Revisiting the management and epidemiology of common bunt (*Tilletia tritici* and *Tilletia laevis*) of wheat in Kansas

by

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Abstract

Common bunt (caused by *Tilletia tritici* and *Tilletia laevis*) is an economically important disease of wheat, resulting in both yield and grain quality losses. Historically, common bunt has been managed effectively by modern fungicide seed treatments. However, a recent rise in the disease's prevalence in Kansas has necessitated a reevaluation of current management recommendations. Current recommendations include preventative seed management practices such as purchasing certified seed and applying a fungicide seed treatment, as well as sowing into warmer soil temperatures to avoid infection. To establish a baseline understanding of producer wheat seed management habits and the prevalence of common bunt in Kansas, a survey was disseminated to growers at several K-State Research and Extension events. The survey instrument collected information on grower demographics, common bunt experiences, seed management practices, and extension information preferences. Survey findings report that, while producers frequently purchase certified seed, the overall percentage of their operation planted with certified seed is low, suggesting supplementation of certified seed with other sources such as saved seed. Over half of respondents reported saving a portion of their seed from a previous season, while only approximately a third reported treating that seed with a fungicide seed treatment. The survey indicated that factors such as grain price, cost of treatment, and past disease pressure influenced a grower's decision to use a seed treatment. Past reports of common bunt experiences in conjunction with local discount schedules provide further evidence for the prevalence of common bunt in the region. To improve planting date recommendations, field experiments were conducted at three locations to evaluate the influence of weather conditions at planting on common bunt infection. Air and soil weather data were collected from soil sensors, HOBO Micro Stations, and Mesonet weather stations were used to create predictors for four fixed-length time windows around planting date. We found that planting date had a significant effect on disease incidence across locations. Generally, soil and air temperatures between 5 and 10 ℃ in the week after planting were positively associated with disease incidence (R_m^2 = 0.42). These results have important implications for improving common bunt management in the state.

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Dedication

This thesis is dedicated to all the individuals that put food on our tables.

To the farmers whose hard work and resilience feed that world,

to the industry professionals that innovate and drive progress,

and to the researchers whose dedication, curiosity, and desire for the greater good pave the way for a sustainable future.

As an individual who grew up in the city, my education has served as a bridge to understanding the complex and remarkable world of agriculture. I am ever grateful for the opportunity to leave a small but influential impact on the industry.

This thesis would have never been completed on an empty stomach. Thank you for your commitment to growing and improving the food we rely on every day.

Chapter 1 - Literature Review

Introduction to Wheat Production and Common Bunt

Wheat (*Triticum aestivum*) is an agricultural crop of significant importance. Accounting for a fifth of the world's food calories and protein, it is consumed in more than 170 countries, with consumption exceeding 50 kg/capita/year in 102 countries (Erenstein et al., 2022). With the global population expected to surpass nine billion individuals by 2050, wheat production must increase by 1 billion tonnes in the next three decades to meet demand (Figueroa et al., 2018). However, plant pathogens remain a substantial obstacle in global crop production. In 2019, it was estimated that global yield losses from pests and diseases for wheat ranged from 10.15% to 28.1% (Savary et al., 2019). Each year around 62 million tons of wheat—enough to feed 173 million individuals—is lost to fungal diseases alone (Chai et al., 2022).

In 2024 the United States harvested approximately 10.6 million ha of winter wheat with 27.4% originating from Kansas (USDA NASS, 2023b). In 2021, wheat losses from disease in Kansas were estimated to be 1.62 MMT—approximately 16.2% (Hollandbeck et al., 2021). Major wheat diseases causing yield losses in the state vary year-to-year, but management practices adopted to control diseases often reduce yield reductions (Cruppe et al., 2021; Jaenisch et al., 2019, 2022). Smuts and bunts are wheat diseases of significant importance (Kumar et al., 2022). Common bunt, caused by the pathogens *Tilletia tritici* (syn. *T. caries*) and *Tilletia laevis* (syn. *T. foetida*), is an important fungal disease of wheat responsible for both yield and quality losses. Believed to have been present for centuries, bunt diseases have been described by Vergil, Theophrastus, and other ancient Romans (Woolman & Humphrey, 1924). The genus Tilletia sources its name from Mathieu du Tillet, whose 1750s studies linked wheat bunt symptoms to the presence of a black, greasy “dust” on seeds—prior to modern understandings of fungal plant diseases (L. M. Carris et al., 2006; Tillet & Humphrey, 1937). His work not only won him an award from the Royal Academy of Literature, Science, and Arts of Bordeaux, but also established a foundation for plant pathology (Matanguihan et al., 2011).

From the late 1800s to 1960s, common bunt was characterized as one of the most devastating diseases of wheat impacting the Pacific Northwest region of the United States, leading to intensive research efforts to address it (Matanguihan et al., 2011; Mathre, 2000). For the Kansas region, losses were estimated to have been between 25 and 50 percent in the 1890s (Gaudet & Menzies, 2012; Holton & Heald, 1941). However, with the development of effective seed treatments, resistant varieties, and better control strategies, common bunt losses have been drastically reduced to less than 1% in areas where seed treatments have been adopted (Hoffman, 1982). Despite this, common bunt remains one of the most problematic diseases in many developing countries, second only to the wheat rusts (Gaudet & Menzies, 2012). These recurring outbreaks are the product of unadopted control practices, leading to variable losses per year (Saari & Burnett, 1996). Additionally, organic systems face re-emerging issues with common bunt due to the lack of available organic chemical control strategies.

Taxonomy

T. tritici and *T. laevis* belong to the kingdom Fungi, phylum Basidiomycota, subphylum Ustilaginomycotina, class Exobasidiomycetes, subclass Exobasidiomycetidae, order Tilletiales, and family Tilletiaceae (Index Fungorum, 2025). The genus name *Tilletia* is a reference to Mathieu du Tillet whose research on the cause and prevention of this disease awarded him the first-place prize by the Royal Academy of Literature, Science, and Arts in Bordeaux (L. M.

Carris et al., 2006; Tillet & Humphrey, 1937). *T. tritici* and *T. laevis* are among the six specialized fungi responsible for causing smuts in wheat, alongside *T. controversa* J.G. Kühn (dwarf bunt), *Urocystis agropyri* (Preuss) A. A. Fisch. Waldh. (syn. *U. tritici Körn.*) (flag smut), *T. indica* Mitra (syn. *Neovossia indica* (Mitra) Mundk.) (karnal bunt), and *Ustilago tritici* (Pers.) C. N. Jensen, Kellerm., & Swingle (syn. *U. nuda var. tritici* G. W. Fisch. & C.G. Shaw) (loose smut) (L. Carris, 2010).

Despite having differing teliospore cell wall morphologies, it remains an open question as to whether *T. tritici* and *T. laevis* are the same species. Recent comparative genomic studies have shown high nucleotide identity, indicating potential for both organisms to be pseduomorphospecies or recently digressed from a shared common ancestor (Sedaghatjoo, 2021; Sedaghatjoo et al., 2022). Recent phylogenetic analyses have grouped both species together, distinguished from a closely related pathogen *Tilletia controversa* Kühn, the causal agent of dwarf bunt of wheat (Nguyen et al., 2019). Blind comparison of *T. tritici* and *T. laevis* using autofluorescence characteristics and germination properties was unable to effectively differentiate the two species (Russell & Dallice, 1994). Furthermore, the two pathogens share the same germination requirements, environmental requirements for infection, and both species can even be found in the same fungal sorus (Saari & Burnett, 1996).

Geographic Distribution and Host Range

The common bunt pathogens (*Tilletia tritici* and *Tilletia laevis*) are capable of infecting wheat (*Triticum aestivum* L.), rye (*Secale cereale*), barley (*Hordeum vulgare*), red fescue (*Festuca rubra*), and several other grass species (Gaudet & Menzies, 2012). Believed to have been present since the beginning of wheat cultivation, common bunt is found in all wheat growing regions of the world (Goates, 1996). There may be some distribution differences described among altitudes, as *T. tritici* has been found in higher abundance in lower elevation collections when compared to *T. laevis* which has been reported at higher altitudes (Goates, 1996; Yüksel et al., 1980). While both are widely distributed, *T. tritici* is more prevalent in the western United States and *T. laevis* is more common in the mid-west and eastern part of the country (Mathre et al., 2001).

Symptoms and Signs

Common bunt results in the replacement of wheat grain with fungal sori containing black, oily teliospores leading to yield losses that are correlated to disease incidence (Matanguihan et al., 2011). The disease's alternative name—stinking smut—is attributed to the fish-like odor produced by bunt sori as a result of the production of trimethylamine (Fernandez & Knox, 2012). During wheat development symptom expression can be highly variable and difficult to detect in a large-scale field setting (Hoffman, 1982) with the most notable symptoms not appearing until heading and later stages (Prescott et al., 1986). Some plant stunting can occur when compared to healthy plants (Hoffman, 1982; Mathre, 2000; Prescott et al., 1986) as well as a "flaring out" or "ragged" appearance of spikelets associated with the enlargement of bunt sori (Goates, 1996; Mathre, 2000). Infected heads may also display awn stunting or absence (Mathre, 2000) and may have a blue-green or grey discoloration (Goates, 1996; Prescott et al., 1986). Bunt sori can be visible following the soft dough stage of development (Prescott et al., 1986). It is also possible for a wheat head to contain both healthy seed and bunt sori (Mathre, 2000). Literature has reported symptoms such as increased head length, seedling vigor, and root length while delaying heading and decreasing yield (Mourad et al., 2018). In most cases, symptomatic plants are hidden lower in the canopy by healthy ones, making pre-harvest scouting difficult. While yield losses are unavoidable due to the replacement of the grain with spores, quality losses can also cause further economic harm. Due to the smell associated with the disease, common bunt-contaminated grain is undesirable in the milling process and therefore subjected to price reductions or discounts (Cass Smith, 1954). Its use in feed applications is also limited, as livestock regularly reject bunted grain (Wegulo, 2009). In some cases, the negative impact of common bunt goes beyond yield and quality losses. There have been reports of costs associated with explosions of harvest equipment and injuries during harvest due to the combustion of thick bunt clouds (Fischer & Holton, 1957; Wegulo, 2009).

