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ENVIRONMENTAL IMPACTS OF RESTRICTING THE HERBICIDE ATRAZINE IN THE U.S. AND ITALY

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ENVIRONMENTAL STUDIES

by

Joanna E. Ory

June 2015

The Dissertation of Joanna E. Ory is approved:

Professor Bent Haddad, chair

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Professor Emeritus Stephen Gliessman

Tyrus Miller
Vice Provost and Dean of Graduate Studies

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Abstract

Environmental impacts of restricting the herbicide atrazine in the US and Italy

Joanna Elinor Ory

Water pollution from the herbicide atrazine impacts public health worldwide, as atrazine is used extensively and is a common water contaminant. My research investigates how restrictions on atrazine have led to changes in water quality, farming practices, and farmer decision-making. My dissertation consists of two case studies. The first case study is on the complete ban of atrazine in Italy. The second case study is on the application rate restrictions and prohibition areas created in Wisconsin. In these two case studies I combine interview data, surveys, water quality analysis, and archival research to investigate what factors led to the policies and whether they resulted in improved environmental outcomes. I conclude my dissertation with a discussion of strategies to reduce pesticide use in agriculture and protect water quality.

This dissertation is dedicated to my incredible family,

Rhona, Val, and Sarah Ory,

for their love and encouragement.

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1. Introduction

Introduction

Pollution from pesticides is a worldwide environmental and human health problem. Pesticides contaminate natural resources and drinking water sources by entering rivers and streams through agricultural runoff and leaching into groundwater. Water pollution from pesticides causes health risks for humans, harm to wildlife, and disruption to ecosystem functions. Human exposure to pesticides in drinking water causes risks of both acute and chronic disorders and diseases including cancer, reproductive disorders, developmental disorders, and cardiovascular diseases (Prüss-Ustün et al., 2011). The most recent EPA data on total pesticide use from 2007 calculates that over one billion pounds of pesticides were used in the US, with herbicides being the most widely used type of pesticide (Grube et al., 2011). This dissertation analyzes the successes and weaknesses of pesticide regulation in the US and EU using a case study of the herbicide atrazine.

The US used over 70 million pounds of the herbicide atrazine in 2007, making it the second most used pesticide in the country (Grube et al., 2011). Atrazine has been used in the US since 1958 as an agricultural herbicide, mainly for weed control in corn, sugar cane, and sorghum. Atrazine is in the triazine chemical family and kills plants by inhibiting photosynthesis. Atrazine is relatively inexpensive, costing $10.25/gal compared with the alternative herbicide mesotrione at $542.66/gal (Kentucky Farm Bureau, 2011). Atrazine is primarily produced by the Swiss agrichemical company Syngenta, which claims that there "is no substitute" and that atrazine is “effective, safe, and integral to agriculture’s success in the United States and worldwide” (Syngenta, 2015).

Atrazine is applied to soil surfaces to kill weeds, which leads to a high risk of contaminating water during rain events. Toxicological studies outline negative impacts on phytoplankton, aquatic insects, amphibians, fish and mammals (Graymore et al., 2001; Rohr and McCoy, 2010). Atrazine, an endocrine disruptor, poses human health risks for development, reproduction, and cancer (Lasserre et al., 2008; Hayes et al., 2002).

According to a Natural Resource Defense Council (NRDC) report, drinking water in the US is being poisoned by atrazine (Wu et al., 2010). The report argues that phasing-out atrazine is needed to protect the health of the environment and drinking water safety. Widespread atrazine contamination in the US spurred the US Environmental Protection Agency (EPA) to initiate a special review process of atrazine’s human health impacts and water contamination in 2009. A special review of this nature can be followed by new regulation of the pesticide. This review has sparked controversy from farmers who say they have no viable alternatives. Farmers and industry argue that because no alternative herbicide with equal economic and agronomic attributes is available, atrazine restrictions would have negative economic impacts from decreased crop yield and costs of substitute chemicals (Ackerman, 2007; Swanton et al., 2007). However, atrazine was banned in the European Union (EU) in 2004 and in Italy since 1990 with little apparent impact on the agricultural sector.

The science and policy surrounding atrazine is politically charged and controversial. Syngenta has fiercely discounted scientific studies and attempted to discredit the work conducted by Prof. Tyrone Hayes showing that atrazine is an endocrine disruptor for frogs (Aviv, 2015). In addition, Syngenta disputes that atrazine is banned in the EU (despite EU agencies stating that atrazine is banned in formal documents), claiming that atrazine is not in use but is not "banned" (Hakim, 2015). On the other side, environmental groups such as The Land Stewardship Project have stated that Syngenta used bullying tactics with the EPA and suppressed science that demonstrated the harmful environmental impacts of atrazine (Land Stewardship Project, 2009). This controversy adds to the complexity of regulating atrazine, as the stakeholders are strongly committed to their diametrically opposed agendas and the issue is a subject of close media scrutiny. Wu et al. (2009), a report from the NRDC entitled "Atrazine: Poisoning the Well," along with the New York Times front page article by Charles Duhigg, "Debating How Much Weed Killer Is O.K. In Your Water Glass," brought forward the US atrazine pollution problem as an issue in need of national attention. Wu et al. (2009) provide several recommendations for policy: (1) the US should phase out atrazine; (2) Farmers should be encouraged to reduce atrazine use; (3) The EPA should increase monitoring in vulnerable areas; (4) the EPA should publish monitoring data in a timely manner; and (5) the public should use home water filtration systems. For recommendation number two, the authors provide several strategies for farmers to reduce atrazine use. These strategies include the IPM techniques of using cover crops, mechanical weed control, delayed fertilizer application, intercrops, and crop rotation.

The policy and agronomic suggestions in these reports refer very little to the different policy tools that would be necessary to achieve the desired outcomes. For example, in Wu et al. (2010), it is unclear how growers should be encouraged to adopt IPM techniques. If the desired outcome of a potential atrazine phase-out is improved water quality, it is important to assess the alternatives and learn from the history of what has occurred in other countries where atrazine has been removed from the market.

Learning from history is an important step in crafting policies and designing them to produce desired environmental outcomes. This study examines the history of atrazine regulation and its associated environmental outcomes in order to learn which policies are most effective for holistically managing water pollution from pesticides. I use case studies in Italy and Wisconsin to analyze the environmental and economic effects of restricting atrazine and other herbicides. In the early 1990s, atrazine use was discontinued throughout Italy and selectively restricted in certain areas of Wisconsin. The research in Italy is focused on a survey I conducted regarding farmer decision-making in response to atrazine restrictions. The Wisconsin research includes close examination of the changes in water quality after atrazine restrictions went into effect. These two cases provide an opportunity for analysis of different herbicide management systems designed to reduce atrazine contamination and provides policy recommendations aimed at increasing water quality protection from pesticides.

Background on atrazine

Pesticides include any product used to kill insects, weeds, fungi, microorganisms, and rodents (EPA, 2014a). Herbicides are a form of pesticide, and throughout this introduction and subsequent chapters both the terms pesticide and herbicide are used to describe atrazine and different herbicides. Herbicides comprise the largest portion of total pesticide use with 531 million pounds of herbicide used in the US in 2007 (Grube et al., 2011; Figure 1).

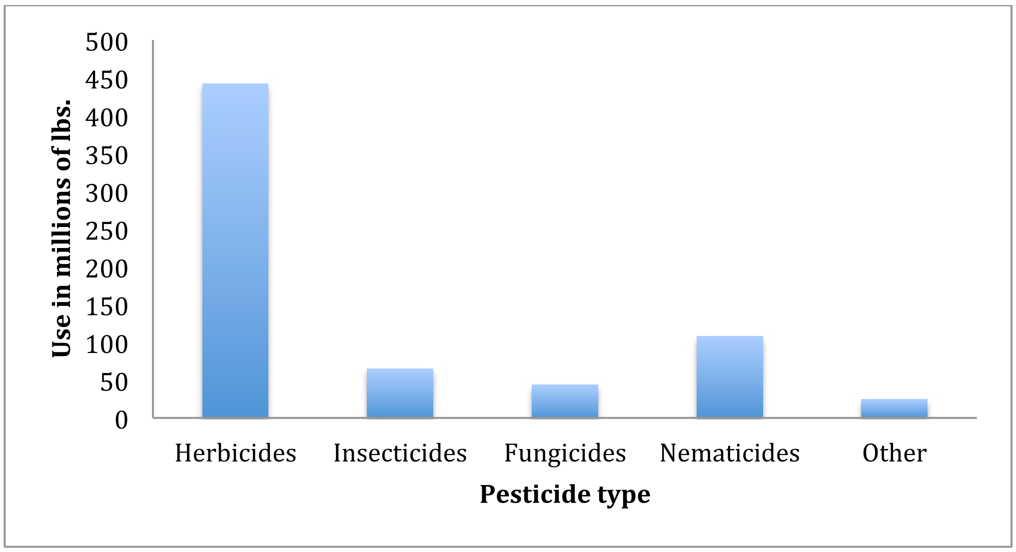

Figure 1. Distribution of pesticide use by type in the US agricultural sector in 2007. Source: Grube et al., 2011.

Of the 531 million pounds of herbicides used in the agricultural sector in 2007, atrazine was the second most commonly used (Figure 2).

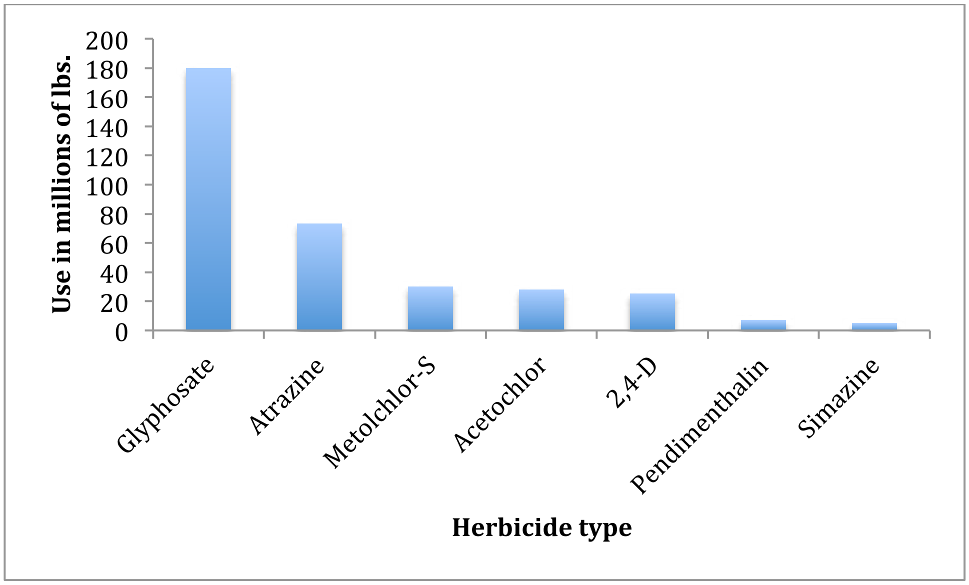

Figure 2. Distribution of herbicide use by active ingredient used in the US agricultural sector in 2007. The data used in the figure is the low estimate of herbicide use reported in Grube et al., 2011.

Atrazine is the second most commonly used herbicide in the US, with an annual use rate of 73-78 million pounds (Grube et al., 2011). It is also a known endocrine disruptor that causes the feminization of males of many wildlife species (Rohr and McCoy, 2011). The US EPA's Atrazine Monitoring Program shows that levels have exceeded the Maximum Contaminant Level (MCL) set by the Safe Drinking Water Act of 3 μg/L in drinking water for 58% of systems sampled in their monitoring program (EPA, 2011). The EPA states that prolonged exposure to atrazine in exceedance of the MCL can lead to cardiovascular and reproductive problems in humans (EPA, 2015). Due to public health risks and effects on wildlife, environmental groups such as the Natural Resources Defense Council (NRDC) and the Pesticide Action Network (PAN) have called for a total atrazine ban throughout the US (Wu et al., 2009). The EPA reviewed the reregistration of atrazine in 2003, and in 2009 after public and media attention about atrazine pollution, the US Environmental Protection Agency (EPA) began a special review to reevaluate the environmental and public health risks associated with the herbicide.

The EPA reevaluation, based on analyses of toxicology and monitoring data, is expected to inform the EPA policy decision on the reregistration of atrazine in 2016 (EPA, 2009). The EPA held scientific advisory panel meetings from 2009 to 2012 to evaluate atrazine risks for humans and non-humans, and to assess the current water monitoring programs. During the review, there was little mention of how atrazine is managed in other countries and whether other countries have had success in reducing atrazine contamination. Agricultural growers associations and chemical companies that produce atrazine argue that because no alternative herbicide with equal economic and agronomic attributes is available, atrazine restrictions would have extreme negative economic impacts from decreased crop yield and costs of substitute chemicals (Ackerman, 2007; Swanton et al., 2007). For example, during the atrazine re-evaluation Scientific Advisory Panel on September 15, 2010, Rod Snyder, the director of public policy for the National Corn Growers Association, presented public comment that described the anxiety growers were experiencing due to the EPA review. He stated:

> We are anxious to be heard because so much is at stake for our farmers and the rural communities that depend on the farm economy. . . a ban on atrazine would cost 48,000 jobs and atrazine's annual production value to corn alone is as high as $5 billion. . . We hope you will consider the precedent setting nature of these decisions and the American agricultural system that will be deeply impacted (Snyder, 2010).

Despite these fears of economic impacts from atrazine removal from the US market, atrazine has been phased out of use in the European Union (EU) without profound impacts to corn production or the economics of the agricultural sector.

The EU as well as specific member states have created policies of varied degrees of restriction for managing atrazine and other chemicals in the triazine chemical family. Atrazine has been de-authorized for use in the EU since March 2004 (EU European Commission, 2004). Before atrazine was prohibited throughout the EU, Italy and Germany banned its use in the early 1990s. Italy began limiting the use of atrazine in 1986 due to groundwater contamination in northern Italy (ISPRA, 2008).

The concentrations of atrazine in parts of northern Italy have been so high on several occasions that authorities disallowed the use of tap water as a drinking source. Atrazine use was prohibited throughout Italy in 1990. France banned the entire family of triazine herbicides in 2005. The fact that atrazine is banned in Europe is an argument used by US environmental policy groups for banning atrazine in the US (Wu et al., 2009). For example, the website atrazinelovers.com, run by Professor Tyrone Hayes, UC Berkeley biologist and proponent of an atrazine ban states: "Atrazine has been denied regulatory approval by the European Union and is, thus, banned, in Europe, even in Switzerland, the home of the manufacturer. Despite the environmental and public health risks, atrazine continues to be used in the US, for economic reasons."

The tremendous use of herbicides in the US has resulted in widespread water pollution. National water quality monitoring of steams and rivers found that the herbicides atrazine, deethylatrazine, metolachor, and simazine were present in more than half the stream samples, with the most common contaminant being atrazine (Stone et al., 2014). Atrazine was also the most frequently monitored and detected pesticide found in groundwater in a USGS national groundwater monitoring study (Toccalino et al., 2014). Surface and groundwater contamination with atrazine potentially exposes millions of people who depend on contaminated source water for their drinking water. In 2010, 16 midwestern cities filed a lawsuit asking the manufacturer of atrazine, Syngenta, to pay reparations for the costs of removing atrazine from drinking water. Two of the cities involved with the lawsuit found atrazine at levels ten times higher than the safe level of 3µg/L set by the EPA (Ivory, 2010). Many water treatment plants do not have the carbon filtration systems necessary to remove atrazine from drinking water, leaving the public at risk if atrazine enters the water supply.

The widespread pollution and associated health risks bring about the question of why atrazine use is still allowed in the US when it is banned in the EU. Although complex, the reason why atrazine is still in use in the US and banned abroad can be traced to the risk-based policy framework in the US and the precautionary framework utilized in the EU.

Policy Background

The risk-based policy framework used in the US for pesticide evaluation includes scientific risk assessment and risk management. Risk assessment involves understanding how much of a pesticide is present in the environment, how much exposure a person has with the contamination, and the toxicity of the chemical (EPA, 2014b). A risk-based framework is not in opposition to the precautionary principle (PP), an approach that requires regulators confronted with uncertainty about a risk to take precautionary action to prevent any risk (Rogers, 2003). In the case of pesticides regulation in the US, the PP is not fully utilized when dealing with uncertainty.

The Pesticides Program at the EPA is based on a risk assessment framework in which pesticides are evaluated for their potential health and ecological effects (EPA, 2014). The Federal Insecticide Fungicide and Rodenticide Act (FIFRA) requires the review of both new and old pesticides to determine whether they meet certain safety standards. The pesticide review process uses specific types of models and data to assess each pesticide's ecological, human health, and cumulative risks (EPA, 2014b). The Safe Drinking Water Act mandates that the EPA set Maximum Contaminant Levels (MCLs) for pesticides in drinking water. The MCL is based on health effects studies and is set at a level that will not cause adverse effects. This risk-based approach is based on the premise that the presence of low levels of pesticides in drinking water is acceptable, and that agencies will enforce standards that prevent contamination above a certain dangerous threshold.

However, the ability for MCLs to fully protect public health is inadequate considering the mixtures and diversity of chemicals simultaneously present in drinking water and uncertainty and data gaps about the risks of many chemicals. There are no US standards for total pesticide concentration, a regulatory weakness because most pesticides occur in mixtures and the public is exposed to multiple pesticides in drinking water at the same time (Copeland, 2012). The EU Drinking Water Directive has a maximum pesticide groundwater contamination standard for total pesticides of 0.5μg/L. In addition to having no maximum total pesticide standard in the US, many pesticides lack MCLs and there is little monitoring for certain pesticides.

In order for a pesticide registration to be cancelled by the EPA, the EPA must determine that a pesticide poses unreasonable dietary risks (either through food and drinking water) or that the ecological or occupational risks outweigh the benefits of the pesticide (EPA, 2014c). If a decision is made to cancel a pesticide, FIFRA requires that the EPA consider restricted use of the pesticide instead of cancellation, and that a cancellation decision must consider impacts on production practices of agricultural commodities, retail food prices, and the agricultural economy (EPA, 2014c). There are complex ethical questions regarding the role of economic impacts in the decision making process of pesticide regulation, such as the risks that economic considerations could outweigh the public health and environmental impacts associated with pesticide pollution or impede precautionary action aimed at protecting public and ecological safety (Pimentel, 2005).

The EU has adopted policies to cope with chemical risks and uncertainties based on the precautionary principle (PP). The PP is incorporated into both the 2007 legislative framework for chemicals, Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), and the Sustainable Use of Pesticides Directive that went into effect in 2014. These two policies aim to reduce human health and environmental risks from chemicals and pesticides through precautionary action to reduce their use and remove the most hazardous substances from the market. For example, the water quality protection plan in the EU has a goal of identifying and phasing out endocrine disrupting chemicals, chemicals like atrazine that interfere with the body's hormone systems (European Commission, 2015). Precautionary action is the basis for the EU groundwater quality standards for pesticide contamination of 0.1µg/L for individual pesticides and 0.5µg/L for total pesticides. These policies recognize the uncertainty of pesticide risks and the inherent danger associated with possible health impacts of large-scale pesticide contamination. The standards of 0.1µg/L for individual and 0.5µg/L for total pesticides represent the philosophy of the EU Environmental Action plans that pesticides should not be present in drinking water regardless of risks (Dolan et al., 2013).

Divergent policy paths

The risk-based approach to pesticide management in the US and the precautionary approach in the EU have created divergent paths for pesticide policies and environmental outcomes. The policies in the US and EU have resulted in a different set of standards for acceptable levels of contamination of drinking water (Table 1). As a result of these different acceptable levels, the EU levels being much lower, there is water contamination in the US that goes unregulated because it falls within the EPA acceptable levels.

Table 1. Standards for four herbicides and total pesticides in the US and the EU.

Pesticide	**US MCL (µg/L)**	**EU Standard (µg/L)**	**Status**
Atrazine	3	0.1	Banned
Glyphosate	700	0.1	Allowed
2,4-D	70	0.1	Allowed
Acetochlor	2	0.1	Banned
TOTAL Pesticides	No limit	0.5	

The differences between the US and EU pesticide policies are apparent in the divergent regulations for atrazine. The integration of the precautionary principle into the EU Drinking Water Directive, which ultimately resulted in the ban on atrazine, is an example that precautionary action can achieve environmental goals. I use the precautionary action explored in both the Italian and Wisconsin atrazine case studies of this dissertation to create a set of recommendations for US pesticide policy that would provide a more holistic approach for managing the risks of pesticides.

Research questions and methodological approach

The main research questions I ask in both of the case studies include:

- What were the political, social, and environmental factors that led to atrazine policy?
- How have atrazine policies impacted water quality?
- What are farmers doing instead of using atrazine?
- What are the most sustainable alternatives?

The study of coupled human and natural systems, like the agricultural systems I study, requires interdisciplinary approaches that incorporate social and natural science (Lui et al., 2010). This dissertation is an interdisciplinary study of pesticide pollution, environmental policy, environmental outcomes, and farmer decision-making. The broad fields from which research methods are drawn include toxicology, environmental policy, agroecology and sustainable agriculture. Specific methods include water quality analysis, surveys and interviews, archival research, regulatory analysis, and GIS mapping.

My study sites represent the US and European cases with the longest history of atrazine regulation. Italy banned atrazine in 1991, using precautionary principles to enforce protection of ground water. Wisconsin has been using atrazine prohibition areas as a way to control groundwater contamination since the early 1990s. Because Italy was one of the first countries to ban atrazine and Wisconsin is the US state with the longest history of atrazine regulation, I am able to look for temporal trends in water quality data and changes in farming practices.

The following chapters explore how the policies in the US and EU have resulted in water quality outcomes related to atrazine and other herbicides and offer a wider insight into how future environmental policies can best protect human health and the environment. This dissertation begins in Chapter Two with an overview of Italy's atrazine ban in the early 1990s and how water quality has been impacted as a result of the ban. Chapter Three uses the results of a farmer survey I conducted to explore what farmers in Italy are using instead of atrazine as well as their views on pesticide regulation, water quality protection, and knowledge transfer. Chapter Four explores the history of atrazine policy in the state of Wisconsin, the US state with the strictest laws pertaining to atrazine use. Chapter Five analyzes water quality monitoring from Wisconsin to assess the impact of the atrazine policy on environmental outcomes. The dissertation concludes with an exploration of the US pesticide policies and recommendations for improvement based on a more precautionary approach that is needed to manage herbicides for the protection of the environment and human health.

2. The Atrazine Ban in Italy and Water Quality Impacts

Introduction

The herbicide atrazine has been in use around the world since the 1950s. The discovery of drinking water contamination from atrazine and other herbicides has prompted regulatory responses in different countries with the aim of controlling atrazine pollution. Italy and Germany were the first countries to ban atrazine in 1991. This chapter is a case study of the Italian atrazine ban that documents the history of what occurred in terms of the policy and its environmental consequences. The historical analysis is complemented in Chapter Two of the dissertation with survey data and interviews from 2012 that describe the agricultural decisions made by corn farmers in response to atrazine restrictions and which atrazine alternatives are currently being used. The conclusion contains lessons learned from the Italian case as well as recommendations for international and US pesticide policy.

This research project provides a case study of the political and historical background on the atrazine ban in Italy, the country with the longest history of regulating atrazine. In addition, this study discusses alternative weed management practices currently being used by Italian growers instead of atrazine. The goal of this chapter is to learn from the history of atrazine use and environmental outcomes in Italy in order to improve future policy decisions related to pesticide regulation. My methodological approach involves mixed methods research, and a combination of quantitative and qualitative research. The methods combine historical analysis, interviews, and survey data to understand both the context and current perspectives relevant to herbicide use in Italy. Mixed methods research has the strengths of allowing the researcher to ask broader questions and combine research tools to be able to produce more complete knowledge (Johnson and Onwuegbuzie, 2004). This approach has been utilized in previous environmental policy research. For example, Kristoffersen et al. (2007) reviewed historical data and performed a survey with policymakers to compare pesticide policies, use patterns and political interest in herbicide use and reductions in multiple European counties (Kristoffersen et al., 2007). The combination of historical review with survey and interview data allows for a comprehensive analysis of the Italian atrazine case. My approach is unique in that I utilize information from archival sources, interviews with a diversity of stakeholders, and a survey focused on corn growers in order to provide a balanced and thorough evaluation.

This chapter begins with background on atrazine and the potential problems associated with its use. With a concern for the human health risks from atrazine, an investigation into the different farming options available is important to finding the best alternatives. I provide information on different weed management techniques available. I follow this background with an historical account of how atrazine was removed from the Italian pesticide market and how the herbicide substitution process has affected the success of the policy. The success of the policy is evaluated through a section on water quality outcomes and current water quality challenges in Italy. The chapter concludes with an analysis of the atrazine policy and future recommendations.

The information in this chapter is based on expert interviews, archival data analysis, field visits, and participant observation. The expert interviews were performed in person and lasted from one hour to several hours over the course of multiple visits (Table 1). In addition to interviews, I reviewed historical agricultural journals and newspaper articles from the University of Bologna, Italy library archive and performed farm visits and tours of agricultural research facilities.

Table. 1. List of Interviewees and their positions.

Interviewee Number	Position Description
1	University Agricultural Scientist
2	University Agricultural Scientist
3	University Agricultural Scientist
4	University Agricultural Scientist
5	University Environmental/Political Scientist
6	President of Corn Growers Association/ Corn Farmer
7	Representative of IGMPM
8	Representative of Growers Association
9	Farmer

10	Farmer
11	Italian National Environmental Regulator
12	Italian Regional Environmental Regulator
13	French National Environmental Regulator
14	Italian Regional Agricultural Regulator
15	Italian Regional Agricultural Regulator/ Scientist
16	Italian Regional Agricultural Regulator/ Scientist
17	Italian Regional Agricultural Regulator

Background

Atrazine Risks

Groundwater Risks

Atrazine has been used in the US since 1958 as an agricultural herbicide that selectively controls broadleaf weeds (Ribaudo and Bouzaher, 1994). Atrazine can be used as both a pre-emergent and post-emergent herbicide, but it is mainly used as a broad-spectrum pre-emergent herbicide. The majority of atrazine is used for corn production (Grube et al., 2011). Atrazine is a widespread water contaminant due to its high mobility in water and persistence in soil and water. It enters groundwater and surface water runoff after it is applied to row crops (Figure 1). Atrazine can be applied during multiple crop stages: pre-plant, pre-emergence, or post- emergence, yet it is primarily used directly on the soil as a pre-emergent herbicide. Its half-life in soil is 60 days, and this persistence along with its mobility creates high potential for groundwater contamination (EXTONET, 1993a). Once in groundwater, atrazine's half-life ranges from 38 days to over 800 days based on oxygen availability (Talja et al., 2008). This long half-life is problematic for contaminated groundwater, as it can take many years for the plume of initial pollution to pass through and degrade in groundwater systems.

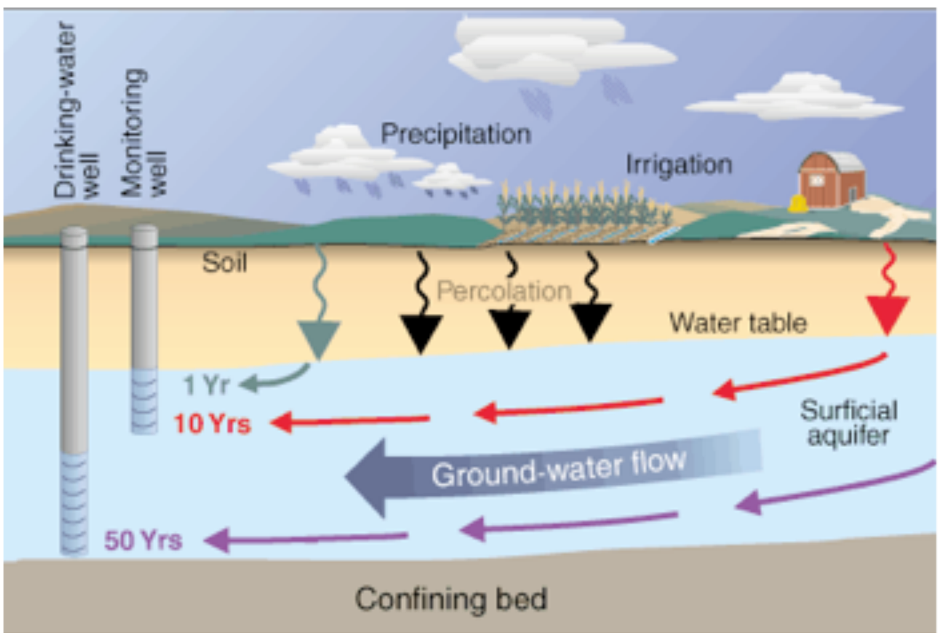

Figure 1. Illustration of the process of agricultural chemicals moving into groundwater (USGS, 2014).

Health Risks to Wildlife and Humans

Exposure to atrazine has negative impacts on phytoplankton, aquatic insects, amphibians, fish and mammals (Graymore and Stagnitti, 2001). Atrazine is an endocrine disruptor, and its effects on frogs have been well studied. Hayes et al. (2002) used coordinated field and lab studies to show that at concentrations of 0.1 μg/L (a concentration thirty times lower than the US drinking water standard), atrazine caused disrupted gonadal development and testicular oogenisis (hermaphroditism) in leopard frogs. Laboratory studies in female rats have shown that atrazine exposure disrupts the hormonal control of ovarian cycles due to its effects on the brain (Cooper et al., 2000).

Atrazine is listed as a likely carcinogen by the EPA, and studies have shown that atrazine exposure can increase risks of hormonally mediated cancers, such as breast cancer (EPA, 2014d). Human breast cancer cells exposed to environmentally relevant concentrations of atrazine exhibited differential protein expression and changes in cell shape (Lassere et al., 2008). Atrazine also affects human fetal development, and its presence in municipal drinking water has been correlated with preterm delivery and small-for-gestational-age status (Villanueva et al., 2005).

Reducing the quantity of herbicides used through an integrated or organic weed management systems is key in reducing risks to the environment and human health caused by herbicides, including atrazine and its chemical alternatives.

Weed control in corn – What are the different options?

Choosing an appropriate weed management strategy varies depending on the specific characteristics of each farm: soil type, tillage, weed types, presence of herbicide resistant weeds, rotations, corn variety, climate, and environmental vulnerability (Penn State Extension, 2012). Cultural, mechanical, and chemicals weed control techniques that do not rely on the herbicide atrazine are available and widely used by farmers in Europe. Considering the environmental and health risks of herbicide use, it is advantageous to design a weed management program that decreases reliance on chemical interventions while achieving goals for agroecosystem function and crop yield.

There are farming practices that can protect water quality from pesticides, such as creating vegetated buffer zones around the field, creating irrigation storage and reuse systems in order for runoff to be reused and treated before entering surface and groundwater, and using Global Positioning System (GPS) technology to detect weeds and target herbicide applications to areas of the field with the most weeds.

Cultural techniques

Weed prevention is a key step to reducing chemical interventions for weed control. Reducing weed seed transfer from field to field can be achieved by cleaning all field equipment. In addition, field borders and surroundings can be managed for weeds to prevent transfer into the field. Cover crops can suppress weeds through competition and allelopathy result in lower weed pressure and biomass. Weed suppression with cover cropping can be effective at reducing weed density and crop rotations can reduce weed infestations by allowing for more diverse weed species and a reduction of the weed seed bank (Murphy et al., 2006). Planting time affects the critical period for weed control, with later plantings reducing weed competition, weed canopy height, and weed biomass (Place and Reberg-Horton, 2014).

Mechanical control

Mechanical weed control is the most effective way to reduce herbicide use, both in combination with chemical control and alone in organic production. Mechanical weed control uses tillage or cultivation to disturb the soil surface and uproot weeds. Before planting corn seeds, fields can be pre-irrigated and tilled to kill weed seedlings through the use of plowing, disking, and field cultivation (Penn State Extension, 2014). After corn planting, rotary hoeing or tine weeding can be used to pull up and shatter weed roots of newly germinated weeds in the zone above where the corn was planted. After the corn emerges, weeds in the inter-row space can be controlled using rolling cultivators or sweeps (Wright et al., 2009). Using mechanical control alone consisting of inter-row cultivation and rotary hoeing has been shown to reduce weed seedling density from 39-74%, and produce comparable yields to chemical control at an increased cost of less than two percent (Mohler et al., 1997). Herbicide use can be reduced when herbicides are applied in bands instead of with broadcast spraying. Banded spraying on the crop row followed by mechanical cultivation can reduce herbicide use by 50%-70% while having no reduction on corn yield as compared with broadcast herbicide application (Bates et al., 2012; Svecnjak et al., 2009).

IPM techniques, and specifically Integrated Weed Management (IWM) in the case of weed control, is a pest management system that relies only on chemical pest control as a last resort. With IWM, the goal of weed management is to prevent weed reproduction, reduce weed emergence, and reduce weed competition with the crop without necessarily eliminating all weeds (Ackerman et al., 2014). IWM uses the agronomic practices of crop rotation, intercropping, cover crops, tillage and cultivation, crop competitiveness, and fertility management as tools for reducing the reliance on chemical herbicides.

Herbicides – pre-emergent control

Most conventional corn production relies on pre-emergent weed control that uses herbicides, such as atrazine or glyphosate, to kill germinating weed seeds before they emerge from the soil. Pre-emergent, pre-plant weed control involves spraying herbicide on the soil surface and incorporating the herbicide into the soil to kill germinating weeds. Corn seeds are then immediately planted afterwards. Pre-emergent herbicides kill weeds before the corn starts to grow, and the corn seedlings are free from weed competition during the critical period for weed control (CPWC), the period of the crop growth cycle when plants are most susceptible to unacceptable yield losses due to weed competition (Knezevic et al., 2002). For corn, the critical period can begin as early as the 3-

leaf stage and on average finishes at the 14-leaf stage (Hall et al., 1992). Pre-emergent weed control is also considered easier to use by farmers as it requires less knowledge of weed species and less field monitoring than post-emergent weed control. When atrazine is applied as a pre-emergent herbicide, it is sprayed on the whole field or in bands on the rows before corn seeds are planted. Atrazine can again be sprayed in post-emergence after the corn develops if weeds continue to be uncontrolled, yet it is primarily used as a pre-emergent herbicide.

The efficacy of pre-emergent herbicides depends on timing of weed seed germination, requiring either planned irrigation or rainfall immediately after herbicide application. Irrigation immediately following herbicide application creates the risk of leaching and runoff into water. In addition, pre-emergent weed control is generally sprayed indiscriminately on the field instead of targeting specific weeds or areas most affected by weeds. The lack of precision involved with pre-emergent herbicide application can lead to excessive herbicide use.

Post-emergent control

Post-emergent weed control can be used on its own or in combination with pre-emergent weed control if satisfactory weed control is not achieved with pre-emergent intervention. Post-emergent weed control occurs after weeds have emerged from the soil and weeds are in the seedling stage. Because weeds have emerged, it allows for more selective herbicides to be used and for reduced use because the areas with weeds can be targeted rather than the entire field. Post-emergent weed control allows the grower to decide where, which, and how much herbicide to use based on the specific type of weed infestation. Post-emergent weed control requires precision in the timing of application in order to inhibit weed competition during the CPWC, which requires a higher level of involvement on the part of the applicator. Because it is disadvantageous to enter the field when the soil is wet after rain or irrigation, post-emergent weed control can be riskier in terms of climactic variability and timing the application.

Research on economic impacts of atrazine bans

Past scholarly work has examined the potential economic impact of an atrazine ban in the US, as well as what has occurred as a result of atrazine bans in Italy and Germany (Ackerman, 2007; Ackerman et al., 2014; Giuopponi, 2001). The Ackerman et al. (2014) study provides information that banning atrazine would benefit not only human health and wildlife, but also provide an economic advantage for corn growers. The report describes how atrazine alternatives can offer equivalent or superior weed control compared with atrazine, and also result in high returns on corn production for the growers. Ackerman et al. (2014) discredit the research being completed by the Atrazine Benefits Team, a group of researchers assembled by Syngenta, a Swiss company specializing in crop protection and the primary manufacturer of atrazine, with the purpose of demonstrating the economic and agronomic necessity of atrazine. The Atrazine

Benefits Team is criticized for failing to assess the full range of atrazine alternatives, consider the synergistic effects of using combinations of alternatives to atrazine, and anticipate changes in costs for atrazine alternatives as the market shifts (Ackerman et al., 2014). Ackerman et al. (2014) suggest the need for Integrated Weed Management (IWM) and a reduction of the reliance on chemical herbicides. Ackerman et al. (2014) suggest that the most appropriate IWM strategies for corn production are tillage and crop competitiveness (improving the fertilization, row spacing, and timing of crop planting in order to out-compete weeds).

Ackerman (2007) uses examples from Italy and Germany to show that the atrazine bans that occurred in those countries in 1991 had no impact on production. He suggests that if atrazine had been a vital tool for corn production in Italy and Germany, there would be decreased yields or harvested areas after the ban as compared to the US where it is still allowed. Instead, Ackerman found that yields increased in Italy and Germany after the ban as did the harvested areas. He uses this information to support the idea that atrazine is not a "magical solution to the problems of productivity in corn production" (Ackerman, 2007, pg. 447).

After the ban of atrazine in Italy, the growers started using different herbicides to replace it. Giupponi (2001) shows that the atrazine substitution process in Italy began with negative impacts for growers and the environment due to increased herbicide costs and use. However, after a period of grower adaptation and new product availability, atrazine substitution in Italy has been described as a success. The report concludes: “from the environmental standpoint we can consider the substitution a success; in fact it ended with the complete substitution of the high impact molecule and a positive trend was seen in the quality of aquifers concerning pesticide concentrations.” However, local and national authorities are criticized for not providing an organized set of actions or guidance for growers or clear information about the water quality standards to the public. The author states that farmers were a passive group that was forced to implement a change in behavior.

Italian case study of the atrazine ban

This research project is a case study of the history, environmental outcomes, and corn grower practices and perspectives relevant to the atrazine ban in Italy. The study of Italy provides a unique insight into agri-environmental policy and practices for international comparison. I use expert interviews, participant observation, and archival analysis to provide the historical and political context surrounding the atrazine ban in Italy.

History of the Italian atrazine case

Atrazine was first introduced into the Italian pesticide market in 1964, with its first registration in 1971 (Giupponi, 2001; Ministero della Salute, 2013).

Atrazine was widely adopted as the main herbicide used on corn and sorghum in Italy. Italy was the first country to ban the herbicide atrazine in 1990.

Italy is one of the top five corn producers in Europe, producing corn for animal feed, human consumption, and energy. A national report on Italian crop production from 2011 shows that 9,948,000 hectares were planted with corn, and 97,526,000 tonnes were harvested at a total value of 22,104,444,000 Euro (INEA, 2013). Northern Italy accounted for 92.4% of the Italian corn produced in 2011, with corn being the major crop produced in the north (INEA, 2013).

In 2013, the major corn producing regions in Italy were Piemonte with a total yield of 11,468,074 tonnes, Lombardia with 17,844,386 tonnes, Veneto with 19,486,851 tonnes, and Emilia-Romagna with 9,565,139 tonnes (ISTAT, 2013; Figure 2). These are historically the major corn producing regions, and these regions are the focus of this study. These regions receive 80% of their drinking water from groundwater, making groundwater contamination from pesticides a serious public health issue.

Figure 2. Map of Italy depicting the twenty regions. Regions marked * located in the Po River Valley (Northern Floodplains in the map). Source: Bottoni et al., (2013).

