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EFFECTS OF VEGETATIVE WINDBREAKS ON DISPERSAL OF HIGHLY PATHOGENIC AVIAN INFLUENZA- A REVIEW OF LITERATURE

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ABSTRACT

Windbreaks have been used in agricultural settings to provide protection from the wind for homesteads, livestock and crops, to reduce soil erosion and blowing snow, provide wildlife habitat, enhance aesthetics in agricultural landscapes, and to help mitigate dust and odor around swine and poultry facilities. By reducing wind speed and physically intercepting dust, particulate matter and even odors, windbreaks can prevent harmful or nuisance material from moving downwind. How well windbreaks serve this function depends on a range of factors including windbreak size, species composition and location on the landscape. This raises the question of whether windbreaks might also be useful to help slow or prevent the spread of infectious diseases, particularly in light of an economically devastating 2014-15 outbreak of highly pathogenic avian influenza (HPAI) among commercial poultry flocks in North America. Although HPAI can be transmitted via large droplets, aerosols and direct contact, it is the latter two that are most likely to lead to transition between poultry barns or farms since droplet transmission requires close physical proximity between subjects. Both aerosol and contact transmission can be affected by wind movement, and therefore might be affected by vegetative windbreaks. Limited empirical research has demonstrated that older windbreaks may have more potential to disrupt the airborne transmission of viruses than younger windbreaks. Given the dearth of empirical research on associations between windbreaks and avian influenza, further study is warranted.

INTRODUCTION

Windbreaks, also known as vegetative environmental buffers (VEB) or shelterbelts are a common feature of agricultural systems around the world. These strips of trees, shrubs and other perennial or annual vegetation provide protection from the wind for homesteads, livestock and crops, reduce soil erosion and blowing snow, provide wildlife habitat and enhance aesthetics in agricultural landscapes (Brandle, Hoges & Zhou, 2004). More recently, windbreaks have been used to help mitigate dust and odor around swine and poultry facilities (Adrizal et al., 2008; Burley et al., 2011; Lin et al., 2006; Colletti, Hoff, Thompson and Tyndall, 2006; Malone, 2004; Malone, VanWicklen, Collier & Hansen, 2006; Tyndall & Colletti, 2007a; Tyndall & Colletti, 2007b; Tyndall, 2008; Ullman, Mukhtar, Lacey & Carey, 2004).

The ability of windbreaks to intercept or slow down particles as they move through the air raises questions about whether they may also be able to reduce the spread of airborne diseases. In the Midwest, this question took on new relevance following an epidemic of highly pathogenic avian influenza (HPAI) in commercial poultry flocks in 2014 (Shriner et al, 2016). This review will explore the potential of windbreaks to help prevent the spread of avian influenza virus (AIV).

WINDBREAKS ON THE LANDSCAPE

To understand the potential for windbreaks to disrupt disease transmission, it is first important to understand how they function on the landscape. The primary purpose of windbreaks in agricultural settings is to reduce wind speed (Brandle, et al., 2004; Tyndall & Colletti, 2007a). Both the internal and external structure of windbreaks affect the relationship to wind and wind speed.

Internal structure is typically defined by porosity, the ratio of perforated area to total area, and this is what allows air to move through windbreaks (Heisler & Dewalle, 1988; Tyndall & Colletti, 2007a). The greatest wind speed reduction over the greatest distance is achieved with a porosity of 40%-60% (Tyndall & Colletti, 2007a).

The external structure includes such characteristics as the height and length of the windbreak, number of rows, species, windbreak shape, angle to the wind, placement on the landscape and how the windbreak is managed. With regard to external structure, the factor that appears to have the most significant impact on wind speed is the height. Wind speeds on the leeward side of a windbreak are reduced in proportion to the height, typically for a horizontal distance between 10 and 30 times the height of the windbreak (Brandle et al., 2004; Ullman et al., 2004).