Morphology and Nuclear Cycle

The two common bunt species, *T. tritici* and *T. laevis*, can be distinguished from one another by teliospore cell wall morphology (Gaudet & Menzies, 2012). *T. tritici* teliospores have reticulated walls, with protrusions measuring 0.5 µm - 1.5 µm, whereas *T. laevis* teliospores are unreticulated and smooth-walled (Goates, 1996; Matanguihan et al., 2011). The diameter of *T. tritici* teliospores range from 14 µm – 23.5 µm, whereas *T. laevis* teliospores range from 14 µm – 22 µm. Both species' teliospores are described as a brownish to pale yellow and globose to ovoid in shape (Goates, 1996). These spores are diploid (2n) and undergo meiosis prior to germination (Saari & Burnett, 1996). Teliospore (syn: chlamydospore) germination results in the emergence of a single haploid (n) promycelium (syn: basidium) that varies in length depending on the surrounding moisture. This length is also impacted by germination location; in soil, it is considerably shorter than media growth (Goates, 1996). Towards the opposite end of the promycelium emerges filiform haploid basidiospores called primary sporidia (syn:

basidiospores), which are organized side-by-side in a bundle containing 4 – 16 cells (Goates, 1996). The promycelium is described as approximately 3 µm – 4 µm wide x 14 µm – 57 µm long, with primary sporidia measuring 0.7 µm – 1.8 µm wide x 37 µm – 57 µm long (Kollmorgen et al., 1978). In cases where a single teliospore produces multiple promycelia, only one will produce primary sporidia (Dastur, 1921). The migration of the cytoplasm from the promycelium into the primary sporidia results in the formation of septations, allowing the primary sporidia to freely detach or remain intact. Primary sporidia can be classified into one of two mating types (+ or -). Those of opposite mating types pair up via the formation of a conjugation peg between them, in a structure referred to as an H-body (Goates, 1996). These H-bodies are dikaryotic (n + n) and are fused at the midsection. Conjugation pegs are approximately 0.9 µm – 1.4 µm long. In some cases, as many as 3 primary sporidia can create an H-body (Kollmorgen et al., 1978). Along with the cytoplasm, one nucleus migrates from one cell, through the penetration tube, and into the other, enclosing two nuclei within one primary sporidia following septation. The binucleate cell develops an apical germ tube (Dastur, 1921) that gives rise to three distinct structures: secondary sporidia, infectious hyphae, or vegetative hyphae, all of which remain dikaryotic (n + n) (Saari & Burnett, 1996). Secondary sporidia are filiform or allantoid in shape and can be expelled forcefully from sterigmata into the air. In many cases, whorls of primary sporidia retain their bunched structure when being expelled (Kollmorgen et al., 1978). Secondary sporidia can also produce infectious and vegetative hyphae as well as more secondary sporidia (Goates, 1996). As the name implies, infectious hyphae are the infectious stage of the life cycle and are described as containing septations and grow more vigorous than vegetative hyphae (Money, 2016). Prior to emergence, infective hyphae must invade and penetrate the coleoptile, reaching the apical meristem prior to elongation. If this is achieved, the fungus will continue to grow throughout plant development. Resistant genotypes prevent the progression of infectious hyphae into the meristem, limiting further infection (Aboukhaddour et al., 2024). The infectious hyphae remain dikaryotic until karyogamy occurs within the developing wheat kernel, forming diploid teliospores (2n) and replacing floret tissue (Aboukhaddour et al., 2024; Saari & Burnett, 1996).

Disease Cycle and Epidemiology

Teliospores serve as the survival structure and source of initial inoculum for these pathogens. Infection occurs below the soil surface and is limited to a narrow infection period, as teliospores must germinate and infect the emerging seedling coleoptile prior to plant emergence (Goates, 1996; Matanguihan et al., 2011; Wegulo, 2009). For both species, teliospore germination is described as occurring between 5°C and 20°C (Hoffman, 1982; Lowther, 1950). In controlled-environmental studies, Kendrick and Purdy (1959) report that the optimum soil temperature and soil moisture required for pathogen infection is between 5°C and 10°C and midway between a soil's wilting point and field capacity (Kendrick & Purdy, 1959). More recent field studies conducted by Johnsson (1992) reported that the optimum temperature for infection was between 6°C and 7°C. In addition, Johnsson concluded that optimum temperatures 1 – 11 days following planting were critical for high infection levels. After 11 days, factors such as soil moisture, temperature, and snow cover had no influence on common bunt infection and incidence (Johnsson, 1992). Under the right conditions, common bunt infection can occur in both spring and winter wheat (Goates & Bockelman, 2012).

For infection to be successful, infectious hyphae must invade the apical meristem before wheat internode elongation (Goates, 1996). After infection, systemic growth occurs until the pathogen proliferates in spike tissue during ovary formation. Within the endosperm, the wheat kernel is replaced by a sorus—also termed "bunt ball"—containing millions of teliospores (Matanguihan et al., 2011). These teliospores are protected by the seed coat, which is left intact by the pathogen (Mathre, 2000). This differentiates common bunt from loose smut of wheat which replaces both the chaff and grain with teliospores (Cass Smith, 1954). Harvest and wind results in the rupturing of bunt sori, dispersing teliospores across the landscape and onto uncontaminated seed in the combine and subsequent grain storage. Millions of teliospores can be dispersed from a single bunt ball, resulting in widespread contamination even when visible disease pressure is not apparent (Cass Smith, 1954; Matanguihan et al., 2011).

Common bunt can be considered both a soil-borne and seed-borne disease (Gaudet et al., 1989). Teliospores can remain viable in soil for up to three years (Hoffman, 1982). However, in most regions, the pathogens are largely considered seed-borne (Goates & Bockelman, 2012). In Kansas, the combination of wet and cool springs limits the persistence of soil-borne inoculum. Teliospores remain on the surface of contaminated grain throughout the storage process, repeating the life cycle upon sowing in cooler soils. Unlike other major crop pathogens, the life cycle for common bunt is monocyclic and only capable of a single infection per growing season (Aboukhaddour et al., 2024).

Management

As a part of his prize-winning research findings presented to the Royal Academy of Literature, Science, and Arts in Bordeaux, Mathieu Tillet included the first seed treatment research for common bunt. His experiments utilized a variety of different grain washes, including cattle urine, lime, lye solutions, salt water, and copper sulfate—all of which provided varying degrees of disease suppression (Tillet & Humphrey, 1937). In the years that followed, several different chemicals were used for common bunt management. Other treatments over time have included formaldehyde, carbon carbonate, and organic mercury; many with significant drawbacks such as seed injury or toxicity (Mathre et al., 2001).

In the 1950's, chemical development provided some of the first effective fungicides for common bunt, including hexachlorobenzene (Aboukhaddour et al., 2024). Hexachlorobenzene provided slightly prolonged protection to the wheat seed/seedling, allowing for management of both seed and soil-borne common bunt inoculum. This was especially significant, as soil-borne inoculum had become increasingly problematic in the Pacific Northwest in the 1940s (Mathre et al., 2001). However, by the 1980s, hexachlorobenzene was replaced by newly developed systemic fungicides such as carboxin. Carboxin, a succinate-dehydrogenase inhibitor, disrupts the citric acid cycle and provided effective control of common bunt (Mathre et al., 2001).

Today, there are a variety of effective seed treatment chemistries on the market for common bunt control. Among them include the demethylation inhibitors (DMI-fungicides) which provide effective control of common bunt by disrupting sterol biosynthesis at low dosages (Mathre et al., 2001). These include active ingredients such as difenoconazole, tebuconazole, triadimenol, and triticonazole. In Kansas, there are over 40 commercially available products that are labeled for control of common bunt (CDMS, 2025). Products include but are not limited to: chemistries including a FRAC group 3 active ingredient such as CruiserMaxx® Vibrance® Cereals (difenoconazole), EverGol® Energy (prothioconazole), Stamina® F4 Cereals (triticonazole), Rancona® Crest (ipconazole), and Raxil® PRO MD (tebuconazole and prothioconazole) (CDMS, 2025). Recent studies show that the effectiveness of these seed treatments remains high for this disease (Abshire, 2023).

Alongside the development of chemical controls in the 1900s, breeding efforts also aimed to create varieties resistant to common bunt. Most identified wheat bunt resistance genes are believed to interact in a gene-for-gene relationship with the common bunt pathogens' avirulence genes (Gaudet & Menzies, 2012; Metzger & Trione, 1962). Currently, there are 16 bunt resistance genes (Bt1 – Bt15 and Btp) used for pathogen race designations that confer varying resistance to common bunt and dwarf bunt (Goates & Bockelman, 2012). While the vertical resistance provided by a single bunt gene can minimize disease levels from 90% to 0% severity, many newly described common bunt races can overcome these race-specific genes (Gaudet & Menzies, 2012). Bt10 and Bt8 still provide strong resistance for breeding programs today, however, their defeat has already been observed (Goates, 2012). The capacity for the pathogens to generate high levels of inoculum makes gene-defeating mutations more common, limiting strong resistance genes (Gaudet & Menzies, 2012). With a variety of effective seed treatment options available on the market, resistance breeding for common bunt has been given low priority by United States breeding programs in recent years (Goates & Bockelman, 2012). The lengthy process of race identification and breeding is considered too costly compared to a seed treatment (Saari & Burnett, 1996). In many cases, simply finding North American fields to study the variation of pathogenic races has been limited due to the disease no longer being widespread due to effective chemical control (Aboukhaddour et al., 2024). Currently, there is no characterized resistance to common bunt in Kansas' wheat varieties. Modification of specific cultural practices can also minimize the impact of common bunt. Planting into warmer soils is advised as the pathogens favor temperatures below 20°C (Gaudet & Puchalski, 1990; Kendrick & Purdy, 1959). Recommendations also include the proper sanitization of harvest and planting equipment to ensure clean seed remains uncontaminated. Additionally, purchasing clean, certified seed can ensure that growers begin the season free of common bunt. This is significant as some growers engage in seed-saving practices, where a portion of each year's harvest is saved for the following season's planting. Also known as a "bin-run", this can cause contamination levels to rise over time, leading to large economic losses (Thomas, 2023; Váňová et al., 2006). Despite the availability of effective chemical control options, common bunt continues to cause significant losses worldwide. In organic and low-input systems, the inability to purchase chemical seed treatments in conjunction with limited resistant cultivars has allowed bunt to remain a significant threat to wheat production (Matanguihan et al., 2011).

