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Herbicide drift can affect plant and arthropod communities

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ABSTRACT

Field edges, old fields, and other semi-natural habitats in agricultural landscapes support diverse plant communities that help sustain pollinators, predators, and other beneficial arthropods. These plant and arthropod communities may be at significant ecotoxicological risk from herbicides applied to nearby crop fields. Recent innovations in herbicide-resistant crop biotechnology may lead to major increases in the use of the herbicides dicamba and 2,4-D. These herbicides selectively affect broadleaf plants, and non-target exposures may therefore lead to a net reduction in the functional diversity and floral resources provided by semi-natural habitats. In multi-year experiments at two sites (a field edge and an old field), we exposed replicated plots to low doses of dicamba designed to simulate herbicide drift and monitored changes in plant and arthropod communities. At the field edge site, we observed a significant decline in forb cover (but not floral resources) in plots treated at doses (~1% of the field application rate) that are substantially lower than those that have been documented to affect plant communities in previous research. We also observed declines in three herbivorous pest species (pea aphids, spotted alfalfa aphid, and potato leaf hopper), increases in one pest species (clover root curculio), and increases in beneficial seed predators (crickets) associated with dicamba exposure. In contrast, at the old field site, drift-level doses did not affect plant community structure but reduced flowering of a key species (*Monarda fistulosa*). Variability across sites and taxonomic groups makes it difficult to offer general conclusions about the risks of dicamba drift to plant and arthropod biodiversity. Factors including the successional age of the plant community and water stress at the time of herbicide exposure likely explain the differing responses at the two sites to simulated drift.

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1. Introduction

Plant biodiversity supports several ecosystem services that are crucial for sustainable agriculture, including pollination and biological pest control, but these diversity resources may be at significant ecotoxicological risk from herbicides applied for weed control in nearby crop fields (Freemark and Boutin, 1995). Agricultural landscapes are typically land use mosaics, with fragments of semi-natural habitat including pastures, grasslands, and forest interspersed within a matrix of arable fields. In contrast to the heavily managed environment of crop fields where growers actively minimize plant diversity to enhance crop production, habitat fragments are the reservoir of plant biodiversity in many agricultural landscapes (Boutin and Jobin, 1998; Egan and Mortensen, 2012a; Liira et al., 2008; Phalan et al., 2011). By providing habitat, floral resources, and other food resources, plant diversity in semi-natural habitats is essential for maintaining diverse communities of beneficial arthropods that provide pollination and biological control (Isaacs et al., 2009).

Herbicides are a primary weed control tactic in most modern cropping systems, and non-target areas outside of crop fields can be exposed to herbicides through a variety of mechanisms. Perhaps most commonly, herbicides can move as particle drift, where water droplets emitted from ground or aerial sprayer are transported via wind (de Jong et al., 2008; Marrs et al., 1989; Wang and Rautman, 2008). Certain compounds (e.g. clomazone, 2,4-D, and dicamba) can move as vapor drift, when a herbicide that has been applied to a field volatilizes and is transported as a vapor (Behrens and Lueschen, 1979; Egan and Mortensen, 2012b; Grover et al., 1972; Locke et al., 1996). Herbicides can also be transported off crop fields in surface or subsurface water flow (Patzold et al., 2007; Reichenberger et al., 2007; Wauchope et al., 2002). Additionally, herbicides can move into the atmosphere attached to soil and dust particles which can then be deposited in rainfall at concentrations high enough to injure

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plants (Hill et al., 2002; Tuduri et al., 2006). Given this variety of transport mechanisms, it is likely that wild plants growing in semi-natural habitats near treated crop fields are consistently exposed to low doses of various herbicides.

Despite the importance of herbicides in modern agriculture, scientific understanding of the response of wild plants and plant communities to low-dose exposures has very significant gaps (Boutin et al., 2012). Although pesticide regulatory agencies in many countries require some plant toxicity testing before registering herbicidal products, these tests rely heavily on greenhouse bioassays of individual plants and are focused on a very small set of domesticated plant species (Boutin et al., 2012; Olszyk et al., 2008). Recent research has expanded our understanding by exploring plant response to herbicides at different phenological stages (Olszyk et al., 2009a,b), by using under-represented taxonomic groups (Boutin et al., 2012), and by using field and greenhouse microcosms to explore the combined effects of plant–plant interactions and herbicide exposure (Dalton and Boutin, 2010; Riemens et al., 2008). However, very little research has explored community-scale responses in realistic field settings. While several observational studies have compared plant communities in habitats adjacent to herbicide-treated and untreated fields (Bassa et al., 2011; Boutin and Jobin, 1998; de Snoo and van der Poll, 1999), very few authors have investigated the effects of non-target herbicide exposures using in situ field experiments (for a rare example, see Kleijn and Snoeijing, 1997). The field experiment approach has largely been avoided because background variation in plant community composition across a field site may make it very difficult to detect subtle impacts of herbicides on plant community structure and function (Marrs and Frost, 1997). On the other hand, field experiments can reveal the range of potential plant responses under realistic environmental conditions.

