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PRODUCTION AND MANAGEMENT: *Invited Review*

Invited Review: Applying fungicide on corn plants to improve the composition of whole-plant silage in diets for dairy cattle*

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ABSTRACT

Purpose: Published literature and data from the author's group pertaining to fungicide application on corn plant used for whole-plant corn silage (WPCS) was reviewed to summarize the effects of the aforementioned strategy for fungi disease control in the corn plant on WPCS quality and dairy cattle performance.

Sources: The main source of data and information for this review was peer-reviewed literature.

Synthesis: Whole-plant corn silage is the most commonly used forage in diets of dairy cattle in the United States. The interaction of fungi and corn plants reduces yields, decreasing the efficiency of food production, and the nutritive quality and value of this material when fed to ruminants. When infecting the corn plant, fungi reduce its nutritional content available by metabolizing sugar compounds within the plant cell. Applying fungicide to corn plants can protect corn plants from fungal infection, therefore limiting yield losses and increasing the nutritive quality of the plant material. There is limited information regarding feeding dairy cows WPCS from corn plants treated with foliar fungicide. However, findings from previous research highlight the negatives of making and feeding WPCS from diseased corn plants.

Conclusions and Applications: Scouting corn plants for foliar disease is an important practice to determine fungicide application. Nevertheless, foliar fungicide application on corn plants used to make WPCS for dairy cattle seems to improve its nutritional composition. Mainly, factors attributed to it are increased milk components and feed efficiency, reduced fiber concentrations, and improved ruminal degradability, independently of visual identification of foliar diseases.

Key words: whole-plant corn silage, mycotoxins, milk per tonne, digestibility, fungus

INTRODUCTION

On a DM basis, whole-plant corn silage (**WPCS**) composition is about 60% corn ears, 12% corn leaves, and 28% corn stalks (Kuehn et al., 1999). For dairy cattle diets, WPCS represents 40 to 60% of the total mix ration in lactating diets (Mueller and Wise, 2014). One of the many parasites that can affect corn plants are fungi. The triangle of the disease is composed of the host (corn plant), pathogen (fungi), and environment (i.e., weather, soil). Corn plant physical barriers such as cell walls and chemical releases (i.e., secondary metabolites) aid plants in protecting from pathogens (Malinovsky et al., 2014). Fungi maintains tissue growth by obtaining nutrients from the plant. That is accomplished consistently if fungi remain undetected on the plant surface, where enzymes degrade cell walls and once inside produce toxins killing the plant tissue (Sexton and Howlett, 2006).

Plants have adapted by increasing the lignin concentration in the secondary cell wall, thus creating a thicker layer for digesting when distressed or infected with a fungal pathogen or insect (Santiago et al., 2013). However, once inside the cell, and growth has ceased, fungi release secondary metabolites, which in some species are toxic. It is generally hypothesized that during the colonization and sporulation phase of a fungus within a plant, mycotoxins are secreted by growing colonies (Calvo et al., 2002). Therefore, one can hypothesize that foliar fungicide application may improve WPCS quality.

Corn plants treated with fungicide had fewer yellow leaves than nontreated corn plants (Kalebich et al., 2017a), and WPCS from corn plants treated with fungicide had improved fermentation profile during the ensiling period compared with WPCS from corn plants that were not treated with fungicide (Kalebich et al., 2017b). Haerr et al. (2015) reported that cows fed WPCS from corn plants treated with foliar fungicide tended to have improved feed efficiency. Therefore, the objectives of this review were to summarize the knowledge available on the fungi and plant relationship, limiting plant infection by

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applying fungicide, and how WPCS from corn plants with fungicide application affects dairy cow performance.

REVIEW AND DISCUSSION

Fungus and Corn Plant

Field Challenges. Corn products are undeniably an important source of feed for cattle in the United States. Whole-plant corn silage is one of the most essential corn products used for dairy operations; approximately 89% of dairy farms incorporated WPCS in diets for lactating cows in 2014 (USDA, 2014). Globally, the United States produced the most corn in 2014 at 327 million tonnes with approximately 14% of total corn production devoted to the production of WPCS (USDA, 2014).

During growth, the corn plant undergoes 2 phases of development: vegetative stages and reproductive stages (Table 1; Mueller and Pope, 2009). The main physical changes occurring in the corn plant at the vegetative stage are the emergence of the tassel and the development of full plant height (Nleya et al., 2016). At the R5 corn stage of growth, the milk line (a distinct horizontal line) forms between the yellow and white areas on the kernel, almost all of the kernels begin to dent, and the moisture of the corn kernels reaches approximately 55% DM (Nleya et al., 2016). This is the stage at which most WPCS reaches between 30 and 38% DM, being mature for harvest (Mahanna et al., 2013).

Due to the importance of WPCS in the diet of lactating dairy cows, WPCS quality control is pivotal for dairy producers' and nutritionists' success. In fact, recent reviews describe in detail the current literature on WPCS feeding management and cow behavior (Grant and Ferraretto, 2018), current recommendations on optimizing WPCS quality at harvest (Ferraretto et al., 2018), and common issues regarding DM and quality loss in WPCS (Borreani et al., 2018). The effects of physical and chemical composition of WPCS during growth, harvest, and ensiling on cow health and productivity are well established. In addition to those results and recommendations, a variety of laboratory tests can easily be performed on WPCS and other feedstuffs to determine nutrient quality and a TMR so the feeding routine can be adjusted accordingly. However, the effects of fungal disease on WPCS both in the field and during storage after harvest are much more difficult to control.

Yield Losses due to Fungal Infections. In 2013, 7.5% of the total estimated corn harvested from 21 corn-producing states was lost to disease, meaning almost 27 million tonnes of corn was lost because of seedling blights and foliar diseases (Mueller and Wise, 2014). Under ideal weather conditions for pathogenesis, a 1% increase in foliar disease severity of gray leaf spot (**GLS**), caused by the fungus *Cercospora zeae-maydis*, reduced corn yields by 47.6 kg/ha when compared with a tolerant hybrid (Nutter and Jenco, 1992; Ward et al., 1999). Furthermore, in a meta-analysis of 20 studies, every 10% increase in rust severity on sweet corn, caused by the fungus *Puccinia sorghi*, reduced corn yields by 2.4 to 7.0% (Shah and Dillard, 2006). Mycotoxins, a secondary metabolite of fungi, contaminated 12.5% of the total harvested grain in the United States in 2013, mostly because of the disease *Aspergillus* ear rot (Mueller and Wise, 2014), caused by the fungi *Aspergillus flavus* and *Aspergillus parasiticus* (Miller, 1995). It is evident that fungal infection and disease in plants can cause devastating losses in corn yield.

