mortensen et al. 2012).

The claimed benefit is also disingenuous, in that it distracts attention from the real concern: the advent of weed resistance to dicamba. There are already initial signs of dicamba-resistant weed emergence in the context of Xtend crops, despite just two seasons of OTT dicamba use (CFS 2017, Section 10.4; Hagny 2017). This outcome is predicted both by theory (Neve 2008) and history, which shows that there is no more effective way to trigger weed resistance to an herbicide than apply it OTT.[73]

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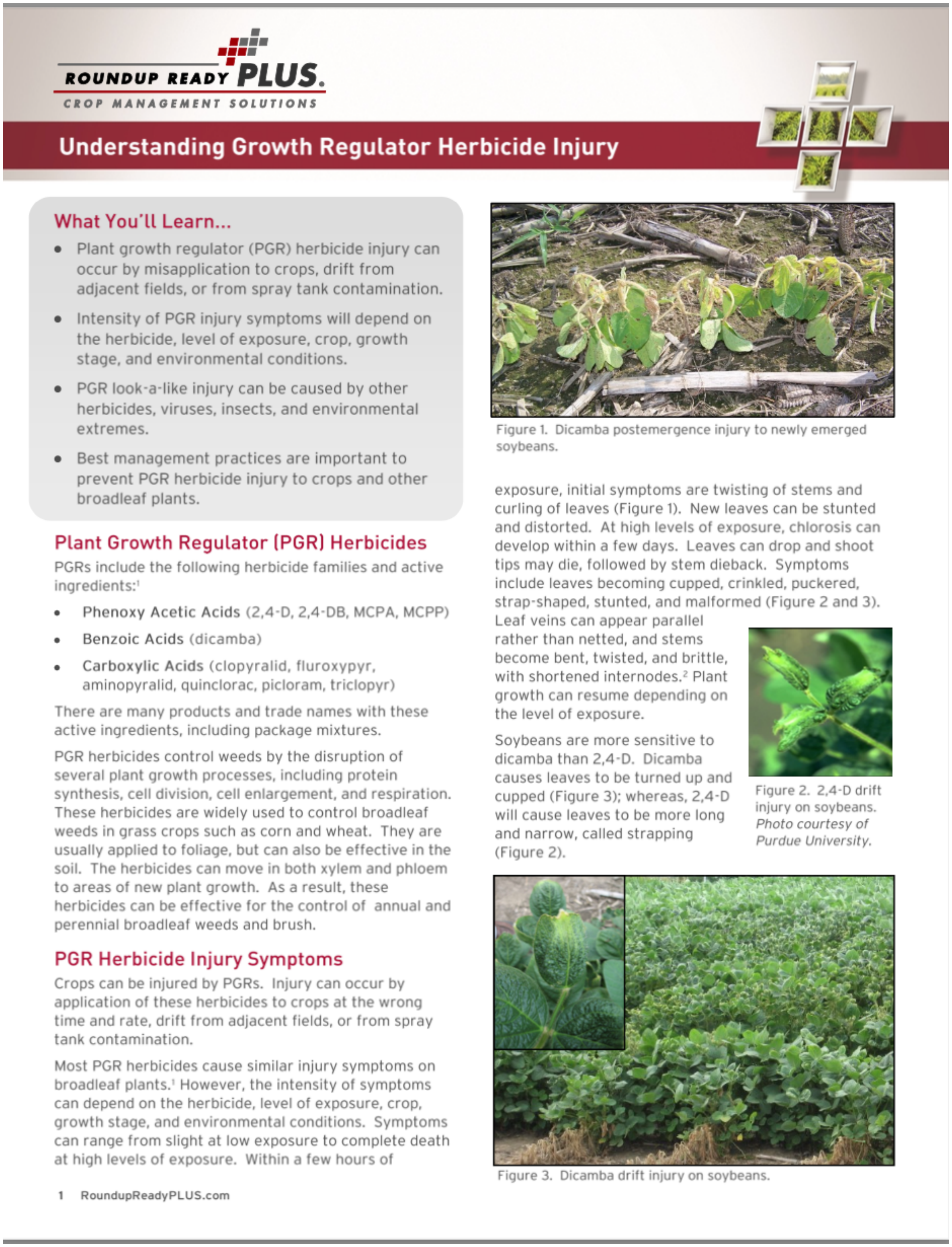
[73] Two major examples. Weeds rapidly evolved resistance to ALS inhibitors in the 1980s and 1990s due in part to their predominant use OTT (Carpenter and Gianessi 1999). Other reasons include overreliance on them and the relative frequency of mutations conferring ALS inhibitor resistance (Tranel and Wright 2002). Glyphosate resistance evolved with equal rapidity after the year 2000 due to widespread and often exclusive OTT use of glyphosate on Roundup Ready crops (Hartzler et al. 2004; Mortensen et al. 2012).

5.3 Impacts Far Outweigh Any Benefits

The foregoing discussion makes it clear that the adverse effects of dicamba OTT far exceed any minimal benefits that might be ascribed to it. It seems clear that EPA failed to provide any cost-accounting of the enormous damage already wrought by OTT dicamba from a prior commitment to extending its registration for two more years. Over-the-top use of dicamba on dicamba-resistant crops violates federal pesticide law by causing huge and unreasonable adverse impacts on the environment, taking into account the economic, social and environmental costs and benefits.