For an average tree windbreak, the wind velocity reduction within a horizontal distance of 10 times the height can be between 60% and 80%, and reduces to about a 20% reduction at a horizontal distance of 20 times the height (Nordstrom & Hotta, 2004). On the windward side, wind speed is also reduced beginning at a horizontal distance between 2 and 5 times the height ahead of the windbreak as air is forced upward and over the structure (Heisler & Dewalle, 1988).

Windbreak continuity is important as well. Any gaps in a windbreak can act like a funnel, creating higher velocity winds on the leeward side of the gap in the windbreak than on the windward side (Heisler & Dewalle, 1988; Brandle et al., 2004).

CAN WINDBREAKS AFFECT THE SPREAD OF VIRUSES?

The ability of windbreaks to trap not only dust and particulates but odors as well has inspired questions about whether they can prevent the spread of airborne diseases between commercial poultry and livestock operations.

Windbreaks are already used in citrus orchards to prevent the spread of citrus canker bacteria. Infections are primarily caused when windblown rain or rain splash force the bacteria into leaf and fruit tissue which is most likely to occur in winds of 18-20 mph. As windbreaks slow wind speed, they also reduce both the likelihood and severity of citrus canker infection outbreaks. They are considered one of the primary means of control for citrus canker in orchards (Dewdney & Graham, 2014; Gottwald & Timmer, 1995).

The use of vegetative windbreaks to control bacterial citrus canker demonstrates that disease prevention and control are potential benefits of windbreaks in agricultural landscapes. There does not appear to be evidence that windbreaks have been adopted for disease control in many other agricultural contexts at this time. The remainder of this review will focus on whether windbreaks could help reduce the likelihood or severity of AIV outbreaks. To understand this potential, it is important to know first how the disease spreads and how the virus likely responds to ambient environmental conditions.

AIRBORNE TRANSMISSION

Airborne transmission often refers to aerosols, tiny airborne droplets, also known as droplet nuclei that are suspended in the air and can be inhaled, spreading the virus (Burley et al, 2011, Weber & Stilianakis, 2008). They differ from larger droplets which cannot be inhaled and are responsible for droplet transmission. There is no clear and agreed upon cutoff point between droplets or droplet nuclei that can be classified as aerosols and those that can't, although distinctions are often made at 5 or 10 micron (μm) diameter size. Larger droplets settle out of the air relatively quickly while smaller particles can remain airborne. A 10 μm particle can settle out of the air from a height of 1.5 meters in about 8 minutes, and settling time drops rapidly as droplet size increases. Droplets that are larger than 100 μm in diameter are not inhalable and take just seconds to settle out of the air (Weber & Stilianakis, 2008).

If the H5 strain of HPAI that spread in 2014-15 was similar to other avian influenza viruses then it is likely that some airborne transmission occurred, though it has neither been confirmed or disproven (APHIS, USDA, 2015). Influenza virus can spread via aerosols, but a number of studies and reviews of transmission indicate that the aerosol pathway for infection is not adequate to explain all transmission (Hanley & Borup, 2010; Tellier, 2006; Weber & Stilianakis, 2008; Zhong et al., 2014; Burley et al., 2011). When AIV becomes airborne, infected birds can expel tiny droplets that remain suspended as aerosols in the air of a poultry barn for several hours (Burley et al., 2011; Weber & Stilianakis, 2008).

It is somewhat unclear how long aerosolized viruses can survive in outdoor conditions that would facilitate airborne transmission between barns or farms. Weber and Stilianakis (2008) reviewed research on influenza viruses in the environment and found evidence that AIV is capable of persisting in an airborne state for 24-36 hours though the majority of studies on influenza virus transmission focus in indoor environments. Most influenza in the outdoor environment appears to be somewhat shorter-lived in comparison; the degree of difference in survival is unknown. Exposure to airborne pollutants, desiccation, ozone and UV radiation from sunlight can significantly shorten the infective lifespan of the virus. However, Weber and Stilianakis (2008) also suggest that when the virus is regularly replenished, by a source such as poultry barn emission fans, even short survival times might be enough to facilitate transmission.