Atrazine became the most widely used herbicide in Italian production in the 1970s and continued to be the top herbicide used until the early 1990s. It was used on multiple crops, primarily corn, sorghum, and soy. In the 1980s, growers in Italy were advised to use atrazine as a pre-emergent herbicide at rates of up to 2kg/ha of principal ingredient (4kg/ha commercial product), and again in combination with 2,4 D if necessary as a post-emergence herbicide at a rate of 1.75 kg/ha (Marocchi, 1980). Marocchi recommended atrazine be applied at a dose of 3.25 kg/ha (2.9 lb/acre active ingredient) over the course of a growing season. This 3.25 kg/ha recommendation may even be conservative, as Italian farmers used rates of atrazine up to 4kg/ha of active ingredient

(Syngenta, 2011). As a reference, in the U.S., the total allowed application rate for a calendar year is 2.5 lb/acre (Syngenta, 2014). The heavy and widespread use of atrazine in Northern Italy led to groundwater contamination with atrazine that was discovered in the 1980s.

Italian water policy and atrazine regulation

The precautionary principle was a driving force in creating the European Economic Community (EEC) environmental action plans of 1973 and 1977. These environmental action plans held the philosophy that drinking water should contain no pesticides (Dolan et al., 2013). In the 1980s, this philosophy was applied to setting the limit for pesticide contamination of groundwater at 0.1 μg/L (European Commission, 2003). Directive 80/778/EEC is the first document to set the pesticide limit for water intended for human consumption for individual pesticides at 0.1μg/L and total pesticides at 0.5μg/L. The level of 0.1μg/L represents the level of detection that was available in the 1970's/80's. Because a "zero level" cannot be assessed, 0.1μg/L was set as the standard based on the technological limit of detection at the time (European Commission, 2003). Under Directive 80/778/EEC, Member States were required to monitor and ensure that pesticide levels did not exceed the 0.1 μg/L limit. In 1985, the Italian Parliament adopted this regulation and adopted the 0.1 μg/L standard for pesticides in source water for drinking water.

Atrazine levels exceeding 0.1 μg/L were detected in Italy in the 1980s. For example, in the fall of 1986, atrazine was found in water destined for human consumption at a level of 2.09 μg/L in an aqueduct leading from the Po River in the province of Ferrara (Fornasari, 1986). Due to atrazine contamination in the Po Valley region, an area of 46,000km^2 that runs from the Western Alps to the Adriatic Sea, ordinances were created to prohibit the use of the tap water for drinking, preparing food, baking bread, and making coffee (Fornasari, 1986; Figure X). Media attention and public awareness of atrazine and water quality risks were strong from 1986 into the early 1990s. In media articles, atrazine was often called a carcinogenic poison (Fornasari, 1986; Cianciullo, 1986). In 1986, newspaper articles stated that atrazine had created an emergency situation or crisis for half of the Po Valley. One article stated that:

> Until 1977 we were traveling in the era of doubt. Since then, we have entered the era of criminality because scientific studies have now proven conclusively the relationship between the abuse of pesticides and the increased number of cases of cancer. The minister of the Environment, Franco de Lorenzo, leaves every problem to fester until it requires emergency intervention. He stated that despite atrazine exceeding the standards set by Italian law and the EEC directive, atrazine is still at levels thousands of times lower than those of toxicity. This is a blunder. We are talking about damage to DNA, the so-called genotoxicity, we must also say there is no safe threshold. Maybe this low dose of atrazine cannot be considered dangerous in isolation, but it continues. The problem is to see what the reaction is when the sum of ten of those doses is unleashed in the body and then multiply their effect. (Cianciullo, 1986).

The atrazine emergency in Italy is considered to be one of the first examples of a shift in the way people perceived agriculture, transitioning from an idealized view to one that considers environmental degradation and adverse human health impacts (Giupponi, 2001).

The pollution problem became such an emergency in the mid 1980s that two thirds of the residents of the Po Valley would not drink their water due to atrazine contamination. The pollution was most severe in the regions of Piemonte, Lombardia, Emilia-Romagna, and Veneto. Beginning in 1986, local and regional administrators provisionally limited the use of atrazine (Giupponi, 2001). The pollution in these regions became known in the media as the “atrazine emergency.” These regions came together to request assistance from the Italian Government in water monitoring, creation of a management plan, and commitment to a reduction to the use of agricultural chemicals (la Reppublica, 1987). The Agricultural Department distributed 80,000 pamphlets to farmers describing how to control weeds in corn, rice, soy, wheat, and sugar beets with more environmentally friendly farming techniques. The pamphlet suggested that farmers use a dose of atrazine of no more than 0.8 kg/ha, lower than the 1kg/ha dose usually recommended (Coen, 1987). There was a call from the media for more long-term and precautionary action. One article stated, “But we also ask for preventive interventions that modify production, interventions that change agricultural production systems, avoiding the use of harmful chemicals” (la Reppublica, 1987). This quote highlights the awareness that a shift in agricultural production methods, not just the restriction of one chemical, would be necessary for environmental protection. In addition to media attention, the political situation in the 1980's was characterized by a strong Green Party and environmental concerns, which created pressure to create environmental referendums (Interviewee 5, 2010). Due to the high levels of contamination in the affected regions, the regional authorities trucked potable water to the affected areas and either provided water bottle filling stations or packets of potable water (Figures 3 and 4).

Figure 3 and 4. Photo of water collection station. Potable water was delivered to residents in plastic packets and by truck in an area affected by atrazine pollution near Ferrara in 1986. b. People collecting potable water. Source: l'Unita, 1986.

On June 25, 1986, The Italian Ministry of Health, under the directorship of Carlo Donat Cattin, responded to the atrazine crisis in the Po Valley by changing the acceptable atrazine standard from 0.1μg/L to 1μg/L, ten times the EEC standard. In April 1987, Cattin further increased the limit for atrazine to 1.7 μg/L. By increasing the standard, the government "cancelled the emergency" and was spared having to close wells with atrazine contamination that exceeded the EEC limit of 0.1μg/L (la Repubblica, 1987b). The ministerial decision to increase the atrazine standard was a source of confusion and controversy for the regions of northern Italy. The regions were unsure which standard (Italian or EEC) to use to make decisions about the safety of well water, and some of the regional leaders refused to accept the increased standard. Citizens held demonstrations outside regional meetings, demanding pure water, asking for low thresholds for pesticides, and expressing concern about the mixtures of pesticides to which they were being exposed (Figure 5) (Coen, 1987). The President of Lombardy, followed by other leaders of regions of the Po, expressed dissent and reluctance to accept the increased threshold beyond 1μg/L (la Repubblica, 1987). Other regions also expressed dissent and citizens created petitions to reduce acceptable atrazine levels back to the EEC standard of 0.1 μg/L. The media published a series of articles describing the conflict between the state and regional levels of government on the topic of atrazine thresholds (Cianciullo, 1987). The Green Party, which was supported by a strong leftist political orientation at the time, criticized Cattin as caring only for the needs of agricultural production and "allowing the distribution and consumption of drinking water poisoned by herbicides at levels dangerous to the health of the citizens" (la Repubblica, 1988). The media was also critical, with one article stating, “Health is being raffled off with the numbers: the emergency cannot be solved by moving the commas in the decrees” (Cianciullo, 1987).

Figure 5 and 6. Photo of demonstrations in 1986 to protest atrazine pollution in Northern Italy. A, The sign in Figure 5 spells “ACQUA,” which means water in Italian (l'Unita, 1986).

In February 1987, the Environmental Minister of the EEC at the time, Stanley Clinton Davis, stated the Italian decision to increase the standard was contrary to the EEC directive and that there were no outstanding circumstances involving the Italian agricultural practices that should allow an exceedance of the 0.1 μg/L standard. In addition, Davis warned that Italy would face infringement proceedings if the limit was not returned to the EEC level of 0.1μg/L (la Repubblica, 1987b). Despite this decision by Davis, controversy surrounding the acceptable level of atrazine in Italy and the EEC continued. Donat Cattin maintained that there had to be exceptions to the 0.1μg/L standard for Italy because of agricultural needs. Cattin kept the standard of atrazine in Italy at 1.7 μg/L based on recommendations set by the World Health

Organization (WHO), which had an atrazine standard of 2 μg/L (Chianura, 1989). Because Italy failed to lower the standard to those mandated by the EEC, infringement proceedings began against Italy in 1989 (la Repubblica, 1989). However, Italian ministers of health, environment, and agriculture met with EEC leaders to present a two-year plan for improving water quality in the affected regions and to stall the infringement proceedings. Several strategies for reducing atrazine contamination were derived from these meetings, such as prohibition of atrazine use in vulnerable areas and funding for organic and IPM agriculture. In February 1989, a two-year plan was created with the goal of atrazine levels falling below 0.1μg/L by 1991. The safety threshold was set at 0.8 μg/L for the regions affected by atrazine pollution (Piemonte, Lombardia, Veneto, Marche, Friuli, Emilia Romagna) as an exception to the EEC standard of 0.1μg/L (Naselli, 1989). The Italian Government pledged 575 million lire (approximately 300,000 Euro) to restore groundwater in the affected regions.

In 1989, under a change of leadership at the Italian Ministry of Health, the new minister Francesco de Lorenzo signed a measure banning atrazine, which was renewed in 1990 and made permanent in 1991 (Cianciullo, 1990). Atrazine, which had become the symbol for water quality problems in Italy, was banned as a political move by the Department of Health after deciding that changes in acceptable thresholds were not sufficient for decreasing the problem (Cianciullo, 1990). The Department of Health was pressured both by the EEC and Italian citizens who demanded precautionary water standards. Farmers and some scientists were critical of the decision to ban atrazine, and the scientific community as a whole had lost credibility on the atrazine issue due to divergent viewpoints regarding what constitutes a safe level of contamination (Interviewee 1, 2010). The problems with atrazine had become clear, however the lack of scientific consensus about safe levels moved the discussion from a scientific realm to a political one. The decision to ban atrazine was ultimately governed by public opinion (Interviewee 5, 2010). "Atrazine was found to be guilty of all the problems, so the ban was done without a rational assessment of the hazard associated with such herbicides and their alternatives" (Interviewee 1, 2010).

Response to the ban

In 1990, with a moratorium on atrazine use, growers were given little guidance from the regional agricultural offices on what to do without atrazine, and no technical alternatives were made clear (Interviewee 1, 2010). Although there was funding to support reduced herbicide use in agriculture due to the atrazine emergency, finding an alternative weed control strategy and alternative herbicide was the main priority for growers at the time (Interviewee 1, 2010). Growers mainly sought advice from chemical distributors about what to use instead of atrazine (Interviewee 5, 2010).

Italian corn growers responded to the atrazine regulations with statements of how the atrazine ban would negatively affect them economically. Growers predicted economic losses due to losing atrazine as their major herbicide (Marocchi, 1991). In the monthly corn growing trade journal, *il giornale dei Maiscoltore*, several articles were published about the atrazine ban, its potential impacts, and advice for growers. For example, Italian agronomist Giorgio Marocchi wrote an article in 1991 titled: "Weed control in corn and sorghum: The absence of atrazine imposes a totally new vision for weed control in corn: not impossible, but certainly more difficult." This article states that characteristics of atrazine that made it appealing to farmers: low cost, maximum selectivity, and efficacy are ironically the reason for its disgrace as a pollutant. The low cost of atrazine was an incentive for heavy over-use, and its efficiency as an herbicide encouraged general use. Marocchi continued by offering advice for alternative herbicides and practices that can be used instead of atrazine. He stated that the two main changes will be the greater reliance on post-emergent herbicides and mechanical weeding. He recommended several choices for pre-emergence alternatives to atrazine, such as alochlor, metolachlor, pendimithalin, and terbuthylazine (TBA) (at doses ranging from 2 to 6.5kg/ha of product in formulation). The article states that TBA is "the product closest to atrazine and it mimics atrazine in its action and persistence." However, he also stated that there are non-triazine products available that are better suited for particular types of weed infestations. He described how without atrazine, a shift towards post-emergent weed control will reduce the overall use of herbicides as an environmental benefit. He recommended several post-emergent herbicides, including dicamba, bromoxinil, and 2,4 D (all applied at doses of 2.5 kg/ha or lower of formula). Some advantages listed for atrazine's absence include reducing the amount of land in corn mono-succession and moving towards more rational rotation plans of 2-3 years as opposed to some corn mono-successions of 25 or more years (Marocchi, 1991). After the ban, farmers experimented on their own for two or three years until they started mainly relying on TBA (Interviewee 1, 2010). Despite Marocchi's article, there was little information or scientific research available to growers regarding what atrazine alternatives would be best suited for their farms. According to weed scientists working on this topic, the main problem of the ban was that government agencies gave no guidance on atrazine alternatives to growers (Interviewee 1, 2010).

In 1990, Italian chemical companies responded to the atrazine ban by transferring their production focus towards terbuthylazine (TBA), N2-tert-butyl-6-chloro-N4-ethyl-1,3,5-triazine-2,4-diamine. TBA, produced by Syngenta, had been authorized for use in Italian agriculture since 1972 (Ministero della Salute, 2014). However, until the atrazine ban, TBA was mainly used for clearing weeds from railways and other non-agricultural uses (Syngenta, 2010). Farmers began using TBA as a main replacement for atrazine in the early 1990s. TBA was less effective than atrazine, and it was used at higher rates than atrazine to compensate for its reduced efficacy. In the early 1990s, TBA was commonly used at rates of 3-5kg/ha of active ingredient (Giupponi, 2001). TBA products were labeled as “poisonous” and “dangerous for the environment” (SIPCAM, 1997).

Monitoring for TBA started to show that it too was present in groundwater at levels exceeding 0.1μg/L. In order to avoid further regulation and the potential loss of TBA, an agreement among major pesticide companies that produce TBA (Syngenta, Oxon, Agan) changed the way TBA was managed in order to protect environmental quality (Interviewee 18, 2010). For example, the prescribed dose for TBA was lowered to 750g/ha active ingredient for Northern EU member states and 850g/ha for southern EU member states. Its use was limited to corn and sorghum, and prohibited for other crops and non-agricultural uses. TBA is only allowed to be used once per year, and as of 2009 it can only be used in combination with other products sold as a pre-mixture (Interviewee 18, 2010). Scientists believe that these changes have decreased pollution from TBA. For example:

> TBA has been a somewhat successful replacement for atrazine because it is less mobile, used at a reduced rate, and used in a mixture. We can make better advice for the next crisis. The lower rate, the reduced soil organic carbon-water partitioning coefficient (a measure used for predicting the mobility of contaminants), and the use of herbicide mixtures are lessons learned from the atrazine crisis. As usually happens with a crisis, you learn after. It took 21 years to learn how to manage triazines (Interviewee 1, 2010).

Water Quality Outcomes

Water quality monitoring for pesticides in Italy was not coordinated as a national effort until 2003 with the implementation of the Plan on the Environmental Effects of Plant Protection Products, the Italian implementation of Directive 91/414/EEC (ISPRA, 2008). Monitoring efforts in Italy are conducted by the Regions of Italy and the regional environmental agencies. After the data are collected, they are reported to ISPRA, which then compiles the data and creates national reports (ISPRA, 2008).

In the Rapporto nacionale pesticide nelle acque dati: 2011-2012 (National rapport on pesticides in water: data 2011-2012) monitoring data are presented for pesticides in freshwater and groundwater (ISPRA, 2014). These monitoring data are intended to be used as a baseline for future comparison as the EU Directive on the Sustainable Use of Pesticides went into effect in 2014 with the goal of reducing water pollution from pesticides (ISPRA, 2014). The director of ISPA introduces the rapport with the following statement (translated from Italian):

> While not questioning the benefit derived from the use of chemicals in agriculture, however, there are issues in terms of possible adverse effects on the environment and through environmental contamination, to human health. Most pesticides . . . are derived from synthetic molecules selected to combat certain harmful organisms and therefore are generally dangerous to all organisms.
> – Prof. Bernardo De Bernardinis (ISPRA, 2014).

Although prefaced with the positive benefit of pesticides, this quote depicts a national attitude and understanding of the dangers of pesticides. Since the beginning of the organized monitoring network in Italy, pesticide pollution has been an environmental and human health concern. In the 2012, 45.5% of surface water monitoring stations and 31.8% of groundwater monitoring wells were contaminated with pesticides (Figure 7; ISPRA, 2014).

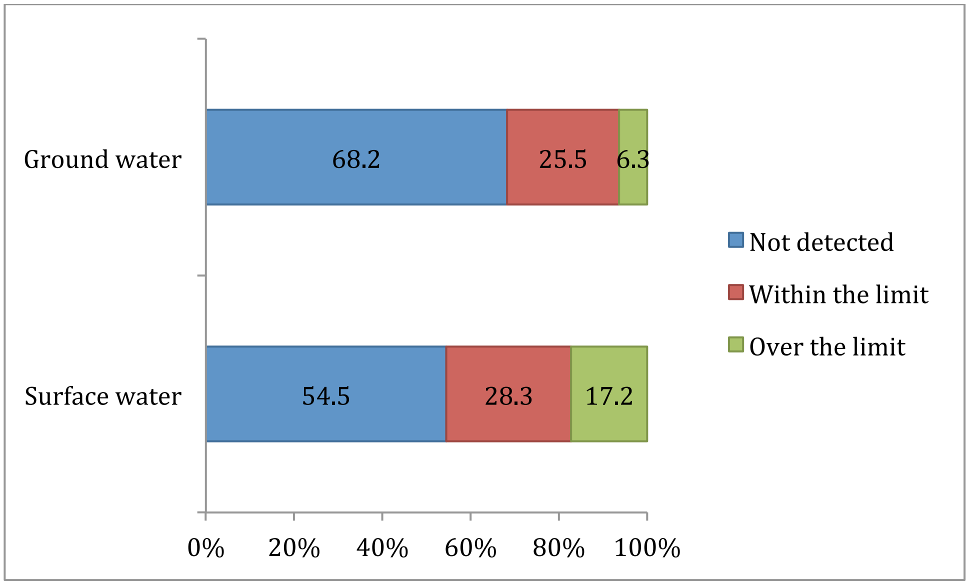

Figure X. National Italian water monitoring results for pesticides in 2012. Reproduction of Figure 6.1 in ISPRA, 2014.

Atrazine is still found in Italian water

In 2012, atrazine was found in 134 wells and atrazine metabolites were present in 200 wells (ISPRA, 2014). 1,957 groundwater wells were sampled for atrazine, and 7.3% of samples were found to contain atrazine with 0.4 % exceeding the limit of 0.1 μg/L (ISPRA, 2014). Atrazine's metabolites, atrazine desethyl and atrazine desisopropyl were also detected. Atrazine desethyl was found above the limit in 0.9% of the 2060 wells for which it was tested and atrazine desisopropyl was found to exceed the limit in 0.2% of the 1097 wells for which it was tested (ISPRA, 2014). Figure 8. shows the frequency of total atrazine detection and areas in red depict exceedances of the limit.

Figure 8. Groundwater contamination with atrazine and atrazine metabolites in 2012. Red dots represent where atrazine was found above 0.1 μg/L and blue dots represent atrazine concentrations below 0.1 μg/L. Source: ISPRA, 2014.

This persistent contamination serves as a warning that atrazine can lead to groundwater contamination even decades after its use has ceased. However, the contamination is greatly reduced from the problematic state of groundwater contamination before the ban in the 1990s (ISPRA, 2014). In 2003, atrazine was found in over seven percent of surface water monitoring samples and it is now found in less than one percent of samples (Figure 9; ISPRA, 2014).

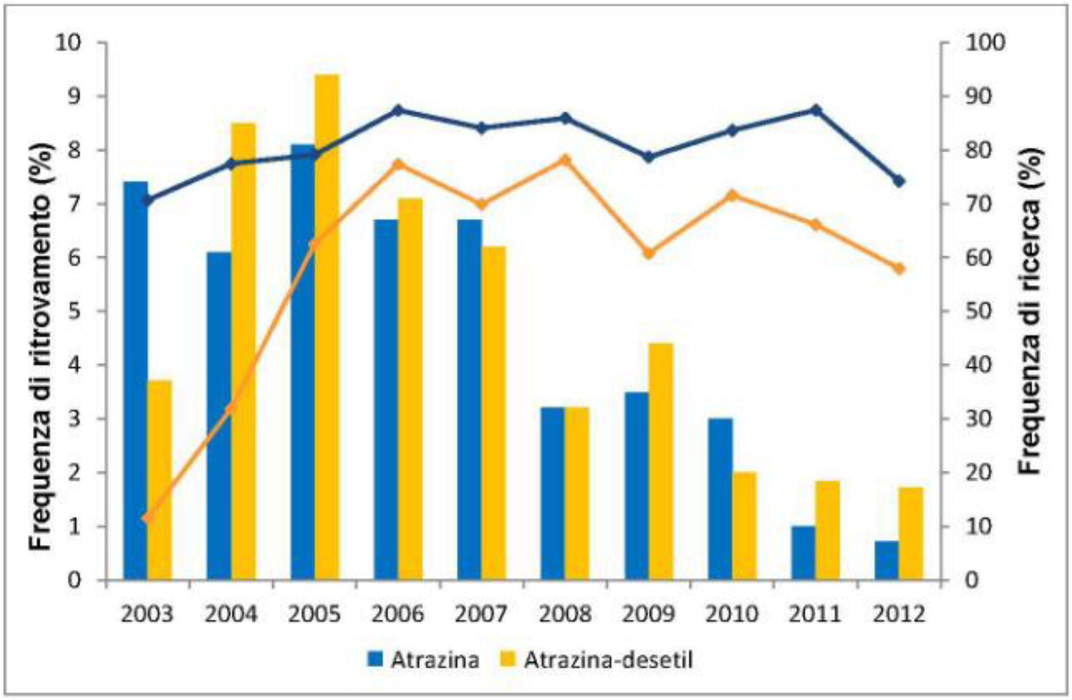

Figure 9. Atrazine trends in surface water. The percent of surface water monitoring cites with atrazine contamination shown in blue and atrazine metabolite shown in yellow (Source: Figure 9.10 from ISPRA, 2014).

Groundwater contamination with atrazine has had a slower yet gradual decline than surface water. In 2003, atrazine was found in almost eight percent of groundwater monitoring samples, and in 2012 it was found in 4.5% of samples (Figure 10; ISPRA, 2014).

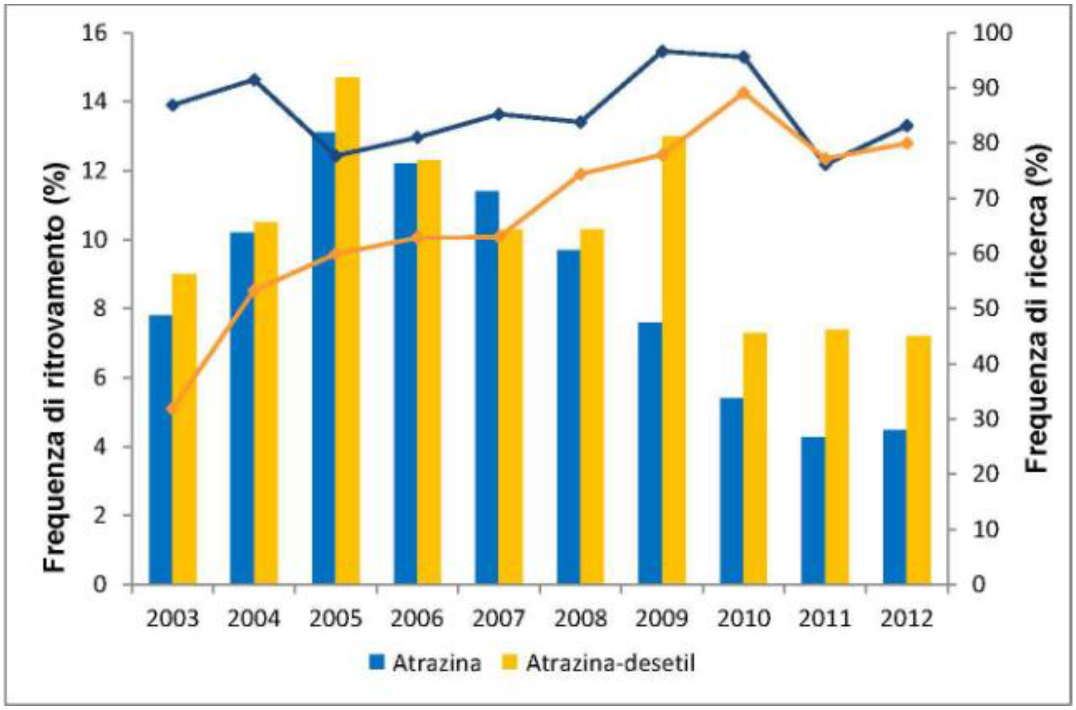

Figure 10. Atrazine trends in groundwater. The percent of groundwater monitoring wells with atrazine contamination shown in blue and atrazine metabolite shown in yellow (source: Figure 9.10 from ISPRA, 2014).

The decreases in atrazine contamination in both surface and groundwater show that the atrazine ban was effective in reducing water pollution from atrazine. However, it has taken many years for groundwater contamination to decrease and atrazine continues to be one of the most commonly found water pollutants in Italy (ISPRA, 2014).

Terbuthylazine in Italian water

TBA was not widely used in Italy before the 1990s, yet by the early 2000s it was routinely found in groundwater. In 2012, 1,835 wells were sampled for TBA nationwide in Italy, and TBA was found to be present in 8% (ISPRA, 2014).

A TBA metabolite, TBA-desethyl, was found to be present in 15.9% of wells sampled. TBA was found to exceed 0.1μg/L in 0.3% of samples and TBA-desethyl was found to exceed the limit in 1% of samples (ISPRA, 2014; Figure 11).

Figure 11. Groundwater contamination with TBA in 2012. Red dots represent where TBA was found above 0.1 μg/L and blue dots represent TBA concentrations below 0.1 μg/L (Source: ISPRA, 2014).

The groundwater contamination from TBA is, like atrazine, concentrated in Northern Italy (Figure 11). Although monitoring data show declines in TBA concentration in surface water in 2010, 2011, and 2012, since high levels reported in 2005, TBA is frequently present and the pollution is diffuse (Figure 12). In 2012, TBA was present in 42.8 % of monitoring wells (15.3% of samples) and it exceeded 0.1µg/L in 3.9 % of samples.

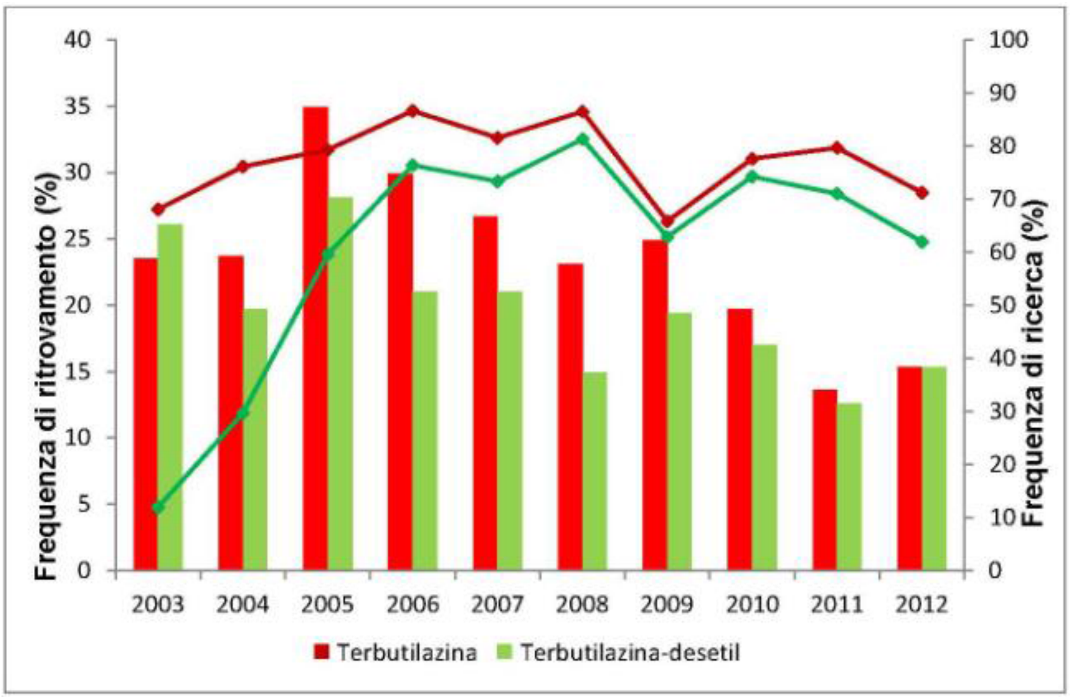

Figure 12. TBA trends in surface water. The percent of surface water monitoring cites with TBA contamination shown in red and TBA metabolite shown in green (source: Figure 9.9 from ISPRA, 2014).

Groundwater monitoring shows a trend of decreasing TBA levels. In 2005 and 2006, TBA was found in more than 12% of groundwater monitoring samples, and in 2012 it was found in only 5% of samples (ISPRA, 2012; Figure 13). The decrease in TBA pollution in groundwater and surface water could be a result from policies such as the regional efforts in Piemonte to limit its use.

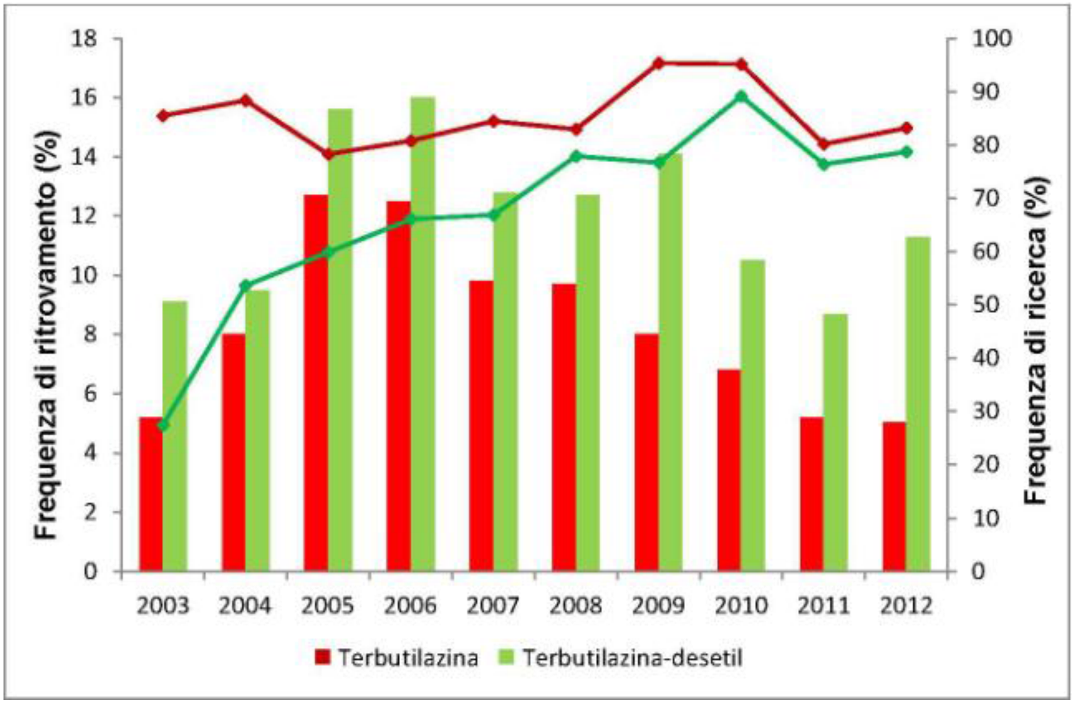

Figure 13. TBA trends in groundwater. The percent of groundwater monitoring cites with TBA contamination shown in red and TBA metabolite shown in green (source: Figure 9.9 from ISPRA, 2014).

Despite the decreased TBA levels, regulators remain concerned about the diffuse nature of TBA pollution. One regulator described the TBA pollution as being just as serious and problematic as atrazine pollution was in the 1990s (Interviewee 16, 2012).

Chemical mixes

TBA is not the only herbicide used to replace atrazine. The use of more post-emergence herbicides as well as a large increase in the use of glyphosate is reported (Interviewee 6, 2012). A major concern for regulators is dealing with not only the risks from individual water contaminants, but also from the synergistic and additive effects of the chemical mix being found in water. One regulator described this emerging problem as it relates to atrazine:

> When atrazine was banned, more post-emergence herbicides started to be used. The post-emergence herbicides are used in multiple applications. Post-emergence herbicides are not necessarily safer, each chemical has different risks. For example, paraquat is effective on weeds but it is a real poison for operators. Glyphosate, which we once thought was safe, is being found more and more in groundwater. There needs to be an evaluation of each substance and all aspects pertaining to risk (Interviewee 11, 2012).

The risks described in the quotation above reveal the complexity of dealing with the pesticide pollution problem. Groundwater monitoring in 2012 shows 23.4% of samples were contaminated with pesticides, and 13.2 % contained at least two substances (ISPRA, 2014). The average number of pesticides found in groundwater samples was 3.4 substances, and well with the maximum contained 36 individual pesticides (ISPRA, 2014; Figure 14).

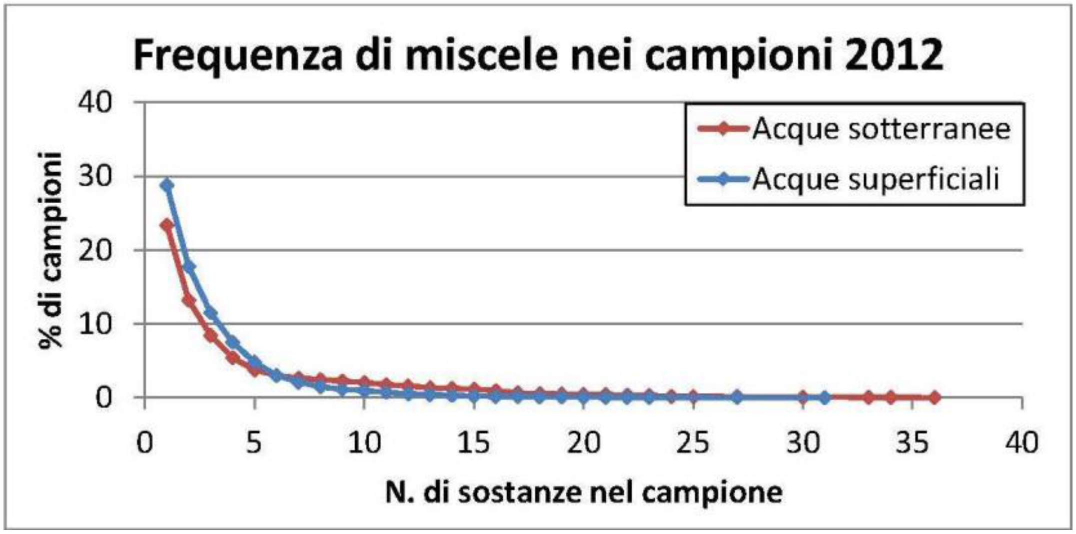

Figure 14. Number of substances found in combination water monitoring samples. Groundwater is shown in red and surface water is shown in blue. Figure 8.1 from ISPRA, 2014.

One of the emerging problems for water quality has been the discovery of diffuse pollution with glyphosate. In the early 2000s, the technological difficulty involved with monitoring glyphosate and its metabolite aminomethylphosphonic acid (AMPA), resulted in very little monitoring and an inability to detect glyphosate. Advances in analytical methods have allowed for more extensive glyphosate monitoring, surface water monitoring in 2012 shows that glyphosate is present in 18.2% of samples and AMPA is present in 46.7% of samples (Figure 15). Although groundwater is not extremely affected by glyphosate because of its short half-life, the extensive surface water contamination represents a shift from groundwater pollution with triazine herbicides to surface water pollution with glyphosate.

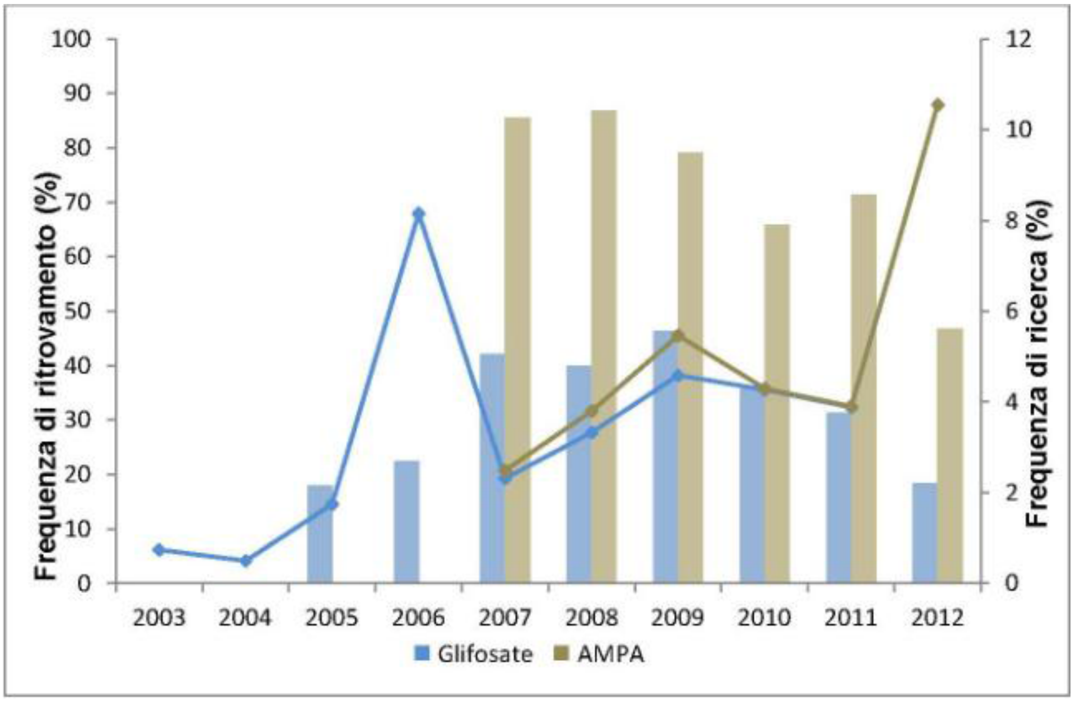

Figure 15. Percent of surface water monitoring wells with glyphosate contamination shown in blue and AMPA shown in beige. Figure 9.13 from ISPRA, 2014.

Policies for TBA pollution reduction

Despite improved management strategies for TBA, pollution from TBA became and still is a major groundwater problem in northern Italy (ISPRA). A weed biologist described TBA as “atrazine's stupid sister,” stating that it is equally polluting but does not work as well (Interviewee 2, 2011). One political scientist described the situation as follows:

> The atrazine ban was not that rational because it only banned a single molecule and then created the basis for a very simple adaptation of the system to a very similar molecule. This probably had more problems than benefits because when you switch from a very effective molecule to one that is less efficient and requires

heavier doses and the effects for the environment are not significantly better" (Interviewee 5, 2010).

The switch from reliance on atrazine to the use of TBA is criticized as a symptom of poor foresight in creating the atrazine ban. One researcher explained, "What prescription are you going to deliver to farmers if you are not really trying to imagine how this system can be reorganized and adapt to a new situation? If you are not trying to preview the alternatives you have no idea what could be the effect of your decision" (Interviewee 5, 2010). In 1995, just a few years after the atrazine ban in Italy, scholars stated:

> The ban on the specific herbicide of atrazine merely accomplished a costly change in the mix of contaminating substances. This is not an example of a comprehensive view when designing restrictions . . . a more satisfactory enforcement strategy would have been to specify input controls that cause a gradual change to a more desirable situation (Sóderqvist et al., 1995).

Approximately 320,000 kg of TBA are used each year in the regions of Lombardy, Veneto, Piemonte, Emilia-Romagna, and Umbria and there are currently 25 commercial products containing TBA authorized for use in Italy (Ministero dell Salute, 2014). These commercial products include mixtures with mesotrione, dimethanamid-P, pendimithalin, isoxaflutole, bromoxinil, sulcotione, S-metalochlor, flufenecet, and pethoxamide.

