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Methods to Enable Coexistence of Diverse Production Systems Involving Genetically Engineered Alfalfa

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During the past decade, genetically engineered (GE) traits have been successfully commercialized in corn, cotton, canola, papaya, squash, and soybean, particularly the Roundup Ready (RR) trait that allows the herbicide glyphosate (Roundup) to be applied to kill weeds without damaging the crop. In June 2005, alfalfa (*Medicago sativa*) varieties with the RR trait were deregulated (APHIS 2005), allowing GE alfalfa varieties to be sold commercially.

In recent years, alfalfa has overtaken wheat as the third most important crop economically in the United States, exceeded only by corn and soybeans. Over 22 million acres (8.9 million ha) are harvested each year, with the largest alfalfa-producing states in the Midwest and West, particularly California, South Dakota, Wisconsin, Idaho, Minnesota, and Iowa (NASS 2005). Alfalfa is California's largest crop by area at 1.05 million acres (425,000 ha), with a value of $800 million to $1 billion. California produces more alfalfa hay than any other state.

When fully commercialized and if adapted by growers, the RR technology may cause profound changes in the way alfalfa growers approach weed control as well as in the varieties that they grow (Van Deynze et al. 2004). However, the introduction of GE alfalfa varieties may also pose challenges to their coexistence with non-GE and organic production and marketing systems (Pridham 2004).

What are the sensitivities of alfalfa markets and consumers?

Crops with GE traits such as the RR trait or resistance to insects using *Bacillus thuringiensis* (Bt) have been used in animal feeding systems for more than a decade, and a number of studies have shown that DNA or proteins from GE crops have not been detected in milk, meat, eggs, or other products from animals that consume these crops (FASS 2005). Government agencies, using the concept of "substantial equivalence" to judge the safety of GE crops have concluded that RR alfalfa is safe to enter the U.S. animal feed market (APHIS 2005). Despite these assurances, some markets are sensitive about the presence of GE traits in alfalfa and wish to maintain alfalfa crops that do not have GE traits.

How is alfalfa used?

While precise alfalfa use patterns in the United States are not known, alfalfa hay has three major markets: dairies, beef, and horses, with minor uses for export, small ruminants (sheep and goats), processed feeds, and alfalfa pellets for pets and rabbits. The market for alfalfa seed presents separate and important issues with regards to GE traits (Mueller 2004), but its scope is smaller in acreage and more localized in western states. The potential for the RR trait to impact the market for hay is described briefly in this publication and was considered in more detail in Putnam 2004b.

Will dairies use genetically engineered alfalfa?

Of the three major uses of alfalfa forage, dairy is clearly the driving force for U.S. alfalfa production. In California, alfalfa for dairy use may consume more than 75 percent of production, and alfalfa is often considered the staple of U.S. dairy production. Alfalfa is either raised by dairies and fed on-farm or raised independently and sold to dairies; these two systems have major differences in terms of marketability and acceptance. For on-farm use, marketing issues are confined largely to views of the dairy producer and the marketers of milk. For cash hay producers, market signals are manifest through price and willingness to buy.

It is anticipated that the dairy industry will not, with some notable exceptions, be highly sensitive to the presence of a GE trait in alfalfa. The dairy industry has already absorbed a sizable number of GE technologies that are currently components of milk production systems:

- *bovine somatotropin* (BST), a naturally occurring hormone produced via GE methods, which has been in use as a supplement for over 10 years
- Roundup Ready and Bt crops, particularly corn, soybean, canola, and cottonseed meal, all of which feature prominently in dairy feed rations
- cheese produced with rennin (chymosin) from GE bacteria

These GE traits in the dairy system have by and large not proved to be major marketing issues for dairies.

The exception is organic dairy producers, who have rejected GE crops as a component of organic certification (NOP 2005). Organic milk is a small but growing component of U.S. milk production, with the number of certified organic milk cows having increased by 277 percent from 1997 to 2001 but still constituting less than 1 percent of total U.S. milk production (Miller 2005). Organic dairy producers demand hay originating not only from non-GE alfalfa but also from fields approved for certified organic crop production.

Will horse owners use genetically engineered alfalfa?

