Topics in Canadian Weed Science Volume 7

The Politics of Weeds

Edited by
K. Neil Harker

Canadian Weed Science Society
Société canadienne de malherbologie

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Foreword

Politics and science...can they complement one another or can one override the integrity of the other? This exciting volume published by the Canadian Weed Science Society- Société canadienne de malherbologie brings together topics that are being debated aggressively within our society. Members of society are demanding answers regarding the sustainability of our crop protection chemistry, the role of climate change, crops for biofuels and the movement of genes from one organism to another. Should the use of crop protection chemistry be restricted to agriculture and banned from the urban environment? These issues affect all of us.

This volume brings these diverse topics together in a clear and concise format in order to provide you the reader with information to assist in formulating your opinion on these issues. Experts from a wide range of specializations provide their unique insights on these issues. You will read of the challenges facing new discovery and innovation in the crop protection industry. The recognition that biofuels have their limitations but there are methods to identify risks and methods for mitigating against the release of potentially invasive species. The ability of genes to move from plants to microbes remains a possibility but little is known about the frequency and our ability to detect these changes is limited by current methodology. And finally, is the perfect lawn a sign of wealth and prestige? Are we able to change our historical view of the perfect lawn and on what principles are we asked to consider this option?

As a scientific society, we encourage open and rigorous debate. It is our goal as a society that science remains the platform upon which political policy is based. If politics can override the integrity of science in the formation of government policy, then we have truly stepped onto a slippery slope. The chapters within this book provide a fair assessment of the strengths and weaknesses and the concerns of the science underpinning the politics of weeds.

The discovery, development and registration of new products that meet exacting safety standards and deliver significant benefits require a highly integrated, multi-disciplinary approach. An understanding of the processes used to assess the risks and benefits of plant protection products is fundamental to the debate on their role in modern agriculture. The industry approach to addressing the challenges and hurdles faced from discovery, through development, product launch and beyond is described.

Here we outline the potential risks posed by biofuel crops, methods for identifying those risks, and recommendations for mitigating against the introduction of future invasive species welcomes you to our seventh volume entitled, “The Politics of

Weeds". This volume brings together current issues that are Horizontal gene transfer (HGT) from plants to microbes is a rare event and methodological constraints to routinely detect such rare events have not yet been overcome. As a result, the consequences of HGT from plants to microbes remain unknown.

Clarence Swanton
President, 2008
CWSS-SCM

Preface

The Canadian Weed Science Society – Société canadienne de malherbologie (CWSS-SCM) is pleased to present the seventh volume of *Topics in Canadian Weed Science.* This volume is a compilation of peer-reviewed papers that were presented at the plenary session of the 2008 CWSS-SCM annual meeting held in Banff, Alberta. '*The Politics of Weeds',* the theme of the plenary session, was addressed in a balanced manner with scientific data and viewpoints presented by a diverse group of speakers.

Topics in Canadian Weed Science is intended to advance the knowledge of weed science and increase awareness of the economic and environmental impact of weeds in agro-ecosystems, forestry, and natural habitats. The volumes cover a wide range of topics and provide a diverse source of information for weed science professionals and the general public.

The plenary session topics at the CWSS-SCM annual meeting are of both national and international interest, and we invite weed science professionals from around the world to attend our annual meetings. The annual meeting is held in mid- to late November, with locations alternating between Eastern and Western Canada. Information on the CWSS-SCM annual meeting is available on the website (www.weedscience.ca/home).

The CWSS-SCM Board of Directors expresses their gratitude to Neil Harker, the Banff Local Arrangements Committee, the contributing authors, and the reviewers who have made this publication possible. Other volumes in this series include:

Volume 1: *Field boundary habitats: implications for weed, insect, and disease management*
Volume 2: *Weed management in transition*
Volume 3: *Soil residual herbicides: science and management*
Volume 4: *Invasive plants: Inventories, strategies, and action*
Volume 5: *The first decade of herbicide-resistant crops in Canada*
Volume 6: *Physical weed control: Progress and challenges*

These volumes are available for purchase and can be ordered through the CWSS-SCM website.

Eric Johnson
Publications Director
CWSS-SCM

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Photograph: Canada thistle in barley by K. Neil Harker

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Introduction

In most scientific forums "politics" can and should be avoided. Politics can hinder or greatly assist scientific inquiry depending on the mood and whims of the voting public and their carefully listening (polling) political leaders. Scientists thrive in environments that guarantee long-term funding for specific questions as opposed to those in which "band-wagons" are encouraged and then promptly discouraged in a matter of months. Indeed, to adequately answer the complex questions they undertake, scientists require long-term, multi-disciplinary experiments; neither of which is feasible in a constantly changing environment. Nevertheless, it is politics, in most cases, that determines the strategic directions of granting agencies and funding levels for government and university research infrastructure and operating costs.

Weeds, weeds research, and weedy issues are certainly not exempt from politics and political influence. In fact, it is rather surprising how many recent, provocative headlines have some relation to weeds and weedy issues. Following is a sample of such headlines:

"Super Crops Lead to Super Weeds"

"Quebec Herbicide Ban Violates NAFTA"

"Death of the Bees: GMO Crops"

"Climate Change: The New Talk of Farm Country"

"Herbicide Ban Causing Headache for Drivers"

"Ubiquitous Herbicide Emasculates Frogs"

"GMOs: Blowin' in the Wind"

"Canadian Cancer Society Applauds Pesticides Ban"

"Paucity of New Herbicide Modes of Action"

“Crop Sprays a Risk to Health, Rules High Court”

“Forget Herbicides, Weed-whackers: Get some Goats”

“Weed-and-feed Ban Spreads to Alberta”

“Who Is Responsible for the Global Food Crisis?”

“Clone Appétit”

Achieving consensus on controversial issues is difficult, but open discussions and presentations can provide the basis for making informed decisions. In the “Politics of Weeds” Opening Plenary Session the following seven speakers addressed topics that related to politics and weeds.

1. Simon Barber (Syngenta Seeds) – “*Politics and Public Perceptions of GMOs*”
2. Dean Thompson (Canadian Forest Service) - *“Glyphosate Impacts on Amphibians (Frogs)”*
3. Iain Kelly* (Bayer CropScience) - *“An Industry Perspective on Product Development Hurdles”*
4. Barry Smit* (University of Guelph) - *“Climate Change and Weeds”*
5. Jacob Barney* (UC Davis) - *“Are the Best Biofuel Crops Potential Invasive Species?”*
6. Rob Gulden* (University of Manitoba) “*Transgene Incorporation into Non-Target Species*”
7. Robin McLeod* (Coalition for a Healthy Calgary) - *“Urban Pesticide Use: Challenges & Problems”*

By supporting this forum, the Canadian Weed Science Society demonstrates its relevance with respect to some of the important political issues of our time. Five* of the seven speakers have summarized their presentations in this volume. I wish to thank the authors and reviewers for their contributions to the session and this monograph. The views expressed herein are from a wide array of interests; I trust that you will enjoy their work.

An industry perspective on challenges and hurdles faced in the development of agrochemicals

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Agricultural production today, faces many competing pressures. As world population grows and wealth in developing nations rises, the demand for high quality food is increasing. This trend is predicted to continue until at least the middle of this century. Today's population of 6.8 billion is estimated to increase to 9.2 billion (medium variant estimate) by 2050 with a projected leveling off around 11 billion (United Nations 2009). Options to meet this growing demand are limited; either increase food production on currently used arable land or put more land into production. Available land, however, is a finite commodity and generally a highly valued natural resource. Increasing yields on currently cropped land will be required for the foreseeable future. Plant protection products play an essential role in ensuring increased yields and stable harvests. Older chemistries are being phased out, requiring that new ones with different modes of action be introduced to meet the challenge of resistance management while delivering product profiles required to meet current societal views of sustainability. Development of a modern plant protection product faces many challenges. The discovery, development and registration of new products that meet exacting safety standards and deliver significant benefits require a highly integrated, multi-disciplinary approach. An understanding of the processes used to assess the risks and benefits of plant protection products is fundamental to the debate on their role in modern agriculture. The industry approach to addressing the challenges and hurdles faced from discovery, through development, product launch and beyond is described.

Role of Agrochemical Development

Many studies have estimated the effect of plant protection products on crop yields. In a detailed review article it was calculated that crop production in the United States would decline by 20% without the use of herbicides alone, even with the substitution of tillage and hand weeding (Gianessi and Reigner 2007). The earth's land surface is approximately 13.4 billion hectares of which 10.5% (or 1.55 billion hectares) is currently arable land. It has been estimated (Avery 2000) that to feed a world population of 8-9 billion people without the use of agrochemicals and fertilizer would require an additional 7.8 billion hectares of forests, prairies and other prime wildlife habitat to be put into production. The FAO has indicated that world resources are adequate to produce the required food supply, acknowledging that agrochemical use will be required along with "smart" pesticides, resistant crop varieties and integrated pest management approaches (FAO, 2002). Non-arable land is a valued resource and necessary for the existence of many species. Maintaining it is a key feature of sustainability and agrochemicals play an important role in this.

To maintain the benefits of agrochemicals, innovation is essential. Although there are a large number of active ingredients on the market, there are only a limited number of modes of action available to growers. Insecticides are probably the most dramatic illustration of this with three modes of action accounting for approximately 75% of insecticide sales (Cheung and Sirur 2003). These are the sodium channel modulators (pyrethroids), acetylcholine esterase inhibitors (organophosphates and carbamates) and nicotinic acetylcholine receptor antagonists (neonicotinoids). Herbicides and fungicides have about six modes of action accounting for 75% of sales. Resistance management, therefore, has limited options and the introduction of new modes of action is critical to our ongoing ability to control pests and disease. Fungicides are particularly vulnerable to the development of resistance due to the multiple generations that must be controlled each season.

In looking for new plant protection products many attributes are considered. A high degree of efficacy that is consistent under a range of conditions and a favorable cost-benefit ratio for the grower is a pre-requisite of any candidate for development, but many other features are taken into account. Rapidity of onset of activity, duration of activity, selectivity, redistribution within the plant, compatibility with integrated pest management techniques and low risk of resistance are desirable properties of an efficacious product. At the same time, low toxicity to beneficial and other non-target organisms, rapid environmental degradation, low mobility in soil and minimal residues in foods and animal feed are desirable environmental properties. Low application rates, low acute and chronic toxicity, formulations that are stable and easy to use and safe packaging contribute to human safety. Balancing all these attributes is not an insignificant task as some of the desirable properties tend to counteract each other. For example, compounds that are translocated effectively within plants tend to be potentially more mobile in soil; compounds that degrade rapidly in the environment tend to have no or limited residual efficacy. Finding appropriate candidates with the best balance of properties, therefore, requires an intensive discovery and investigation process. Bringing the right candidates to market does not only ensure a supply of new, safe, efficacious products but can also reduce energy inputs. Improved efficacy results in less material being transported since reduced amounts of materials are applied. Good residual activity results in fewer applications requiring less passes across the field again lowering fossil fuel use. The continued development of new plant protection products therefore contributes significantly to the sustainability of agriculture.

Agrochemical Discovery

Figure 1 shows Bayer CropScience's estimate of the number of compounds screened each year (averaged for a decade) to discover one to two new commercial products. The numbers are increasing continually and today it is approaching 1 million.

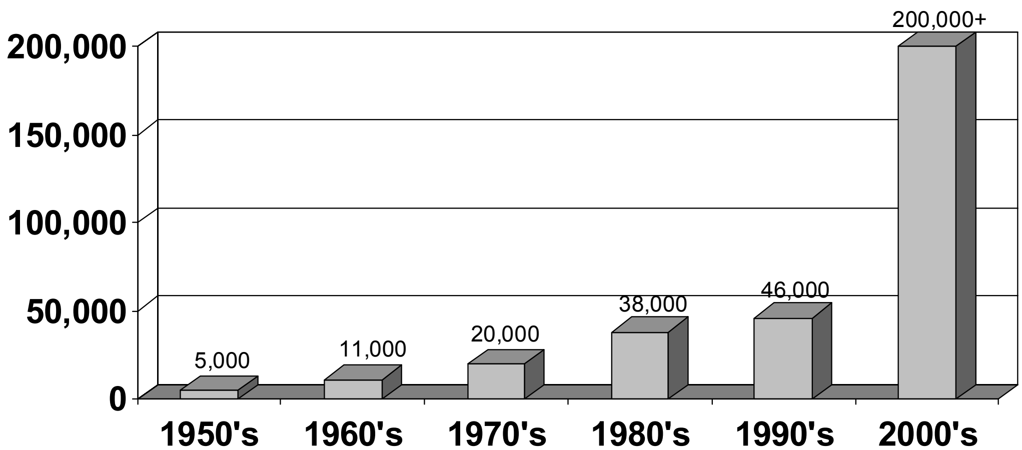

Figure 1. Compounds Screened per Year to Deliver One to Two Commercial Products.

Screening success is diminishing while time to first sales is getting longer; this contributes to increased development costs. However, innovative ways are being found to improve the chances of screening success using target-based discovery (Wolfgang et al. 2004). Typically this uses high throughput (10,000 plus assays/day) or ultra-high throughput (100,000 plus assays/day) screening coupled with combinatorial chemistry (Petsko et al. 1999). High throughput screening is based on the use of micro titer plates (96-well, or multiples thereof) to conduct the assays. Within these plates, tests can be either conducted on molecular targets, or in the case of herbicides, *in vivo* tests on whole plants (Kraehmer et al. 2007).

The capability to conduct large numbers of chemical screens has been accompanied by the ability to produce large numbers of novel chemicals to test in these screens. Combinatorial chemistry has been a major source of novel chemistry. A chemical is bound to polymer beads and aliquots reacted with a range of secondary chemicals. The products can then either be released from the beads for screening or aliquots of each reacted with a range of tertiary chemicals. The process can be repeated multiple times, increasing the number of compounds produced exponentially. Libraries of compounds for testing are produced internally by basic manufacturers and sourced from external collaborators. The whole process of synthesis and screening is highly automated but still requires considerable skills from the chemist to focus the process on producing leads that will have the desirable attributes required of plant protection products.

An advantage of this approach to finding new active ingredients is that specific biochemical sites within an organism are targeted. Once lead compounds are found that effectively interact with or inhibit a target, leads can be optimized for efficacy by repeating the screening process. Promising leads undergo a tiered selection process, starting at micro-screening that may use cell suspension or small plants, through greenhouse screening and finally screening at multiple field locations representing the major climatic zones for crops of interest. The number of compounds at each stage of screening varies somewhat based on indication area and company but a typical progression is shown in Figure 2.

The move to target driven research has greatly increased the multidisciplinary nature of the agrochemical discovery program. Traditional areas of scientific expertise in chemistry, plant pathology, entomology, microbiology, plant breeding, seed technology, toxicology, human exposure, ecotoxicology and environmental fate have been augmented with genomics, robotics, biochemistry, bioinformatics, combinatorial chemistry and nanotechnology.