Fungal Interactions with Plants. There are fungi that are not parasitic to the corn plant. Most fungi associated with plants are saprotrophs, responsible for decomposing OM as their substrate for existence (Carris et al.,

Table 1. Corn plant growth stages

Stage	Abbreviation	Description
Vegetative[1]	V_E	Emergence of the shoot from the soil
Vegetative[1]	V_1	Development of a collar on the lowest leaf
Vegetative[1]	V_2	Development of a collar on the 2 lowest leaves
Vegetative[1]	$V_{(n)}$	Development of up to 17 to 22 leaf collars
Vegetative[1]	V_T	Appearance of the lowest branch of the tassel (tasseling)
Reproductive[2]	R_1	Any silk visible on the cob
Reproductive[2]	R_2	Kernels are small and white and the endosperm fluid is clear
Reproductive[2]	R_3	Kernels are yellow with milky white fluid
Reproductive[2]	R_4	Kernel contents are pasty as starch accumulates
Reproductive[2]	R_5	Most kernels are dented due to starch hardening at the top of the kernel
Reproductive[2]	R_6	Milk line is no longer visible and a black layer forms at the kernel's attachment (end of DM accumulation)

[1]The vegetative stages are determined based on the total number of leaves with a visible collar (off-white band at the base of the leaf blade where it extends away from the stalk; Mueller and Pope, 2009).

[2]The reproductive stages are determined based on kernel maturity (Mueller and Pope, 2009).

2012). Other fungi, about 160 known species, reside on the roots of growing plants in a mutualistic relationship (i.e., phylum Glomeromycota—the arbuscular mycorrhizal fungi). Carbohydrates produced by the plant feed the fungus, and the fungus transports nitrogen, phosphorous, and other minerals to the plant (Carris et al., 2012). Meng et al. (2015) reported that inoculating with both arbuscular mycorrhizal fungi and rhizobium in the soybean–maize intercropping system improved the N fixation efficiency of soybean and promoted N transfer from soybean to maize, resulting in the improvement of yield advantages of legume–nonlegume intercropping. A very small amount of fungi are disease causing, totaling less than 10% of about 100,000 known species, that colonize plants (Knogge, 1996).

Disease in Corn Plants and Pathogens. Plant pathologists use the disease triangle for assistance when evaluating the likelihood of a disease outbreak. A susceptible host (plant), a pathogen, and a favorable environment are all necessary for development of plant infection, but the presence of just 2 is unlikely to result in disease. The relationship between fungi and plants is sometimes referred to as an arms race (Malinovsky et al., 2014). By definition, to be a pathogen, an organism must be able to cause disease and complete its life cycle on a host (Sexton and Howlett, 2006). Historically, fungi can be divided into 2 main groups, both of which originate in the field. Fungi produce toxins in the plant before harvest and a plant–fungus interaction is stablished. Fungus can be a problem after harvest and a function of crop nutrients, physical, and biotic factors (Miller, 1995).

Once in the cell and after growth, the fungal pathogen either adapts to the host's physiology or modifies the environment for nutrient uptake to allow for colonization within the host (Knogge, 1996; Sexton and Howlett, 2006). Once fungal pathogens invade, plant cell oxidative bursts signal other metabolic pathways of an invasion (Boller and Felix, 2009) but in doing so locally kill plant tissue providing immediate nutrients to the fungus (Sexton and Howlett, 2006). For more long-term nutrition, a haustorium, a specialized fungal structure, can be inserted into the plant cell for water and nutrient uptake, especially hexose carbohydrates including sucrose, glucose, and fructose (Voegele et al., 2001). The diversion of plant nutrients can be used for fungal growth and development.

Once inside the cell and growth has ceased, fungal pathogens release secondary metabolites, which in some species are toxic. It is generally hypothesized that during the colonization and sporulation phase of a fungus within a plant, mycotoxins are secreted by growing colonies (Calvo et al., 2002). The exact function of fungal toxins in the plant is unclear. Fungal phytotoxins can cause direct plant cell death (Sexton and Howlett, 2006) by overactivation of the plant plasma membrane enzyme, H^+ATPase, which disrupts energy transfer during the light reactions in the chloroplasts (Knogge, 1996), the closing or opening of the stomata, and the redirection of ion channels (Elmore and Coaker, 2011). However, mycotoxins threaten food safety and security worldwide.

Five agriculturally important mycotoxins resulting from corn ear rot include deoxynivalenol (**DON**) from the fungus *Fusarium graminearum*; zearalenone (**ZEA**) from the fungus *F. graminearum*; ochratoxin A from the fungi *Piper verrucosum* and *Aspergillus ochraceus*; fumonisin from the fungus *Fusarium moniliforme*; and aflatoxin from the fungi *A. flavus* and *A. parasiticus* (Miller, 1995). Development of mycotoxins within the plant occurs later in the growth and development of the corn plant. One study reported that fumonisin concentration within corn kernels increased greatly as the corn plant became more mature, with only 33% of corn kernels infected at the fourth reproductive stage but 62.5% of corn kernels infected at harvest (Ariño et al., 2009). Furthermore, although it is generally thought tilling fields may reduce fungi colonization, this may not be the case as Ariño et al. (2009) reported no difference in fumonisin concentrations in varying degrees of tilled fields. The most prevalent mycotoxin present in WPCS in the United States in 2017 was DON (Table 2).

Corn Plant Defense Mechanisms. The plant cell wall is composed of a primary cell wall, providing structural support for the plant, and a secondary cell wall, developing inside the primary cell wall only after the plant cells stop growing (Freeman and Beattie, 2008). The primary wall of plant cells is composed of cellulose, cross-linking glycans, also known as hemicellulose, and pectins. Cel-

Table 2. Total number of positive samples, percentage of all samples that were positive, and percentage of total positive samples affected by each mycotoxin for whole-plant corn silage samples as analyzed by Agri-King Inc. (Fulton, IL), Rock River Laboratory Inc. (Watertown, WI), and Dairyland Laboratories Inc. (Arcadia, WI) in 2017

Mycotoxin	Total positive samples per mycotoxin[1]	Positive samples,[2] %	Total positive samples affected by each toxin,[3] %
Aflatoxin	1,332	2.39	25.38
Zearalenone	988	1.78	18.82
Deoxynivalenol	2,701	4.85	51.46
Fumonisin	53	0.10	1.01
T-2 Toxin	175	0.31	3.33

[1]Total number of samples that were positive for each mycotoxin upon analysis. Table created for Weatherly (2018).

[2]Percentage of all samples analyzed that were positive for each toxin out of all corn silage samples analyzed (n = 55,641).

[3]Each mycotoxin's specific contribution to the total number of positive samples (n = 5,249).

lulose is a polysaccharide, composed of β (1,4)-glyosidic bonds between glucose molecules, and very resistant to degradation by hydrolysis (Ferrari et al., 2013). Hemicellulose is also a polysaccharide, where a pentose is bonded with a hexose (e.g., arabinoxylans, xyloglucans, mixed linked β glucans, and galactomannans). The cross-linking of hemicellulose aids in the fortification of cellulose for both structural support and prevention of microbial invasion (Endler and Persson, 2011). Enzymes such as xylanase, produced by some fungi, weaken the cell wall and allow fungal entry into the plant cell (Belien et al., 2006). Lignin, a phenolic polymer, is deposited during the last stages of secondary cell wall formation. Lignin reinforces plant cells and allows transport of water under negative cellular pressure (Albersheim et al., 2011). When cell walls become lignified, they become highly impermeable to pathogens and hard for insects to digest, limiting access to cell wall sugars (Freeman and Beattie, 2008).