In 2006, the region of Piemonte responded to diffuse groundwater pollution from TBA by creating a directive to limit its use (Regione Piemonte, 2013). One regulator described the problem with triazine herbicides and the Piemonte's reasoning for creating specific rules as follows: "The problem with atrazine and TBA is the persistence. Pesticides are in groundwater throughout Italy. In Piemonte we have strong monitoring programs and have found high levels, so we had to change" (Interviewee 14, 2012). In the directive, TBA cannot be used within a buffer of 5 meters of any waterbody, and within designated vulnerable zones it can only be used every other year and in a banded application (only on the crop row, not in the inter-row space) (Regione Piemonte, 2013; Figure 16). The designation of the vulnerable zones was completed in 2003, but due to resistance from the agrichemical industry it was not finalized until 2007 (Interviewee 14, 2012). The resistance from the agrichemical industry as well as the national Italian ministries to limit the control of TBA has been strong (Interviewee 15, 2012).

The decision to create vulnerable areas and provisionally limit TBA instead of banning TBA completely in the Piemonte region because the region perceived that eliminating TBA would be catastrophic for farmers. One regulator stated, "It isn't possible to say close the farms. To completely ban TBA is to say close the farms. There isn't an alternative product as effective as TBA for corn" (Interviewee 14, 2012). The rule gives power to farmers and hopes that farmers will abide by the recommendations. For example, the rule encourages crop rotation with the goal of reducing water pollution over time by decreasing the amount of mono-succession corn being grown in the region. While buffer zones are commonly implemented by organic growers and growers receiving funds for IPM and habitat conservation, most conventional growers do no have buffers

(Interviewee 14, 2012). There is hope among regulators that the implementation of the EU directive on the Sustainable Use of Pesticide, Directive 2009/128/EC, will have a positive impact on water quality through mandatory buffer zones and reduced pesticide rates for all farms (Interviewee 15, 2012).

A similar plan is being created in the region of Veneto in order to protect vulnerable areas from TBA (Interviewee 16, 2012). In addition to regional interest in creating pesticide rules for designated vulnerable areas, the EU Sustainable Use of Pesticides Directive contains language in support of such measures. For example, one of the main measures of Directive 2009/128/EC is minimizing or banning the use of pesticides in critical areas for environmental and health reasons (European Parliament, 2009). For example, Italy's National Action Plan for Directive 2009/128/EC states that aquatic environments will be protected by mitigation measures, replacement/use limitation/ elimination of pesticides, and information and training initiatives (Italy's National Action Plan, 2012). Although regulators are hopeful, there is the sentiment that reducing pesticide use and creating buffer zones will be a challenge for many growers. One regulator stated, "The IPM and organic growers use buffer zones, but the other growers don't. It will take a lot of information for the farms to understand how to reduce pesticide use" (Interviewee 15, 2012). One regulator expressed the hope that the Sustainable Use Directive will result in the changes needed to improve water quality:

> I think the measures that will work the best will be limits on use – less use, banned substances, and reduced dose. If you want to reduce water pollution you need to reduce overall use. The newer more evolved pesticides can be used at lower doses and won't impact the water as much. Agronomic practices need to change so pesticides are used when they are needed and not as a routine preventative measure. We need evolved substances and more evolved agronomic practices. We have over 30 pesticides we find in the water. We need the Sustainable Use Directive that deals with the problem from a more holistic way. (Interviewee 15, 2012)

The impact of the vulnerable zones and rules in Piemonte has yet to be quantified, as it can take many years to see changes in the quality of groundwater. In the case of surface water pollution, regulators feel that using buffer zones is the most important factor for reducing pesticide runoff into rivers and streams. Anecdotally, one scientist described the situation in Piemonte as follows:

> In Piemonte, there has been a clear reduction in the amount of atrazine in surface water since the ban in the 1990s. Now there is almost zero atrazine in surface water. It is very rare to find atrazine, and if we do it is way under the allowable limit. The substance most commonly found is now TBA. When atrazine was substituted with TBA, any decrease in atrazine contamination was replaced with an increase in TBA pollution. This is the phenomenon, and it has played out over time with changes taking longer to appear in ground water (Interviewee 15, 2012).

Figure 16. Vulnerable Zones in Piemonte. The green areas are the zones with highly permeable soil that have been labeled vulnerable zones in the region of Piemonte (Piemonte, 2013).

Conclusion

Italy's efforts to ban atrazine are widely criticized for the lack of planning on the part of the administrators in terms of recommending to farmers the least harmful atrazine alternatives, and for not going beyond a single product ban. Farmers replaced atrazine with the very similar TBA and the environment suffered new impacts from the replacement herbicide. One researcher explained, "What prescription are you going to deliver to farmers if you are not really trying to imagine how this system can be reorganized and adapt to a new situation? Farmers think in those terms. If I cannot do this anymore, I will explore the alternatives. If you are not trying to preview the alternatives you have no idea what could be the effect of your decision" (Interviewee 5, 2012). However, TBA pollution has been mitigated to some extent by rules that limit its use. Despite mitigation efforts, environmental experts believe the only real solution is to remove all triazines completely from agriculture.

There are lessons to be learned from the Italian atrazine case study that apply generally to chemical regulation of herbicides as well as many other chemical products. This research indicates the complexity of finding alternatives in response to an atrazine ban. It is crucial for risk assessment policy in the US and elsewhere to included alternatives assessment, foresight and prescriptions for the people who will be affected and need to change their behavior in response to a product ban. The Italian case study shows that eliminating the most polluting herbicides from use as well as reducing overall herbicide applications should be part of a strategy for comprehensive water quality protection.

There is a need to go beyond product substitution. Encouraging system-wide changes such as increased crop diversity, awareness of the risks pesticides pose to the environment, and knowledge transfer about sustainable growing practices will increase the health of agricultural systems. Without these broader changes, a ban on one or a group of herbicides will result in a substitute product being adopted, with its own adverse side effects. A single-chemical or suite-of-chemicals ban can only be viewed as an interim policy if ground and surface water quality restoration and long-term system sustainability are the goals.

3. Farm level decision-making for herbicide use in Italy: Survey Results and Analysis

Introduction

Learning from history is an important step in crafting policies that produce desired environmental outcomes. In the case of the herbicide atrazine, Italy is the country with the longest standing atrazine restrictions and can provide information about what happens after atrazine use is restricted. If atrazine were to be banned in the US, would farmers adopt a chemical substitute? Would substituting atrazine with other chemicals lead to improved water quality? Can policies that promote reduced herbicide use improve water quality, and how can policies be implemented most effectively? These questions motivate this chapter.

The choice of non-chemical weed management techniques over potentially harmful chemical herbicides involves complex social, economic, and technological considerations. Given restrictions, farm managers most often make the decision to use alternative chemicals with their own contamination risks (Wolf and Nowak, 1996). My research in Italy shows that after the atrazine ban, many Italian farmers switched from using atrazine to terbuthylazine (TBA), a similar chemical that created its own problems with water contamination. In some situations, farm managers adopt lower-input weed management practices in response to chemical restrictions. For example, some have adopted Integrated Pest Management (IPM) and agroecological strategies. IPM practices involve using multiple techniques in an ecosystem-based strategy. Agroecological practices such as using crop rotation, cover crops, soil management, crop diversity, and nutrient management, can reduce impacts on the environment (Horrigan et al., 2002).

This study aims to fill a gap in the research by providing an account of what is happening at the farm level when atrazine is not being used. Are farmers using organic techniques such as cover crops and mechanical weed control instead of atrazine, or are they using other herbicides that could be equally as damaging to the environment? Understanding what production options are available for farmers and what options would actually be implemented in the case of an atrazine phase out is key to assessing the alternative strategies and how to encourage the most environmentally beneficial outcome.

Survey data and interviews from 2012 are used to describe the agricultural decisions made by corn farmers in response to atrazine restrictions in Italy and which atrazine alternatives are currently being used.

The research approach included direct engagement with farmers, specifically corn farmers, to examine what alternative practices and chemicals are being used instead of atrazine. I surveyed corn farmers in northern Italy, an area with ongoing diffuse pollution from triazines and intensive corn production. In addition to the survey with conventional corn farmers, I interviewed and performed field visits with organic farmers in order to understand the non-chemical approaches to agriculture in my study regions.

The main research areas of this chapter are:

1) The farming practices and atrazine alternatives used during the 2011 corn-growing season.

   Research questions include: (a) What weed control practices (herbicides and cultural practices) are being used instead of atrazine? (b) Did the atrazine ban affect yields? (c) What criteria are most important for selecting new herbicides? (d) What sources of information are most commonly used for making decisions about new herbicides? (e) Is atrazine a product that farmers wish they could still use?
2) What informational sources are most important for corn farmers?
3) Farmer perspectives on water quality protection.

<u>Herbicide use as of 2012</u>

Italian farmers have several choices for weed control without atrazine. TBA is an obvious choice for pre-emergent control due to its similar qualities to atrazine, yet there are several other products and weed control strategies being implemented. Understanding which weed control strategies and chemicals are being used instead of atrazine provides insight into whether corn production without atrazine is more sustainable. In addition, understanding what criteria is valued by farmers when selecting herbicides and what information sources are relied on is critical for providing tools to farmers for making decisions that consider the environmental impacts of herbicide use.

Italy provides an interesting case study with its history of coping with atrazine and TBA pollution, and yet remaining one of Europe's top corn producers. I surveyed Italian corn farmers and interviewed scientists, chemical company representatives, and policymakers to learn about the history and current issues associated with the atrazine ban. The goal of this research is to discuss how farmers have responded to the unavailability of atrazine as the major weed management tool and how the Italian case can be a learning tool for moving towards a more environmentally sustainable system in the U.S.

Methods

Farmer survey

To understand Italian farmer perceptions of herbicide use and stewardship practices, an online survey questionnaire was prepared in Italian and distributed to a sample of corn farmers. An Italian corn farmers' association, Associazione Italiana Maiscoltori, assisted in the survey design and generated a mailing list of approximately 100 corn farmers predominantly in the Piemonte and Veneto regions of Italy. The survey was distributed via the association's e-mail list on May 7, 2012. The survey may have reached more than the original 100 farmers on the e-mail list, as participants were asked to send the survey to other farmers within their personal networks.

The online survey resulted in 58 completed surveys, for a participation rate of approximately 58% of the targeted group. The online survey was chosen as the most efficient way to engage with farmers who already use the Internet as a primary mode of communication within their association. The survey consisted of a one-page introductory letter written by the association's president explaining the survey and its goals followed by both quantitative and qualitative questions. The survey was adaptive to the individual survey participant's responses and the survey length ranged from 30-45 questions. The survey questions included specific questions about the size and type of the agricultural operation, requests for quantitative information about the types and quantities of herbicides used, and inquiry into the impacts of the atrazine ban and perceptions about environmental stewardship.

The survey asked farmers about the acreage of all of the crops grown, followed by questions specific to corn production for the growing season of 2011. Participants were asked if they grow organically, and the survey questions were adapted for both organic and conventional responses. Information collected about corn production included the end use of the corn, the sale price received, and the yield per acre. Questions shifted to weed control practices and decisions. Participants completed a table by listing all the different herbicides they applied for weed control in corn including the application rates, time of application, number of acres treated, number of applications, and the amount paid per kilogram. Participants were asked if they rotate herbicides to reduce weed resistance, if they scout for weeds, what non-chemical weed management they conduct, and how they decide what products to use. The survey then focused on the history of atrazine use and perspectives on how the atrazine ban affected farmers economically. The survey concluded with questions about ecological stewardship practices, preferred sources of information, and opinions on how to best protect water quality. The survey design and likert type questions on information sources was adapted from the NASS corn survey form 2010.

In addition to the survey, I performed in-person interviews, farm visits, and participated in IPM trainings. Table 1 is a list of interviewees and their respective roles. In order to understand organic possibilities, I performed farm visits with three organic farmers and one farmer that used a combination of organic and integrated production. The interviews with organic farmers were aimed at understanding the practices used and challenges of growing corn and controlling weeds without chemical herbicides. The results from the interviews are summarized after the results from the survey.

Table 1. List of interviewees and their positions.

Interviewee Number	Position Description
1	President of Corn Farmers Association/ Corn Farmer
2	Organic Farmer 1
3	Organic Farmer 2
4	Organic Farmer 3
5	Organic/Conventional Farmer

6	Regional IPM specialist
7	President of Corn Farmers Association
8	Representative French Corn Farmers Association (IGPM)
9	Regional Regulator on Agriculture and Water
10	Representative of Corn Farmers Association
11	Representative of Agricultural Non-profit Organization

Results

Farm characteristics

The 58 completed survey responses are from farmers from three regions of Italy: Veneto (11 responses), Piemonte (45 responses), Lombardia (one response), and one response did not list the region. The average size of farms in the survey was 100 hectares, with farms ranging in size from 7.2 to 800 hectares. The survey data represents a total of 5500 hectares of farmland and 2,788 hectares devoted to corn production. Most farmers grew multiple crops with corn as the predominant crop. Other crops grown included soy, vegetables, fruit, wheat, and grass. Fifty-six farmers stated that their farm was conventional, and one farmer grew some crops organically and some crops conventionally. Seventeen farmers received regional government monetary contributions to implement environmental stewardship practices at least once from 2006-2011. Farms ranged from 0-10,000 m in their distance from the nearest freshwater source (either a river, stream, or aquifer). Twelve farms reported a distance of

0m from the nearest freshwater source, with several indicating that their farms lie directly above an aquifer.

<u>Weed control strategies in corn production</u>

All conventional farmers reported using herbicides as their main tool to fight weeds. Tillage was reported as a practice implemented to control weeds for 34 farms (58.6%). Three farmers also reported using "falsa semina," a practice of pre-irrigation followed by weed removal through tillage. Crop rotation was listed by 80% of farmers as a tool that was used to decrease weed pressure.

Alternative herbicides used

Data from 46 farmers that provided full details on their herbicide use programs was used to gain a picture of what herbicides are commonly used. A total of 18 different active ingredients for weed control were used (Table 2). Most farmers used a combination of both pre and post-emergent weed control. The most commonly used herbicide was TBA, used primarily as a pre-emergent herbicide, with 67% of surveyed farmers reporting TBA use during the 2011 growing season (Figure 1). TBA is always sold and used in a mixture with at least one other herbicide, most commonly mesotrione, acetochlor, or S-metolachlor. The dose per hectare used for TBA products ranged from .9 to 4.5 kg/ha, with an average dose of 2.87kg/ha. The second most commonly used herbicide was nicosulfuron, a post-emergent herbicide from the family of sulfonylurea herbicides. Other sulfonylurea herbicides used include rimsulfuron, prosulfuron, and foramsulfuron. Sixty-eight percent of farmers reported using a sulfonylurea herbicide for post-emergent weed control. S-matolachlor is the third most reported herbicide used, with 19 farmers reporting its use either in combination with TBA or on its own as a pre-emergent herbicide.

Farmers ranged in their herbicide use from using one to eight active ingredients on their cornfields. Herbicide application rates ranged from a low of 0.06 kg/ha of herbicide product to a maximum reported of 10.875 kg/ha of herbicide product (note that commercial herbicide product is not the same as active ingredient). On average, farms used 3.59kg/ha of commercial herbicide product. Of this average 3.59 kg/ha, 2.29 kg/ha constituted pre-emergent herbicide use and 1.3 kg/ha constituted post emergent herbicide use.

Table 2. Herbicides used by survey respondents

Herbicide active ingredient	Number of farmers using (%)	Chemical family	Pre or post emergent
terbuthylazine	31 (67%)	chlorotriazine herbicides	Pre and post
nicosulfuron	23 (50%)	sulfonylurea herbicides	Post
S-metalochlor	19 (41%)	chloroacetanilide herbicides	Pre
mesotrione	17 (40%)	triketone	Post
dicamba	15 (33%)	chlorophenoxy	Post
acetochlor	12 (26%)	chloroacetanilide herbicides	Pre and post
rimsulfuron	11 (24%)	sulfonylurea herbicides	Post
isoxaflutole	10 (22%)	isoxazole	Pre
pendemethalin	8 (17%)	dinitroaniline	Post
aclonifen	6 (13%)	diphenylether (DPE)	Pre

foramsulfuron	5 (11%)	sulfonylurea herbicides	Post
isoxidifen	5 (11%)	triketone	Post
foramsulfuron	5 (11%)	sulfonylurea herbicides	Post
glyphosate	3 (7%)	Phosphonate	Pre
flufenecet	2 (4%)	oxyacetamide	Post
tritosulfuron	1 (2%)	sulfonylurea	Post
fluroxypyr	1 (2%)	pyridinoxy acid	Post
sulcotrione	1 (2%)	triketone	Post
prosulfuron	1 (2%)	sulfonylurea herbicides	Post
bromosinil	1 (2%)	nitrile herbicides	Post

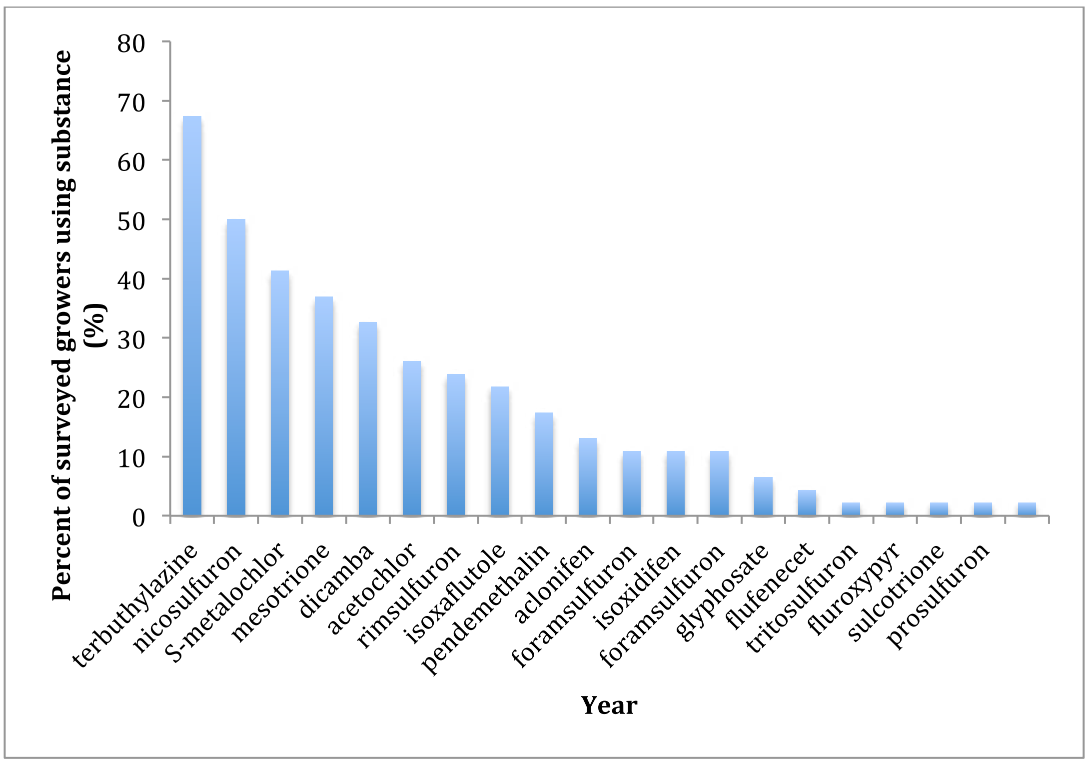

Figure 1. Distribution of herbicide use by type.

Herbicide Costs

Farmers reported spending a range of 22 Euro/ha to a maximum of 190 Euro/ha for the cost of herbicides, with an average cost of 71.5 Euro/ha. An expert interviewee reported that herbicide costs usually average 60 Euro/ha and the total cost for inputs (seeds, herbicides, fertilizer, and insecticides) is 640 E/ha (Interviewee 1, 2012). Corn production costs including tillage, planting, spraying, irrigation, harvest, transport, drying and stocking are 920 Euro/ha. Total costs, inputs and production, are 1,560 Euro/ha. The average value of the crop is 2,000 Euro/ha, so there is a profit margin of 440 Euro/ha. Therefore, herbicide costs reported in the survey of 71.5 represent 11.2% of input costs and 4.6% of total expenses.

Practices

Thirty-three of 56 (58.9%) farmers reported that they rotate herbicides with the intention of reducing the risk of herbicide weed resistance.

Fifty-two of 57 (91.2%) farmers reported that they do field-scouting to check for the presence and types of weeds in order to make decisions about the type and quantity of herbicide to apply.

Atrazine questions

Past atrazine use

Thirty-six of 57 (63.2%) farmers reported that atrazine was once used on their farms. Of farmers that reported using atrazine, the dose of application ranged from 0.3kg/ha to 5kg/ha, with an average application rate of 3.7 kg/ha.

Three farmers reported not knowing or having records for the atrazine application rates, and they were not included in calculations.

Response to atrazine ban

All farmers who reported using atrazine stated that the main response in their practices to the atrazine prohibition was to switch to a different chemical herbicide (Figure 2). One farmer reported that they reduced the amount of land dedicated to corn production. Three farmers (8.3%) reported planting more of other crops and less corn. Four farmers (11.1%) reported changing their weed control practice. No farmers reported increased tillage. Two farmers (5.6%) reported switching to IPM management. No farmers reported adopting buffer zones or increased their efforts for water quality protection as a response to the atrazine ban.

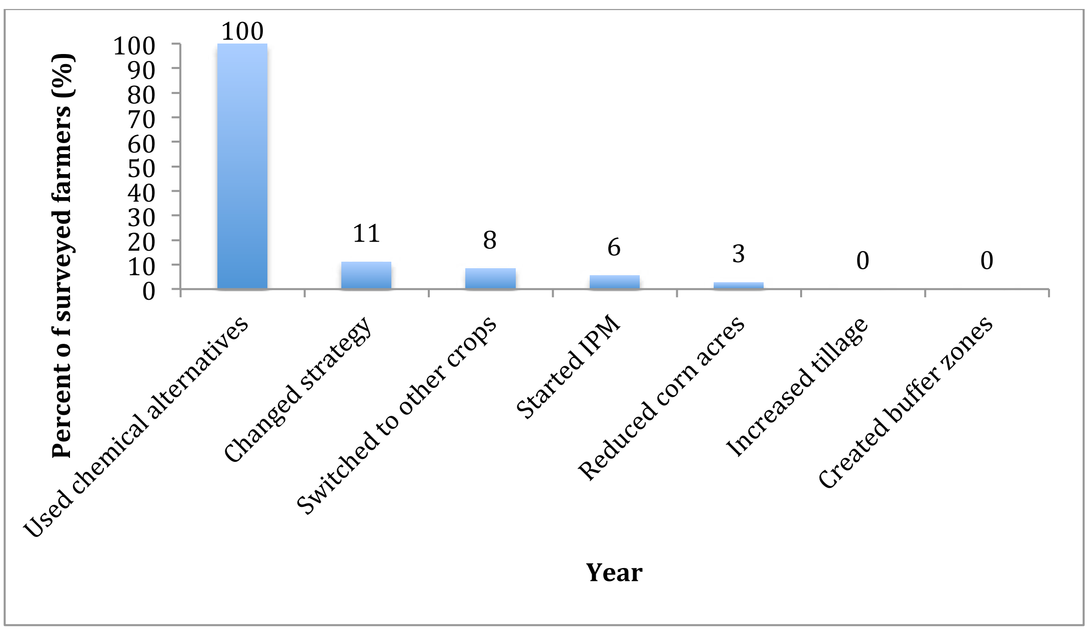

Figure 2. Farmer response to the atrazine ban.

Impact of ban

All but one farmer who had used atrazine (97.2%) reported having no impact on yields from the unavailability of atrazine. The remaining farmer reported reduced yields as a result of not having atrazine available for weed control. Thirty farmers (83.3%) reported spending more money on the cost of alternative herbicides to atrazine, and four farmers (11.1%) reported not knowing if their herbicide costs had changed. Farmers that reported an increase in herbicide costs calculated that they pay an average of 39.3% more currently for herbicides than they once did for atrazine.

Would you use atrazine?

Nineteen of 56 respondents (34%) reported that if given the legal opportunity they would like to use atrazine on their farms (Figure 3). Participants were asked to give their reasons for wanting or not wanting to use atrazine. Participants who wanted to use atrazine gave reasons such as low cost, better control than current options, and atrazine's efficacy as a weed killer (Table 3).

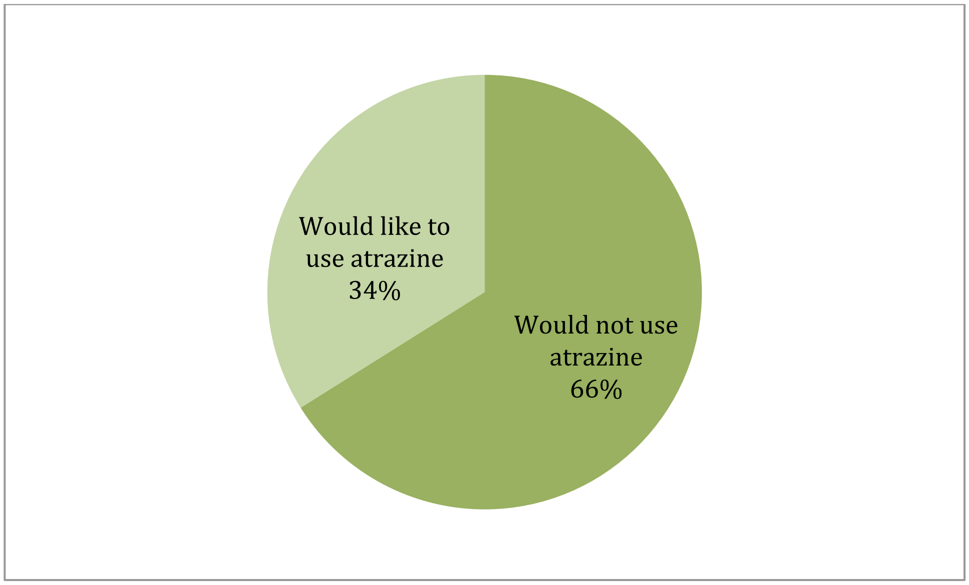

Figure 3. Farmer response to the opportunity to use atrazine again.

Table 3. Rationale for wanting to use atrazine again.

Category	Response (number of responses in is parentheses)
Efficiency	• It works well (6) • Efficient (3) • With just atrazine it is possible to get the best result, and now I need to use several products (3) • More convenient • It controlled more of the weeds • Better control of weeds in pre emergence. Absence of the need to intervene in post emergence • It has an excellent selectivity for corn • Ample spectrum of action
Cost	• Lower cost (14)
Mode of action	• Rotation of principal active ingredient

Participants that stated that they would not use atrazine gave a range of reasons focused on damage to human health, harm for the environment, and preference for more modern herbicides with higher selectivity (Table 4).

Table 4. Rationale for not wanting to use atrazine again among farmers.

Category	Response (number of responses in is parentheses)
Health	• Atrazine damages health (3) • Atrazine is a harmful product for human health • It causes cancer
Environmental impact	• I wouldn't use it because I want to protect the environment (2) • Atrazine polluted the water • It causes residues • It harms the environment and health • It is damaging • It does environmental harm • It is too dangerous
Satisfaction with current products	• There is no need, because current weed control is complete • New technology has exceeded atrazine • Existing products are more functional • I do well with the alternatives • Available herbicides have the same efficacy • The available herbicides guarantee an adequate defense from weeds • Atrazine is outmoded by other active ingredients • There are more selective herbicides that don't harm the corn crop • The results from the available products on the market are satisfactory • The available herbicides work better

Decision making

Values

Farmers were asked about what their priorities are when they decide to use a particular herbicide. They were asked a likert-type question in order to characterize the relative importance of herbicide cost, harm to the environment, ease of use, and efficiency. These categories were selected as a result of farmer interviews that often reported these elements as important. This question was assessed by assigning a value of 0-4 (zero being not at all important and four being very important) for each category. Farmers reported the most important factor when choosing an herbicide is efficiency in weed control, with 84.81% of respondents stating it is very important (Table 5; Figure 4). Cost was the second most important factor, with the majority (88.7%) of farmers labeling it as either very important or important. Ease of use was the third most important factor, with almost all farmers considering it from moderately important to very important. Environmental impacts were listed as the least important factor and the only factor listed as of no or little importance by more than 10% of the farmers. Most farmers listed environmental impacts as important, but it was the category with the fewest respondents (20%) listing it as very important. A Chi-squared Test was performed to test for statistical differences among the rankings for the different categories. The null hypothesis that cost, environment, ease of use, and efficacy are of equal importance to farmers. The Chi-squared Test shows there are significant differences in terms of importance for the different criteria, which allows for a rejection of the null hypothesis, $\mathbf{c}^2$ (12, N= variable, see Table) = 71.50, p = <0.005.

Table 5. Importance of herbicide attributes for chemical choice. N= ().

Category	Not at all important	Little importance	Moderately important	Important	Very important	Total respondents
Cost	0.00%	0.00%	11.3% (6)	41.51% (22)	47.17% (25)	53
Environment	4% (2)	8% (4)	14% (7)	54% (27)	20% (10)	50
Ease of use	2.17% (1)	0.00%	28.26% (13)	41.30% (19)	28.26% (13)	46
Efficiency	0.00%	0.00%	0.00%	15.09% (8)	84.91% (45)	53

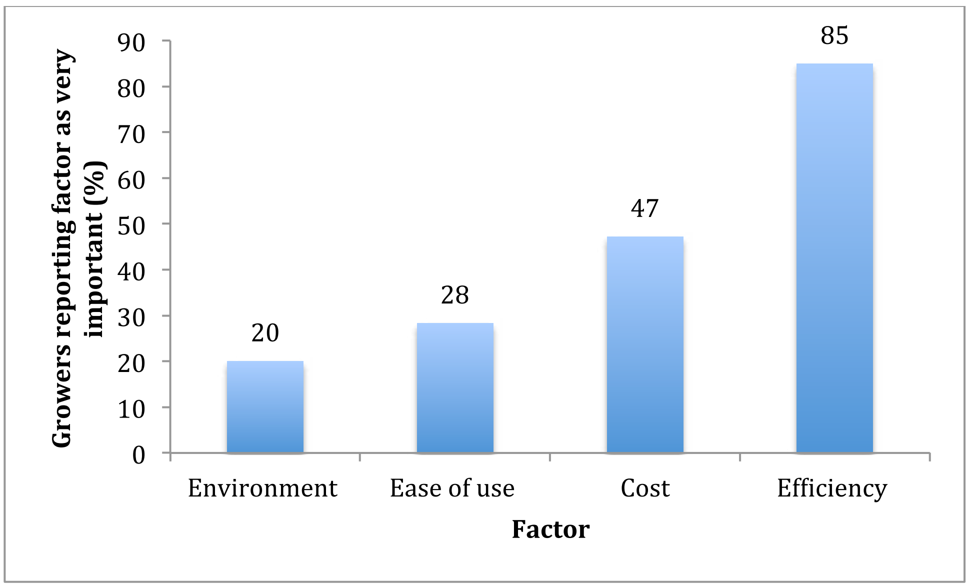

Figure 4. Importance of herbicide attributes for chemical choice among farmers.

Information sources

Farmers were asked to rank the importance of the sources of information used to make decisions about which herbicides to use. This question relates to knowledge transfer and trust in particular groups and information sources. Information learned from various sources was listed by farmers in the following order from most important to least important: personal experience, chemical companies, regional or university research publications, monitoring service advice, technical magazines, farm advisors, other farmers, producers associations, research on the internet), and lastly information from employees (Table 6; Figure 5).

Table 6. Importance of various information sources for farmers.

Category	Not important	Little importance	Moderately important	Important	Very important	Total respondents
Personal experience	4.2% (2)	0.00%	27.1% (13)	33.3% (16)	35.4% (17)	48
Advice from chemical company representatives	3.8% (2)	9.4% (5)	28.3% (15)	37.7% (20)	20.8% (11)	53
Regional or university research publications	13.3% (6)	22.2% (10)	26.7% (12)	33.3% (15)	17.8% (8)	45
Monitoring service advice	4.0% (2)	24.0% (12)	30.0% (15)	36.0% (18)	6% (3)	50
Technical magazines	10.4% (5)	14.6% (7)	35.4% (17)	29.2% (14)	10.4% (5)	48
Advice from farm advisors	12.2% (6)	26.5% (13)	22.5% (11)	28.6% (14)	10.2% (5)	49
Advice from other farmers	8.2% (4)	26.5% (13)	30.6% (15)	28.6% (14)	6.1% (3)	49
Producers associations	13.7% (7)	27.5% (14)	29.4% (15)	23.5% (12)	5.9% (3)	51
Research on the internet	27.1% (13)	31.3% (15)	20.8% (10)	12.5% (6)	8.3% (4)	48
Advice from employees	46.8% (22)	14.9% (7)	25.5% (12)	8.5% (4)	4.3% (2)	47

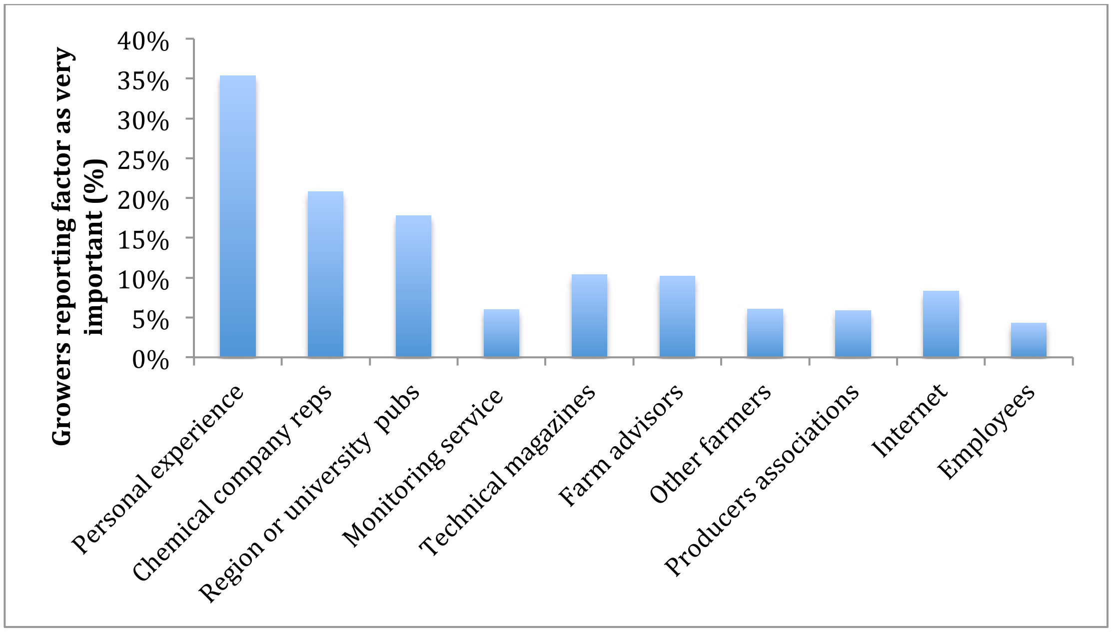

Figure 5. Farmer's preferences for informational sources.

Water quality protection

Farmers were asked in an open-ended question about how they could personally best protect water quality from herbicides. Fifty-three respondents gave answers to the question (Table 7; Figure 6). The responses included behaviors related to reducing herbicide applications, making informed choices, and using environmentally friendly behaviors (such as buffers). One farmer stated that the most important factor is to "make conscious use of chemical herbicides. We farmers need to use our heads, not only the pesticide products."

Table 7. Farmers' perceptions of farming techniques to best protect water quality.

Category	Response (Number of responses is in parentheses)
Limit pesticide use	• Use a reduced/ minimal dose per hectare (15) • follow the suggested directions and use for the product given by the manufacturer (13) • Targeted use of pesticides (2) • When possible, do not use herbicide products (1) • Do not use herbicides (1) • Limit the number of treatments (1) • Limit the amount of herbicide used in pre-emergence (1)
Informed use of pesticides	• Precise information on the consequences of active substances on health and the environment (1) • Respect the ministerial regulations (1) • Use modern pesticides and pesticides characterized as non carcinogenic (1) • Conscientious behavior and attention form the farmer (1)
Field practices	• Avoid use of herbicides before it rains or when it is windy/ poor weather (6) • Proper disposal of pesticides and packages used for plant protection products (4) • Correct timing of herbicide application (3) • Rotate principal active ingredients of herbicides (2) • Apply herbicides in pre and post emergence (1) • Use crop rotation (1) • Use cover crops (1) • Adjust field drainage so it doesn't drain into waterways (1) • Careful container washing (1)
Buffer zones	• Respect the distance from the waterways (13) • Maintain a buffer with no herbicide spraying in the areas close to waterways (2) • Grassed buffer zones (2) • Do not plant corn seeds close to waterways (2) • Pay attention to aquifers and groundwater (2)

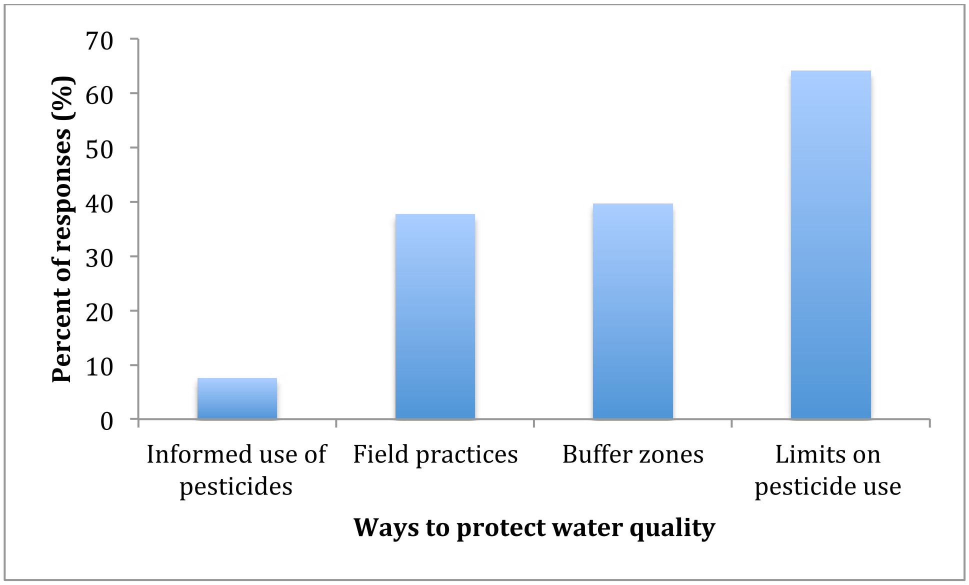

Figure 6. Percent of farmers employing various water quality protection measures.

Organic production

Farm locations:

All farms were located in the Veneto Region of Northern Italy. The farms ranged from 3ha-70ha, and all grew a mixture of crops.

Motivations for organic production

Farm No.1, is a biodynamic, 6.5 hectare farm of vegetable, mixed fruit, forest, and corn production (Figure 7). The farm transitioned to organic production in 1994 as a personal choice made by the farm owner and his family, who live on the farm property. The farmer explained that before transitioning to organic production he grew only corn:

> I used to produce only corn. It requires too many chemicals to produce this mass of corn. I was sick of the poison. I was sick of the chemicals that damaged the environment, our family, my flowers. Everyone has cancer around here. We still have a high

> presence of atrazine in the ground water we use. I decided to change. I took courses and returned to school. To have other farms become more sustainable is a question of the mind. It has to be within the heart of each person to change – Interviewee 2, 2012

The farmer from Farm No. 2, a three hectare mixed vegetable farm converted to organic production in 1996, explained that he had worked for many years in conventional agriculture. He did not like herbicides and the harm they cause to human and environmental health. He was interested in an agricultural system that did not pollute and worked with nature. He rejected chemically intensive agriculture by cultivating diversity through planting many crops, maintaining the wild areas, and planting trees. He stated, “All this monoculture corn, it's not good for the human soul.” The farm was originally in only corn and soy production, and now they grow potatoes, lettuce, leeks, cauliflower, squash, and tomatoes.

