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Practices that Support Coexistence: A Survey of Alfalfa Growers

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Abstract

The alfalfa industry has worked hard to foster the coexistence of genetically engineered and conventional alfalfa production by developing a set of best management practices that aim to limit adventitious presence (AP) of genetically engineered traits in conventional seed. The general goal is to minimize transgene movement by controlling inadvertent admixture (in this case admixture refers to genetically engineered material in conventional seed lot) or gene flow using practices that ensure seed is pure, sanitation is prioritized (i.e., avoidance of seed mixing), spillage is minimized, and pollination is prevented. However, the success of coexistence is dependent on grower adoption, which has not been monitored. To assess adoption we surveyed 530 alfalfa hay and seed producers in three major alfalfa production areas in the western United States in 2013. Based on a 33% response rate, we found that although many respondents reported practices that supported coexistence, the survey identified differences in grower perception and practices in the three states surveyed and identified perceptions and practices that may undermine coexistence. We found that very few respondents (4%) tested hay seed prior to planting, and no respondents in Washington reported testing seed despite reporting the highest level of export. Growers also underestimated the risk of seed spillage during planting and seed harvest and transport. Most respondents controlled feral plants, but control was limited to their own property. Some respondents were using glyphosate to control volunteers and roadside plants. Management of hay fields also varied in terms of cutting time, frequency of delayed cutting, and occurrence of field obstructions that prevented cutting. Our survey suggested that grower education would benefit coexistence, as would research to better understand the potential of genetically engineered hay fields to contribute to economically adverse AP.

Core Ideas

- Genetically engineered alfalfa adoption is higher in areas where alfalfa is not exported.
- Most respondents practice coexistence strategies, but only 4% test hay seed prior to planting.
- No respondents in Washington reported testing seed, despite reporting the highest level of export.
- Growers underestimate the risk of seed spillage during planting and seed harvest and transport.
- Hay and seed growers need education about transgene dispersal risk and coexistence practices.

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Abbreviations: AP, adventitious presence; ASSP, Alfalfa Seed Stewardship Program; GOZ, Grower Opportunity Zone; NAFA, National Alfalfa and Forage Alliance.

Conversions: For unit conversions relevant to this article, see Table A.

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Alfalfa, an important livestock feed, especially in the dairy industry, is the fourth most widely grown field crop in the United States, only after corn, wheat, and soybean. The crop, worth roughly $10 billion, was grown on more than 18 million acres in 2014, according to the USDA (USDA-NASS, 2015). Because of its adaptability, alfalfa production occurs in almost all growing regions of the United States. The western United States is the most important production area for both alfalfa forage and alfalfa seed. The outcrossing nature of alfalfa and its dependence on insects for pollination makes gene flow a common phenomenon in this species. Alfalfa can also survive outside of cultivation, in natural and unmanaged environments such as roadside right-of-ways (Bagavathiannan et al., 2012; Greene et al.,

Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.405	acre	hectare, ha
1.609	mile, mi	kilometer, km (10^{-3} m)

2015; Kendrick et al., 2005; Kesoju et al., 2016). Recognizing the probability of cross-contamination and importance of maintaining seed-variety purity, the alfalfa seed industry follows long-standing seed-production isolation practices outlined in the Code of Federal Regulations (7 CFR 201.76) and upheld by the Association of Official Seed Certifying Agencies. In 2005, genetically engineered glyphosate-resistant alfalfa (also known as Roundup Ready alfalfa) was deregulated by the USDA (USDA-APHIS, 2005). In March 2007, an injunction prohibiting further planting of genetically engineered alfalfa was passed. In 2011, following extensive regulatory review, genetically engineered glyphosate-resistant alfalfa was deregulated a second time. This was followed by the deregulation of genetically engineered low-lignin alfalfa in 2014 (USDA-APHIS 2014, findings of no significant impact [FONSI]).

The natural outcrossing characteristics of alfalfa raised concern about AP of the transgene in conventional seed and hay. The concern was raised by producers who market seed and hay to countries that have low or no tolerance for the presence of genetically engineered traits. Other AP-sensitive markets include organic-hay producers and consumers that prefer hay that has not been genetically engineered. The presence of different market classes and the need to support consumer preferences and farmer choice has brought the concept of agricultural coexistence to the forefront. For this paper we adopt the coexistence definition put forward by Putnam et al. (2016): "Successful coexistence" is "the ability of diverse systems (GE [genetically engineered], organic, non-GE) to thrive without undue influence of neighbors or resorting to extraordinary protection measures."