Plants have a recognition system controlled by resistance genes within the plant cell known as plant triggered immunity (Jones and Dangl, 2006). Pathogen associated molecular patterns, also known as PAMP, which may include fungal chitin or bacteria flagellin, can trigger a plant triggered immunity response within the plant cell to prevent microbial colonization (Medzhitov and Janeway, 1997). Also, damage associated molecular patterns, known as DAMP, which may include parts of the plant cell wall released possibly due to fungal enzymes, trigger an immune reaction (Boller and Felix, 2009). An activated plant triggered immunity in a plant cell may cause localized death (Jones and Dangl, 2006), an oxidative burst of reactive oxygen species to signal neighboring cells of invasion (Freeman and Beattie, 2008), a rapid fluctuation in the calcium gradient to signal that a pathogen has been detected (De Falco et al., 2010), release of pathogenesis related enzymes including chitinase, to degrade fungal chitin (Sexton and Howlett, 2006), activation of enzymes to strength the cell wall, activation of defense genes, and induction of phytoalexins, which are antimicrobial substance synthesized de novo (Knogge, 1996).

Disease in WPCS. Fungi can also attack the plant material in storage. To limit the growth and colonization, generally, it is recommended to store corn material in dry conditions and as mature crops (Richard, 2007). The occurrence of fungi in silages usually is the result of poor sealing and poor compaction causing aerobic conditions in the silo, not only causing losses of feed but also reductions in palatability (Pahlow et al., 2003). Furthermore, visibly molded areas of silages underestimate the amount of fungi within the silage content, as well as the high probability of mycotoxins (Pahlow et al., 2003).

Fungal disease on corn plants ensiled as WPCS can affect the nutritional content within the plant material. Inoculation of northern leaf blight, caused by the fungus *Exserohilum turcicum*, on corn plants increased the NDF (from 39.2 ± 3.2% to 49.9 ± 4.1% of DM) and ADF (from 21.7 ± 3.0% to 26.3 ± 3.2% of DM) concentrations compared with nondiseased corn plants (Wang et al., 2010). Dry matter digestibility was less for sheep consuming WPCS from diseased corn plants (0.665 ± 0.029) compared with control (0.725 ± 0.012), measured using metabolic crates (Wang et al., 2010). Yet, DMI was not different for sheep consuming WPCS from diseased corn plants (3.46 ± 0.41% of $BW^{0.75}$/d) compared with control (4.09 ± 0.41% of $BW^{0.75}$/d; Wang et al., 2010).

Fungal colonization on the corn plant causes a competition for nutrients between the plant and the fungus. The plant has many mechanisms (e.g., lignification and leaf shedding) to attempt to hinder the growth of the fungal infestation. These mechanisms may potentially decrease the digestibility of the plant (Venancio et al., 2009). The fungal infestation can change the chemical composition of the plant and compete for nutrients (Venancio et al., 2009).

In another study, corn plants were ensiled with no fungi (no rust) or a medium concentration (all leaves on the lower half of the plant affected) or high concentration (all leaves affected) of southern rust, caused by the fungus *Puccinia polysora*, and then ensiled (Queiroz et al., 2012). Increasing the rust infestation from no rust to medium rust to high rust concentration on corn plants ensiled as WPCS increased concentrations of DM, NDF (no rust: 44.1% of DM, medium rust: 47.7% of DM, and high rust: 48.5% of DM), and ADF (no rust: 23.1% of DM, medium rust: 25.1% of DM, and high rust: 25.3% of DM) and decreased the in vitro DM true digestibility (no rust: 66.9%, medium rust: 63.2%, and high rust: 60.1%) and in vitro NDF digestibility (no rust: 38.1%, medium rust: 39.8%, and high rust: 36.2%) (Queiroz et al., 2012). Additionally, increased rust infestation on WPCS resulted in worse fermentation conditions exhibited by increased pH (no rust: 3.65, medium rust: 3.71, and high rust: 3.97) and decreased lactate (no rust: 4.99, medium rust: 4.02, and high rust: 2.28%). Aflatoxin was detected in WPCS from corn plants with a high concentration of southern rust at a concentration of 5.20 mg/kg of DM (Queiroz et al., 2012). Zearalenone was detected only in WPCS with no concentration of southern rust at a concentration of 0.64 mg/kg of DM (Queiroz et al., 2012).

Other researchers evaluated the effects of physically damaging the ears of corn in the field before harvest on the production of mycotoxins and fermentation when ensiled as WPCS, to represent insect or hail damage on corn plants. In the first experiment, physical damage to corn kernels occurred at the milk stage of corn development (R3) by slashing a knife through the kernels (Teller et al., 2012). Corn plants from the first experiment were ensiled as WPCS for 126 d. Physical damage to the corn ear resulted in an increased concentration of fumonisin B1 (8.50 mg/kg for damaged and 4.00 mg/kg for undamaged) and DON (3.12 mg/kg for damaged and 0.92 mg/kg for undamaged) but a decreased concentration of ZEA (1.03 mg/kg for damaged and 0.46 mg/kg for undamaged) in WPCS (Teller et al., 2012). Neutral detergent fiber and

ADF were not different for WPCS physically damaged (45.0 and 26.8% of DM for NDF and ADF, respectively) compared with undamaged (45.2 and 27.3% of DM for NDF and ADF, respectively). In the second study, physical damage to the corn kernels occurred either 27 or 9 d before harvest, and they were ensiled for 95 d. Damage to corn kernels 27 d prior (29.5% of DM) to harvest increased the ADF content in WPCS compared with 9 d prior (25.2% of DM) or no damage (25.7% of DM; Teller et al., 2012). Whole-plant corn silage damaged 27 d before harvest resulted in an increased concentration of ADF (31.9% of DM) and NDF (48% of DM) when compared with WPCS from nondamaged ears (22.3 and 36.3% of DM for ADF and NDF, respectively; Teller et al., 2012). Furthermore, WPCS from corn plants damaged 27 d before harvest resulted in an increased concentration of DON (14.77 mg/kg), fumonisin B1 (7.63 mg/kg), and ZEA (3.66 mg/kg) when compared with WPCS from undamaged corn kernels (0.18, 1.03, and 0.99 mg/kg for DON, fumonisin B1, and ZEA, respectively; Teller et al., 2012).

Environment. A favorable environment is needed for the development of plant disease, completing the final side of the disease triangle. The favorable environment for one species of fungi may be different for another. For example, when growing conditions for corn plants include a warm ambient temperature and drought conditions, corn plants are more susceptible to the fungi *A. flavus* and *A. parasiticus*, which produce aflatoxin as a secondary metabolite (Richard, 2007). Yet, the foliar fungus *E. turcicum*, causing northern leaf blight in corn, favors cool and humid conditions for colonization of foliage (Wise, 2011). Understanding the role of the complex relationship among plant cells, fungi, and the environment is crucial for the future production of corn and those whom consume it.

