On the Practical Implications of Roundup Ready (RR®) Alfalfa[1]

E. Ann Clark, Warkworth, ON (eaclark@uoguelph.ca) April 2012

Canadian farmers, consumers, and policymakers have an opportunity to act on the threats posed by Roundup Ready (RR) alfalfa. This paper provides the background information needed to assess the foreseeable impacts of this technology, and to decide whether the claimed benefits are greater than the risks.

To level the playing field and encourage informed action, evidence is provided to address the following questions:

1. What is genetic modification (GM) and what has it done for contemporary agriculture?
2. What is Roundup Ready (RR) technology, and why has it expanded so rapidly and extensively - at least in a few major grain-producing regions?
3. How do the risks of RR alfalfa differ from other RR crops? What is meant by terms such as *perennial*, *forage*, and *legume*? How do the physiological and managerial limitations of alfalfa distinguish the implications of RR technology on alfalfa - a perennial, forage, legume - versus on annual grain crops such as corn, soybean, and canola?
4. Is the rapid evolution of resistant weed biotypes - resistant to glyphosate, the active ingredient in Roundup - a pending disaster or a pre-planned profit centre for Monsanto?
5. Is the RR trait, coupled with glyphosate, compromising plant growth, nutrition, and health?

---

1. What is genetic modification (GM) and what has it done for contemporary agriculture?

Genetic modification, also termed genetic engineering (GE) and transgenics, is the forcible insertion of an alien gene packet into the DNA of a recipient species, such as corn or alfalfa. The packet consists of several unrelated genes or parts of genes that either code for the new trait or enable/control the trait and selection process.

The original view was that GM offered big advantages over conventional plant breeding, because you could identify, extract, and then insert a specific trait into a new host, rather than going through more time-consuming, traditional breeding methods. GM was framed as a *revolutionary* technology[2], greatly accelerating crop improvement and medical breakthroughs. As framed at the time, GM was poised to achieve everything from higher photosynthetic rate and tolerance to such stresses as frost or salinity, to making corn into an N-fixing crop, and even introducing novel floral scents and coloration into ornamental flowers. Starting in the mid 90s, authorities from government and academia, as well as industry, spoke convincingly - and often - about the critical

[1]Throughout, RR is understood to be RR®

[2]For explanation and rebuttal, see Nightingale and Martin (2004)

need for GM to address everything from increasing yield[3], feeding the world[4], and protecting the environment to increasing farmer profitability. Second and third generation claims related to production of pharmaceuticals and industrial feedstocks, respectively, in field-grown plants.

In reality, after 30 years of unwavering, uncritical, and dogmatic support at all levels of government, in many countries, in the form of:

- ▸demonstrably lax regulation (Andrée 2006 and 2011; Royal Society of Canada, 2001)
- ▸hundreds of billions of dollars in global public funding, and
- ▸the wholesale transformation of academia to where 'agriculture' is increasingly indistinguishable from molecular genetics,

what has been accomplished? GM technology has contributed a grand total of two traits to contemporary agriculture,

herbicide tolerance and Bt,

fitted almost entirely to four crops - corn, soy, cotton, and canola. As is characteristic of this sector since 1996, much more is promised, pending, approved, in the pipeline and so on, but what has actually made it into commerce is almost wholly just two traits in four crops.

What is herbicide tolerance? Conveying the herbicide tolerance trait to a crop means inserting a gene allowing a crop to tolerate 'over-the-top' applications of an herbicide which would normally kill it, but which now kill everything but the crop. The type of tolerance inserted into most GM crops is tolerance to glyphosate, the active ingredient in Roundup. The tradename for crops fitted with glyphosate tolerance is 'Roundup Ready' or RR.

Mutagenesis is a different process - not GM - which has also been widely used to manufacture another kind of herbicide tolerant crops, known by the common name of Clearfield. Clearfield crops are tolerant to the herbicide imidazolinone.

What is Bt? Bt, short for *Bacillus thuringiensis*, is a naturally occurring bacteria which has genes coding for a number of Bt endotoxins specific to particular kinds of pests. The two kinds of GM Bt traits now in the marketplace express Bt that is toxic to a) lepidopterans (moths and butterflies), such as European cornborer (and monarch, black swallowtail, and other butterflies) and b) coleopterans (beetles) such as corn rootworm.

---

[3]For an in-depth analysis of GM yield claims, see Gurian-Sherman (2009)

[4]For an alternative and recent reassessment, see McIntyre et al. (2009)

So, over 15 years of a near-continuous, commercialization green-light from both government and academia in many countries around the world, the net result of the GM 'revolution' is two traits accounting for almost all of GM-sown cropland to date.

1. Synthesis. By almost any objective criterion bearing on social benefit, GM would have to be rated an abysmal failure. Returns to societal investment in GM are completely out of balance - at least to society.

But the really key point to understand from the above is that apart from these two traits, all the other genetic improvements in modern agriculture - even today, despite 30+ years and countless scientist-years of concerted effort - are the result of **conventional plant breeding - not GM.** The only thing that distinguishes a GM from a non-GM variety is the forcible insertion of transgenic packets conveying herbicide tolerance or Bt or both. The other tens of thousands of genes and myriad desirable traits in contemporary crop varieties are entirely the result of conventional plant breeding.

An objective analyst might wonder why, of all the traits that could have been added to actually deliver on the well popularized claims of feeding the world, saving the planet, and enriching farmers, by far the most prominent even today is tolerance to an herbicide owned by an agrochemical company, which also owns the herbicide tolerance gene(s).

---

2. What is Roundup Ready (RR) technology, and why has it expanded so rapidly and extensively - at least in a few major commodity-producing regions?

Since release of the first GM crop varieties in 1996, RR crops - fitted either with the RR gene alone or in combination with other transgenic traits - have grown to account for about 70% of all the land sown to GM on the planet today (Lotter, 2009). By 2008, the RR trait accounted for 63, 68, and 92% of US corn, cotton, and soybean hectarage, respectively (Duke and Powles, 2009, cited in Mortensen et al., 2012).

And just how important is GM crop production today? According to Lotter (2009), GM crops occupied 80 million ha of land in 2006, amounting to 1.5% of global crop hectarage. The pro-biotech organization ISAAA (2009) stated that GM crops occupied 134 million ha in 2009, of which three countries - the US, Argentina, and Brazil - accounted for 64, 21.3, and 21.4 million ha, respectively or 80% of the total. Add in India, Canada, and China for another 20.3 million, making 95% of global GM hectarage (total of 2.5% of global crop hectarage).

Thus, almost all GM land is contained within a few countries of global prominence, growing several industrial (not directly human consumable) commodity crops. Again, an independent analyst might wonder why a technology purported to be of such great advantage as to have captured such a large majority of the hectarage of US and CA corn, soybean, cotton, and canola has attracted so little enthusiasm from the farmers in the rest of the world.

Why are farmers growing RR crops? It is claimed that the astonishingly rapid take-over of sown crop hectarage by RR varieties in the above countries means that farmers genuinely value RR technology. It cannot be denied that herbicide tolerance, to glyphosate, glufosinate ammonium, imidazolinone, and now other herbicides, greatly facilitates - dumbs down - the complex process of conventional weed control with herbicides. Whether the economic benefit of thus facilitating weed management equals or exceeds the cost of the RR technology remains to be seen (various, cited in Lotter, 2009). A question not asked in such analyses is why weeds have become such a problem that such draconian measures are even considered.