Alfalfa and alfalfa-grass mixtures are the most important hay crop for the U.S. horse industry (Shewmaker et al. 2005). It has been estimated that there are 650,000 horses in California (Rodiek 2004). Horses are likely to be significant consumers of alfalfa, but the exact size of this market is not known. Horse owners are individual buyers, each with their own prejudices that likely influence their hay-buying decisions, a situation markedly different from the dairy and beef industries (Rodiek 2004; Lawrence 1998). As a result, it is probable that some horse owners will resist feeding RR alfalfa, but this is also not likely to be universal. Important to consider is the fact that sizable numbers of horses are sickened or die from poisonous weeds in hay each year (Pushner 2004), a quality aspect that may tip customer preference in favor of RR alfalfa over time.

Will the beef, sheep, and goat industries use genetically engineered alfalfa?

The quantity of alfalfa used in the beef industry is not known, but a larger percentage of nonalfalfa forage is fed to beef cattle than to dairy cattle. Less than 1 percent of beef production is organic (NCBA 2005); however, for the reasons described above for dairy, it is unlikely that most beef producers will be sensitive to GE alfalfa. Food safety concerns with beef are generally more focused on specific disease issues (e.g., BSE, or mad cow disease), or on the use of antibiotics or chemicals. Organic beef requires non-GE hay. GE (or even conventional) alfalfa will not be important for grass-fed beef (another marketing category) for obvious reasons. Sheep and goat enterprises are tied to ethnic or specialty uses and may be more sensitive than beef to GE alfalfa, but the quantity of alfalfa used by this sector is very small.

Table 1. Total production and exports of alfalfa and alfalfa mixtures, six western U.S. states (CA, ID, NV, OR, UT, WA) and U.S. total

	1997	1998	1999	2000	2001	2002	2003
Alfalfa production (metric tons)	17,585,823	17,868,807	17,678,337	17,362,701	17,475,169	18,852,902	18,478,311
Alfalfa exports (metric tons)	841,748	790,769	827,303	853,268	782,137	782,137	839,532
Percentage of alfalfa production exported (six states total)	4.79	4.43	4.68	4.91	4.48	4.15	4.54
Percentage of U.S. alfalfa exported	1.06	0.96	0.98	1.06	0.97	1.06	1.10

Sources: Production data is from NASS 2005; export data is from the Journal of Commerce 2004 and includes compressed hay and cubes.

What effect will genetically engineered alfalfa have on exports?

It is clear that the majority of exporters will be sensitive to the presence of GE alfalfa, at least in the initial few years of production. Across six western states, over 800,000 metric tons (881,000 t) of alfalfa, or 4.5 percent of production, is exported (table 1). Less than 1 percent of U.S. alfalfa is exported, and other classes of hay (e.g., sudangrass, timothy) now exceed exports of alfalfa. However, in some regions, such as the Imperial Valley of Southern California and in central Washington, the percentage of alfalfa grown for export is higher. In these regions, growers may export only one or two cuttings of their hay per year, but the exporter's acceptance impacts the grower's variety decision for the whole production season. Japan is the dominant recipient of U.S.-grown hay. Exporters in many cases have insisted on written contracts in which producers guarantee non-GE alfalfa. In 2005, growers who purchase the RR trait license had to restrict their hay production to domestic use, and seed sales have been restricted in regions such as the Imperial Valley and central Washington where exports are important. Roundup Ready alfalfa hay currently may be legally exported to Canada and Mexico. Deregulation of RR alfalfa use for feed in Japan occurred in February 2006, but importers may nevertheless require imported alfalfa hay to be non-GE.

How much of the alfalfa market will be sensitive to GE traits?

When considering alfalfa markets, it is important to note that alfalfa growers do not receive government subsidies, that alfalfa marketing is highly decentralized, and that its markets follow free-market conditions to a greater degree than do most agricultural commodities. Although markets reward genuinely higher-quality hay according to laboratory tests (Putnam 2004a), highly subjective and nonscientific factors frequently enter into sales. This is pertinent to the GE question. Perceptions are often more powerful than scientific arguments for buyers, and subjective factors related to forage quality and feed safety must be considered by producers who wish to sell to those markets.