Attachment 2



ROUNDUP READY PLUS
CROP MANAGEMENT SOLUTIONS

Understanding Growth Regulator Herbicide Injury

What You'll Learn...

- Plant growth regulator (PGR) herbicide injury can occur by misapplication to crops, drift from adjacent fields, or from spray tank contamination.
- Intensity of PGR injury symptoms will depend on the herbicide, level of exposure, crop, growth stage, and environmental conditions.
- PGR look-a-like injury can be caused by other herbicides, viruses, insects, and environmental extremes.
- Best management practices are important to prevent PGR herbicide injury to crops and other broadleaf plants.

Plant Growth Regulator (PGR) Herbicides

PGRs include the following herbicide families and active ingredients:[1]

- Phenoxy Acetic Acids (2,4-D, 2,4-DB, MCPA, MCPP)
- Benzoic Acids (dicamba)
- Carboxylic Acids (clopyralid, fluroxypyr, aminopyralid, quinclorac, picloram, triclopyr)

There are many products and trade names with these active ingredients, including package mixtures.

PGR herbicides control weeds by the disruption of several plant growth processes, including protein synthesis, cell division, cell enlargement, and respiration. These herbicides are widely used to control broadleaf weeds in grass crops such as corn and wheat. They are usually applied to foliage, but can also be effective in the soil. The herbicides can move in both xylem and phloem to areas of new plant growth. As a result, these herbicides can be effective for the control of annual and perennial broadleaf weeds and brush.

PGR Herbicide Injury Symptoms

Crops can be injured by PGRs. Injury can occur by application of these herbicides to crops at the wrong time and rate, drift from adjacent fields, or from spray tank contamination.

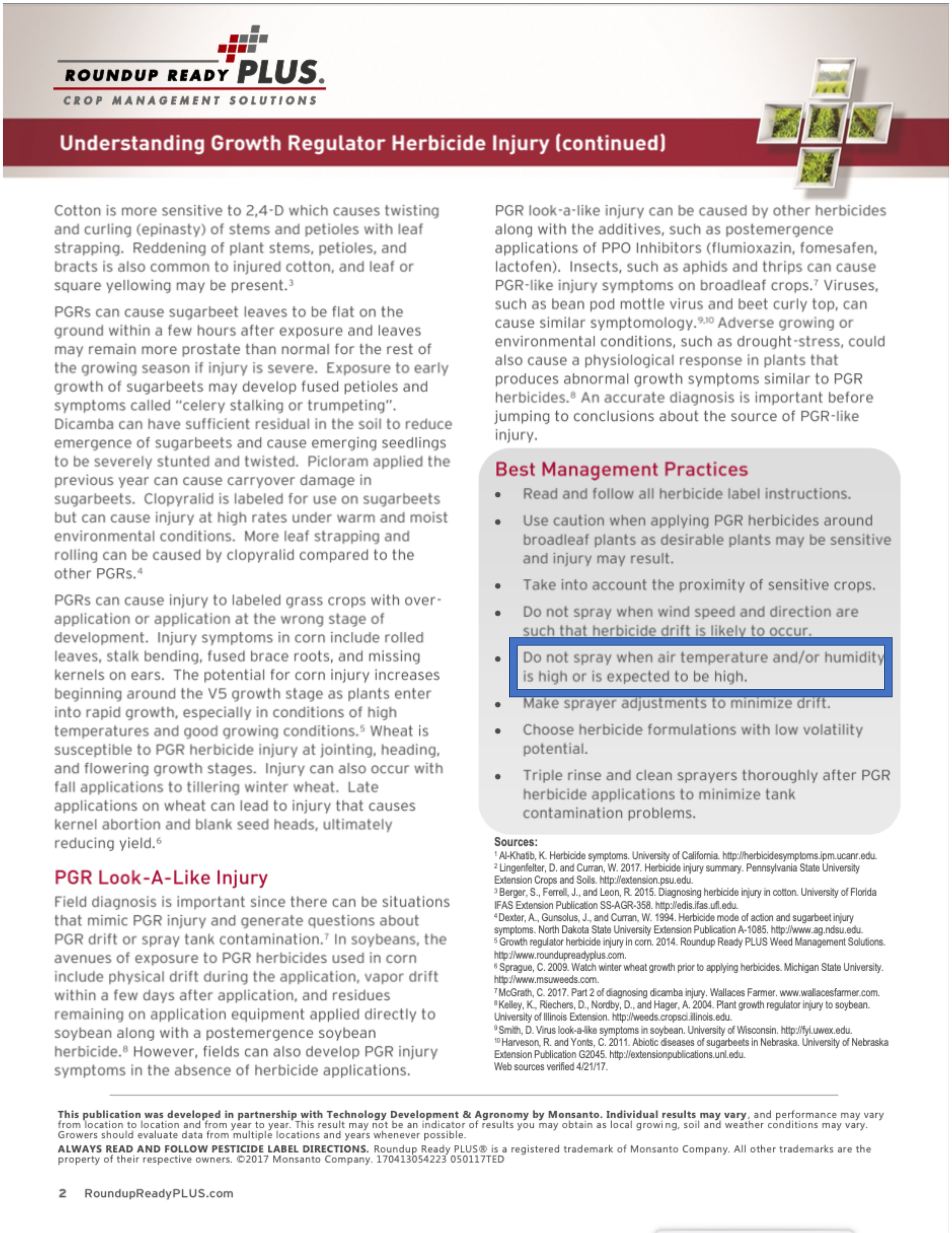
Most PGR herbicides cause similar injury symptoms on broadleaf plants.[1] However, the intensity of symptoms can depend on the herbicide, level of exposure, crop, growth stage, and environmental conditions. Symptoms can range from slight at low exposure to complete death at high levels of exposure. Within a few hours of exposure, initial symptoms are twisting of stems and curling of leaves (Figure 1). New leaves can be stunted and distorted. At high levels of exposure, chlorosis can develop within a few days. Leaves can drop and shoot tips may die, followed by stem dieback. Symptoms include leaves becoming cupped, crinkled, puckered, strap-shaped, stunted, and malformed (Figure 2 and 3). Leaf veins can appear parallel rather than netted, and stems become bent, twisted, and brittle, with shortened internodes.[2] Plant growth can resume depending on the level of exposure.