Even with these advances, very few new modes of herbicidal action have been introduced in the last 20 years with the HPPDase inhibitors (Pallett et al. 2001) being one of the few. Several reasons exist for this (Kraehmer et al. 2007). These include the move to genetically-engineered herbicide tolerance in several crops, particularly soybeans, with a resultant decline in the number of different herbicides used on the crop. Despite this, numerous technology gaps remain with the need for innovative herbicide solutions. Many companies, however, have moved their focus away from herbicide screening with lower research and development funding being allocated to the area. Probably two, or at most three, companies are likely to remain committed to the field of herbicide screening employing screening methodologies that are still improving. The introduction and refinement of Ultra-High-Throughput-in-Vivo-Screening (UHTVS), Target-based Ultra-High-Throughput-Biochemical Screening (UHTBS) and Virtual-Target-Based-Screening (VTBS) hold hope for new modes of herbicidal action. New insecticidal modes of action have been introduced recently such as the acetyl CoA carboxylase inhibitors (ketoenols, e.g. spirotetramat) and the phthalic acid diamides (e.g., flubendiamide, chlorantraniliprole), which activate the ryanodine-sensitive calcium ion release channel in insects. The phthalic acid diamides, critical for maintaining calcium ion balance, are an excellent example of the benefit of ongoing research. The insect ryanodine receptor is different from the human receptor (Ebbinghaus-Kintscher et al. 2006), and therefore insecticides can be developed with high activity against insects while exhibiting low human toxicity.

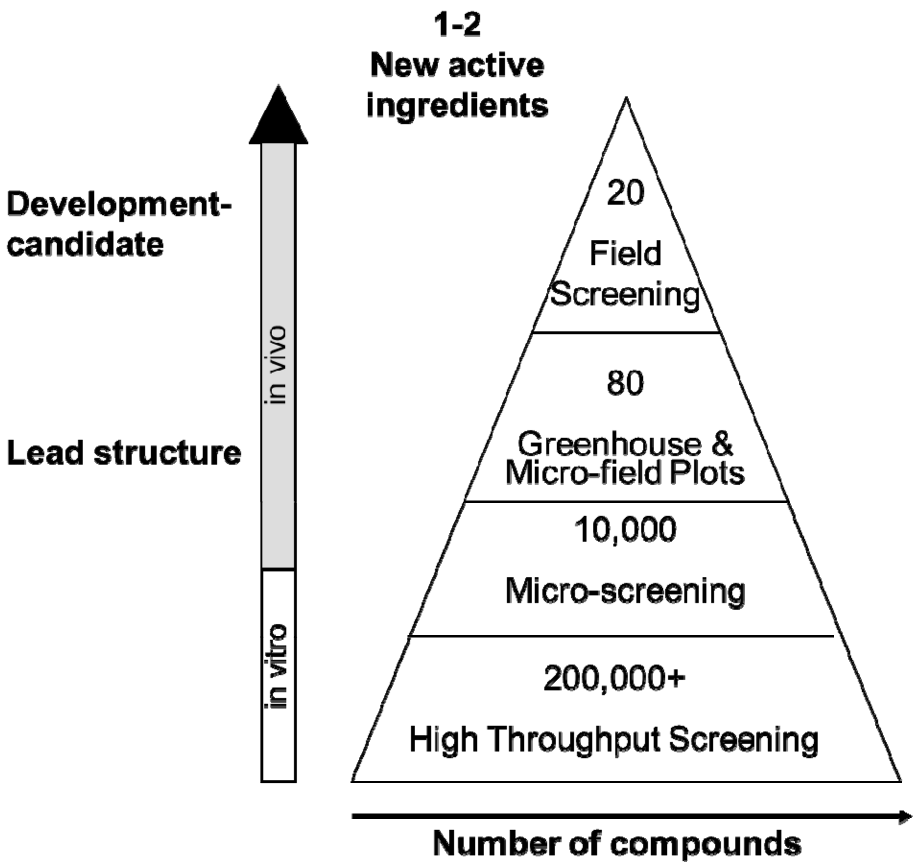

Figure 2. Screening Process for New Active Ingredients.

Assuring the Safety of Agrochemicals

Plant protection products have arguably the most extensive and diverse testing scheme for any class of chemistry used today. From a public perspective it is critical that a new product has been assessed to be safe prior to introduction. Rigorous well-designed schemes have been developed to assess the risk to both humans and the environment and these are carried out under strict guidelines laid out by national and international authorities. In the U.S., the Office of Pesticide Programs (part of the EPA) and in Canada the Pest Management Regulatory

Agency (part of Health Canada), have primary responsibility for assessing safety and authorizing the use of plant protection products. Both have extensive web sites that describe their processes and give detailed descriptions of the data evaluated and the conclusions reached. Overviews are available (Whitford et al. 2003, 2004). Both agencies use a risk based assessment to ensuring the public and the environment are protected. Risk is a function of both toxicity and exposure, which are evaluated separately then integrated in a risk characterization to predict the likelihood of adverse human health or environmental effects.

Evaluation of human toxicity includes studies on a wide range of surrogate species including rats, mice, rabbits, guinea pigs, dogs and occasionally on human subjects when it can be ethically justified under strict international standards. All critical stages of the human lifecycle are considered. Short (acute), intermediate and long-term (chronic) effects are investigated. Particular attention is paid to potential effects on reproduction and development. As well as investigating toxicity, the source of potential exposure is considered. All sources and routes of exposure are addressed and the contribution summed or “aggregated”. This may include residues in food or drinking water or for residential exposure through contact with treated areas such as turf. In addition to assessing the risk from individual chemicals, the risk from multiple chemicals that share a common mechanism of toxicity is also considered. Specific risk assessments are conducted for workers who mix, load and apply chemicals as well as come into contact with treated areas through crop management practices

Evaluation of the risks to the environment is also extremely extensive. Ecotoxicologists test for potential short and long-term effects on birds, aquatic organisms including fish and invertebrates (freshwater and marine), sediment dwelling organisms, and non-target plants. Potential effects on beneficial organisms such as bees and earthworms are also assessed. At the same time, the processes of degradation and dissipation in the environment are assessed as part of the exposure characterization. Routes of dissipation of a product applied to a crop include volatilization from soil and water, run-off, leaching, spray drift, drainage, uptake by plants and rotational crops; all of these are assessed. Degradation can occur via sunlight, hydrolysis, soil microorganisms, sediment microorganisms and plant metabolism. Exposure models can be used to determine chemical concentrations in the compartments within which an organism may be exposed, e.g., soil, water, and sediment. Conservative assumptions are made in the parameters used in these models to ensure risks are not underestimated. At times monitoring data may be developed and used to give a more accurate determination of exposure.

Only after risk characterization is complete and it has been assessed that a new product can be used with minimal risk is it allowed to be sold. Safety assessment, however, is not a once only operation. Plant protection products are continually assessed throughout their lifecycle including when new uses are being considered and under formal periodic regulatory review.

The development of a new active ingredient is now estimated to take approximately 10 years from discovery to launch at a cost of about US$270 million. Prior to making this investment a company wants assurances that the final product will meet today's exacting safety standards. As soon as lead structures are identified safety testing begins. This will start with limited testing using small amounts of compound either *in vivo* on small organisms such as algae or daphnia or *in vitro* testing such as the Ames bacterial test for mutagenicity as a potential carcinogenicity indicator. Structure activity relationships and knowledge of the mode of action can also identify specific tests that will be conducted. This information will be used with the screening information (Figure 2) to select candidates that are highly efficacious with optimal safety profiles. By the time a candidate molecule is selected that has a high probability of becoming a commercial product (approximately three years before submission for regulatory approval), detailed information is available about its acute and prolonged toxicity to wildlife, and its acute, subchronic and development toxicity to humans. Surrogate information and past experience can be used to estimate exposure and thus characterize risk to provide a high level of assurance that the final product will be registerable and safe to use. This information notwithstanding, the major expenditure in safety testing occurs after this assessment and prior to regulatory submission as confirmatory long term toxicity and extensive residue and environmental field studies are conducted.

Following registration, the assessment of safety continues. Any potentially adverse effects that come to the manufacturer must, by law, be promptly reported to the appropriate agency to allow the authorities to determine whether it is a justified concern that warrants regulatory action. Additionally, authorities (EPA and PMRA) periodically, generally on a ten to fifteen year cycle, undertake a complete review of products on the market to ensure that they have a database that meets current standards and integrates all available information into the risk characterization.

Public Environment

Since their introduction, there has been tremendous progress in reducing the potential risk that synthetic chemicals pose. Improved screening processes, identification of taxa-specific modes of action, extended and better validated testing protocols have all contributed to this. Use rates have fallen significantly, environmental detections are generally tending downwards (Gilliom et al. 2006) and overall safety has increased, but paradoxically, so has public concern. Incorporating the views of concerned citizens into environmental policy debates is a core value of a democratic society, but in the case of plant protection products, its application is a complex one. Non-governmental organizations, regulatory authorities, the crop science industry, scientific community, consumers, food retailers and growers all have valid inputs from a domestic perspective, but the discussion also has implications for global trade. Lay persons and a range of technical experts have to be able to interact on the issue. Grounding such discussions by first undergoing a structured approach to assessing stakeholder values rather than initially focusing on arcane technical details has been proposed as a way of developing a more rational approach to the subject (Gregory et al. 2001).

Addressing and incorporating stakeholder concerns is well beyond the scope of this paper but it is important to recognize the role of risk assessment in the debate. Risk assessment quantifies the probability that an effect may occur and, therefore, attributes a number to it even though that number may be extremely small and essentially *de minimis* or indistinguishable from background. Under this process, by definition, no technology is completely free from risk. At the same time, given financial constraints, no technology is likely to be widely accepted if it is without significant benefit. In the area of plant protection products the debate frequently centers on conventional versus organic agriculture. The focus of this debate, however, often centers on the risks of synthetic chemicals and then often on one component of the risk such as toxicity, e.g., levels at which effects are seen, or exposure, e.g., detections in biomonitoring studies. A compound with low inherent toxicity but high exposure because it is used in high amounts can pose the same risk as a compound with high inherent toxicity that is used in low amounts. Risk assessment is a quantitative science whereas toxicity end points and exposure values, in isolation, are solely numbers. Any debate on the merits of a technology should quantify the risks and quantify the benefits while at the same time doing the equivalent calculation for the alternatives.

Summary

Plant protection products are an essential component in producing the constantly improving yields delivered by modern agriculture. Rising populations and the increasing demand for high quality food in developing nations will lead to the need for increased yields on available arable land or will put more arable land into production with the consequent loss of habitat. Continued development of new active agrochemicals is critical to increasing, or even maintaining, current yields. Novel synthesis methods and screening techniques have been developed to meet this challenge which now requires in the region of 1 million molecules to be screened to bring one new active ingredient to the market. Relatively prohibitive costs associated with the process, however, have resulted in only a handful of companies involved in novel product development.

Current regulatory requirements demand very strict safety standards for any agrochemical, and to ensure this, extensive safety testing starts early in the development of a new active ingredient and continues throughout its lifecycle.

There is also a need to ensure public participation surrounding questions of potential environmental impact. The latter requires that a platform be found to allow rational discussions of risks and benefits between lay stakeholders and a range of scientific experts.

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Climate change, agriculture and weeds

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Introduction

The agricultural sector worldwide has always had to deal with a wide range of conditions, which vary over time from day to day, season to season and year to year. Markets, inputs, costs, technologies, and government programs all affect how farmers and others in the industry operate, what they produce, and how they balance their books. Among the variable conditions that matter to agriculture is the weather, which varies over the short-term, and its manifestation in the climate which is the average of weather. It is now known that the world's climate is changing, a phenomenon commonly referred to as global warming. The changes in temperature and precipitation are expected to profoundly affect global agriculture, providing opportunities in some places and presenting risks, constraints or disasters in others.

Most studies of climate change impacts on agriculture are rather coarse scale estimates of yield changes under assumed average temperature scenarios. Much less attention to date has been given to changes in growing conditions associated with variability and extremes, and little attention has been given to the ways in which producers, and the industry generally, manage risks and opportunities, and even less attention has been given to indirect effects of factors such as diseases and weeds. As evidence of climate change has grown and as knowledge about its impacts has become more comprehensive, international organizations, national governments and other stakeholders have considered policy responses. These involve both attempts to "mitigate" climate change by reducing greenhouse gas emissions and initiatives to "adapt" to climate change and its effects.

This paper provides a summary of the state of knowledge on climate change, including what we know about extremes and variability; it then provides a review of the changes in climate that are expected to have implications for agriculture; it outlines the roles of greenhouse gas mitigation and adaptation as policy initiatives that have implications for agriculture, particularly in Canada; and it provides some insights into how climate change may affect weeds from the limited work in this area in the international literature.

Climate Change Science

The basic science of greenhouse gas emissions and climate change is now well established (IPCC, 2007). Human-induced climate change refers to the changes in temperature and other climate variables associated with the increasing accumulation of greenhouse gases in the atmosphere resulting from emissions from various human activities. These "anthropogenic" changes occur on top of the various "natural" variations in climate related to such phenomena as the earth's orbit, variations in the sun's energy, sun spots, volcanic activity and the El-Nino – Southern Oscillation (ENSO).

Increases in the atmospheric concentrations of greenhouse gases are unequivocal. Significant post-industrial increases in concentrations of carbon dioxide (CO_2), nitrous oxide, (N_2O), methane (CH_4), chloroflurocarbons (CFCs) and others have been documented (Fig. 1). The sources of the greenhouse gas emissions are well understood: CO_2 is released when coal, oil or natural gas are burned; N_2O is released from heavily fertilized soil, wood burning and some industrial processes; CH_4 comes from rice fields, wetlands, ruminants and biomass burning; CFCs are entirely human made (IPCC, 2007).

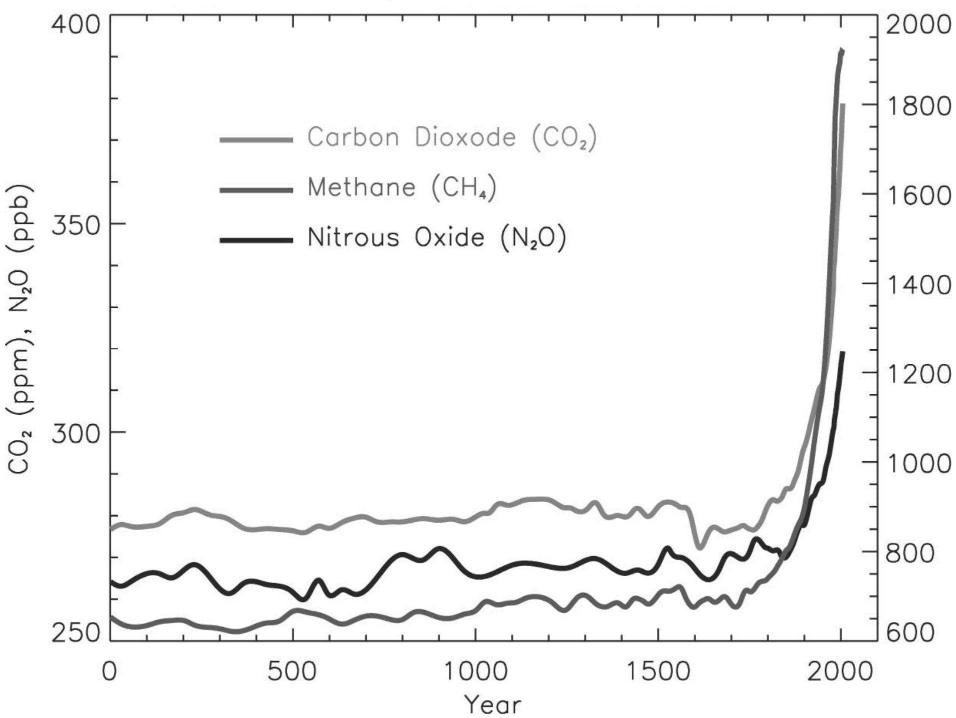

Figure 1. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 2000 years (IPCC 2007).

