GENETIC ENGINEERING IN FIELD CROP AND FORAGE PRODUCTION: CROPPING CONSIDERATIONS FOR HERDS CONSIDERING NON-GMO PRODUCTION

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INTRODUCTION

Over the past two decades a number of genetically engineered (GE) field crops have been released for commercial production, with nearly all being utilized in the dairy industry as sources of forage and concentrate feed. The adaption by crop growers has been rapid as these crops offer a range of management benefits and conveniences for common challenges troubling the production of key field crops.

While the public dialogue has centered on the term genetically modified organism (GMO), this term characterizes a much wider spectrum of naturally occurring and man made changes to living organisms well beyond the scope of GE techniques. In this paper the terms GE and transgenic are used as they more accurately describe how the crops traits addressed here were derived.

With the rapid adoption of these technologies has come a level of misunderstanding and mistrust from the general public. A phenomenon that has negatively impacted consumer acceptance of foods derived from production systems utilizing GE crops. This is despite the lack of peer reviewed studies showing any evidence that these technologies expose the food system to any safety concerns and the lack of evidence they have created any negative effects on human or animal health in the over two decades since their introduction (NASEM, 2016).

The dairy industry has faced significant stress in balancing growing supply with less robust demand leaving many farmers with an increasingly volatile and unstable milk market. Additionally, due to these supply and demand issues food companies continue to look for marketing opportunities that differentiate their products. This has included the strategy of labeling the absence of an ingredient or production technique, a strategy that often misleads consumers into believing the presence of that particular ingredient or technique is somehow unhealthy or dangerous. This practice adds to the misconceptions surrounding food production and threatens the availability of safe and accepted production technology and techniques.

GE crops have become a target of this labeling practice, with the Danone Food companies “The Dannon Pledge” (Dannon, 2017) being one of the most significant. This leaves some farmers with the tough decision of forfeiting a valuable management tool in an attempt to insulate their business from some of the volatility in commodity markets. Additionally, farms may be able to realize a price premium for agreeing to production practices excluding the technology, a point that should not be lost as forfeiting an important management tool provides significant justification for additional compensation.

For dairy products it should be noted that milk is a natural product with no genetic modification. Furthermore, the animal products (milk and meat) produced from cows fed GE ingredients are not altered in any way compared to these same products from cows fed a diet containing no GE ingredients.

Unfortunately, as has been the case with other marketing strategies which exclude modern production techniques, what starts as an opportunity for a small percentage of milk producers can have far greater impacts on the industry. Often absence labeling results in many misconceptions about food safety and an erosion of consumer confidence in the approved technologies. The risk exists that over time all producers could loses access to the technology, and the associated premiums for forfeiting the technology, as market share for products produced with the technology diminish.

HISTORY AND TRAIT OPTIONS

After several years in development the first GE field crops were approved for use in the United States (U.S.) in 1995 with commercial acreage planted in 1996. Since that time the number of different crops as well as the number of pest protection traits available has increased. The list of field crops with an herbicide and or insect pest tolerance trait include corn, soybeans, cotton, canola, sugar beets and alfalfa.

The first herbicide tolerance genes introduced into a field crop were designed to allow the crop to tolerate an application of the broad spectrum herbicide glyphosate, under the Roundup Ready trademark. Currently, tolerance traits for glyphosate, glufosinate, dicamba and 2,4-D are commercially available in certain field crops.

Insect resistances traits are derived from the bacterium, Bacillus thuringiensis (Bt). A gene from the Bt bacterium is incorporated into a crop and produces an insecticidal crystalline (Cry) protein that is toxic to certain groups of insects when ingested. It is important to recognize that each Cry proteins effect is specific to a certain group of insects and will not affect other insects or outside of the targeted group or mammals. Numerous Cry proteins have been identified with activity against the larvae of certain types of moths, flies and beetles (Hardee, 2001).

Drought tolerance traits have also been introduced into field crops; however, not all drought tolerance traits are derived from GE techniques with some coming out of conventional plant breeding techniques.