Since 2008, the National Alfalfa and Forage Alliance (NAFA) had been developing and refining coexistence strategies. NAFA facilitated the development of Grower Opportunity Zones (GOZ), areas where the production of genetically engineered or AP-sensitive alfalfa seed is concentrated. Genetically engineered GOZs allow the production of genetically engineered and conventional AP-tolerant seed lots, while AP-sensitive GOZs support the production of AP-sensitive seed lots, since genetically engineered seed production is not allowed (Cornish et al., 2015d). NAFA has led efforts to develop a set of best management practices for genetically engineered and AP-sensitive seed producers (Cornish et al., 2015a, 2015b, 2015c). They have also developed coexistence documents for alfalfa hay and seed exports and organic hay and seed markets (Cornish et al., 2014; McCaslin and Van Deynze, 2014; Putnam et al., 2014). The Association of Official Seed Certifying Agencies has developed the Alfalfa Seed Stewardship Program (ASSP), a certification program to support marketing of AP-sensitive alfalfa seed (AOSCA, 2015).

However, the question remains: how effective have industry efforts been on influencing production practices that support coexistence? A grower survey conducted by Putnam and Orloff (2011) reported that if certain conditions were met, about 65% of growers felt that coexistence was either definitely possible or possible. Seventy-one percent of their respondents were willing to change practices or adjust to neighbors' practices. But the success of coexistence is dependent on the degree that growers actually adopt industry-devised strategies. Although genetically engineered alfalfa has been available to growers since 2011, and industry has been diligent in developing coexistence strategies, little research has focused on assessing the level of compliance. The objective of our study was to survey alfalfa hay and seed producers in three major alfalfa production areas in the western United States to assess the prevalence of management practices and perceptions that support or undermine industry coexistence.

Survey Method, Data Collection, and Analysis

The US Agriculture Census was used to identify survey participants growing more than 25 acres of alfalfa (hay or seed), in three alfalfa seed production areas: Fresno County, CA, Canyon County, ID, and Walla Walla County, WA. A questionnaire was developed and mailed to 530 participants in February 2013. We did not verify the information provided by participants or the correctness of their responses. Question types consisted of yes-or-no, multiple choice, and fill-in-the-blank. Responses recorded as Yes or No were recoded as 1 and 2, respectively (Likert, 1932). Multiple-choice questions with answers of highly likely, likely, not likely, and impossible were recoded as 1, 2, 3, 4, respectively. General multiple-choice answers were coded numerically (i.e., 1, 2, 3, 4, 5), and fill-in-the-blanks were classified into categories and coded numerically. Responses were tabulated and the percentage response calculated. Pearson's chi-square test for count data was used to determine if there were significant overall differences between growers' perceptions and production practices among the three counties. When there was no county difference, data for the same question were combined across counties and tested to determine if there was any significant difference among responses. The data analysis was performed using the Chisq function from the R Stats Package (Patefield, 1981).

Table 1. Number of growers surveyed and response from each county

County, State	Number of participants	Number of respondents
Fresno County, CA	167	41
Canyon County, ID	289	105
Walla Walla County, WA	74	30
Total	530	176

Overview of Respondents

We surveyed a total of 530 participants, and 176 questionnaires were returned, for an average return rate of 33% across states; but there was a higher response rate from Idaho (36%) and Washington (40%) growers compared with California (24%) growers (Table 1). Eleven percent of total respondents had grown either genetically engineered hay or seed or both, during the first period of deregulation (2005–2007). In 2013, nearly 22% of total respondents reported growing either genetically engineered hay (19%) or seed (3%). This is in line with adoption rates of 30% in 2014, as reported by Putnam et al. (2016). We found that the number of seed producers who reported growing genetically engineered seed in 2013 did not differ by study area and ranged from 11 to 17%; across the three study areas; the majority of seed producers were producing conventional seed (Table 2). However, we found that the number of genetically engineered hay producers differed significantly by study area ($p = 0.00$). Of the respondents who reported growing glyphosate-resistant hay, almost half—(42%) in Fresno County, CA; 22% in Canyon County, ID; and 8% in Walla Walla County, WA—reported they were growing glyphosate-resistant hay. In contrast, hay was exported by 8, 3, and 35% of respondents from California, Idaho, and Washington, respectively (Table 3). Putnam et al. (2016) reported that current rates may be at 50% in some regions but significantly lower in others. Our survey reflected uneven adoption rates as well and suggested that export concerns may limit adoption in areas where a large number of growers produce for the export market.

