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Widespread occurrence of neonicotinoid insecticides in streams in a high corn and soybean producing region, USA

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ABSTRACT

Neonicotinoid insecticides are of environmental concern, but little is known about their occurrence in surface water. An area of intense corn and soybean production in the Midwestern United States was chosen to study this issue because of the high agricultural use of neonicotinoids via both seed treatments and other forms of application. Water samples were collected from nine stream sites during the 2013 growing season. The results for the 79 water samples documented similar patterns among sites for both frequency of detection and concentration (maximum:median) with clothianidin (75%, 257 ng/L:8.2 ng/L) > thiamethoxam (47%, 185 ng/L:<2 ng/L) > imidacloprid (23%, 42.7 ng/L: <2 ng/L). Neonicotinoids were detected at all nine sites sampled even though the basin areas spanned four orders of magnitude. Temporal patterns in concentrations reveal pulses of neonicotinoids associated with rainfall events during crop planting, suggesting seed treatments as their likely source.

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1. Introduction

Insecticide use has long been an integral part of crop protection and management strategies in the United States (U.S.). Historically, insecticides in Midwestern U.S. streams have been less frequently detected and at lower concentrations (Gilliom et al., 2006; Schnoebelen et al., 2003) than the ubiquitous occurrence of herbicides and their associated degradation products (Battaglin et al., 2005). In recent years, however, insecticide use on crops has changed dramatically in terms of both active ingredients used and application techniques. The use of organophosphate (*e.g.*, chlorpyrifos, methyl parathion, phorate, terbufos) and carbamate (*e.g.*, carbaryl, carbofuran) insecticides on corn and soybeans has declined while use of neonicotinoid insecticides across the U.S., particularly in the Midwestern U.S., has dramatically increased over the last decade (USGS, 2014; Fig. SI-1). The most commonly-used neonicotinoids on corn and soybeans include clothianidin, imidacloprid, and thiamethoxam (Table 1). Imidacloprid also has a variety of other uses including lawn and garden and topical flea medicines (Jeschke et al., 2011).

In addition to changes in active ingredients, there has also been a corresponding change in insecticide management techniques. This is primarily reflected in a switch from broadcast applications for insect control to the use of pesticide-treated seeds, coinciding with a push in precision agriculture (Elbert et al., 2008). The use of treated seeds in the U.S. has tripled in the last decade (Haire, 2014) to the point where nearly all corn and soybeans planted in the U.S. have a seed treatment (*i.e.*, coating), many of which include neonicotinoids. This rapidly growing neonicotinoid use is clearly shown for both Iowa (Fig. 1) and the Midwestern U.S. (Fig. SI-1).

Neonicotinoids are receiving increased scrutiny since they have been implicated in adversely affecting pollinators and linked to colony collapse disorder in bees (Spivak et al., 2011; vanEngelsdorp et al., 2009). Thiamethoxam has been linked to decreased survival in honeybees (Henry et al., 2012), while imidacloprid has been linked to reduced colony growth and queen performance in bumble bees (Whitehorn et al., 2012) and sublethal affects to flies (Charpentier et al., 2014). An important mechanism of neurotoxicity for neonicotinoids is the almost irreversible binding to nicotinic acetylcholine receptors in insects (Jeschke and Nauen, 2008). Therefore, continued exposures to neonicotinoids may lead to a cumulative effect in insects (Tennekes and Sanchez-Bayo, 2011). Birds are also susceptible to neonicotinoid exposure, including both the direct ingestion of treated seeds and through contamination of the aquatic

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Table 1
Properties of commonly used neonicotinoid insecticides and the amount applied in Iowa in 2013.

Neonicotinoid	Log K_{ow}[a]	Log K_{oc}[a,b]	Aqueous dissipation half-life (days)[a]	Soil degradation half-life (days)[a]	Amount applied to crops in Iowa in 2013 (kg)[c]
Acetamiprid	0.80	2.3	4.7	3	–
Clothianidin	0.91	2.1	40.3	545	215,000
Dinotefuran	−0.55	1.4	–[d]	82	–
Imidacloprid	0.57	2.1–2.5	30	191	70,700
Thiacloprid	1.26	NA	8.5	15.5	–
Thiamethoxam	−0.13	1.8	30.6	50	49,900

[a] UOH (2013).
[b] CDPR (2006).
[c] Baker and Stone (2014).
[d] – = not available.

food chain (Mineau and Palmer, 2013). There is evidence that neonicotinoids can cause immune suppression in insects (bees) and in fish (Di Prisco et al., 2013; Mason et al., 2013). In 2013, the European Commission adopted a proposal to restrict the use of 3 neonicotinoids (clothianidin, imidacloprid and thiamethoxam) for a period of 2 years, including their use for seed treatment (EU, 2013).