According to Wu et al. (2011), aflatoxin and fumonisin concentrations in corn will likely increase, whereas DON concentrations will decrease if the current climate patterns continue in this century. Nonetheless, alterations in cropping patterns or shifts caused by climate change could create new opportunities for DON in areas where corn plants are scarcer. In Poland, a study reported that the concentrations of corn grain contaminated with ZEA and DON were low. One of the plausible explanations hypothesized by the authors for the aforementioned low concentrations was that mean and maximum temperatures during yield formation and grain ripening stages are usually lower than 25°C in Poland. Optimal temperatures for fumonisin biosynthesis are between 25 and 30°C (Marin et al., 1999), and DON is usually produced more rapidly at 25°C (Ramirez et al., 2006). Miller (2001) preconized that the best strategy available for lower risks of fumonisin in corn plants and grain is to guarantee that hybrids are adapted to the environment, to limit drought stress and insect herbivory. The author suggests that it may be necessary, in the future, to create hybrids that contain enzymes to degrade fumonisin as it is produced.

Fungicides and Corn Plants

Fungicide Classes and Mode of Action. Countries around the world seek to control fungal pathogens through various methods, including fungicide application on plants, in hopes that chemical application will alleviate their effect on corn plants. In keeping with the disease triangle, fungicide's aid in plant defense from fungal invasion. The Food and Agricultural Organization estimated in 2013 that Brazil applied the most fungicide on crops, using 40,000 t of active ingredients, followed by Mexico and then Spain, using 38,000 and 29,000 t of active ingredients, respectively (FAO, 2015). In 2007 producers in the United States applied 20,000 t of active ingredients on crops (FAO, 2015).

Strobilurins fungicides, also known as QoI fungicides, are natural chemical structures isolated from the genera *Strobilurus*, in wood-rotting mushrooms. Because natural strobilurins break down quickly in UV light, synthetic analogs were developed for disease control (Balba, 2007). Strobilurin fungicides are broad-spectrum fungicides, meaning the fungicide controls a wide array of fungal diseases in a variety of crops including cereals, fruits, vegetables, tree nuts, turf grasses, and ornamentals (Vincelli, 2002). Strobilurins bind to the quinol oxidation (Qo) site of cytochrome b. This binding stops the electron transport between cytochrome b and cytochrome c, stopping the oxidation of nicotinamide adenine dinucleotide and synthesis of ATP. Once on the waxy leaf surface, strobilurins move throughout the plant translaminarly, systemically, or both (Vincelli, 2002).

A second group of fungicide commonly used today is carboxamide fungicides, also referred to as succinate dehydrogenase inhibitors. Within the succinate dehydrogenase inhibitor class of fungicides is the active ingredient fluxapyroxad. Succinate dehydrogenase inhibitors are broad-spectrum fungicides and can have translaminar or systemic activity within the host, depending on the pathogen and host (McKay et al., 2011).

A third group of fungicide is known as the demethylation inhibitors or sterol biosynthesis inhibitors, which contain the triazole fungicides. Within the triazole class is the active ingredient metconazole. Demethylation inhibitor fungicides are systemic (Lepesheva and Waterman, 2007) and single-site specific inhibitors commonly used on cereal grain (Lucas et al., 2015).

Fungicide Application in Corn Plants. In recent years, some researchers and chemical companies have concluded that foliar fungicide application on corn plants may increase yields even in the absence of disease (Wise and Mueller, 2011). In the US Corn Belt, several foliar diseases are of concern, depending on the production region, but GLS has been the disease of greatest concern since first becoming a problem in the 1980s and 1990s (Lipps, 1987). The elevation of GLS from a disease of secondary importance to a major problem throughout the eastern United

States and the Midwest paralleled the adoption of reduced tillage (Lipps, 1987).

In a meta-analysis on yield response and pyraclostrobin fungicide treatment, the mean difference in grain yield for plots treated with foliar fungicide increased 255.91 kg/ha compared with untreated plots (Paul et al., 2011). Authors concluded that when corn foliar disease (e.g., GLS) incidence in the field was less than 5%, the likelihood of an advantageous yield (i.e., bushels per acre) increase and beneficial physiological response from fungicide application was minimal and not enough to be able to cover the costs of the application. However, when disease incidence in the field was greater than 5%, fungicide application was more likely to lead to a return in profit due to increased corn grain yield. Furthermore, in a consecutive 2-yr study, Bradley and Ames (2010) did not report an increase in grain yield in 2008, under low disease severity environments, but in 2007 did report a grain yield increase when under higher disease severity. Routine scouting for disease in the cornfield is crucial for determining when fungicide application will be most profitable.

When a producer's field is diseased, proper timing of fungicide application on the plant may also provide beneficial results. Under pressure from fungal disease, application of pyraclostrobin (Headline, BASF Corp., Florham Park, NJ) on corn plants at the vegetative stage increased grain yield by 550 kg/ha compared with untreated fields of corn plants (Nelson and Meinhardt, 2011). But others (Mueller and Pope, 2009; Wright et al., 2014) have reported earlier applications to be beneficial as well. In a year with high incidence of common rust, foliar fungicide applied as a preventative at V6 increased corn grain yield by 362.9 kg/ha compared with application at before tassel, when 6% of the total leaf area was diseased (Wright et al., 2014). Yet, in a different year of the same study, when disease incidence was low, foliar fungicide applied as a preventative at V6 did not increase corn grain yield when compared with application at tassel (Wright et al., 2014).

Fungicide applications on corn plants can improve the nutrients within the plant material. In 2007 the University of Wisconsin reported a possible trend for a 1 percentage unit decrease (40.6 vs. 39.6%) in NDF concentration when comparing WPCS from corn plants treated with foliar fungicide with untreated corn plants (Blonde and Esker, 2008). On a DM basis, the average yield was 9.2 t of DM per hectare and 0.7 t of DM per hectare more (+9%) for treated areas. The increased WPCS DM yield per hectare for corn plants treated with fungicide could have caused a dilution effect of NDF (Blonde and Esker, 2008). Yates et al. (1997) proposed that when a corn plant had fungal infestation of the root, the structural components and rigidity increased, which the authors attributed to the plant attempting to decrease further infestation into the upper portion of the plant by increasing the structurally rigid components of the plant such as lignin.