Table 4 compares average field size for genetically engineered and non–genetically engineered seed and hay fields in each county. Walla Walla respondents reported the largest seed acreage (glyphosate-resistant and conventional seed), followed by Canyon, then Fresno respondents. In hay acreage (glyphosate-resistant and conventional hay), Fresno and Walla Walla respondents reported similar acreage, and acreage size was three times greater than the acreage reported by Canyon growers. These observations suggested that most respondents in Canyon County tended to have smaller fields, whereas in Fresno and Walla Walla counties, some of our respondents represented large commercial hay operations. Conventional hay fields tended to be twice as large as glyphosate-resistant hay fields. A possible explanation may be that adoption of glyphosate-resistant hay may be higher among small farm holders than large farm holders. It may also reflect the perennial nature of the crop and different replacement rates in different regions (Putnam et al., 2016). Only 1.5% of the respondents replied that their hay or seed was certified organic (Table 3). Although the ASSP provides a market-specific certification program for AP-sensitive seed, only 13% of respondents reported being enrolled (Table 3).

Table 2. Percentage of respondents in three counties growing genetically engineered alfalfa hay or seed in 2013.

County, State	Growers responding			
	Glyphosate-resistant seed	Conventional alfalfa seed	Glyphosate-resistant hay	Conventional alfalfa hay
	%			
Fresno Co, CA	11	89	42	58
Canyon Co, ID	14	86	22	78
Walla Walla Co, WA	17	83	8	92

Table 3. General questions for alfalfa hay and seed growers and the percentage response.

	Fresno County, CA	Canyon County, ID	Walla Walla County, WA
	%		
Did you grow genetically-engineered hay or seed in 2005– 07?			
Yes	20 ($n = 25$)	8.70 ($n = 92$)	5 ($n = 21$)
No	80 ($n = 25$)	91 ($n = 92$)	95 ($n = 21$)
Do you export hay or seed?			
Yes	8 ($n = 25$)	3 ($n = 89$)	35 ($n = 20$)
No	92 ($n = 25$)	97 ($n = 89$)	65 ($n = 20$)
Is your hay or seed certified organic?			
Yes	4 ($n = 24$)	0 ($n = 90$)	5 ($n = 20$)
No	96 ($n = 24$)	100 ($n = 90$)	95 ($n = 20$)
Did you test for AP seed lots prior to planting?			
Yes	8 ($n = 24$)	3 ($n = 85$)	0 ($n = 18$)
No	62 ($n = 24$)	97 ($n = 85$)	100 ($n = 18$)

Table 4. Average field size during 2013 in each county.

County, State	Average field size			
	Glyphosate-resistant seed	Conventional alfalfa seed	Glyphosate-resistant hay	Conventional alfalfa hay
	acres			
Fresno Co, CA ($n = 41$)	200	198	168	428
Canyon Co, ID ($n = 105$)	425	306	79	121
Walla Walla Co, WA ($n = 30$)	503	484	219	411
Average	376	329	155	320

Prevalence of Practices and Perceptions that Support or Undermine Coexistence

To be effective, coexistence practices need to occur during all phases of production. The general goal is to minimize transgene movement by controlling inadvertent admixture (in this case admixture refers to genetically engineered material in conventional seed lot) or gene flow using practices that ensure that the seed is pure, sanitation is prioritized (i.e., avoidance of seed mixing), spillage is minimized, and pollination is prevented. Our survey questions focused on understanding current practices and perceptions of hay and seed growers, regarding how they accomplished tasks ranging from planting to transport, that could potentially influence transgene flow and AP.