Ambient temperature and relative humidity (RH) may also affect how long an aerosolized virus remains viable as an airborne pathogen (Burley et al., 2011; Lopez, McFarlane & Scott, 2006; Lowen, Mubareka, Steel, & Palese, 2007). For humans, the influenza virus appears most infective at RH 20%-40%, and 60%-80% and significantly less infective at greater than 80% RH, though this data is based on a study of indoor air conditions (Hanley & Borup, 2010). Other studies indicate that as RH increases, rates of infection decline for both AIV (Weber & Stilianakis, 2008), and infectious bronchial virus (Lopez et al., 2006). Lower temperatures also appear to support influenza virus survival better than high temperatures, although both this and the RH findings are complicated by research in tropical regions. One, as yet unproven, theory posits that lower RH and lower temperature facilitate airborne transmission because larger droplets are more likely to settle out of the air at higher humidity and remain viable for contact infection, and contact transmission may not be affected by RH or humidity (Weber & Stilianakis, 2008).

Airborne transmission, then, appears to also facilitate some contact transmission. Viral diseases, just like bacterial and fungal diseases, can travel on wind borne soils (Brandle et al., 2004; Burley et al., 2011; Jonges et al., 2015). As a result, dust and particulate matter may be an important mode of dispersal for disease (Burley et al., 2011). These windborne particles can carry both aerosolized virus, and small amounts of potentially infectious fecal matter and so can contribute to both aerosol and contact transmission (Weber & Stilianakis, 2008).

This infection route appears possible in the 2015 outbreaks where ongoing USDA (APHIS, USDA, 2015) studies indicate a connection between wind, aerosols, and some infections. In plume studies of wind speed, direction, and aerosolized virus transmission, there appears to be a slight link between being downwind of an infected farm and contracting the virus, though proximity appears to play a bigger role than actual wind speed or direction in determining likelihood of infection. When farms were exposed to prolonged or multiple plumes of wind and aerosols over the course of 6-11 days, they were more likely to see infection develop 5-7 days later. The data and results make it impossible to confirm or rule out the role of aerosolized transmission. There may also have been a link between dust and infection. HPAI virus was detected in the air up to 1,000 meters from infected farms, making it possible that driving or walking across the ground where dust particles carrying the virus have settled could contribute to its spread. Lending credence to the possibility of some airborne dispersal, the virus was found in several air samples both inside and outside infected poultry barns. Positive virus samples were associated with particles in all size ranges from .01 µm up to 10 µm and many environmental surfaces were also found to be contaminated. Despite the evidence to support some airborne transmission, the researchers argue that it is clear airborne transmission alone does not account for all of the dispersal of the virus (APHIS, USDA, 2015).

ROLE OF WINDBREAKS IN INFLUENZA DISPERSAL

Given that windbreaks have been shown to reduce the flow of dust and particulate matter, and to slightly reduce odor in emissions from poultry barns, it is reasonable to assume they could help reduce the airborne dispersal of both contaminated dust and aerosols. Despite this potential, few studies have directly explored the relationship between windbreaks and virus transmission.

Only one study appears to have empirically examined whether the dispersal of airborne viruses affecting poultry or livestock can be affected by vegetative buffers. Burley et al. (2011) tested whether vegetative windbreaks could reduce the spread of Newcastle disease virus and infectious bronchial virus (IBV). Their experiment began with establishing new 4-row buffers containing a mix of species and vegetation types downwind of emission fans on 3 of 6 poultry barns. Virus-free chickens were then placed in coops downwind from all 6 emission fans. In a series of three trials, beginning in the year of establishment, they sampled for dust and particulate matter, as well as signs of the viruses. Surprisingly, they found no evidence that the buffers reduced dust or particulate matter, although this may have been the result of experimental design which did not account for the creation of dust by the birds in the downwind coops. They also saw no evidence of either virus in dust or foliage samples, though they posit this may be because viruses trapped on windbreaks and exposed to environmental elements deactivate rapidly. It was not until the final trial in the third year that the authors found evidence that windbreaks reduced transmission of either virus. In this last trial, there was a significant reduction in transmission of IBV and the authors speculate that the greater size, maturity, and associated density of the vegetative buffers contributed to this result. Therefore, it seems possible the external and internal structure of windbreaks are essential n determining whether and to what degree they can reduce disease transmission.