Farm No. 3 is a 70ha mixed vegetable farm that also raises goats and cows for milk. The farmer stated that they became part of an organic coop in 1987. He explained that at age 20, he had a strong experience that motivated him to grow organically. He stated, “I was walking in the field and saw the chemicals being sprayed. In the canals near the field, there were many frogs and fish belly-up. I was really affected and it impressed upon me that there should be a different solution.” His farm was one of the early farms to go organic, and the coop performed selfcertification as there was not yet state recognition of organic production methods.

Experiences with neighbors

One farmer expressed that his neighbors, all owners of conventional corn farms (Figure 8), have shown little interest and mistrust of his practices. “My neighbors think I am crazy,” he stated explaining that although he feels negative pressure from his neighbors for his non-traditional farming practices, he is grateful for his independence from contracts and his ability to sell his produce at the cooperative (Interviewee 2, 2012).

Figure 7. Photo of mixed vegetable production at the biodynamic farm with trees and bird boxes to promote wildlife. Figure 8. Photo of a neighboring corn farm with bare soil and corn that has not yet emerged.

Farm No. 2 maintains strong relationships with neighboring farmers. The farm offers a field school with educational classes for both organic and conventional farmers interested in learning about organic production methods. The farmer stated:

> The biggest problem is that farmers are closed to sharing information and are competitive. For big farms, it is mentally harder to change because they always think about the safe things, to have no risk. Direct information, relationships, and personal experiences are the basis for change to less polluting agriculture (Interviewee 3, 2012).

Growing corn organically

The farmer from farm No. 1 stated that growing corn organically was not difficult given the small scale of his production. He weeds by hand, with a hoe (Figure 9), and pre-irrigates to germinate weed seeds before planting, although sometimes it required four weeding passes per season. He stated that weeds are a problem on the farm, but that it is not his goal to eliminate 100% of weeds.

Figure 9. Farmer demonstrating weed control by hand hoeing. Figure 10. Herbicide application made by a sprayer tractor (Source: Altland, 2014).

Two farmers stated that they no longer grow organic corn because it is too labor intensive to control weeds. One farmer stated that he will grow corn some years, but recently he has stopped because it is not profitable because of the high labor costs. Farm No. 3 stated, “We don't grow organic corn because it is almost impossible because the weeds are too difficult to control. Weeds are one of the biggest problems for organic farms. For small farms it is easier, but when farms get bigger weeds are a problem that cannot be solved because it costs too much for labor” (Interviewee 4, 2012).

Discussion

The sample of farmers surveyed allows for analysis of the situation in northern Italy, yet the size and sampling method does not allow for broad generalizations that apply to the entire population of Italian corn farmers. For example, there may be several biases in the sample due to the nature of an online survey. For example, older farmers may have been less familiar with an online survey tool and less likely to complete the survey. To correct for this bias, I interviewed in person two older farmers that had been influential as leaders in farming associations but who were unable to take a computer based survey. I did not include these interviews in the results above, however, the interviews yielded information that was considered consistent to the survey results. Another issue with the survey is that some respondents did not answer all of the questions. For this reason, the number of responses varies from 45 responses to 59 depending on the question. I adjusted my analysis to reflect the difference in total responses for each question, yet this issue leads to questions about why certain respondents decided not to respond to some of the questions. Despite these biases, the survey is a useful tool for obtaining information from farmers about their practices and perspectives.

Past atrazine use and impacts

The majority of farmers surveyed reported past atrazine use on their farms. It may be the case that atrazine had been used at more farms than for which it was reported either because the farmers did not know about its use by previous farm managers or a reluctance to report its use. The rates of atrazine use reported in the survey match the recommended doses from the 1980's. However, during an interview with a corn farmer it was stated that one year the amount of atrazine applied to the farm was accidentally doubled to 8kg/ha because they mixed the chemical incorrectly (Interviewee 7, 2010). Such a mistake could lead to years of soil and water contamination.

Almost no farmers reported a change in yield as a result of the atrazine ban. The absence of yield reductions is an important finding in the face of economic reports that estimate that banning atrazine in the US would result in yield losses of 10-40% (EPA, 2003). When faced with losing a key chemical product, industry will often report the potential for high losses. For example, when France was on the verge of a triazine ban in 2005, the French Corn Farmers Association (IGPM) reported potential yield losses of between 20-25 E/ha/year (Renoux et al., 2003). However, such yield losses did not come to pass. With actual costs estimated at closer to 10 E/ha, the actual cost of losing triazines was far lower than anticipated (Interviewee 8, 2012).

The increased cost for alternative herbicides reported in the survey is consistent with current herbicide cost disparities. For example, atrazine costs approximately one fifth the price of an alternative herbicide, S-Metalochlor (Kentucky Farm Bureau, 2011). The increased cost of herbicides may also contribute to the lower use of herbicides all together as the high cost acts as a negative incentive for indiscriminate herbicide use.

Thirty-four percent of farmers expressed the willingness or desire to use atrazine if it were legal, yet 66% of farmers stated that they would not use atrazine. Farmers that would like to use atrazine seemed to want it as another option in their toolbox, but no farmers expressed an intense need for using atrazine. Considering the argument that farmers need diverse herbicides in order to cope with herbicide resistant weeds, it is interesting that only 58.9% of surveyed growers report rotating the herbicides they use. Farmers that would not use atrazine again stated that their current methods are sufficient and that atrazine is too risky for health and the environment. Many farmers state they would not use atrazine because of health and environmental safety concerns, yet many of those same farmers are currently using TBA, which carries those same risks. It may be a case that the risks of TBA are not as well studied or made available to farmers, and therefore they perceive atrazine as risky and TBA as a safe product.

Current weed control in Italy - Is it more sustainable than using atrazine?

Herbicide use in conventional corn is standard, and it was expected that farmers in the survey would all report the use of herbicides. This is congruent with the situation in the US, where herbicides are applied to 98% of the conventional acres planted in corn (USDA, 2011). In fact, herbicides make up two thirds of the active ingredient inputs (insecticides, herbicides, and fungicides) applied to these corn crops (USDA, 2011).

Tillage was a main tool to fight weeds used by the respondents. Minimum tillage or no-till farming is growing in popularity in Italy, especially among farmers that prefer to use post-emergent weed control. However, the 58.6% of farmers that reported full field tillage represents a significantly higher rate of tillage than what is found in the US. In the US, only 38% of farms use full tillage, and 62% of farms use minimal or no tillage (USDA, 2011). The high rate of tillage in the Italian sample is indicative of lower overall herbicide use. Tillage allows for inter-row weed cultivation. It is a common practice to not spray the inter-row spaces with herbicides if they will be tilled, called a banded application, which therefore reduces by half the area to which herbicides are applied. Crop rotation was popular among the sample, with 80% of farmers reporting its use. This is a higher rate of crop rotation compared to US farms, where 71% of farmers reported rotating crops at least every three years (USDA, 2011). These results suggest that farmers in the sample are relying more on mechanical tillage and crop rotation as ways to decrease weed pressure than do US farmers.

Herbicide use

The types and quantities of herbicides that are used as atrazine alternatives are important to understanding the sustainability of input substitution. The survey respondents report using a wide variety of active ingredients from 11 different chemical families. The list of chemicals used by respondents in the survey is not an exhaustive list of what is available, but it does provide information on what products are actually being used. The respondents report using both pre and post emergence herbicides. In fact, the second most commonly used herbicide in the sample is a post-emergence herbicide, nicosulfuron. There is a concerted effort in Italy's Rural Development Plan to promote the use of post-emergent herbicide use. For example, there are funds/incentives available for farmers who implement IPM strategies such as reduced pesticide doses, post-emergence weed control, and spraying only on the crop row and not on the whole field (Interviewee 9, 2012). According to one agricultural specialist at a farmers' association, 80% of corn farmers use both pre and post emergent herbicides, and 20% use only post (Interviewee 10, 2012). This is a very different situation to the typical herbicide use program in the US. In the US, the top three herbicides used for corn are glyphosate isopropylamine salt (RoundUp), atrazine, and acetochlor. These three herbicides are all pre-emergence, broad spectrum herbicides that are applied to the entire field. The comparatively increased use of post-emergence herbicides used by the Italian sample suggests higher specificity and targeted use of the products for an overall lower application rate.

The use of TBA instead of atrazine in corn production in Italy is an example product substitution having unintended environmental consequences. TBA and its metabolite desethyl-terbuthylazine are two of the most commonly found water contaminants in Italy's national monitoring program of surface and groundwater (ISPRA, 2013). TBA is the third most common contaminant of surface water and was detected in 19.75% of all surface water monitoring stations in 2010 (ISPRA, 2013). Desethyl-terbuthylazine is the second most commonly found water contaminant found in groundwater, present in 10.52% of monitoring wells across all regions (ISPRA, 2013).

Researchers have suggested the need to remove TBA from the Italian herbicide market in order to reach groundwater quality goals, but there is a contrary pressure from the industry (Interviewee 11, 2012). One regulator characterized the situation by stating:

> The problem of atrazine is now the problem of TBA. We proposed to ban TBA in 2006, but such a proposal has not been accepted by the Ministry of Health. There are hundreds of sites in Italy with the level of TBA above the water quality limit. The risk is unacceptable. We are dealing with a cocktail of substances. Mitigation for TBA is completely ineffective. TBA is a substance that contaminates the water. We need to eliminate all triazines (Interviewee 11, 2012).

Despite recommendations from regulators to remove TBA, it was re-approved by the EU in 2011 for continued use until 2020. There is strong opposition for regulation and mitigation of TBA from corn farmers and chemical companies (Interviewee 8, 2012).

Instituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) is a government institute focused on environmental research and protection. ISPRA published a pesticide and water quality report in 2013 based on data from 2009-2010 (ISPRA, 2013). The report states that 7.4% of freshwater monitoring samples and 7.2 % of the monitoring wells have pesticide levels exceeding the 0.1μg/L standard. The most common water pollutants found are TBA, atrazine, and their breakdown products.

Regions have decided to try and ameliorate the TBA pollution problem independently from the national government. The region of Piemonte identified vulnerable zones based on soil characteristics and created a set of rules for corn farmers within the vulnerable zones (see Figure 2.16). Piemonte started this process of identifying vulnerable zones in 2003, but the process of creating rules for TBA mitigation in those zones was delayed and took four years due to resistance from farmers and the chemical industry. When asked why TBA is not banned completely in the vulnerable zones, one regulator responded that:

> It's not banned because it is a substance that is fundamental to corn production - it is necessary to guarantee a high production of corn. To ban it completely is to say 'Close the farms.' There are not sufficient alternatives for weed control in corn in terms of efficacy. We thought about rotation. We hope that the farms will respect the law to grow one year corn and one year another crop. Over time this will be useful to reduce the pollution. (Interviewee 11, 2012).

This perspective, that a triazine herbicide is fundamental to corn production, is contrary to other views that highlight how countries like France have completely banned all triazine herbicides and continue to maintain successful corn production. Despite not using triazines, which the US EPA estimates would cause a US corn crop loss of 10-40%, France's average corn yield has increased since the triazine ban in 2003 with an all time high yield in 2007 with 96727 hg/ha (EPA, 2003: FAOSTAT, 2015; Figure 11). French farmers have transitioned to less use of pre-emergent herbicides and an increased use of low-doses of weed specific, post-emergence herbicides (Interviewee 8, 2012). In France, currently 50% of farmers use exclusively post-emergent weed control, an increase of 17% since triazines were banned. This transition to post-emergent weed control required farmers to rapidly acquire skills and knowledge about weed species, techniques, and accurate timing of applications (Interviewee 8, 2012).

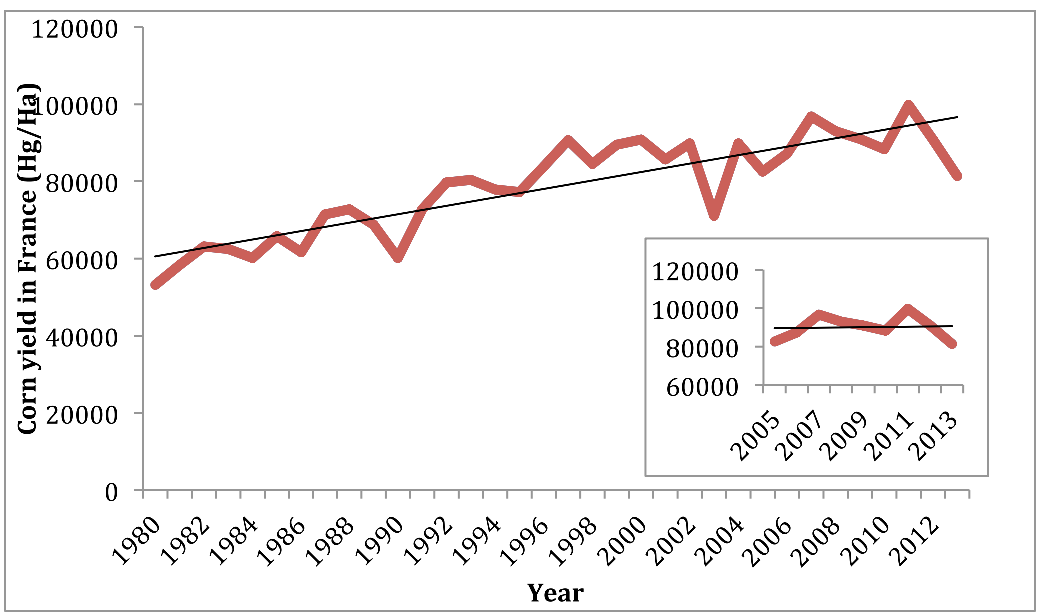

Figure 11. Corn yield in France from 1980 to 2013 with inset highlighting minimal changes from 2005-2013 (Source: FAOSTAT, 2015).

TBA is not the only atrazine alternative with its own risks. Substitutes for atrazine, such as acetochlor, sulcotrione, and mesotrione pose their own risks as water pollutants (EPA, 1994). These alternative herbicides have different chemical properties, and they are variable in their ability to enter water, persistence, and toxicological effects. Some of these herbicides are known carcinogens. For example, mice fed 75 mg/kg/day of acetochlor developed liver carcinomas, lung carcinomas, and uterine histiocytic sarcomas in females (EPA, 1994). The risks involved with existing atrazine alternatives highlight the need to move towards more sustainable approaches of weed management that reduces the overall amount of herbicides used. The interviews with organic farmers show the potential for replacing herbicide use with non-chemical techniques. Not only is there a need for overall reductions in herbicide use, but also a shift towards better alternatives assessment in the risk assessment and policy decision framework for chemical regulation.

Although the situation in 2014 is still problematic in terms of water pollution from herbicides, in some ways it has improved from the time when atrazine was still being used. Doses of TBA have decreased from the 1990s and are lower than application rates of atrazine. This reduction in application rate is a step towards less water contamination. The steps taken to reduce pollution in Italy can be seen as lessons that creating rules to reduce doses and restrict the use of herbicides in vulnerable zones is at least a first step towards increased water quality protection.

Farmer Decision Making

Perspectives on atrazine

Herbicide choice

Based on the survey responses of 53 farmers, the most important factor reported for choosing an herbicide, more important than cost, ease of use, or environmental safety, is efficacy: how well a product works. This is an expected response, for no farmer wants to pay for a product that does not work well. The low ranking of environmental safety as a decision making factor perhaps serves as an opportunity for education among farmers about the importance of choosing the least harmful available products. Choosing the least harmful products can be a challenge for farmers who may not understand how to rank products in terms of environmental risks. Many farmers believe that if a product is on the market, it is adequately safe to use and it is not necessary to distinguish different risks among products (Interviewee 1, 2012). Some farmers perceive certain herbicides as posing no risks at all. For example, one farmer stated, "Glyphosate is safe enough to put in a baby's bottle." Although this comment was made in a light-hearted fashion, it reveals a sense that farmers see little risk of herbicides causing harm to human health. The ability of farmers to choose products based on environmental risk is one of the targets of the EU Sustainable Use of Pesticides Directive. In this directive, farmers and farm advisors are being educated and databases are being built to systematically compare the environmental risks of different pesticides.

The most important sources of information reported by farmers in the survey were personal experience and advice from chemical company representatives and distributors. Based on the survey, personal experience, one's agronomic experience, education, and experimentation are driving forces in making decisions on one's own land. The importance of chemical company distributors is a complicated factor, as the distributor is both offering advice and selling a product. One farmer interviewed stated, "I trust the dealer I buy my herbicides from. I have known him for many years and he knows he cannot give me a bad deal" (Interviewee 1, 2012). The ongoing business and friendship relationships between chemical company distributors and farmers are influential on farmers' chemical choices. This type of personal relationship may be something to be enhanced for other types of knowledge transfer. For example, creating long-standing, positive relationships between farmers and extension agents may increase the trust and variety of information to which farmers will respond. Extension agents trained and experienced in organic and alternative management strategies could also begin to build this trust.

Protecting water quality

Survey respondents most reported reducing the use of herbicides and knowing how to use them correctly as actions to protect water quality. These responses reveal awareness about careful and limited herbicide use. Farmers also commonly reported the need for buffers, yet very few farmers actually reported using buffer zones or grassed buffers. It seems that there is an obstacle in implementing buffers, such as the cost of taking land out of production or a lack of training on how to create effective buffer zones. The combination of awareness and inaction may be an opportunity for more robust incentive programs to be implemented to protect the environment.

Organic production

Interviews and farm visits with organic farmers have elucidated the challenges of growing corn at a large scale without herbicides. Of the organic farmers interviewed who grew corn, it was grown as one of many crops or a small portion was grown organically while the rest was conventional. Despite the challenges of high labor demands for weed control when there is not chemical intervention, there are techniques that can transfer from organic growing that could reduce reliance on herbicides. For example, pre-irrigating the soil to germinate weed seeds followed by tillage can greatly reduce weed presence. The Sustainable Use of Pesticides Directive (Directive 2009/128/EC), which went into effect throughout the EU on January 2014, establishes the requirement for National Action Plans (NAP) intended to reduce pesticide use through training, equipment checks, and increased involvement in organic and IPM production. In fact, the directive mandates basic IPM be practiced by all farmers. The NAPs, plans that are created by each member state, often involve voluntary, more restrictive IPM programs that are specific to particular crops and regions. For example, Italy has created voluntary IPM programs in each of the regions as part of their NAP. For example, in the region of Emilia Romagna, weekly IPM and organic production bulletins are written for farmers. These bulletins specify when, which, and in what quantity pesticide products should be used for specific pests and weeds. For corn, the bulletin prescribes the use of many different herbicides in both pre-emergence and post-emergence, yet provides no guidance for organic corn production (perhaps because it is so uncommon). The hope is that the guidelines given will allow for proper timing and dosage to avoid over-use of herbicides. However, it seems that there is the potential for further communication and knowledge transfer about organic production methods that could be used by IPM farmers. The bulletins are produced by regional employees specialized in plant protection as well as by crop technicians. The bulletins are made available online to farmers, and there is an IPM section followed by an organic section, each which is divided into the different crops. Despite the availability of these regionally produced bulletins, farmers are often rely on companies that distribute seeds, fertilizer, and pesticides for guidance for what products to use. These distributors create their own set of weekly bulletins based upon the regional bulletins, but the products recommended have been altered to only represent what is available in the commercial lines the company carries and the information on organic production techniques in often removed completely. One member of an organic advocacy group described the problem as a lack of access to IPM and organic information:

> Most advisory services work so closely with industry that you can't get advice on organic. There is a problem with knowledge transfer. A farmer might revert back to conventional agriculture if their crop is threatened and they are not given advice for how to cope with the problem organically. Data and research is not always accessible. We need advisory services that work between research and practice, and

innovative partnership between researchers and farmers (Interviewee 11).

It seems that inclusion of the organic practices in bulletins produced by distributors would be useful in order for conventional farmers to see that there are other practices available as well as for organic farmers to get adequate support.

Conclusion

The results from the survey provide insights into the response to atrazine restrictions as well as opportunities for intervention. The ban on atrazine in Italy reduced atrazine use, yet resulted in the unintended consequences of increased use of TBA and other herbicides. The transition from widespread pre-emergence pesticide use to greater use of weed specific post-emergence herbicides is a positive transition towards less reliance on chemicals. However, this is only a small improvement where rapid changes are needed in order to protect human health and the environment.

Policies based on alternatives assessment with goals for farmer learning about the different risks of pesticides will be the most effective in protecting the environment. Although in its infancy, the Sustainable Use of Pesticides Directive offers a model for farmer engagement and sets goals for pesticide reduction. The study of the implementation and impacts of the Sustainable Use Directive will be valuable to future policies designed to reduce environmental impacts from agricultural pesticides.

4. Atrazine Policy in Wisconsin

Introduction

Herbicides are applied to 98% of acres planted to corn in the US (NASS, 2011). This widespread use creates risks of water pollution in agricultural areas. There has been a shift from little herbicide use in the 1950s to over one hundred million pounds of herbicides applied to US corn crops alone in 2010 (NASS, 2011). The reliance on herbicides to control weeds leads to questions about how to design policies that protect the environment. Environmental problems caused by herbicide pollution include contamination of streams, rivers, lakes, groundwater and acute and long-term consequences for the health of wildlife species. The pollution of drinking water also translates into threats to human health including cancer, immunologic abnormalities, reproductive problems, and adverse developmental effects (Weisenburger, 1993). This chapter addresses the question of whether the regulation of a single herbicide, in this case the herbicide atrazine, causes environmental improvements.

Water contamination with atrazine, especially in groundwater, is an environmental and public health problem faced in every US state where corn is grown. Atrazine use has been prohibited in some European countries since 1990 and throughout Europe since 2004, yet it remains one of the most commonly used herbicides in the US. The ongoing problem in Europe of groundwater contamination with atrazine even thirty years since its discontinued use serves as a warning that the US must consider policy changes for atrazine or face potential long-term environmental consequences (Jablonowski et al., 2010). Wisconsin is the US state with the strictest rules for atrazine use. Pesticide pollution became a major regulatory issue in Wisconsin from the mid 1980s to the early 1990s. During that period, Wisconsin created broad legislation for pesticides and groundwater and created a rule that specifically targets pollution from atrazine. The Atrazine Rule (ATCP 30, Wis. Adm. Code) set a series of general requirements on the types of atrazine uses that are acceptable, created maximum allowable application rates specific to soil type, and limited the areas where atrazine can be used through the creation of atrazine management and prohibition areas (PA). These strategies have periodically been evaluated by the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP), the agency that is responsible for implementing the atrazine rule.

There is pressure from the Wisconsin Corn Growers Association to maintain atrazine use in the state and possibly reintroduce it into the PAs. This research project will contribute to the ongoing discussion of the value of PAs and the risks involved with reintroducing atrazine into areas where it has been prohibited. In 2015, the U.S. Environmental Protection Agency (EPA) will finish the reregistration process for atrazine. Understanding the strengths and weaknesses of a statewide program like the one in Wisconsin can provide insights into how atrazine should be managed throughout the U.S. In addition, the Wisconsin case study allows for comparison with other methods of atrazine restrictions, such as the total ban in the European Union.

This chapter reviews the factors that led to the adoption of the Atrazine Rule in Wisconsin, analyzes how successful it has been at protecting water quality, and explores farmers' perspectives on the policy change. The chapter begins with a discussion of research methods, followed by background on the different options for managing weeds in corn. Next, the atrazine rule and the political and social forces that contributed to its evolution are discussed. Herbicide use patterns are evaluated using both US and Wisconsin data. The conclusion provides policy recommendations for encouraging reduced herbicide use.

Research Questions and Methods

This chapter addresses the following research questions:

- What processes led to the adoption of the Atrazine Rule?
- How have Wisconsin corn farmers complied with restrictions on atrazine?
- What herbicides are being used instead?

A case study method is used because it allows for conceptual validity, creation of new hypotheses, exploration of causal mechanisms, and the assessment of causal relationships (George and Bennett, 2005). My exploration of the reactions to and perceptions of atrazine restrictions requires the use of multiple data sources and is well suited for a mixed methods case study.

Research methods include in-person stakeholder interviews (Table 1) with key players involved with atrazine regulation in Wisconsin as well as quantitative analysis of archival materials and existing pesticide use and water quality monitoring databases. This mixed methods approach of combining both qualitative and quantitative research methods allows me to answer questions that have diverse components and allows me to provide a more comprehensive set of recommendations based on the research (Tashakkori and Creswell, 2007). The use of mixed methods that include surveys, interviews, and document reviews is becoming more common with environmental research. For example, research that evaluates questions in agroecosystems often used mixed methods to take into account the social, environmental, and market considerations as well as stakeholder (Cole et al., 2011). My methodological approach contributes to this growing body of work, and is also unique in its rigorous quantitative analysis of water quality changes.

Table 1. List of interviewees and their positions

Interviewee Number	Position Description
1	Public County Official, Wisconsin
2	Regulator at the Wisconsin Department of Agriculture, Trade, and Consumer Protection
3	Researcher at the Wisconsin Department of Agriculture, Trade, and Consumer Protection
4	District Attorney Department of Justice, Wisconsin State

5	Coordinator at the Department of Natural Resources, Madison, Wisconsin
6	Professor/ Agronomist at University of Wisconsin, Madison
7	Professor/ Agronomist University of Wisconsin, Madison
8	Researcher University of Wisconsin, Madison
9	EU Agricultural Regulator
10	Toxicologist

Weed control in US corn

There are a variety of weed control techniques and chemicals used to control weeds in corn production in the US. The National Agricultural Statistics Service (NASS) routinely assesses chemical use in US corn production by surveying corn farmers from the 25 states that represent 93% of the corn acreage in the country (NASS, 2011). The 2010 survey showed that 98% of corn acres were treated with herbicides (NASS, 2011). The most commonly used herbicide was glyphosate isopropylamine salt, which was applied to 66% of acres (NASS, 2011). Atrazine was the second most commonly applied herbicide, with 61% of acres treated. Total herbicide applications have varied over the course of the survey data, with declines from 1990 until the early 2000s, and increasing for the most recent years of the survey (Figure 1).

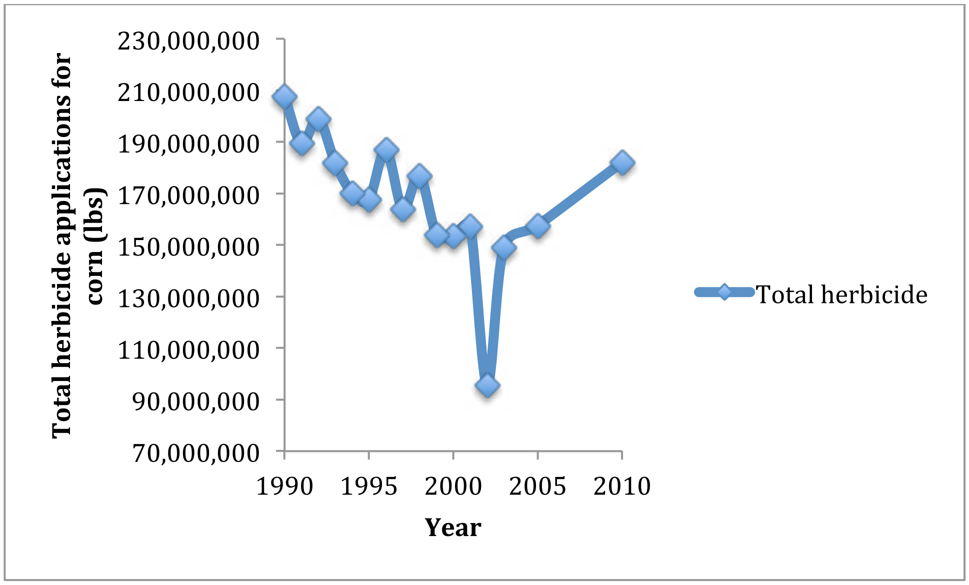

Figure 1. Total herbicide use in corn production in the US (data source NASS, 2014).

The NASS surveys also reveal interesting trends in atrazine use in U.S. corn production over time. The percentage of corn acres treated with atrazine ranges with slight fluctuations from 61% in 2010 to a peak of 75% in 2001 (Figure 2). The average application rate for atrazine shows minimal variation over the period of 1990-2010, deviating slightly from 1lb/acre. The average application for atrazine in 2010 was 1.034 lbs./acre/year with a total of 51,129,000 lbs./year used in program states that were part of the survey[1] (NASS, 2011).

[1] NASS program states include: Arkansas, Colorado, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New York, North Carolina, North Dakota, Ohio, Pennsylvania, South Dakota, Tennessee, Texas, Washington and Wisconsin.

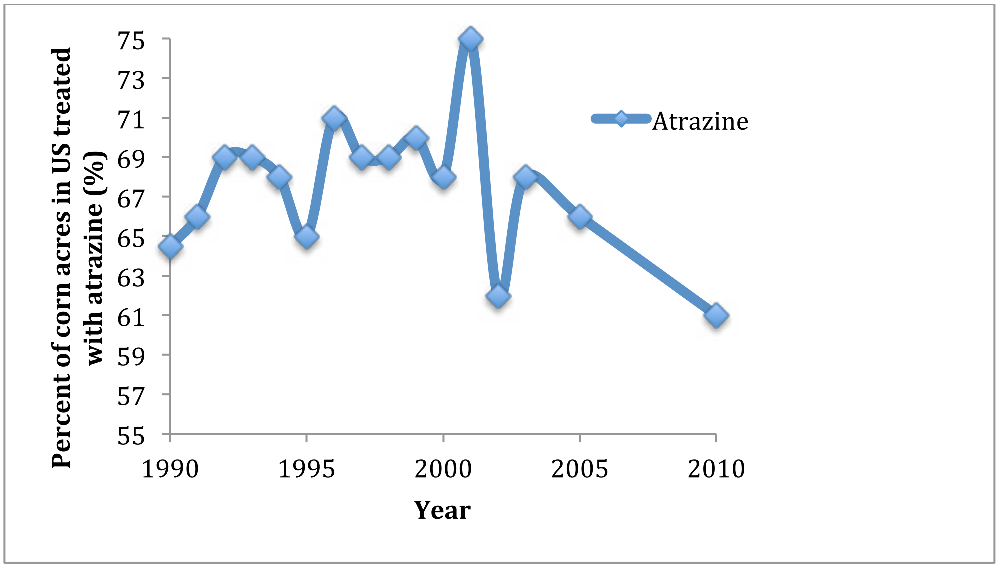

Figure 2. Percent of US corn acres treated with atrazine from 1990-2010.

The use of genetically engineered variants has transformed how corn is grown in the U.S. and represents a divergence from Europe where GMOs are not permitted. Herbicide resistant corn became commercially available in 1996, when Monsanto introduced its Roundup Ready® variety, which is resistant to glyphosate products. In 2013, herbicide tolerant corn made up 85% of corn planted (USDA, 2013). The availability of Roundup Ready corn and the resultant increases in glyphosate applications changed the herbicide market, pushing glyphosate from one of the least commonly used herbicides to the predominant herbicide applied to corn. In 1991, only 2% of U.S. corn was treated with glyphosate, whereas in 2014, 89% of corn acres planted were transgenic for herbicide resistance (USDA, 2014a; NASS, 2011; Figure 3). Although the acreage treated with glyphosate has increased tremendously, it did not replace atrazine or trigger a reduction in the use of atrazine as one might have expected (Figure

4). Conversely, both atrazine and glyphosate are applied to the majority of corn acreage and the intensive use of glyphosate has led to herbicide resistance problems and super weeds, which has led to increased herbicide use (Benbrook, 2012).

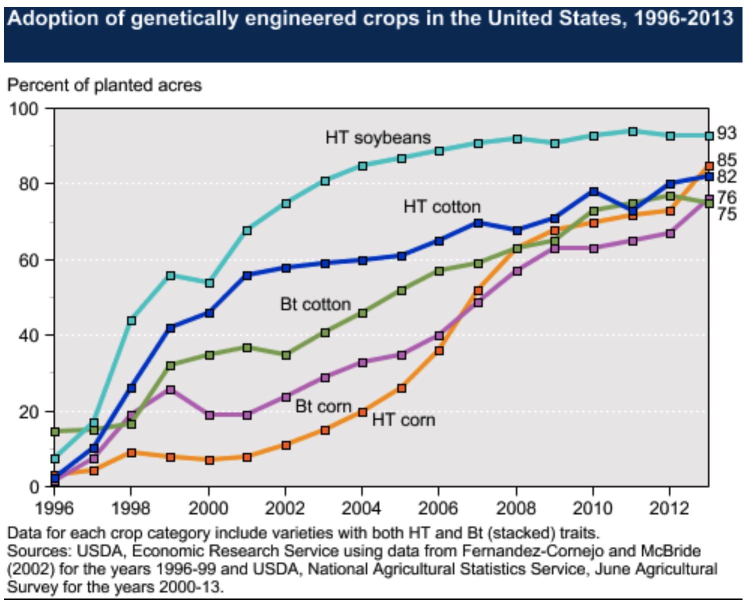

Figure 3. Percent of planted acres planted with genetically engineered crops. The orange data series represents herbicide tolerant corn reaching a maximum of 85% of acres planted in 2013. Source: NASS, 2014.

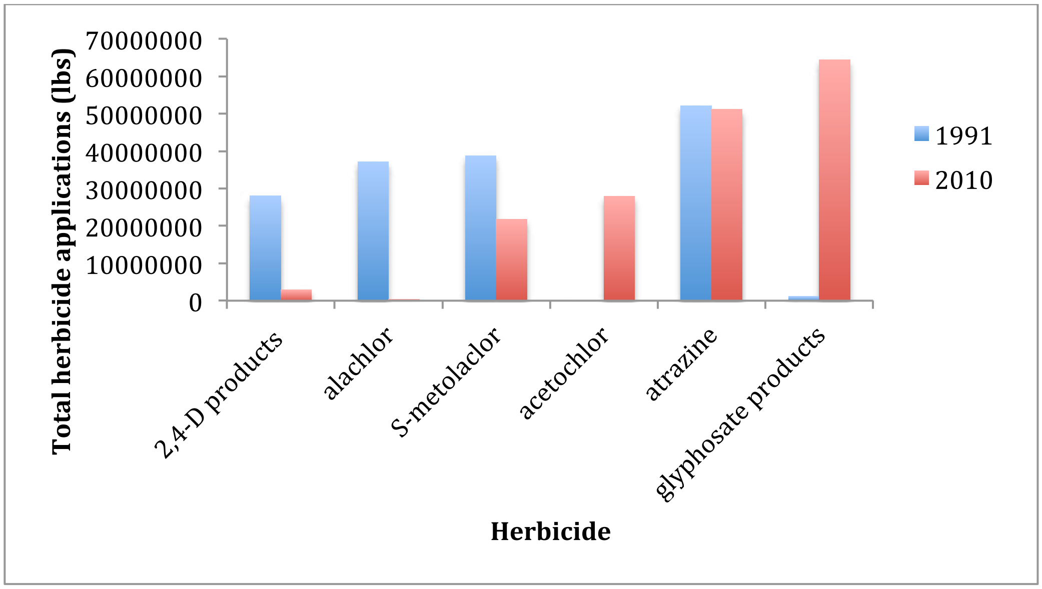

Figure 4. Total amounts of six major herbicides used for corn (NASS, 2011).

Increasing the use of non-chemical techniques is one potential avenue for reducing the amount of herbicides used on conventional corn farms. Corn farmers rely on a mixture of chemical interventions and non-chemical techniques for weed control. For conventional corn farmers, the top non-chemical pest management practices for corn production are described as no-till or minimum till for weed prevention (62% of acres), crop rotation (71% of acres in the past three years), weed scouting (88% of acres), and weed suppression using ground covers or mulches (34% of acres) (NASS, 2011). Organic corn farmers performed more weed prevention, suppression, and monitoring activities than conventional farmers. For example, organic corn farmers practiced crop rotation in the past three years on 84% of planted acres and scouted for weeds on 95% of acres. Despite the availability of non-chemical tools for weed management, the conventional corn farmers predominantly rely on herbicides to control weeds.

Federal and state atrazine regulation

Federal regulation

Atrazine was first registered for use as a pesticide in 1958 under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The EPA regulates atrazine under FIFRA at the state and federal levels, requiring any state laws to be equivalent or stricter than the federal standards. FIFRA mandates that all pesticides be registered with the EPA's Office of Pesticide Programs. This includes older pesticides that must go through the reregistration process. In order for a pesticide to be registered, the manufacturer must provide the pesticide's composition, a compliant label, evidence that the pesticide will perform its intended function without unreasonable risks to people and the environment, and that it will not cause unreasonable risk to the environment within the bounds of common use (Kubasek, 2002). However, many pesticides lack basic risk data.

If the EPA obtains information that a pesticide causes an unreasonable risk, action can be taken to cancel the registration or change the use. In order to begin this process, the EPA performs a review and then makes a decision for action if necessary. The EPA must prove that the chemical causes unreasonable risk to warrant cancellation.

Atrazine is also subject to regulation under both the Safe Drinking Water Act of 1974 (SDWA), which sets standards for drinking water quality, and the Clean Water Act of 1972 (CWA), which sets water quality standards for pollutants in surface water. Under the SDWA, the EPA sets a Maximum Contaminant Level (MCL) allowed in drinking water supplies for different chemicals based on the threats they pose to human health. The MCL for atrazine was set at 3μg/L in 1991. As a result of the 3μg/L standard, manufacturers voluntarily changed the labels for atrazine in order to reduce contamination. For example, label changes were made in 1993 that listed atrazine as a Restricted Use Pesticide; set limits for where atrazine could be mixed, loaded, and applied; reduced the quantity that could be applied at any one time; and eliminated non-crop uses (Cornell University, 2014).

In 1994, after new research was released about atrazine's potential to act as an endocrine disruptor, the EPA began a Special Review of atrazine to evaluate its risks as a potential carcinogen. In 2003, the EPA re-registered atrazine on the condition of watershed monitoring, evaluation of the risks to amphibians, and additional study of human cancer risks. Also in 2003, under the CWA, the EPA released a Draft Ambient Water Quality Criteria Document for atrazine, which proposed the freshwater aquatic life criteria concentration of atrazine to be 1,500 μg/L for acute exposure based on an one-hour average (EPA, 2003). This is equivalent to 1.5 ppm, substantially less strict than the well-water standard of 3 μg/L because it applies to aquatic species and not drinking water. The final version of the atrazine water quality document was expected in 2009, but has not been published as of 2014. In 2009, the EPA began a multi-year Special Review of atrazine that involved Scientific Advisory Panel (SAP) meetings to evaluate health risks and water monitoring studies. In 2013, the EPA began registration review for atrazine, and is expected to publish a registration decision in 2015.

As of 2014, the label for Aatrex 4L, a common commercial atrazine herbicide produced by Syngenta, sets the maximum application rates for the product based on soil type and plant residue coverage (Syngenta, 2014). There is a maximum application rate of 2.0 lbs. of active ingredient per acre for pre-emergence applications on highly erodible soils with 30% of the soil covered with plant residues at the time of planting. If there is less than 30% soil coverage with plant residue the maximum application rate is 1.6 lbs/acre. On not highly erodible soils, the maximum application rate is 2.0 lbs. per acre. For post emergence application, Aatrex can be applied up to 2.0 lbs. of active ingredient per acre as long as the total atrazine applied does not exceed 2.5 lbs. per acre per calendar year. The dose of atrazine and the soil type are two of the strongest predictor of whether atrazine will exceed the 3 μg/L drinking water standard (Stackelberg et al., 2012). For example, a model developed based on the USGS atrazine monitoring data suggests that the highest level of contamination is in areas of shallow groundwater in agricultural areas where high atrazine use levels are coupled with permeable soils and high groundwater recharge (Stackelber et al., 2012; Figure 5).