So, do these dramatic adoption trends amount to a glowing testimonial from farmers? Or are they simply an affirmation of the effectiveness of Monsanto's marketing strategy? Arguably, what we are actually seeing is the expected fruits of the seed trade takeover by a double handful of agro-chemical companies - dominated by Monsanto - leaving farmers little choice but to buy whatever Monsanto and associates choose to offer. According to ETCGroup (2008), 10 corporations controlled two-thirds of the global proprietary seed market[5] in 2008, which in turn accounted for 80% of the commercial seed supply. That is 80% of all commercially traded seed on the planet - not counting farmer-saved seed - is controlled by a 10 corporations. Owning the seed trade allows Monsanto to fit new varieties with the RR or other GM traits - whether they are wanted or not (Benbrook, 2009; Mortensen et al., 2012) - leaving farmers no choice but to pay the hefty premium if they want to access the best available - conventionally bred - genetics for such traits as yield, disease resistance, standability, and quality.

It is therefore misleading to attribute rapid spread of RR technology solely to farmer enthusiasm for the trait. Buying a cultivar fitted with the RR trait, whether you want it or not, is like obliging one's family to consume brussel sprouts, whether they like them or not, before they can tuck into a favourite dessert. Apparent farmer 'adoption' of RR technology needs to be viewed in the context of 'the take-it or leave-it' status of field crop variety selection in a market controlled by a few corporations.

2. Synthesis. So the question is: are farmers growing RR varieties because they value the ease of weed control (doubtless true initially, but today...? not so much), or because they can't get access to premium, conventionally bred genetics unless they pay the extra price for the RR (and other GM) traits?

It appears that by buying into GM, but especially RR, technology in the 90s, farmers and the institutional authorities who encouraged them have effectively oiled the trap that is now springing shut. The very real takeover of the seed trade starting in the 90s - fueled by farmer seed purchases and enabled by governmental disinclination to see the threats of wholesale consolidation of the seed trade - means that it no longer matters if GM traits are wanted, or even

[5]Three companies - Monsanto (23%), DuPont (15%), and Syngenta (9%) control 47% of the global proprietary seed market, and roughly two-thirds and >50% of the global propriety corn and soy markets, respectively (ETCGroup, 2008)

if they do what is promised, as they are the only game in town. For more on this, see Question 4 below.

---

3. How do the risks of RR alfalfa differ from other RR crops? What is meant by terms such as *perennial*, *forage*, and *legume*? How do the physiological and managerial limitations of alfalfa distinguish the implications of RR technology on alfalfa - a perennial, forage, legume - versus on annual grain crops such as corn, soybean, and canola?

The marketing of RR alfalfa in Ontario would pose significant, crop-specific risks to both adopters and non-adopters of the technology, and owing to the scale of production, to agriculture as a whole. Improved forages (pasture and hay), often including alfalfa, are the single largest agricultural land use in the province of Ontario, accounting for 43% of all agricultural land as of the 2006 census. In addition, like all perennial forages, alfalfa is only moderately domesticated, and survives well as a feral plant in the wild (Bagavathiannan and Van Acker, 2009). Thus, whether sown or feral, alfalfa plays a prominent role in the overall agricultural landscape of the province.

Many of the risks associated with RR alfalfa are common to other RR crops. However, here we will focus on problems caused by the environmental and managerial sensitivities of alfalfa, owing to innate features of its growth habit and physiology as a perennial. As will be discussed below, adding the RR trait to alfalfa necessarily - unavoidably - expands the suite of problems already evident in fields growing RR annuals, such as corn, soybean, and cotton. Attention is given to problems that will occur on farms which adopt this technology, but it is also recognized that the wide genetic contamination radius of alfalfa - like canola and other insect-vectored, cross-pollinating species - will extend to non-adopters, the same kinds of liability and market rejection concerns (Furtan et al., 2003) already evident with RR canola and other crops. The bridging effect of feral alfalfa, as noted by Bagavathiannan and Van Acker (2009), will further compound inadvertent liability issues.

To provide a sense of context for what follows, an overview of agricultural background and terminology specific to alfalfa is presented, followed by consideration of the crop-specific implications of RR alfalfa.

Background/Definition of Terms

Forage Species. Alfalfa is one of a number of perennial forage species that are grown both for livestock nutrition/health and for environmental stewardship. Common forage grasses are timothy, bromegrass, reed canarygrass, tall fescue, orchardgrass, Kentucky bluegrass, and perennial ryegrass. Common forage legumes include birdsfoot trefoil, sweetclover, red clover, and white clover - and of course, alfalfa. Alfalfa is the most highly bred and widely sown forage species, accounting for 52 of the 100 forage varieties recommended in 2012 in ON (OFCC, 2012) . Alfalfa and timothy - a mixture most commonly sown on dairies and some other operations - jointly account for nearly two-thirds of all recommended forage varieties in 2012.

Species differ greatly in adaptation to both predictable and unpredictable stresses. For example, unlike alfalfa, species such as timothy, red clover, and alsike clover are tolerant to imperfect drainage. Unlike alfalfa, which requires a soil pH between 6.5 and 7, birdsfoot trefoil can grow down to pH 4.5. Alfalfa, birdsfoot trefoil, and sweetclover thrive in hot dry conditions, unlike Kentucky bluegrass and white clover. Drainage, pH, drought, fertility, and other stresses vary both among and within fields. Precision farming evolved specifically to compensate for variable growing conditions within a field. Differences in species adaptation enable effective use of many land types and compensate as well for variability within a given field.

Legumes. Legumes are species that form a symbiotic relationship with special rhizobial bacteria, enabling the conversion of gaseous nitrogen from the atmosphere into biologically useful nitrogen, as for protein synthesis. One of the services provided by perennial forages is introducing nitrogen - a key plant nutrient - into farmland, for subsequent crops to use.

Perenniality. A perennial is a species that survives for multiple years from a single planting, like asparagus, rhubarb, and apple trees. Most sown forages are perennial, but a few, such as red clover, alsike clover, and sweetclover, are biennial - living for 2 years. Thus, unlike annual crops such as corn, cauliflower, and carrots, which must be planted each year to produce a crop, the individual plants in a perennial forage sward live for several to many years after a single seeding.

Although a perennial, the lifespan of individual alfalfa plants is often short, owing to sensitivity to a range of stress factors (see below). Even with good management, alfalfa plant populations typically decline to unacceptable levels within 2 or 3 years of seeding, after which the sward is either plowed under to go back to grain (dairy) or reassigned to pasture use.

Harvest. Unlike annuals, which grow without interruption between planting and harvest, perennial forages are harvested repeatedly within a single season. Whether cut mechanically or grazed by livestock - or both - harvest management imposes specific stresses, including some bearing on weed control. Unlike annuals, in which weed control depends at least in part on suppressing weeds until the crop fully covers the ground and shades out the weeds, periodic forage harvest affords repeated openings for weeds to grow. Thus, differences in harvest management mean that the utility of herbicides differs fundamentally between annual crops and perennial forages.

Forage species differ in their adaptation to harvest management, with some better adapted to infrequent mechanical hay/haylage harvest, while others are better suited to frequent harvest by grazing animals on pasture. The actual harvest interval varies greatly among regions, but in Ontario, alfalfa, birdsfoot trefoil, timothy, bromegrass, and reed canarygrass are best adapted to infrequent harvest, 2 or 3 times over the growing season. Infrequent harvest means allowing lengthy regrowth intervals between harvests, in order to accumulate a large biomass for mechanical harvest as hay or haylage.

What does this have to do with RR alfalfa? The lengthy regrowth intervals needed to sustain health in alfalfa and other hay-adapted species cause the base of the sward to be in the dark long enough to kill short-statured species, such as Kentucky bluegrass and white clover, as well as the young tillers or branches on the hay-adapted species themselves. In practical terms, this means that even with good management, a hayfield typically consists of a relatively low density of large, aggressive plants, separated by bare ground that is exposed after each harvest: an open invitation to windblown weed seed, such as dandelion and Canada thistle.