At the same time, earth ecosystem capture or sequestration of greenhouse gases (notably CO_2 in "carbon sinks") has been diminished, particularly as the area of forests has continued to be reduced. The net effect of increased emissions and reduced sinks has been a rapid growth in the "radiative forcing" of the atmosphere, manifest in increasing temperatures ("global warming") and changes in other climatic conditions (IPCC 2007).

Climate models, known as Global Circulation Models (GCMs), show very consistent projections for common emission scenarios, and their backcasting closely matches the observed variations in temperature (Fig.2). The IPCC (2007) and all the major national academies of science confirm that anthropogenic climate change is real, we are already experiencing its effects, and with the continued acceleration of greenhouse gas emissions, we will experience more profound effects over the coming decades.

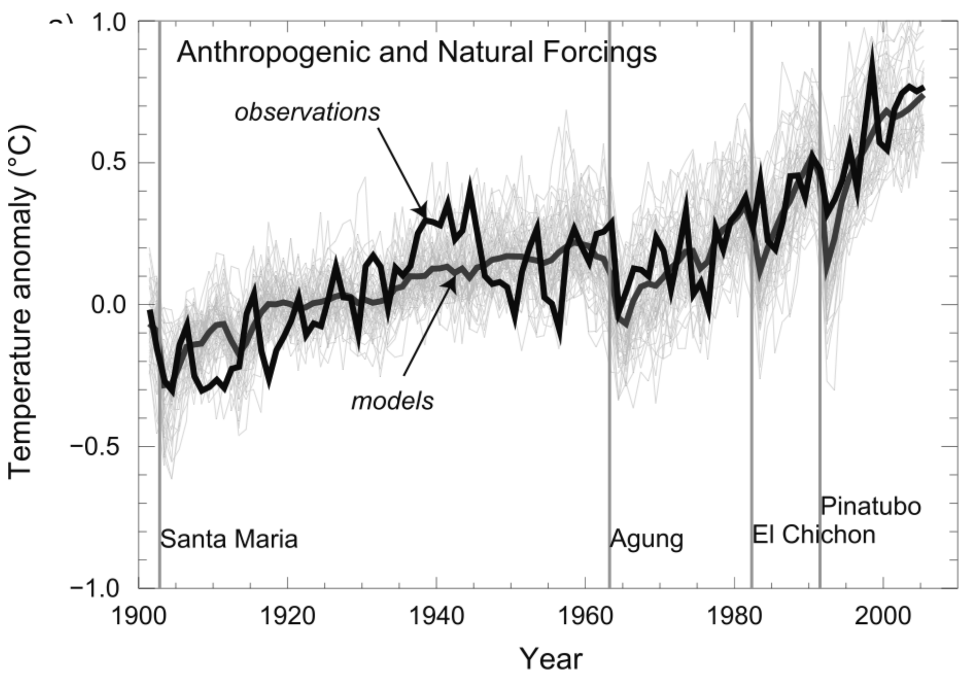

Figure 2. Global mean temperature as obtained from simulations with both anthropogenic and natural forcing compared with observations. Named verticals refer to volcanic eruptions (IPCC 2007).

Climate change is not only about increasing temperatures; it also affects precipitation, evapotranspiration, growing season length, droughts, frosts, extreme heat spells, etc. Fig. 3 shows a hypothetical time-series for drought severity (e.g., as per Palmer Drought Index). Drought severity varies considerably from year to year. The average (or "norm") is rarely experienced. Producers (and the sector generally) have the capacity or resilience to cope with the modest deviations from the norm, but they are vulnerable to extremes (i.e., where a moisture deficit or surplus exceeds their coping range or threshold). With changing climate, the norm may still fall within the coping range, yet there may be significant increases in the frequency and severity of some extremes beyond the coping range (droughts in Fig. 3).

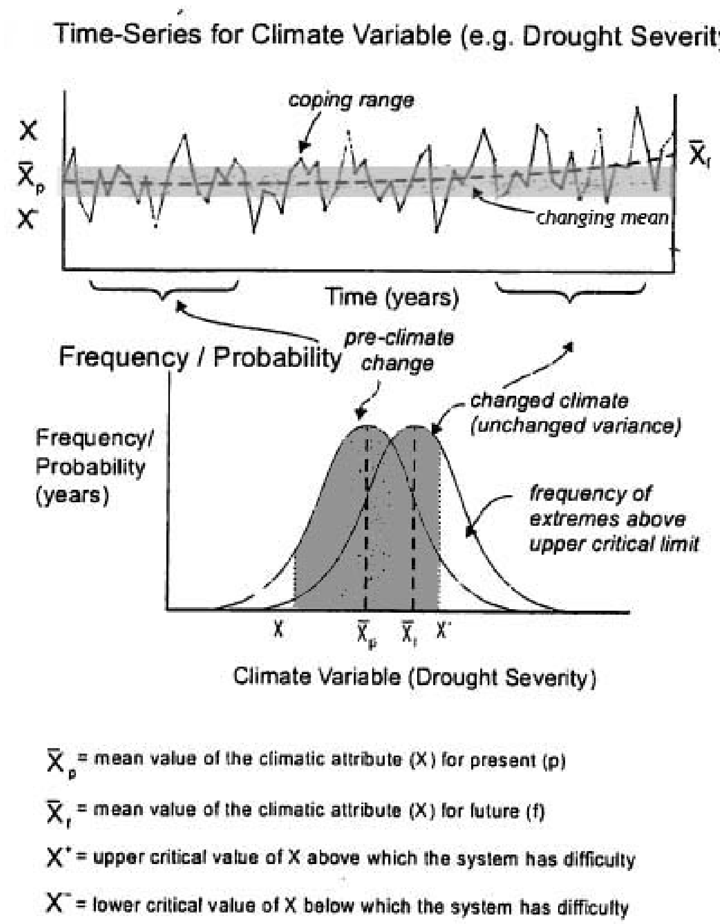

Figure 3. Climate change, extremes and coping range (Smit and Pilifosova 2003).

Climate Change and Agriculture

Climate change affects agriculture through the impacts of changes in climate and through possible policy responses, both mitigation and adaptation (Wall et al. 2007). The relationship among impacts and responses is summarized in Fig. 4. Climate change has physical-ecological impacts (e.g., heat, moisture, yield) and social-economic impacts (e.g., production, income, returns). The "mitigation" response aims to slow down or stop human modification of climate itself (via reducing greenhouse gas emissions and protecting or enhancing greenhouse gas "sinks"). The complementary "adaptation" response aims to modify agriculture so that it is not so vulnerable to the changing climate conditions (or so that it can benefit from the opportunities).

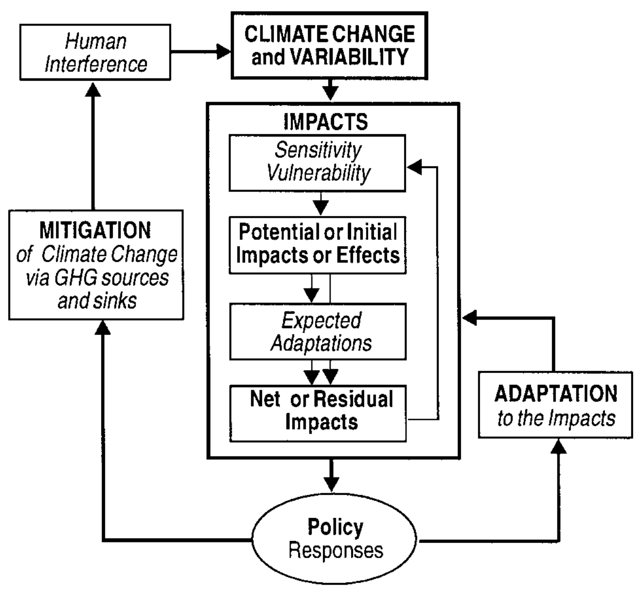

Figure 4. The relationship among impacts and responses in adaptation (Smit et al. 1999; Smit 1993).

Climate Change Impacts for Agriculture

Increases in temperature, the most widely modelled climate variable, are expected to be generally beneficial for Canadian agriculture, because of longer growing seasons and more available heat (Brklacich et al. 2007). Analysts have suggested higher yields for many crops in the major producing regions of Canada, including canola, wheat and corn in the Prairies, corn and sorghum in Quebec, and corn and soybeans in the Atlantic provinces (Lemmen and Warren 2004). Warmer temperatures may allow expansion of crop production areas and the introduction of new crops. Horticulture and wine production may benefit from increased heat. In addition, elevated levels of CO_2 can boost yields through a "CO_2 fertilization" effect in so-called C3 plants, which include wheat and barley (Wall et al. 2007).

However, climate change also brings constraints and risks for Canadian agriculture, particularly via moisture availability and extremes (Lemmen et al. 2008; Wall et al. 2007). Increases in the severity, duration and frequency of droughts pose serious threats in areas already susceptible to moisture deficits, and water supplies will be an issue in many parts of the country. Periods of extreme heat can cause problems for crops and livestock. The prospect of more intense storm events is also a risk for agriculture (Lemmen et al. 2008; AAFC 2005).

Less direct impacts include increases in disease and pest infestations, possible changes in weed growth and in herbicide efficacy, soil degradation through changes in cover and moisture cycles, and threats to crop insurance and support programs as the frequency and scale of claims exceeds the values estimated on past experience (Wall et al. 2007).

Mitigation of Climate Change in Agriculture

Primary agricultural activities account for about 10% of Canada's greenhouse gas emissions. The major sources are manure (methane and nitrous oxide), enteric fermentation (methane), crop production (carbon dioxide) and fertilized soil (nitrous oxide) (AAFC 2005).

Various strategies exist for mitigating greenhouse gas emissions in agriculture. Reducing machinery use reduces CO_2 emissions as well as saves money; reduced tillage systems also have soil benefits. More efficient fertilizer and manure management systems can reduce emissions. Land use practices that retain vegetation and soil organic matter can sequester carbon, introducing the possibility of an income source through carbon credits.

Agriculture also has a role to play in providing alternative energy sources to fossil fuels. Bio-fuels such as bio-diesel and ethanol represent a growing market opportunity for the farm sector. Wind power is another growing alternative energy source that some farmers have already adopted as an income generator. While there is some support for these mitigation initiatives by federal and provincial governments in Canada (AAFC 2005), there is much progress to be made before the agricultural sector is no longer a significant net emitter of greenhouse gases.

Adaptation to Climate Change in Agriculture

Adaptation involves changes in enterprises, investments, land use and/or management in order that farming operations are suited to the changing climatic regime (Smit et al. 2000). Some adaptations are desired to reduce risks (such as those associated with increased droughts), while others are intended to realize opportunities (such as those associated with longer growing seasons).

Agriculture has always adapted to changing conditions. Spontaneous or autonomous adaptations after impacts have been experienced are considered to be risky and costly relative to planned, anticipatory adaptations. Most broad scale agricultural impact models based on long-term climate change scenarios incorporate adaptation via heroic assumptions related mainly to average temperature. Analyses of adaptation processes in the sector (Wall et al 2007; Reid et al. 2007; Belliveau et al. 2007; Bryant et al. 2000) reveal several key commonalities:

- most adaptations are less related to temperature norms 50-100 years in the future than to variations and extremes in conditions that already matter to producers
- adaptations are rarely undertaken (and unlikely to be undertaken in the future) in light of climate change in isolation; the adaptive initiatives are also reflective of changing markets, prices, etc.
- adaptations tend not to be new measures or distinctly oriented to climate change risks or opportunities; rather climate change is incorporated into ongoing management processes related to enterprise choice, resource management, risk management, etc.
- tactical adaptations are short term responses to a particular climate stimulus (such as a drought) to get by (e.g., buy in feed); whereas strategic adaptations refer to more structural changes (land use, crop choice etc.) to reduce susceptibility to climate hazards in future years.

Various types of climate change adaptation have been identified for Canadian agriculture (Smit and Skinner 2002):

Technological developments include new crop varieties and water management innovations.

Farm production practices include crop and variety choice, diversification strategies, land use and tillage practices, use of irrigation and water conservation.

Farm financial management options include the use of crop insurance, crop shares or income stabilization programs.

Government programs and insurance influence producer decisions and adjustments in the sector through agricultural subsidies, support programs, sponsored crop insurance, and various incentives and disincentives.

Climate Change and Weeds

The IPCC (2007) provides only modest insight into the impacts climate change might have for weeds and for weed management (a type of adaptation). The projected warming of North America, with an earlier spring and longer growing season, is expected to encourage proliferation of some weed species. Extremes of heat and moisture may promote plant disease and pest outbreaks. The mountain pine beetle illustrates how a modest change in climate can trigger a massive proliferation with major ecological, economic and social consequences.

There seems to have been more attention given to the impacts of changes in ambient CO_2 on weed growth and herbicide efficacy than the impacts of changes in climate (heat, moisture, extremes, etc.). Increased levels of CO_2 are expected to enhance the growth of *Xanthium strumariu* (common cocklebur) and *Abutilon theophras* (velvet leaf), both C3 plants, and C4 *Amaranthus retroflexus* (redroot pigweed), leading to increased competition and losses in *Sorghum bicolor* (sorghum) (Ziska 2001, 2003).

With increases in temperature and CO_2 *Ambrosia artemisiifolia* (ragweed) is expected to grow faster, flower earlier and produce more pollen, with implications for public health (Ziska et al. 2003; Wayne et al. 2002). *Toxicodendron radicans* (poison ivy) and *Cirsium arvense L. Scop* (Canada thistle) are also expected to benefit from elevated ambient CO_2 levels (Ziska 2001; Ziska et al. 2004). On the other hand, studies suggest that increased temperature and CO_2 levels are not beneficial for *Hypochaeris radicata* (hairy cat's ear) and *Leontodon taraxacoides* (lesser hawkbit).

Under climate change in many agricultural areas, crops selected for certain conditions are expected to experience increased heat stress and moisture stress, and in some cases increased pressure from invigorated weeds. Climate change is likely to increase the need for effective weed management. There has not been a great deal of work on weed management products and strategies under changing climatic conditions, but there has been some on the efficacy of products under elevated CO_2 levels.

The efficacy of glyphosate on Canada thistle, *Elytrigia repens L. Nevskr* (quackgrass) and *Chernopodium album L.* (common lambsquarters) is reduced under elevated CO_2 (Ziska and Teasdale 2000). The CO_2 effect on the glyphosate efficacy on Redroot Pigweed is unclear. Canadian research has indicated that the efficacy of Fusion (fenoxaprop-p-ethyl / fluazifop-p-butyl) in wild oat is reduced by approximately 50% under a doubling of ambient CO_2 concentrations (Archambault et al. 2001). Increasing daytime temperatures from 23°C to 29°C caused decreases in the efficacy of Fusion (fenoxaprop-p-ethyl / fluazifop-p-butyl) and Liberty (glufosinate ammonium), but not Assert 300 (imazamethabenz) on wild oat.

Conclusion

Climate change is real. The world's efforts to reduce greenhouse gases have been largely ineffectual, greenhouse gas concentrations are increasing, and climate change is accelerating. Producers, industry and governments in the agricultural sector would be well-advised to identify those changing climate conditions to which they are vulnerable, and those from which they can benefit, and assess adaptation options. Adaptations may be as simple as incorporating risks associated with climate change into on-going investment and management decision-making.

Among the impacts of climate change on agriculture are the effects on weeds. On the basis of the limited research to date, it appears that changing climatic conditions may provide growth benefits for certain weeds, at the same time as some crops are under additional stress related to variable heat and/or moisture. This potential "double-whammy" is likely to provide an enhanced competitive advantage for the weeds, highlighting a need for more diligent weed management. Unfortunately, the limited evidence to date suggests that with enhanced CO_2 levels (if not other aspects of climate change) the efficacy of important weed management agents (notably glyphosate) is reduced, in exactly the circumstances when the need for effective control is increased.