Furthermore, a study at the University of Illinois evaluated the effects of fungicide application on the physical and nutritional content of corn plant leaves, ears, stalks, and flag leaves (Kalebich et al., 2017b). Fungicide applications on corn plants during the summer of 2015 were as follows: control (CON), corn receiving no foliar fungicide application; treatment 1 (V5), where corn plants received a mixture of pyraclostrobin and fluxapyroxad (PYR+FLUX) foliar fungicide at V5; treatment 2 (V5+R1), where corn plants received 2 applications of foliar fungicide, a mixture of PYR+FLUX at V5 and a mixture of pyraclostrobin + metconazole (PYR+MET) foliar fungicide at corn reproductive stage 1 (R1); treatment 3 (R1), in which corn plants received one application of PYR+MET foliar fungicide at R1. Corn plants with fungicide treatment were taller compared with untreated (2.7, 2.9, 3.0, and 2.9 m for CON, V5, V5+R1, and R1). Corn leaves in V5+R1 and in R1 had less yellow lower leaves than in CON and V5 (0.85, 0.77, 0.42, and 0.44 leaves for CON, V5, V5+R1, and R1, respectively). Corn stalks in V5+R1 had greater lignin concentration compared with CON and R1 (4.6, 5.6, 6.4, and 5.0% of DM for CON, V5, V5+R1, and R1). Corn leaves in V5+R1 had lower ADF and NDF concentrations (28.3 and 52.4% for ADF and NDF, respectively) compared with leaves in CON (33.3 and 56.9% for ADF and NDF, respectively; Kalebich et al., 2017b).

Additionally, the group determined the effects of foliar fungicide (**FUN**; Headline AMP; BASF Corp., applied at vegetative tassel growth stage) and ensiling time (0, 30, 90, and 150 d) on fiber composition of 2 corn varieties [brown midrib (**BMR**) and floury (**FLY**); Hollis et al., 2019]. Treatments were assigned to sixteen 3.38-ha plots in a completely randomized split-plot block design. Treatments were BMR without FUN, FLY without FUN, BMR with FUN, and FLY with FUN. Samples of whole corn plants were collected and separated into leaves, stalks, flag leaf, and cobs. Corn plants in CON exhibited greater incidence of GLS disease than FUN corn plants with 6.52 and 1.75 ± 0.16% of leaf area, respectively. Corn plants in CON exhibited greater incidence of ear leaf injury than FUN with 2.74 and 0.72 ± 0.13% of leaf area, respectively. Corn plants in CON exhibited greater incidence of ear leaf injury at one leaf below the highest ear leaf compared with FUN with at 3.97 and 1.22 ± 0.17%, respectively. Brown midrib corn plants had a greater number of green leaves than FLY with 11.81 and 11.34 ± 0.09 leaves, respectively. Corn plants in control (BMR without FUN and FLY without FUN) had a greater number of yellow leaves than FUN corn plants with 0.28 and 0.08 ± 0.02, respectively. Corn plants treated with FUN were heavier (737 ± 18 g) than control corn plants (672 ± 18 g).

Most recently, our group determined the effects of cut height at harvest and foliar fungicide application on BMR WPCS yield, chemical composition, and in situ degradability (Damery, 2018). Foliar fungicide (prothioconazole and trifloxystrobin; Delaro, Bayer Crop Science, Monheim am Rhein, Germany) treatments were randomly assigned to one of sixteen 0.21-ha plots as follows: control (CON), plants received no application; treatment 1 (V5), plants

received one application at corn vegetative stage 5 (V5); treatment 2 (V5R1), plants received 2 applications at V5 and corn reproductive stage 1 (R1); treatment 3 (R1), plants received one application at R1. At R5, corn plants in R1 and V5R1 had less yellow leaves (0.35 and 0.47 ± 0 0.19, respectively) than CON and V5 (0.63 and 1.08 ± 0.19, respectively). Disease prevalence was recorded as percentage of the total individual plant infected. Fungicide application had no effect on disease prevalence (1.62, 1.07, 1.23, 1.48 ± 0.30% for CON, V5, V5R1, and R1, respectively). There was no effect of fungicide treatment or cut height on the degradability of OM, NDF, or ADF. Raising the cut height from low cut (30.5 cm) to high cut (55.9 cm) increased the effective degradability of DM (0.565 and 0.577 ± 0.01, respectively), CP (0.565 and 0.576 ± 0.01, respectively), and starch (0.825 and 0.847 ± 0.01, respectively). Independently of corn variety, disease pressure, and fungicide active ingredient, corn plants seemed to have positively responded to fungicide application.

Nonetheless, it is important to highlight that miss use of fungicide can result in fungicide resistance. The Fungicide Resistance Action Committee (FRAC, 2010; CropLife International, Bruxelles, Brussels) has determined that quinone outside inhibitors (QoI; strobilurins) fungicides pose a high risk of resistance development, and over 30 fungal pathogen species across 20 genera have been reported to show field resistance toward QoI fungicides. Preventing resistance should involve choosing a resistant corn hybrid, scouting fields regularly, implementing crop rotation, mixing and rotating fungicide classes, and following label recommendations. A proactive fungicide application (i.e., before the disease can be seen when scouting) could have a positive effect on plant health due to the time between the initial infection and symptom appearance. For instance, GLS has a 2-wk latent period from infection to considerable amounts of lesion formation (Wise and Mueller, 2011).

Fungicide on Corn Ensiled as WPCS. Researchers at the University of Wisconsin applied pyraclostrobin on corn plants and ensiled it as WPCS. Using the WPCS Milk2006 performance calculator from the University of Wisconsin–Madison extension (Shaver et al., 2006), which predicts the amount of milk to be produced if the WPCS were to be fed to cows, pyraclostrobin application on corn plants numerically increased projected milk production by 37 kg of milk/t of DM (75 lb milk/ton of DM) when compared with control (Blonde and Esker, 2008).

As previously mentioned, Haerr et al. (2015) fed mid-lactation cows WPCS from corn plants with either 0, 1, 2, or 3 applications of foliar fungicide. A decreasing linear relationship was reported for the number of fungicide applications and DMI (23.8, 23.0, 19.5, and 21.3 kg/d for CON, 1X, 2X, and 3X, respectively), but milk production was constant among treatments (34.5, 34.5, 34.2, and 34.3 kg/d, for CON, 1X, 2X, and 3X, respectively; Haerr et al., 2015). Therefore, cows fed WPCS from corn plants treated with foliar fungicide tended to have better feed efficiency measured as milk yield/DMI (1.46, 1.47, 1.70, and 1.70 kg/kg, for CON, 1X, 2X, and 3X, respectively), 3.5% FCM (1.47, 1.51, 1.71, and 1.73, for CON, 1X, 2X, and 3X, respectively), and ECM (1.43, 1.46, 1.66, and 1.69 for CON, 1X, 2X, and 3X, respectively; Haerr et al., 2015). The authors hypothesized that improved feed efficiency occurred because WPCS from corn plants treated with foliar fungicide application may have had increased nutritive quality compared with untreated WPCS. Haerr et al. (2016) reported that application of fungicide on corn plants and then ensiled as WPCS (same treatments as in Haerr et al., 2015) resulted in higher DM degradable fraction, which increased with the number of fungicide applications. It tended to linearly decrease DM solubility. The authors reported that the soluble fraction of NDF and ADF decreased linearly with fungicide applications.