Other species, such as Kentucky bluegrass, perennial ryegrass, tall fescue, and white clover, are well suited to pasture, which means frequent grazing of smaller accumulated yields, 4 or 5 times a season - a frequency which would readily kill alfalfa or timothy. Under good management, frequent grazing keeps the base of the sward in light, promoting a dense population of small plants, no bare space, and hence, little opportunity for weed establishment.

These differences between hay- and pasture-adapted species illustrate the point that a) no single species is able to supply the full range of services expected of forages, and further, that b) the harvest regime to which alfalfa is best suited is predisposed to weed encroachment.

Flowering. While perennial forages do not need to set seed to perenniate - they can persist vegetatively as well as reproductively - they do flower and will set seed if given the opportunity. Most legumes, including alfalfa, will flower and set seed two or more times during a season - each time being subject to genetic contamination from neighbouring fields - unless harvested in a timely fashion. In fact, repeated flowering multiplies the risk of genetic contamination in perennial forages as compared to annual crops.

Seed set and fall to the ground is one of the means by which alfalfa can disperse, germinate, and persist within a sward when the originally sown alfalfa plants die. Proponents of RR alfalfa argue that flowering and seed set do not occur in well managed alfalfa - to refute the risk and liability of genetic contamination of neighbouring non-RR alfalfa-containing fields. In the event this improbable claim is validated, then failure to set and disperse seed in an RR alfalfa field would preclude this avenue for alfalfa persistence and further shorten stand life.

Services Provided. While we think of perennial forages primarily as livestock feed, they perform a broader range of services to whole farm management and land stewardship, including the addition of nitrogen to the land. For this reason, the fate - financial and agronomic viability - of perennial forages bears not simply on the livestock sector but on agriculture and the environment as a whole. Should a significant fraction of producers foreswear alfalfa, to avoid some of the kinds of risks and liabilities discussed in this and other reports, effects on environmental sustainability would be expected.

‘Grass’ - meaning all kinds of forages - has been termed ‘the forgiveness of Nature’, and so it is. Because they are perennial, forages withhold land from annual cultivation, a process which breaks down soil organic matter and degrades structure, affecting everything from tilth and nutrient cycling to water infiltration. Unlike annual grain and vegetable crops, forages are a net contributor of nitrogen and organic matter to the soil, enhancing soil health, and also providing habitat to support biodiversity and biocontrol of pests. Species such as red clover are grown primarily for these reasons, but all forages, including alfalfa, help steward land to recovery following years under annual cropping.

Environmental and Managerial Weaknesses of Alfalfa Bearing On Weed Management

At issue is the foundational premise of RR alfalfa - monoculture alfalfa, and whether this premise is realistic in commercial agriculture. Evidence presented above, and following, demonstrates that alfalfa is inherently prone to both a short lifespan and to weed encroachment. Such traits make it a desirable product for those selling both alfalfa seed and herbicides. However, farmers seeking to sustain alfalfa have evolved a range of managerial approaches centering on growing it in mixture with other species - a concept incompatible with RR alfalfa. It should be noted that most of the arguments that follow pertain to any forage monoculture - not just alfalfa - but alfalfa is the focus of this analysis.

a. Why mixtures? Perennial forages are one of the few modern crop types that is routinely sown in mixture, rather than in monoculture. The reasons are many, but one is the need to accommodate the wider range of stresses and performance expectations that pertain to perennial forages, in comparison with annual crops like corn. As noted above, a single seeding of forages is expected to grow and regrow multiple times within a single growing season, and to persist over years. In contrast, grains grow and are harvested just once from a single seeding.

More is expected of forages, than of annual crops. As a full-season crop, forages are expected to convert solar radiation over a full growing season - between late April and October in ON - which means coping with the full range of seasonal growing conditions. Most annual crops occupy only a fraction of the growing season, between April and August for spring cereals, for example, or mid May to Sept for soybean. Furthermore, apart from dairy and commercial hay operations (see below), forages are commonly grown on more stressful land, receiving lesser levels of management, including drainage, fertility, and pesticides.

No single species can do everything well or persist long enough to be commercially viable under all conditions (see text box). Unlike grain and vegetable crops, what matters to a forage producer is the performance and longevity of the *sward* - not of any single species - although alfalfa is the most valued sward component for many operators.

The need for longevity. Forage seeding is costly, amounting to \$327/ac in 2011 (OMAFRA, 2012). This is an acceptable cost if amortized over several-to-many production years, in other words, assuming the sown sward persists acceptably. Such an expenditure becomes economically unrealistic if required every year or two - as it surely would with any forage monoculture.

Unlike grains and vegetables, forages - including alfalfa - are virtually always sown in mixtures of 2 or more species, commonly including 1 or more grasses and 1 or more legumes. Unlike a monoculture, a mixture harnesses the diverse adaptations of several species to achieve built-in resilience or buffering against the managerial and environmental stresses which may weaken or kill an individual species.

Thus, a precondition to the presumed viability of monoculture alfalfa - irrespective of the RR trait - is either a) that the already highly bred alfalfa will be further selected to tolerate the range of stresses and performance expectations that are currently accommodated by a mixture of diverse species' adaptations, or b) that the current range of stresses will be minimized by all farmers, as is more commonly achieved on dairy and commercial hay farms, by application of exogenous energy in the form of fertilizer, lime, tile drainage, and pesticides.

b. Timing of growth during the season. Seasonal growth patterns differ among species. Grasses are more prominent in the cool, moist conditions of spring and fall, while deep-rooting legumes, such as alfalfa and birdsfoot trefoil, are better adapted to the heat and drought of summer, although there are also species-specific variations. These differences are critical to enable forage growth throughout the long growing season.

Thus, because of innate differences in timing/adaptation, a monoculture of alfalfa would necessarily invite encroachment from spring-vigorous weeds, such as dandelion and quackgrass, simply because alfalfa doesn't grow well in spring. A mixture of species which jointly cover off the season, such as spring-vigorous timothy with summer-vigorous alfalfa, makes more effective use of the growing season and as such, reduces weed encroachment. In essence, growing forage species in mixture overcomes temporal weaknesses that pertain intrinsically to a monoculture of any one species.

In effect, because of seasonality in growth, the presumption that alfalfa can or should be grown in monoculture - to utilize the RR trait - necessarily opens a window for weed encroachment - and hence, dependence on herbicides - and specifically glyphosate - for weed control[6].

c. Growth habit. Some species, such as alfalfa and timothy, stay where they are sown. Unless they are allowed to mature seed and disperse, their inability to spread outwards causes sown rows to be visible for years after planting. In contrast, other species, such as Kentucky bluegrass and white clover, are laterally invasive. Both of these species have horizontal stems, whether as underground rhizomes or aboveground stolons. These species have the capacity to spread outwards and fill in spaces left empty by winterkill, disease, or other mishap.

Species that spread outwards compete more effectively with weeds. This is one reason why traditional (pre-herbicide era) forage mixtures included 'bottom' species like Kentucky bluegrass and white clover - to forestall weed encroachment.

The growth habit of alfalfa is particularly vulnerable to weed encroachment because a) it is best adapted to infrequent harvest, which leaves openings that invite weed seeds to germinate, and b) individual alfalfa plants lack the capacity to spread outwards to compete with weeds.

---

[6]Mechanical tillage is not an option, because this is a perennial sward. Tillage would destroy the sward.