Acknowledgements

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Mitigating the invasive risk potential of biofuel crops

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The global energy portfolio is projected to become increasingly reliant on bio-based products, with government mandates likely to be met with up to 1500 million ha of dedicated energy crops by 2050. Biofuel crops will likely comprise many species globally, and will be selected to require minimal inputs, tolerate marginal growing conditions, and exhibit rapid growth rates—agronomically desirable traits that also characterize many of our worst invasive species. Many of the candidate biofuel crops are known invasive or noxious species in portions of their non-native range, or demonstrate a high likelihood of becoming invasive in the target cropping region. Necessary elements for the sustainable production of bioenergy include assessment and subsequent mitigation of the invasive potential of biofuel crops prior to large-scale adoption, as the economic benefits of bio-based energy may be offset by environmental damage and management costs. Here we outline the potential risks posed by biofuel crops, methods for identifying those risks, and recommendations for mitigating against the introduction of future invasive species.

Why dedicated energy crops?

The US, Canada, and the European Union have mandated that bio-based fuels be integrated into the transportation energy portfolio to reduce gasoline usage, lower greenhouse gas emissions, and contribute to national security. For example, the US passed the Energy Independence and Security Act in 2007 that sets a 136 billion L goal for renewable liquid fuels by 2022, with a significant proportion being cellulose derived (Fig. 1). Canada and the EU have set similar goals for the coming decades, with provisions to reduce the prominence of first-generation biofuels (i.e., corn-based ethanol) and focus on cellulosic bioenergy. Additionally, a section of the 2008 US Farm Bill provides subsidies for growers ($45 USD per ton of biomass) to encourage adoption of dedicated energy crops, which currently have no market.

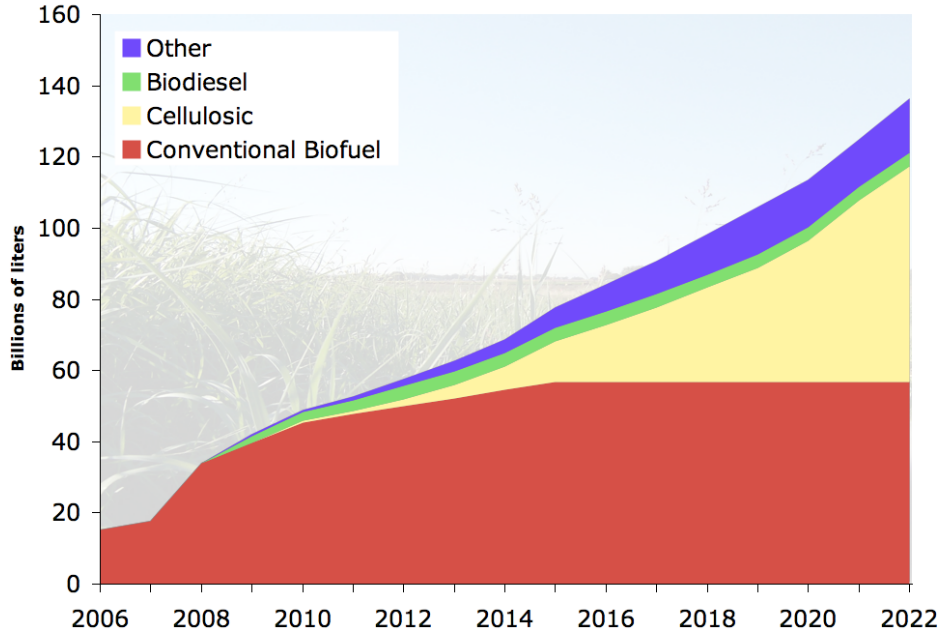

Figure 1. Sources of biomass-derived liquid fuels as mandated by the US Energy Independence and Security Act of 2007. Corn-based ethanol (red area) reaches a ceiling of 56 billion liters by 2015, and is projected to be surpassed by cellulosic-based fuels by 2022.

The mandated 61 billion L of cellulosic-based fuels cannot be met with agricultural, forestry, and municipal residues alone; this mandate requires large-scale planting of dedicated energy crops that do not compete with food or feed (Perlack et al. 2005). Field et al. (2008) estimate up to 1500 million ha of land will be under cultivation of dedicated energy crops globally by 2050, with the US cultivating an area equivalent to that currently in row crops (Robertson et al. 2008). Therefore, research effort is focused on identifying crops that will maximize yield while allowing cultivation on less productive, marginal lands. The most promising crops are perennial rhizomatous grasses that exhibit rapid growth rates, possess broad climatic tolerance, tolerate poor growing conditions, harbour few pests, and require minimal inputs (Lewandowski et al. 2003). However, many of these agronomically desirable characteristics are shared by many of our worst invasive species (Raghu et al. 2006). Additionally, several candidate crop species are known invasive or noxious species, for which risk analyses indicate a high likelihood of invasiveness in regions where these crops will likely be cultivated as biofuels (Barney & DiTomaso 2008). The majority of our worst invasive species were intentionally introduced (Simberloff 2008), and we would be remiss to assume widespread adoption of novel crops is inherently safe, or dangerous (Cousens 2008). Therefore, there exists a need to evaluate the invasive potential of candidate biofuel crops in each region of production and weigh the results of the evaluation against the economic and national security benefits of the nascent bioeconomy (Meyerson 2008).

Evaluating the invasive risk of biofuel crops

The Biomass Crop Assistance Program of the US Farm Bill states that crops eligible for the grower subsidy do not include "*any plant that is invasive or noxious or has the potential to become invasive or noxious*." This removes the possibility of using plants like kudzu (*Pueraria montana* var. *lobata*) in the southeastern US, or purple loosestrife (*Lythrum salicaria*) in the eastern US and Canada. More importantly, it dictates that plants that have the *potential* to become invasive or noxious are not eligible, but gives no information on how to evaluate this potential. Unfortunately, there is no prescription for identifying which plants will become invasive. Therefore, we propose a series of studies (Table 1) that aim to identify the invasive potential of candidate biomass crops that can be performed in parallel with agronomic trials (DiTomaso et al. 2007). Information generated from these studies then serve to inform policy, mitigation protocols, and management plans.

Table 1. Protocol for evaluating the risk of biofuel crops becoming invasive. All steps should be carried out for each cultivar/genotype within each unique cropping region.

	Evaluating the risk potential of biofuel crops – qualitative and quantitative studies
1.	Perform risk assessment using a science-based protocol to determine invasion potential qualitatively (see Barney & DiTomaso 2008)
2.	Determine the potentially invasible range using climate-matching analyses (e.g., CLIMEX) under various assumptions (e.g., drought tolerance) and scenarios (e.g., irrigation, climate change)
3.	Evaluate environmental tolerance (e.g., soil moisture stress) of target biofuel crops
4.	Quantify invasibility of susceptible habitats (e.g., riparian areas, rangeland)
5.	Perform propagule biology studies – seeds, stem and rhizome fragments
6.	Assess hybridization potential with related native and non-native taxa
7.	Evaluate competitive interactions with desirable species relative to known invasive species

Risk Assessment

Screening non-native species through a risk assessment framework has proven economic benefits (Keller et al. 2007), and should serve as a first step in evaluating the invasive risk of biofuel crops. Barney and DiTomaso (2008) performed a weed risk assessment for three leading biofuel crops for the US and Canada, and found that switchgrass (*Panicum virgatum*) – the leading biofuel candidate in the US, which is native to most of North America – has a high invasive potential in California where it is non-native. Interestingly, when a hypothetical sterile cultivar was evaluated, the weed risk assessment yielded an acceptably low risk of becoming invasive (Barney & DiTomaso 2008), suggesting the invasiveness risk for switchgrass lies in seed production. However, lack of seed production does not guarantee a low risk of invasion, as the sterile giant reed (*Arundo donax*) has a high probability of becoming invasive in the US Gulf Coast region where biofuel plantations are under negotiation (Barney & DiTomaso 2008). The sterile miscanthus hybrid (*Miscanthus* × *giganteus*) has a low invasive risk in the US, despite sharing similar life history characters and growth habit with the known invasive giant reed (Barney & DiTomaso 2008). The widely used Australian weed risk assessment achieves >90% accuracy in identifying harmful invasive species (Gordon et al. 2008), but should be viewed as a first step in evaluating invasive potential, rather than the end point. For example, despite our analysis showing a high invasive potential for switchgrass in California, there are few documented cases of escape in agricultural or natural ecosystems where switchgrass has been introduced (Riefner & Boyd 2007). Thus, it is important to conduct ecological studies to quantify and subsequently mitigate risk. Similar studies should also be conducted for the "safe" miscanthus hybrid. A biofuel crop-specific risk evaluation would greatly increase confidence and robustness of results.

Climate-matching

One aspect of risk assessment that is rarely quantified is climatic suitability of the introduced range for the new species (Weber et al. 2009). Climate is a primary abiotic driver of habitat suitability, and is typically assumed to be appropriate when conducting a risk analysis (Pheloung et al. 1999), which may over-estimate invasion risk when evaluated at large spatial scales. Climatic suitability can be easily modeled to various resolutions, which provides an estimate of range suitability for the species outside cultivation, and also the agronomic potential of the biofuel crop in the target region. The strength of climate-matching analyses, especially using CLIMEX, is the ability to base a predictive model on the established range (e.g., from herbarium specimen data) and to supplement the model with empirically derived biological and physiological data (Sutherst et al. 1999).

For example, we performed a CLIMEX analysis of switchgrass using the native range to build the model, supplemented with physiological data generated in a greenhouse study on soil moisture-stress tolerance (Fig. 2a). Our analysis demonstrates that the western US, where switchgrass currently does not occur, is climatically unsuitable for switchgrass on the whole, which is likely due to the very dry summers in a Mediterranean climate (Barney & DiTomaso 2010). To test this hypothesis of summer moisture limitation, we ran another analysis assuming access to a perennial source of water. This analysis demonstrated that much of the West would be suitable for switchgrass as an agronomic crop with summer irrigation, and that riparian areas are most susceptible to a switchgrass invasion (Fig. 2b). This analysis will be used to target specific habitats in the non-native range of the western US to conduct field studies evaluating the susceptibility to switchgrass invasion.

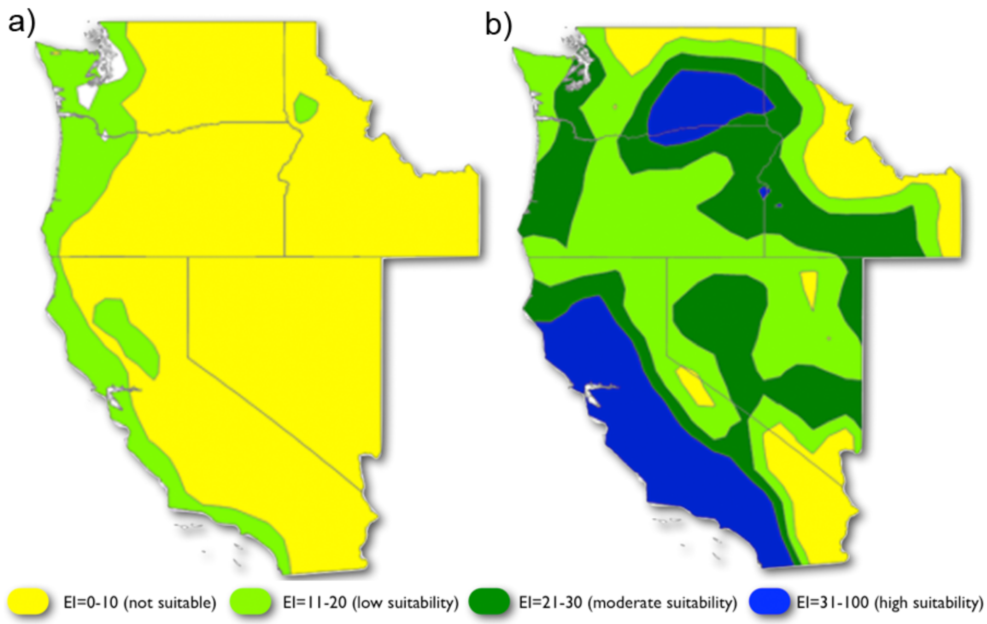

Figure 2. CLIMEX climate-matching results for switchgrass (*Panicum virgatum*) based on climate preferences estimated for the non-native range of a) the western US, and b) the western US assuming yearlong access to water (e.g., along a stream or irrigated land). The colors represent CLIMEX Eco-Climatic Index (EI; 0-100), where higher numbers represent a more suitable environment (see legend).

Habitat modeling would be well served if climate-matching analyses were also performed under currently predicted IPCC climate change scenarios (IPCC 2007). The IPCC has made available their potential climate scenarios for North America under various assumptions, which can be integrated into habitat modeling to forecast range shifts in the coming century. This is particularly relevant to evaluating the invasive risk of biofuel crops, as future climates may make currently unsuitable regions potentially invasible in the near future (Dukes & Mooney 1999).

Environmental tolerance

To be competitive with conventional energy sources and reduce the food/feed versus fuel antagonism, biofuel cultivation must be relegated to less productive soils in locations where they can be grown with minimal inputs of water, fertilizer, and pesticides (The Royal Society 2008). Therefore, there exists the need to characterize the environmental tolerances of each biofuel crop, regardless of species' nativity, and to identify ecosystems most susceptible to invasion. Once described, these factors can be integrated into risk analysis and bioclimatic and agronomic models to estimate, and subsequently mitigate, the likelihood of invasion (Barney & DiTomaso, 2008), thus leading to safer and more sustainable use of these important potential crops (Robertson et al. 2008).

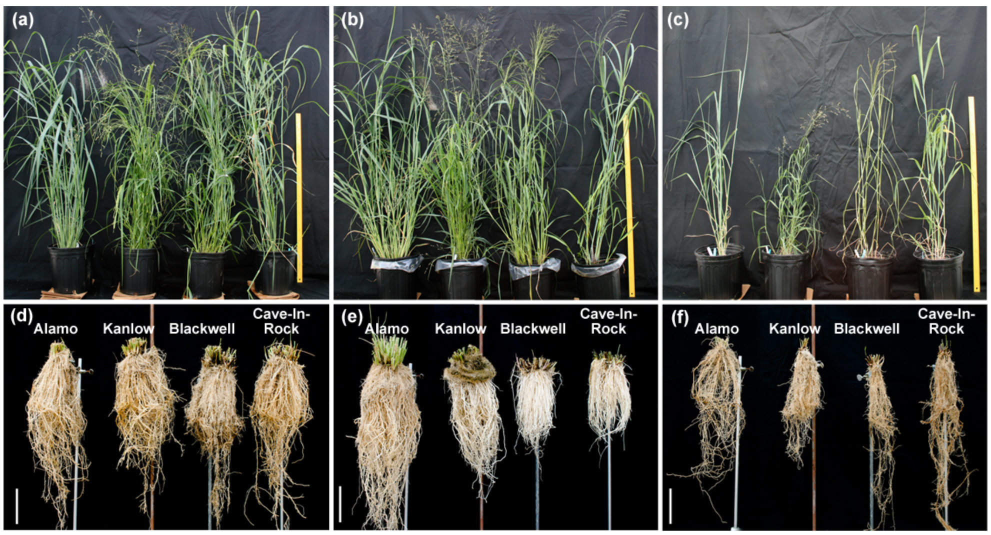

Figure 3. Photographs of shoots and roots of lowland (Alamo, Kanlow) and upland (Blackwell, Cave-In-Rock) switchgrass ecotypes in control (a, d), flooded (b, e), and -4 MPa drought (c, f) moisture conditions. White bars in lower root panels represent 10 cm.