Ensuring Seed Purity

An important industry coexistence strategy recommends that growers producing for AP-sensitive markets test their seed prior to planting. Across counties, only 4% of respondents indicated they tested alfalfa seed for AP prior to planting (Table 4). In Fresno County, 8% of our respondents reported testing their seed. In Canyon County, 3.5% of respondents tested seed, while in Walla Walla County, despite 35% of respondents indicating they exported alfalfa, no respondents indicated they tested their seed prior to planting. Additional efforts may be warranted to educate growers about the value of testing AP levels in conventional seed in areas that export hay. Unfortunately, no industry-wide AP threshold for conventional seed has been adopted, and companies have established their own internal standards that range from non-detectable (<0.1% to 0.9% AP) (personal communication, various seed-company representatives). However, seed companies routinely test their seed lots to monitor the efficiency of best management practices for genetically engineered seed production (Cornish et al., 2015a). The routine inclusion of this data on seed labels would support coexistence; such transparency would enable growers to make informed buying decisions without incurring the burden of testing seed. Some companies are labeling seed as genetically engineered non-detect (i.e., <0.1% AP). This strategy would support coexistence, especially if adopted by all seed suppliers so that grower choice is not impeded. Coexistence would be further supported if genetically engineered non-detect seed lots are available for the same cost as unlabeled seed.

Sanitation and Spillage Prevention

Transgene dispersal can readily occur when genetically engineered seed is advertently mixed with conventional seed when planted or harvested, resulting in admixed seed lots. Genetically engineered seed that escapes during planting and harvesting can also result in genetically engineered plants that can contribute to pollen flow (Greene et al., 2015). There was no significant difference in planting method between counties. Nearly 70% of the respondents planted alfalfa fields using a seed drill, and 30% used a broadcast seeder. When respondents were asked how likely seed was to escape during planting, either when equipment was moved from shop to field or from field to field, 87% of respondents reported seed spillage was not likely or was impossible (Table 5). Given the small, round seed shape of alfalfa, growers seemed over-optimistic regarding the risk of spillage during planting. However, we would expect seed escape to be less likely with a seed drill compared with broadcast planting. Inadvertent admixture may occur if machinery is not thoroughly cleaned since alfalfa seed can easily be left behind during seeding and harvest (Sharratt, 2013), and best management practices recommend that equipment is carefully cleaned. When asked how planting equipment was cleaned between genetically engineered and conventional seed lots, only 7 respondents out of 88 indicated that no special measures were taken for planting equipment. The use of air compressors was the most prevalent sanitation practice. Equipment sharing due to borrowing or contracting can increase the risk of admixture if proper sanitation is not practiced. Sixteen percent of 124 respondents borrowed planting equipment, and 26% of 128 respondents reported hiring contractors to plant. Generally, Washington growers did not share planting equipment. For seed harvest, 14% of seed growers reported sharing combines, and 30% reported hiring contractors to harvest, mainly in California. Generally, most growers appeared to diligently practice sanitation. Contractors were also aware of the importance (Robert Motte, personal communication, 2013).

Nine respondents reported on measures taken to avoid admixture during combining. Sixty-six percent harvested conventional seed first, and/or cleaned their combine between harvests, and 34% indicated that no special measures were taken to keep genetically engineered and non– genetically engineered seed separate during combining. When seed growers were asked how likely seed was to escape during harvest, either when combines moved from field to field or field to truck, 5% felt seed escape was highly likely, 30% felt it was likely, and 65% responded it was not likely. The distance that combines travel would also influence transgene dispersal: extended travel would contribute to seed dispersion. Twenty-five seed growers reported the distance their combines traveled: 37% reported combines traveled less than 1 mi, 42% traveled between 1 and 3 mi, and 20% traveled greater than 3 mi. When asked how seed was transported, 72% reported sealed bins, and 28% reported truck beds. Greene et al. (2015) reported that the locations of transgenic feral populations were statistically associated with locations where risk of seed escape was high: either on roads close to genetically engineered seed fields or on roads used to transport seed to conditioning plants. The responses from our survey suggested that growers may underestimate the risk of seed spillage from planting, harvesting, and transport and that greater care is needed to reduce spillage since it is a major contributor to feral roadside plants. Similarly, a report from Canadian Biotechnology Action Network reported that alfalfa seed escape occurs during planting, harvesting, and transport (Sharratt, 2013).When asked if feral plants were controlled around conventional and genetically engineered

Table 5. Hay and seed grower perceptions in all the three counties (Fresno County, CA; Canyon County, ID; and Walla Walla County, WA).