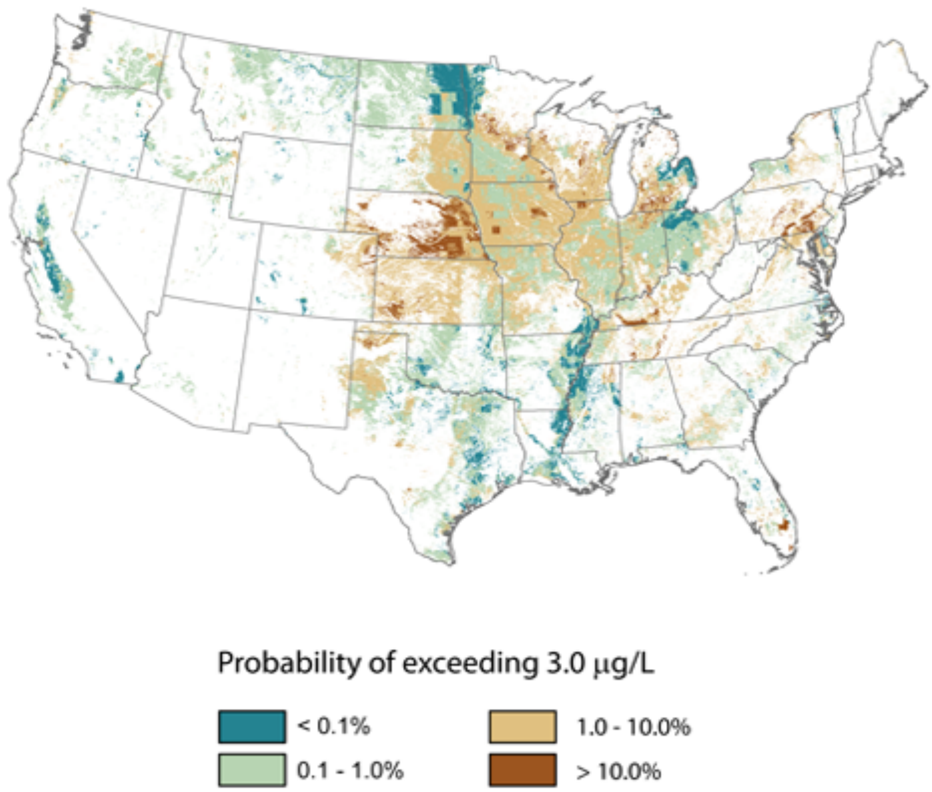

Figure 5. USGS model depicting the probability that atrazine plus deethylatrazine will exceed the drinking water standard (Source: Stackelber et al., 2012).

State regulation

Several states have adopted policies for managing atrazine, yet Wisconsin is the only state with a strict non-voluntary program (Table 2). State policies range in the type of policy tools used from voluntary Best Management Practices (BMPs) to strictly enforced atrazine prohibition areas.

Table 2. Atrazine management policies at the state level

U.S. State	Policy	Policy Type
Minnesota (Source: Minnesota Department of Agriculture, 2011)	BMPs are presented as a series of options and Integrated Weed Management is encouraged for all farmers • Limit total atrazine use to 0.8 lbs. of active ingredient per acre • Consider protective practices such as planted buffers and setbacks for vulnerable areas • Adopt conservation tillage • Rotate the use of atrazine with herbicides from different chemical classes	Voluntary
Nebraska (Source: Nebraska Department of Agriculture, 2012)	Encouragement of general IPM practices and specific atrazine BMPs • Incorporate atrazine as a pre-emergent application • Use in post-emergence only • Use banded applications (not broadcast) to reduce the amount applied by 50% • Use an alternative to atrazine	Voluntary
Illinois (Source: Illinois Environmental Protection Agency, 2014; McKenna and Czapar, 2009)	In the process of creating TMDLs for water bodies impaired with atrazine and simazine under the Clean Water Act. For example, the Draft Report TMDL for Spring Lake sets a goal of atrazine contamination reduction by 44%. The report suggests several BMPs such as: • Grassed waterways and buffers • Proper application rates and timing • Tank mix with other herbicides • Shallow incorporation to reduce run-off • Post-emergence applications • Band apply to reduce application area	Voluntary
Wisconsin	Legislation includes: • The creation of atrazine prohibition areas when levels exceed the standards • The reduction of application rates depending on the soil type and location	Mandatory

States have also attempted to ban atrazine. New York experienced problems with atrazine contamination and New York State Senate bill number S3531 was a statewide attempt to ban atrazine, however, it was unsuccessful (New York Senate, 2014).

Legislation and lawsuits

In addition to EPA's regulatory activities, Congress has attempted to ban or further restrict atrazine several times. In 2013, Representative Keith Ellison (DEM-MN) introduced a bill to ban atrazine (U.S. House of Representatives, 2013). The last action on this bill was its referral to the Subcommittee on Horticulture, Research, Biotechnology, and Foreign Agriculture in May 2013, and it has remained in that committee with no action ever since.

Environmental advocacy groups have also worked for further restrictions on atrazine. In 2011, the amphibian conservation group Save the Frogs collected over 10,000 signatures on a petition calling for the EPA to ban atrazine (Figure 6). The EPA responded by opening a 60-day public comment period, but the agency's Office of Pesticide Programs (OPP) ultimately denied the petition (EPA, 2011). OPP Director Steven P. Bradbury wrote that the petition had failed to note incorrect assessments in Past EPA findings regarding the safety of atrazine or identify new information that would warrant a different regulatory determination (Bradbury, 2011). The letter also draws attention to the risk-benefit decision making approach and requirement under FIFRA that in order to cancel a pesticide's registration, the EPA must make a determination that the use of the pesticide "generally causes unreasonable adverse effects on the environment . . . taking into account the economic, social, and environmental costs and benefits of the use of any pesticide" (Bradbury, 2011). Save the Frogs continues to work towards banning atrazine, calling it the 21st century DDT. A

2014 article in the group's newsletter exemplifies their characterization of the atrazine threat: “If you live in America, you are drinking and eating Atrazine,” the article declares. “And if you think your government is working hard to protect you from Atrazine, you are wrong! Take action, be proactive and don't depend on the government” (Kriger, 2014).

Figure 6. Save the Frogs poster for the petition to ban atrazine.

Cities in several states have also challenged the use of atrazine by filing lawsuits in response to atrazine contamination. In 2010, 16 cities in Kansas, Illinois, Indiana, Ohio, Missouri, and Iowa filed a lawsuit against atrazine manufacturer Syngenta in the U.S. District Court for the Southern District of Illinois. The lawsuit sought funds to recuperate costs the cities incurred for water monitoring, testing, and installing filtration systems because of atrazine contamination of the water supplies. The costs the cities incurred were over $350 million due to the installation of water treatment facilities. Two of the cities involved with the lawsuit found atrazine at 30μg/L, ten times the MCL, in the source water for their drinking water systems (Ivory, 2011). The case was ultimately settled outside of court in 2012 with Syngenta paying $105 million dollars to the plaintiffs. An attorney representing Syngenta, Michael Pope, stated that the settlement entails "10 years of peace" for Syngenta, a break in litigation related to atrazine contamination (Krajelis, 2012).

Wisconsin Case Study

Corn production in Wisconsin

Wisconsin grew 4.1 million acres of corn during the 2013 growing season (USDA, 2014). In 2012, the value of Wisconsin's corn production was calculated to be $2.76 billion, making corn the most valued crop in the state (USDA, 2013b). Most of the Wisconsin corn crop comes from Dane, Rock, Grant, Fond du Lac, and Marathon Counties (Wisconsin Agricultural Statistics Service, 2013). Planting dates range from late April to early June, with grain harvest beginning in October and silage harvest starting in September.

Atrazine has been used in Wisconsin since the late 1950s, peaking in 1985 (DATCP, 1992). Before atrazine became widespread, weeds were controlled primarily by mechanical cultivation (DATCP, 1992). Atrazine is used in Wisconsin in continuous corn production, and in alfalfa and corn rotations for dairy operations (DACTP, 1992). Atrazine was used on 62% of acres planted in corn and was the one of the most common herbicide used in Wisconsin in 2010 (NASS, 2014). This intensity of use— along with atrazine's persistence in groundwater and its solubility— is regarded as one of the main reasons atrazine contamination had become a serious problem by the 1990s (DATCP, 1992).

Pesticides and Groundwater Law

Groundwater protection in Wisconsin is vital to maintaining public health because over 95% of Wisconsin communities receive their drinking water from groundwater sources (US Geological Survey, 2008). The eventual creation of groundwater laws in Wisconsin, especially those concerning pesticides, involved several key actors. The institutions involved were DATCP and the Department of Natural Resources (DNR). On the environmental front, the Public Intervenor, Thomas Dawson, was crucial in his push for pesticide legislation.

The Public Intervenor was a unique and progressive feature of the Wisconsin State Government at the time. The office was created in 1967 for the purpose of protecting public rights regarding water and natural resources with the power to sue the Department of Natural Resources (DRN) if public rights were infringed upon (Interviewee 4, 2013). Dawson was appointed as the Public Intervenor in 1976 and reinvented the office so it would be a strong actor involved with environmental advocacy and the ability to intervene not only with matters involving the jurisdiction of the DNR but also with DATCP (Interviewee 4, 2013). The Public Intervenor's played an important role in the development of environmental laws until the funding for the office was for the most eliminated in 1995.

Researchers from the University of Wisconsin were influential in the discovery that herbicides were causing water contamination. Pesticide pollution in groundwater was not monitored nor was it a concern prior to the discovery of the pesticide aldicarb in groundwater in 1980. A team from the University of Wisconsin, the DNR, and the Portage County Community Human Services Department discovered water pollution from aldicarb, a toxic insecticide applied directly into the soil for potato crops. This was the first major incident of pesticide contamination of groundwater in Wisconsin. Dr. Byron Shaw, from the University of Wisconsin, found levels of aldicarb exceeding the drinking water standard in 5% of the 363 wells that were sampled. Shaw contacted Dawson after the discovery, and Dawson worked with an environmental reporter to make the news public. In 1981, an article appeared in the *Madison Capital Times* entitled, "Pesticide found in drinking water." This article described the discovery of aldicarb and how several families were being told to no longer use their well water (Associated Press, 1981b). There was extensive media coverage of the aldicarb pollution, which received much political notice. Researcher Byron Shaw described how the discovery of pesticides in water shifted public perception:

> Chemical contamination of groundwater is not new. Nitrate levels have exceeded the 10 μg/L drinking water standard in many wells for over thirty years. However, the pin that burst the bubble of trust was the discovery of pesticides in 1980. These disclosures caused the public to demand better protection of their groundwater supplies and resulted in Wisconsin groundwater legislation (Wisconsin Act 410) in 1984 (Shaw, 1985).

In 1981, Dawson and the environmental group Citizens for a Better Environment urged DATCP to perform an EIS studying the human health and environmental effects of pesticides prior to setting limits for pesticides like aldicarb (Madison Wisconsin State Journal, 1981). Aldicarb restrictions were put in place in 1982 by DATCP. These restrictions included a one year ban on its use in areas (moratorium areas) where groundwater was polluted beyond that safety limit of 10μg/L as well as restrictions on the quantity and timing of its use (Associated Press, 1982; Holden, 1985).

As a result of the aldicarb pollution and growing public concern surrounding groundwater contamination, a Special Committee on Groundwater management was created in January of 1982 by the Legislative Council to make recommendations for Wisconsin's groundwater policy (Patronsky and Bogar-Rieck, 1983). The Special Committee pushed for groundwater laws that were "hammered" out between the legislature, Wisconsin agriculture, businesses, and the environmental movement (Interviewee 4, 2013). The process of creating the groundwater law was considered difficult because of both the compromises needed from various stakeholders and because it was an unusual strategy for a state to create new environmental legislation without federal involvement. Rep.

Mary Lou Munts, the chairperson of the groundwater management committee, described the creation of the groundwater bill as “charting new territory,” because previous environmental laws had been created based on federal mandates (Stoeffler, 1983). Munts created a consensus based approach to the Special Committee meetings, which largely served as an opportunity for members from different stakeholder groups (agriculture, environment, and industry) to share information and make compromises that would eventually allow for the passage of legislation (Crowfoot and Wondolleck, 1990). Munts perceived the need for a groundwater bill to be supported by the agricultural sector in order for it to be politically feasible (Crowfoot and Wondolleck, 1990). In order to ensure that agricultural perspectives were being supported, Munts asked an influential farmer and an agricultural lobbyist to be part of the Special Committee (Crowfoot and Wondolleck, 1990). In addition to the farming sector, the environmental interests were represented by the participation of Thomas Dawson on the Committee (Crowfoot and Wondolleck, 1990). Dawson described the success of being able to create the Groundwater Rules as a result of communication and a shared environmental agenda: “We didn't have political gridlock. People talked to each other. The conservatives, liberals, and business leaders were all concerned about the environment” (Interviewee 4, 2013).

In May of 1984, Wisconsin passed the groundwater protection law, 1983 Wisconsin Act 410. At the time it was passed, some environmental groups opposed the law for not being strict enough. The groundwater protection law has several main elements (Wisconsin Groundwater Coordination Council, 2013):

- Establishment of groundwater quality standards
- Regulatory programs implemented by state agencies
- Aquifer classification
- Monitoring and data management
- Research
- Coordination among agencies
- Local groundwater management

Atrazine pollution became a known problem in Wisconsin after the creation of the Groundwater Law and the increased monitoring for pesticides in groundwater. The groundwater protection law provided the framework for how atrazine pollution management would be implemented. In July of 1983, DATCP created a list of 45 pesticides with the greatest risk for groundwater pollution, with the top 22 listed as high priority (Holden, 1985). The DNR began increased sampling and monitoring for these substances using a state funding allotment of $100,000 per year for the pesticide monitoring (Holden, 1985). Atrazine was not among the top 22 pesticides listed as high priority, but it was listed as part of the 45 substances to be monitored due to its high use (Ground Water/ Pesticide Surveillance Committee Subcommittee, 1983).

An important part of the groundwater protection law was the creation of water quality standards for different substances, outlined in Chapter NR 140 of the Wisconsin Administrative Code. The DNR set standards for substances of public health concern based on recommendations from the Department of Health Services. The groundwater standards have two parts, an Enforcement Standard (ES) and a Preventative Action Limit (PAL). The ES is a level that if exceeded requires intervention from the appropriate authority. In the case of pesticides, DATCP is required to intervene if levels exceed the ES. The PAL is a percentage of the ES; 10% of the ES for carcinogenic, mutagenic or teratogenic properties and 20% of the ES for all other substances. The intention of the PAL is for it to act as a trigger for intervention before a pollutant has become a serious risk to public health.

The creation of these standards was seen as a threat to the agricultural sector, and was contentious in the case of atrazine. One newspaper article reported, "the first ever ground water standards being proposed for a list of other chemicals could be a nightmare for many farmers, farm and chemical company spokesmen say" (Eggleston, 1986). In 1987, the Department of Health and Social Services recommended setting a standard of 1µg/L for atrazine (Wisconsin State Journal, 1987). In response to a proposed standard of less than 1µg/L, the Executive Director of the Wisconsin Agri-Business Council told the *Wisconsin State Journal*, "We absolutely can't afford these standards on workhorse agrichemicals in this state" (Wisconsin State Journal, 1987). There were a series of hearing held by the DNR on setting the standard for atrazine and other pesticides, with one meeting drawing about 400 agribusiness representatives (Eggleston, 1987). The DNR eventually set the ES for atrazine at 3.5 μg/L in the late 1980s. However, the 3.5μg/L standard was updated based on EPA national guidelines and the ES for atrazine, including its metabolites, is set at 3μg/L and the PAL is 0.3μg/L (DNR Chapter NR 140).

The Atrazine Rule

In 1984, after 15 months of groundwater monitoring of wells that were suspected of possible contamination, the DNR released a report that showed that 47 of 499 wells had detectable levels of pesticides (Smith, 1984). DATCP performed a study of 534 Grade A dairy farm wells checking for pesticides and nitrates (LeMasters et al., 1989). The DATCP report, which made the front page of the Capital Times newspaper, revealed that atrazine was possibly present in as much as 29% of the groundwater in the south-central part of Wisconsin (Blaska, 1989; Figure 7). This study found that 60 of the 534 wells had atrazine present and three wells were found to exceed the ES of 3.5 μg/L (Bjorklund, 1989). Thirty-nine wells exceeded the atrazine PAL of 0.35 μg/L, a trigger for intervention from DATCP.

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Dog's Best Friend trains pet owners
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BILLIKENS BEAT BADGERS:
Suddenly, the joy ride is over!
Dennis Punzel: Sports

NIT BASKETBALL:
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City Final

THE CAPITAL TIMES

Tuesday afternoon, March 21, 1989 — Madison, Wisconsin — 35¢/50¢ outside Dane County

Study: Atrazine may taint 29% of area rural wells

By DAVID BLASKA
Capital Times Staff Writer

As many as 12 percent of the drinking water wells in rural Wisconsin could be contaminated with atrazine, a commonly used agricultural herbicide.

The level of contamination in the south-central part of the state, including Dane County, could be as high as 29 percent, according to an ambitious state study — the first of its kind in the nation — that is still under way.

Officials from the state Department of Agriculture, Trade and Consumer Protection stress that the final numbers could change before a complete report is presented to its board of directors on April 12.

Atrazine is considered a carcinogen. But department officials stressed that the state's food supply is not in danger. The substance does not accumulate in milk or meat.

"We found a lot more than we anticipated," said Deputy Agriculture Secretary Helene Nelson.

The study also found something that was expected — nitrates — in 7 percent of the samples. Nitrates are a byproduct of chemical fertilizers, manure, and naturally decomposing vegetative matter.

State agriculture department officials said the south-central reporting region, encompassing Dane, Columbia, Rock, Green, and Jefferson counties, may have the highest occurrences of atrazine because the region is one of the heaviest corn-producing areas in the state.

Atrazine, also sold under the trade name of Aatrex, is one of the most commonly used and inexpensive chemicals on today's farms. The herbicide has been used for about 25 years, almost exclusively on corn to control broadleaf weeds.

The study checked for nitrates and 40 kinds of pesticides on 534 Grade A dairy farms chosen at random throughout the state. Dairy

Please see ATRAZINE, Back Page

What is the risk of 3.5 ppb of atrazine in your water? If a million people drink one liter of that water a day for 70 years, one person will develop cancer due to the contaminant.

Figure 7. Front-page news article about atrazine contamination in Wisconsin. Source: (The Capital Times, 1989).

The discovery of the tainted dairy wells prompted DATCP to perform further tests and create restrictions. In 1990, DATCP took action to control atrazine pollution by issuing an order for four farmers in the Spring Green region of the Lower Wisconsin River Valley, the river terraces and flood plain on either side of the Wisconsin River (Figure 8) to discontinue the use of atrazine or face daily penalties (Blaska, 1990). The 1990 Spring Green atrazine ban was implemented because DATCP found levels of atrazine that were much greater than 3.5µg/L, in one case a well had 19 µg/L. One farmer in the area where atrazine was banned stated it would cost $4 more per acre to use different herbicides (Milwaukee Journal, 1990). A committee was organized to create more comprehensive atrazine rules, and on April 1, 1991, the Wisconsin Atrazine Rule, Wisconsin Administrative Code Chapter ATCP 30 Pesticide Product Restrictions Subchapter 8, went into effect (Waunakee Tribune, 1991).

The 1991 rule 1) reduced allowable statewide application rates from 4.0 pounds/acre to 2.0 pounds/acre, 2) designated the Lower Wisconsin River Valley, as an atrazine management area with maximum application rates of 0.75 pounds/acre, and 3) created six atrazine prohibition areas in the Lower Wisconsin River Valley (Postle et al., 1997). In addition to these three main restrictions, atrazine was prohibited for non-crop uses, the applications were restricted to April 1 to July 31, and all applicators were required to keep records of atrazine use (Wisconsin Administrative Code Chapter ATCP 30). To inform the approximately 40,000 Wisconsin corn farmers about the Atrazine Rule, DATCP produced fact-cards, posters, and brochures and worked with the USDA, University of Wisconsin Extension services, and with chemical company representatives to distribute information on the new rules (Waunakee Tribune, 1991). In 1992, the US EPA acting under the Safe Drinking Water Act, set the maximum contaminant level (MCL) for atrazine in drinking water at 3 μg/L (EPA, 2014d). The MCL set by the EPA caused a change in the Wisconsin atrazine ES to be reduced to 3 μg/L, which includes atrazine as well as its breakdown products, and the PAL to 0.3 μg/L.

One of the most salient parts of the atrazine rule is the creation of PAs, zones where no atrazine can be applied, in areas where the PAL is exceeded. Throughout the early 1990s, DATCP increased the number of PAs, with the greatest increase in the number of PAs in 1993 with 45 new PAs. In addition to increasing the PAs, DATCP lowered the statewide allowable application rate for atrazine to 0.75 lbs./acre for course soils and 1.5 lbs./acre for medium and fine soils in 1993 (Postle et al., 1997; DATCP, 2014).

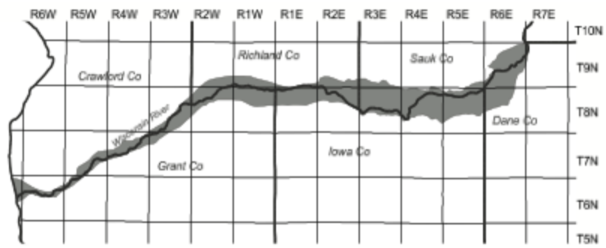

Figure 8. The Lower Wisconsin River Valley. The areas shaded grey is the PA for the Lower Wisconsin River Valley. Source: ATCP 30, Appendix A, Wis. Adm. Code

Prohibition Areas

There are several steps involved with the creation of new PAs that are outlined by DATCP (DATCP, 2014). If a well is found to contain a level of atrazine and its metabolites exceeding the ES of 3μg/L, a follow up environmental investigation is required. The environmental investigation includes well water testing, an inquiry into farming practices and hydrological characteristics. If the environmental investigation finds that continued atrazine use would result in additional groundwater contamination, a PA is proposed. When a new PA is proposed, it is vetted before a board before being taken to public hearings where stakeholders can provide comments on the proposed rule. DATCP creates a final PA rule proposal considering the public comments and recommendations of the staff that undergoes legislative review and is subsequently published (DATCP, 2014).

In 2014, there were 102 PAs in Wisconsin totaling approximately 1.1 million acres (DATCP, 2008; Postle, 2014; Figure 9). These PAs range from 500 – 500,000 acres, and the size of the PA depends on the number of contaminated wells in the region (DATCP, 2011). Dane County is the county with the most acreage in PAs with 531,830 acres of land belonging to PAs (US Geological Survey, 2014b; Figure 10). Dane County, home of Wisconsin's capital city of Madison, is also an area of intensive dairy livestock and corn production (Bohn, 1993). The Rural Well Survey of 1990 found that 50% of rural wells in Dane County had detectable levels of triazines, and this widespread contamination led to the creation of extensive PAs in the county (Bohn et al., 1993; Milwaukee Journal, 1990).

Figure 9. Map of Dane County, Wisconsin with atrazine PAs shaded grey. Source: ATCP 30, Appendix A, Wis. Adm. Code

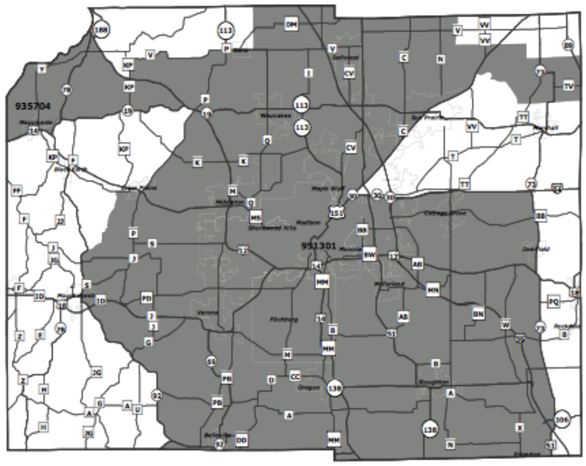

Figure 10. Map depicting atrazine PAs in Wisconsin. Source: ATCP 30, Appendix A, Wis. Adm. Code

In 2010, there were 3.9 million acres of corn planted in Wisconsin (Postle, 2014). One might think that with PAs covering 1.1 million acres, one fifth of corn acreage could potentially be in PAs. However, PAs are not entirely composed of farmland or areas of corn production. For example, in 2011, of the 1.1 million acres in PAs, only 260,000 acres were in corn production (Postle, 2014). Although the PAs might cover a large number of acres, in actuality the 260,000 acres in PAs planted in corn only makes up 6.6% of the total corn acres in Wisconsin (Postle, 2014). Although the corn acres in PAs where atrazine use is currently forbidden are some of the areas most vulnerable to groundwater contamination, they only make up a small percentage of the total number of corn acres planted statewide (Postle, 2014).

Environmental groups have been critical that the use of PAs is insufficient for controlling the atrazine problem. In 1995, the Public Intervenor's Office was planning to sue DATCP in order to ban atrazine statewide. However, before a total ban on atrazine could be pursued, conservative Wisconsin Governor Tommy Thompson abolished the Public Intervenor's Office due to the Public Intervenor being "a thorn to Thompson and business interests on a variety of issues from transportation to pesticides" (Ivey, 1996).

Impacts of Wisconsin's atrazine restrictions

- How have Wisconsin corn farmers complied with restrictions on atrazine? What is being used instead?

Herbicide Use Trends

The NASS houses the Agricultural Chemical Use program, which since 1990 has collected data on chemical ingredients applied in agriculture using surveys with US farmers. Annual data on pesticide use in corn are available from 1990 until 2003. After 2003, the Chemical Use Program began rotating surveyed commodities, and data on chemical use in corn were not collected again until 2005 and 2010. Although there are gaps, this data set allows for analysis of the trends of herbicide use in corn in Wisconsin from the time atrazine restrictions began in the early 1990s until 2010.

Atrazine use

Application rate

The Atrazine Rule reduced the allowed application rate, which immediately reduced the average application rates used by farmers. The application rate at which atrazine is used is considered to be one of the most important factors as to whether atrazine and its metabolites will become a problem for groundwater, a concept that influences DATCP's limits on use rates (Hanson et al., 1997). In fact, the USGS used application rate as the strongest predictor for water quality problems in its atrazine pollution model (Stackelberg et al., 2012). In 1990, Wisconsin corn farmers were using atrazine on 58 percent of corn acreage at a rate of 1.29 lbs./acre (NASS, 2015). That translates to a total of 2,790,000 pounds of atrazine applied to the 3.7 million acres in corn production. However, historic rates were likely higher (Wisconsin Statistical Reporting Service, 1971). For example, DATCP recorded one farm's historical application rates exceeding 5 lbs./acre (DATCP Archive, 1992). In 1961, 5 lbs./acre was actually the rate recommended by at least one county agricultural agent for fields in continuous corn production in 1961 (Buchholz, 1961). In 1991 the first year of atrazine regulation in Wisconsin, there was a sharp decline in the average application rate from 1.29lbs/acre to 1.01 lbs./acre as well as a decline in the extent of its use (to 52 percent of corn acres). This was in spite of the 100,000 additional corn acres planted that year. The initial reduction in application rate continued, with some outlying years, and atrazine was used at its lowest recorded rate in 2010 at 0.71lbs/acre (Figure 11).

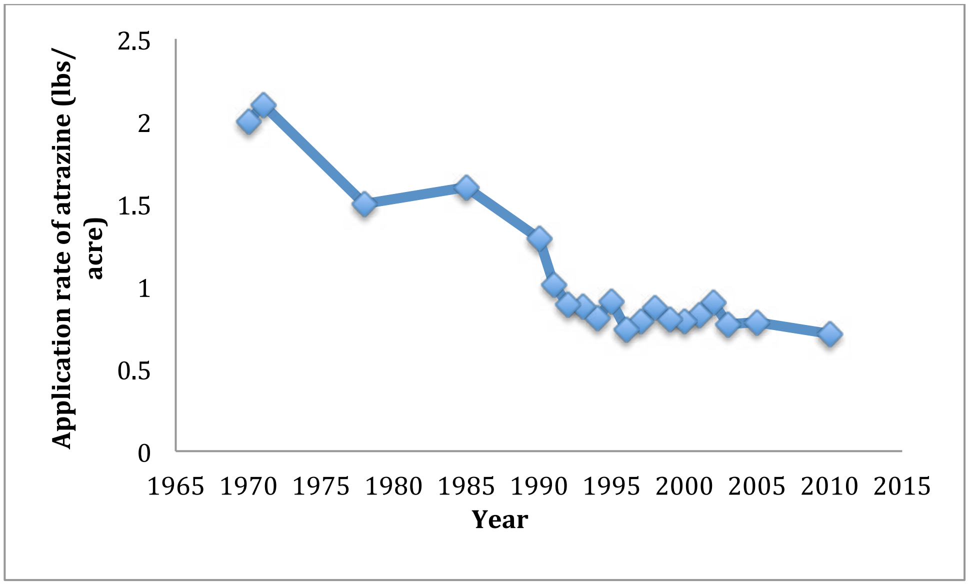

Figure 11. Mean application rate of atrazine for corn in Wisconsin from 1970-2010 (NASS, 2015; Wisconsin Statistical Reporting Services, 1971).

The DATCP has periodically performed its own evaluations of the atrazine rule. DATCP has three different well sampling programs to monitor groundwater for changes in atrazine concentration (Postle et al., 1997). A 1997 report on the findings of these programs evaluates the trends in how much atrazine was used, how effective the PAs have been, and how water quality changed over time. The report found that there was a reduction on 73% of total applications in Wisconsin from a peak of 5.17 million pounds in 1985 to 1.39 million pounds in 1996 (Postle et al., 1997). The reasons for such a decline are listed as: a) the implementation of DATCP's Atrazine Rule, b) farmers' concern about atrazine remaining in the soil and harming the crops of the subsequent year, c) farmers' concern regarding water pollution, d) the availability of atrazine alternatives e) shifts to growing other crops f) conversion to growing practices that use fewer chemicals, g) the need to use other herbicides because of atrazine's ineffectiveness for certain types of weeds (Postle et al., 1997).

Area treated with atrazine

The percent of corn acres treated with atrazine has fluctuated over the years. After regulation began in 1991, there was a dip in the percent of acres treated from 58 percent in 1990 to 52 percent in 1991. In 1997, 64 percent of corn acres were treated with atrazine, the highest on record, and in 1999, only 37 percent of acres were treated, the lowest on record. The most recent trend is an increase in the percent of acres treated, with 62 percent treated in 2010, up from 54 percent in 2005 (Figure 12).

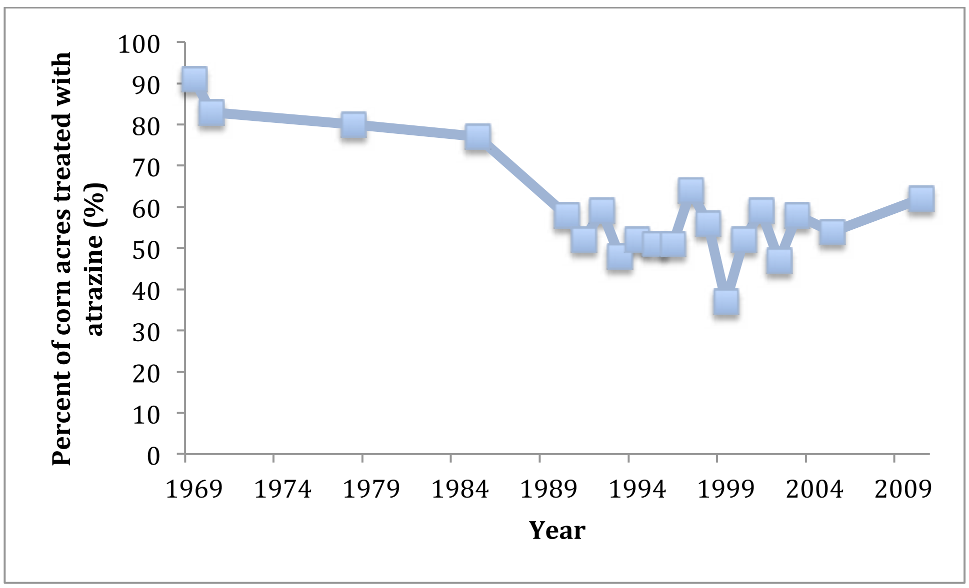

Figure 12. Percent of acres planted with corn treated with atrazine in Wisconsin from 1990-2010 (NASS, 2015).

Due to the decreased application rate and the only slight increase in the percent of acres on which atrazine is used; there have been overall decreases in the total amount of atrazine used in Wisconsin corn. From 1990 to 2010, the total atrazine applied in Wisconsin has decreased from 2,790,000 lbs. to 1,627,000 lbs. for an overall reduction of more than one million pounds (Figure 13). This reduction highlights that although the amount of corn planted has increased over the past twenty-five years, the overall amount of atrazine use has decreased.

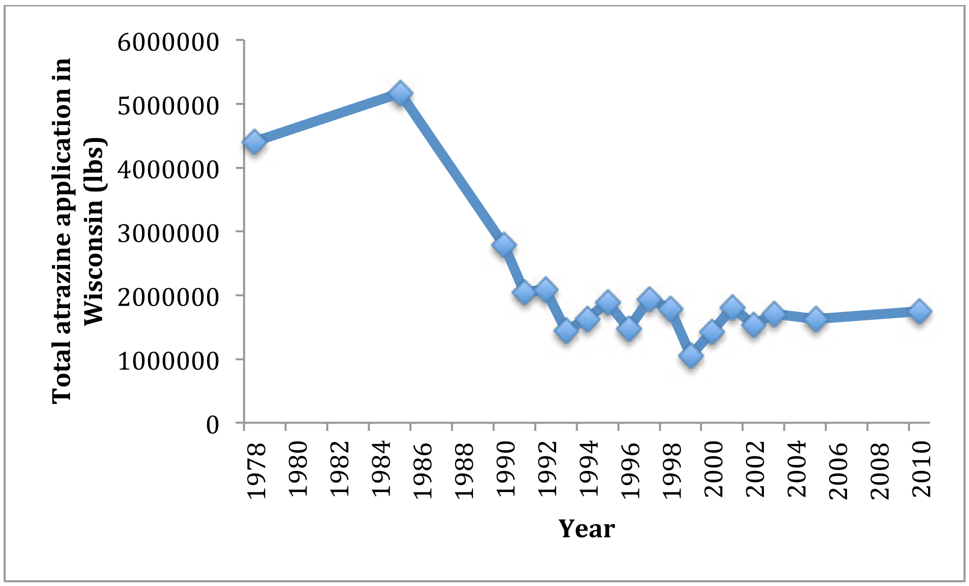

Figure 13. Total atrazine applications in Wisconsin (Source: NASS, 2015).

The reduction in the total atrazine used in Wisconsin seems to be greatly correlated with the reduction in application rate. The reduced application rate was most likely a result of lowered allowable rates and the availability and use of other products. The DATCP evaluation of 1997 stated that the reduction in the application rate observed in the early 1990s was due to using atrazine in combination with other herbicides, applying it in a band over the row, and using more mechanical weed control (Postle et al., 1997). Farmers were aware of the pollution caused by atrazine, and also feared the possibility that the government would completely take away the ability to use atrazine. Farmers voluntarily reduced atrazine in order to avoid stricter regulations. In addition, Postle et al. (1997) described the reduction in use as being attributed towards fear that atrazine could damage the following year's crop, concern for the environment, availability of alternatives, conversion to practices requiring less herbicide, and finding other solutions to weed problems not controlled by atrazine.

It is surprising that the PAs made little difference in the percent of acres treated with atrazine from 1990-2010. Postle et al. (1997), document a sharp decline in the percentage of acreage treated with atrazine from 1985 to 1996, but this decline cannot be attributed to the atrazine rule considering that most of the decline occurred before the atrazine rule went into effect. Considering that 30.8% (1.2 million of the 3.9 million) acres planted with corn are now in PAs, it was expected that the percent of acreage treated with atrazine would have decreased instead of increasing by four percent over the period of 1990-2010 (NASS, 2015).

Comparison with other states

A comparison with neighboring corn growing states Illinois, Indiana, Iowa, Michigan and Minnesota provides insights into whether the policies in Wisconsin have led to different pesticide use patterns. These states were selected because they have been historically used for comparison. Wisconsin, Michigan, and Illinois all experienced a reduction in the percent of planted corn area treated with atrazine from 1990 to 1995, whereas Iowa and Minnesota experienced increases over that time period (Figure 14). All states except for Illinois, which experienced a 17% increase, experienced little changed between 1995 and 2005 in the percent of corn acres treated. From the period of 2005 to 2010, Illinois, Indiana, Michigan and Minnesota all experienced decreases in the percentage of acres treated with atrazine, whereas Wisconsin and Iowa have experienced increases. Like Wisconsin, Iowa has seen an overall increase in the percent of acres planted in corn that are treated with atrazine. However, Iowa increased from 58% to 65% from 1990 to 2010, an increase of 8% of planted acres, whereas Wisconsin only increased by four percent over the same time period (NASS, 2015). The state that stands out from the others is Minnesota, which has a historically smaller atrazine usage compared with the other states and experienced a decrease of 20% of the area treated with atrazine from 2005 to 2010.

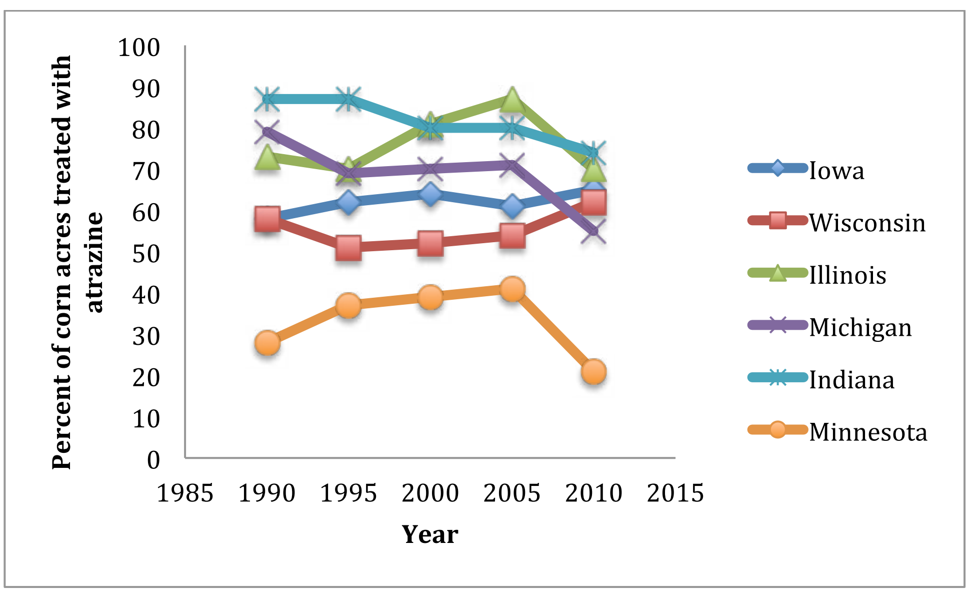

Figure 14. Comparison of the percent of acres treated with atrazine from 1990 to 2010 in Iowa, Wisconsin, Illinois, Michigan, Indiana, and Minnesota (Data Source: NASS, 2015).