Currently it is common to find seed options where multiple traits are stacked in a single crop variety or hybrid. A common example of this is a triple stacked corn hybrid, a corn hybrid containing a gene for glyphosate tolerance as well as having two different Bt proteins, one for European Corn Borer and one for Corn Rootworm.

The approval and introduction of Roundup Ready (herbicide tolerant) alfalfa in 2006 was an early example of the expansion of this technology from annual crops to a perennial crop. While alfalfa remains the only example in field crops there are other perennial GE crops used in the turf industry. The release of low lignin alfalfa in 2016 marked a shift from GE use as a pest management tool in field crops to a role in increasing the feed quality of a forage specific crop.

A MANAGEMENT TOOL

The introduction of GE crops added a valuable new option to the crop management toolbox and offers a number of potential benefits in management flexibility, cost, producer safety and environmental impact. However, this does not mean that GE crops are the only management options or even the most economical for a specific situation. It is quite easy to generate real world field scenarios related to pest pressure and growing conditions where GE crops have a large benefit on field performance, while in other common real world scenarios their use may not be warranted or provide any clear benefits to the field's outcome. Fernandez-Cornejo et al. (2006) report increased returns from the adoption of Bt corn and cotton when pest pressure is high, highlighting the effectiveness of these management tools against their targeted pest.

Cultural and chemical control options, with varying levels of effectiveness, existed prior to the availability of GE crops and continue to be viable options for management. Additionally, new cultural, biological and chemical control options have continued to be develop since the advent of GE technology and the need to continue their development in parallel with GE technology remains very important for the long term sustainability of all crop management tools. A report from the National Academies of Science, Engineering and Medicine (NASEM) states, "Genetic engineering and conventional breeding are complementary approaches, and more progress in crop improvement will be made by using both conventional breeding and genetic engineering than by using either alone.", (NASEM, 2016).

The key to the sustained efficacy and availability of each of these management tools is having continued access to all of them. Access to all available tools and utilizing each tool where it presents the best fit for managing a field will reduce the chances of pest developing resistance to any one tool and is consistent with the principals outlined in Integrated Pest Management (IPM). The New York State IPM website states, "Integrated pest management rarely relies on just one tactic—it integrates tactics to prevent pests entirely or reduce them to levels you can live with.", (NYSIPM, 2017).

UTILIZATION BY FARMS

GE crops dominate U.S. acreage of field corn, soybeans and cotton (Figure 1) with GE Canola and Sugar Beets also representing significant acreage. In 2017, U.S. acreage of GE field corn, soybeans and cotton all exceeded eighty percent with herbicide tolerant soybeans leading the way, representing ninety four percent of U.S. soybean acres (USDA-ERS, 2017).

Additionally GE alfalfa acreage are expected to grow with the introduction of the Low Lignin trait which improves the fiber digestibility of the plant. Currently the Low Lignin trait is only available stacked with the herbicide tolerance (Roundup Ready) trait and is marketed under the tradename HarvXtra.