In Kansas, grain elevators have notified researchers of a growing number of rejected and discounted grain lots infested with common bunt. Although effective chemicals are available on the market, a lack of seed treatment adoption coupled with seed-saving practices may be responsible for rising common bunt outbreaks. Currently, with a few exceptions of selected surveys (Jaenisch et al., 2021), the extent of seed-saving practices, seed treatment adoption, and awareness of common bunt is unknown. Additionally, given the limited and conflicting nature of the existing literature on environmental influences, there is a need to re-evaluate the conditions required for infection. Such understanding is essential for developing more informed planting date recommendations.

Research Objectives

With the rising prevalence of common bunt in the region and its significant impacts on wheat production and wheat grain quality, it is critical that current management recommendations be re-evaluated. The objectives of this thesis were to develop a baseline understanding of seed management practices currently adopted by Kansas wheat producers with an emphasis on common bunt control, and to investigate the environmental requirements favorable for common bunt infection in wheat field environments and to improve planting date recommendations. It is the intention of this research to improve upon management recommendations and educational outreach in the state of Kansas.

Chapter 2 - Survey of Integrated Seed Management Practices of Winter Wheat Producers in Kansas with a Focus on Common Bunt

Introduction

In 2023, the United States harvested approximately 9.91 million ha of winter wheat, valued at 8.5 billion dollars. Kansas is often the largest wheat-producing state in the country with an average production of 7.82 MMT of wheat and 2.95 million ha of winter wheat planted (2019-2023). The industry is valued at approximately $1.76 billion (USDA NASS, 2019, 2020b, 2021, 2022, 2023b). Wheat productivity in this region is influenced by a variety of limiting factors (Jaenisch et al., 2021), including diseases. Diseases account for approximately 21.5% of global wheat production losses (Savary et al., 2019) and are a significant contributor to yield losses in Kansas wheat. For 2021 and 2020, estimated cumulative disease losses for Kansas wheat were 16.2% (1.91 MMT) and 10.8% (865,454 MT) respectively (Hollandbeck et al., 2020, 2021). With the progressive loss of arable crop land and an ever-increasing population, the need for management of economically important diseases is critical for the future of food security.

Common bunt (syn. stinking smut) is a fungal disease of wheat caused by the closely related pathogens *Tilletia tritici* and *Tilletia laevis*. Common bunt is responsible for both quality and yield losses in spring and winter wheat. During grain fill, wheat kernels are replaced with fungal sori containing millions of black teliospores that rupture during harvest and contaminate healthy grain. The disease's other name, stinking smut, is a reference to the fish-like odor of trimethylamine that is produced by these pathogens (Cherewick, 1953). This odor is undesirable in products destined for human or livestock consumption (Wegulo, 2009), leading to quality losses even when yield losses are minimal. Even a low concentration (0.05% by weight) of spores is sufficient to produce the odor (Gaudet & Menzies, 2012) and cause economic losses.

Additionally, there can be discounts or dockages for grain contaminated with common bunt at the elevator.

Symptoms of common bunt can be difficult to detect prior to harvest and can include a blue to grey discoloration of heads and mild stunting of wheat plants. In some cases, awns can also be stunted or absent entirely and florets can appear flared (Goates, 1996; Wegulo, 2009). When stunting occurs, symptomatic plants can be hidden below the canopy of healthy plants, complicating scouting efforts. In most cases, the presence of common bunt is not known until grain fill or crop maturity (Mourad et al., 2018) when dark "clouds" of airborne spores are dispersed during harvest, contaminating healthy seed and equipment.

Common bunt is a disease of significant historical importance (Gaudet & Menzies, 2012). Through the 1900s common bunt remained one of the most destructive diseases in the Pacific Northwest of the United States, with reports of fields with 40 to 87 percent of bunt being found (Cherewick, 1953), prompting intensive research efforts into management strategies. Seed-borne spores have a limited window of infection between planting and emergence, making them the primary focus for management efforts (Goates, 1996; Matanguihan et al., 2011).

Recommendations for common bunt management range from physical, chemical, and biological management options. Seed cleaning involves the physical removal of spores and affected grains through air screening, the use of a gravity table (Pinto et al., 2019), and in more advanced systems, color sorting (Giordano et al., 2025). Other physical processes may include the use of hot water or steam to sanitize seeds, while biological processes can include using plant extracts, biological compounds, or biological control agents (fungi and bacteria) (Mancini & Romanazzi, 2014). Fungicide seed treatments are another seed management option (McGee, 1995). Fungicides are typically applied to the seed coat in addition to adhesives to provide a uniform application (Taylor & Harmon, 1990). Fungicides can be applied alone or in combination with insecticides or other compounds. General benefits of seed treatments can include improving emergence, protection from insect pests, vigor improvement, crop growth uniformity, minimizing root rots, and inhibiting foliar disease development all of which serve to improve and maximize crop yield and quality (Andersen Onofre & De Wolf, 2023; Munkvold et al., 2014). Additionally, fungicide seed treatments are considered by some to be a more economic and sustainable management option when compared to broadcast fungicide applications as rates per hectare are lower and delivery is restricted to the target site (Taylor & Harmon, 1990). In the case of common bunt, the introduction of polychlorinated benzene seed treatment fungicides in the late 1950's led to the near widespread eradication of the disease, with disease outbreaks primarily occurring due to the improper use (or relaxed usage) of seed treatments (Mathre & Johnston, 1976).

Today, common bunt is widely controlled by a variety of effective commercially available seed treatments. In Kansas, there are over 45 available products labeled for the control of common bunt (CDMS, 2025). Due to the effectiveness of a single chemical seed treatment, most wheat breeding programs have deprioritized breeding for bunt resistance (Hoffman & Waldher, 1981; Matanguihan et al., 2011). Current management guidelines for the disease recommend the purchase of certified seed with a fungicide seed treatment. When the seed is treated on-farm, ensuring that the seed is cleaned and that the coverage is applied uniformly is critical (Wegulo, 2009). Seed saving is a common practice in which producers reserve a portion of one year's harvest to be planted a subsequent season. In many cases, saved seed reserves are mixed with new seed in preparation for wheat planting. Even given a low initial concentration of bunt inoculum, saving seed over time can lead to a buildup of spores, increasing the risk of severe and sudden yield losses (Váňová et al., 2006).

Despite the availability of effective seed treatments on the market, common bunt continues to threaten wheat production in Kansas and the surrounding hard red winter wheat growing region. Understanding current producer seed management practices is critical to modify extension programming around the topic. The objective of this survey was to establish a baseline understanding of Kansas wheat producers' seed management practices and extension preferences to better inform extension education on common bunt and other economically important diseases in the region.

Materials and Methods

Survey Instrument

The survey instrument consisted of 27 questions separated into four distinct sections: (i) farm operation demographics, (ii) common bunt experiences, (iii) seed management practices, and (iv) an optional section on extension outreach preferences (Appendix A). Operational demographics aimed to gather data on farmer production practices such as wheat acreage and planting specifications including row spacing, seeding rate, and irrigation. The common bunt section provided a description of common bunt symptoms and a colored image for visual reference. Respondents were asked if they had ever noticed common bunt on their farm and if they had ever received a price discount or rejection because of the disease. The seed management section, which comprised the majority of the survey, gathered information on practices from the 2022-23 and 2023-24 growing seasons, including acreage planted, seed purchasing and/or saving, and chemical seed treatment usage. The final section was optional and included questions aimed at understanding producer preferences for receiving extension information. Questions were organized into open-ended responses, yes or no, or multiple-choice responses. The survey instrument received review from Kansas State University Extension professionals and from a small group of Kansas wheat farmers prior to deployment. The survey received approval from the Kansas State University Institutional Review Board (IRB-11517).

Survey Deployment

The survey targeted Kansas wheat farmers who were in attendance at several wheat demonstration field days in May 2024. The demonstration events occurred from May 14th, 2024 to May 17th, 2024 and were located in Kinsley, Isabel, Pratt, Spivey, Protection, Riley, Marquette, Moundridge, Inman, and Smith County, KS. These programs were hosted by county extension agents and Kansas wheat farmers with the goal of hearing research updates and learning about new wheat varieties. We intend the interpretation of these results to be limited to the scope of the surveyed population which was those that would attend wheat programming offered by Kansas State University. Producers were presented with the paper survey and were given the duration of the program to complete their responses. Participation in the survey was completely voluntary.

Data summarization

All data summarization was conducted in the R programming software (R Core Team, 2024). Four respondents did not complete questions past the first page and were removed from summarization for the questions that followed. For median planting dates calculations, some growers reported a window for planting. For planting date windows, the beginning date was used for median planting date calculations as opposed to the midpoint. We believe this best represents the earliest date a producer would plant given suitable environmental conditions for planting.

Results

Operation demographics

Overall, 77 Kansas wheat producers responded to the survey representing 107 operations from 14 counties across Kansas (Figure 2.1). These 14 counties account for ~ 20% of planted wheat acreage in Kansas. The total acreage of respondents' farms ranged widely, with the smallest operation being 81 ha and the largest 4,330 ha (Table 2.1). In total, the survey represented approximately 57,909 ha. None of the respondents identified any portion of their wheat operation as organic. Approximately 82% of respondents answered every question on the first page of the survey including questions on operational demographics and common bunt experiences. The opened-ended nature of several questions in the survey made response rate unrepresentative for some portions following the first page. For example, there were three questions related to seed management practices that were most frequently left unanswered. The first question asked producers what components they include in their seed treatments. Due to the structure of the question, it was difficult to discern respondents who did not include any of the components in their seed treatment from those who disregarded the question, leading to a lower response rate.

More than half (64.9%) of the wheat producers surveyed use a row spacing of 19.05 cm, followed by 32.5% using 25.4 cm, and 1.3% using 30.48 cm (n = 77) (Table 2.2). Seeding rates were reported in either kg/ha or seeds/ha and varied from approximately 9.18 kg to 22.03 kg and 404,685.64 seeds to 607,028.46 seeds per ha, respectively (n = 77). Most operations were not irrigated, with 76.6% using no irrigation, 9.1% having only 1–5% of their operation irrigated, 6.5% having 6–15% of their operation irrigated, 6.5% having 16–30% of their operation irrigated, and 1.3% having 31–50% of their operation irrigated (n = 77) (Table 2.2).

In preparation for planting, reduced, conventional, and no-till methods were all utilized nearly equally with 31.2%, 31.2%, and 27.3%, respectively. Some respondents had mixed tillage practices across their operations as 5.2% of respondents use both reduced and conventional, 2.6% use reduced and no tillage, and 2.6% use all forms of tillage in their production practices (n = 77) (Table 2.2).