Soybeans are more sensitive to dicamba than 2,4-D. Dicamba causes leaves to be turned up and cupped (Figure 3); whereas, 2,4-D will cause leaves to be more long and narrow, called strapping (Figure 2).

Figure 1. Dicamba postemergence injury to newly emerged soybeans.

Figure 2. 2,4-D drift injury on soybeans. *Photo courtesy of Purdue University.*

Figure 3. Dicamba drift injury on soybeans.



ROUNDUP READY PLUS.
CROP MANAGEMENT SOLUTIONS

Understanding Growth Regulator Herbicide Injury (continued)

Cotton is more sensitive to 2,4-D which causes twisting and curling (epinasty) of stems and petioles with leaf strapping. Reddening of plant stems, petioles, and bracts is also common to injured cotton, and leaf or square yellowing may be present.[3]

PGRs can cause sugarbeet leaves to be flat on the ground within a few hours after exposure and leaves may remain more prostate than normal for the rest of the growing season if injury is severe. Exposure to early growth of sugarbeets may develop fused petioles and symptoms called "celery stalking or trumpeting". Dicamba can have sufficient residual in the soil to reduce emergence of sugarbeets and cause emerging seedlings to be severely stunted and twisted. Picloram applied the previous year can cause carryover damage in sugarbeets. Clopyralid is labeled for use on sugarbeets but can cause injury at high rates under warm and moist environmental conditions. More leaf strapping and rolling can be caused by clopyralid compared to the other PGRs.[4]

PGRs can cause injury to labeled grass crops with over-application or application at the wrong stage of development. Injury symptoms in corn include rolled leaves, stalk bending, fused brace roots, and missing kernels on ears. The potential for corn injury increases beginning around the V5 growth stage as plants enter into rapid growth, especially in conditions of high temperatures and good growing conditions.[5] Wheat is susceptible to PGR herbicide injury at jointing, heading, and flowering growth stages. Injury can also occur with fall applications to tillering winter wheat. Late applications on wheat can lead to injury that causes kernel abortion and blank seed heads, ultimately reducing yield.[6]

PGR Look-A-Like Injury

Field diagnosis is important since there can be situations that mimic PGR injury and generate questions about PGR drift or spray tank contamination.[7] In soybeans, the avenues of exposure to PGR herbicides used in corn include physical drift during the application, vapor drift within a few days after application, and residues remaining on application equipment applied directly to soybean along with a postemergence soybean herbicide.[8] However, fields can also develop PGR injury symptoms in the absence of herbicide applications.

PGR look-a-like injury can be caused by other herbicides along with the additives, such as postemergence applications of PPO Inhibitors (flumioxazin, fomesafen, lactofen). Insects, such as aphids and thrips can cause PGR-like injury symptoms on broadleaf crops.[7] Viruses, such as bean pod mottle virus and beet curly top, can cause similar symptomology.[9,10] Adverse growing or environmental conditions, such as drought-stress, could also cause a physiological response in plants that produces abnormal growth symptoms similar to PGR herbicides.[8] An accurate diagnosis is important before jumping to conclusions about the source of PGR-like injury.

Best Management Practices

- Read and follow all herbicide label instructions.
- Use caution when applying PGR herbicides around broadleaf plants as desirable plants may be sensitive and injury may result.
- Take into account the proximity of sensitive crops.
- Do not spray when wind speed and direction are such that herbicide drift is likely to occur.
- Do not spray when air temperature and/or humidity is high or is expected to be high.
- Make sprayer adjustments to minimize drift.
- Choose herbicide formulations with low volatility potential.
- Triple rinse and clean sprayers thoroughly after PGR herbicide applications to minimize tank contamination problems.

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