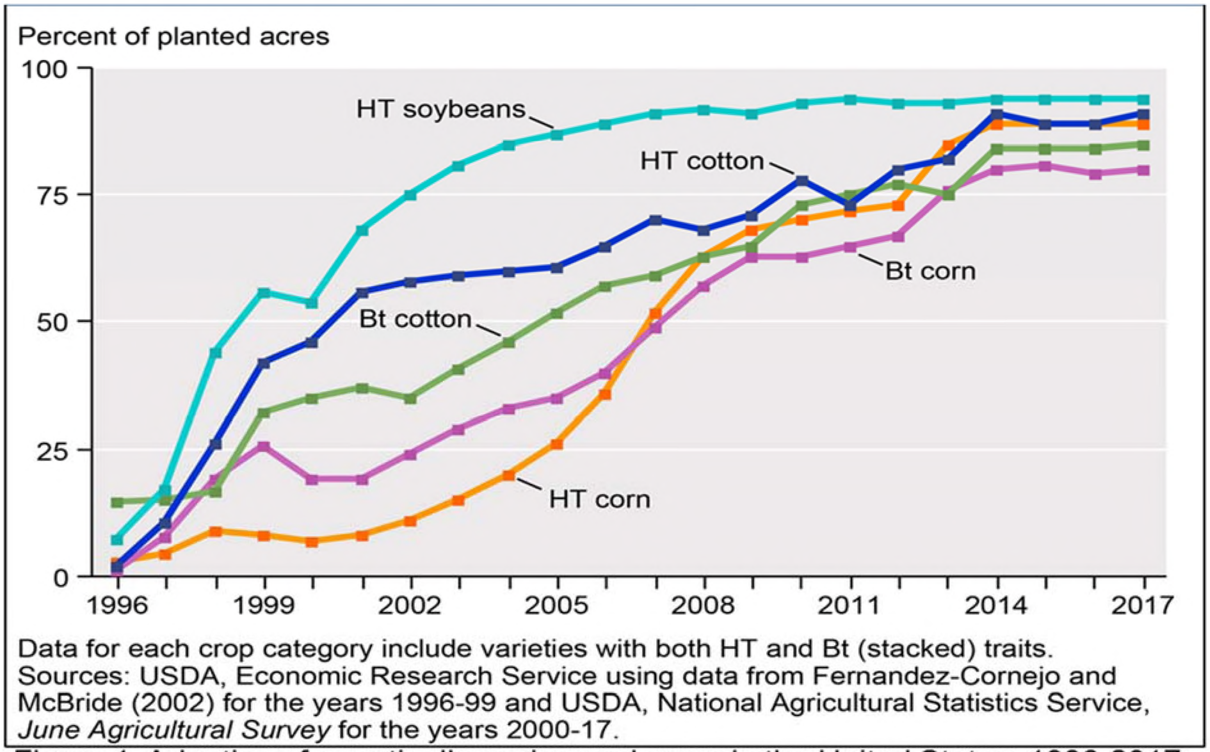

Figure 1. Adoption of genetically engineered crops in the United States, 1996-2017. Source: Recent Trends in GE Adoption, USDA-ERS

While the infinite range of field specific outcomes has made it difficult to document the overall impact of GE technology on the yield (NASEM, 2016; Zulauf and Hertzog, 2011a) and economics of crop production, the overall positive impact of GE crops is generally accepted. “At the farm level, soybean, cotton, and maize with GE herbicide-resistant or insect-resistant traits (or both) have generally had favorable economic outcomes for producers who have adopted these crops, but there is high heterogeneity in outcomes.”, (NASEM,2016). A meta-analysis by Klumper and Qaim (2014) reported that on average farmer adoption of GE crops reduced pesticide use while increasing yields and profits, with greater gains realized in developing countries.

In addition, GE crops can play an important role in farmer adoption of other practices recognized as critical to agricultural sustainability. The use of reduced or no-tillage and cover crops are well established as important practices in long term agricultural and environmental sustainability (Gould et al., 1989; Hobbs et al., 2008). However, these practices also present additional challenges associated with pest management such as increased plant residue which attracts certain insect pest and the termination of living cover crops required when establishing the subsequent field crop.

As with the pest management options discussed above it should be noted that these conservation practices were implemented prior to the availability of GE crops and remain viable practices without GE technology. However, the availability of GE crops as a management tool greatly expands the options for control and flexibility in control timing that can be critical to successfully managing these practices with the wide range of weather events and growing conditions present in any given season.

Pesticide Usage Trends

With the widespread adoption of GE crops questions have arisen about the potential overuse of these technologies and corresponding management practices. One aspect of this debate centers on the total pounds of pesticides used annually. GE crops have been touted for their role in reducing pesticide use; however, this has not necessarily been the case as it is necessary to dig beyond the total pounds of pesticides used to understand the changes associated with GE crops.