Respondent experiences with common bunt

One of the main objectives of this survey was to identify any past producer experiences with common bunt. Respondents were asked if they have ever noticed common bunt on their farm. Twenty-five respondents (32.5%) reported having had an issue with common bunt in the past, while 51 (66.2%) reported no experience with common bunt on their farm (n = 77). When respondents were asked to list the years these experiences occurred, all reported that occurrences happened between 2000 and 2021. Only 8 (10.4%) growers reported a price discount or rejection due to common bunt (n = 77) (Table 2.3). Reported discounts ranged from 0.01 cents to 0.5 cents, with most (n =10) occurring within the last seven years.

Seed management practices

Of the 77 total growers surveyed, four respondents did not complete the survey past the common bunt section. Those respondents were excluded from the remainder of the analysis. During the 2022-23 growing season, the average planted area by surveyed producers was approximately 434 ha, with 1,618 ha being the largest area reported. For the 2023-24 growing season, the average wheat area planted was 443 ha, with 2,023 ha being the largest planted area reported by a single surveyed producer (n = 73) (Table 2.1). The total reported area planted was 26,637 ha and 26,480 ha for 2022-23 and 2023-34 respectively.

For both seasons, most reported planting dates and planting date windows occurred between late August and late October, with one respondent reporting their planting window ending as late as December (Figure 2.2). One respondent reported their planting window beginning as early as mid-July for both seasons, which may be a grower who plants wheat for grazing. Median planting dates were calculated to be October 15th for the 2022-23 season and October 1st for the 2023-24 season.

When respondents were asked if they purchased certified seed for either the 2022-23 or 2023-24 season, 55 (75.3%) and 58 (79.5%) growers reported doing so, respectively (n = 73) (Table 2.4). When asked what percentage of their operations were planted with certified seed, the distribution for both seasons appears bimodal, with a larger cluster of respondents planting little to no certified seed (n = 72) (Figure 2.3).

Respondents were asked if they used a seed treatment that included a fungicide. For 2022-23, 38.4% of respondents reported that they used a fungicide seed treatment. For 2023-24, 37.0% of respondents reported using a fungicide seed treatment (n = 73). For both growing seasons, a higher percentage of individuals did not use a fungicide seed treatment: 49.3% and 53.4% for 2022-23 and 2023-24 respectively (Table 2.4). When asked specifically what percentage of their seed received a fungicide seed treatment, growers seem to either treat all their seed, or little to none. For 2022-23 season, 39.7% (29) of growers reported treating 0–10% of their seed with a fungicide while 31.5% (23) growers reported treating 90–100% of their seed with a fungicide. For the 2023-24 season, 45.2% (33) of growers reported treating 0–10% of their seed with a fungicide while 32.9% (24) of growers reported treating 90–100% of their seed with a fungicide (n = 73) (Figure 2.4).

Respondents were asked to circle components (aside from a fungicide) that were a part of their seed treatments. Options included an insecticide, growth regulator, and nutrient supplement. Few respondents reported using any components. Insecticides were included the most, with 14 (2022-23; 19.2%) and 15 (2023-24; 20.5%) respondents reporting using just an insecticide. For both seasons, one respondent (1.4%) reported using only a nutrient supplement while another respondent (1.4%) reported using all three components. Two respondents (2.7%) reported using both an insecticide and nutrient supplement for both seasons. Most respondents (>70%) did not circle any options for both seasons (n = 73) (Table 2.5).

To identify the prevalence of seed-saving during the two growing seasons, respondents were asked approximately what percentage of their seed was saved on-farm from a previous season. For the 2022-23 and 2023-24 seasons, 43 (58.9%) and 44 (60.3%) of growers respectively reported saving a portion of their seed for the following growing season. For 2022-23, 17.8% (13) of growers reported not saving seed, while 20.5% (15) of growers reported not saving seed in 2023-24 (n = 73) (Table 2.4). The distribution of the percentage of seed saved shows that a larger group of individuals tended to save 50% or more of their seed when compared to those who saved 50% or less for both seasons (n = 73) (Figure 2.5).

Respondents were asked if saved seed was treated with a fungicide and/or cleaned. For the 2022-23 growing season 25 (34.2%) growers reported cleaning, one (1.4%) grower reported treating, 23 (31.5%) growers reported cleaning and treating, and seven (9.6%) growers used neither. For the 2023-24 growing season 27 (37.0%) growers reported using cleaning, one

(1.4%) grower reported treating, 26 (35.6%) growers reported cleaning and treating, and 7 (9.6%) growers used neither (n = 73) (Figure 2.6).

Growers were asked to circle factors that influence their decision to use a seed treatment. Cost of treatment and grain price (25 respondents; 34.2%) were equally selected as the most significant factors that influence seed treatment usage (n = 73), followed by disease pressure (22 respondents; 30.1%) (n = 73), crop consultant recommendation (17 respondents; 23.3%) (n = 73), planting date (8 respondents; 11.0%) (n = 73), insect pressure (7 respondents; 9.6%) (n = 73), number of years seed has been saved (5 respondents; 6.8%) (n = 73), and finally seed germination results (5 respondents; 6.8%) (n = 73) (Figure 2.7).

Optional section on extension outreach preferences

Growers were asked where they received information about wheat disease management. Most respondents (57 respondents; 78.1%) indicated that Kansas State Research and Extension was their primary source for information about wheat diseases (n = 73). This was followed by private crop consultants (29 respondents; 39.7%) (n = 73), another local producer (23 respondents; 31.5%) (n = 73), agrochemical company representative (17 respondents; 23.3%) (n = 73), and finally receiving their information from another university (5 respondents; 6.8%) (n = 73) (Figure 2.8).

Respondents were asked what their preferred method for receiving new information regarding wheat disease management. The preferred method was in-person programs (37 respondents; 50.7%), followed by email newsletters (30 respondents; 40.1%), radio (25 respondents; 34.2%), websites (22 respondents; 30.1%), and both Facebook and Twitter respectively (7 respondents; 9.6%) (Figure 2.9).

Discussion

A survey of 77 wheat growers in the largest wheat growing state in the United States investigated the prevalence of seed treatment and certified seed adoption, seed-saving practices, and past experiences with common bunt. Findings highlight the prevalence of common bunt occurring in the region. Results also suggest a large portion of growers supplement their planting with saved-seed, despite a majority purchasing certified seed each season. Additionally, a majority of growers reported forgoing a seed treatment application on their saved seed. For many growers, factors such as grain price, cost of treatment, and disease pressure were among the most important factors that influenced their decision to use a seed treatment.

Common bunt

Nearly a third of growers surveyed reported experiences with common bunt in the past. This was surprising considering that for 2022-23 and 2023-24 yield loss estimates due to common bunt were reported to be 138.067 MT ($4.5 million) and 27,734 MT ($770 thousand) (Crop Protection Network, 2024), lower than what would be expected. In conjunction with discount schedules at a variety of Kansas grain Co-ops list 'smutted grain' discounts ranging from $0.10 to $0.30 (Alliance Ag & Grain LLC, 2023; American Plains Co-op, 2024; Central Prairie Co-op, 2022; Garden City Co-op, 2023), these findings suggest that there could be underreported yield and quality losses occurring in these regions regularly. Common bunt is a difficult disease for extension personnel and researchers to scout as it cannot be easily identified pre-harvest.

Certified seed and saved seed

Across each season included in this survey (2022-23 and 2023-24), over 75% of growers reported purchasing certified seed (55 or 75.3% in 2022; 58 or 79.5% in 2023). Interestingly however, 31.9% (2022-23) and 41.7% (2023-24) of growers planted only 0 – 10% of their operation with certified seed while 16.7% (2022-23) and 18.1% (2023-24) planted 90 – 100% of their operation with certified seed. Our findings suggest that while a majority of growers purchase certified seed, a larger proportion of those growers are only planting a small portion of their operation to certified seed in any given year. Currently, there are 90+ varieties of certified hard red winter wheat seed available for purchase, including many of which that are annually evaluated for performance (Kansas Crop Improvement Association & Kansas State University, 2024). In addition to minimizing the risk of disease contamination, certified seed is produced by rigorous standards that ensure seed has high varietal purity, physical quality, and germination rates , and no noxious weed seed (Kansas Crop Improvement Association, 2025). Comparison of the agronomic benefits between certified and non-certified seed use has also shown that certified seed use decreased production costs and increased yield (J. Edwards, 2017; Sofijanova et al., 2012). In countries with low certified seed adoption rates, producer demographics such as increased crop income, higher education level, larger farm size, more experience, and more access to extension may also influence growers to adopt or purchase more certified seed (Baglan et al., 2020; Nandi, 2024; Riaz et al., 2024; Sandita et al., 2024).

Not only did most of the growers report purchasing some amount of certified seed, but more than half (59% in 2022-23 and 60% in 2023-24) of growers also reported saving seed from the previous season indicating many are supplementing planting with saved seed. Choosing to save seed over purchasing certified seed is influenced by a wide variety of factors ranging from the price of certified seed, seed dealer, and extension education to costs associated with seed storage, cleaning, and testing (Knudson & Hansen, 1990). Many growers may opt to purchase a small percentage of certified seed to evaluate performance on their farm. If the variety performs well, a grower will save seed and plant that variety on more acres in the future. Generally, there is evidence for increased average yields by planting certified seed compared to saved seed, however yield differences can vary by year and environment (J. Edwards, 2017; Knudson & Hansen, 1990). In some cases, the economic cost of farm-saved seed was lower than certified seed, with few differences in emergence, seedling vigor, and yield observed despite higher quality and consistency of certified seed (Hall et al., 2019). Additionally, effective farmer quality control practices may minimize the grain yield differences (J. T. Edwards & Krenzer Jr., 2006)—limiting the need for purchasing certified seed. However, the quality of farmer seed-saving practices in the region was beyond the scope of the current work and warrants further research.

For some growers, access to certified seed may be limited in some cases. Notably, season long drought stress in Kansas during the 2022-23 season resulted in a 22% drop in the state's winter wheat bushels compared to the previous year (Lingenfelser et al., 2023; National Agricultural Statistics Service, 2023). Despite the reliability usually afforded to certified seed availability, the previous season's decrease in yield led to winter wheat seed shortages prior to the 2023-24 season (Debes, 2023).