Based on results from our CLIMEX analysis of switchgrass in the western US, which demonstrated water as a major limiting factor for switchgrass naturalization, we conducted a greenhouse study to evaluate the soil moisture-stress tolerance of four common agronomic accessions (Barney et al. 2009). We subjected two upland (Cave-In-Rock and Blackwell) and two lowland (Alamo and Kanlow) accessions to the soil moisture conditions of water deficit (-11 MPa and -4 MPa), control (field capacity), and flooded root zone for 11 weeks. All accessions survived and flowered under the stressful environments of -4 MPa and flooded root zones (Fig. 3; Barney et al. 2009). Our results suggest that as a species, established switchgrass plants demonstrate broad tolerance to soil moisture availability and are able to tolerate very dry environments to standing water conditions. Lowland ecotypes display higher fitness under all conditions, and are the target of germplasm improvement for biofuel cultivation (Parrish & Fike 2005). Similar studies can be conducted to evaluate salt, heat, and cold tolerance, which would also provide agronomically valuable information for breeding and can be integrated into climate-matching analyses to refine model precision.

Invasibility of susceptible habitats

As a result of complex biotic and abiotic factors, invasive species are not invasive in all habitats where introduced (Barney & Whitlow 2008). Climate-matching analyses and biological and physiological studies will aid in identifying habitats most susceptible to invasion by biofuel crops, which can then be tested empirically. Introducing propagules into potentially susceptible habitats under controlled conditions will allow determination of survival and establishment potential under field conditions. Target plants should be monitored throughout all life stages over multiple years to determine if survival, sexual reproduction, and local population growth can be achieved.

Our work with switchgrass and sterile miscanthus (*M.* × *giganteus*) has demonstrated that areas with perennial soil moisture availability such as riparian corridors (i.e., streams, irrigation canals) are potentially susceptible to switchgrass and miscanthus invasion in California (Barney & DiTomaso 2010). Therefore, we will focus quantitative field studies on identifying the probability of switchgrass and miscanthus entering and naturalizing in riparian corridors. Additionally, due to the flooding tolerance of switchgrass and miscanthus (Mann et al. 2009), rice paddies may be more susceptible than surrounding habitat. Results from habitat invasibility studies will inform crop developers (e.g., reduce flooding tolerance) and growers (e.g., do not cultivate or transport in rice production regions) on mitigation strategies that minimize escape from cultivation.

Propagule biology

The number of introduction events and the number of propagules within an event, or propagule pressure, has been cited as a strong determinant of successful invasions (Lockwood et al. 2005). The probability of establishing in a new environment is proportional to the propagule pressure from outside reservoirs (Barney & DiTomaso 2008), which in the case of biofuels will be production fields, harvest and transportation equipment, and feedstock storage sites. An estimated 60 million ha of dedicated energy crops in the US alone amounts to a potentially sizable propagule load to surrounding ecosystems. Most dedicated biofuel crops will be perennial rhizomatous grasses, with seeds and stem fragments as the propagules with the highest likelihood of being unintentionally introduced off-site. Rhizome fragments may also serve as potential propagules under large disturbance events (i.e., floods, hurricanes).

The risk analysis we performed with switchgrass demonstrated that seeds comprise the greatest threat of switchgrass becoming an invasive species in California. Therefore, studies should be performed to identify the conditions under which switchgrass seedlings perform well. For example, we conducted an experiment with four common switchgrass accessions to evaluate the soil moisture conditions under which switchgrass can germinate and survive. Switchgrass germinated and survived under conditions ranging from 10% soil moisture (-0.3 MPa) to submerged (Fig. 4). These data combined with ecological field studies will provide information that can be incorporated into breeding programs (e.g., introduce sterility into biofuel cultivars) and management plans (e.g., harvest before seed set).

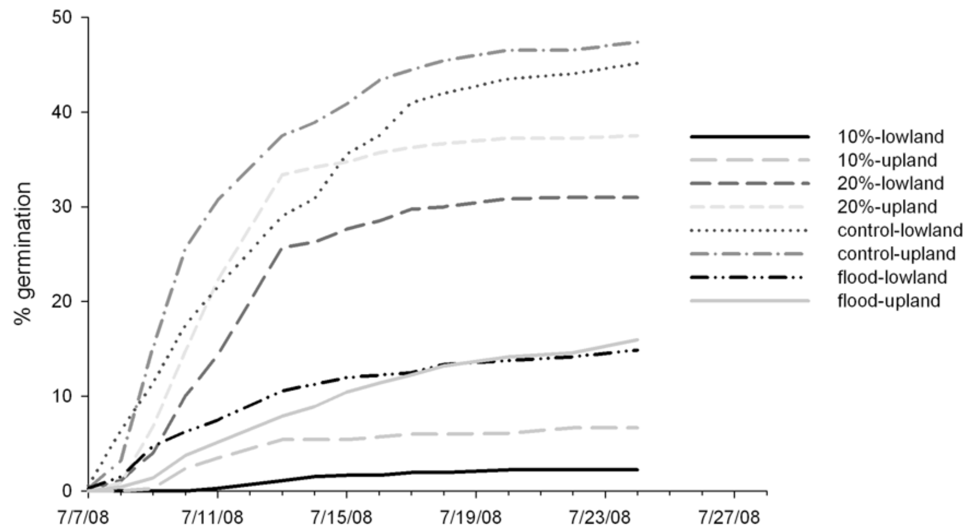

Figure 4. Cumulative percent germination of two upland (Cave-In-Rock, Blackwell) and two lowland (Alamo, Kanlow) switchgrass accessions under drought (10% and 20% volumetric soil moisture), control at field capacity, and under water (flooded). Data from Barney et al. 2009.

Unlike switchgrass, miscanthus and giant reed both reproduce exclusively via vegetative fragments in the US, and both share similar growth habits. In the invaded range of California and Texas, giant reed disperses along riparian corridors primarily through stem and rhizome fragments that are carried downstream. Therefore, studies should be conducted to determine the minimum dispersible stem fragment size for miscanthus and giant reed and the timing of stem node viability. For example, we investigated the interaction between miscanthus rhizome fragment size and burial depth, mimicking dispersal in a riparian corridor following a disturbance (Fig. 5). We found that pieces as small as 1 g (with a viable node) can emerge from 5 cm burial (Mann et al. 2009). Based on results from propagule biology studies, recommendations can be made to mitigate unintentional dispersal of viable propagules. For example, if stem fragments appear to be the primary source of viable propagules and green biomass is to be harvested (i.e., biomass is harvested before the aboveground material naturally senesces) then a shredding harvester should be implemented to minimize the chance of producing fragments with viable nodes.

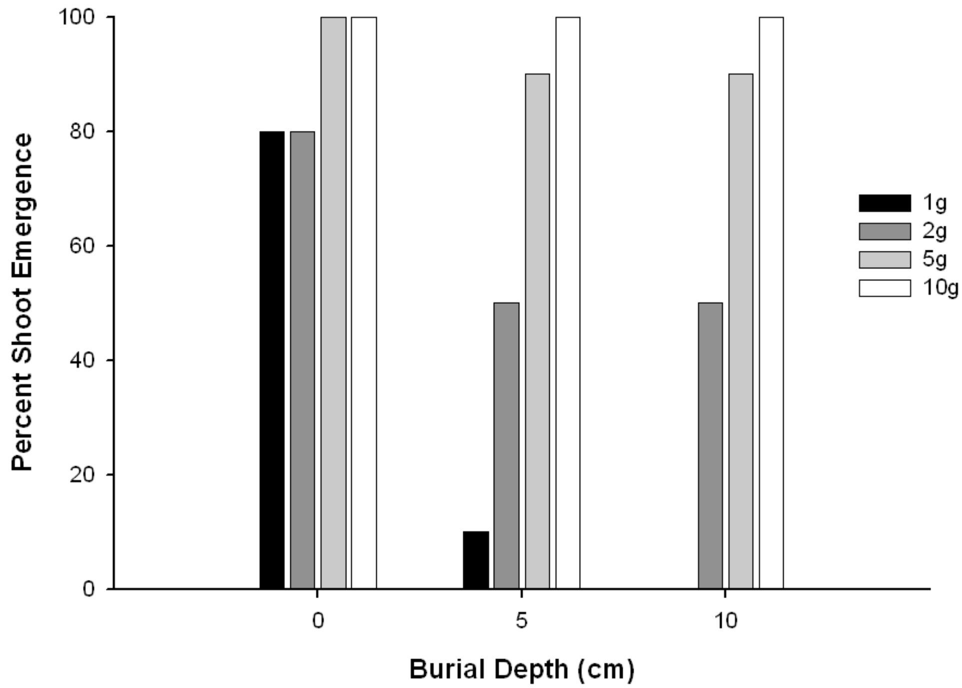

Figure 5. Percent of *Miscanthus* × *giganteus* rhizome fragments producing shoots when buried at three depths. Data from Mann et al. 2009.

Hybridization potential

Breeding and genetic modification of biofuel crops will introduce novel species and genotypes into the agricultural landscape (Chapotin & Wolt 2007). As with genetically modified food and feed crops, screening for possible hybridization with related species should be obligatory to reduce genetic contamination or creation of novel hybrids (DiTomaso et al. 2007). Crop adaptation to drought, salt, and temperature extremes as well as yield improvements will likely be necessary to meet many of the mandated biofuel targets (Chapotin & Wolt 2007). Despite many of the crops being non-native to the US and Canada (e.g., giant reed and miscanthus), close relatives exist that should be screened for possible hybridization, introgression or gene flow. Similarly, crops that are native to North America (e.g., switchgrass) should be held to the same standards as non-native crops where novel genotypes are introduced. Switchgrass comprises a dominant species in many relict prairie stands across North America and serve as the remaining genetic repository, which could be swamped with pollen from millions of cultivated hectares of modified switchgrass. Hybridization studies would determine genetic safety of introduced biofuel crops.

Competitive interactions

Many of the potential biofuel crops are not native to the regions where cultivation is likely in North America, and present an unknown threat to native communities and managed crop production (DiTomaso et al. 2007). Additionally, the likely genetic enhancement of both native and introduced biofuel crops will further reduce the predictability of ecological interactions, even of native species like switchgrass (Chapotin & Wolt 2007). Therefore, quantitative studies identifying the competitive interactions with desirable native species and crops in relation to known invasives of similar habit should be performed. This relative comparison with known invasives serving as positive controls will inform of potential ecological interactions should the biofuel crops escape cultivation into natural and managed landscapes. Target species of conservation or agronomic value can be identified via the studies mentioned above.

Our work with switchgrass (Barney et al. 2009) and miscanthus (Mann et al. 2009) has demonstrated that both species perform as well under flooded conditions as when grown in field capacity conditions. Therefore, we will target desirable native species of riparian areas to assess the direct competitive effects of each biofuel crop. We will also assess the competitive effects of switchgrass and miscanthus on rice, which is a major commodity of California and the southeastern US. The primary weed control practice in rice cultivation is flooding of paddies, which may unintentionally select for switchgrass and miscanthus should these biofuel species become established in rice paddies. Controlled studies evaluating yield reductions and competitive outcomes in both glasshouse and field conditions will aid in evaluating the potential consequences of biofuel crop escape.

Mitigating the invasion risk

The global rush to incorporate biologically based liquid fuels into the transportation sector will usher rapid adoption of new technologies and crops to meet governmental mandates. Each biofuel crop will possess some level of invasive risk, and the studies proposed above will not result in a strictly dichotomous prediction of invasive or non-invasive. Therefore, efforts must be made to reduce the invasive properties of new crops, as well as mitigating the likelihood of escaping cultivation and subsequently establishing in natural and managed landscapes. Below we outline a framework for mitigating the invasion risk at several stages along the biofuel chain: i) crop selection and development, ii) field-level grower practices, and iii) refinery transport and storage of feedstocks.

Crop selection and development

As mandated by Section 9011 of the 2008 US Farm Bill, known invasive species and potentially invasive species are not eligible for grower subsidies, which will likely be necessary to foster the emerging market. Companies developing crops for the biofuel industry should not utilize known invasive species from the target region in their program. Many developed countries, as well as US states and Canadian provinces, maintain noxious weed lists, which should be consulted to determine which species are known pests within the target region. Additionally, more comprehensive lists of known invasive species at state and regional levels are maintained by Invasive Species Councils (e.g., California IPC, Mid-Atlantic and Florida Exotic Pest Plant Councils), which should serve as secondary sources. Despite invasiveness elsewhere being the most robust predictor of invasive potential in new ranges (Reichard & Hamilton 1997), this should be viewed at a regional level, because all known invasive species are not invasive everywhere within an introduced range. If a target biofuel crop is not known to be established in the target region then follow-up studies should be performed to quantify the invasive potential as outlined above.

Secondarily, crop developers should make every effort not to utilize or create crops that have a significant potential of becoming invasive. Crop developers should partner with researchers to perform the studies outlined above to quantify the invasive potential of each new crop for each distinct region of cultivation. Each crop should be screened through qualitative risk assessment, followed by biological, ecological, and ecophysiological studies of the target crop combined with identification of susceptible habitat within the target region. The species/genotype-specific studies will identify specific autecological traits that contribute to potential invasiveness (Barney & Whitlow 2008), which can then be targeted for mitigation via breeding. For example, our work with miscanthus and giant reed has demonstrated that each species easily regenerates from very small (< 5 g) stem propagules (Mann et al. 2009). Therefore, breeding or genetic modification may be able to target and reduce stem propagule fecundity.

Prior to commercialization of any biofuel crop, it would be prudent to have management plans in place that are distributed with the purchase of biofuel crop seed. In the event that a feral population is identified, a management plan can be consulted providing eradication techniques for either selective (e.g., escape into riparian habitat) or nonselective (e.g., escape along roadsides) removal. Management plans would also serve growers interested in taking biofuel crops out of production, or managing abandoned production sites. A suite of chemical and cultural management practices can be pursued alongside agronomic field trials during crop development.

Grower mitigation practices

With an aim toward the sustainable production of dedicated energy crops, grower practices will also play an integral role in minimizing escape of biofuel crops (Robertson et al. 2008). Growers agree to certain terms when planting genetically modified (GM) crops (e.g., planting non-modified buffer strips), which could serve as a model for dedicated energy crops. Compulsory grower practices have dramatically reduced unintentional ecological harm from growing GM row crops. Similar to GM crops, restrictions and guidelines to growing dedicated energy crops, genetically modified or not, should not be overly costly to the grower or crop developer (Bradford et al. 2005), but should be practical in mitigating invasion risk. Information regarding the risks of cultivating dedicated energy crops will be known before grower adoption, and can be integrated into grower practices.

Growers should make every effort to plant biofuel crops away from propagule dispersal corridors (e.g., streams, roads), while creating buffers larger than minimum dispersal distances when biofuel fields must be located near such corridors. Growers should institute routine scouting of field margins and bordering habitat for crop escapes, followed by prescriptive management of feral populations (see above). Cleaning of planting and harvesting equipment prior to inter-field movement, combined with crop-specific harvest practices and techniques, should minimize unintentional dispersal of propagules. For example, if the target crop produces fertile seeds, where possible, crop harvest should occur prior to seed maturity. Alternatively, when biofuel crops are capable of reproducing via stem fragments, harvesting and transport after senescence in the field will reduce the dispersal of potentially viable propagules. Best management practices should be established for each crop.