Statement	Among the counties	Among the responses
	——— *P* value ———	
All growers		
1 Planting method	0.50	0.00*
2 How likely seed escapes during planting		
a. From field to field	0.36	0.00*
b. Between fields	0.23	0.00*
3 Do you share/borrow planting equipment	0.20	0.00*
4 Do you use custom equipment	0.01*	0.00*
5 How do you clean equipment between planting glyphosate resistant alfalfa and conventional fields	0.54	0.00*
6 How do you take out old fields of conventional seed/hay	0.00*	0.00*
7 How do you control alfalfa volunteer in fields	0.90	0.00*
8 What herbicides do you use to control alfalfa volunteer in subsequent crops?	0.00*	0.02*
Hay growers		
9 What is % bloom when you cut hay?	0.33	0.00*
10 Do you delay your last cut?	0.31	0.00*
11 In the last 5 yr, how many times has cutting been delayed due to weather or other event?	0.04*	0.00*
12 Considering all your fields, what is the average % of field area that is hard to cut due to obstructions such as telephone poles, irrigation structures, etc.?	0.22	0.00*
Seed growers		
13 Are any of your seed fields enrolled in the Alfalfa Seed Stewardship Program?	0.97	0.00*
14 All the bees you rely on:	0.00*	0.06
15 What is your primary pollinator?	0.00*	0.00*
16 Based on your direct field observations, are native pollinators (bumble bees, other bees) present:	0.29	0.00*
17 Are hives/bee boards moved from field to field?	0.04*	0.01*
18 How is seed transported?	0.79	0.00*
19 Distance the combine travels from farmyard to fields and back to farmyard	0.86	0.04*
20 Are feral plants eradicated around conventional seed fields?	0.38	0.00*
21 Are feral plants eradicated around glyphosate-resistant alfalfa seed fields?	0.13	0.62

* Significant at $P \leq 0.05$.

seed fields, only 4 out of 17 respondents in California and Idaho reported that they did not control feral plants. Most of the respondents indicated they controlled feral plants only on their own property. In Washington, all six respondents reported that they did not control feral plants.

Removal of conventional hay and seed fields was significantly different between counties. In Fresno County, out of 24 respondents, 70% used tillage, 20% used herbicide and tillage, 5% reported herbicide only, and 5% reported other techniques. In Canyon County, out of 83 respondents, 49% used tillage, 38% used herbicide and tillage, 10% reported herbicide only, and 3% reported other techniques. In Walla Walla County, out of 16 respondents, 31% used tillage, 62% used herbicide and tillage, and 7% reported herbicide only. Similar methods were used for removal of glyphosate-resistant hay and seed fields. We found no difference among counties in how alfalfa volunteers were controlled. Respondents tended to use herbicides (24%) and crop rotation (16%) to control alfalfa volunteers. Some growers (14%) reported that they did not follow or take preventive measures to control volunteers. All three counties use herbicides to control alfalfa volunteers, but different counties use different herbicides. In Fresno County, 60% respondents use dicamba; in Canyon County respondents use 2,4-D (44%) and 2,4-D + dicamba (15%); and in Walla Walla County, 57% respondents use either dicamba, 2,4-D, or 2,4-D + dicamba (Fig. 1). Similar results were reported by Ogg and Parker (2000) to suppress and control alfalfa volunteers in subsequent crops. In all three counties, growers reported using glyphosate to control volunteers (Fresno County 20%, Canyon County 10%, and Walla Walla County 43%). Use of glyphosate herbicide may become less effective as adoption of glyphosate-resistant varieties increases. Growers in the Midwestern United States experienced problems managing volunteer corn with glyphosate even if transgenic corn was not planted the year before the transgenic glyphosate-resistant soybean (Beckie and Owen, 2007).

The County Road Department in Fresno County reported using glyphosate to clear roadways of weeds. There was evidence from Greene et al. (2015) that roadside glyphosate applications influenced glyphosate-resistant transgene presence in feral populations in Fresno County. For general best management practices, the use of glyphosate to control volunteer or roadside plants should be avoided in areas where glyphosate-resistant crops are grown.