Chemical seed treatment usage

We found that approximately half of surveyed farmers (49.3% in 2022-23; 53.4% in 2023-24) used a seed treatment that included a fungicide on a portion of their wheat seed. When asked about their saved seed management, approximated approximately 32.9% (2022-23) and

37% (2023-24) of growers reported treating saved seed with a fungicide seed treatment. Although many growers did not identify specific components included in their seed treatments, those that did respond indicate that some growers (20%) used an insecticide in their seed treatment. Findings correspond with agricultural chemical use surveys conducted in Kansas which report that approximately 31.75% of the winter wheat area planted in Kanas was treated with a preventative seed treatment for insect or disease control (2012, 2017, 2019, 2022) (USDA NASS, 2012, 2018, 2020a, 2023a).

Research conducted on fungicide seed treatments has reported inconsistent impacts on grain yield, disease management, and economic returns. When evaluating the impact of seed treatments on *Fusarium graminearum* infested wheat seed, May et al. (2010) reported no consistent improvement on agronomic performance. Only seed lots with high levels (>63%) of infection showed improved emergence and yield in comparison to lots with low levels of infection (5 – 10%) (May et al., 2010). When evaluating seed cleaning and treatment options following a season with high Fusarium graminearum incidence and severity in Kansas, Pinto et al. (2019) suggested that seed cleaning increased winter wheat stand count, yield, and test weight, while seed treatment increased grain yield and 1000-kernel weight (Pinto et al., 2019). Experimentation with thirteen seed treatments in winter wheat in Oregon reported that all treatments failed to control Rhizoctonia root rot and did not consistently improve grain yields across three sites (Smiley et al., 1990). Cook et al. (2002) reported that fungicide seed treatments increased wheat yield but not significantly in most cases (Cook et al., 2002). In soybean, the addition of a seed treatment enhanced profitability across most study conditions but was maximized by using high quality seed (Poag et al., 2005; Popp et al., 2010). In many cases, a fungicide seed treatment alone may not consistently provide an increase in yield or net returns.

However, when used in a dual application alongside an insecticide, some studies have reported significant economic returns (Bradley, 2008; Cox & Cherney, 2014; Gaspar et al., 2014; Turkington et al., 2016). For some growers, these inconsistencies may be responsible for lower adoption rates of fungicide seed treatments.

However, the cost effectiveness of fungicide seed treatments alone is difficult to evaluate without holistic evaluation of conditions during the growing season. Grain price, seed treatment cost, and pathogen pressures all influence the significance of economic returns (DeVuyst et al., 2014). For example, high-quality seed treated with fungicide led to maximum yields under lower plant densities as compared to lower-quality seed without fungicide seed treatment in a 27 site-year study (Giordano et al., 2025), suggesting that growers could reduce their seeding rate under these conditions. Beres et al. (2016) reported increased yields for agronomic systems with low seeding rates and thinner wheat seeds when treated with seed treatments (Beres et al., 2016). In a multi-year and location study conducted in Oklahoma, DeVuyst et al. (2014) reported that fungicide and insecticide seed treatments improved yield and economic returns, but varied due to differences in grain prices across years. Additionally, the use of a dual fungicide and insecticide never reduced average economic returns (DeVuyst et al., 2014). This is reflected by survey respondent selected factors that influence the decision to use a seed treatment: cost of treatment (34.2%), grain price (34.2%), and disease pressure (30.1%) received the greatest selection. The influence of these factors on grower decision making reflects their impact on economic returns. In addition, rising input costs may also influence the decision to use a fungicide seed treatment. The most recent input cost survey in Kansas found consistently rising input costs for non-irrigated wheat in the North-Central, Central, and South-Central Kansas crop reporting districts. Across all three districts, prices for fertilizer, herbicide, and seed for non-irrigated wheat have risen from 2018 – 2022 (Tsoodle & Li, 2022)—increasing producer costs, which may influence a grower's decision to purchase chemical seed treatments. Additionally, drought conditions during both years may have increased productions costs, influencing producers to cut costs—including fungicide seed treatments.

In Kansas, several seed-borne, seedling, and root rot diseases are present that may influence a grower to use a fungicide seed treatment. These diseases include the loose and flag smuts, common bunt, seed-borne Fusarium, Pythium and Rhizoctonia damping-off, Take-all, and Common and Fusarium root rots (Andersen Onofre & De Wolf, 2023). Without high levels of disease pressure, a grower may not see economic returns.

Planting date

In Kansas, the date of wheat planting influences tiller development, which could be responsible for up to 70% of grain yield under normal conditions (Thirty et al., 2002). Current recommendations for winter wheat planting in the state are determined by county location within four distinct climate zones. Planting date recommendations range from September 10th to October 25th, with Northeast Kansas planting as late as September 30th and Southwest Kansas planting as late as October 25th (Shroyer et al., 1996). More recently, Munaro et al. (2020) fine-tuned optimum planting dates for wheat in Kansas and neighboring states using boundary functions of wheat yield potential versus date of planting for subregions defined based on climate properties that drive the biophysical aspects of crop development. These resulted in similar optimum dates to the above but without the determination by county; instead, by climate zones. Optimum sowing dates are early enough to allow for sufficient tiller development to maximize yield without increasing the risks of viral diseases early in season (Munaro et al., 2020; Thirty et al., 2002). Of the 92 operations captured in the survey, approximately 17 reside in Zone 2 and 75 reside in Zone 3. For the 2022-23 growing season the median planting date of surveyed growers was October 15th, while the median planting date was October 1st for the 2023-24 growing season. The median planting date in 2022-23 is close to the end of the recommended planting date window (October 20th) for both zones, which appears to be late. Reasons for this are most likely attributed to climatic factors during that season. In the 2022-23 growing season, drought conditions during the entire growing season resulted in poor wheat conditions throughout the state. Precipitation in September 2022-23 was very limited, with most precipitation—if any (less than 50.8 mm)—having occurred prior to September 15th. Having followed a previously dry season in 2021-22, the soil available water at wheat sowing throughout the state—which depends on fallow precipitation and weather conditions (Lollato et al., 2016)—was severely limited, exacerbating the need for precipitation. Producers may have delayed planting, holding out for any possible favorable precipitation in October (Lingenfelser et al., 2023). The 2023-24 growing season had far better conditions in terms of precipitation with September having up to 88.9 mm of precipitation during the first half of the month and precipitation also occurring between October and November. Overall, parts of the state received between 0.63 – 16.5 cm of precipitation from September 1st to the end of November (Lingenfelser et al., 2024). This may be the reason why the median planting date for the 2023-24 growing season was earlier than that of the 2022-23. Other reasons for planting later rather than earlier in the region could be due to pest pressures. Planting too early in September increases the risk of curl mite (*Aceria tosichella*) and aphid transmitted viruses in region such as wheat streak mosaic virus (WSMV), barley yellow dwarf virus (BYDV), high plains mosaic virus (HPWMoV), and Triticum mosaic virus (TriMV). Early sown seed is also at greater risk of developing root rot diseases such as take-all (caused by *Gaeumannomyces graminis* var. *avenae and tritici*) and dryland foot rot (*Fusarium* spp.). Other insect pests also become more prevalent in warmer temperatures such as Hessian fly (*Mayetiola destructor*) and wheat head armyworm (*Faronta diffusa*). Alongside increased pest pressures, warm soil planting can reduce germination and emergence rates of some varieties that are heat sensitive (Andersen Onofre et al., 2021; Lollato et al., 2017).

Considering the multitude of risk factors and the critical need for precipitation near the time of planting, it is understandable that grower planting habits may tend to favor planting at the later end of the recommended planting date window. However, producers that continuously save seed and forgo fungicide seed treatment applications are at greater risk of increasing common bunt infestation levels, leading to eventual large economic losses. It is important that extension professionals include common bunt in planting date recommendations alongside other diseases, especially since seed-saving habits are shown to be prevalent among surveyed growers.

Extension information sources and preferences

Unsurprisingly, most growers (78.1%) selected Kansas State University Research and Extension (KSRE) as a primary source for receiving disease management information. Because the surveys were administered at an extension-related event, the growers surveyed may represent Kansas wheat growers that regularly use KSRE for wheat management recommendations. The number of growers depending on Extension as a primary source of information has decreased over time (Edge et al., 2017), with private sources of information becoming the leading source for production management recommendations (Borrelli et al., 2018; Houser et al., 2018; Stuart et al., 2018). In many cases, Extension is not a primary source of information, rather supplementary and mostly commonly used in combination with other sources of information such as other farmers and/or private consultants and dealers (Crawford et al., 2015; Velandia et al., 2010). The present study found that private crop consultants were the second most common source of management recommendation (39.7%). These results also highlight the importance of Extension and industry collaboration, and that continued partnership is critical for reaching grower audiences. Diversification of information sources can further the impacts of extension outreach.

Even with increasing technological outlets, results also show that growers still utilize word-of-mouth sources (in-person programs and radio) nearly as much as email and websites. Growers selected in-person programs (50.7%) as the most preferred method for extension communication, while email newsletters (41.4%), radio (34.2%), and websites (30.1%) received similar results. There may be regional variation as well. For example, a survey of Pacific Northwest cereal farmers in the United States found that approximately 85% utilized the internet for agriculture-related information a few times a month, with 63.6% stating they use the internet for agriculture-related information daily (Borrelli et al., 2018). These findings highlight the importance of utilizing both traditional and digital communication methods to effectively reach and engage with growers.

Challenges and opportunities for producer surveys

Obtaining high quality, representative survey data from agricultural producers can be challenging. Agricultural producers often receive frequent survey requests from the private sector, the government, and academic institutions regarding farming practices, leading to survey fatigue (Avemegah et al., 2020). The USDA’s National Agriculture Statistics Service (NASS) distributes hundreds of surveys each year covering nearly every facet of U. S. agriculture. Perhaps due to this, yield and acreage surveys have seen declining response rates from growers in recent years (Johansson et al., 2017), emphasizing the need for optimization of survey instruments. Response rate to surveys is dependent on a variety of factors including but not limited to the number of questions, number of pages, layout, instructions, color, structure, and anonymity (Childers et al., 1980; Harvey, 1987). Survey modes, such as paper or digital also impacts grower responses, with paper surveys generally seen as preferable to online surveys as they minimize possible non-response bias (Avemegah et al., 2020; Zahl-Thanem et al., 2021). Pennings et al. (2002) investigated factors that influence farmer response rates to surveys. Factors such as production and harvest schedules make completing surveys a low priority if deployed at the wrong time. Additionally, many growers can afford little time to surveys that do not include compensation or require consulting farm records (Pennings et al., 2002).