Over the period of 1990-2010, the application rate for atrazine has declined for all six states used in this comparison (NASS, 2015) (Figure 15). Wisconsin is remarkable from the other states because Wisconsin had one of the highest atrazine application rates at 1.29 lbs./acre in 1990. This rate has been reduced to 0.714 lbs./acre in 2010, for a total reduction of 0.576lbs/acre from 1990-2010. Michigan followed a similar trajectory, reducing the application rate from 1.3 lbs./acre in 1990 to 0.794 lbs./acre in 2010. Minnesota has also shown a dramatic reduction from 0.98lbs/acre in 1990 to 0.477 lbs./acre in 2010. Illinois, Iowa, and Indiana all showed reductions, but not at the same magnitude as the other states. Minnesota is unique in the relatively low average application rate used in 2010 (NASS, 2015).

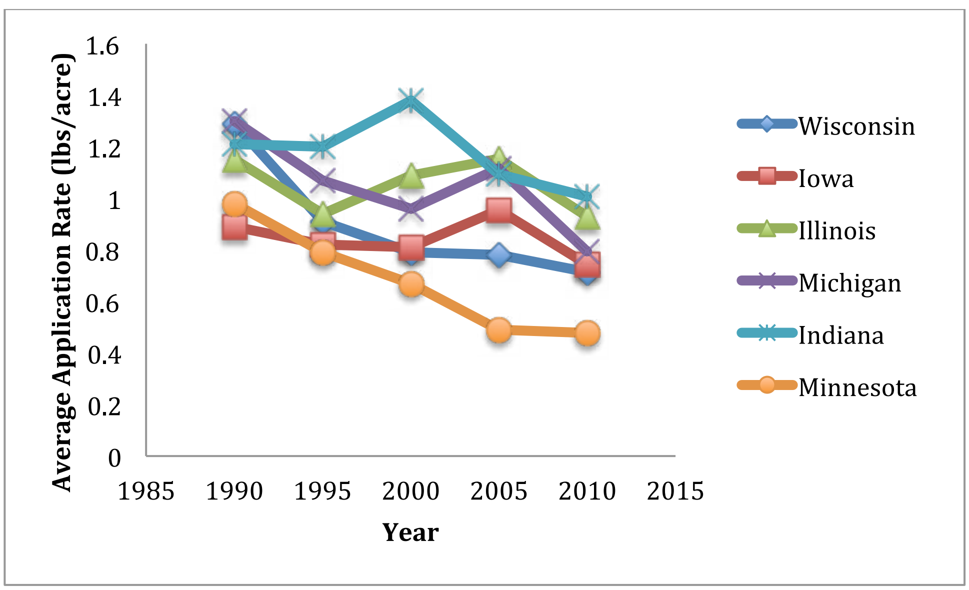

Figure 15. Comparison of average atrazine application rate from 1990 to 2010 in Iowa, Wisconsin, Illinois, Michigan, Indiana, and Minnesota (Data Source: NASS, 2015).

Use of alternative herbicides in Wisconsin

The use of alternatives to atrazine was recommended by DATCP officials beginning with the atrazine rules of 1991. Alan Tracy, Secretary of DATCP at the time urged farmers to adopt alternatives: "Corn farmers should seriously consider this growing season as a transition period for using alternatives to atrazine" (Tracy, 1992). DATCP encouraged farmers to seek recommendations for alternatives from the University of Wisconsin extension offices, agrichemical dealerships, and private agricultural consultants (Tracy, 1992). Over the period of 1990-2010, there have been two main changes to the way corn is grown: the use of genetically modified herbicide tolerant corn seeds and the increased use of minimal or no-tillage farming systems. Specifically, the introduction of Roundup Ready corn marks a shift to reliance on glyphosate herbicides. In addition to the availability of GMO corn, other herbicides such as acetochlor became available weed control tools in the mid 1990s. For example, acetochlor, a selective herbicide for broadleaf weeds and annual grasses, was granted registration in 1994 by the EPA in an effort to reduce the use of atrazine and other herbicides in corn (EPA, 2009).

For the purposes of this analysis, I evaluated trends for six major herbicides, alachlor, atrazine, acetochlor, dicamba, glyphosate, and s-Metalochlor over the period of 1990-2010 in Wisconsin corn. All of these herbicides are primarily used for pre-emergent weed control. In terms of the percent of acres planted with corn that are treated with atrazine, the percentage has remaining fairly constant between 50 and 60%, except for 1999. The use of acetochlor, introduced in 1994, has steadily increased from 2% in 1994 to 37 percent in 2010. Dicamba, increased from 17% in 1990 to a peak of more the 50% in the late 1990s, but has since experienced a decline in use and was only used on five percent of the acres in 2010. Alachlor experiences a steady decrease from a peak use on 30% of acres in 1993 to not being used in the late 2000's. s-Metalochlor has increased in use from being used on 16 percent of acres in 1990 to 32% in 2010 (for this analysis metalochlor and s-metalochlor were grouped together if both were used in the same year). Glyphosate and later glyphosate isopropylamine salt have increased from being used on 4% of corn acres in 1990 to 47% in 2010. Because Roundup Ready corn comprises 85% of corn planted, the amount of glyphosate has most likely increased from 47% since 2010. Overall, since 1990, the acres treated with atrazine, acetochlor, glyphosate and s-metalochlor have all increased (Figure 16). Alachlor and dicamba are the only herbicides that experienced a decline in use.

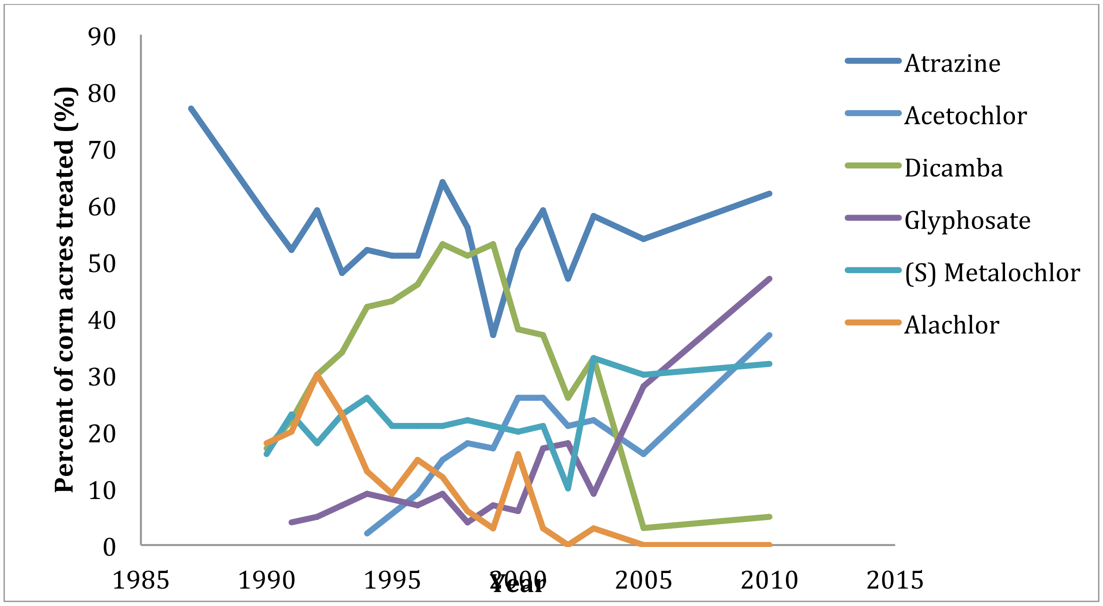

Figure 16. Percent of corn acres in Wisconsin treated with different herbicides (Source data: NASS, 2015).

The 2010 Survey of Weed Management Practices in Wisconsin's Atrazine Prohibition Areas asked farmers what were the top three herbicides used as atrazine alternatives in terms of the number of acres on which each herbicide was applied (DATCP, 2011). The predominant atrazine alternative was glyphosate, with 92 of 102 respondents (90%) listing it as one of their top three. Twenty-two percent of farmers listed s-Metolachlor, 21% listed mesotrione, 19% listed acetochlor, 10% listed dicamba, 10% listed clopyralid, 10% listed flumetsulam, 6% listed 2,4-D, 4% listed tembotrione, 4% listed diflufenzopyr, 4% listed a product that contained atrazine unbeknownst to the farmer, and 2% listed simazine (DATCP, 2011).

The 2010 survey also compared how prevalent different herbicide use was inside and outside of PAs for the top six herbicides used (DATCP, 2011). They asked farmers inside PAs to calculate the percent of their acres treated with each herbicide as well as the application rate used, and then compared the herbicide data from within PAs to statewide data from 2010. Below is a reproduction of Table 8 from the DATCP report with the addition of values for atrazine from NASS (Table 3).

Table 3. Comparison of area treated and application rate of active ingredient for seven major herbicides both inside and outside of PAs in 2010 (Source: DATCP, 2011).

Herbicide	Area applied inside PAs (%)	Area applied outside PAs (%)	Application rate per crop year inside PAs (lbs./acre)	Application rate per crop year outside PAs (lbs./acre)
Glyphosate	0.48	0.51	1.08	0.97
S-Metolachlor	0.24	0.26	1.34	1.39
Clopyralid	0.23	0.25	0.14	0.12
Acetochlor	0.18	0.26	1.49	1.78
Mesotrione	0.2	0.27	0.12	0.13
Flumetsulam	0.23	0.25	0.053	0.043
Atrazine	0	0.62	0	0.71
TOTAL	**1.56**	**2.42**	**4.223**	**5.143**

In order to approximate the how much herbicide is used on the average corn acre inside and outside of PAs, the application rate for each herbicide was multiplied by the percent of acres treated. The results show that overall for the seven herbicides used for this analysis, herbicide use was heavier both in terms of the application rate and the number of acres for corn grown outside of PAs.

The average total application rate for all seven herbicides inside PAs was 1.18 lbs./acre of active ingredient (2.2 lbs./acre commercial product) as compared with 1.83 lbs./acre active ingredient (3.5 lbs./acre commercial product) outside of PAs. Acres inside PAs experience a reduction of pesticide application rate by 36% for the seven major herbicides (Figure 17).

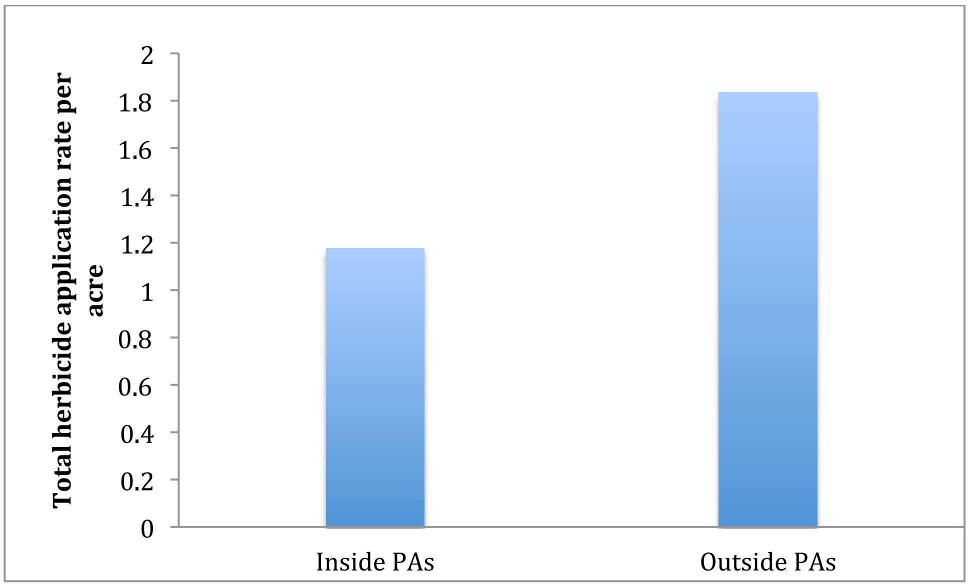

Figure 17. Comparison of the total application rates for glyphosate, s-Metolachlor, clopyralid, acetochlor, mesotrione, flumetsulam, and atrazine inside and outside of PAs.

It is a surprising finding that the percent of corn acres treated with these various herbicides have all increased except for dicamba. The decline in alachlor right after its peak in 1993 may be due to the introduction of acetochlor in 1994, which was specifically meant to reduce the use of alachlor. It seems that perhaps the more recent increases from 2005-2010 could be due to new problems with herbicide resistant weeds.

Diversity of major herbicides

Fluctuation in the diversity of types of herbicides used each year from 1990-2010 allows for insights into the diversity of products used and reliance on particular weed control strategies. For example, if after atrazine legislation went into effect, farmers experimented more with alternatives, the number of herbicides of significant use would increase. Farmers often state the importance of not losing an active ingredient because the range of tools available would decrease and cause over-reliance on only a few products. Over-reliance on a few products can lead to herbicide resistant weeds or super weeds that are difficult to control. I evaluated the number of herbicides used on 15% or more of corn planted from 1990-2010. 15% was selected as a level to represent significant use. For example, in 1990 alachlor, atrazine, cyanazine, dicamba, and metalochlor were each used on more than 15% of the acres planted with corn. The diversity of products used peaked from 1999-2001 when nine herbicides were used on more than 15% of corn acres. This number has since decreased, and in 2010 seven herbicides were used at significant levels. In 1990, none of the significant use herbicides were post-emergent herbicides. In 1994, nicosulfuron use increased to above 15% and from 1994 to 2003 one or two post-emergent herbicides were used on more than 15% of the acres. However, no post-emergent herbicides were used at the 15% acreage threshold in 2005 or 2010.

Farmer Attitudes and Compliance

DATCP field inspectors are responsible for enforcing the Atrazine Rule. Inspections from 1991, the first year of the rule, showed broad compliance (DATCP/ARM, 1992). Reports evaluating the Atrazine Rule from the 1990s conclude that because there is little new atrazine contamination, farmers have followed the guidelines of the Atrazine Rule and complied with the non-use mandates within PAs (Postle et al., 1997). Water quality tests from 1996 showed a reduction in atrazine in some wells within PAs, but constant levels of propylatrazine, a metabolite produced by simazine and/or cyanazine (Postle et al., 1997). The constant levels of propylatrazine led researchers to surmise that although atrazine use was curtailed, its use had been replaced by that of other triazines (Postle et al., 1997).

With few exceptions, compliance with the Atrazine Rule and atrazine ban in PAs is considered to be extremely high. Wolf and Nowak et al. (1992) performed a study with farmers and found that 98% of farmers were complying with the Atrazine Rule.

There have been several accounts of willful atrazine use within PAs. In the early years of the Atrazine Rule, complaints about atrazine use within PAs led DATCP to investigate several farmers (Postle et al., 1997). For cases where there was a willful breach of the Atrazine Rule, farmers were taken to court and forced to pay fines (Postle et al., 1997).

In 2008, farmers from a 2,800-acre farm operation in Columbia and Dane counties were fined $14,000 in penalties for illegally using atrazine within a PA

(Wisconsin Agriculturalist, 2008). DATCP investigators used evidence from sales receipts from pesticide distributors to confirm that the atrazine use was intentionally taking place (Wisconsin Agriculturalist, 2008).

DACTP periodically reminds farmers of the Atrazine Rule through outreach activities and has encouraged farmers to check product labels to make sure they do not contain atrazine (Associated Press, 2011). For example, DATCP official Stan Senger stated that many premix herbicides contain atrazine even though farmers may not be aware of its presence due to the name alone (Associated Press, 2011).

Many farmers were initially willing to have their well water tested because farmers also want to know about pollutants in their families' drinking water (DATCP/ARM, 1992). However, having a well tested also comes with the risk that a PA could be created if the atrazine level exceeds the ES.

Farmer survey

In 2010, the USDA National Agricultural Statistics Service (NASS) performed a survey with 102 Wisconsin corn farmers located inside PAs in order to assess weed management practices and farmer perspectives on atrazine regulation (DATCP, 2011).

The survey asked if atrazine use was legal if farmers would use it. Forty-one percent of respondents said they would use it, 33% they would not use atrazine, and 25% stated they were unsure (Figure 18) (DATCP, 2011).

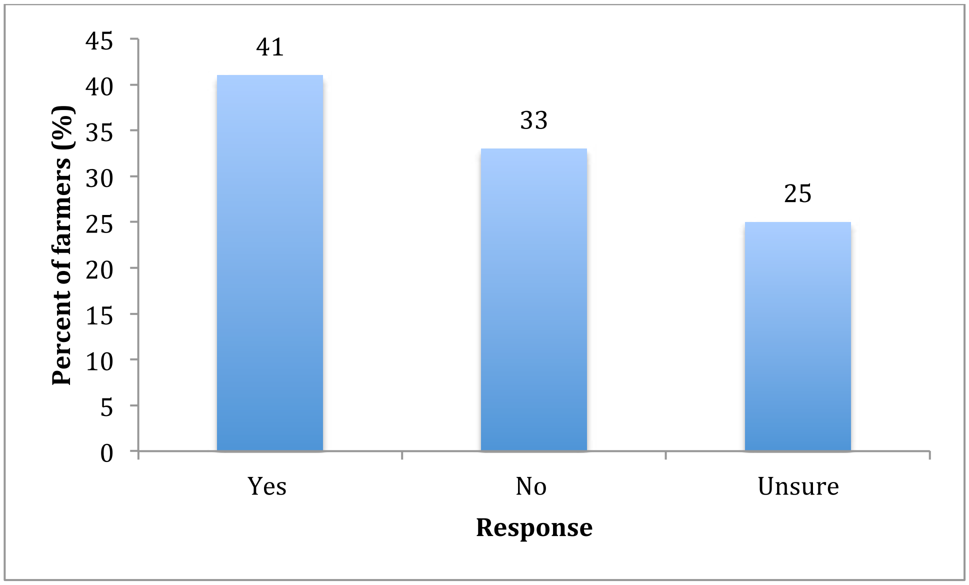

Figure 18. Percent of farmers who would like to use atrazine (source: DATCP, 2011).

An assessment of the relative difficulty of growing corn in PAs was carried out by asking a series of questions to 38 farmers with farmland both within and outside PAs. Of these farmers, 50% of the sample responded that it was not more difficult to grow corn within a PA, 32% responded that it was somewhat more difficult, and 7.9% stated that it was much more difficult (Figure 19) (DATCP, 2011).

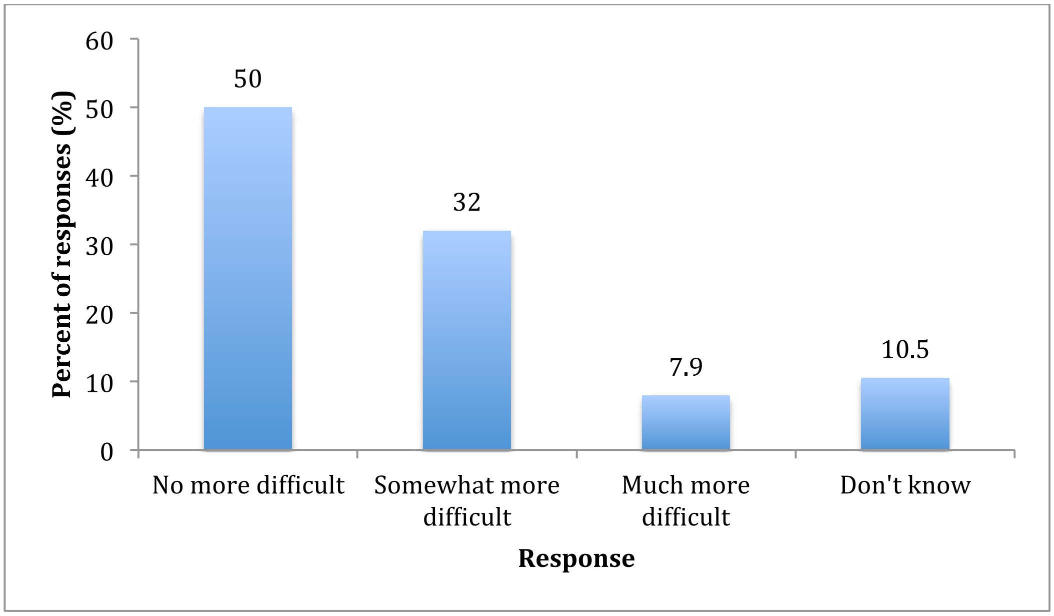

Figure 19. Farmers' assessment of the difficulty of not using atrazine (DATCP, 2011).

Thirty-nine respondents (40%) stated they spend more money controlling weeds on corn within PAs, and 39% stated they did not spend more money (21% stated they did not know) (DATCP, 2011). Only two of the 38 farmers (5%) reported that they experienced a reduction in yield for corn grown within a PA compared with their fields outside of PAs.

The survey asked participants the open-ended questions of: "What do you think about PAs and growing corn inside PAs?" (DATCP, 2011). The question was extremely broad and produced a variety of responses ranging showing both favorable and critical attitudes. The answers to the question can be grouped into categories (Table 4).

Table 4. Attitudes about growing corn in PAs (source: DATCP, 2011).

Category	Response	#
General dissatisfaction with PAs	• Work around it. • Atrazine is not a problem if atrazine is not abused by farmer. • It's not fair – we are restricted and people nearby aren't. • They should do away with PAs. So people could use anything within reason. • Should have no problems if atrazine is used correctly. • PAs should be eliminated.	5
Reduced weed control	• Didn't have to battle weeds that badly when we could use atrazine – it had residual effect. • Real problem with giant ragweed. Goes back to products advertised nationally that he can't use – says he doesn't like to have all the tools in the toolbox not available to him. • Should be able to use a small amount of atrazine to control weeds. • Last four years its been easier since Roundup, but I need to change my herbicide program soon and I want there to be something else available.	4
Economic impacts	• Spray cost more inside the PA than outside of it • More expensive. More work. • Atrazine was very effective. It has affected economically. • Slightly more costly. • More costly • Not a change except cost. • It raised the cost of production.	7
Neutral opinion	• Think of it not very much • Didn't think much of it. • Don't know, already a PA when I started farming. • A rule we had to follow. • Doesn't make a difference to me. • Haven't thought about it. • Too busy to worry about it. • I don't know what difference it makes. • Doesn't make any difference. It would be nice to know what the atrazine levels are and if they changed since PA came. • We treat everything the same (inside and outside PAs). • Any product used as long as atrazine is going to show up (in water) – too long of a shelf life • Doesn't matter, used herbicides other than atrazine before the PA. • Not very much, too many people over-use it. • Make do with it. • Don't care. • I know that it was cheap. I have never used it! • Not really a concern at this time. • No difference between the two (PA and non PA). • Don't think there is any problem with the PAs. • Area probably needs to be retested to see if there is still a concern.	23

	He feels there might be no concern anymore. • More study needed. • Haven't thought about it. • Doesn't really influence his operation.	
General favorable attitude	• I think some farms used too much atrazine. • Didn't use atrazine before so it doesn't make any difference. It's good to have PAs. • Advantage • I haven't used atrazine so I can guess that there is a good reason not to use it. • Good idea. • Lot easier without atrazine because I can direct seed alfalfa. • In PA you can grow fall winter wheat or rye which is harvested early and can be a form of weed control and it gives you another crop in the same field. • Good idea to prohibit. • Glad atrazine not used in restricted areas. • I suspect that there was a good reason to ban atrazine. • Restriction was a good idea. • Don't need atrazine. • PAs don't make any difference. Atrazine is nasty stuff and I wouldn't use it anyways.	13
Concern for water quality	• If atrazine is getting into well water, we can do without it • Don't want atrazine in water either. • Benefit about ground water quality. • Would rather not be in a PA, but worries that others might not be careful and his water would get contaminated. He could not sell milk then.	4
Happy with alternatives	• Other products also work, no need to change • Other products available instead of atrazine. • Round-up better. More weed control. • I am happy with the results using products I use. • Don't have a problem with restricted area as long as other herbicides on market provide weed control without carry over, will not need atrazine products. • Easy to control weeds without atrazine. Not needed. • As long as other herbicides do the job, don't need atrazine. • As long as other herbicides do the job there is not a need for atrazine. • Don't need to use atrazine. There are other ways to control weeds. Atrazine is bad stuff.	9
Benefits for health	• It is all right as long as there is a good health reason. • Helpful to health. • Should keep restrictions on atrazine to keep family's health. • If it helps keep us healthier, I'm all for it. • If it's good for humanity, I am all for it.	5

Seventy-five percent of responses to this open ended question either expressed a neutral or positive attitude towards the PAs (Figure 20).

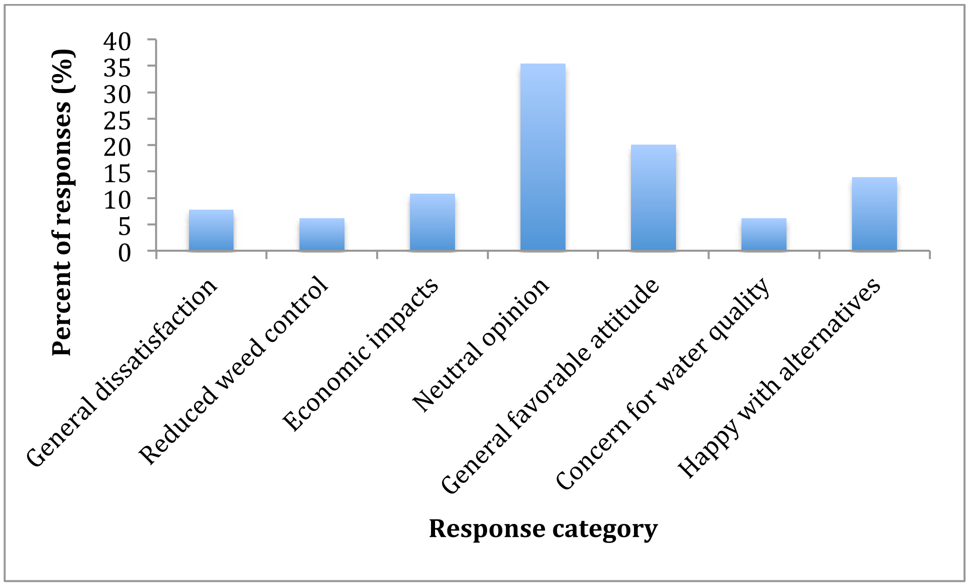

Figure 20. Farmer satisfaction with the Atrazine Rule.

Public Attitudes

Public involvement was a driving force in creating the Atrazine Rules and promoting changes to Wisconsin's groundwater protection strategies. For example, the media was a major tool utilized by the Public Intervenor's Office during the time when atrazine was first discovered through the creation of the Atrazine Rule. Thomas Dawson explained, "We used the media as a big tool, we ran many editorials. Our office was ultimately abolished because we were too effective. With atrazine, public support built, stories on toxicity, wildlife, and health. The papers were interested in environmental reporting. I knew all the reporters on TV and radio. I was interviewed and the issue was kept in the public eye. The pressure was kept on the agencies. Law is one tool, but not the only tool" (Interviewee 4, 2013).

Early public involvement at hearings was limited, and State Government committees felt the Atrazine Rule should be more restrictive. In addition the Public Intervenor and environmental groups wanted stricter regulations of either a 3 year phase-out or a total ban on atrazine instead of the PAs (DATCP/ARM, 1992). The Public Intervenor was critical of DATCPs efforts, stating in written testimony:

> . . . the DATCP board has continued to adopt atrazine rules that are not based on good science. Nothing has changed since 1990 that would indicate the Department should do anything short of banning atrazine use in the state. . . In fact, the new information and knowledge we have gained over the last several months only further compels a ban on this dangerous chemical . . . Farmers already are using available alternatives to atrazine. From this we know farmers can, and are, doing without atrazine. Farmers and other rural residents are willing to have the Department do the right thing to protect their water, even if it means inconvenience or increased costs. The farmers of this state are leading the way. The biggest question remains whether the DATCP Board is willing to follow (Dawson, 1992).

At a public hearing in 1994, a member of the public, Paul Klein, presented DATCP with a carved wooded placard engraved with the title "Certificate of Non Appretiation" (Figure 21). This scathing placard, decorated with images of corn and an image of DATCP in bed with the chemical producer CIBA is engraved with six complaints against DATCP and a plea for a complete ban on atrazine.

Figure 21. Wooden placard presented to DATCP at the Atrazine Public Hearing on September 27, 1994 (Source: Klein, 1994 from the DATCP archive).

Conclusion

Creating the groundwater protection laws and the Atrazine Rule in Wisconsin was a result of public and media attention on the topic of pesticide pollution combined with the political will to protect the environment. The role of the Public Intervenor in calling attention to the issue of atrazine pollution and holding agencies accountable for protecting water resources is an example of the impact that one individual can achieve in creating momentum for legislative change. High levels of compliance and acceptance of the atrazine restrictions by the farming community was due to an inclusive and collaborative decision making process combined with strong disincentives for noncompliance. However, the corn growing association is funding research in support of atrazine reuse in PAs and environmentalists desire a total ban of atrazine.

Unlike in Italy, the farmers in the PAs did not turn to increased use of alternative herbicides, but rather made do with less herbicide. As stated earlier in the chapter, the rate for seven major herbicides was 1.18 lbs./acre inside PAs as compared with 1.83 lbs./acre outside of PAs. It was expected that farmers inside the PAs would use atrazine alternatives in greater amounts so that the total amount of herbicide would be equivalent to that used outside of PAs. In actuality, farmers inside PAs are using fewer total pounds of herbicide; making a case that atrazine prohibition is feasible and leads to a desired environmental outcome of reduced overall pesticide use. This case study shows that the reduced rate laws both had the desired effect of reducing atrazine use and decreasing atrazine pollution. The success of reduced rates builds a strong case for such rules to be applied throughout the US, not only for atrazine but for other pesticides as well. The only way to guarantee that atrazine will not become a groundwater contaminant is to completely prohibit its use. Until such as ban occurs, the Wisconsin example provides evidence for other states and countries that less atrazine can be used to successfully grow corn without causing as much of a risk to water resources.

5. Impacts of the Atrazine Rule on Water Quality in Wisconsin

Summary

This chapter examines how agricultural policies and grower decision-making have influenced the success of efforts to reduce water pollution from herbicides. Water pollution from herbicides causes serious health risks for humans, harm to wildlife, and disruption to ecosystem functions. In the US, the widely used herbicide atrazine, used for corn, sugar cane, and sorghum, is commonly found in drinking water. Atrazine, an endocrine disruptor, is linked to abnormal development and reproduction in multiple species. Atrazine contamination of drinking water is a public health concern in the US, and Wisconsin has been a leader in limiting the use of atrazine. This research project addresses the problem of water pollution from atrazine and other herbicides by using two main research components: (1) analysis of existing water quality monitoring data to examine the impacts of atrazine prohibition areas in Wisconsin (2) social science research using survey data and semi-structured interviews of stakeholders. This chapter complements Chapter Three of the dissertation as the second part of the Wisconsin case study. In Chapter Three, the current risk posed by atrazine was presented, along with grower and public attitudes toward the risk and toward the potential transition to Prohibition Areas where atrazine is banned. This chapter provides a quantitative analysis of water quality changes in atrazine and other herbicides from the 1980s through 2014.

Introduction

Each year, farmers in the US use 80 million pounds of the herbicide atrazine, which is the most common water contaminant found in surface and groundwater (Soloman et al., 1996). The US EPA's Atrazine Monitoring Program shows that levels have exceeded the Safe Drinking Water Act permissible levels of 3 ppb in drinking water for 58% of the systems sampled in the Midwestern US (Wu et al., 2009). Atrazine is used for 66 percent of US corn, the predominant crop grown in the US, and it is also used for sorghum and sugar cane (USDA, 2010). Corn production is widespread and integral to US agriculture and its associated pollution has impacts on environmental health and drinking water safety.

Atrazine has been used in the US since 1958 as an agricultural herbicide that selectively controls broadleaf weeds (Ribaudo and Bouzaher, 1994). It is commonly applied to soil surfaces, which leads to a high risk of contaminating water during rain events (USDA, 2010). Monitoring has shown that it is the most common contaminant of groundwater and surface water in the US (Capel and Larson, 2001). Toxicological studies outline negative impacts on phytoplankton, aquatic insects, amphibians, fish and mammals (Graymore et al., 2001; Rohr and McCoy, 2010). Human health impacts include risks for development, reproduction, and cancer (Lasserre et al., 2008; Hayes et al., 2002). Widespread atrazine contamination in the US spurred the Environmental Protection Agency (EPA) to initiate a review of atrazine's human health impacts and water contamination in 2009. This review may prompt new regulation of atrazine, and has sparked controversy from farmers who say they have no viable alternatives. The toxicology of atrazine is being carefully studied, yet attention is needed on alternatives to atrazine and what insights current atrazine regulations provide for the creation of future policies.

This chapter completes the Wisconsin case study by analyzing the environmental effects of the atrazine prohibition areas (PAs) and application rate limits that have been in place in Wisconsin since 1991. In the 1990s, the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) created 102 atrazine PAs in 33 counties (totaling 1.2 million acres), making Wisconsin the state with strictest atrazine regulations in the US.

I study how policies have impacted the water quality, how farmers respond to atrazine regulation, and how policies can be used to promote reduced herbicide contamination of water.

Research Questions and Methods

This chapter is an evaluation of the environmental outcomes of the Atrazine Rule and future policy recommendations. The main question explored is:

- How have herbicide concentrations in ground and surface water changed since the atrazine restrictions in Wisconsin?

To answer this question, I use existing, statewide quantitative water quality monitoring data collected by DATCP from the 1980s until 2014. I then created a mixed effects model to explore the relative significance of the creation of the PAs, the reduced rate rule of 1991, and changes over time. In addition, I also look for interaction effects among these different variables. The mixed effects model allows me to compare trends in average groundwater atrazine concentrations in PAs and non-PAs to investigate the impact of atrazine policy. This method isolates the effect of management changes. I also use GIS to spatially depict the changes in groundwater quality over time and the number of exceedances of the drinking water standard. Interviews helped inform my recommendations for US agricultural policy designed to benefit the environment, public health, and livelihoods of farming communities in this chapter (See Table 3.1 for list of interviewees).

Water Quality Impacts of the Atrazine Rule

The 1997 report on groundwater protection (Postle et al., 1997) examined the efficacy of the PAs, yet it was not entirely conclusive regarding changed in groundwater quality because the report was produced only seven years after the atrazine regulations began and some of the main water quality analyses were performed over a short timespan that was insufficient for determining a trend (Postle et al., 1997). A study called the DATCP *Exceedence Well Survey* resampled private wells 1-5 years after they were initially found to exceed the limit of 3µg/L and had been placed in PAs (Postle et al., 1997). The repeat monitoring found that 76 of the 90 wells experienced a decrease in the concentration of atrazine and its metabolites, however the 1997 report had a limited timeframe (Postle et al., 1997). Another DATCP investigation, the Paired Well Survey, looked at atrazine concentrations over the course of one year for 17 wells within PAs and 17 wells outside of PAs. DATCP stated the study was inconclusive due to its short duration. These initial results from 1997 showed some evidence that PAs were effective at controlling atrazine from entering groundwater wells, but they lacked long-term data necessary to look for changes over time (Postle et al., 1997).

The DATCP Exceedance Well Survey was revisited in 2010 in the DATCP report, *Fifteen Years of the DATCP Exceedance Well Survey* (DACTP, 2010). This report uses 15 years of data collection to look at herbicide concentration trends in 161 of the most highly polluted wells. Atrazine PAs were created surrounding the 161 wells in the survey, and therefore looking for improvement in well water quality for these wells indicates if the PAs have been effective. The results showed that atrazine concentration combined with that of its metabolites (atrazine TCR) decreased in the vast majority of wells and that the number of wells exceeding the enforcement standard of 3μg/L has also declined (DATCP, 2010; Figure 1). For the cases where atrazine levels did not decrease as expected, DATCP attributes the continued atrazine contamination to there not being enough time to see a change, illegal use of atrazine, residues from other triazines influencing the monitoring, the well being located too close to the edge of a PA, and the possibility of an unidentified point source (DATCP, 2010).

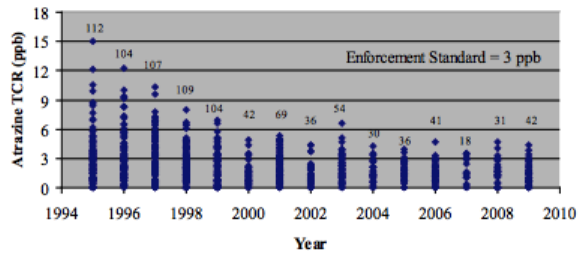

Figure 1. Distribution of Atrazine TCR Results and Number of Samples in the EX Survey by Year. Source: Figure 2. from *Fifteen Years of the DATCP Exceedance Well Survey* (DACTP, 2010).

The Exceedance Survey also sampled and studied eight wells more closely to better understand how long it takes for atrazine to dissipate, or to reach or fall below the level of detection. They found that dissipation rate is dependent on the types of soil, and that sandy soils had a quicker dissipation time than did bedrock wells. The time for a well exceeding the 3μg/L standard, having a PA created, and then falling below the detection level ranged from 11 years to 17 years (DACTP, 2010). An example of atrazine dissipation in well number FF907 is seen in Figure 2.

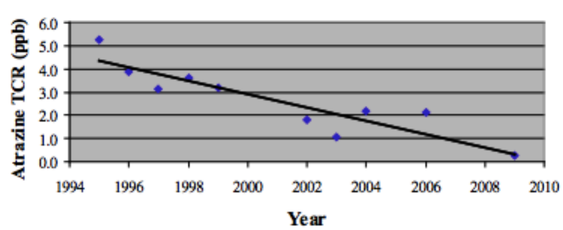

Figure 2. Atrazine TCR Results over Time in Well FF907. Source: Figure 3. from *Fifteen Years of the DATCP Exceedance Well Survey* (DACTP, 2010).

In addition to atrazine, the survey also looked for well contamination with the herbicides metolachlor, alachlor, acetochlor, metribuzin, cyanazine, and simazine (DACTP, 2010). Metolachlor and alachlor are the most common contaminants found other than atrazine. Metolachlor concentration has a constant trend line and alachlor has a declining tend due to its decreased use (DACTP, 2010).

The report, *Fifteen Years of the DATCP Exceedance Well Survey* does not analyze any wells that are outside of PAs (DATCP, 2010). The analysis would benefit from a comparison of trends of atrazine contamination in wells both inside and outside of PAs in order to establish if the PA is responsible for the decreased atrazine levels or if it is a trend caused by other factors. One regulator describes the monitoring program as follows:

> It is a numbers game. We sample 100 wells a year; maybe we are missing some with problems. But it seems the way agriculture is using atrazine it is not leading to new well contamination, it's good. We don't know if the use at reduced rates is causing zero or 1µg/L contamination. We need to assess the impact of reduced rates. - Interviewee 2, 2013

DATCP also performed an analysis of water quality in 2008 in order to compare progress with water samples taken in the 1990s and early 2000s (DACTP, 2008). This report, *Wisconsin Groundwater Quality: Agricultural Chemicals in Wisconsin Groundwater*, used data collected in 2007 from 398 private drinking wells to generate a picture of what types of pollutants are in groundwater and in what quantities. The report found that 33.5% of wells in Wisconsin contained a detectable level of a pesticide (DATCP, 2008). Out of 32 compounds, the herbicide metabolites of alachlor ESA and metolachlor ESA were the highest with each being estimated as present in 21.6% of Wisconsin's wells. The third most common contaminant was atrazine total chlorinates residues (TCR), which is estimated to be present in 11.7% of statewide groundwater (DATCP, 2008). Atrazine TCR was found to exceed the enforcement standard of 3μg/L for 0.4% of the samples (DATCP, 2008).

To further examine the trend in water quality for this case study, specifically comparing wells inside and outside PAs, a data set of all groundwater monitoring data was obtained from DATCP. Two main analyses were performed: 1) comparison of well water herbicide concentration before and after the 1991 Atrazine Rule 2) Comparison of highly contaminated wells within and outside of PAs. This data analysis contributes to the previous DATCP reports by looking at the trends going back before the 1991 Atrazine Rule and also examining how both PAs and application rate reductions may have separately contributed to decreased atrazine pollution.