Schofield, L., Ho, J., Kournikakis, B., & Booth (2005) did not examine the role of windbreaks, but they did attempt to assess whether aerosolized transmission was occurring during an LPAI infection event in the Fraser Valley of British Columbia. They found that when emission fans were directed into the wind, the air particles exiting the barn were often forced upward and in some cases, over or even back into the barn. In these cases, any aerosolized, infectious plumes did not reach the ground where their sampling equipment was located. And, the concentrations of circulating virus, if there were any, at 75-100 meters from the barns, were too low to be picked up by slit samplers. They did, however, collect a positive LPAI sample in an open field 800 meters away from an infected barn. Some of their observations suggest that placement of buildings and windbreaks, in addition to the angle of emission fans can affect the way plumes exit and move away from, or recirculation around the fan and barn. Their work demonstrates the importance of understanding plume movements leaving poultry barns.

The dearth of studies addressing windbreaks and virus transmission is surprising given the evidence that windbreaks reduce a number of other windborne nuisances. With limited empirical evidence to demonstrate the effects of windbreaks on virus transmission, further research is both needed and warranted.

IMPLICATIONS FOR FUTURE RESEARCH

Airborne transmission of aerosolized HPAI and contaminated dust appears likely to have at least contributed to the 2015 outbreak but whether windbreaks played any role is still unclear. Although studies demonstrating the ability of windbreaks to capture and remove airborne particles from the air suggest that windbreaks would most likely work to reduce disease transmission, there is also a possibility that they could facilitate transmission under particular conditions.

Influenza viruses broadly tend to thrive in relatively dry conditions and cooler temperatures. By increasing humidity and temperature in their immediate vicinity (Brandle et al., 2004), and reducing air speed, windbreaks could help contribute to virus deactivation by creating a less hospitable environment. And by creating conditions of higher humidity, windbreaks may contribute to infectious droplets, dust and aerosols settling more quickly out of the air. Whether this would have a positive or negative impact on disease transmission may depend on the surfaces the virus settles onto and whether the settled particles are exposed to desiccating winds, particularly on the windward side of a windbreak, or to UV radiation. Tyndall and Colletti (2007a) have shown that windbreaks absorb more airborne odor and particulate matter in warmer and more humid conditions, so the combination of ambient and windbreak-generated environmental conditions is likely to play a role. Further, it may be worth exploring whether windbreaks can affect ambient RH and temperatures within poultry barns enough to influence viral survival in the indoor environment.

The interaction of feathers and windbreaks poses some interesting questions. Windbreaks often collect feathers, especially if they are fairly dense near the ground and feathers are one of the few porous substances that can sustain viable virus for long periods of time. Do those trapped feathers contribute to the spread of AIV? Can feathers caught in a windbreak become dislodged and serve as fomites themselves? How easily could a contaminated feather facilitate mechanical transmission by transferring viable virus to farm workers' boots, equipment, vehicles or synanthropic species who then transfer the disease to a barn? Is a windbreak that contains many feathers and is positioned to intercept an infectious plume more likely to trap and reduce the spread of the virus, or to enhance transmission?