Unambiguously, growing alfalfa in monoculture will promote weed encroachment, obliging greater dependence on herbicides, while augmenting selection pressure for weed resistance.

d. Stress tolerance. Perennial forages have to survive various kinds of stress, including the protracted 'dead' interval in winter. Unlike annual crops, stresses can accumulate and manifest in the strength and composition of a perennial forage stand months or years following a tough winter or droughty summer. If a forage plant doesn't survive or is weakened, neighbouring plants invade and occupy the space - whether from the sown mixture or from waiting weed populations in the soil seedbank - which may number 10,000 viable weed seeds per square meter of arable crop land - or the seed 'rain', meaning windblown weed seeds. For this reason, a species weakened by a single stressful event can result in long-lasting changes to sward composition. Thus, sward resilience depends integrally on the ability of one or more components of a mixture to compensate for events that weaken other species.

Alfalfa growers are compelled to supply management to overcome its various sensitivities to stress. For example, both alfalfa and birdsfoot trefoil require a lengthy, undisturbed interval in the fall to achieve satisfactory levels of winter dormancy. This obliges modifications to harvest scheduling and risk. To a greater extent than most other species, winterhardiness in alfalfa is also dependent upon proper levels of potassium fertilization (Bowley and Wright, 1991). Of the forages, alfalfa is more vulnerable to a range of insect and disease pests, such as alfalfa weevil and potato leafhopper, as well as *Phytophthora* root rot and *Verticillium* wilt. Alfalfa is also sensitive to soil pH - requiring a narrow range near neutrality - and requires good soil drainage.

Thus, those aspiring to grow good alfalfa even for 2 or 3 years must be prepared to **tailor the environment** to the crop, including timely harvest management, particularly in the fall; an hospitable soil pH, through suitable liming; a well drained soil, typically through tile drainage; and when needed, insect/disease control through purchased pesticides.

The obligation to homogenize the environment to sustain a particular species means that commitment of fossil fuel-based resources is implicit to growing monoculture alfalfa. In contrast, the traditional use of forage mixtures employs the diverse tolerances of individual species to cope with environmental stress. A mixture of species differing in tolerance to stresses effectively **tailors the crop** (the forage sward) to meet the demands of a variable field environment. Diverse neighbouring plants serve as a buffer, to fill-in gaps and compensate when plants of any one species are weakened or killed by stress. The fossil fuel/resource use implications of these contrasting approaches - tailoring the environment or tailoring the crop - bear on the economic as well as environmental sustainability of forage farming in the future.

Alfalfa plays somewhat different roles on dairy versus other farm operations. Dairy operators don't want or expect an alfalfa seeding to survive for more than 2 or 3 years, because alfalfa is in a planned crop rotation with corn and other annuals to provide balanced nutrition for the herd. Dairy farms arguably account for the lion's share of alfalfa seed sales, specifically because a) dairy herd rations rely heavily on alfalfa for protein and fibre, b) due to its rotation with annual grains, alfalfa is necessarily re-seeded much more often on dairy than on beef or sheep farms, and

c) dairy is a supply managed sector, ensuring sufficient income to be able to afford the timely management, fertilizer, lime, tile drainage, and pesticides needed for optimal alfalfa performance. Thus, it could be argued that the short lifespan on alfalfa doesn't matter to a dairy producer.

Nonetheless, the tendency for individual alfalfa plants to succumb to stress within 2 or 3 years of seeding is tolerable - both to dairy and to other operators - *only* because there are other species in the sward to sustain sward productivity. Even dairy farmers seed alfalfa in mixture with other species, for this and other reasons. To illustrate, assume a sward was not a mixture of alfalfa and other sown species, but rather, monoculture alfalfa. If the sward suffered 20 or 50% alfalfa loss due to a severe winter or another of the stresses to which alfalfa seems especially prone, weeds would necessarily encroach - there being nothing else there to take up the slack - and the field would have to be resown. A monoculture means no back-up, no buffer, no fall-back option - apart from weeds - to fill-in and compensate for the wholly predictable, progressive loss of alfalfa plants. Spraying yet more Roundup would kill the encroaching weeds in such a circumstance[7], but the alfalfa population would remain sub-par because the remaining plants do not spread outwards. Yield would necessarily be reduced, and the only remaining option would be routine, regular - and costly - reseeding.

Could the RR trait enhance the persistence of monoculture alfalfa simply by eliminating all competition - and specifically, competition from other forages? Timothy is the preferred companion for alfalfa because it is a sparsely tillering, weakly competitive species whose season of greatest growth overlaps only modestly with that of alfalfa. Other possible companions, such as orchardgrass, will most assuredly outcompete alfalfa, but for that reason, are not preferred for alfalfa-based mixtures (see text box).

Given the known range of stress sensitivities for alfalfa, from winterhardiness to soil pH, imperfect drainage, and pests, and the known compatibility of timothy with alfalfa, a beneficial direct effect of the RR trait on alfalfa persistence seems improbable.

Alfalfa Companions. To illustrate, a study at Elora, ON involved 8 alfalfa cultivars each grown with each of 3 companions: a) nil (e.g. monoculture alfalfa), b) alfalfa-timothy, or c) alfalfa-orchardgrass. After three years of hay and/or grazing management, alfalfa contribution to yield averaged 86, 87, and 76% in the monoculture alfalfa, alfalfa-timothy, and alfalfa-orchardgrass mixtures, respectively (Clark, unpublished). First cut yield the following spring averaged 6.0, 6.2, and 6.6 t/ha for the monoculture alfalfa, alfalfa-timothy, and alfalfa-orchardgrass mixtures, respectively. The reason why timothy is the preferred companion for alfalfa is clear - enabling alfalfa to persist as well as in monoculture, without compromising overall yield.

3. Synthesis. Innate differences in physiology and growth habit distinguish annual crops from perennial forages and invalidate the fundamental logic of herbicide tolerance for alfalfa. Alfalfa, like all perennial forages, is grown in mixture with other species, to achieve a range of services

[7] Apart from those weeds resistant to glyphosate; see below

of which one is weed control. RR alfalfa - of necessity - would be monoculture alfalfa. Denying the presence of companion species to an alfalfa sward eliminates those services.

Herbicides cannot replace the services lost by forcing alfalfa into monoculture, simply because no single species can do what a mixture does:

- season-long growth, to efficiently capture solar energy;
- tolerance of a wide range of managerial and environmental stresses, which vary both within and among fields and years;
- suppression of weeds, by competing effectively before and after each harvest; and
- persistence over years, to amortize the high cost of establishment over sufficient years to make a profit.

Alfalfa is considered the 'queen of forages' in North America. But just as a queen relies integrally on a cadre of retainers to perform her state functions, so too alfalfa relies intrinsically on companion species to achieve the yield and performance expected of the species. The predictable net effect of growing alfalfa in monoculture, to enable the utility of the RR trait, will be shorter standlife, lower and less reliable yield, greater costs for tailoring the environment to the narrower adaptations of alfalfa, and greater costs for weed and other pest control.

---

4. Is the rapid evolution of resistant weed biotypes - resistant to glyphosate, the active ingredient in Roundup - a pending disaster or a pre-planned profit centre for Monsanto?

Target pest resistance is not unique to GM, nor is it limited to glyphosate. As known for over half a century, indiscriminate use of herbicides, insecticides, and fungicides leads to resistant biotypes of the target pest, often within just a few years, as has occurred with glyphosate. Biotypes from an increasing number of weed species resistant to glyphosate exhibit resistance to two or more 'modes of action' - different herbicide families - demonstrating the fallacy of relying on pesticides as a primary control method.