Comparison of well water herbicide concentration before and after the Atrazine Rule

The data set used for this analysis contains groundwater-monitoring data of well water samples taken by DATCP from 21,899 groundwater from 1985-2014. These wells vary in their types of uses, with many of them being private wells used for potable water. The DATCP sampling program began in 1950s with monitoring for atrazine. The sampling protocol has varied depending on the year and technology from monitoring solely for atrazine to monitoring for the atrazine breakdown products of deethyl atrazine, deisopropyl atrazine and diamino atrazine. The atrazine breakdown products are considered to be equally as toxic and have the same human health risks as atrazine. For the purpose of this analysis, I studied total atrazine concentration, the sum of atrazine and its degradation products, because Wisconsin uses the concentration of total atrazine as its measurement for either exceeding or complying with the health based standard of 3µg/L. To assess total atrazine, yearly averages of atrazine and its degradates were calculated for each well.

Sampling Frequency

8,864 wells were sampled for atrazine at varying frequencies, with some wells sampled only once while one well was sampled a total of 176 times. Sampling frequency not only varied by the specific well site, but also by year. Sampling for atrazine and other triazines was not organized and widespread until the late 1980s. In 1982 only one well had monitoring data, whereas the peak of sampling occurred in 1994 with 4,162 samples. Since early 1990s, sampling has had a downward and variable trend, with most recent data from 2013 consisting of 1330 samples for that year (Figure 3). Because sampling data were sparse until the mid 1980s, the following data analysis has been narrowed to cover the time period of 1985 to 2014. This time period provides data from seven years before the Atrazine Rule (1985-1991) and 23 years after the rule (1992-2014).

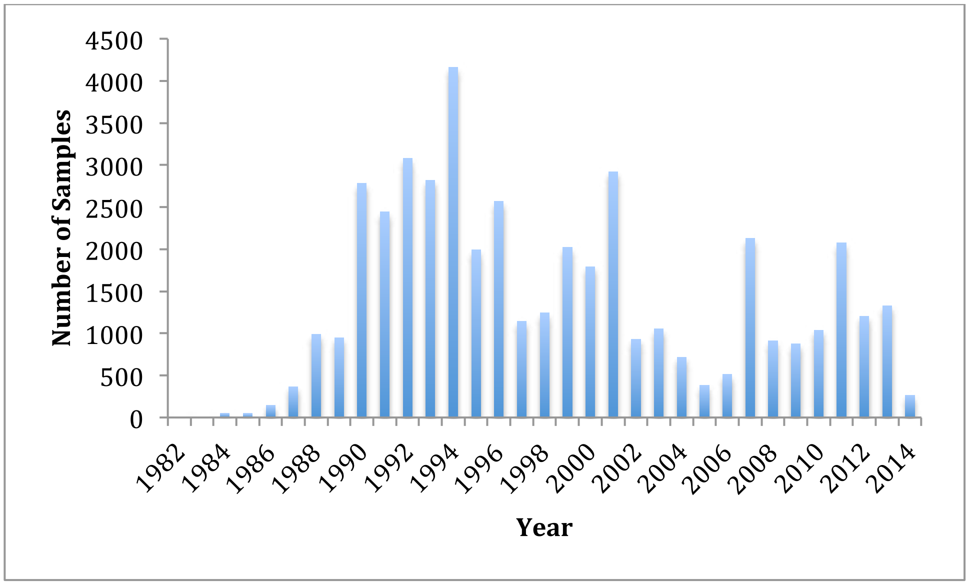

Figure 3. Plot of the frequency of well sampling by year for atrazine and atrazine breakdown products.

Data set

The data set contains a total of 44,899 samples that were collected for atrazine or atrazine breakdown products from the time period 1985-2014. Figure 4 depicts all monitoring data with the corresponding concentrations for total atrazine. 7,732 samples were taken from 1985-1991 and 37,167 samples were taken from 1992-2014. Atrazine concentrations varied dramatically depending on the well site. Atrazine concentrations ranged from zero to 191 μg/L. The samples with the highest concentrations, like the 191 μg/L sample, were most likely affected by point source well contamination. Improper atrazine handling leading to point source contamination was recorded by DATCP. Samples with concentrations exceeding 30 μg/L were excluded from the analysis because they represent point source contamination instead of leaching from normal atrazine use. Of the 44,899 total samples, 26,314 samples (59%) were positive for total atrazine. The enforcement standard of 3μg/L was exceeded in 963 samples with 602 exceedances occurring from 1985-1991 and 361 exceedances recorded from 1992-2014 (Figure 5). The data from the entire data set show that the mean atrazine concentration for the 6,363 samples with atrazine detections before the Atrazine Rule from 1985-1991 was 1.4 µg/L and after the Atrazine Rule from 1992-2014 the mean concentration was 0.86 µg/L for 8,058 samples (Figure 6).

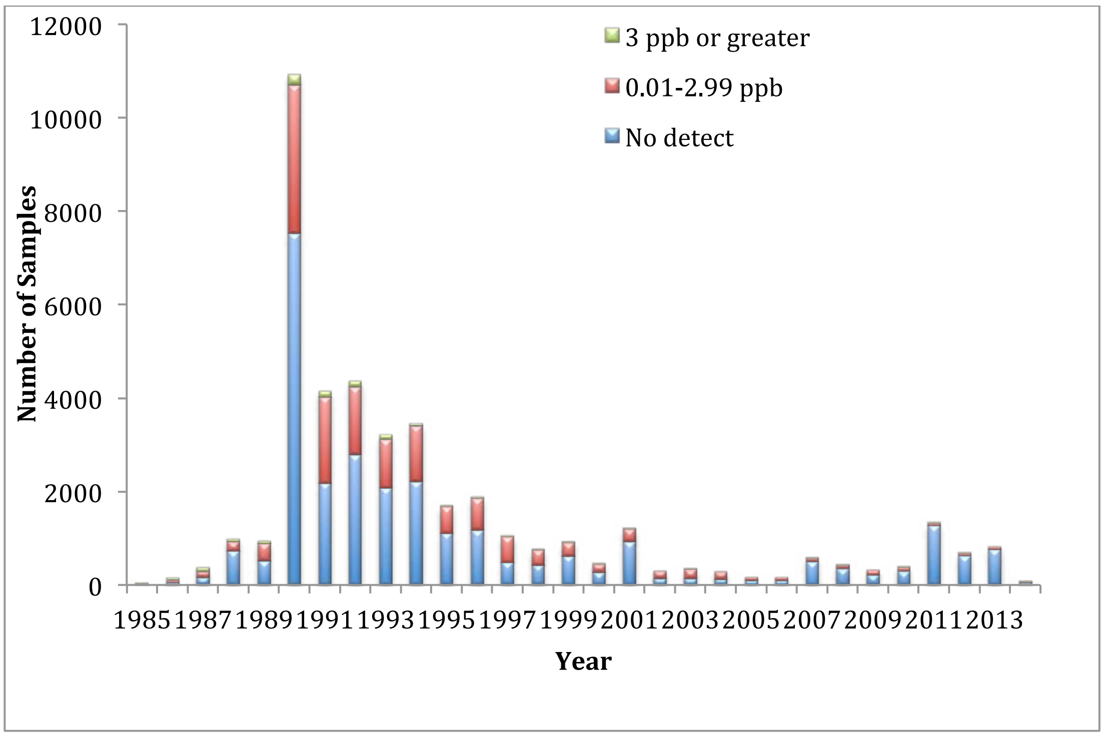

Figure 4. Number of samples with no detection, atrazine detections and exceedances of the ES from 1985 to 2014.

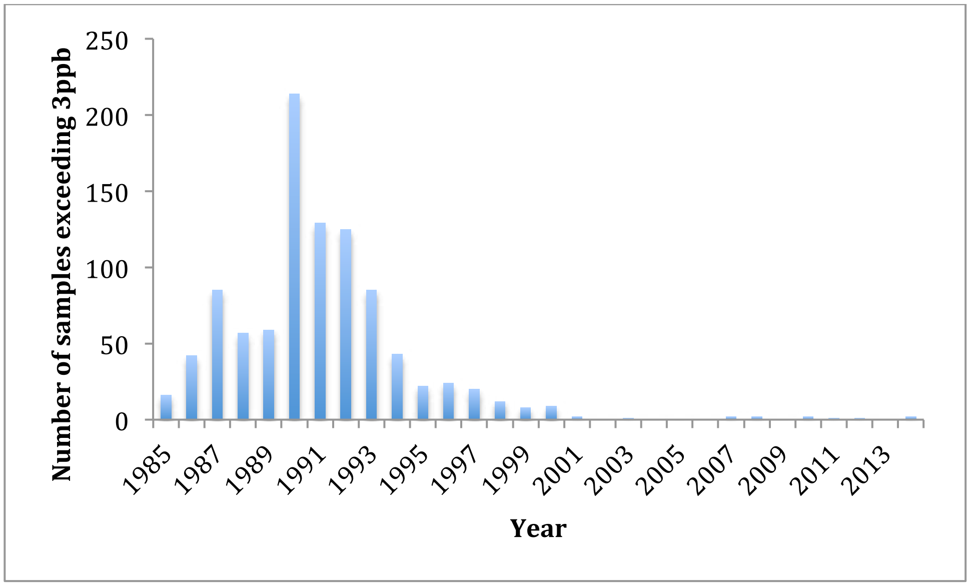

Figure 5. Number of samples over 3 µg/L for atrazine from 1985 to 2014 in Wisconsin.

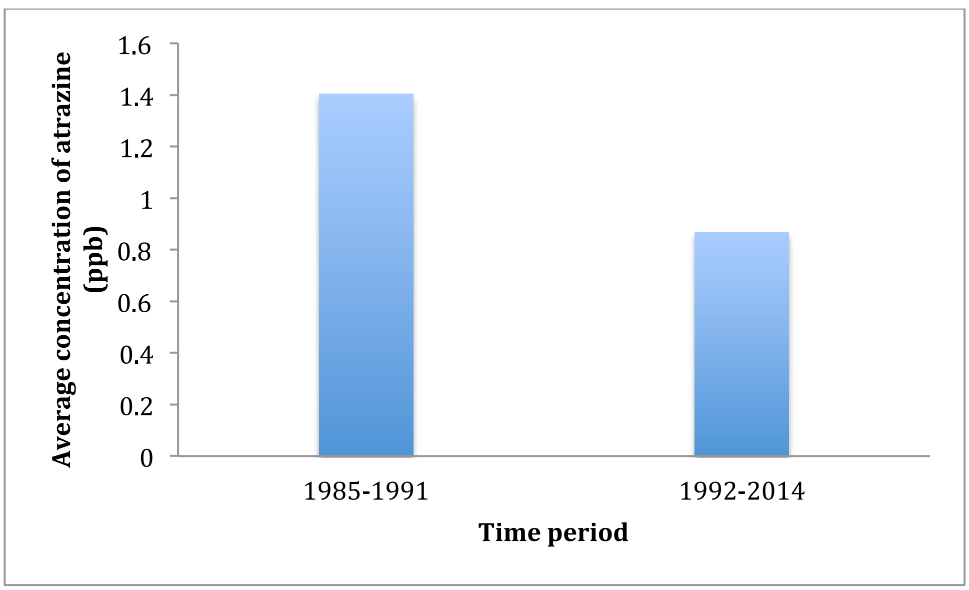

Figure 6. Average atrazine concentration before and after 1991.

To visually depict the atrazine monitoring, detections, and exceedances, I created Figure 7 in GIS. The trend shows that total atrazine exceedances peaked from

1995-1999 with an average of 14% of sampled greater than 3 μg/L and has decreased to a low from 2010-2014 of 1% of samples exceeding 3 μg/L.

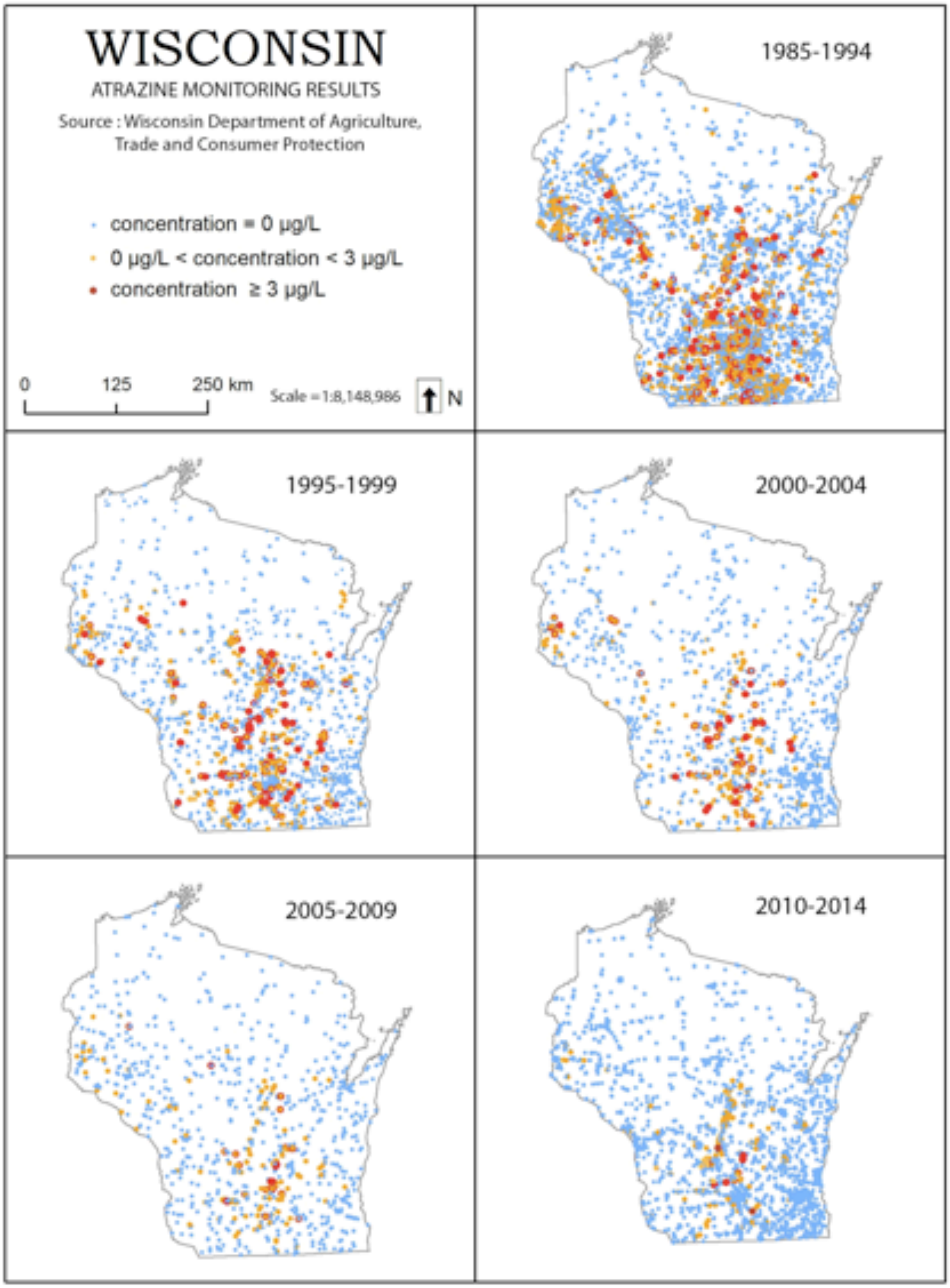

Figure 7. Total atrazine concentration results for wells sampled from 1985-2014.

There is little statistical relationship, R^2=0.0057, between the magnitude of sampling and the number of atrazine detections (Figure 8). The weak relationship indicates that even though sampling rates have been variable over the years, the increasing the number of samples does not necessarily influence the likelihood of positive atrazine detections.

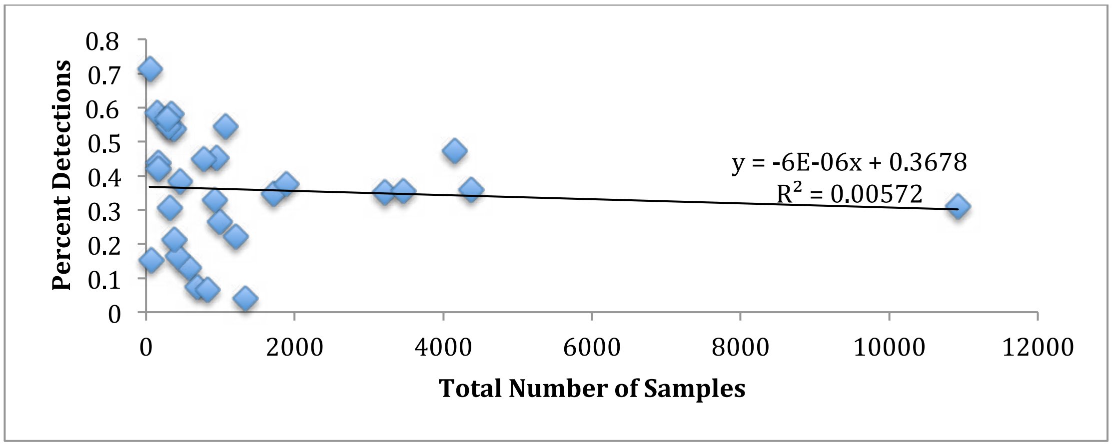

Figure 8. Relationship between the sampling magnitude and the number of atrazine detections from 1985-2014 in Wisconsin.

Mixed-effects model

A mixed-effects model, also known as a linear mixed model (LMM) was used to evaluate the longitudinal data set of monitoring data. The mixed-effects model is a procedure that allows for analysis of change over time by fitting an advanced regression model to the longitudinal data set (West, 2009). Mixed-effects models allow the inclusion of both fixed effects as well as random effects. SPSS software was used to create a model that evaluated the change in atrazine concentration over time as well as the impact and interaction effects of the 1991 Atrazine Rule and the creation of the PAs. In the atrazine model, the fixed effects were (a) time, (b) being in a PA or not being in a PA and (c) the year being before or after 1991 (the year of the Atrazine Rule). The random effect in the model was the difference between individual wells.

In order to determine if total atrazine concentrations changed after the Atrazine Rule, I narrowed the analysis to data wells which had at least one detection of atrazine or a breakdown product and overall had more than three samples taken over the time period of 1987-2013. The data from 1985 and 1986 were excluded because there were few readings with many outliers for those years. By excluding wells that always had zero values, I was able to focus on wells where change over time could be documented. Concentrations over 30 μg/L were also excluded from the analysis because they most likely represent point source well contamination and are more than 2.5 standard deviations away from the mean and are not connected to the other data points. This subset of the data set contains 3,719 data points from 610 monitoring wells.

The model was created using a log transformation of the total atrazine concentrations found in the wells. The values for concentration were widely variable between the early monitoring data and the later monitoring data. For example, in 1987 the variance for well concentration was 19.03, whereas the variance in well concentration in 2013 was 0.81. Large differences between variances such as the one between 1987 and 2013 break the linear model's assumption of heteroscedasticity. After the log transformation, the variances in concentration are substantially more stable over time. After transformation, the variance in 1987 was 9.95 and the variance in 2013 was 8.47.

To test for the best fit of the model to the data, the model was executed with a variety of parameters including random slopes, random intercepts, both random slopes and intercepts, and also with no random effects. The random effects did not improve the model's fit to the data. The mixed-effects model was used even though there were no random effects in order to specify the covariance structure, which was fist order autoregressive heterogeneous (AR1 heterogeneous). AR1 heterogeneous means that variances in concentration will be more similar the closer the time periods are to one another. AR1 is often the most appropriate covariance structure for a longitudinal model. The heterogeneous AR1 model was selected because the data set includes differences in variance for the different sampling years. The final model included the following three independent variables as fixed effects: year, status of being in a PA as an interaction with year, and an interaction of year being after 1991 and year. These two interaction effects test whether the slope of the mean concentration changed when a site became a PA and if the slope changed after the 1991 Atrazine Rule.

Change over time

The data set used in the model and analysis was reduced from the original set of 44,899 samples to 3,719 samples that met our criteria. For these samples, the mean atrazine concentration peaked in 1992 at 3.0 µg/L and experienced a variable yet consistent decline to 0.67 µg/L in 2013 (Figure 9).

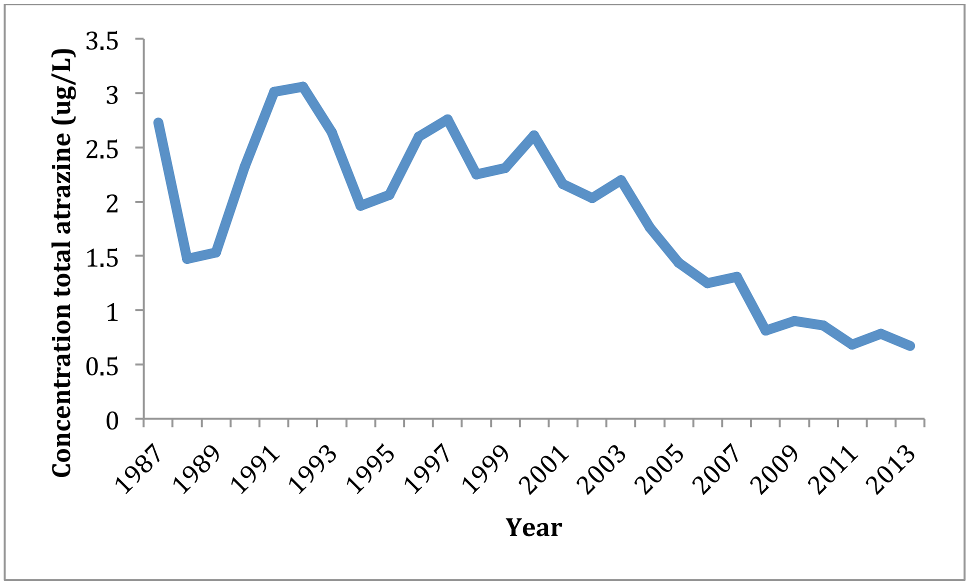

Figure 9. Mean concentration of total atrazine over time.

The mixed-effects model was used to evaluate if the creation of the 1991 Atrazine Rule reduced atrazine concentration. For the data set, the model shows that concentrations in wells experienced a steady and statistically significant decline from year to year. The log-transformed concentration allows us to report the decline in concentration as a percent decline per year rather than the change in concentration in μg/L. The model showed that for each additional year, the total atrazine concentration in wells experienced a 16% decrease (*F* (1, 179) =, *p* = <0.005, 95% CI [14%, 19%]. The difference of slopes is statistically different for wells sampled before and after 1991 (*p* = <0.005) (Figure 10). From 1987-1991, the data from 821 samples from 370 wells showed an increase in year-to-year atrazine concentration of 26.7% (*F* (1, 369) = 7.826, *p* = <0.005, 95% CI [7%, 40%]). From 1992-2013, the data from 2,898 sampled from 519 wells showed that the slope of the well concentrations declined year-to-year by 17%

(F (1, 704) = 172.401, p = <0.001, 95% CI [-27%, -20%]). The shift from a positive slope before 1992 to a negative slope from 1992-2013 indicated a shift from the atrazine problem getting worse to the situation improving.

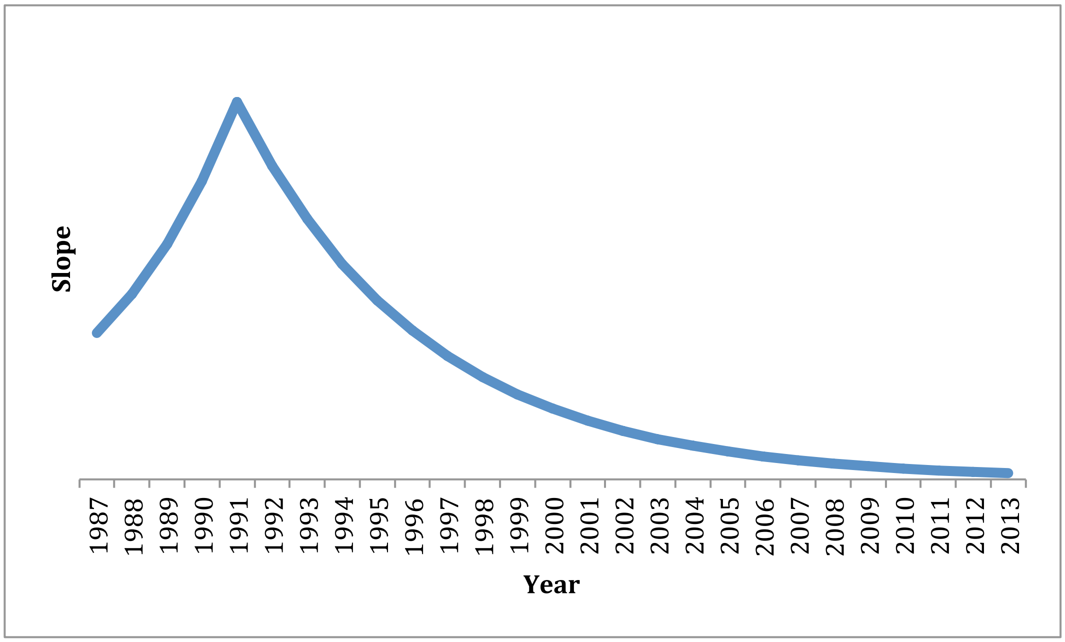

Figure 10. The year-to-year change in atrazine concentration as characterized by the mixed-effects model.

This model did not detect a difference between the rate of concentration decline for wells inside and outside of PAs. The model found that 1267 samples from 423 wells that were not in a PA experienced a year-to-year decline in concentration of 21% after 1991 (F (1, 226) = 151.409, p = <0.001, 95% CI [-27%, -20%]). For the 1631 samples from 290 wells that entered Pas after 1991, the decline in concentration was also 21% (F (1, 393) = 149.733, p = <0.001, 95% CI [-27%, -20%]). These finding suggests that the most important intervention by DATCP was the 1991 Rule that decreased application rates for atrazine statewide. There is a decline in atrazine concentration over time, and this decline is present only after 1991. The model does not show that the institution of the PAs had an effect on atrazine concentration decline. Because a reduced data set is used in the model, there is the possibility that wells which were not frequently sampled were not part of the analysis and their absence may have influenced the findings.

Implications of Atrazine Rule

Farmers reduced the application rates for atrazine when the rule went into effect in 1991, although they had already started to reduce atrazine use before the rule went into effect. The mandate of lower application rates reinforced the trend already underway to reduce atrazine use in the state. "Atrazine is being used a lot differently than in the 70s and 80s. The rule is part of it, but hasn't driven all the change. The rule has been successful in being a key player in atrazine use reduction" (Interviewee 2, 2013).

The switch to other herbicides other than atrazine comes with new challenges and environmental risks. The DATCP monitoring program detected the herbicides acetochlor, alachlor and its breakdown products, metolachlor and its breakdown, dicamba, and AMPA in groundwater samples. Figure 11 shows the total presence of herbicides in groundwater wells from 1985-2014 with red wells indicating an exceedance of the EU drinking water standard of a maximum of 0.5µg/L total pesticides. Figure 11 also shows that total herbicide concentration was above 0.5yg/L in 15.3% of samples in the mid 1990s, and decreased to 7.5% in 2010-2014. This decrease is largely due to decreased atrazine contamination, but it also represents a general trend of decreased herbicide pollution throughout the state.

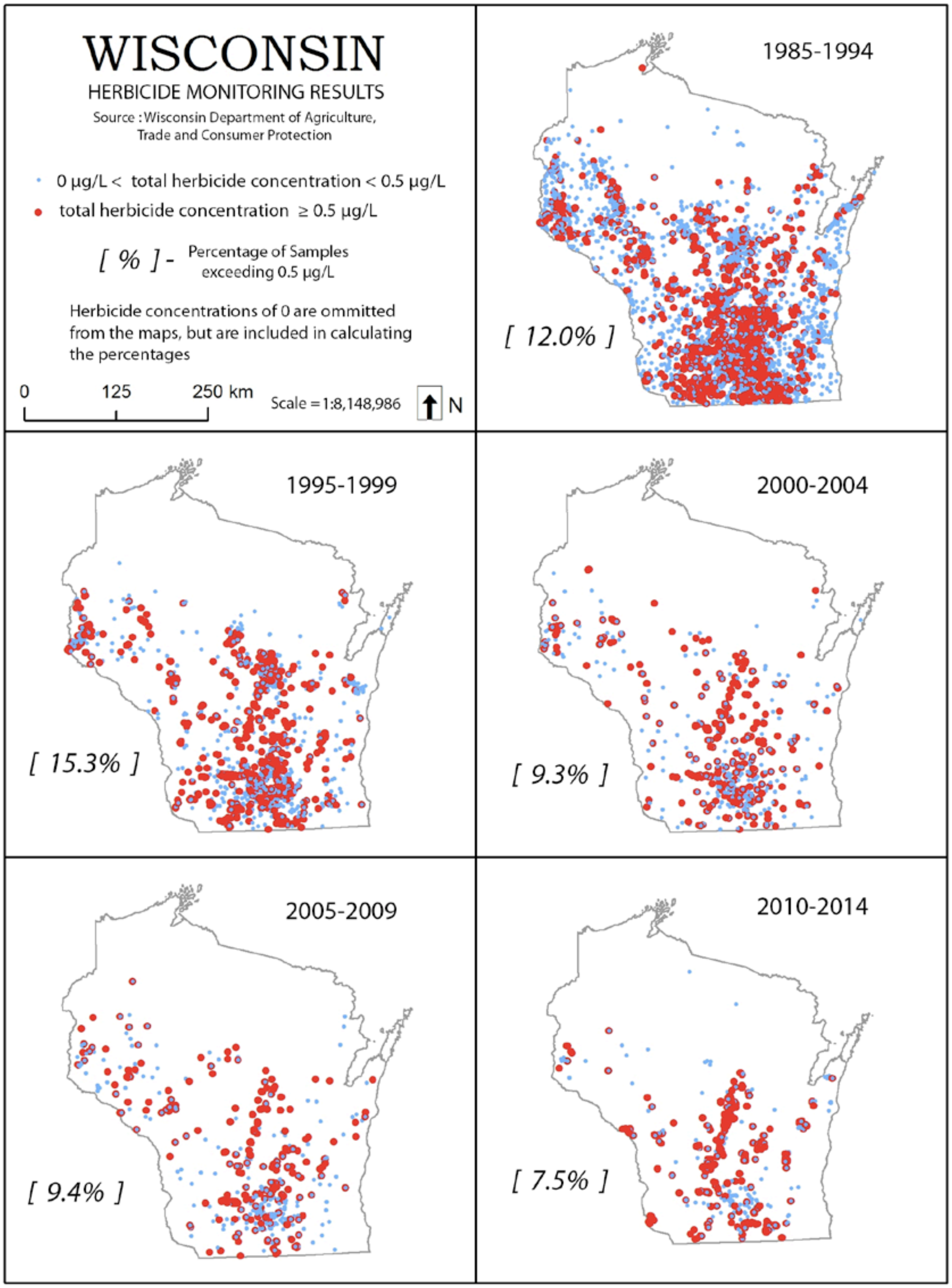

Figure 11. Total pesticide concentration found in groundwater. Red dots represent wells with levels exceeding the EU standard.

Despite the presence of different herbicides in groundwater, herbicides other than atrazine rarely have been found to exceed their health based standards. Acetochlor and its degradation products were detected in 9,833 samples from 209 wells from 1995-2014.

One official stated:

> I don't know of any other compounds that cause widespread exceedances like atrazine did. There have been two groundwater investigations for non-atrazine herbicides that have exceeded the limits. Metalochlor has a 100µg/L limit and was found at a level of 180. Alachlor has a limit of 20 and it was found at 28µg/L. NR 140 sets the enforcement standards driven by the toxicity of compounds. Some people think a shortcoming of the groundwater law is that it allows pesticides to get into water without triggering action. The law didn't contemplate the stew of chemicals at sub enforcement standards. One well example has 11-12 individual compounds and none of them exceeded the enforcement standard and didn't trigger an investigation (Interviewee 2, 2013).

As this quote depicts, one criticism of the atrazine rule and the groundwater law in Wisconsin is the inability for these policies to address the issue of chemical mixes. The exposure to a combination of pesticides can result in both adverse synergistic and additive effects, especially in the potential for estrogenic effects from endocrine disruptors (Hernández et al., 2013). Unlike the EU standard for total pesticides in water of 0.5µg/L, there is no set safety level in the US for combined chemicals. The threat of individual chemicals and chemical mixes to drinking water can be expected to increase as seen in the most recent upward trend in overall herbicide use in Wisconsin (Figure 12).

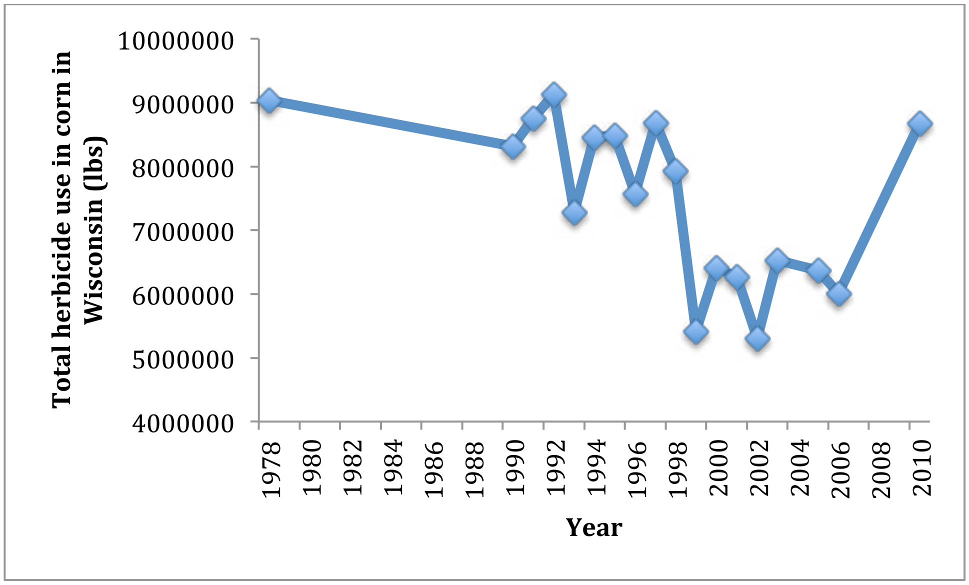

Figure 12. Overall herbicide use in corn in Wisconsin from 1978 to 2010 (NASS, 2014).

There are also specific risks associated with different herbicides that are potential atrazine alternatives. The major herbicide used in corn production is glyphosate, the most commonly used herbicide in the US (Figure 13). Glyphosate, long considered by many to be of low environmental and health risk, is under scrutiny for possible environmental and human health impacts. A 2015 report from the WHO classified glyphosate as a propable carcinogen. Samsel and Seneff (2013) has gained attention because of the hypothesis that links glyphosate exposure to autism and other neurological diseases. These studies linking glyphosate to major health risks have sparked controversy and alarm concerning the high levels of glyphosate use. That a pesticide can be used in a widespread manner in agriculture and other settings without its risks fully understood brings into question how we should best manage chemicals and their risks.

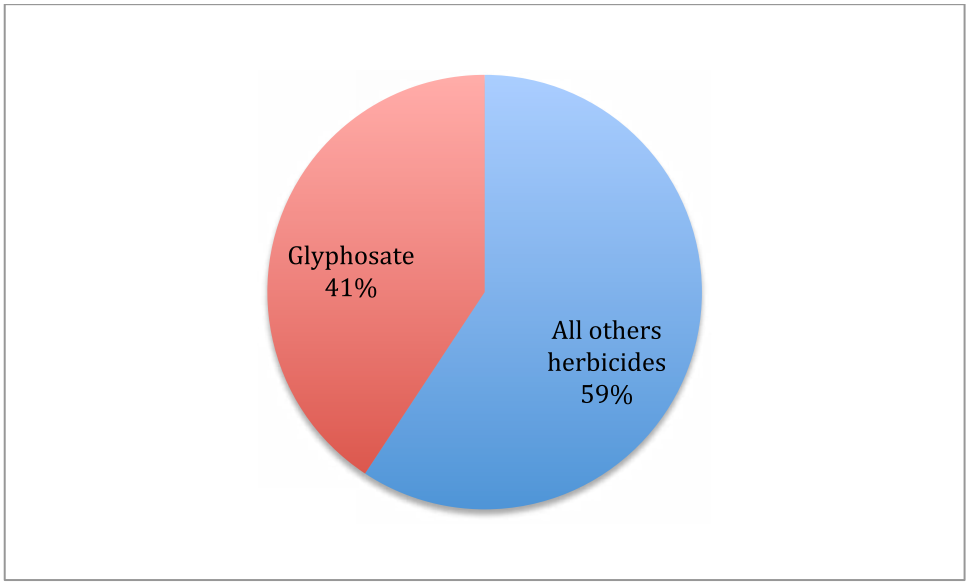

Figure 13. Glyphosate use in the US. Figure shows that glyphosate makes up 41 percent of herbicide use in the US agricultural sector in 2007 (Source: Grube et al., 2011).

Wisconsin regulators expressed hope that the atrazine rule has led to a greater awareness in the harms of pesticides among farmers, who in response may have moved towards systems that rely less on herbicides. When asked if the atrazine rule has led to increased sustainability for farming practices, one agency employee responded: "It raised awareness about potential impacts of agricultural chemical use. Wisconsin farmers are more aware of impacts and it has led them towards more integrated production. It is anecdotal but I would like to think it is a possibility (that agriculture became more sustainable)" (Interviewee 2, 2013).

Perspectives on success of the program

There are varied perspectives on the Wisconsin approach to managing atrazine. The environmental perspectives is that Wisconsin is not addressing issues of herbicide combinations in drinking water and that total atrazine ban is needed.

> The Wisconsin law is not a model because it has a deficiency of too high of an enforcement standard. It is important because it imposes a duty on the regulators. I would have liked the enforcement standard at a preventative action limit, at a level below when it is fit to drink and without economic and feasibility influences. The groundwater law doesn't deal with the problem of chemical soup. It needs to look at the compounding load of multiple chemicals. We need to worry about synergistic effects. We should have a trigger for multiple/total contaminants. This is a reason the Wisconsin groundwater law isn't a model. - Interviewee 1, 2013

Totally opposing the environmental view above, the Corn Growing Association sees the PAs as a burden and has expressed the desire to get rid of the PAs as well as supported research to show that the PAs are no longer needed. However, the voice of the growers' associations may not be representative of all farmers, as many farmers in the Wisconsin growers survey expressed no need for atrazine. One researcher stated:

> Farmers have very different views about the atrazine rule. Farmers are not a monolithic group. They get information from agricultural associations. Some farmers are close to the lobby groups, and some farmers don't want to use chemicals that contaminate our water. More conservative ones are the ones that are more vocal. The secretary of the ag associations and the manufacturers do their lobbying through the more conservative farmers. – Interviewee 2, 2013

The agencies involved with the atrazine rule take pride in monitoring and protecting water quality. One researcher described the situation as follows:

> Any time a new well is found to exceed 3μg/L, a new PA is created. We have had no new wells with exceedances. This indicates that the rules are effective. We have a lot less of a problem than in the 1990s. This isn't proof that the rule has been successful, but a combination of the rule and a change in the way atrazine is used is responsible for this improvement. During the 1970s, farmers used 4lbs./acre of atrazine to kill the alfalfa in

> preparation for planting corn. The rule and less intensive use has been a positive change. Now, atrazine is mainly used in pre-mix at a rate of .5-1lb./acre and it works synergistically with other herbicides. – Interviewee 2, 2013

Another regulator spoke of the changing attitude towards atrazine by farmers who have come to cope well with restrictions on atrazine. “In the early days, farmers were apprehensive. Time passed, it's quite possible to grow corn without atrazine. It became easier and easier to grow without atrazine. There is life after atrazine” (Interviewee 4, 2013). This attitude is confirmed by the NASS survey described in Chapter Four in which 50% of farmers with farms inside PAs said it was not more difficult to control weeds without atrazine (DATCP, 2011).