In the environment, neonicotinoids are highly soluble in water (log K_{ow} −0.55 to 1.26) and somewhat persistent (Table 1), with clothianidin having the longest soil degradation half-life (545 days). Thus, neonicotinoids are likely to be transported away from the initial application area to surface water and groundwater. The transport to surface water can occur via overland runoff from rainfall or irrigation, or through tile drain lines. Monitoring data for neonicotinoids in the environment are limited, with most studies only analyzing for imidacloprid. Of the studies that measured multiple neonicotinoids, two were in wetlands (Anderson et al., 2013; Main et al., 2014) and two were in streams (Hladik and Calhoun, 2012; Sanchez-Bayo and Hyne, 2014). More detailed research on the geographic occurrence and concentrations of neonicotinoids in surface waters, especially from use on treated seeds, is essential in determining possible implications to biota, including pollinators and aquatic invertebrates.

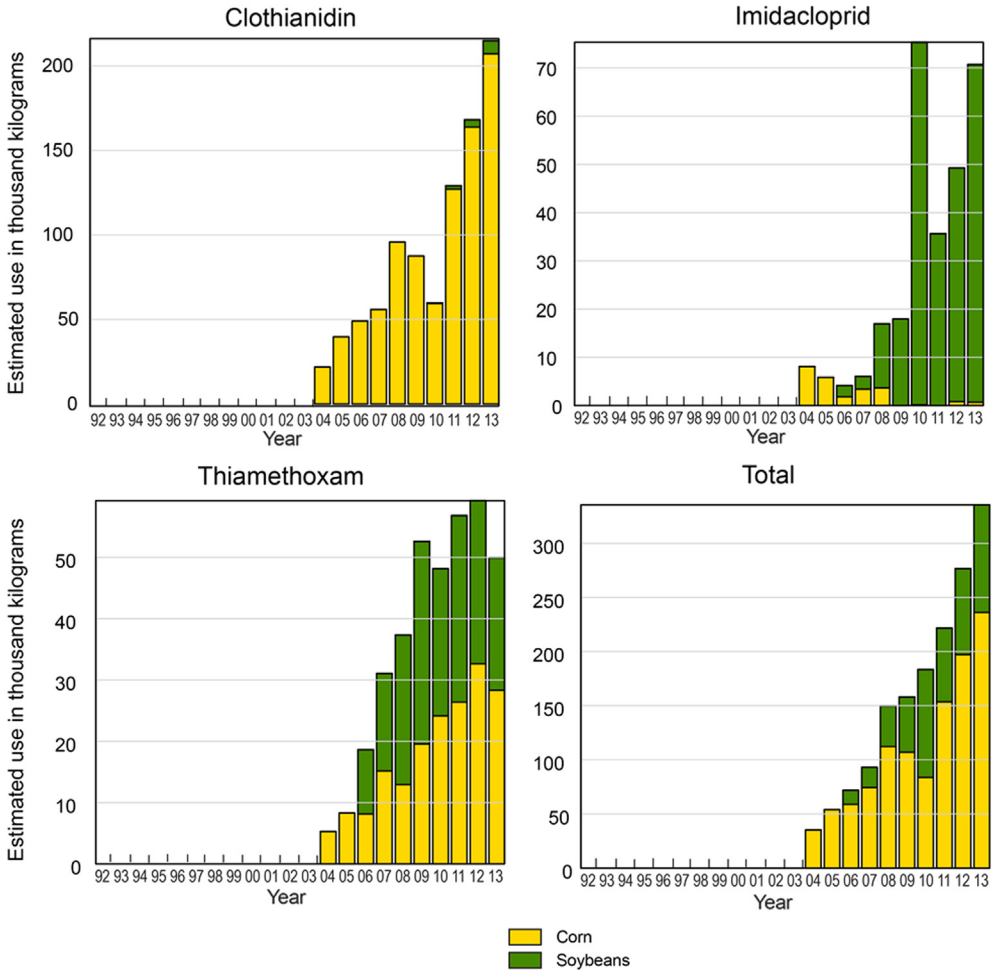

Fig. 1. Estimated annual pesticide (Epest-high) use for Iowa 1992–2013 for the three most commonly applied neonicotinoids and the total for all 3 compounds (data from Baker and Stone, 2014).