Current Snapshot of Weed Resistance to Glyphosate. According to www.weedscience.org, glyphosate-resistant weed biotypes from seven species, Palmer Amaranth, Common Waterhemp, Common Ragweed, Giant Ragweed, Sourgrass, Kochia, and Johnsongrass, have been identified exclusively in land sown to annuals such as soy, cotton, and corn, which were among the first crops fitted with the RR trait. Glyphosate-resistant biotypes from another five species, Horseweed, Sumatran Fleabane, Junglerice, Goosegrass, and Italian Ryegrass, have been reported from both GM crop-bearing land and non-GM venues, such as orchards and vineyards. Another ten species have evolved biotypes resistant to glyphosate, but solely in non-GM settings - demonstrating that overuse of glyphosate in any setting screens for resistance to glyphosate.

Of the (currently) 146 resistant biotypes reported from 22 weed species to date, 83 or 60% were reported in the US, and two have been reported in Canada - Giant Ragweed in Ontario 2008, and Kochia in Alberta in 2012. While the first glyphosate-resistant biotype was reported in 1996, a total of 36 biotypes or 25% occurred just in 2010, 2011, and 2012, indicating that loss of efficacy is accelerating.

Why the Rapid Rise in Resistance? The rise of glyphosate-resistant weed biotypes is wholly predictable. As of 2008, the most recent year for which data are available, more than 2 million kg of glyphosate (the active ingredient in Roundup) were applied annually in Ontario agriculture, most of it to corn and soybeans (McGee et al., 2010a). Between 1993 (just prior to release of GM crops) and 2008, glyphosate use in Ontario increased from 17,210 to 527,952 kg in corn (a 30-fold increase), and from 164,784 to 1,253,773 kg in soybean (a 7.6-fold increase) (McGee et al. 2010b).

As of 2008, glyphosate accounted for roughly 55% of all the herbicide active ingredient applied to all ON crops. It cannot be doubted that glyphosate use has further increased since 2008, in both absolute and relative terms, and that the cause is RR-crops. The wholly predictable outcome of overdependence on a single herbicide - a trend which would be further exacerbated by the introduction of RR alfalfa - is the skyrocketing costs to producers of controlling weed biotypes resistant to glyphosate (Mortensen et al., 2012).

For just one example involving a million acres in the southern US, see http://abcnews.go.com/WNT/video?id=8767877

How Do Farmers Respond? One of the unambiguous outcomes of weed resistance to glyphosate - as occurs with any pest resistance to any pesticide - is producer efforts to maintain control by increasing both the rate of application and the number of applications of pesticides. Benbrook (2009) calculated trends in glyphosate use in the US, starting in 1997 - when industry still claimed that GM would save the environment by reducing pesticide use - until the USDA stopped conducting annual surveys of pesticide use (see table).

Trends in glyphosate use per acre in US crops
(from Benbrook, 2009)

Crop and Period	Glyphosate Rate in 1996, lb a.i./ac	Total *Increase*, lb a.i./ac	% Change	Average Annual % Change over Period
Corn (1996-2005)	0.68	0.27	39	4
Cotton (1996-2007)	0.63	1.26	200	18
Soybean (1996-2006)	0.69	0.67	98	10

Adapted from USDA National Agricultural Statistics Service annual surveys of pesticide use, integrating not just rates per application, but number of applications per crop year. USDA NASS last surveyed pesticide use in 2005, 2007, and 2006 for corn, cotton, and soybean.

Comparable trends in ON, between 1998 and 2008, showed mean glyphosate application rate (total used divided by harvested hectares) increasing from 0.1 to 0.75 kg/ha in corn - partially displacing atrazine and metalochlor, and from 0.44 to 1.48 kg/ha in soy, partially displacing metalochlor.

Thus, contrary to one of the claimed pillars of societal benefit - that GM would reduce dependence on pesticides, and hence, protect the environment - the RR trait has in fact increased - not decreased - use of Roundup. And the increase was entirely predictable.

But increasing the rate and frequency of application of glyphosate can only keep weeds under control for so long, particularly in the face of resistant weed biotypes. What then?

It bears repeating that the clear breakdown of the efficacy of this technology has occurred *prior to* the release of RR alfalfa. That RR alfalfa has been developed, approved, and at least in the US, released into commerce means that both industry and government regulators fully expect adopters of RR alfalfa to buy tainted goods, to willingly absorb the escalating costs of a demonstrably failing technology.

Monsanto's Response to Weed Resistance. To maintain market share, and in fact, benefit from the predictable rise in weed resistance to glyphosate, Monsanto is employing a range of tactics:

‣paying farmers to use competitors' herbicides, to offset the problem of weed resistance in the immediate term (Brasher, 2010); and
‣engineering resistance to additional herbicides, as 2,4-D and dicamba, to complement the RR trait in the near future (Mortensen et al., 2012), to enable
‣applying Roundup in tank mixes with other herbicides, as with 2,4-D and dicamba[8] (Monsanto, 2012)

Stacked Traits. So, is the RR technology really failing, or is this just the preamble to the latest version of the 'take-it or 'leave-it' strategy for separating farmers from their money? Enter the phenomenon of multiple-trait or 'stacked' varieties as widely reported in Monsanto, ISAAA, and other industry promotions.

At issue is whether stacking multiple traits - 'SmartStax' corn, for example, has 8 genes - 2 conferring herbicide tolerance (to glyphosate and to glufosinate ammonium) as well as 6 different Bt endotoxin genes - is:

‣ a desperate effort to redress the mounting weed resistance and other failures of the technology, or rather,
‣ a water-tight method of obliging farmers to pay for superfluous GM traits. It bears repeating that this notion only arises once you have cornered the market for seed - as have Monsanto and its associates.

To diverge with an example from GM-Bt, two different types of genes coding for two different endotoxins have been separately marketed, to treat two kinds of corn pests, European cornborer

---

[8] herbicides which selectively kills broadleaf plants - including soy, cotton, canola, and alfalfa

(ECB) and corn rootworm (CRW). The two pests do not necessarily occur together (Knodel, 2011). Early Bt corn hybrids targeted solely ECB (and Western Cornborer in some areas), a pest which arises sporadically and unpredictably. Farmers have to pay for it up-front, on the chance that this might be a year of ECB outbreak. As a result, uptake of GM-Bt targeting ECB was far less enthusiastic than that for RR, for example, where weeds are a consistent issue. The more recent entry of GM-Bt to control CRW, a more consistent pest, began showing resistance problems starting in 2009 and ongoing (Gassmann et al. 2011; Fyksen, 2011).

So, how to sustain payback for the investment in developing and marketing these two, less-than-fully successful types of Bt? Stack them onto RR offerings. Benbrook (2009) cited Monsanto's forecast for it's US 2009 trait-acres, as:

▸corn expressing ONLY the GM-Bt for CRW:	no acres
▸corn expressing GM-Bt for both ECB and CRW but not RR:	<1 million ac
▸corn expressing both CRW and RR but not ECB	<1 million ac
▸corn expressing CRW/ECB/RR (triple stack):	32-33 million ac

He noted the industry terminology applied to this strategy is 'biotech trait penetration', to enhance returns from 'fee-per-trait' pricing used by industry. And then most recently, given the pending failures of the RR trait, stack all of this onto a second herbicide tolerance - to glufosinate ammonium or Liberty (the Liberty Link or LL trait) - e.g. SmartStax.

Likewise, the ETCGroup (2008) reported that:

> "A Monsanto spokesman told *Progressive Farmer* that 76% of the maize seed it sells in the U.S. in 2009 will be triple-stack varieties. Syngenta aims to make triple-stack maize account for 85% of its portfolio by 2011. In the U.S. – where half of the world's GE crops are grown – 37% of all transgenic crops contained two or three biotech traits in 2007."