Kalebich (2016) fed cows WPCS from corn plants with 0, 1, 2, or 3 applications of fungicide. Treatments were as follows: control (CON), WPCS with no application of foliar fungicide; treatment 1 (V5), WPCS received one application of pyraclostrobin and fluxapyroxad (PYR+FLUX) foliar fungicide at corn vegetative stage 5 (V5; when the emergence of the fifth leaf is visible); treatment 2 (V5/V8), WPCS received one application of PYR+FLUX at corn stage V5 plus another application of PYR+FLUX at corn stage vegetative stage 8 (V8; when the emergence of the eighth leaf is visible); and treatment 3 (V5/V8/R1), WPCS received one application of PYR+FLUX at corn stage V5, one application of PYR+FLUX at corn stage V8, plus a third application of pyraclostrobin and metconazole (PYR+MET) foliar fungicide at corn stage reproductive stage 1 (R1; when the silks are fully extended). No differences in DMI, milk yield, or feed efficiency were reported among treatments. However, cows in V5 compared with cows in V5/V8 tended to produce more 3.5% FCM (32.42 and 28.58 kg/d, respectively) and ECM (31.35 and 27.76 kg/d, respectively). Furthermore, concentration of milk lactose tended to be greater for cows fed WPCS treated with foliar fungicide when compared with CON (4.63, 4.77, 4.76, and 4.72% for CON, V5, V5/V8, and V5/V8/R1, respectively). The authors hypothesized that WPCS from corn plants with fungicide application may improve the digestibility compared with untreated WPCS (Kalebich, 2016).

As a follow-up study to evaluate the effects of fungicide on fermentation and composition of WPCS, Kalebich et al. (2017a) prepared 0.9-kg laboratory silos of treatment chopped corn plants material. Fungicide applications on corn plants during the summer of 2015 were as follows: control (CON), corn plants received no foliar fungicide application; treatment 1 (V5), where corn plants received a mixture of pyraclostrobin and fluxapyroxad (PYR+FLUX) foliar fungicide at V5; treatment 2 (V5+R1), where corn plants received 2 applications of foliar fungicide, a mixture of PYR+FLUX at V5 and a mixture of pyraclostrobin + metconazole (PYR+MET) foliar fungicide at corn reproductive stage 1 (R1); treatment 3 (R1), in which corn

plants received one application of PYR+MET foliar fungicide at R1. Fungicide-treated WPCS had decreased DM (33.5, 31.9, 31.5, and 31.7% of DM for CON, V5, V5+R1, and R1, respectively) but increased CP (8.1, 8.5, 8.2, and 8.7% of DM for CON, V5, V5+R1, and R1, respectively), water-soluble carbohydrates (3.8, 4.0, 4.6, and 5.2% of DM for CON, V5, V5+R1, and R1, respectively), and lactic acid concentration (4.65, 5.01, 5.09, and 5.50% of DM for CON, V5, V5+R1, and R1, respectively). Whole-plant corn silage in R1 had a lower lignin concentration (2.4, 2.4, 2.6, and 2.0% of DM for CON, V5, V5+R1, and R1, respectively), and WPCS in V5 had more kilograms of milk per tonne of DM (1,511, 1,631, 1,585, and 1,576 kg/t of DM for CON, V5, V5+R1, and R1, respectively). Whole-plant corn silage from corn plants with fungicide application may enhance the nutritive and fermentative profile for ruminants (Kalebich et al., 2017a).

Hollis et al. (2019) collected fresh-cut WPCS at harvest and sealed it inside mini silos (0, 30, 90, and 150 d ensiled). Whole-plant corn silage in CON resulted in greater DM and DM yield than WPCS from corn plants treated with fungicide (FUN). Interestingly, on an as-fed basis, corn plants treated with FUN tended to yield more WPCS than CON with 63,634 and 60,488 ± 1,533 kg/ha, respectively. A variety-by-treatment interaction was observed for kernel vitreousness score with scores of 3.23, 2.99, 2.49, and 2.80 ± 0.14 for BMR/CON, BMR/FUN, FLY/CON, and FLY/FUN, respectively. The BMR corn plants treated with FUN and ensiled for 90 to 150 d seemed to be the best WPCS for feeding dairy cows due to its potential to be converted into milk (Milk2006; Shaver et al., 2006).

Most recently, Damery (2018) reported that fungicide application had no effect on BMR WPCS DM, gross yield, or DM yield, but ensiled in mini silos over time (90 d), fungicide-treated corn plants had increased VFA scores, lactic acid, acetic acid, and total acid concentrations compared with BMR corn plants not treated with fungicide (CON). It seemed that foliar fungicide application on BMR corn created a better fermentation environment for corn plants ensiled as WPCS, as fungicide-treated corn plants ensiled over time had higher VFA scores, lactic acid, acetic acid, and total acid concentrations. Data for WPCS from all published experiments completed in our group were evaluated using Milk2006 (Shaver et al., 2006) and summarized in Table 3 and Figure 1.

Mycotoxin and Fungicides. Fungicides have been tested for preventing fungal colonization and mycotoxin contamination in cereal grains. Results of studies have been conflicting in their ability to control mycotoxin concentration within crops. Authors reported mycotoxin presence in WPCS samples without visual observation of fungus noted in the corn plants in the field (Haerr, 2015). Interestingly, a study done by Eckard et al. (2011) concluded that when corn plants were diagnosed visually, only 1 to 3% of corn plants showed signs of infection on the surface; however, when the corn particles were plated, it was found that the average *Fusarium* incidence was 46%. Corn plants harvested by Haerr et al. (2015; Haerr, 2015) could have been infected, even though visual symptoms were not present. Applications of metconazole and tebuconazole, another active ingredient of fungicide, reduced concentrations of DON mycotoxin and head blight in winter wheat more than applications of azoxystrobin, another active ingredient (Edwards et al., 2001). However, researchers hypothesized fungicides act as an additional stress factor for the fungus and stimulate mycotoxins as a defense mechanism (Magan et al., 2002).

Some toxigenic fungal species that may affect plants before and after harvest are *Penicillium nordicum* and *Penicillium verrucosum* (Schmidt-Heydt et al., 2013). These penicillia are able to produce the mycotoxins ochratoxin and citrinin (Schmidt-Heydt et al., 2013). Both toxins have polyketide backbones and are structurally highly related. Ochratoxin A as well as citrinin are mainly nephrotoxic and hepatotoxic and may act synergistically (Braunberg et al., 1994). For ochratoxin A, which is rated as a class B carcinogen, regulatory limits have been set in several countries. The level of citrinin is not currently regulated. *Penicillium verrucosum* adapts its secondary metabolite profile depending on the environmental conditions (Schmidt-Heydt et al., 2012). For example, oxidative stress usually induces defensive reactions such as radical scavenging mechanisms for reactive oxygen species. Schmidt-Heydt et al. (2013) reported that the biosynthesis of the mycotoxins ochratoxin A/B and citrinin were strongly induced when grown on malt extract glucose agar medium supplemented with the fungicide Rovral (Bayer Crop Science).