It is clear from the above discussion and other analyses (Putnam 2004b) that the vast majority of alfalfa is grown for uses or markets that are not highly sensitive to the presence of GE traits. The primary markets sensitive to the GE trait in alfalfa are export markets, organic markets, and some hay grown for horses. This is likely to be less than 5 percent, and probably less than 3 percent, of annual U.S. production, but the degree of sensitivity will become more apparent as the trait is tested by growers. These sensitive markets require that GE traits successfully coexist with non-GE traits on farms and in regions where those markets are important. The presence of GE alfalfa may actually increase the demand for non-GE alfalfa or organic alfalfa, sharpening the need for product identity, trait stewardship, and coexistence on farms and in markets.

What practices can be used to allow GE and non-GE alfalfa varieties to coexist?

Coexistence between GE and non-GE alfalfa depends on understanding the biology of alfalfa production and techniques to assure market identity. The stewardship of purity of non-GE and GE traits for hay production within a region or farm depends on a range of practices, beginning with seed selection, and including the following eight points.

1. Select certified varieties for seed purity and quality

The first step in stewardship of GE and non-GE alfalfa hay is the choice of high-quality seed. Only certified seed should be grown. This is likely to be the most crucial step in assuring purity in a hay product for growers selling into sensitive markets. While it is very difficult for traits (genes) to pass from one alfalfa hay field to another, some adventitious presence (AP) may occur during seed production if care is not taken to prevent it. Adventitious presence is a low level of presence of a trait (such as a GE trait) in a variety meant to be free of that trait. Crop inspection and certification services in each state have standards and recommendations to assure seed purity, which include variety identity, seed quality, and lack of contamination with weeds or foreign matter (Mueller 2004). However, testing and reporting of AP in certified seed is not required; growers who are concerned about AP of a GE trait in alfalfa seed should ask the seed company about it, and ask that it be tested or test the seed themselves. Strip tests are available for seed that can be used by growers interested in maintaining non-GE alfalfa.

2. Understand the potential for gene flow

Alfalfa is cross-pollinated, requiring insect pollinators, usually honey bees (*Apis mellifera)* or leafcutter bees (*Megachile rotundata* F.) to transfer pollen from one plant to another for seed production. Cross-pollination is not required for forage production. The potential for gene flow in alfalfa grown for hay is not the same as that for alfalfa grown for seed crops due to very different production methods. The upper limits for gene flow in hay fields, however, can be estimated by looking at what happens during seed production (Mueller 2004; Rincker et al. 1988). Studies in seed fields in Idaho using leafcutter bees as pollinators showed gene flow from an RR alfalfa seed crop to a non-GE crop to be about 1.5% at 500 feet (152 m), less than 0.5% at 900 feet (274 m), and zero at 2,000 feet (610 m) (Fitzpatrick et al. 2002). Honey bees generally have longer flights than leafcutter bees; a study in California using honey bees as pollinators showed gene flow to be 1.5% at 900 feet (274 m) and below 1% at 2,500 feet (0.8 km), but sporadic gene flow (< 0.03%) could be detected up to 2.5 miles (4 km) away (Teuber et al. 2004; Van Deynze et al. 2004). These estimates were obtained under conditions that maximize pollination and seed production, conditions that are unusual in alfalfa hay fields.

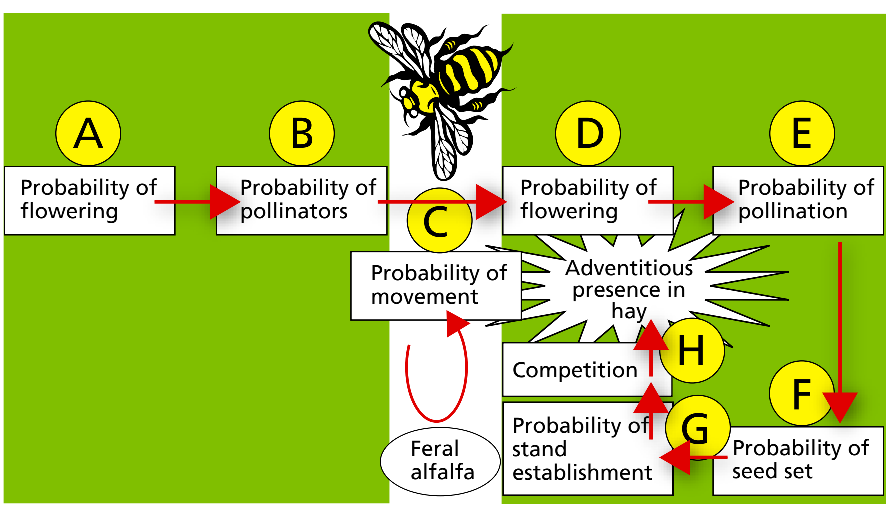

Figure 1. Steps necessary for gene flow to occur between alfalfa forage production fields sufficient to cause adventitious presence (AP) of GE traits in hay.