For exhaustive promotion of dual, triple, and SmartStax (8-trait) offerings, see the 2012 Monsanto Canada Technology Use Guide (Monsanto Canada, 2012).

Returning now to stacking herbicide tolerance to overcome resistant weed biotypes, obliging farmers to pay for stacked traits - whether they want them or not - in order to access the superior, conventionally bred genetics that they *do* want, has several predictable effects:

▸It looks good on the books, Monsanto's books, that is. Stacking varieties with specious GM traits boosts trait-hectares, allowing the continued disingenuous inference that hectarage trends equate to farmer demand for GM

▸Stacking RR varieties with resistance to dicamba or 2,4-D prolongs economic returns from Monsanto's Roundup herbicide, which would otherwise be dropped owing to mounting weed resistance,

▸Boosting herbicide tolerance genes boosts herbicide use - and sales - and environmental impact. For stacked varieties, Mortensen et al. (2012) referenced Dow and Monsanto scientists as advocating current rates of glyphosate *plus* 225-2240 g ha^{-1} of dicamba or 560-2240 g ha^{-1} of 2,4-D. In other words, stacking herbicide tolerances does not replace or substitute one herbicide with another, but rather, *adds* to total herbicide usage. Increasing herbicide use not only challenges the premise of the early GM claims of greater profitability for farmers - because this all costs money - but also threatens the environment. While dicamba and 2,4-D are rated as relatively benign for human risk, both are extremely toxic to a wide range of terrestrial and aquatic plant species - a direct and unequivocal refutation of early claims that GM would benefit the environment by reducing pesticide use.

▸Stacking RR varieties with resistance to dicamba and 2,4-D raises a fresh suite of hazards - to both adopters and non-adopters. Both dicamba and 2,4-D are synthetic auxins, to which broadleaf crops such as soybean, cotton, and alfalfa are extremely sensitive - vulnerable to injury. This is why they are (were) used *not* on broadleaf crops (as they will be with stacked soybean or canola varieties), but on grass crops, such as cereals and lawns. As reviewed by Mortensen et al. (2012), stacking these herbicide tolerances - and hence, using these herbicides in the tank mix along with glyphosate - poses high risks of:

a) application error to a susceptible crop (one fitted with RR but not RR+dicamba, for example);
b) damage from residual herbicides, owing to extreme difficulties in cleaning synthetic auxins out of sprayer tanks; and
c) high volatility of some formulations of dicamba and 2,4-D, leading to spray drift

Mortensen et al. (2012) speculated that this ‘perfect storm’ of likely risk factors may well oblige farmers to buy stacked varieties as a pre-emptive precautionary strategy - irrespective of actual need for the traits.

▸Owing to high sensitivity to synthetic auxins, the viability of many broadleaf fruits and vegetables, including potatoes, tomatoes, and grapes would be increasingly threatened by the widespread use of tank mixes to support stacked GM crops (Mortensen et al., 2012).

4. Synthesis. Arguably, contrary to the many claims made 20 years ago, GM has not afforded traits of service to farmers, society, or the environment. Instead, GM has functioned as a proprietary, liability-based hook to enable the takeover of the seed trade, and ultimately, the global food supply.

Resistance of weed biotypes is a given, when the screen for resistance - enhanced glyphosate use attributable to the RR trait - occurs over vast hectarages. The resultant rise in use of glyphosate and more recently, stacked trait herbicides is both predictable and unavoidable, given consolidated ownership of the seed trade. Adopters, as well as those under no contractual obligation to Monsanto - non-adopters, the environment, and ultimately, society - are paying the price to sustain this technology (see also Clark, 2007).

It does not seem impertinent to ask when regulators are going to acknowledge the intrinsic unfairness and unsustainability of a technology - GM, and specifically RR - which exists *only* because it is permitted to externalize a wide range of costs to everyone else.

---

5. Is the RR trait, coupled with glyphosate, compromising plant growth, nutrition, and health?

The intent of glyphosate, and of the RR trait that enables its direct application to field crops, is weed control. Yet extensive research dating back at least 30 years has documented additional, unintended impacts on crop growth and health. For example, soon after commercialization of the RR technology, farmers reported an upsurge in 'sudden death syndrome' (*Fusarium solani*) in the newly available RR soybean varieties (Sanogo et al., 2000 and 2001). Indeed, the diversity of non-herbicidal ways that many herbicides act on plants has encouraged an analysis of potential intentional uses of herbicides in ripening, growth promotion, and drought tolerance (Velini et al., 2010).

Crop growth and health - and presumably that of those who consume the crop - depend integrally on a balanced relationship with the soil microbial community. The balance, which affects everything from nutrient and water uptake to pest resistance, is maintained in part by purposeful excretion of substances by the plant into the rhizosphere, the cylindrical zone immediately around each root. In broad terms, the excreted substances are intended to selectively stimulate beneficial organisms, such as those which facilitate uptake of nutrients and antagonize pathogens.

The following brief overview of some adverse secondary impacts of glyphosate and of the RR trait illustrates some the many hidden costs externalized by this technology.

Mode of Action of Glyphosate. Glyphosate, like all herbicides (Velini et al., 2010), acts by interfering with plant metabolism. A primary herbicidal effect of glyphosate is the inhibition of a key enzyme in the shikimic acid pathway. This pathway is a major metabolic trunk producing a range of key aromatic amino acids, and precursors to plant growth regulators, phytoalexins, and other intermediates. Because even low rates of application cause glyphosate to accumulate to high concentrations in metabolic sinks, impacts are most pronounced in active sink tissues, such as shoot meristems and root tips, and are greater in reproductive than in vegetative tissues (various, cited in Cakmak et al. (2009). The pivotal importance of the shikimic acid pathway means that even spray drift levels of glyphosate exert diverse physiological effects on susceptible (not RR) plants, including everything from photosynthesis and sucrose translocation to nitrogen assimilation and fixation, as well as uptake of macro- and micronutrients and defenses against pathogens (various, cited in Cakmak et al. (2009).

Macro- and Micronutrient Availability. Cakmak et al. (2009) conducted greenhouse experiments with a susceptible (non-RR) soybean variety, to assess the effects of non-lethal

Unintended Side Effects of GM. For clarity, unintended trait expression from forcible transgene insertion (e.g. traits unrelated to the transgene) can and does arise from several sources, ranging from interference with metabolic pathways to inadvertent expression of unrelated genes. As stated by Facchini et al. (2000), "... efforts to alter plant metabolic pathways....have often produced unpredictable results, primarily due to our limited understanding of the network architecture of metabolic pathways...most current models of metabolic regulation in plants ... do not consider the integration of several pathways sharing common branch points....".

Many examples of GM-induced unexpected trait expression have been identified in both procaryotic and eucaryotic species, and are by no means limited to RR. For examples, see Inose and Murata, 1995; Bergelsen et al., 1998; Saxena and Stotzky, 2001; Hjältén et al., 2007.

levels of glyphosate on macro- and micronutrient uptake. Glyphosate levels (ranging up to 1.2% of recommended herbicidal rate) were based on spray drift concentrations, and were applied at growth stages recommended for weed control.

At maturity, spray drift levels of glyphosate reduced growth by over half, while grain yield was reduced by over 80%. Glyphosate increased or did not affect concentration of N, P, K, Cu, and Zn, but strongly reduced concentration of the divalent cations Ca and Mg (macronutrients), Fe and Mn (micronutrients), particularly in mature grain. Thus, the impact of glyphosate was nutrient-specific, rather than a generic effect on growth. Both Ca and Mg bind with and inactivate glyphosate, reducing availability of Ca and Mg for growth. Uptake of Fe and Mn has been shown to be inhibited by glyphosate. The authors noted that reductions in macro- and micronutrient levels in grain - whether due to spray drift or to conventional uses of glyphosate - adversely affect seed quality, manifesting in the viability, vigor, and effectiveness of seedling establishment. This phenomenon pertains to RR as well as non-RR applications of glyphosate, thus affecting nutrient management and seed quality from both adopters and non-adopters of the technology. The article does not address the issue of how the compromised nutritional content of impacted grain affects livestock nutrition and health.