Conclusions

These survey results established baseline information regarding the adoption of seed-saving and seed treatment practices for winter wheat growers participating in K-State Research and Extension programs (our audience of interest). Although many producers purchase certified seed, the overall percentage each of operation planted with certified seed was low. Furthermore, farmers who are saving seed are not always treating and cleaning that saved seed. The combination of saving seed continuously while forgoing a seed treatment application increases the risk of seed-borne disease outbreaks such as common bunt. To improve the management of common bunt, it is critical that planting and seed management recommendations be included in conversations about the risks of seed-saving and the benefits of seed treatments. Surveyed growers indicated that grain price, cost of treatment, and the perception of disease risk influenced their willingness to use a fungicide seed treatment. Future programs addressing the use of seed treatments should also include a discussion of these practices in light of overall farm economics and return on investment for growers.

Future work may explore environmental conditions that indicate a seed treatment would be beneficial, making the use of these products more targeted. Re-visiting the environmental requirements for common bunt infection in Kansas can better inform planting date recommendations for growers. Finally, it is the intention of the investigators to survey Kansas growers in the future to evaluate how seed management practices have changed over time with improved extension outreach education.

Table 2.1. Summary of grower demographic farm size (ha) and area (ha) planted to wheat for the 2023-24 and 2022-23 growing seasons.

Question	Growing season	Minimum	First quartile (*Q1*)	Median	Mean	Third quartile (*Q3*)	Maximum
Farm area (ha)		81	323	515	851	1,041	4,330
Wheat area planted (ha)	2023-24	40	202	323	434	526	1,618
	2022-23	0	198	344	443	577	2,023

Table 2.2. Respondent reported row spacing, irrigation, and tillage methods.

Characteristics	**Number of respondents (%)**
Row spacing (m)	
0.19	50 (64.9)
0.25	25 (32.5)
0.30	1 (1.3)
Non-response	1(1.3)
Irrigation (%)	
0	59 (76.7)
1 - 5	7 (9.1)
6 - 15	5 (6.5)
16 - 30	5 (6.5)
31 - 50	1 (1.3)
51 - 57	0
76 or more	0
Non-response	0
Tillage method	
No-till	21 (27.3)
Reduced till	24 (31.2)
Conventional till	24 (31.2)
Reduced and conventional till	4 (5.2)
Reduced and no-till	2 (2.6)
Conventional and no-till	0
All	2 (2.6)
Non-response	0

Table 2.3. Respondent reported experience with common bunt and associated price discount, or rejection received.

Question	Number of respondents (%)
Noticed common bunt (stinking smut) on farm?	
Yes	25 (32.5)
No	51 (66.2)
Non-response	1 (1.3)
Received a price discount or rejection due to common bunt?	
Yes	8 (10.4)
No	67 (87.0)
Non-response	2 (2.6)

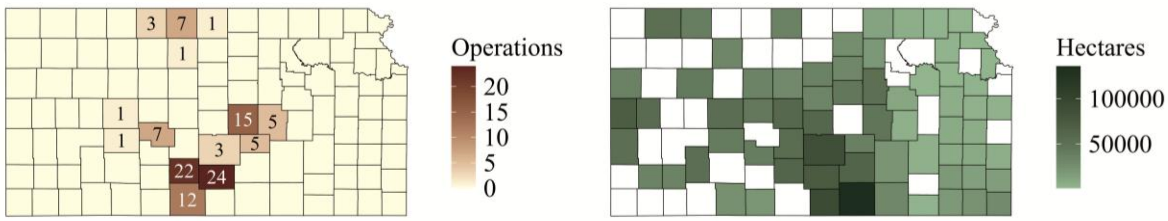
Table 2.4. Grower reported responses to questions regarding certified seed purchase, fungicide seed treatment usage, and seed saving practices.

Question	Growing season	Number of respondents (%)		
		Yes	No	NA
Purchased certified seed	2022 - 2023	55 (75.3)	12 (16.4)	6 (8.22)
	2023 - 2024	58 (79.5)	13 (17.8)	2 (2.74)
Used a seed treatment that included a fungicide	2022 - 2023	28 (38.4)	36 (49.3)	9 (12.3)
	2023 - 2024	27 (37.0)	39 (53.4)	7 (9.6)
Saved seed on-farm from a previous season	2022 - 2023	43 (58.9)	13 (17.8)	17 (23.3)
	2023 - 2024	44 (60.3)	15 (20.5)	14 (19.2)

Table 2.5. Grower reported seed treatment components for the 2022-23 and 2023-24 growing seasons.

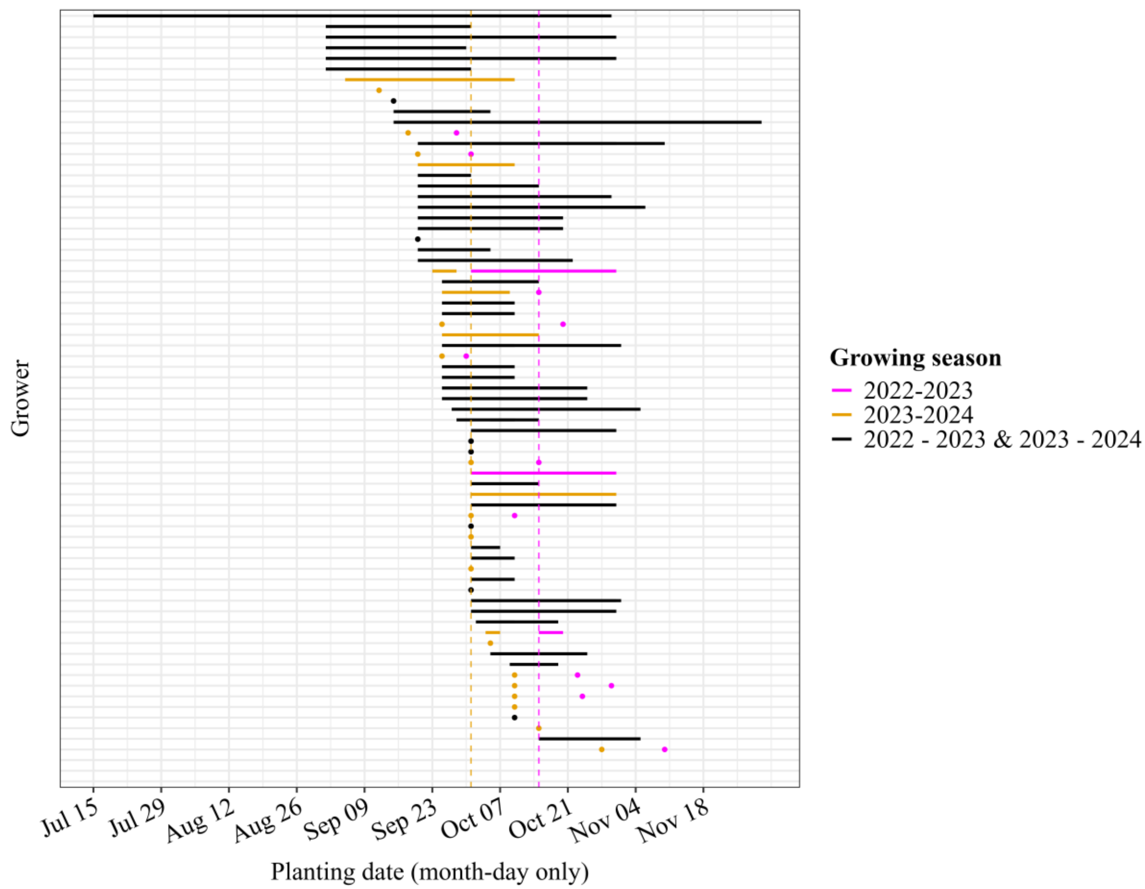
Growing season	Component	Number of respondents (%)
2022 - 2023	Insecticide	14 (19.2)
	Nutrient supplement	1 (1.4)
	Growth regulator	0
	Insecticide and nutrient supplement	2 (2.7)
	Insecticide and growth regulator	0
	Nutrient supplement and growth regulator	0
	All	1 (1.4)
	Non-response	55 (75.3)
2023 - 2024		
	Insecticide	15 (20.5)
	Nutrient supplement	1 (1.4)
	Growth regulator	2 (2.7)
	Insecticide and nutrient supplement	0
	Insecticide and growth regulator	0
	Nutrient supplement and growth regulator	0
	All	1 (1.4)
	Non-response	57 (74.0)

Figure 2.1. Heatmap of surveyed operations (left) and winter wheat acreage (ha) planted (right) in 2023 in Kansas.



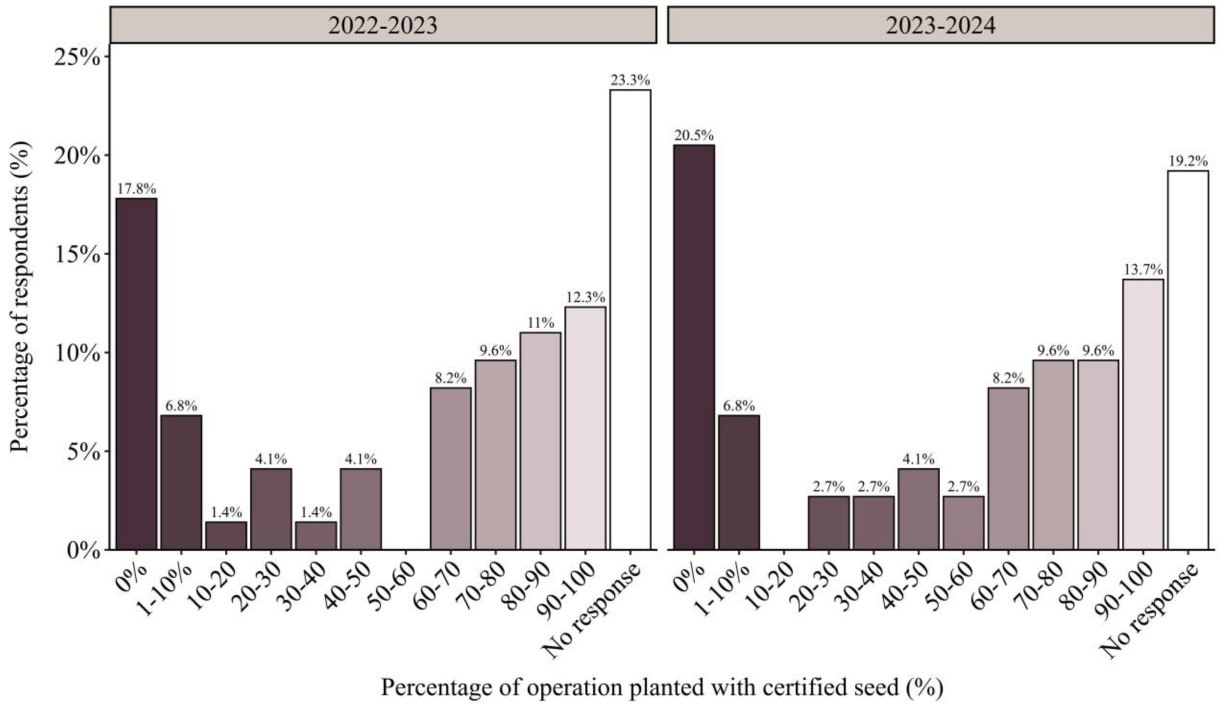
Location and number of respondent operations (left) that were reported by surveyed growers. Hectares of winter wheat planted in 2023 by Kansas counties (right). White counties indicate counties where acreage planted data was not available (USDA NASS, 2023).