In a study of total pounds of pesticide active ingredients used in 21 major crops in the U.S. from 1960 to 2008 Fernandez-Cornejo et al. (2014) found that by 2008 total usage, in pounds of active ingredient, had trended downward since its peak in 1981 but had year to year fluctuation. The authors credit this downward trend to a number of factors including the adoption of GE crops. Klumper and Qaim (2014) noted that "Yield gains and pesticide reductions are larger for insect-resistant crops than for herbicide-tolerant crops.".

In a study of U.S. corn and soybean producers from 1998 to 2011 Perry et al., (2016) found that the total amount of soybean herbicides increased by 28% compared to farmers who had not adapted GE crops, while when comparing adopters of GE corn to non-adopters, herbicide use dropped by 1.2% and insecticide use dropped by 11.2%. A second step taken by Perry et al. (2016) was to adjust these pesticide numbers based on the environmental impact quotient (EIQ) of each pesticide. When adjusted for the EIQ the study found that soybean herbicide use by adopters of GE crops was equal to non-adapters while corn herbicide use dropped by 9.8% and corn insecticide use decreased by 10.4%. This highlights a key argument associated with GE crops which suggest that while total pesticide use is not necessarily down in every category, in certain crops the environmental impact of the pesticides being used has lessened.

Pest Resistance

Aside from general usage trends a consequence of the increased use of GE crops has been an increased reliance on certain pesticide active ingredients that are compatible with the GE crops. This has led to documented pest resistance to both the GE trait as is the case with populations of western corn rootworm that are resistant to the Cry3Bb1 Bt protein (Gassmann et al., 2011) and an increase in the number of herbicide resistant weed populations (Heap, 2016).

The convenience of use created by GE crops in conjunction with the economic pressures on grain and livestock farmers have had an impact on the development of resistant pest populations. In years of very low margins growers often look for the least cost option and when put under financial stress for consecutive years these least cost options may be used repeatedly despite the known risk that repeated use could increase the chances of pest developing resistance. This is notable in the use of glyphosate for broad spectrum weed control in corn and soybean rotations where both crops are glyphosate tolerant.

In the case of corn rootworm resistance to corn with the Bt trait, a combination of factors related to crop management logistics, financial considerations, inadequate crop rotations and improper implementation of Bt refuge areas in the field has contributed to the current resistance issues.

The industry has worked to address this by developing seed trait packages that include multiple modes of action (MOA) for the control of a target pest as well as premixed pesticide packages also offering multiple MOA for application on targeted pest populations. While this does offers farmers a means of combating resistance development, its effectiveness in combating resistance is limited. Having multiple MOA present is only useful if all MOA are still effective against the pest. Pairing an effective MOA with one that the target pest population is already resistant to only places further selection pressure on the MOA that is working (Shields, 2017). These technological solutions need to be paired with greater use of other currently available management tools to enhance their effectiveness.

It is difficult to pin the blame for resistance issues in any one place; however, it is clear that they are becoming an increasing threat to the viability of GE crops and need to be addressed by the industry to assure the continued availability of GE technology as a management tool in an integrated approach to crop management. Without a greater emphasis on the stewardship of these technologies the discussion regarding their voluntary forfeiture for potential marketing advantages becomes a moot point.

PREVELENCE OF GE CROPS IN DAIRY RATIONS

In addition to the substantial acreage of GE corn grown for on-farm use as silage and grain and the growing interest in GE alfalfa, the high percentage of acres growing major feed commodities such as corn, soybeans, cotton and canola at the national level assures that feed ingredients derived from GE crops are common on any dairy farm that is not actively choosing to exclude them.

Consequently a dairy farms transition away from GE crops and feed ingredients will include changes to the entire supply chain of major feed ingredients well beyond any home grown forage or grain crops (Chase, 2017).

A list of field crops relevant to dairy production and the corresponding traits that are derived from conventional and GE techniques was developed for a PRO-DAIRY Forage Management sheet (Lawrence, 2017) and is presented here (Figure 2).