The relationship between windbreaks, synanthropic and wild species is similarly unclear. There does not appear to be a clear link between the presence of windbreaks and an increased likelihood that synanthropic species contribute to disease dispersal, but the relationship may be worth examining. Testing of several synanthropic species showed that European starlings, American robins, sparrows, rock pigeons, common grackles and mice had all been exposed to the virus during the recent outbreak, but there are questions about whether they actively shed the virus, though regardless, they could certainly contribute to mechanical distribution (Shriner et al., 2016; Grear et al., 2016, Brown et al., 2009). Almost all of these species have been observed using windbreaks, but many have been observed on farms without windbreaks as well (Burns et al., 2012). Perhaps importantly, as windbreaks age, they also attract a broader range of species (Johnson & Beck, 1998). Birds and mice are not the only species with the potential to spread HPAI. Other rodents, insects, and even larger mammals may contribute to the spread (Perkins & Swayne, 2003; Olsen et al., 2006; Wanaratana, Panyim, Pakpinyo, 2011; Shriner et al., 2016; Shriner et al., 2012; Barbazan et al., 2008; Sawabe et al., 2006; Sawabe et al., 2011; Grear, Dusek, Walsh, & Hall, 2016), and may find food, shelter, or other benefits in windbreaks. So, if mature windbreaks are beneficial for interrupting the windborne spread of HPAI, it will be important to be mindful of the unintended effect they may have on wildlife.

A windbreak's age may be a critical factor in whether and how it affects disease transmission. Burley et al.'s (2011) experiment with windbreaks and virus transmission demonstrated a potential link between windbreak maturity and viral transmission reduction. This is consistent with other assessments that older windbreaks are more effective at capturing dust, particulate matter and odor (Tyndall & Colletti, 2007a). If it is true that older windbreaks are more likely to reduce disease transmission, it will be important to account for this relationship in future empirical studies. It will also be important to understand what causes this effect. Greater windbreak maturity is correlated with greater species complexity (Johnson & Beck, 1988). It is possible that the associated complexity of vegetative textures contributes to greater efficiency in reducing odor and particulates. Or perhaps the effect is related to decreased porosity in older windbreaks. Understanding what aspects of older windbreaks makes them more effective could lead to management recommendations that ultimately enhance windbreak effectiveness as early as possible.

Species composition may also play a role in reducing disease transmission, though this has not been tested. Conifers and hybrid willow have been shown to be more effective at trapping dust and particulate matter, while deciduous trees are better at trapping ammonia (Adrizal et al., 2008). Hybrid willow appears to have the most all around potential for trapping odor, dust and particulate matter and so may be worth including in future tests of windbreaks and disease transmission.

The size and location of windbreaks are also likely to affect disease transmission. A windbreak must be tall and wide enough to intercept a plume carrying infectious material in order to disrupt transmission. Just how tall and wide they need to be will likely depend on the source of airborne virus. When a plume exits an exhaust fan, it is concentrated, but quickly disperses as it moves out into the landscape (Schofield et al., 2005). If the combination of wind, exhaust fan placement and angle, and windbreak structures simply diverts a plume of infectious air upwards, it may lead to dilution, but might not allow the airborne pathogens to be physically intercepted or trapped. In cases where the placement of physical structures, including windbreaks, causes recirculation of air (Heisler & Dewalle, 1988) or forces air back into the barns (Schofield et al., 2005), it is worth asking whether this could lead to a concentration of viral pathogens in and near poultry barns, and whether this might increase the likelihood or severity of an outbreak. Windbreaks are also most effective at reducing wind speeds when they are perpendicular to the wind, and it is plausible that a perpendicular angle could be important for disrupting disease transmission as well.

CONCLUSIONS

The effectiveness of windbreaks to reduce emissions from poultry barns (typically odor, dust, particulate matter and other aerosols), appears highly site and context specific. It stands to reason, then, that the ability of buffers to mitigate disease dispersal would also be highly contextual. Factors likely to impact effectiveness include windbreak age, porosity, height, species, angle to the wind, the wind's velocity and where along a windbreak travelling plumes are actually intercepted. There may be parameters related to HPAI or particular strains of HPAI that could affect this process as well. Currently, there is insufficient data to determine whether and when windbreaks will be most effective. Therefore, conducting tests in a variety of conditions will be important to understand whether, under what conditions, and to what degree vegetative windbreaks effect the spread of AIV.

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