Fungal contamination of WPCS can lead to DM loss, nutrient loss, and reduced palatability (Alonso et al., 2013). Foliar pathogens decrease the area of photosynthetic tissue, which reduces the transfer of assimilates to grain production by diverting assimilates to fungal growth, defense systems, and increased respiration (Agrios, 1997). Whitlock et al. (2000) reported that feeding spoiled WPCS from the surface of a bunker silo depressed nutrient digestibility and DMI of steers. Gerlach et al. (2013) fed spoiling silage to goats and reported negative correlations between ethyl-lactate and ethanol with DMI, but the strongest negative relationship with intake was from silage temperature. Application of fungicide in corn plants does not seem to have any effect on reducing molds responsible for WPCS aerobic deterioration (Blonde and Esker, 2008; Haerr et al., 2015; Kalebich et al., 2017a). A variety of mycotoxins produced from fungi can be found in silages that are fed to dairy cattle (Driehuis et al., 2008). Their presence is undesirable because they have the potential to induce negative effects on the health of animals (Adesogan, 2006). Mycotoxins can accumulate on the plant in the field before harvest (Doerr, 2010), during storage, or during processing or feeding (Whitlow and Hagler, 2008). Korosteleva et al. (2009) reported that *Fusarium* mycotoxins decreased some cellular aspects of immune function in dairy cattle, while stimulating primary humoral

Table 3. Experiments [whole-plant corn silage (WPCS) sample no.] from which data were used to examine the association of WPCS nutritional value with potential for milk production

WPCS sample no.[1]	Year of harvest	Corn hybrid[2]	Treatment[3]	Foliar disease,[4] %	DM, %	DM yield, t/ha	NDFD30,[5] % NDF	Reference[6]
1	2013	Conventional	FUNV5	0	30.98	16.77	49.67	Haerr et al., 2015
2	2013	Conventional	FUN2X	0	34.41	19.98	49	Haerr et al., 2015
3	2013	Conventional	FUN3X	0	30.37	16.85	48.82	Haerr et al., 2015
4	2013	Conventional	CON	0	30.63	16.99	50.09	Haerr et al., 2015
5	2014	Conventional	CON	0	31.98	21.97	51.8	Kalebich, 2016
6	2014	Conventional	FUNV5	0	31.92	22.03	53	Kalebich, 2016
7	2014	Conventional	FUNV5V8	0	31.14	21.72	49.2	Kalebich, 2016
8	2014	Conventional	FUNV5V8R1	0	31.84	22.41	51.2	Kalebich, 2016
9	2015	Conventional	CON	19	33.5	23.69	47	Kalebich et al., 2017a
10	2015	Conventional	FUNV5	21	31.9	24.01	48.3	Kalebich et al., 2017a
11	2015	Conventional	FUNV5R1	3.44	31.5	23.22	49.3	Kalebich et al., 2017a
12	2015	Conventional	FUNR1	1.63	31.7	23.83	50.5	Kalebich et al., 2017a
13	2016	BMR	CON	20	32.1	18.85	59.3	Hollis et al., 2019
14	2016	BMR	FUNR1	5	30.7	18.92	60	Hollis et al., 2019
15	2016	Floury	CON	19	33.5	19.01	47.8	Hollis et al., 2019
16	2016	Floury	FUNR1	5.25	33.5	20.55	49.1	Hollis et al., 2019
17	2017	BMR	CONLC	1.62	34.2	13.74	54	Damery, 2018
18	2017	BMR	FUNV5LC	1.07	32.5	12.37	55.9	Damery, 2018
19	2017	BMR	FUNV5R1LC	1.23	32.7	12.10	54	Damery, 2018
20	2017	BMR	FUNR1LC	1.48	32.7	12.04	53.8	Damery, 2018
21	2017	BMR	CONHC	1.62	35.1	12.44	56.8	Damery, 2018
22	2017	BMR	FUNV5HC	1.07	33.2	11.68	56.1	Damery, 2018
23	2017	BMR	FUNV5R1HC	1.23	33.5	11.43	60.5	Damery, 2018
24	2017	BMR	FUNR1HC	1.48	34	11.63	58.5	Damery, 2018

[1]Whole-plant corn silage sample from a determined experiment.

[2]BMR = brown midrib.

[3]Experimental treatment applied to corn plants. FUNV5 = fungicide applied at corn-plant stage of growth V5 (vegetative stage 5); FUN2X = fungicide applied at corn-plant stages of growth V5 and R1 (any silk visible on the cob); FUN3X = fungicide applied at corn-plant stages of growth V5, R1, and R3 (kernels are yellow with milky white fluid); CON = no application of fungicide; FUNV5V8 = fungicide applied at corn-plant stages of growth V5 and V8 (vegetative stage 8); FUNV5V8R1 = fungicide applied at corn-plant stages of growth V5, V8, and R1; FUNV5R1 = fungicide applied at corn-plant stages of growth V5 and R1; FUNR1 = fungicide applied at corn-plant stage of growth R1; CONLC = no application of fungicide and corn plant chopped at 30.5 cm (low cut; 12 in) from the soil; FUNV5LC = fungicide applied at corn-plant stage of growth V5 and corn plant chopped at 30.5 cm (low cut; 12 in) from the soil; FUNV5R1LC = fungicide applied at corn-plant stages of growth V5 and R1 and corn plant chopped at 30.5 cm (low cut; 12 in) from the soil; FUNR1LC = fungicide applied at corn-plant stage of growth R1 and corn plant chopped at 30.5 cm (low cut; 12 in) from the soil; CONHC = no application of fungicide and corn plant chopped at 55.9 cm (high cut; 22 in) from the soil; FUNV5HC = fungicide applied at corn-plant stage of growth V5 and corn plant chopped at 55.9 cm (high cut; 22 in) from the soil; FUNV5R1HC = fungicide applied at corn-plant stages of growth V5 and R1 and corn plant chopped at 55.9 cm (high cut; 22 in) from the soil; FUNR1HC = fungicide applied at corn-plant stage of growth R1 and corn plant chopped at 55.9 cm (high cut; 22 in) from the soil.

[4]Disease evaluations were conducted before each fungicide treatment and before harvest. Ten random plants from each of the plots were evaluated. The same evaluator conducted all evaluations to minimize error.

[5]A 30-h in vitro digestion of NDF was conducted in buffered rumen fluid (NDFD30) using procedures described in detail by Kruse et al. (2010) and Coblentz et al. (2017) using the Ankom Daisy batch culture system.

[6]Reference for complete description of the experimental design and treatments.

response to specific antigens. The authors concluded that feeding of contaminated materials to dairy cows should be minimized. Recently, Ferrero et al. (2019) demonstrated that improved WPCS aerobic stability (due to the inoculation of the chopped corn plant with *Lactobacillus buchneri*, *Lactobacillus hilgardii*, or both) reduced the risk of *A. flavus* outgrowth and aflatoxin production after WPCS opening. Nonetheless, Charmley et al. (1993) reported that the inclusion of the mycotoxin DON in the diet of primiparous dairy cows yielding 20 to 25 kg/d milk, at up to 6 mg/kg of total diet DM over a 10-wk period, had no effect on volume of milk produced.