Plant Disease. Because the shikimic acid pathway has such a major role in producing metabolic intermediates, interference necessarily has downstream effects on other processes. For example, because phytoalexins are fundamental to pathogen defense mechanisms, glyphosate use has been associated with infection by *Phytophthora*, *Fusarium*, *Pythium*, and other diseases (various, cited in Johal and Huber, 2009 and Kremer and Means, 2009). Gressel (2010) provided an overview of synergistic effects between herbicides and 'mycoherbicides' - plant-specific fungal pathogens. He stated that "Glyphosate is the most common herbicide to synergize [e.g. enable, encourage, promote] - mycoherbicides". In a review of the impacts of herbicides on plant pathogens and disease, Sanyal and Shrestha (2008) identified both positive and negative effects of herbicides, including glyphosate, on plant defenses against pathogens.

Glyphosate is commonly believed to be tightly bound to soil and inactivated by absorption to both biotic and abiotic media. However, as demonstrated by Neumann et al. (2006), glyphosate excreted by the roots of RR-soybeans or released from the roots of dying non-RR soybeans can be taken up by non-target plants, which then exhibit the same responses as plants sprayed with glyphosate. This bridging effect means that glyphosate impacts can spread laterally, beyond the plants actually sprayed.

Kremer and Means (2009) demonstrated that glyphosate - which is applied in both conventional and RR systems - exerts a range of adverse effects on soil microbiology, and hence, on crop disease suppression efforts. In conventional use, for example, they cited evidence that:

- glyphosate applied to a susceptible (not RR) plant is excreted intact by the roots into the rhizosphere,
- where it can be metabolized and mineralized as a nutrient source,
- selectively favouring those species able to metabolize it, including the fungal pathogen *Fusarium*,
- which colonizes the roots, and as a result,
- increases residual propagule density (inoculum) in the soil,
- increasing risk of disease in subsequent crops.

They concluded:

> "glyphosate exhibits non-herbicidal effects manifested by enhancement or suppression of activity of latent pathogenic and/or plant growth-promoting bacteria and fungi, which may subsequently impact growth of non-target plants"

The increased risk of cereal pathogens in western Canada as a result of use of glyphosate in conservation tillage (Fernandez et al., 2009) would be one example of a cost externalized by the use of glyphosate. Likewise, Neumann et al. (2006) predicted increased disease pressure on orchard-grown trees from glyphosate transfer from the dying roots of sprayed weeds.

In a 9-year study, Kremer and Means (2009) showed that *Fusarium* colonization of roots was typically 2 to 5 times greater when glyphosate, as compared to other herbicides or no herbicide, was applied to RR soybean. Likewise, a 3 to 10 fold increase in root colonization by *Fusarium* was shown with RR corn, demonstrating similar pathogen stimulation in both corn and soy. The effects reported by Kremer and Means (2009), which were consistent over time (9 years) and space (2 research station and 6 on-farm sites in Missouri), suggest a robust *Fusarium* risk to growers of RR corn and soy in similar environments.

However, adverse impacts on soil-borne microbes derive from the RR trait itself, in addition to those from the glyphosate itself. Kremer and Means (2009) demonstrated that soil levels of the beneficial antagonist *Pseudomonas* sp. were significantly reduced in RR crops, both with and without glyphosate. Thus, the suppressive effect on beneficial soil microbes - and hence, greater vulnerability to pathogens - occurred not simply with glyphosate, but with the RR trait itself.

5. Synthesis. Evidence has been presented to suggest that life itself is incompatible with the fundamental premise of genetic modification:

▸that a single alien gene can be forcibly inserted into a host genome,
▸achieve stable expression by overriding the complex regime of safeguards which evolved to prevent or silence such intrusions, and then
▸express one, but only one trait.

The same argument pertains to the use of herbicides, and specifically glyphosate. Incontrovertible, widely published evidence shows that glyphosate acts not simply to kill weeds but also to reduce availability of selected macro- and micronutrients, compromise plant defense mechanisms, and adversely affect whole plant physiology in far-reaching, agronomically important ways.

None of this should be a surprise. Life - biology - is by its very nature holistic, able to integrate an unimaginable complexity of genetic, environmental, and managerial signals to produce the sequenced, orderly, and consistent growth that we call agriculture. It follows, unambiguously, that crudely interfering with so delicate a web of pathways and processes to achieve commercializable traits necessarily evokes unintended outcomes. Those contemplating the costs and benefits of RR alfalfa need to factor in the costs of accommodating impaired nutrient availability, disease outbreaks, and other far-reaching impacts in the budget. Yet, recognition of inadvertent side-effects - and externalized costs - that necessarily accompany the process of genetic modification is nowhere in evidence in the pre-approval testing mandated for either the US or Canada.

In a nutshell, GM technology in general, and the RR trait in particular, have been commercialized for profit, not - as claimed - for societal benefit. Nothing illegal about that - profit is what corporations are about. But when applied using long-outdated dogma for genes and gene function, unpredictable and often adverse outcomes arise. This is where governmental regulators might have been expected to insert a pro-active, pre-emptive influence to protect the health and safety of farmers, society, and the environment. Unless and until government regulators oblige the purveyors of this technology to absorb the downstream costs of their technology - in a manner completely analogous to what happened with the tobacco industry - then those under no contractual responsibility to Monsanto and colleagues will continue to pay the price.

Andrée, Peter. 2006. An analysis of efforts to improve genetically modified food regulation in Canada. Science and Public Policy 33(5):377-389.

Andrée, Peter. 2011. Civil society and the political economy of GMO failures in Canada: a neo-Gramscian analysis. Environmental Politics Vol. 20 (2):173-191

Bagavathiannan, Muthukumar V. and Rene C. Van Acker 2009. The biology and ecology of feral alfalfa (*Medicago sativa* L.) and its implications for novel trait confinement in North

America. Critical Reviews in Plant Science 28:69–87.

Benbrook, Charles. 2009. *Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Thirteen Years*. Critical Issue Report. The Organic Center. http://www.organic-center.org/science.pest.php?action=view&report_id=159

Bergelson, J., C.B. Purrington, and G. Wichmann. 1998. Promiscuity in transgenic plants. Nature 395:25

Bowley, S.R. and H. Wright. 1991. Risk of alfalfa winterkill. http://www.omafra.gov.on.ca/english/crops/facts/91-072.htm

Brasher, Philip. 2010. Monsanto paying farmers to increase herbicide use. Des Moines Register Oct 19, 2010. http://blogs.desmoinesregister.com/dmr/index.php/2010/10/19/monsanto-paying-farmers-to-increase-herbicide-use/

Cakmak, Ismail, Atilla Yazici, Yusuf Tutus, and Levent Ozturk. 2009. Glyphosate reduced seed and leaf concentrations of calcium, manganese, magnesium, and iron in non-glyphosate resistant soybean. European Journal of Agronomy 31:114–119

Clark, E. Ann. 2007. GM crops are uncontainable: so what? pp. 139-152 In: R.H. Gulden and C.J. Swanton (eds) the First Decade of Herbicide-resistant Crops in Canada. Topics in Canadian Weed Science Vol. 4. Sainte Anne de Bellevue, Quebec: Canadian Weed Science Society

ETCGroup. 2008. *Who Owns Nature? Corporate Power and the Final Frontier in the Commodification of Life.* ETCGroup Communique #100 http://www.etcgroup.org/upload/publication/707/01/etc_won_report_final_color.pdf

Facchini, P.J., K.L. Huber-Allanch, L. W. Tari. 2000. Plant aromatic L-amino acid decarboxylases: evolution, biochemistry, regulation, and metabolic engineering applications. Phytochemistry 54:121-138

Fernandez, M.R., R.P. Zentner, P. Basnyat, D. Gehl, F. Selles, and D. Huber. 2009. Glyphosate associations with cereal diseases caused by *Fusarium* spp. in the Canadian Prairies. European Journal of Agronomy 31:133–143.