Genetically Engineered	**Conventional**
CORN	

• Herbicide Tolerance
    o Glyphosate tolerance
        ▪ Roundup Ready (RR)
        ▪ Glyphosate Tolerant (GT)
    o Glufosinate tolerance
        ▪ Liberty Link (LL)
    o 2,4-D tolerance
        ▪ Enlist
    o Dicamba tolerance
        ▪ Roundup Ready Plus Extend
• Bt Insect Protection
    o Corn Rootworm
    o Lepidoptera (Moths & Butterflies)
• Drought Tolerance
    o ***SOMETIMES***, check with seed supplier
	• Brown Mid Rib (BMR)
	• Floury Starch Silage Hybrids
	• Disease Tolerance
	• Drought Tolerance
	    o ***SOMETIMES***, check with seed supplier

SOYBEANS	

• Herbicide Tolerance
    o Glyphosate tolerance
        ▪ Roundup Ready (RR or RR2)
        ▪ Glyphosate Tolerant (GT)
    o Glufosinate tolerance
        ▪ Liberty Link (LL)
    o 2,4-D tolerance
        ▪ Enlist
    o Dicamba tolerance
        ▪ Roundup Ready Plus Extend
• High Oleic
    o ***SOMETIMES**, check with seed supplier*
	• Disease Tolerance

ALFALFA	

• Herbicide Tolerance
    o Glyphosate tolerance
        ▪ Roundup Ready (RR)
• Low Lignin
    o HarvXtra
	• High Quality (HQ)
	• Low Lignin (other than HarvXtra)
	• Hybrid
	• Multifoliate
	• Potato Leafhopper Tolerance
	• Alfalfa Snout Beetle Tolerance
	• Disease Tolerance
	• Branch Rooted

COTTON	
• Herbicide Tolerance • Bt Insect Protection	
CANOLA	
• Herbicide Tolerance	
SUGAR BEETS	
• Herbicide Tolerance	

Figure 2: Crops Relevant to Row Crop, Dairy and Livestock Production

MANAGING CROPS WITHOUT GENETIC ENGINEERING TECHNOLOGY

As discussed, in the majority of situations viable management alternatives to GE technology exist and their use in conjunction with biotech is encouraged in an integrated management approach. Additionally a number of important crop traits, ranging from disease resistance to improved quality, continue to be available through conventional plant breeding (Figure 2). With that said, the absence of these management tools creates a void in the crop management toolbox that may expose a crop production program to increased variability in yields, cost and environmental impact.

While a direct increase in yield from the adoption of GE crops is hard to quantify and Zulauf and Hertzog (2011b) found that the decline in yield variability was not unique to GE crops when compared to non-GE crops in their study, The National Academy of Science, Engineering and Mathematics did note that GE crops have facilitated a narrowing of the gap between a crops yield potential and actual yield (NASEM, 2016).

Given the desirable characteristics of GE crops in addressing defined management challenges related to growing conditions, their use is likely to increase in importance in stabilizing production levels and lessening the chances of major crop failures as farmers have experienced an increased frequency in extreme weather events during critical periods in a cropping season. Strategic planning will be needed to compensate for the absence of these tools and minimize the potential upturn in production variability. For individual farms, considering a shift to a non-GE production system, it will be critical to carefully evaluate the expected economic impacts specific to their operation and what level of price premium is necessary to justify this shift.

Weed Management

In the absence of herbicide tolerate crops growers will need to rely heavily on a well-planned pre-emergence (PRE) herbicide program to minimize weed impact. This will necessitate a greater understanding of specific weed populations in each field to customize the PRE program to the weeds present. While post emergence (POST) products exist for control of emerged weeds in non-herbicide tolerant crops their cost, specificity and window of effectiveness are all highly variable relative to the options present in herbicide tolerant crops.

The herbicide options present for non-herbicide tolerant corn often have a longer residual time in the soil and may also carry additional crop rotation restrictions that will need to be accounted for in crop management plans.