Figure 2.2. Respondent reported planting date(s) for the 2022-23 and 2023-24 wheat growing seasons.



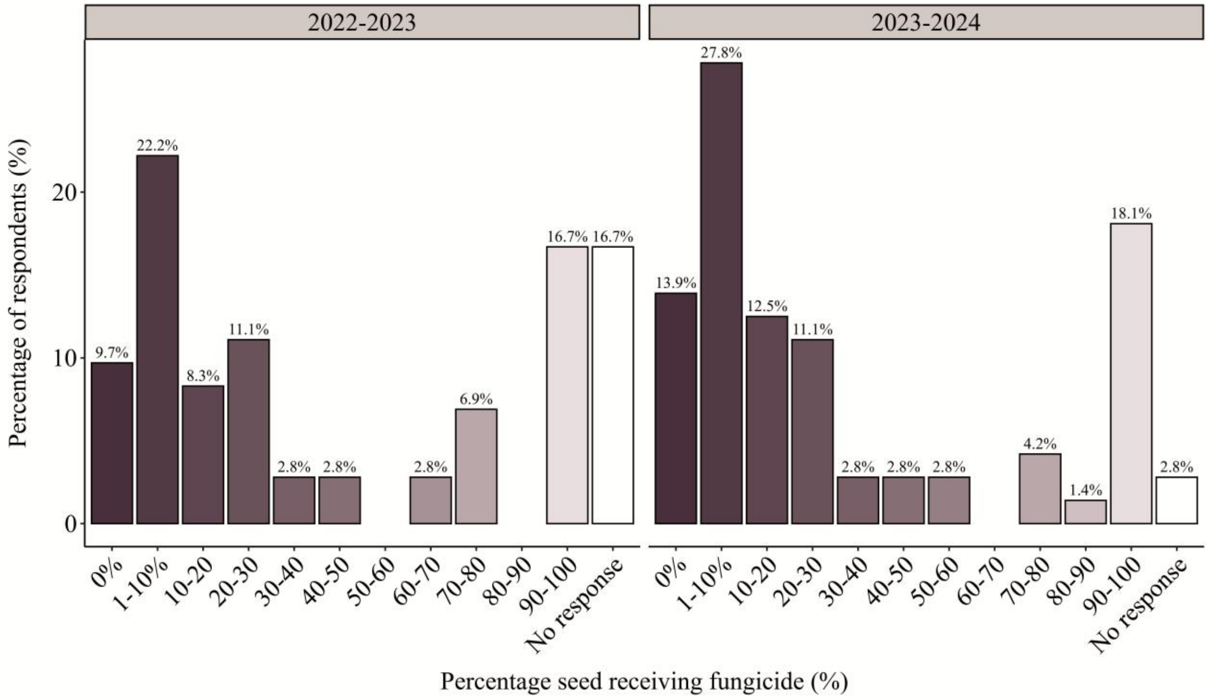
Summary of reported planting date(s) for the 2022-23 and 2023-24 wheat growing seasons across respondents. Points represent a single reported planting date for that season. Bars represent planting date windows where a producer may plant. Cyan represents dates reported for the 2022-23 growing season and yellow represents dates reported for the 2023-24 growing season. Black represents cases where respondents indicated a single planting date or date window across both seasons. Dashed lines indicate median planting dates across all growers within the respective season.

Figure 2.3. Reported percentage of operation planted with certified seed for the 2022-23 and 2023-24 growing seasons.



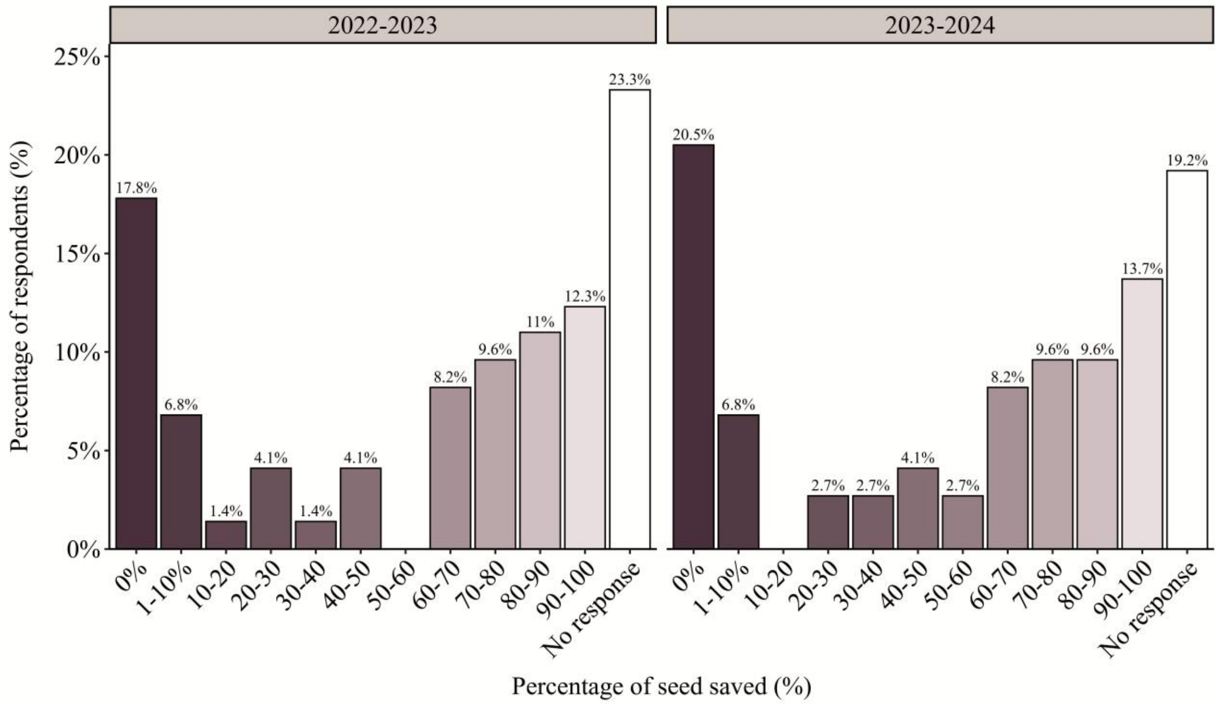
Growers were asked what percentage of their operation was planted with certified seed for both growing seasons (n = 73). Faceted plots represent bins from 0 – 100 percent with a separate bin for no response. Percentage of total respondents are located above each bar.

Figure 2.4. Respondent reported percentage of seed receiving a fungicide seed treatment for the 2022-23 and 2023-24 growing seasons.



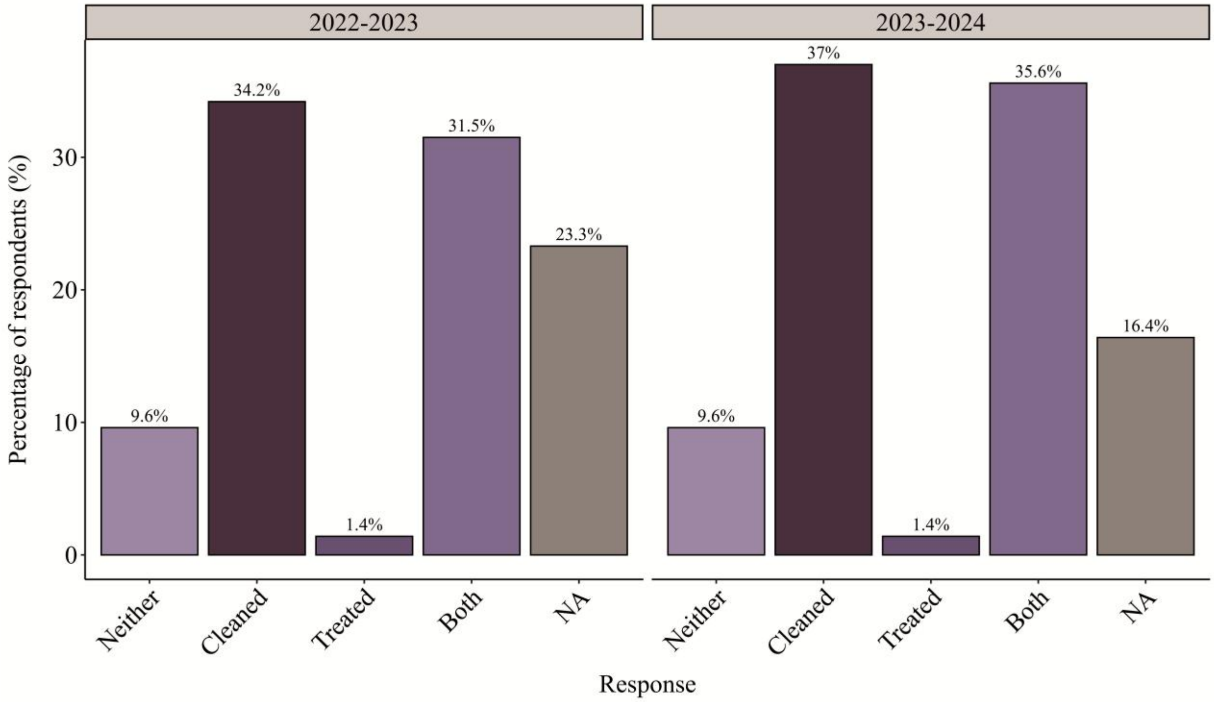
Growers were asked what percentage of their seed received a fungicide seed treatment for both growing seasons (n = 73). Faceted plots contain bins from 0 – 100 percent with a separate bin for no response. Percentage of total respondents are located above each bar.