Furtan, W.H., R. S. Gray, and J. J. Holzman. 2003. The Optimal time to license a biotech "Lemon". Contemporary Economic Policy 21:433-444

Fyksen, Jane. 2011. Further cautions about WCR resistance to Bt corn. Agri-View 29 Dec 2011 http://www.agriview.com/news/crop/further-cautions-about-wcr-resistance-to-bt-corn/article_c43dcec6-3271-11e1-a6e3-0019bb2963f4.html

Gassman, Aaron J., Jennifer L. Petzold-Maxwell, Ryan S. Keweshan, and Mike W. Dunbar. 2011. Field-evolved resistance to Bt maize by Western corn rootworm. PloS One 6(7) e22629

Gressel, Jonathan. 2010. Herbicides as synergists for mycoherbicides, and vice versa. Weed Science 58(3):324-328.

Gurian-Sherman, Doug. 2009. *Failure to Yield. Evaluating the Performance of Genetically Engineered Crops*. Union of Concerned Scientists. Cambridge, MA. http://www.ucsusa.org/food_and_agriculture/science_and_impacts/science/failure-to-yield.html

Hjältén, Joakim, Anna Lindaua, Anders Wennström, Patrik Blomberg, Johanna Witzell, Vaughan Hurry, Lars Ericson. 2007. Unintentional changes of defence traits in GM trees can influence plant–herbivore interactions. Basic and Applied Ecology 8:434-443

Inose, Tomoko and Kousaku Murata. 1995. Enhanced accumulation of toxic compound in yeast cells having high glycolytic activity: a case study on the safety of genetically engineered yeast. International Journal of Food Science und Technology 30:141-146

ISAAA (International Service for the Acquisition of Agri-biotech Applications). 2009. Brief 41-2009: Executive Summary Global Status of Commercialized Biotech/GM Crops: 2009 The first fourteen years, 1996 to 2009. http://www.isaaa.org/resources/publications/briefs/41/executivesummary/default.asp

Johal, G.S., and D.M. Huber. 2009. Glyphosate effects on diseases of plants. European Journal of Agronomy 31:144–152.

Knodel, Janet J. 2011. Do We Need BT Corn For Control of European Corn Borer and Corn Rootworm in North Dakota? (5/5/11) http://www.ag.ndsu.edu/cpr/entomology/do-we-need-bt-corn-for-control-of-european-corn-borer-and-corn-rootworm-in-north-dakota

Kremer, Robert J. and Nathan E. Means. 2009. Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. European Journal of Agronomy 31:153–161.

Lotter, Don. 2009 The genetic engineering of food and the failure of science – Part 1: the development of a flawed enterprise International Journal of Sociology of Agriculture & Food 16 (1):31–49

McGee, Bill, Hugh Burges, and Denise Beaton. 2010a. Economics Information. Survey of Pesticide Use in Ontario, 2008 Estimates of Pesticides Used on Field Crops, Fruit and Vegetable Crops, and Other Agricultural Crops. Appendix VII. Quantities of Specific Pesticide Active Ingredients Used on All Surveyed Crops in Ontario, 2008 http://www.omafra.gov.on.ca/english/crops/facts/pesticide-use-appendix7.htm

McGee, Bill, Hugh Burges, and Denise Beaton. 2010b. Economics Information. Survey of Pesticide Use in Ontario, 2008 Estimates of Pesticides Used on Field Crops, Fruit and Vegetable Crops, and Other Agricultural Crops. Appendix IX. Comparison of Total Active Ingredients Used on Major Crops and for Selected Pesticide Groupings, 1983, 1988, 1993, 1998, 2003 and 2008 http://www.omafra.gov.on.ca/english/crops/facts/pesticide-use-appendix9.htm

McIntyre, Beverly D., Hans R. Herren, Judi Wakhungu, and Robert T. Watson (Eds). 2009. *Agriculture at a Crossroads*. International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD).
http://www.agassessment.org/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Synthesis%20Report%20%28English%29.pdf

Monsanto. 2012. Tough to control weeds.
https://www.roundupreadyplus.com/Agronomics/Tough-To-Control-Weeds/Pages/Common-Ragweed.aspx

Monsanto Canada. 2012. TUG 2012 Technology Use Guide.
http://www.monsanto.ca/ourcommitments/Documents/TUG_English.pdf

Mortensen, David A., J. Franklin Egan, Bruce D. Maxwell, Matthew R. Ryan, and Richard G. Smith. 2012. Navigating a critical juncture for sustainable weed management. BioScience 62:75-84.

Neumann, G., S. Kohls, E. Landsberg, K. Stock-Oliveira Souza, T. Yamada, and V. Römheld. 2006. Relevance of glyphosate transfer to non-target plants via the rhizosphere. Journal of Plant Diseases and Protection (Suppl. 20):963-969

Nightingale, Paul, and Paul Martin. 2004 The myth of the biotech revolution. TRENDS in Biotechnology Vol. 22(11):564-569.

OFCC (Ontario Forage Crops Committee). 2012. 2012 *Ontario Forage Crop Variety Performance*
http://www.plant.uoguelph.ca/performance_recommendations/ofcc/pdf/ofcc_performance.pdf

OMAFRA (2012). Alfalfa-Timothy Hay Enterprise Budget
http://www.omafra.gov.on.ca/english/busdev/bear2000/Budgets/Crops/Forages/hay_static.htm
Nightingale, Paul and Paul Martin. 2004. The myth of the biotech revolution. TRENDS in Biotechnology 22 (11):564-569

Royal Society of Canada. 2001. *Elements of Precaution: Recommendations for the Regulation of Food Biotechnology in Canada. An Expert Panel Report on the Future of Food Biotechnology* prepared by The Royal Society of Canada at the request of Health Canada, Canadian Food Inspection Agency, and Environment Canada. Ottawa, ON
http://www.rsc.ca//files/publications/expert_panels/foodbiotechnology/GMreportEN.pdf

Sanogo, S., X. B. Yang, and H. Scherm. 2000. Effects of herbicides on *Fusarium solani* f. sp. glycines and development of sudden death syndrome in glyphosate tolerant soybean. Phytopathology 90:57–66.

Sanogo, S., X. B. Yang, and P. Lundeen. 2001. Field response of glyphosate tolerant soybean to herbicides and sudden death syndrome. Plant Dis. 85:773–779.

Saxena, Deepak and G. Stotzky. 2001. Bt corn has a higher lignin content than non-Bt corn. American Journal of Botany 88:1704-1706.

Sanyal, D. And A. Ahrestha. 2008. Direct effect of herbicides on plant pathogens and disease development in various cropping systems. Weed Science 56(1):155-160

Velini, Edivaldo D., Maria L. B. Trindade, Luis Rodrigo M. Barberis, and Stephen O. Duke. 2010. Growth regulation and other secondary effects of herbicides. Weed Science 58:351–354.