Refinery mitigation practices

Refineries will likely be the direct consumers of the biofuel feedstocks and will dictate which crops are preferred, how the feedstock is harvested, and the location and manner of storage. Therefore, refineries should require that all feedstocks be from non-invasive species, and manage feedstock transport and storage to ensure minimal propagule load.

Transportation of feedstocks from grower fields to refineries and storage locations will serve as an important means of dispersing biofuel crop propagules. Cellulosic crops are likely to be harvested with existing agricultural equipment, and later baled and hauled on open-bed trucks. If harvest techniques are not used to minimize propagule viability, the probability of unintentional dispersal along roads will be very high. Therefore, refineries should organize with growers to coordinate efficient harvest and transport that also minimizes propagule loads to outside environments.

Biomass refineries will likely operate year-round converting feedstocks into primary and secondary products. However, feedstocks will likely be harvested once, or at most three to four times a year – primarily in mid-summer through late fall. Therefore, feedstocks will be baled and stored for most of the year on either grower property, or more likely, refinery property near the conversion facility. Depending on the feedstock crop and the method and timing of harvest, storage sites may serve as propagule reservoirs if not managed properly. As with cultivation fields, storage sites would be ideally located away from dispersal corridors.

Summary

The global demand for biomass-derived liquid fuels is rising at an unprecedented rate, and is projected to require up to 1500 million ha of dedicated energy crops by 2050. Crop development programs are selecting and engineering biofuel species to be fast growing, easy to establish, tolerant of poor growing conditions, and low maintenance. Unfortunately, these agronomically desirable traits are closely aligned with characteristics of many of our worst invasive species. This character overlap combined with the fact that most of the biofuel crops are not native, and the likely scale of cultivation, amounts to a non-trivial risk of biofuel crops escaping cultivation and becoming invasive species.

We believe, however, that through a detailed assessment of the biology and ecology of each crop, the invasion risk of most species can be mitigated to an acceptable level. Each crop should be screened through a risk assessment protocol followed by studies assessing the crop's environmental tolerance, competitive ability, and propagule biology for each target region. Crop-specific information should then be incorporated into modeling procedures to identify susceptible habitats followed by field evaluation. Information generated from biofuel crop ecological studies will serve as entry points for invasion risk mitigation in crop development and grower and refinery practices. Previous developments in agricultural production have included pesticides, GM crops, and biocontrol agents, each of which has proved beneficial following proper vetting and responsible management. Likewise, if dedicated energy crops are developed, grown, harvested, transported, and stored responsibly the unintentional ecological risk may be acceptably low, and their cultivation will promote sustainable energy production. Mitigating against a biofuel crop-based invasion will require collaboration and involvement of crop developers, growers, conversion facilities, and regulators.

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Transgene incorporation into non-target organisms: Horizontal gene transfer

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The introduction of transgenic herbicide-resistant crops has increased the interest in the fate of plant DNA in the environment. A main reason for this is the process of horizontal or lateral gene transfer (HGT) which is the successful movement of individual genes or gene clusters among species. Horizontal gene transfer is an important mechanism for increasing genetic diversity in microbes, particularly bacteria. Early transgenic crops contained antibiotic resistance genes as selection markers and the ubiquitous presence of these in many environments contributed to increased interest in HGT with respect to transgenic crops. Horizontal gene transfer requires the presence of free DNA in close proximity to competent microbes, however, HGT is a highly regulated process that is influenced by many factors. In soil, plant DNA is an ephemeral component of total DNA, however, recognizable sequences may persist for some time. HGT from plants to microbes is a rare event and methodological constraints to routinely detect such rare events have not yet been overcome. As a result, the consequences of HGT from plants to microbes remain unknown.

Horizontal gene transfer

Horizontal gene transfer (HGT), also known as lateral gene transfer, refers to the movement of genes among species that are not able to reproduce sexually (Dubnau 1999). Horizontal gene transfer typically involves genes or gene clusters and is an important evolutionary method for increasing genetic diversity and adaptation in microbes. Although HGT is more prominent among prokaryotes, recent evidence of mitochondrial gene transfer from parasitic to host plant species has been documented, indicating that this process is not unique to prokaryotes (Mower et al. 2004). Transfer of genes from prokaryotic to eukaryotic organisms also has been documented. A recent example of transfer of genetic material from bacteria to higher organisms involves the adzuki bean beetle (*Callosobruchus chinensis* L.) and its bacterial endosymbiont *Wolbachia* (Kondo et al. 2002). *Wolbachia* live within cells of many insects where they impact reproduction and it has recently been discovered that a portion of the *Wolbachia* genome has transferred to the x chromosome of the host beetle. The impact of the *Wolbachia* genes on the beetle genome is not known. Within plant cells there is significant evidence of genes that have been transferred from mitochondria and chloroplasts to the nucleus. Mitochondria and chloroplasts are believed to have originated as endosymbionts before becoming functional organelles. Transformation of genes from prokaryotes to eukaryotes has been commercialized as one of the main methods for introducing new genes into plants via *Agrobacterium* mediated transformation (Zhu et al. 2000).

HGT also occurs in fungi where it is of significance in agriculture. Many host specific toxin producing genes of plant diseases such as toxA of *Pyrenophora tritici repentis* (Friesen et al. 2006) share large or complete sequence identity with those of other known plant diseases indicating HGT. The process of HGT, however, is best understood in bacteria where it occurs more frequently (see below) and constitutes an important mechanism for evolution. Perhaps the most prominent example of HGT in bacteria is the rapid movement of antibiotic-resistance among bacterial species (Dionisio et al. 2002). The increase in antibiotic-resistance genes from virtually non-detectable several decades ago, to an almost ubiquitous presence in many environments including those where the selection pressure to retain these genes is thought to be low is an example of rapid bacterial evolution with unforeseen consequences. The virtually ubiquitous presence of antibiotic-resistant bacterial populations is becoming an increasing public health concern (e.g., Levy 1998). Clearly, HGT is an important microbial evolutionary process with consequences that may not always be obvious immediately.

HGT and weed science

The link between weed science and HGT stems from two seemingly unrelated events; the commercial release of herbicide-resistant crops and research findings of antibiotic-resistance in bacteria in the health care field and elsewhere. Herbicide-resistant crops constituted the bulk of the first commercialized genetically-engineered (GE) organisms and in these early generation GE crops, antibiotic-resistance genes served as selection markers for generating the transgenic event with no functional purpose in the final product.

In addition, in the mid-1990s, an increase in the incidence of multiple antibiotic-resistant bacteria such as methicillin-resistant *Staphylococcus aureus* in the health care field was observed. Moreover, antibiotic-resistance genes and bacteria were discovered in natural environments and waterways (recently reviewed by Baquero et al. 2008). This led to studies on HGT of antibiotic genes from plants to microbes in soil (e.g., Gebhard and Smalla 1999) and in animal digestive tracts (e.g., Kharazmi et al. 2003). The transfer of other genes such as herbicide-resistance genes for which phenotypic selection is not as convenient as antibiotic-resistance genes has not be studied to date. Therefore, consequences which may include shifts in structure or function of the soil microbial community by conferring resistance to herbicides in species naturally susceptible to these herbicides are not known. Also, the speed at which such genes would move within microbial populations is not understood, but would depend on selection pressure. Plant roots exude herbicides with which they have been treated into the rhizosphere (e.g., Dinelli et al. 2007), and soil microbes show differential tolerance to herbicides (Grossbard and Davies 2006). Thus, it is conceivable that potential alterations to rhizosphere microbial communities with unknown impacts as a consequence of natural transformation could occur.

Mechanisms of HGT

Although HGT can occur in fungi, the mechanisms of HGT are best understood in bacteria where this phenomenon has been studied extensively. To understand the potential of HGT from plants to bacteria, the mechanisms that comprise HGT in bacteria which include conjugation, transduction, and transformation, must be appreciated. These processes have been reviewed extensively elsewhere (e.g., Thomas and Nielsen 2005, Dubnau 1999) and will only be described briefly. Conjugation is the process by which antibiotic resistance and other genes can move rapidly among bacterial populations (Dionisio et al. 2002). This process involves a temporary physical connection between two bacterial cells through which an entire plasmid or some genomic genes are exchanged before the cells separate and continue having gained novel genetic information.

Transduction is a second mechanism of gene transfer in bacteria. In transduction, bacteriophages serve as vectors for HGT among bacteria. Bacteriophages are viruses that specialize in targeting bacteria and some DNA is transferred during the infection process. This process however, does not assist with taking up plant DNA and also is likely not to play a significant role in transferring plant DNA among bacterial cells once incorporated.

Transformation is the third mechanism and the only one by which bacteria would be able to acquire plant DNA (Bertolla and Simonet 1999). Transformation is a highly regulated mechanism by which bacteria acquire free or naked DNA from their surroundings and incorporate this DNA into their genomes. The ability of bacteria to take up external DNA is referred to as competence and this is influenced by many factors including bacterial species, growth stage, density, DNA sequence, and environment such as water content and nutrient status. For example, *Acinetobacter*, a highly competent species that does not discriminate source DNA becomes more competent during water and nitrogen stress (Nielsen et al. 1997a). About 90 species of prokaryotes are now known to be able to acquire DNA via natural transformation (deVries and Wackernagel 2004) and more transformable species continue to be discovered. Of course, little is known about the transformability of unculturable bacterial species which comprise the vast majority of bacterial species.

Transformation has been separated into two broad categories referred to as homologous (=legitimate) and illegitimate recombination. The distinction is based on sequence similarities between foreign and indigenous DNA. In homologous recombination some sequence similarities between the foreign and indigenous DNA exist, while there are no sequence similarities between foreign and indigenous DNA during illegitimate recombination (de Vries and Wackernagel 2004).

Requirements for HGT

For HGT from plants to microbes to occur, competent bacteria or fungi must come in contact with naked or free DNA. HGT from plants to microbes is thought to occur most likely in so-called hotspots where plant DNA and microbes co-exist at high concentrations. Hotspots include the rhizosphere as well as vertebrate and invertebrate digestive systems. The fate of target DNA in animal digestive tracts was reviewed extensively in a previous issue in this series by

Alexander et al. (2007). In brief, ingested plant DNA is present in the crop and stomach in poultry, but is difficult to detect further along the digestive tract. Similar findings have been made in ruminants where ingested genes may persist into the intestines. In swine, plant DNA can be detected throughout the intestines. There is some evidence of HGT in the rumen. For example, glycoslyl hydrolases are suspected to have been transformed from the rumen bacteria *Fibrobacter succinogenes* to the rumen fungus *Orpinomyces jotonii* (Garcia-Vallve et al. 2000). Recently, intact plant DNA has been detected in goat's milk, however detected DNA fragments were from chloroplasts only, of which there are 500 to 50,000 per cell compared to only a single nucleus (Rizzi et al. 2008). A marker rescue assay was constructed and *Acinetobacter baylyi* was able to take up plant chloroplast DNA in milk.

The fate of plant DNA in the soil environment has recently been reviewed by Levy-Booth et al. (2007) and Pietramellara et al. (2009). A brief summary on the fate of DNA in the soil and water environment (Gulden and Swanton 2007) was provided in a previous issue of this series as Alexander et al. (2007). Briefly, plant DNA enters the soil throughout the life cycle of the plant either through sloughing of root cells during growth, as pollen released into the environment, or when plant biomass decays or is incorporated. Rapid restriction of DNA within plant cells limits the quantity of free DNA that enters the soil at maturation or after cutting and incorporation of plant biomass (Pote et al. 2005). Free plant DNA that enters the total soil DNA pool is subject to three basic fates, namely adsorption, metabolism, or transformation.

Intact DNA may bind to soil colloids or organic matter. Depending on pH, this occurs directly or via cation bridging (Crecchio and Stotzky 1998). Binding to soil protects plant DNA from metabolism and transformation and is thought to be the mechanism for long-term persistence of free plant DNA in the soil environment. Field studies in Canada have shown that some plant DNA can persist over winter and in rare cases for up to two years in rotation (Gulden et al. 2008).

In the soil environment, most free DNA is subjected to rapid enzymatic restriction and degradation which is facilitated by soil microbes (reviewed by Levy-Booth et al. 2007 and Pietramellara et al. 2009). Soil microbes release DNAses that quickly restrict free DNA sequences to smaller fragments thereby destroying the integrity of genes and genetic information. Soil microbes, particularly bacteria, use the labile constituent parts of free DNA as an energy source and/or building blocks for *de novo* DNA synthesis. Each base pair contains ribulose (a 5 carbon sugar), a phosphate group, and 2 or 3 nitrogen atoms, making it a valuable source of energy and nutrients. Direct incorporation of restricted nucleotides into bacterial *de novo* DNA synthesis does not constitute transformation as the sequence identity and therefore genetic information is lost during this process.

Third, soil microbes can take up foreign DNA and incorporate this into their genomes via natural transformation. This is a complicated and highly regulated process that has been reviewed elsewhere (e.g., Lorenz and Wackernagel 1994, Dubnau 1999). There are many potential barriers to successful incorporation of foreign DNA into soil bacteria (Bertolla and Simonet 1999). These include factors that affect competence, sequence recognition sites on the exterior of bacterial cells, and metabolism once inside bacterial cells. Successful fixation of an HGT event is also influenced by the type of DNA transformed. Microbes do not contain mechanisms for post-transcriptional processing, resulting in the translation of non-functional proteins from eukaryotic DNA containing introns. In such an event, or if a functional gene does not provide a selective advantage, it is possible that such genes are purged and lost (Maiden 1998).

Case studies in the soil environment

Soil DNA

In light of the potential concerns outlined above, the commercial release of GE herbicide- and insect-resistant crop genotypes provided a renewed impetus to study DNA processes in the soil. The release of GE crop genotypes facilitates studying the DNA cycle in soil as the release date of these crops containing known unique DNA sequences was known. Some studies in Europe measured plant DNA cycling in the soil environment at disposal sites of GE plants, however, only in Canada has DNA cycling in long-term crop rotations been studied to date (Lerat et al. 2007, Gulden et al. 2008). A total of six factors [crop (corn, soybean), sampling depth (7.5, 15 cm), sampling time (May, July, Aug., Oct.), year (2003-2006), location (Elora ON, Woodstock, ON, Lethbridge, AB) and herbicide application (glyphosate, conventional herbicides)] were studied and it was found that sampling time was most significant in contributing to the presence of plant DNA in the soil environment in these crop rotations (Fig. 1). The contribution of all other factors was much less significant. In all instances, total plant DNA in soil increased many orders of magnitude while plants are growing in fields, but returned rapidly to low levels shortly after harvest. HGT is directly related to the concentration of transformable DNA sequences (Weinrauch and Dubnau 1983).

The behaviour of total soil DNA was much different. Total soil DNA levels were most responsive to year, location, and crop which reflect the importance of these factors in supporting soil life. Total soil DNA levels were much more static and these studies showed that plant DNA forms a dynamic, but small component of total soil DNA. These studies also showed no difference in the behaviour between indigenous and transgenic plant DNA. Another study (Gulden et al. 2005) showed that free plant DNA was exuded from plants and moved through the soil profile via leachate water suggesting that leachate water may also be a hotspot where competent microbes (mostly bacteria) and plant DNA are in close proximity. The half-life of free plant DNA in leachate water, however, is short (hrs) and greater bacterial concentrations shorten the half-life of free plant DNA sequences significantly (Gulden et al. 2005). Together these studies showed that there is an opportunity for natural transformation in soil and water, despite free plant DNA forming only a transient component of the total DNA pool.