3. Understand the limits of alfalfa gene flow from one hay field to a neighboring hay field

Although gene transfer from one alfalfa hay field to another is theoretically possible, a range of environmental barriers make gene movement very unlikely. For AP to occur in a hay field from a neighboring GE hay field, flowering must be simultaneous between fields (A and D, fig. 1); pollinators must be present (B); they must move significantly between fields (C); the pollen must accomplish fertilization by tripping flowers and fertilizing the ovule of the flower (E); those fertile embryos must mature into seeds (F); those seeds must be retained in the field, fall to the ground, and germinate (G); and those germinating plants must survive the competition of existing alfalfa plants and contribute significantly to the dry matter yield of the subsequent hay crop (H). The vast majority of alfalfa fields are harvested with only a small amount of flowering (0 to 25%) and zero viable seed production. Most hay harvested for the dairy market in California is harvested in the prebloom (bud) stage for high quality. The whole crop is usually removed during harvesting. A long history of failure to intentionally overseed alfalfa into existing alfalfa fields (Canevari et al. 2000) provides evidence that even in the rare case that seed were produced and left in the field, it would not be likely to germinate, grow, and compete with the existing crop and contribute significant biomass to the subsequent hay crop. Although the probability of each of these steps is not fully known, if one starts with an upper limit of 1.5% AP in seed fields at 900 feet (274 m) and applies the estimated probabilities above, the likelihood of AP occurring between hay fields becomes infinitely small, likely to be far less than 0.001% of field biomass even under high estimates of each of these probabilities. The combination of frequent harvests, lack of significant flowering, lack of significant seed production, and the highly competitive and allelopathic nature of alfalfa that prevents ready germination of alfalfa seeds in existing fields should prevent most if not all gene transfer. However, growers should be aware that conditions that increase the potential for AP include excess flowering, high levels of pollinator activity, and conditions such as excess heat and late harvests where seed is allowed to mature, and should take steps to prevent or avoid these conditions.

4. Control feral alfalfa near hay fields

Cultivated alfalfa is not known to cross with any wild non-alfalfa *Medicago* species plants or with any weed present in the United States. It will, however, cross with feral, or wild, alfalfa (*Medicago sativa* L.) plants. Feral alfalfa is alfalfa that grows along ditch banks or roadsides that remains unharvested. It can originate from highway plantings, spilled seed, small amounts of seed from hay, or movement by birds. Since feral alfalfa is more likely to flower and set seed than alfalfa grown for hay, it may act as a bridge for pollinators between distant fields. Controlling feral alfalfa is a prudent measure to prevent movement of genes between hay fields.

5. Identify non-GE alfalfa hay

The coexistence of GE and non-GE alfalfa requires a high level of awareness of crop identity for products destined for sensitive markets. This may require identification of hay lots to assure that hay lots are not mixed, a process currently practiced on commercial hay farms by growers who mark, test, and sell lots by field and farm. Organic growers already have a process by which they identify and document organic hay, so no greater paperwork burden would be generally required to deal with this situation.

A “lot” for forage quality testing purposes is defined as a stack from the same field, same cutting, weighing less than 200 tons (1,814 metric tons), with identification as to farm and field and cutting (Putnam 2002). This definition should also be used for GE as well as non-GE hay product identification.

6. Prevent mixing of hay lots

Growers wishing to sell into sensitive markets must take steps to prevent the mixing of haystacks, to maintain identity, and to assure customers of that identity throughout harvesting, storage, and transport. For example, growers may use specific colors of twine to assist farm managers, farmworkers, truckers, buyers, and sellers to maintain product identity during marketing and shipping. Export and organic markets already require paperwork that identifies the lot, seller, and origin of hay, so a GE or non-GE label may be relatively simple for these marketers.