Moreover, the direct and indirect effects of herbicides on arthropods are not well understood, and of the available studies, results are often variable. While most herbicides do not appear to be directly toxic to arthropods (Norris and Kogan, 2000), herbicides do affect plant nutrient levels and hormone pathways used in defense, both of which may influence plant susceptibility to herbivores (Bohnenblust et al., 2013; Grossmann et al., 2004; Oka and Pimentel, 1976). For instance, aphids can perform better on herbicide-stressed plants (Adams and Drew, 1969; Oka and Pimentel, 1976). However, in most instances where arthropods are affected by herbicides, the driving mechanism often appears to be changes in features of the vegetation, such as plant species composition, habitat structure, or the ability of plants to defend themselves from herbivores (Norris and Kogan, 2005; Taylor et al., 2006). Therefore, if low-dose herbicide exposures affect plant community structure and function, arthropod communities may change due to factors like reduced availability or suitability of host plants.

In the U.S. and other countries where crops with genetically modified resistance to the herbicide glyphosate (i.e. Roundup Ready, Monsanto Company) are widely adopted by farmers, patterns of herbicide use are expected to change significantly over the next five years (Mortensen et al., 2012). In glyphosate-resistant cropping systems, glyphosate has become the most widely used herbicide, and an over-reliance on this single weed management tactic has led to a severe outbreak of weed species with evolved resistance to glyphosate. As a potential solution to glyphosate-resistant weed problems, biotechnology companies are currently developing second-generation herbicide-resistant crops with new traits that confer resistance to additional herbicide chemistries (Waltz, 2010). Currently, companies are pursuing U.S. regulatory approval for dicamba-resistant soybean and 2,4-D resistant corn and soybean (Dow AgroSciences, 2011; Monsanto Company, 2012). Both dicamba and 2,4-D are synthetic-auxin herbicides, and because they effectively control many of the most problematic glyphosate-resistant weeds, the resistance traits and associated herbicide programs are likely to be widely adopted by growers (Mortensen et al., 2012).

Dicamba and 2,4-D are toxic to many broadleaf plant species but generally well tolerated by grasses, and so they have been widely used in cereal crops and pastures for decades (Monaco et al., 2002). The new resistance traits will allow these compounds to be used in new crops, at new times during the growing season including more postemergence applications, and over vastly expanded areas. From their historical uses in corn and cereals, both dicamba and 2,4-D are known to move out of crop fields via particle and vapor drift (Auch and Arnold, 1978; Behrens and Lueschen, 1979; Grover et al., 1972; Marple et al., 2007), residue contamination in spray rigs (Boerboom, 2004), and deposition in rainfall (Hill et al., 2002). Consequently, the Association of American Pesticide Control Officers consistently ranks 2,4-D and dicamba at or near the top of herbicide active ingredients implicated in crop injury complaints (AAPCO, 2005). Several U.S. municipalities where highly sensitive crops like cotton are widely grown have special restrictions on use of these compounds to help prevent crop injury problems (LDFA, 2011; TDA, 2012). Although drift reducing application technologies and product stewardship may help prevent problems (Dow AgroSciences, 2011; Monsanto Company, 2012), the new resistant traits in corn and soybean (with traits in cotton and canola also in development) will likely lead to major increases in application of 2,4-D and dicamba and potential increases in non-target exposures to semi-natural habitats (Mortensen et al., 2012).

Because dicamba and 2,4-D are selectively toxic to broadleaf plants but not monocots (Monaco et al., 2002), we expect that non-target herbicide exposure could have significant impacts on plant and arthropod communities in semi-natural habitats. Specifically, we predict that low-dose herbicide exposures will reduce the diversity and abundance of forbs and cause an associated decline in the diversity and abundance of floral resources provided to beneficial insects. We therefore expect a decline in pollinators and parasitoids that utilize floral resources and a decline in herbivorous arthropods that specialize on forbs. We tested these predictions through multi-year field experiments in which replicated plots at a field margin and old-field site were treated with a range of dicamba doses. We focused our research on dicamba due to constraints in time and resources, but because dicamba and 2,4-D have similar plant toxicity profiles, we expect that our findings may be broadly applicable to 2,4-D as well.

2. Materials and methods

2.1. Study sites

We conducted our experiments over 2010–2012 at two sites near State College, Pennsylvania, U.S.A., that represent common semi-natural habitats in temperate agricultural landscapes.

The first site was a field edge comprising a grassy field margin and a forest edge located at the interface of a large (~20 ha) forest fragment and an alfalfa field managed by the Pennsylvania State University. The alfalfa field was established in April 2009 and remained in alfalfa throughout the experiment. Because herbicides were only needed in alfalfa during the spring of the establishment year and no other crop fields were nearby, this site did not experience herbicide drift during the experiment. The field margin at this site was 3–5 m wide and contained a high diversity of plant species with dominants including *Poa pratensis*, *Juncus tenuis*, *Solidago* spp., and *Taraxacum officinalis*. The forest edge was dominated by *Lonicera maackii*, *Celastrus orbiculatus*, and *Parthenocissus quinquefolia*. As part of normal farm management,