Practical Economical Considerations. Paul et al. (2011) calculated a 10-yr average corn grain price of \$0.12/kg (\$2.97/bushel) and application costs of \$40 to \$95/ha and showed that the probability of failing to recover the fungicide application cost (P_{loss}) for disease severity less than 5% was 0.55 to 0.98 for pyraclostrobin. However, when disease severity was greater than 5%, the corresponding probability was 0.36 to 0.95. They concluded that the high P_{loss} values found in most scenarios suggest that the use of these foliar fungicides is unlikely to be profitable when foliar disease severity is low and grain yield expectation is high (Paul et al., 2011).

However, some value may be returned to producers by increasing the efficiency of converting feed to milk when feeding feedstuffs with fungicide application in the field to dairy. The section below will discuss data reported by Haerr (2015) but in an economic analysis. The total income from milk yield over feed costs was \$7.35, \$7.54, \$8.31, and \$7.83 for 0, 1, 2, or 3 applications of fungicide, respectively. Therefore, it seems cows fed WPCS from corn plants with fungicide treatment were more profitable than cows fed WPCS with no treatment. Additionally, even though the authors reported a positive linear effect for the number of fungicide applications and feed efficiency, the income over feed cost was not enough to offset the cost of a third fungicide application (~\$30.00).

On-Farm Evaluation. Evaluating current on-farm practices and relaying those practices to the public is of paramount importance. Illinois dairy farms were evaluated in 2016 regarding corn plants fungal and toxin contamination in the field to understand how those issues are combated on farm along with management practices (Weatherly, 2018). The survey was initially distributed to every dairy farmer on file (n = 635) as reported by the Illinois

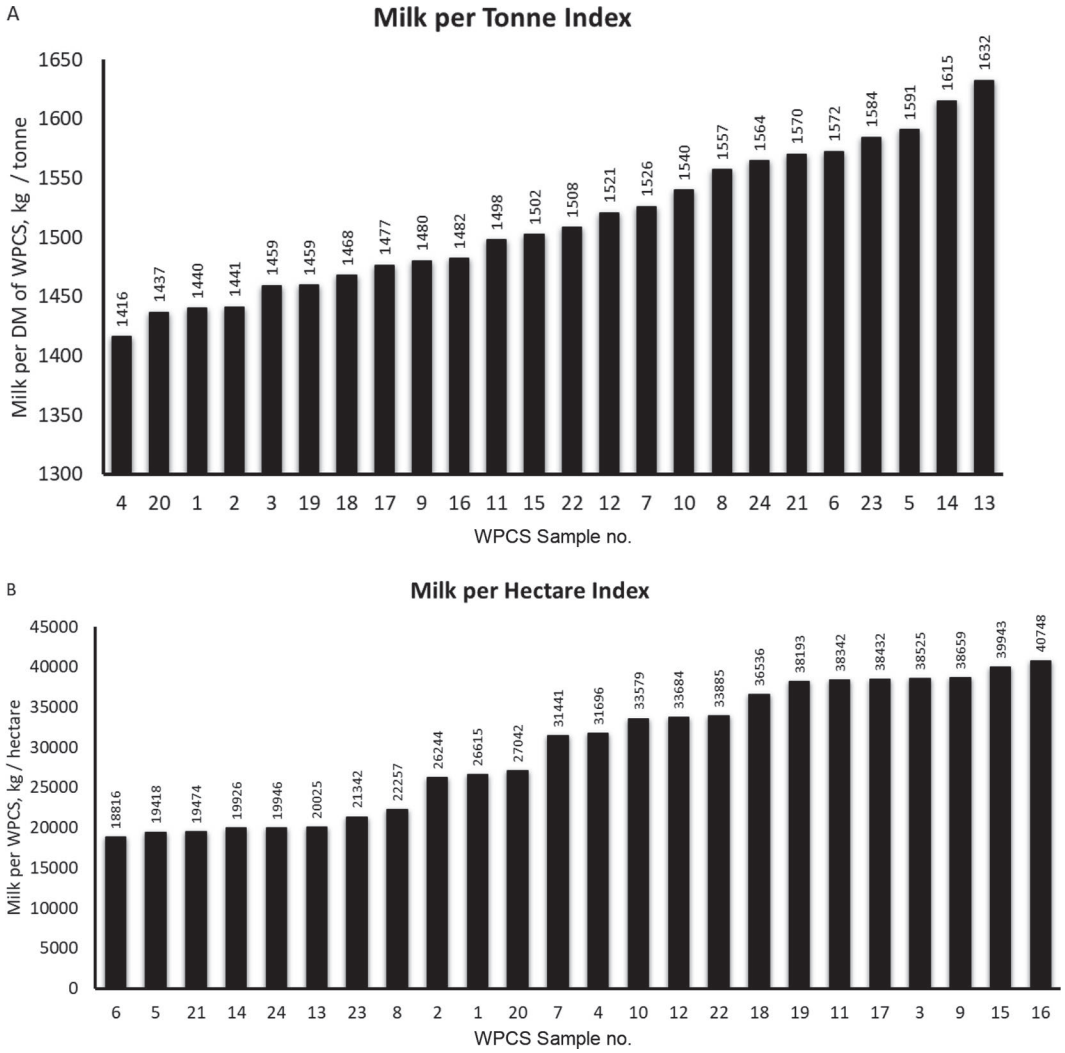

Figure 1. (A) Whole-plant corn silage (WPCS) from different experiments (WPCS sample no.) indicated in Table 3 from which data were used in Milk2006 (Shaver et al., 2006) to examine the association of WPCS nutritional value with potential for milk (kg) per tonne of WPCS DM. (B) Whole-plant corn silage from different experiments (WPCS sample no.) indicated in Table 3 from which data were used in Milk2006 (Shaver et al., 2006) to examine the association of WPCS nutritional value with potential for milk (kg) per hectare of corn plant harvested.

Milk Producers' Association by way of mail on September 7, 2016, with an overall 22.7% return rate (n = 135). Not surprisingly, 58% of the respondents included WPCS between 30 to 60% in the lactation diet (% of DM) of their herd. Interestingly enough, 46% of the respondents did not scout or apply fungicide on corn plants for WPCS and 51% of the respondents had WPCS ensiled for no longer than 49 d (Weatherly, 2018).

APPLICATIONS

It is well known that responsible applications of foliar fungicide on corn plants assist in limiting devastating losses in yield. Cows fed WPCS from corn plants with fungicide application improved feed efficiency and were more profitable than cows fed WPCS with no fungicide application. Whole-plant corn silage from corn plants with fungicide application reduced the fiber concentration and, therefore, improved its nutritive value. Additionally, corn plants treated with fungicide had an improved fermentation process during ensiling due to higher concentrations of lactic acid and sugar when compared with untreated corn plants. More research is needed to understand how fungus diversity and soil microbiology are affected by fungicide application. Cows around parturition (transition period) could potentially receive more benefit from WPCS from corn plants treated with fungicide than mid-lactating cows. However, the aforementioned hypothesis is still to be tested. Overall, fungicide application seems to be maximized when converted into feed (e.g., WPCS) and fed to dairy cattle.

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