7. Test for GE traits in hay

Testing procedures and test strips (available from, for example, EnviroLogix, http://www.envirologix.com/, and Strategic Diagnostics, http://www.sdix.com/) for market identification of GE traits are routinely used for corn, soybean, and other crops, and they are now available for RR alfalfa hay. There are leaf tests for field-side analysis of fresh plant samples, mobile cored sample hay kits for testing haystacks, and commercial laboratory tests for testing of routine cored and ground hay samples. Early tests have shown that test strips detect RR hay successfully at levels of 5% or 100% and show lack of response at 0% (fig. 2). Using these tests should enable growers to confirm the absence of GE traits in their hays destined for sensitive markets and provide assurances to buyers as to the stewardship of non-GE hay.

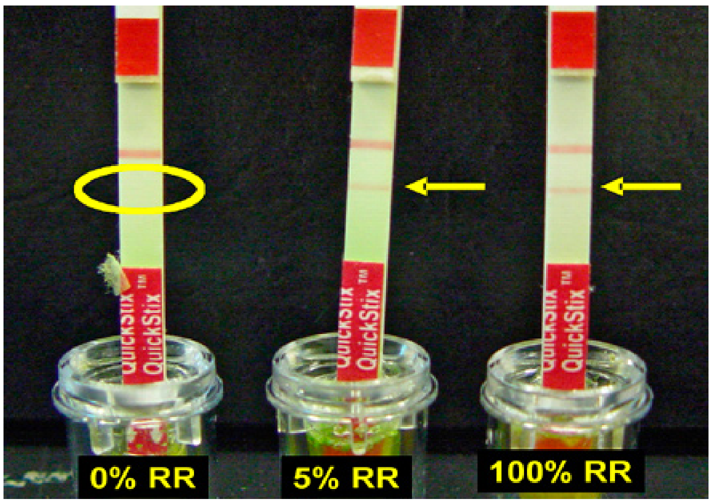

Figure 2. Test strips can differentiate Roundup Ready (RR) alfalfa from non-GE alfalfa for sensitive markets. Arrows show a horizontal red band, indicating a positive reading for 100% RR and 5% RR samples; a circle shows a negative reading for a control sample. The top red band indicates that the strips are functioning properly.

8. Understand tolerances

Given that the tolerance (requirements for labeling) for GE traits in food crops in Japan is 5% and 0.9% in Europe, the very small probabilities described above for AP in hay (animal feed) crops should not normally present difficulties for buyers of non-GE hay. For organic producers, the very small potential for AP should not ordinarily present significant worries for their markets, akin in many respects to the probability of influence of any nonorganic practice (such as spraying or fertilizing) from nonorganic fields that are grown in proximity to organic fields. The probability of gene flow and adventitious presence is quite low. Growers should be aware of conditions that facilitate gene movement (abundant flowering, seed production in hay crops) and should take steps to limit the potential for gene flow for markets sensitive to the presence of GE traits.

CONCLUSIONS

Roundup Ready alfalfa was deregulated in June 2005, the first GE trait to be commercialized in alfalfa. A large majority of alfalfa growers will choose or reject this technology based on need and economic factors, since the vast majority of their markets are insensitive to the presence or absence of GE alfalfa varieties. However, some growers (estimated to be 3 to 5%) producing for organic uses or export to countries or buyers concerned about GE crops must grow non-GE varieties and assure customers of the stewardship of the non-GE status of their crop. Simple methods to assure coexistence without disruption of these markets should be effective under most conditions. The probabilities of gene transfer are estimated to be very low between alfalfa hay fields. The most important steps to assure hay trait purity are selecting non-GE varieties using certified seed from reputable companies, testing this seed for adventitious presence before planting, and maintaining product identity. Prudent steps to prevent excess flowering or seed production during hay production will be beneficial to maintain coexistence of GE and non-GE alfalfa. Steps to identify lots and maintain product identity are already in place for most commercial hay growers for organic and export markets, but these steps become more important to maintain non-GE identity for sensitive markets. Analytical test strips provide further assurance to customers of product identity. An understanding of biological and commercial factors affecting trait conservation is important in maintaining successful coexistence between GE and non-GE alfalfa production systems.

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