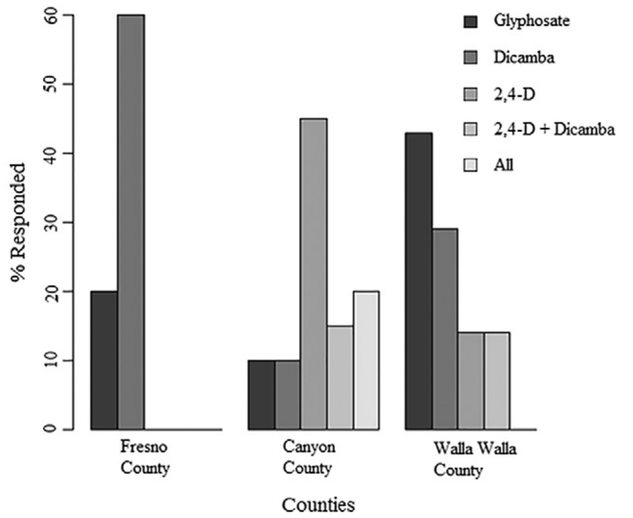

Fig. 1. Control of alfalfa volunteers in subsequent crops.

Managing Pollen Flow

Coexistence strategies are aimed at minimizing the insect-vectored movement of genetically engineered pollen to receptive flowers in a conventional field so that AP remains at a level low enough to avoid negative impact (i.e., >0.1% AP for AP-sensitive seed lots). Gene-flow issues are mainly a concern in alfalfa seed production since pollen transmission from genetically engineered seed and hay fields to conventional hay fields has a very low probability of causing AP in hay, since hay is generally harvested before seeds mature. Additionally, the rarity of mature seed and autotoxicity makes it difficult for genetically engineered seedlings to become established in hay fields (Van Deynze et al., 2008). Putnam et al. (2016) reported the AP contamination in hay is probably a result of genetically engineered seed contaminating conventional seed stocks used to plant hay fields.

Hay-Field Management

Genetically engineered hay fields do have the potential to contribute genetically engineered pollen that could negatively impact conventional seed fields, depending on how hay fields are managed to limit the occurrence of flowers. A grower survey conducted by Putnam and Orloff (2011) reported that to prevent gene flow, 41% growers were cutting fields at pre-bloom stages, while 48% growers were not doing anything and did not believe it was a problem. We found no significant difference between counties with regard to when hay fields were harvested. Out of 96 respondents, 54% reported cutting hay at 10% bloom, 32% at mid-bud stage, and 14% at pre-bud stage (Table 5). Ideally, fields should be cut before flowering to preclude the occurrence of genetically engineered pollen, especially in AP-sensitive GOZs, where AP-sensitive conventional seed fields may occur adjacent to genetically engineered hay fields. When asked if they tended to delay the last cutting of the season, about half of Fresno respondents reported they did. This was in contrast to Idaho and Washington respondents, of whom only about 25% reported they delayed the last cutting. When asked the number of times harvest was delayed in the past 5 years due to weather or other events, growers from each state responded similarly. Sixty-six percent reported 0–4 delays, 26% reported 5–10 delays, and 8% reported more than 10 delays. Flowering in hay fields can also occur in areas where mowers cannot reach. When ask what percentage of their fields could not be cut due to obstructions, 80% of growers in California reported <1% of their fields could not be cut, while 62% and 50% of respondents in Idaho and Washington reported the same. Ten percent of growers in California reported 1–3% of their fields could not be cut, while 23% and 20% respondents in Idaho and Washington reported the same. Ten percent of growers in California reported 4–6% of their fields could not be cut, while 15 and 30% of respondents in Idaho and Washington reported the same. The results of our survey suggested that hay fields do have the potential to contribute pollen, the amount being dependent on cutting practices, weather, and the topography of individual fields. Research efforts are needed to determine if the harvest flexibility provided by genetically engineered low-lignin varieties may inadvertently contribute to AP in conventional seed fields since growers will be able to maintain hay quality even when harvest is delayed. That 15% of Idaho respondents and 30% of Washington respondents reported 4–6% of their fields could not be cut due to obstructions was also a concern. Further research is needed to determine if cutting delays and field obstructions in genetically engineered hay fields is sufficient to generate enough genetically engineered pollen to adversely impact conventional seed, especially AP-sensitive seed produced in AP-sensitive GOZs.