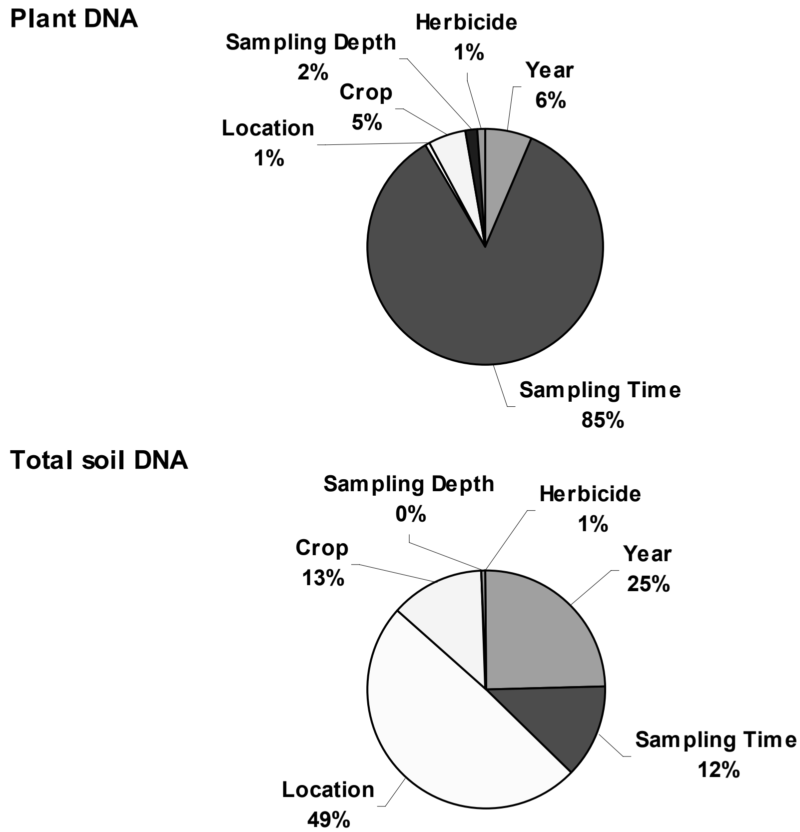

Figure 1. Relative contribution to total variance of six factors (location, sampling time, crop, sampling depth, year, and herbicide treatment) for plant and total soil DNA (adapted from Gulden et al. 2008).

Natural transformation

Natural transformation is typically studied via homologous recombination on the lab bench or in microcosms. Due to the 'artificial' nature of these studies, the results are difficult to extrapolate to field scenarios, where transformation rates tend to be much lower. Homologous transformation is studied typically using marker rescue systems (e.g., citations in Table 1) which involve generating GE bacterial strains. This limits these studies to the bench top and soil microcosms. In marker rescue studies, a truncated version of a target gene, preferably an easy phenotypic marker such as antibiotic-resistance, is inserted into a plasmid which in turn is transformed into the target bacterial species. The transformed bacteria are exposed to non-truncated copies of free DNA of the target gene and homologous recombination is measured as the frequency of transformations or the proportion of bacterial cells in which the truncated gene was replaced/repaired to be functional.

To identify positive natural transformants, the bacteria must be exposed to a selective agent (e.g., an antibiotic) that selects for natural transformants. A common target organisms used for marker rescue studies is *Acinetobacter,* which is a highly transformable common soil bacteria that does not discriminate among foreign DNA. Marker rescue studies conducted on this organism in various environments have shown transformation frequencies ranging from 10^{-5} to 10^{-10} depending on the environment and other factors (Table 1). In general, as the media becomes more complex, the transformation frequency declines.

Table 1. Examples of the frequency of homologous recombination in soil bacteria in different media. Frequency refers to number of homologous recombination events expressed as a proportion of the total number of bacterial cells present.

Organism	Media	Frequency	Source
Acinetobacter	on filter paper in soil	$\sim 10^{-6}$	Nielsen et al. 1997b
Acinetobacter	soil microcosm	10^{-9} to 10^{-5}	Nielsen et al. 1997a
Acinetobacter	sugar beet tissue homogenate	$\sim 10^{-10}$	Gebhard and Smalla 1999
Acinetobacter	tobacco DNA	$\sim 10^{-8}$	Kay et al. 2002
Pseudomonas	*in vitro*	10^{-10} to 10^{-9}	de Vries et al. 2001

Due to the lack of any sequence similarity, illegitimate recombination is a substantially less common event than homologous recombination. For example, in *Pseudomonas* and *Acinetobacter*, the frequency of illegitimate recombination was 10^8-fold and 10^9-fold, respectively, less common than homologous recombination in one study (de Vries et al. 2001). In fact, illegitimate recombination is so uncommon that only a few studies have been able to measure this phenomenon at detectable levels.

Challenges to the study of HGT

There are a number of substantial obstacles to studying HGT in soil microbes *in situ* (reviewed by Nielsen and Townsend 2004, Pietramellara et al. 2009). For example, HGT events and fixation of the genes in the genome are so uncommon that frequencies of transformation are estimated most effectively using easy selectable phenotypic markers such as antibiotic resistance. This limits the type of genes that can effectively be investigated and also limits investigations to culturable microbes which comprise only a small portion of all microbes. Marker rescue which requires the generation of GE bacteria precludes field studies using this approach and therefore reliable field estimates of HGT from plants to bacteria do not exist. Because transformation rates are so rare and reliable estimates in soil systems are not available, estimates of the amount of soil required for detection is not possible.

Polymerase chain reaction is one of most sensitive techniques for detecting genes in culturable and unculturable microbes. Screening larger volumes of soil (> 1 g which contains ~10^5 microbes) presents technical limitations such as the co-extraction of PCR inhibitors (e.g., humic acids) which influence the detection limit (Lerat et al. 2005). Moreover, competitive interactions between target and non-target DNA during PCR influence the detection limit. Thus, even quantitative real-time PCR is not sensitive enough for routine detection of HGT. In addition, extraction of DNA from soil samples is destructive and therefore the consequences of suspected transformants are difficult to study. Other challenges are outlined in Nielsen and Townsend (2004).

A foreign gene that can be expressed in microbes whose protein provides a selective advantage only needs to be transformed once via natural transformation before is can readily move among microbial species via other processes. Similar to the antibiotic story, it may take a long time before the impacts and consequences of such a rare event are understood.

Summary

Over the past decade, research has shown that HGT from plants to microbes is a rare event. To this, add that plant DNA is ephemeral in the soil and water environment which further reduces the possibility of HGT from plants to soil microbes. Possible consequences of HGT which may be unique to each transformation event are not known. Therefore, the risk of HGT from plants to microbes is difficult to estimate. Given this lack of knowledge, some degree of monitoring soil microbial populations for HGT and other unforeseen impacts is prudent. Continued monitoring reduces the possibility of unforeseen consequences that may not be immediately obvious such as those observed with antibiotic-resistance genes in the environment.

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Urban Pesticide Use Obstacles and Challenges: An exploration of the history of the lawn

Is the grass always greener on the other side of the fence?

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Spring is lurking around the corner. After months of spotty brown and snow covered lawns, yard work is about to begin. The turf-obsessed are ready, their tools dancing in the shed. Dreams of velvety green are fading into reality, if only spring could come faster. And so the cycle begins, once again.

Surprisingly, lawn turf occupies an estimated 32 million acres of land in North America. Americans spent more than $35 billion on do-it-yourself lawn and garden care products according to the 2007 US National Gardening Annual Survey. Of the 82 million American households with lawns and gardens, lawn care (at 48%) was reported as the most popular activity of 10 or more garden activities identified in the National Gardening Institute 2007 Annual Survey.

Naturally a smaller market, Canadians spend over $2 billion on lawn and garden products, equipment and plants. A 2007 Statistics Canada survey indicated that almost three quarters of Canadian households had a lawn and/or garden. On a typical day in 2005 the Survey estimated that 11% of Canadians, 30 years of age and older, spent an average of 2 hours outside performing yard work.

Needless to say the lawn care and garden industry is big business in North America engaging a significant portion of the population on both sides of the border. The focus of the following paper is on the lawn element of the built landscape. First, the input of resources required to care for and maintain the lawns of today are documented. Then, the history of the lawn is explored to demonstrate how we got to where we are today in terms of the managed lawn. Finally, the challenges faced in adopting a more relaxed approach to lawn management are examined.

Input of Resources Required for the Care and Maintenance of Lawns

The typical lawn of today represents a large investment in terms of resources employed: pesticides to eradicate blemishes and pests; fertilizers to encourage growth; water for irrigation and; fossil fuels, directly or indirectly, to run gas-powered or electric mowers and leaf blowers. A snapshot of the Canadian resource inputs reveals the following (Statistics Canada Enviro Stats 2007).

Although pesticide use decreased nationally from 31% of households with lawns and gardens in 1994 to 29% of households in 2005, the downward trend can be attributed to the impact of municipal bylaws, particularly in Quebec, banning the use of pesticides for cosmetic or aesthetic purposes beginning in the early 1990s. However, in the Prairie Provinces where there are no municipal restrictions, pesticide use exceeded the national trend. In 2005 in Saskatchewan, 48% of households with a lawn or garden used pesticides (followed closely by Alberta and Manitoba at 47% of households). The proportion of households using pesticides more than doubled in Newfoundland and Labrador and increased by almost half in Manitoba.

Similarly, household use of chemical fertilizers was highest in the Prairie Provinces where close to half of the households with lawns or gardens in Alberta and Saskatchewan applied fertilizers in 2005. Manitoba followed at 40% with Quebec having the lowest percentage of households applying fertilizers at 15%.

Over the summer months, domestic water consumption can jump by as much as 50% due to watering of lawns and gardens. Over half of Canadian households with lawns and gardens watered their lawns in 2006. The provinces of Alberta, British Columbia, Saskatchewan and Ontario used the most water with six out of ten households watering their lawns. Prince Edward Island and New Brunswick watered their lawns the least (20%of households).

In 2006, over two-thirds of Canadian households with lawns and gardens owned a gasoline powered lawn mower. Depending on the age and model of the device, lawn mowers contribute to diminished air quality. Studies have revealed that running a gas-powered lawn mower for an hour can emit the same amount of pollution as a car driven 32 to 322 km (Statistics Canada 2007). Over the year, based on averages, a gas-powered mower can emit the same amount of particulate matter under 2.5 microns as the car traveling 3300 km (Statistics Canada 2007).

To what end does the amount of resources, energy and time devoted to lawn turf contribute? Does the aesthetic value of and economic spin-offs generated by a highly managed landscape with little productive or ecological value outweigh the environmental and potential health impacts incurred to achieve the perfect lawn?

We know that today's lawn, coined the "industrial lawn" by F. H. Borman (Borman et al. 1993), represents a structurally simple ecosystem whereby natural insect predation is threatened by insecticides, diversified plant species are reduced with herbicides, naturally occurring nutrient cycles are upset with fertilizers, drought is avoided by irrigation, native grasses are replaced with engineered grasses and the soil structure is disturbed by mechanical aeration. The result is a broken web of life of which the consequences are

- a decline in insect and bird species that have co-evolved with native vegetation over thousands of years;
- a decrease in the pollination services performed by insect, bird and animal species, a value ranging between $112 and $200 billion annually on a global scale (Kremen, et al. 2007);
- increased surface run-off containing fertilizers and pesticides entering drainage water, downstream water supplies and

groundwater thereby contributing to eutrophication and contamination;

- threats to aquatic habitats, wildlife, the food chain and human health by pesticides and fertilizers;
- stress on municipal infrastructure designed for peak water demand;
- use of precious, potable water for irrigation and;
- reliance on fossil fuels in the making of fertilizers (natural gas) and pesticides (oil) and in the fueling of powered lawn maintenance equipment.

An investigation into the value of aesthetics, the economics of the lawn care industry and a review of the scientific literature on the human health and environmental impacts of pesticide use is outside the scope of this paper. Instead, the question to be answered through an exploration of the history of the lawn is: “Why are millions of households across North America so focused on and preoccupied with the state of their lawns?”

Advent of the Lawn: Historical Sources

The advent of the lawn is a relatively recent phenomenon. The word itself dates back to the Old French word launde, denoting a “wooded area”. By the 16th Century the Middle English word “laund” had evolved to mean a “grassy plain or pasture especially surrounded by a woodland.” Today, the lawn is described as a stretch of grass-covered land, especially near a house or in a park, that is regularly and closely mowed, continuously green, and, free of weeds and pests to the greatest extent possible (ENFO-The Environmental Information Service).

The English Influence

Although gardens were popular in Europe from the Middle Ages onward, the rise of Romanticism in the late 18th Century represented a fundamental shift in the design of the landscape and the rise of the lawn. Moving from the very formal symmetrically designed gardens created by Andre Le Notre (1613-1700) at Versailles, as an example, the English led the way to a less disciplined approach with emphasis on a natural look and the picturesque.

Lancelot Brown (1716-1783), otherwise known as “Capability” Brown for recommending to his clients that their estates possessed great “capability for change”, was one of the first proponents of the new English style. During his lifetime, Capability Brown designed over 170 estate gardens marked by “great expanses of grass running straight to the house” (Turner, R. 2008). These expanses were punctuated by a scattering of trees in clumps or belts and the occasional water feature. In comparison to the previous highly disciplined, patterned styles evident throughout Europe, Brown’s designs were described as a "gardenless form of landscape gardening” (Turner, R. 2008). That is, he tried to suggest the wildness of nature while retaining a subtle degree of control.

This new parkland style of gardening moved across the English Channel to France where it played a role in the design of the great parks in Paris under the guidance of French engineer, Jean Charles Adolphe Alphand (1817-1891). Germany, Austria and Italy, not to be left behind, adopted the English way as promoted in the manual, *Hints on Landscape Gardening*, published by Prince Hermann von Puckler-Muskau, Berlin, Germany in 1835.

It is interesting to note that, from the start, designed landscapes, including those created and influenced by Capability Brown, came to denote class, status and privilege. Who else but the landed gentry, the aristocracy, could afford a designer and an army of labourers marching across the pastoral setting taming the grass with scythes in hand or a sheep dog, with herder in tow, working a flock of sheep across the landscape? In addition, Man's ever-present drive to tame nature was also reflected in early landscape design, which moved along a continuum of the highly formalized to a less disciplined approach adopted in the Age of Romanticism.

The Lawn Crosses the Atlantic Ocean

Moving across the Atlantic Ocean, one discovers that the idea of kept lawns was not part of the initial colonized 18th Century landscape in North America. In a very literal sense, early settlers were too busy taming nature, hewing trees, breaking ground and drawing water in order to, "just survive". In the small towns or cities that sprung into existence one was more likely to see small, fenced-in, vegetable gardens or spaces left to grow on their own initiative. The throne, other wise known as the outhouse, would be found in the backyard with a well-beaten track leading to the throne's door. Large expanses of maintained grass such as the lawns found on the estates of George Washington (Mount Vernon) or Thomas Jefferson (Monticello and the University of Virginia) were exceptions, once again associated with privilege and wealth.

However, Andrew Jackson Downing, an American landscape designer and writer in the 1830s and 40s, was about to change the face of the American yard. Appalled by the "general slovenliness of rural America where pigs and poultry were allowed to run free, and bare and bald houses were thrown up and trees planted haphazardly, if at all," Downing urged Americans to improve themselves by improving their front yards (Kolbert 2008). In 1841, the landscape designer published the first gardening treatise focused on the American public, *The Theory and Practice of Landscape Gardening*. The book was an incredibly popular reference for the time, going through 8 editions and 16 printings. According to Downing, "Grass mown into a softness like velvet was an essential element of any perfect garden" (Kolbert 2008).