Agency regulators involved with the atrazine regulation in Wisconsin see its successful components, such as lowering the allowed application rate, as a strategy that should be adopted nation wide. One regulator described the problem that the EPA has not adopted strict atrazine regulations in the US and references the need for a balance between the power of chemical lobbies and environmental protection.

> “PAs and reduced rates seem to work and not too many farmers complain about allowable rates. If we set the allowable rates too low, it would be a default ban. We set the rates for limited use and for combinations with other chemicals. Our rule is designed to allow the lowest effective rates. We don't have many complaints. No one says it doesn't work. Why does the EPA allow two times what we allow when it is effective at our amount? Because there are lobbyists working for the high rate. Atrazine has definite benefits, but you need to look at the cost side too. Who is paying to study the costs? It is unfair for Syngenta to spend money looking at the benefits and no one pays to research the costs. “ – Interviewee 2, 2013

Conclusion

The Wisconsin case offers insights into the politics, evolution, and outcomes of a policy designed to prevent and correct atrazine pollution. The water quality analysis of this chapter complements the qualitative study of the political process and stakeholder views described in Chapter 3.

The mixed-effects model demonstrates that wells experienced significant concentration reductions in total atrazine contamination over time. Wells sampled before 1991 had significantly higher atrazine concentrations than wells samples after 1991. The factor of being put into a PA did not have a significant effect on atrazine concentration in the model. This indicates that the most influential aspect of the atrazine rule is the rate reduction that went into effect in 1992, and that wells experienced reductions in atrazine concentration regardless of being put into a PA. Although this does not indicate that PAs are ineffective, it does mean rate reductions are a significant driver of atrazine pollution control throughout the Wisconsin. The PAs may have encouraged lower application rates statewide, as growers may have been incentivized to use less to ensure that new PAs and restrictions would not be created.

The policy of reducing atrazine rates and creating PAs largely met its goals, and well water contamination has been reduced and there have been very few exceedances of the health standard since 2005. However, the problem of atrazine contamination in Wisconsin remains and is a cautionary tale of the long lasting effects herbicides can have on the environment and it inspires the question of whether there are safe limits for chemicals like atrazine or if the only groundwater solution is to remove its use entirely. In addition, atrazine alternatives pose their own risks to water quality. As seen in Figure 11, there are 11282 samples that have at one time equaled or exceeded the 0.5µg/L standard for total pesticides in the EU. A major criticism of the Wisconsin policy is it does not set a standard for total pesticides, therefor ignoring the risk of the additive and synergistic effects of multiple pesticides in water resources. That such a standard is present throughout the EU and absent in the US represents an urgent need for policy development in the US that is based on the precautionary principle.

The Wisconsin atrazine case study also allows for a discussion of how management of pesticides can go beyond targeting one troubling substance to reducing the total use of pesticides. To achieve the goal of improved water quality from a holistic point of view, and not only pollution from one pesticide, there must be a change in the agricultural system and habitual use of pesticides. In addition to heavy reliance on a few main herbicides, monoculture corn production simplifies the agroecosystem in terms of the crops grown and the diversity of beneficial species. There is growing concern about herbicide resistant weeds caused by the blatant over use of glyphosate. In 2014, the USDA approved 2,4D ready corn and soy, which will allow for the use of both glyphosate and 2,4D to be used widely and in combination. The race to develop new herbicides or herbicide combinations to combat the herbicide resistance problem does not address its root cause of herbicide overuse. The adoption of integrated management and diversified systems is a way forward that will help produce more stable and sustainable agricultural systems. This strategy of promoting pesticide reductions and integrated management is being adopted throughout the EU with Directive on the Sustainable Use of Pesticides (Directive 2009/128/EC). The Atrazine Rule in Wisconsin is a policy that has contributed towards strong improvements in water quality protection, and it can be seen as a first step in the types of policies that are needed nation wide. However, a holistic policy approach that sets overall health standards for total pesticides in water as well as a plan for reducing overall pesticide use would be the strongest way forward in insuring cleaner environments and lower human health risks from agriculture.

6. Conclusion

Introduction

Humans are exposed to a diverse array of toxic chemicals at levels without precedent due to the rapid development of new chemicals in the past 100 years. Our water, air, food, homes, cars, and personal care products are just some of the pathways of exposure to chemicals that cause cancer, birth defects, developmental disorders, cardiovascular diseases, respiratory diseases, and endocrine diseases (Prüss-Ustün et al., 2011). Pesticides contribute to the chemical burden and pose a particular risk, not only for workers who may handle them directly, but also for the public exposed to pesticides in drinking water contaminated by agricultural run-off. The US is the leading manufacturer of pesticides and chemicals, and also the largest consumer of chemicals (Goldman, 2009).

Government strategies for coping with chemical risks, and pesticide risks in particular, vary greatly among countries. The US strategy for pesticide regulation (embodied in the Federal Insecticide Fungicide and Rodenticide Act (FIFRA)) involves assessing each chemical individually based on its risks to human health. This policy does not comprehensively address the problem of pesticide pollution because it is not designed to include alternatives analysis into its scientific review nor does it set goals for decreasing overall pesticide use. Although the US Department of Agriculture (USDA) has incentive programs to reduce water pollution from agriculture through conservation practices like buffer zones, there is not a strong public policy agenda for reducing pesticide use throughout the agricultural sector. The new policy for pesticides in the European Union (EU), the Sustainable Use of

Pesticides Directive (Directive 2009/128/EC), which went into effect throughout the EU in January of 2014, establishes the requirement for National Action Plans (NAP) intended to reduce pesticide use through training, equipment checks, and increased involvement in organic and IPM production. This directive was designed to address the problem of pesticide pollution at the farm level, focusing on pollution prevention rather than cleaning up environmental impacts. Although in its infancy, the directive offers an opportunity to reevaluate the US pesticide program and consider ways in which the EU policy may be a model for moving towards a safer and more sustainable agricultural system with benefits for water quality.

The Italian and US strategies to control water pollution from the herbicide atrazine were examined in the previous chapters of this dissertation. Chapters one and two of the Italian case study demonstrate how, after the atrazine ban in the early 1990s, atrazine was replaced with the similar herbicide terbuthylazine (TBA), which had its own unintended water quality impacts. The complete ban on atrazine in Italy was more effective at removing atrazine from groundwater than the Wisconsin policy examined in Chapters three and four. The Wisconsin policy of atrazine use limits and prohibition areas implemented in 1991 is associated with lower atrazine levels in groundwater, but atrazine detection is still common. National monitoring in Italy from 2012 detected atrazine in 7.3% of samples and 0.4 % of samples exceeded the EU limit of 0.1 μg/L (ISPRA, 2014). In statewide monitoring in Wisconsin from 2012, 7.8% of samples contained atrazine or its metabolites and 5.6% of those samples contained atrazine above 0.1μg/L. Italy and Wisconsin had similar rates of detection, but atrazine was present at higher concentrations in the samples from Wisconsin. This indicates that continued atrazine use, even at lower rates as in the case of Wisconsin, has the potential to contaminate groundwater at low levels.

These examples of pesticide policy efforts represent a positive move towards environmental protection and public awareness about the risk of pesticides and water pollution. However, both of these policies are incomplete in terms of reaching the goal of unpolluted water from atrazine and its alternatives. These two case studies also illustrate that pesticide pollution has lasting effects, with contamination persisting even decades after policies were implemented to stop the pollution. Building off of the case studies in the previous four chapters, this conclusion offers recommendations and describes a new model for more comprehensive pesticide policy.

Background

The US Geological Survey program to assess pesticide pollution in the nation's streams and rivers from 1992-2011 found at least one pesticide or pesticide degradation product in more than 90 percent of samples (Stone et al., 2014). A study from 1993-2011 of well networks throughout the US showed that pesticides were detected in 53 percent of samples, with the most commonly found compound being atrazine (Toccalino et al, 2014). Pesticides are commonly present in surface water and groundwater, but at levels that rarely exceed Human Health Benchmarks (HHBs) or drinking water Maximum Contaminant Levels (MCLs) set by the EPA. HHBs include acute (one-day) and chronic (lifetime) exposure scenarios, providing more complete information about the risks of exposure is needed, yet they are only HHBs available for 363 pesticides. Among the substances for which HHBs are not yet available are some of the most commonly detected drinking water contaminants, including atrazine and glyphosate (EPA, 2015). Furthermore, setting HHBs and MCLs based on health risks of particular compounds does not address the problem of synergistic and additive effects of total pesticide exposure when mixtures of pesticides are present in drinking water.

Pesticide Policy in the US

The US federal government regulates chemicals by using an approach that relies on chemical registration and requires that costs and benefits be considered as part of the decision making process. The major government legislation for pesticides is the Federal Insecticide Fungicide and Rodenticide Act (FIFRA), rewritten in 1972 to ensure that the use and sale of pesticides is protective of human health and the environment (EPA, 2015). FIFRA mandates that all pesticides be registered with the EPA's Office of Pesticide Programs, including older pesticides that must go through the reregistration process. In order for a pesticide to be registered, the manufacturer must provide the pesticide's composition, a compliant label, evidence that the pesticide will perform its intended function without unreasonable risks to people and the environment, and that it will not cause unreasonable risk to the environment within the bounds of common use (Kubasek, 2002).

The EPA can cancel the registration of a pesticide if it makes a formal finding that the chemical poses an unreasonable risk. In order to begin this process, the EPA performs a review process and then makes a decision for action if necessary. The EPA must prove that the chemical causes unreasonable risk to warrant cancellation, putting the evidentiary burden on the regulator instead of the polluter.

Since the creation of FIFRA and the widespread use of pesticides that began in the 1940s and 1950s, our understanding of the risks of pesticides has changed. Pesticides are now known to cause a suite of human health problems, and for some pesticides such as endocrine disruptors, negative repercussions can occur at very low doses. We also know that different populations, such as pregnant women and children, have different vulnerabilities. In addition, we are not only exposed to one pesticide at a time, but rather many different pesticides that can interact and compound their effects on the human body. Setting scientifically grounded exposure limits for single pesticides is time and resource-intensive (resulting in inadequate completion rates for HHBs and MCLs) and ignores synergistic effects.

Pesticides Directive in the EU

The EU has approached the health risks of pesticides from a precautionary perspective. EU Directive 80/778/EEC set limits for pesticides in groundwater with a standard of 0.1µg/L for individual pesticides and 0.5µg/L for total pesticides. The level of 0.1µg/L represents the level of detection that was available in the 1970s and 1980s, and was deliberately set at a "zero" level to imply that any pesticides found in groundwater is essentially unacceptable.

In 2009, the European Parliament established a framework for Community action to achieve the sustainable use of pesticides with Directive 2009/128/EC

(SUD). The SUD is overseen by the EU Directorate General of Health and Food Safety and implemented by National Action Plans (NAPs) created by each member state to reduce risks and impacts of pesticide use. The directive was created to reduce the dependency on pesticides by member states. The SUD has direct links with the Water Framework Directive, creating overlap between farming practices and the water quality goals of the Water Framework Directive. The SUD has several main components including: (1) training for pesticide users, distributors, and advisors; (2) regulation of pesticide sales (3) raising public awareness of pesticide poisoning and providing information on how to prevent it; (4) a prohibition on aerial pesticide spraying; (5) minimizing or banning the application of pesticides in critical areas; (6) inspection of pesticide application equipment in use; and (7) mandatory implementation of the general principles of integrated pest management (IPM) by all professional pesticide users (Directive 2009/128/EC).

National Action Plans

The SUD gives member states control to develop their own sets of standards, goals, and implementation plans. While there is the opportunity to use the SUD to create new and hard-hitting policy changes, there is a concern among some environmental groups that the NAPs will not result in significant changes. Discrepancies in the stringency of the NAPs also bring up the question of competition and fairness, considering that some counties may have comparatively less stringent NAPs. The interpretation of the general principles of IPM could cause major changes for farmers, or very few, depending on the way the member states interpret the guidelines. The following sections will go into detail for the training, IPM, and water quality components of the SUD as well as give examples of strategies developed by different countries in their NAPs.

Training for farmers and pesticide users

Training is a major component of the SUD, and it is a necessary pairing with the mandatory IPM production requirement. Training involves education on the general principles of IPM, knowledge of organic agriculture, label reading, proper use of chemicals and knowledge of alternatives, access and training in comparative assessment and knowledge of all available products. A major obstacle for organic and IPM growers is access to information and advisors educated in sustainable production. One regulator stated the importance of training of advisors. "A key action of the SUD is the availability of advisors. Not all farms are prepared for IPM. IPM requires observation, monitoring, prevention, and technological tools. These skills require support for skilled and knowledgeable advisors." - Interviewee 9, 2012

Many NAPs set a requirement for training and certification for all who work with pesticides, and many countries already have such training programs in place. In the UK, there already existing training and certification programs in place, and the SUD will only require a slight reframing of the existing arrangements (UK NAP, 2013). The UK NAP explains that trainings should teach applicators to use pesticides sustainably and keep up to date with legislation, technology and methodology, pest monitoring, and alternative crop management approaches (UK NAP, 2012). The NAP for Ireland also sets a goal to reduce unintentional application of pesticides such as from drift, spillages, and overlapping application (Ireland NAP, 2013). There is little mention in the NAPs of training in IPM or organic agriculture, which may be an area that will be developed as the NAPs are implemented.

Requirement of IPM

The SUD states that member states must promote low pesticide-input pest management including IPM and organic farming. The directive also specifically encourages the support of organic agriculture as a form of low-input agriculture, yet programs to encourage or support organic agriculture are missing in many of the NAPs. The SUD mandates that all professional users must implement the general principles of IPM by January 1, 2014. The SUD set general IPM guidelines, and left specific IPM guidelines to be decided upon by the member states. Country guidelines are needed because of the difficulty of creating crop specific guidelines due to the crop variety and pest differences among member states. The general principles of IPM outlined in the SUD include: (1) preventing and/or suppressing harmful organisms by crop rotation, cultivation techniques, use of resistant cultivars, use of balanced fertilization, liming, and irrigation/drainage practices, preventing spread of harmful organisms by hygiene measures, and the protection and enhancement of beneficial organisms, (2) monitoring of harmful organisms, (3) decision-making of whether and when to apply pesticides based on consideration of harmful organism threshold levels, (4) sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control (5) pesticides applied shall be as specific as possible to the target organism and have the fewest side effects on human health, non-target organisms, and the environment, (6) The professional user should keep pesticide levels low through reduced doses, reduced application frequency or partial applications, (7) anti-resistance strategies should be applied, (8) the professional user should check the success of the applied pesticide.

Water Quality Protection

The SUD calls for the harmonization of methods, standards, and reporting on contamination from pesticides of surface water and ground water. This harmonization will allow for evaluation of the SUD against water quality benchmarks. For example, the national water-monitoring program implemented under the Water Framework Directive (WFD) in Italy will be used to assess if water contamination with pesticides is achieving the SUD goal of reduced contamination (ISPRA, 2014). The Belgian NAP sets actions for water quality protection that integrate the SUD with existing policies. The actions include enforcement of mandatory 1-meter buffer zones for horizontal crops, and mandatory 3-meter buffer zones for vertical crops along surface water, demarcating protected zones for the use of pesticides in order to protect drinking water. The SUD further requires the use of mandatory use of drift-reducing nozzles, designation of vulnerable zones to protect groundwater, and creation of informational and advisory activities to promote good agricultural practices (Belgian

NAP, 2014). The convergence of the WFD is vital to achieving measurable environmental improvements through the SUD's goal of reduced reliance on pesticides.

Need for a different model in the US

The problems associated with US pesticides regulation highlight the need for a more comprehensive model. Such a model should bridge the gap between water pollution and agricultural practices with a goal of reducing pollution and pesticide use. The Sustainable Use of Pesticides Directive in the EU offers insights into the components of such a model and the potential benefits.

Pervasive pesticide risks require changes to several components of the US pesticides program in order to fully protect human health and the environment. The pesticide program in the US can be improved through coordinated action by the EPA and USDA to achieve a more holistic strategy focused on reducing agricultural pesticide use. A comprehensive program would include: (1) alternatives assessment as part of the scientific review of pesticides, (2) limits on total pesticide concentrations in water and, (3) lower limits for pesticide MCLs based on precautionary standards and sensitive populations, (4) removal of the most problematic water pollutants, and (5) mandatory requirements for reduced pesticide use in agriculture.

Need for alternatives assessment

The EPA currently uses Chemical Alternatives Assessment (CAA) to assess chemical alternatives within the same functional group to find safer, alternative chemicals. The aim of CAA is to give stakeholders the information to choose safer chemicals without switching to less well understood and potentially hazardous substitute chemicals (EPA, 2015b). CAA is a tool that could be broadened to compare risks among pesticides in different functional groups, yet it is not routinely part of the pesticide review process. CAA could provided valuable information for finding pesticide alternatives, as is demonstrated in the case of pesticide switching from the soil fumigant methyl bromide (MeBr) to methyl iodide in California.

The *Montreal Protocol on Substances that Deplete the Ozone Layer,* which went into effect in 1989, banned MeBr because it depletes the stratospheric ozone layer. However, MeBr is still being used in California under a critical use exemption. In 2007, the EPA approved an alternative fumigant to MeBr, methyl iodide (iodomethane), and it was later approved for use in California in 2010. The review of methyl iodide included analysis of exposure and human health risks and is listed on the EPA website as "one of the most thorough risk assessment processes ever completed by the agency" (EPA, 2008)). Despite Agency review and the assumption that methyl iodide would be a safer alternative to MeBr and other fumigants, scientists, environmental and farm-worker groups saw the approval of methyl iodide as a major risk due to its carcinogenicity, developmental toxicity, and propensity for offsite drift (Bergman, 2009). Pesticide Action Network stated "Methyl iodide is arguably even more toxic for workers and rural communities than methyl bromide." Pesticide Action Network sued the California Department of Pesticide Regulation for violating the California Environmental Quality Act (CEQA), which states that alternatives must be studied (Standen, 2012). Ultimately, the manufacturing company, Arysta LifeScience, removed methyl iodide from the US market before a court ruling could be made that methyl iodide's approval was in violation of CEQA and the California Department of Pesticide Regulation's own rules (Pesticide Action Network v. California Department of Pesticide Regulation, 2012).

The approval of methyl iodide at both the national and state levels without full analysis of alternative fumigants reveals a weakness in the pesticide review process. A thorough analysis of fumigant alternatives, as well as non-chemical options such as anaerobic soil disinfection (ASD), could have been performed in order to ensure public safety and sustainable production practices. The legal framework for alternatives assessment for pesticides is in place through the laws like the National Environmental Protection Act, yet more integration of alternatives assessment into the review of pesticides under FIFRA, especially during scientific advisory panel review, would result in better decision-making during pesticide evaluation.

The EU integrates alternatives assessment in the SUD with the specification that pesticides used must have the fewest impacts on the environment and human health (General IPM principle #5 described earlier). The requirement implies that the regulators and pesticide users must be able to make decisions to evaluate relative risks of different pesticides and only allow the use of the safest options. In the SUD, organic and non-chemical options are part of the alternatives assessment, going beyond the narrow lens of comparing chemicals with other chemicals with slightly different compositions to evaluating divergent sets of both non-chemical and chemical practices. The EPA could build on the scientific review process for pesticides by requiring an alternatives assessment of non-pesticide alternatives as well as other pesticides outside of the chemical's functional group.

Limits on total pesticides in drinking water

Agricultural crops are treated with multiple different pesticides, leading to pesticide mixtures entering the environment and our bodies. Pesticide mixtures at low exposures may interact and cause increased risk for particular diseases, especially endocrine disorders, neurobehavioral abnormalities, cancer, and cardiovascular disease (Carpenter et al., 2002). USGS water monitoring data from 1992–2001 show that U.S. streams in areas of urban or agricultural land use had detections of two or more pesticides or pesticide breakdown products more than 90% of the time, five or more pesticides approximately 70% of the time, and 10 or more pesticides about 20% of the time (Gilliom et al., 2006). The impacts of pesticide mixtures on human health are only beginning to be understood, as there are many combinations and interactions among pesticide groups. Pesticide in mixtures can have independent, dose additive, or interactive impacts on wildlife and humans (Hernández et al., 2013). A study of healthy women and breast cancer patients found higher total levels of organochlorine pesticides and different types of pesticides in breast cancer patients, indicating that particular mixtures may contribute to the environmental factors associated with breast cancer (Boada et al., 2012). Wickerham et al. (2012) found that greater presence of pesticide mixtures in cord blood of infants was associated with lower birth weight, supporting evidence that combinations of pesticides have a greater impact on fetal development than would be expected with individual exposures.

Researchers call for a regulatory response to emerging evidence that pesticide mixtures can cause harmful human health effects at low doses (Hernádez et al., 2013). Increased EPA funding of research on the health impacts of pesticide mixtures through the Office of Pesticide Programs would help fill the toxicological data gap for commonly detected mixtures of pesticides. In addition to research, regulations are necessary that address the issue of pesticide mixtures from a precautionary standpoint. The US has no standard to ensure that many pesticides at levels below individual MCLs do not combine to cause additive and synergistic harmful effects. The EU limit set in the Drinking Water Directive of 0.5 µg/L of pesticides in groundwater is a precautionary benchmark that can be enforced and is protective of public health. The EU limit of 0.5µg/L is grounded in the EU environmental philosophy that pesticides should not be present in water regardless of actual risks (Dolan et al., 2013). Considering scientific uncertainties about risk of pesticide mixtures, the EPA Office of Pesticide Programs needs to define a regulatory benchmark for total pesticide concentration in surface water and groundwater in the US.

Need for increased monitoring and precautionary MCLs

Water quality monitoring is insufficient for some of the most frequently used pesticides leading to unknown and pervasive risks. For example, the USGS NAWQA includes the broadest range of pesticides monitored in the US, yet it lacks adequate monitoring data on glyphosate, the most commonly applied herbicide in the country (Stone et al., 2014). The USGS states that the difficulty and cost of monitoring glyphosate have limited USGS's ability to measure its impacts on rivers and streams (Stone et al., 2014). Other monitoring studies have found that glyphosate is a common polluter of surface water and groundwater, which is to be expected considering that over 80,000 tons of glyphosate are used each year. Battaglin et al., (2014) found that of 318 large river samples from 47 sites, glyphosate was detected in 53.1% and its degradation product AMPA was detected in 89.3% of samples. The researchers also found glyphosate in 52.5% and AMPA in 71.6% of stream samples (Battaglin et al., 2014). Pervasive yet under-monitored glyphosate contamination in U.S. waters creates both environmental and human health risks, especially considering research suggesting that glyphosate may have low-dose human health repercussions. Recent studies have claimed that glyphosate is a probable carcinogen, an endocrine disruptor, and may affect the gut microbiome and contribute to many potential diseases and disorders (Thongprakaisang et al., 2013; Samsel and Seneff, 2013). Considering the uncertainties about both exposure and health impacts, there is a need to prioritize and allot increased funding towards water quality monitoring of the most commonly used pesticides like glyphosate. USGS monitoring priorities should be focused on the most commonly used and frequently detected pesticides regardless of the comparative high costs of monitoring.

The current MCL in drinking water for glyphosate is 700 µg/L. This MCL based on health risks is seven thousand times higher than the allowable limit in the

EU. With an MCL of 700 µg/L, it is rare for glyphosate to exceed this standard and trigger regulatory action. Setting lower water quality limits for glyphosate and other pesticides would serve as a precautionary action that would protect public health from yet to be discovered adverse pesticide impacts. The EPA should prioritize funding towards toxicological study and monitoring of the most commonly used pesticides.

Removal of the most problematic water pollutants

For some pesticides, any use may lead to environmental pollution and undesirable public health risks. The herbicide atrazine is one of the most commonly used pesticides in the US, as well as one of the most common water pollutants. Persistent problems with atrazine use and contamination in the US highlight the fact that US pollution control policy is doing a poor job of targeting the pollutants that are mostly likely to cause widespread and persistent contamination. Atrazine is a widespread water contaminant, an endocrine disruptor, and a likely carcinogen (Hayes et al., 2002; EPA, 2014). The US EPA's Atrazine Monitoring Program shows that levels have exceeded the Safe Drinking Water Act permissible levels of 3 µg/L in drinking water for 58% of the systems sampled in the Midwestern US (Wu et al., 2009).

The question arises of whether chemicals that are widespread pollutants can be used safely at all. The EU made the decision that atrazine posed too a great a risk for water pollution, and its use was banned in 2004. Atrazine is still a persistent problem in Europe, where its presence in water resources is often detected. In Italy, where atrazine was banned in 1990, atrazine was found in 7.3% of groundwater samples monitored nationally in 2012 (ISPRA, 2014). This persistent contamination serves as a warning that atrazine can lead to groundwater contamination even decades after its use has ceased. Environmental groups in the US have called for a total phase-out of atrazine in the US (Wu et al., 2009). One atrazine scientist stated that the only safe level of atrazine in water is zero (Interviewee 10, 2010). The EPA performed a scientific review of atrazine, which began in 2009, and the Agency is currently reviewing atrazine for reregistration expected in 2016. This review offers the opportunity to change the registration or restrict the use of atrazine.

Certain states have created state laws to cope with atrazine pollution. Wisconsin created the Atrazine Rule (ATCP 30, Wis. Adm. Code) that set a series of general requirements on the types of atrazine uses that are acceptable, created maximum allowable application rates specific to soil type, and limited the areas where atrazine can be used through the creation of atrazine management and prohibition areas (PA). Although such state legislation has been effective in reducing atrazine pollution, it demonstrates the need for federal rules that adequately protect water quality in all US states.

In considering a phase-out of atrazine, it is necessary to couple the phasing out of atrazine with a clear recommendation strategy for alternatives to be used. A shortcoming of the atrazine ban in Italy was the replacement of atrazine with TBA, leading to new water pollution. In Wisconsin, atrazine use was shifted towards an increase in the use of glyphosate. Overcoming the propensity for farmers to switch from one chemical to another is a challenge, but also offers government an opportunity to intervene and propose the most sustainable alternatives. In the case of atrazine, there are several main pre-emergent alternatives available. Table 1 presents pre-emergent chemical atrazine alternatives for weed management along with their risks. The propensity for herbicides to enter water and their persistence are main factors affecting the risk of human exposure. EPA lists certain chemical properties as “red flags” for water contamination. These red flags are marked by the color red in the table and include: half-life in soil above 21 days, solubility in water greater than 30 mg/L, and adsorption to soil (Koc) less than 300-500 (Struss and Becker, 2007).

Table 1. Herbicides and their chemical characteristics, health impacts, and legal limits in water.

Herbicide	Solubility (mg/L)	Koc (ml/g)	Persistence (Aerobic soil half-life average in days)	Human health impacts	EPA MCL (µg/L)
Atrazine (for comparison) (EPA, 2015)	20 to 35	122	60-100	Reproductive disorder, endocrine disorder, liver, kidney, and heart damage, possible carcinogen	3
Acetochlor (Struss and Becker, 2007)	223	176	14	Developmental abnormalities, neurologic abnormalities, thyroid disruption, likely carcinogen	2
Dicamba (NIH, 2015; Bunch et al., 2012)	4,500	7-34	4.4-60	Reproductive disorder, developmental disorder	NA

Flumetsulam (EPA, 2014)	5,650	28	45	None found, no cancer study performed (EPA, 2014).	NA
Glyphosate (Battaglin et al., 2005)	10,000 to 15,700	9 to 24,000	47	Probably carcinogenic (Guyton et al., 2015), possible endocrine disruptor	700
Mesotrione (Toxnet, 2005)	160	15-390	4.5-32	Developmental Toxicity	NA
Paraquat	620,000	~1,000,000	1000	Moderate to high acute toxicity (EPA, 1997)	30 (advisory level, no MCL)

The table above shows that for many of the pre-emergence herbicides listed, there are risks associated with entering water resources, persistence, or health impacts. Although there are no known human health impacts for the herbicide flumetsulam, its properties make it highly likely to enter water resources, creating a risk that it may be used and enter water resources only later to have the health impacts discovered. There is not a clear, low-risk pre-emergent herbicide alternative to atrazine that should be recommended.

The survey with corn growers in Italy described in Chapter Two showed that farmers reported no changes in yields as a result of the atrazine ban. This is in opposition of studies funded by Syngenta that estimate that corn yields would decrease in the US if atrazine were banned. In addition, 66% of the Italian survey respondents reported that they would not use atrazine if it were legal, stating that atrazine is an antiquated herbicide, the alternatives work just as well, and it is too dangerous for human health (Chapter Two, pages 12-14). As described in Chapter Three, the Wisconsin NASS survey of growers found that 50% of growers found growing corn without atrazine to be no more difficult than growing with atrazine, and that only 5% of growers not using atrazine experiences a decline in yield (Chapter Three, page 45). The assertion by many Italian and Wisconsin farmers that they do not require atrazine, nor would many want to use it if it were possible, illustrates that alternatives are being used and that atrazine is not essential for corn production.

Alternatives to atrazine are being used both in Italy and Wisconsin, but at different rates. On average, Italian farmers surveyed in Chapter Three used 3.3 lbs./acre of commercial herbicide product. In Wisconsin, farmers inside PAs used on average 2.18 lbs./acre of commercial herbicide product. The smaller amount of herbicides used in Wisconsin within the PAs may be due to a greater use of glyphosate and less of a reliance on different alternative herbicides.

One possible alternative path away from atrazine is to transition from the over-reliance on pre-emergence herbicides towards the use of targeted applications of selective post-emergence herbicides. Post-emergence herbicides have their own risks, but they are generally applied to less surface area and in lower doses. This strategy of precise post-emergence applications and a reduced use of pre-emergent herbicides was adopted by French corn farmers after a ban on all triazines in 2005.

The atrazine example demonstrates the need for policies like the SUD that include banning the most polluting pesticides as well as decreased reliance on pesticides all together. The survey of Italian growers in Chapter Two found that 74%

of farmers reported reducing pesticide use as a key factor in water quality protection. This finding demonstrates that farmers are aware of the potential environmental benefits of reducing pesticide use, yet they must receive the technical and advisory support needed to make reduced use widely adopted.

Mandatory requirements for reduced pesticide use in agriculture

The SUD uses its mandate that all farms adopt the general principles of IPM as a tool to decrease pesticide use. Learning from the goals and early implementation of this aspect of the SUD offers insights into how a similar program could be adopted in the US. The US Farm Bill could transition from voluntary measures and incentives for environmental protection to mandatory requirements for pesticide reduction through the adoption of IPM. An important first step in creating this type of policy in the US would be cultivating the political will to set a goal for reduced pesticide use. For example, the French NAP for the SUD, Écophyto 2018, set a national goal of reducing pesticide use by 50% over the period of 2010-2018. Such a goal demonstrates the commitment of government officials to protect the environment even when faced with strong pressure from the chemical industry and agricultural lobbyists. There is an opportunity for the US to set its own goals for pesticide reduction and use the tools of IPM and education already underway in the EU to achieve such a goal.

Conclusion

The health risks from widespread pesticide pollution in the US create a need for new rules to reduce pesticide use and protect environmental resources. A US policy that draws upon the components of the SUD would fill a policy gap by nationally promoting safer pesticide stewardship and reduced use. For such policy changes to occur, there needs to be the understanding that water quality protection requires a reduction in pesticides use. Pairing precautionary environmental standards and decision-making with the commitment of US federal agencies to reduce agrichemical use would improve the quality of our water resources and public health.

7. Appendices

Appendix 1. Italian survey questions

Caro/a Partecipante,

Le chiedo la cortesia di compilare il seguente questionario sull'uso del diserbante per il mais e sulle decisioni degli agricoltori. Questo é parte di un progetto del mio dottorato per confrontare le pratiche agricole in Italia, in altri paesi europei e negli stati uniti. I risultati di questo progetto saranno utilizzati per lo sviluppo delle politiche per la produzione agricola e la conservazione dell'ambiente.

Questa ricerca é il risultato di una collaborazione tra le universitá della California, di Bologna, e di Padova.

Questo questionario é interamente anonimo e lo si può compilare in 10-15 minuti. Le domande richiedono informazioni riferite all'anno scorso (2011).

Premio iPad!: Apprezzo la sua partecipazione e, alla fine di questo progetto, verrà estratto un participante che riceverà in premio di un iPad nuovo.

Grazie mille per le sue informazioni, le sue opinioni saranno molto utili.

In che regione é l'azienda?

Quali sono le colture principali realizzate in quest' azienda?

	Ettari
mais	
soia	
orticoltura	

frutta

altri cereali

colture foraggere

Altri (specifica sotto)

Altri (specifica sotto)

Totale

Le seguente domande riguardano il mais. Se non produca mais, Lei puó rispondere invece sulla coltura pricipale della azienda.

Le seguente domande riguardano il mais.

Il mais prodotto é certificato "Biologico" ?

L'azienda é certificata "Biologica" sin dall'inizio dell'attivitá agricola?

Il mais é stato coltivato per essere raccolto come_______________________?

Avete ricevuto negli ultimi cinque anni (ad eccezione dei contributi UE per le colture o pagamento diretto) finanziamenti pubblici per la tutela e la conservazione ambientale (eg. schema agri-ambientali, fasce tampone, lotta integrata, colture di copertura, Quali motivazioni l'hanno spinta a produrre biologico?

Quali pratiche usate per la lotta contro la erbe infestanti?

Qual'é la parte piú difficile nella lotta biologica alle erbe infestanti?

C'é una differenza di costo nella lotta contro le erbe infestanti tra prima e dopo il passaggio al biologico?

Quantifica la differenza di costo nella lotta contro le erbe infestanti:

Materiali

Lavoro

Altro (specifica sotto)

Altro (specifica sotto)

Qual'é il costo per la lotta contro le erbe infestanti?

Materiali

Lavoro

Altro (specifica sotto)

Quale é Il prezzo di vendita del tuo mais per quintale per l'anno 2011?

Prezzo (Euro/quintale)

2011

Quale é la resa per ettaro?

quintale/ettaro

Secondo la sua esperienza, l'agricoltura biologica é economicamente piú conveniente rispetto a quella tradizionale?

Secondo Lei cosa dovrebbe cambiare per incoraggiare piú agricoltori a usare l'agricoltura biologica?

Quali pratiche usate per la lotta contro la erbe infestanti?

Per il mais, quali sono i diserbanti utilizzati nel corso del 2011

Qual e' stato il costo medio dei trattamenti di controllo delle erbe infestanti per ettaro/anno?

	Costo (€)
Costo del diserbante	
Costo applicazione	
Altri costi (specifica sotto)	

Qual e' stato il costo medio dei trattamenti di controllo delle erbe infestanti per ettaro/anno?

	Costo (€)
Costo del diserbante	
Costo applicazione	
Costo falsa semina	
Costo sarchiatura	
altri costi (specifica sotto)	

Sono stati utilizzati, in rotazione, diserbanti diversi con lo scopo di prevenire la resistenza degli infestanti ai diserbanti?

Effettua verifiche e monitoraggi dell'infestante per sapere la tempistica, il dossaggio, e il prodotto giusto del diserbante?

E' mai stata usato il diserbante "atrazina" in quest'azienda agricola?

Quantitativo medio di atrazina che é stato usato per ettaro/anno?

Quali pratiche sono cambiate nella sua azienda in seguito al divieto di utilizzo dell' atrazina?

Se fosse permesso, userebbe atrazina?

La resa del campo é cambiata in seguito al mancato utilizzo di atrazina?

Si ricorda se il prezzo di vendita del suo mais aumentó per effetto del divieto di utilizzo dell'atrazina?

Quantifica sotto:

Il prezzo che paga per il diserbante é cambiato rispetto all' atrazina?

Quanto (in percentuale) paga in piu per i diserbanti chimici usati attualmente rispetto all'atrazina?

Quando e' necessario prendere una decisione riguardo le pratiche e i prodotti per il controllo degli infestanti, quali canali informativi consulta?

Quali sono i criteri piú importanti quando scegli un nuovo diserbante?

Secondo Lei, quale é la definizione per la lotta integrata (IPM)? Per favore, includa le pratiche usate per la lotta integrata

Ha sentito della direttiva della Commissione Europea sull'uso sostenibile degli agrofarmaci (Sustainable Use Directive)?

Selezioni tutte le tecniche che utilizza per la protezione dell'ambiente.

Quanto incidono i seguenti aspetti sulle scelte (di tecniche, procedure etc...) da lei effettuate in materia di protezione ambientale?

Perche non ha adottato queste tecniche per l'ambiente come lotta integrata degli infestanti, colture di copertura, e fasce tampone?

Proverebbe una delle strategie di tipo ecologico se ricevesse?

Quanto dovrebbe essere l'incentivo per ettaro affinchè lei adotti una di queste tecniche?

lotta integrata degli infestanti

colture di copertura

fasce tampone

rotazione delle colture

agricolura biologica

Secondo Lei, quale sono le pratiche piú importanti che gli agricoltori possono fare per proteggere l'acqua dall'inquinamento del diserbante chimico?

Qual'e' la distanza della sua azienda dal piu' vicino corso d'acqua o ricarica delle acque sotterranee?

Quali sono secondo lei i principali bisogni / necessitá (es. specifica tipo di informazioni, supporto economico, consulenza etc...) per chi pratica l'agricoltura biologica ?

Indirizzo email:

Appendix 2. Syntax from Mixed Effects Model

Main mixed model with all effects:

```
USE ALL.
COMPUTE filter_$=(Concentration < 30 and Year > 1986 and Year < 2014).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1986 and Year <
2014 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
MIXED logConcentration BY PAByYearnomissings After1991 WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year PAByYearnomissings*Year After1991*Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

Pre-1991:

```
COMPUTE filter_$=(Concentration < 30 and Year > 1986 and Year < 1992).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1986 and Year <
1992 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
MIXED logConcentration WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

Post-1991:

```
COMPUTE filter_$=(Concentration < 30 and Year > 1991 and Year < 2014).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1991 and Year <
2014 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
```

```
EXECUTE.
MIXED logConcentration BY PAByYearNoMissings WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year PAByYearNoMissings*Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

Concentration by PA status and year:

```
COMPUTE filter_$=(Concentration < 30 and Year > 1986 and Year < 2014).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1991 and Year <
2014 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
MIXED logConcentration BY PAByYearNoMissings WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

PAByYear=0 All years:

```
COMPUTE filter_$=(Concentration < 30 and Year > 1986 and Year < 2014
and PAByYearNoMissings = 0).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1991 and Year <
2014 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
MIXED logConcentration BY PAByYearNoMissings WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

PAByYear=1 All years:

```
COMPUTE filter_$=(Concentration < 30 and Year > 1986 and Year < 2014
and PAByYearNoMissings = 1).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1991 and Year <
2014 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
MIXED logConcentration BY PAByYearNoMissings WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

Post-1991 PAByYear=0:

```
COMPUTE filter_$=(Concentration < 30 and Year > 1991 and Year < 2014
and PAByYearNoMissings = 0).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1991 and Year <
2014 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
MIXED logConcentration WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

Post-1991 PAByYear=1:

```
COMPUTE filter_$=(Concentration < 30 and Year > 1991 and Year < 2014
and PAByYearNoMissings = 1).
VARIABLE LABELS filter_$ 'Concentration < 30 and Year > 1991 and Year <
2014 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
```

```
FILTER BY filter_$.
EXECUTE.
MIXED logConcentration WITH Year
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10)
SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0, ABSOLUTE)
LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=Year | SSTYPE(3)
  /METHOD=REML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=Year | SUBJECT(Well) COVTYPE(ARH1).
```

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