Insect Management

The control of key insect pest in the absence of Bt crops will require an emphasis on short crop rotations and an increased reliance on insecticides. Corn Rootworm, a major pest in almost all corn producing areas of the U.S. (Marra, 2012), can be effectively controlled using crop rotation, though the practicality of this does not always fit into overall farm management strategies and can be limited by available crop acreage, geography and rotation resistant variants of the insect. Western Bean Cutworm, a relatively new pest of concern in corn production is not affected by crop rotation leaving treatment with insecticide as the leading alternative for control.

Increased insecticide usage in the form of planter application may necessitate additional application equipment on planters. Post emergence control measures may require additional passes over the field which can cause additional physical damage to the crop and may require specialized high clearance spray equipment. Farm owners and employees may need to hold valid pesticide application licenses in their state to legally apply insecticides required in the absence of Bt crop traits.

Drought Management

The availability of drought tolerance traits are relatively new in the history of GE crops but present an important tool in reducing the impact of increasingly variable weather patterns. The use of GE methods to develop these drought tolerance traits are company specific. If a grower desires drought tolerant traits it will be important to verify with each company the method in which the trait was added to the plant and if it qualifies as not being derived from genetic engineering.

FUTURE USES OF GENETIC ENGINEERING

In any discussion regarding the implications of product marketing and consumer perception on a producer's access to and use of a technology it is critical to not only consider the current applications of said technology but also the future potential. GE techniques continue to be employed in a wide array of uses, not only in field crops but also in fruit and vegetable crops central to human nutrition. Additionally the applications of the technology continue to reach beyond their common use in field crop pest management to altering the nutritional profile of plants, both for direct human consumption and in forages for livestock. Moving away from GE management tools should be looked at in the context of not just the current technology that will be forfeited but also how it will jeopardize the development and accessibility of future crop enhancements.

Forage Quality

Improving forage quality remains a key focus in dairy production and continues to be addressed at the field management and plant breeding level. An example of this was noted in a 2016 webinar presented by Hay and Forage Grower Mark McClaslin of Forage Genetics International was asked about future developments in improving the forage quality of alfalfa. He responded that one of the most promising advancement currently being worked on is the introduction of tannins into the alfalfa plant that would slow the rate of protein degradation in the rumen, thereby increasing the bypass protein available from the plant allowing ruminant animals to utilize a greater percentage of the protein available in the alfalfa plant (McClaslin, 2016).

Gene Editing

The gene editing technology commonly referred to as CRISPR, an acronym for clustered regularly interspaced short palindromic repeats, is garnering great interest in applications ranging from reducing disease susceptibility in plants to addressing genetic diseases in mammals, including humans. This technology is generally considered to hold great potential in a range of applications (Folta, 2016; Zaidi, 2017; Zhang, 2016).

From a scientific standpoint the precise method in which CRISPR edits a targeted part of the genome is very different than GE (Folta, 2016); however, it remains unclear how the general public will differentiate the two techniques and what their acceptance of gene editing will be in comparison with GE.

CONCLUSIONS

The ability of farmers to produce crops for GE free markets is feasible with the economic and environmental outcomes of doing so highly tied to economic premiums for the product and specific growing conditions, which will vary by farm and growing season. Producers considering this production system should recognize the added planning and management required, the chances of increased production and cost variability and the broader implications these decision may have on the access to these technologies in the future of food production.

Currently available genetic engineering techniques and emerging techniques in gene editing offer producer and consumers a range of potential benefits in the efforts to increase the sustainability of food production. Responsible management of these technologies requires; continual advancement of technologies, sound and on-going scientific review of their safety and effectiveness, producer accountability in proper use of technologies, public confidence in the scientific process, food chain support of sound production practices. Additional in-depth analysis to better understand the economic impacts of GE technology both at the farm level and the global societal scale is needed.

It is critical the entire supply chain from crop developers and growers to food manufacturers and consumers be engaged in a scientifically based dialogue regarding the role of this technology in food production and the implications of using exclusionary tactics in marketing food.

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