Pollinator Management

Alfalfa pollen is moved by foraging insects, and commercial pollinators are used to produce alfalfa seed. Different pollinators have different foraging ranges, and best management practices suggest isolation distances based on the specific pollinator used (Van Deynze et al., 2008). Our survey confirmed that seed producers relied on different pollinators in different counties ($p = 0.00$; Table 5) but also showed that many seed growers rely on two species of commercial pollinators. A combination of leafcutting bees and honey bees were used by 86% of California respondents, with the remaining respondents reporting honey bees only. In Idaho, 75% reported using only leafcutting bees, 16% used both leafcutting and honey bees, and 8% used honey bees. All Walla Walla County respondents reported using a combination of alkali bees and leafcutting bees. When asked about the occurrence of native pollinators, 58% of California respondents reported observing native pollinators rarely or not at all, while 42% reported observing pollinators occasionally. In Idaho, native pollinators were observed rarely by 18%, occasionally by 68%, and frequently by 18% of respondents. In Washington, native pollinators were observed rarely by 33% and occasionally by 67% of respondents. Results from our survey suggest that seed growers using two species of bees need to use isolation distances recommended for the most robust foraging species. Research focused on how foraging interactions between multiple species of commercial pollinators influence the movement of transgenic pollen would be beneficial. Also, research focused on pollen movement by native pollinators would be beneficial since previous research has indicated that they can be effective pollinators (Brunet and Stewart, 2010; Van Deynze et al., 2008). Producers of AP-sensitive alfalfa seed have expressed concern that the movement of honey bee hives and leafcutting domiciles may contribute to the dispersal of genetically engineered pollen. Boyle et al. (2017) found that 8 h of isolation from a transgenic alfalfa source reduced the incidence of cross-pollination between two alfalfa varieties to almost zero. Moving leafcutting bee domiciles disoriented most nesting females and increased genetically engineered pollen dispersal (Pitts-Singer and Cane, 2011). Fifty-eight percent of Fresno respondents reported they moved hives or domiciles from field to field, while only 8% and 14% moved pollinators in Canyon and Walla Walla Counties. Growers should be aware of the possible AP risks of moving pollinators, especially in areas where AP-sensitive seed is being produced.

Conclusions

The results of our survey may be somewhat biased since those likely to respond would have had a stronger interest in genetically engineered alfalfa and coexistence practices than the general population of alfalfa growers. However, the high response rate suggested that this issue is important to many alfalfa producers. The survey confirmed that adoption rates in 2013 were in line with those of the Putnam et al. (2016) report in 2014 and that adoption is greater in areas where alfalfa is not exported. Genetically engineered hay fields tended to be smaller than conventional hay fields. Further study is needed to determine if adoption of genetically engineered hay fields is greater among small-farm holders. Our survey suggested that most respondents were aware of and practiced coexistence strategies. However, there were surprising gaps. Only 4% of all respondents tested hay seed prior to planting, and no respondents in Washington reported testing seed, despite reporting the highest level of export. Growers also underestimated the risk of seed spillage during planting and seed harvest and transport. Most respondents controlled feral plants, but that control was limited to their own property. Some respondents were still using glyphosate to control volunteers and roadside plants. Management of hay fields was also variable in terms of the frequency of delayed cutting and the occurrence of field obstructions that prevented cutting. In AP-sensitive GOZs, where genetically engineered hay can be produced in proximity to AP-sensitive seed, further research is needed to determine if stricter hay-management strategies may need to be deployed to minimize the occurrence of AP to ensure that AP-sensitive seed growers are not negatively impacted. Further research is also needed to determine if the harvest flexibility of genetically engineered low-lignin alfalfa will contribute to AP that has a negative consequence for conventional seed producers. The results of our grower survey suggested that efforts are needed to educate hay and seed growers, both large- and small-farm holders, about transgene dispersal risk and coexistence practices, especially in areas where alfalfa is exported or where AP-sensitive alfalfa seed is produced. Successful coexistence depends on the widespread implementation of practices that minimize the movement of transgenes by either seed or pollen. These practices will help ensure alfalfa producers can continue to target genetically engineered and non–genetically engineered markets.

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