Downing died an early death at the age of 36 years in 1852, a result of a boat wreck on the Hudson River in New York. Despite his early demise, Downing's effect on the American landscape was profound. His influence continued on in the work of Calvert Vaux and Frederick Law Olmstead, well known as the designers of New York City's Central Park, with its broad lawns and; the layouts of new suburbs, Riverside, Illinois close to Chicago and Sudbrook Park, Maryland. This new form of living arrangement called suburbs, replaced large expanses of lawn with a series of much smaller lawns, more affordable to those of lesser means.

The Rise of Suburbia and the New Lawn

Facilitated by the electric streetcar in the latter half of the 19th Century and the car in 1920s, suburbia grew; spawning the detached house with a 25' to 30' setback from the street or sidewalk. This setback was a perfect venue for the lawn to take hold in the American landscape. Typically absent of fences, hedges or walls, the lawn served to unify the landscape while an imaginary line separated one's property from another. With the increasing prominence of the front yard lawn, Frank J. Scott, a Cincinnati landscape architect, wrote in *The Art of Beautifying Suburban Home Grounds* in 1870, "A smooth closely shaven surface of grass is by far the most essential element of beauty on the grounds of a suburban house." (Steinberg, T. 2006 p. 12). Scott's exalted view of the lawn was not dissimilar from Downing's comments pronounced in the 1840s.

Coinciding with the lawn's early evolution and contributing to its popularity were certain technological innovations during the 1800s that made the lawn more accessible to the less privileged. For example, in 1830 John Ferrabee, a factory owner, and Edwin Budding, a mechanic, from Thrupp, England invented the lawn mower inspired by rotating blades used to trim the nap on carpets. By 1873 inventors had registered 38 patents on various versions of the lawnmower (Steinberg 2006). In 1885, 50,000 lawn mowers were rolling out into the market place on an annual basis. The first gas powered mower made its debut in the 1920s. The result was the ability to maintain grass at the "right" height with one machine at lesser cost and increased efficiency versus the hiring of 2 or 3 labourers. During the same period, the lawn sprinkler was patented (1871), aiding the green appearance of the lawn for those with access to municipal water systems.

From a symbol of status and gentrification in the 16th Century the lawn was becoming a more common feature due to the influence of early landscape designers, the new built-form found in suburbs and technological innovations of the 1800s. However moving into 20th Century, the lawn was about to become more than a place for leisure, entertainment or lawn sports like croquet, badminton and bowling. The lawn was to become a statement of one's self worth, moral standing and civic duty measured by the level of turf perfection achieved. In other words, one might say, an obsession facilitated by more technology, increased suburban development, lifestyle changes; and a wave of consumerism. However there was one major problem in the quest for the perfect lawn, the predominance of Kentucky bluegrass (*Poa pratensis*).

Kentucky Blue – the new turf grass in North America

Turf grass as we know it today was not native to North America. When the Europeans migrated to North America they brought with them their domesticated livestock. The indigenous grasses had a difficult time withstanding more intense and concentrated grazing. This prompted the new Americans to import seed including grass seed from their former homes across the Atlantic. One of the species was none other than Kentucky bluegrass, a grass believed to have had its origin on the cool, moist fringes of northern European forests.

With its colonial introduction Kentucky, bluegrass quickly became the foundation of the “American lawn” as the lawn phenomena spread across North America. First Nations nicknamed it “white man’s tracks” - wherever white man went Kentucky bluegrass was not far behind. It was a species of grass favoured by growers because it was aggressive, it grew quickly in a variety of conditions, it formed a dense green cover and it tolerated the colder climes in North America. Its biggest weakness, however, was its failure to withstand drought conditions due to its short root system. Perhaps an ideal species for the moister, cooler areas of North America, Kentucky bluegrass was less suitable in the mid-west and the drier southern and west coast areas of the continent. As a result, where conditions were not conducive to the growing of Kentucky bluegrass, perfection was difficult to achieve. Of course, the rise of public golf courses in the late 1800s did nothing to assuage the green grass fetish of the lawn owner. The old American proverb “The grass is always greener on the other side of the fence” began to take on a new meaning and sense of urgency.

New Innovations in the 1900s

However a series of fortuitous discoveries and events helped “the obsessed” get closer to illusory perfection. In the early 1900s, Fritz Haber, a German chemist, succeeded in fixing nitrogen from the air using high pressure and a catalyst. Reacting nitrogen gas achieved through the Linde process with hydrogen gas produced ammonia from which nitric acid was derived. Nitric acid was then used to manufacture explosives for the war and fertilizers to nurture the feedstock of soldiers. For his efforts, Haber was awarded the Nobel Prize for Chemistry in 1918.

After the end of World War I manufacturers found an eager market to sell the synthetically derived fertilizers outside of the agricultural industry - the homeowner. Just think of the acres of turf grass rolling out across the continent and the culturally inherited pre-occupation with green grass sweeping in behind. Fortunately for manufacturers of fertilizers, turf grass, due to its seasonal cycle, tended to deplorable shades of yellowy brown during its slow growth phase in the heat of summer months. However, with repeated applications of fertilizer, one could trick the grass to keep growing; thus prolonging the colour of green until the first couple of frosts hit and a prolonged period of dormancy set in.

In 1938, labour legislation in the United States introduced the 40-hour work week. Previous to the legislation it was common to work Saturday mornings with Sunday reserved for the House of God and family. With more leisure time available, apparently there was no excuse for poorly kept lawns. According to Thorstein Veblen writing in “The Theory of the Leisure Class” the lawn became an “index of social standing and a register of civility” (Centre of Canadian Architecture, The American Lawn). This echoed Downing’s observation that, “We are a better country for our lawns and we need more – not less - grass” (Centre of Canadian Architecture) .

Post World War II

Similar to World War I, the second Great War stimulated a growing chemical industry. After the end of World War II, industry refocused on new and emerging markets for its chemical products developing insecticides, herbicides, fungicides and rodenticides with applications for the residential market. This happened to coincide conveniently with a boom in housing construction as soldiers returned home from abroad. Other factors such as the growing car culture and the creation of an interstate highway system, helped to accelerate the pace of urban sprawl to new heights; each home having a lawn.

Owner of a construction firm and a modern day developer of mass production, Abe Levitt constructed 17,000 homes between 1947 and 1951 in the potato fields of Long Island that came to be known as Levittown. For Levitt, the lawn was an attribute that served to offset the normal depreciation of housing. (Steinberg 2006). Perhaps hinting at the value of "curb appeal" Levitt stated, "It has been truthfully said that no single feature of the garden contributes as much to beauty and utility as the lawn" (Steinberg 2006).

The uniformity of post-war housing and the associated grass monoculture was the final death knell to any vestiges left over from the pre-war functional yard where vegetables were grown and animals wandered. Open and exposed, the front lawn became a show-piece, symbolic of one's integrity, morality and civic duty. An overgrown lawn desecrated by weeds, brown and patchy could not, would not be tolerated. Laws, codes and/or covenants often encapsulated in community standards or "good neighbour" legislation cemented visual conformity but also set the stage for a certain degree of competitiveness with the state of one's turf. However, there was a hitch in the competitive game.

Maintaining high standards of respectability through perfection of the lawn was beginning to enslave its owner and take a toll on his psyche. In a 1959 article in the Journal of the American Medical Association on the psychomatic effects of suburban development and conspicuous consumption, the lawn is mentioned as a source of tension, "Many of our patients are over-concerned about keeping up appearances: there can not be a blade of crabgrass in the lawn" or dandelions or clover for that matter.

Removing clover, crab grass and the detested dandelion by hand was a time consuming business for the upwardly mobile. Cinch bugs and voles could wreak havoc, overnight, on closely shaved turf. However, with use of several pesticides and repeated applications, blemishes on the landscape could be treated. In the United States, the Environmental Protection Agency estimated that the annual maintenance program for a typical lawn included 4 or more applications of high-nitrogen fertilizer and 10 or more doses of various kinds of pesticides (Bormann et al. 1993).

Thus, in the 20th century, we have an historical, culturally programmed audience stressing-out over the aesthetics of their lawn, and an eager chemical and lawn care industry feeding the "stressed and obsessed" with ever new and time saving products and services. Why? To obtain a monoculture of engineered grass heavily dependent on pesticides, fertilizers, water, gas-powered mowers and leaf blowers with no real productive or ecological value? So, here we are back to the discussion of the "Industrial Lawn" with a question, "Where do we go from here?"

A Change in the Air

The highly managed, unnatural lawn took over 200 years in the making. Who knows if we would be discussing the lawn today if it wasn't for Capability Brown and his obvious influence on prominent landscape designers for a brief time? It is hard to say. We do know, however, that it is difficult to change peoples' behaviours, habits and social attitudes once engrained over time. Effective marketing campaigns extolling the virtues of the latest pest killer or the permanently green grass that never dies makes change doubly hard.

However, there is a groundswell of reaction to the monoculture lawn. Perhaps the pendulum is swinging towards a more purposeful and ecological approach to design and maintenance. In juxtaposition to the "Industrial Lawn" there is the "Freedom Lawn" (Bormann et al. 1993) whereby:

- species diversity is promoted using native vegetation well-adapted to local soil and climatic conditions;
- natural processes are encouraged to flourish recognizing the complex and dynamic interactions between vegetation, animals, insects, bacteria, fungi and other beneficial organisms many of which are not visible to the naked eye;
- inputs are minimized resulting in less pressure exerted on municipal infrastructure and water supplies, cleaner water devoid of synthetic pesticides and fertilizers entering streams or groundwater, carbon dioxide output less than input and nil or low demand on fossil fuel supplies.

A reflection of this movement is found in the increasing numbers of municipalities across Canada and, the provinces of Quebec and Ontario that have enacted legislation banning pesticides used solely for the purpose of improving and/or enhancing landscape aesthetics on private and public property. To date, 154 Canadian municipalities have passed pesticide bylaws with an additional 8 municipal bylaws in draft stage pending adoption. Overall, 17.5 million Canadians, 49% of Canada's total population, are benefiting from enhanced protection through reduced exposure to pesticides as a result of municipal bylaws or provincial legislation.

Provinces and municipalities have resorted to bylaws, as education alone has not been effective at changing people's attitudes and behaviours. A study on the impact of bylaws and education programs on pesticide reduction found that pesticide use was reduced between 51-90% when communities passed bylaws supported by education versus the 10 to 24% reduction in pesticide use achieved through education alone (The Canadian Centre for Pollution Prevention & Cullbridge Communications and Marketing, 2004).

In addition, national retailers have recognized the changing market place fueled by increasing environmental literacy and concern for the environment. Traditional pesticide products have been withdrawn voluntarily from the shelves at Home Depot and RONA stores across Canada as of December 2008 and July 2009, respectively. Canadian Tire and Wal-Mart are moving in the same direction. This is a positive and welcome trend. However, a major obstacle on the road to less inputs and behaviourial change are legal challenges directed against jurisdictions enacting pesticide legislation.

Challenge to Change

Manufacturers of chemicals and lawn care service providers have the most to lose as the result of municipal or provincial pesticide legislation and a changing market and retail environment. "Industry" has mounted legal challenges questioning the right of municipalities to enact pesticide legislation within their jurisdiction, all the way up to the Supreme Court of Canada. In 2001 it was 114957 Canada Ltée (Spraytech, Société d'arrosage) v. Hudson (Town), and in 2006 CropLife v. City of Toronto. Both challenges were denied in favour of the municipalities. More recently, on August 25, 2008, Dow AgroSciences LLC (DOW) filed a notice of intent under the North American Free Trade Agreement (NAFTA), Chapter 11, over the ban of 2,4-D within the Province of Quebec. Dow claims that Canada has breached its obligations to provide fair and equitable treatment under international law and that the ban of 2,4-D in Quebec is not based on scientific criteria. No doubt, another objective of filing under NAFTA is to serve notice and stall other jurisdictions in Canada which are considering legislation restricting the sale of pesticides considered cosmetic or non-essential in their use.

The question must be asked, "Is pursuing legal channels and appeals to international trade agreements to protect sales and ultimately profits the way to go, or, might recognition of change and the opportunities represented by change be the better solution to explore?" If the affected industries fail to consider production, marketing and maintenance practices, it may be that other factors will force change in how lawns are perceived and maintained.

Lawns and other forms of managed landscapes including manicured parks, play fields and golf courses, in their present form, cannot thrive in most parts of North America without the application of water. With the looming shortage of water: as glaciers melt; as rivers dry; as groundwater is contaminated and; as population increases; quenching the thirst of humans will trump the requirements of landscapes dependent on irrigation. Perhaps synthetically derived fertilizers will become the next target of supporters advocating for more natural and ecologically functional urban landscapes. It is well known that the spreading of homegrown compost and leaving grass clippings are far better sources of nutrients and carbon sinks (Lindsey 2005) than a closely shaven, synthetically-derived, immaculate lawn. Food safety and food security may prompt a return to the fenced-in, organic, vegetable garden. Heather C. Flores, in *Food Not Lawns,* estimates several hundred pounds of vegetables and fruits could be harvested from a yard of average size (Kolbert 2008). And then, there is the heavy reliance on fossil fuels and subsequent increases in green house gas emissions and the pace of climate change. Will the indigenous flora and fauna which have co-evolved over thousands of years, be able to adapt fast enough to keep up with the anticipated rate of change? Only time will tell.

So, as the seasons cycle, a return to the initial inquiry is required: "Is grass always greener on the other side of the fence?" James Pomerantz (1983) provides a scientific explanation to answer the question. Based on optical and perceptual laws, grass appears greener (even with weeds) to the human eye when viewed at a distance versus looking at blades of grass, perpendicular to the ground, at close proximity. Armed with this knowledge, "green" envy of the neighbour's lawn ought to be abandoned in favour of various hues and shapes of green - healthier for one and all.

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The thistle is one of the most common and iconic agricultural weeds across Canada. It has tremendous significance to the Canadian Weed Science Society/Société canadienne de malherbologie (CWSS-SCM) as our logo and to our country. It is usually stated that, in North America, the thistle (*Cirsium arvense*) was the first noxious weed to be identified in legislation as a serious threat to agricultural production. The law passed by the state of Vermont in 1795 usually being cited as the first such recognition of this. However, as pointed out by Richard Cayouette (Bulletin de la Société d'Histoire Régionale de Lévis 24: 2-12), a law was passed in Quebec in 1667 by the King's council assembly, obligating land owners (particularly farmers) to control "le chardon" (undoubtedly *Cirsium arvense*) and to prevent the production of seed which will spread infestations into areas of cereal production. Le chardon was the first weed and introduced alien plant to become such a problem that it was broadly recognized as a significant pest and "legislated" against by government authorities. Pre-dating the Vermont action by 128 years, this is the first "noxious weed" in Canada and probably the New World.

The 'thistle' was probably the first candidate for discussion in the politics of weeds in Canada. Today, weeds, weeds research, and weedy issues are certainly not exempt from politics and political influence. Achieving consensus on controversial issues is difficult, but open discussions and presentations can provide the basis for making informed decisions. In the "Politics of Weeds" Opening Plenary Session, seven speakers addressed topics that related to politics and weeds. By supporting this forum, the CWSS-SCM acknowledges the relevance of important political issues in weed management.

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