Figure 2.5. Respondent reported percentage of seed saved on the farm from a previous season for the 2022-23 and 2023-24 growing seasons.



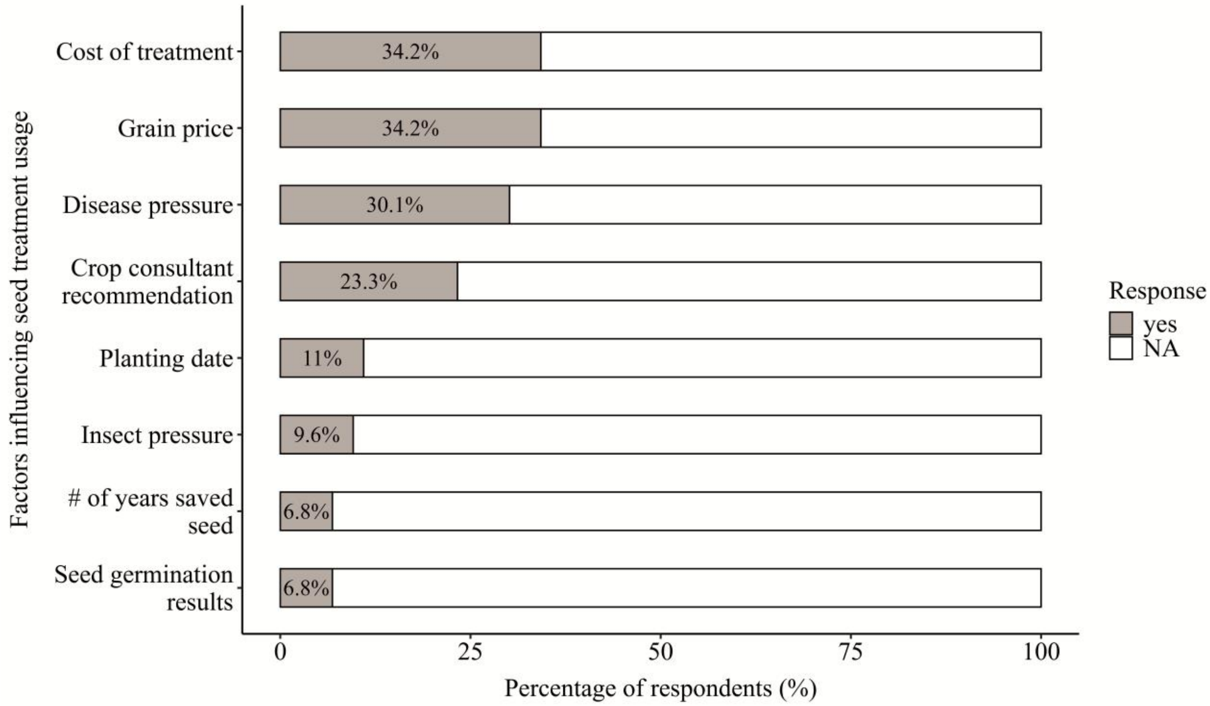
Growers were asked what percentage of their seed was saved from a previous growing season (n = 73). Respondents were able to list a single percentage. Faceted plots contain bins from 0 – 100 percent with a separate bin for no response. Percentage of total respondents are located above each bar.

Figure 2.6. Reported seed treatment and cleaning practices for saved seed lots in 2022-23 and 2023-24 growing seasons.



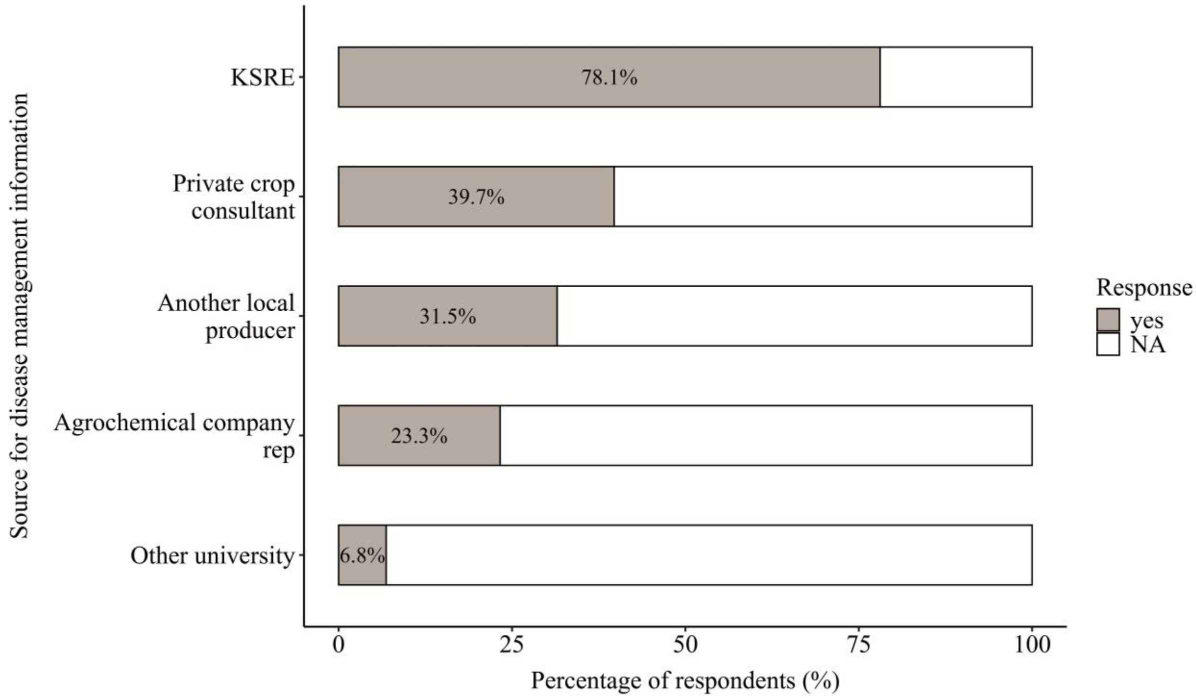
Growers were asked if they cleaned and/or treated their saved seed with a fungicide seed treatment (n = 73). Respondents were able to select four options: none, cleaned, treated, or both. Faceted plots contain the results of each selected option as well as an NA option for those who did not select an option. Percentage of total respondents are located above each bar.

Figure 2.7. Factors that influenced decisions to use a seed treatment.



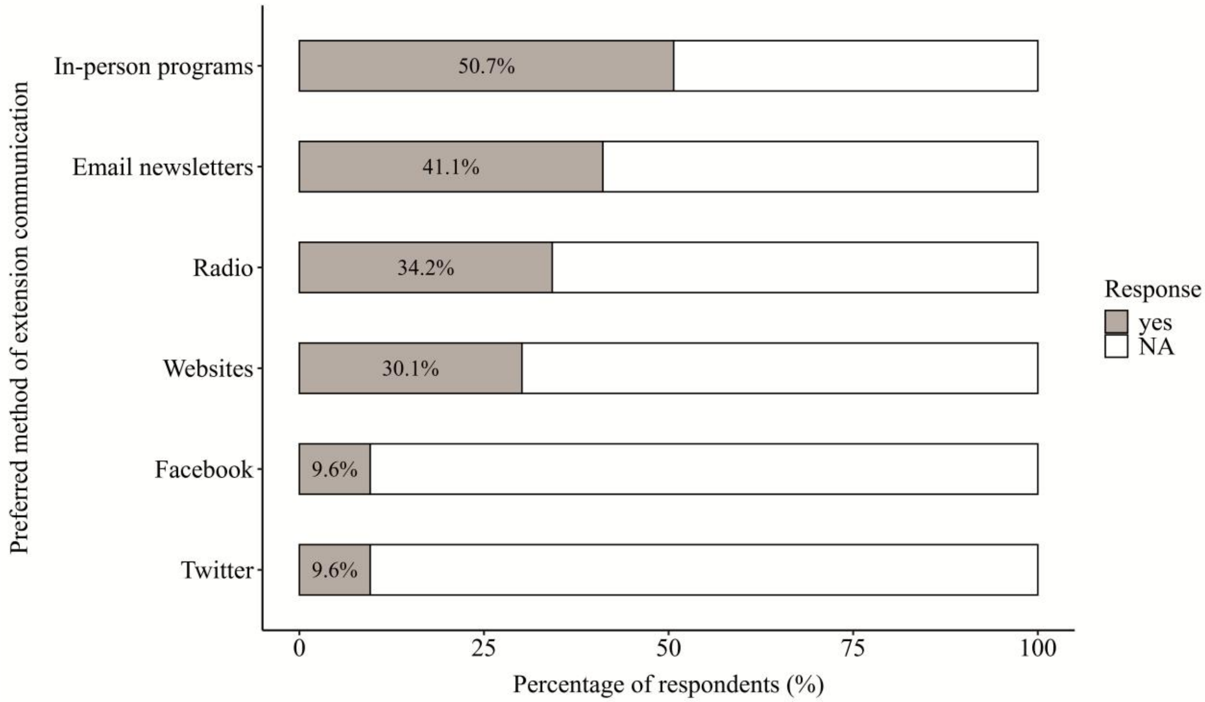
Growers were asked to select what factors influenced their decision to use a seed treatment. Respondents were presented with the eight factors above and were able to circle as many as desired. Bars display percentages of those who circled the factor (grey) or did not circle (white).

Figure 2.8. Preferred information sources for wheat disease management information.



Growers were asked to select what sources they preferred to receive wheat disease information. Respondents were presented with the five sources above and were able to circle as many as desired. Bars display percentage of those who circled the information source (grey) or did not circle (white).

Figure 2.9. Preferred methods for receiving information about wheat disease management



Growers were asked what their preferred methods for receiving information about wheat disease management. Respondents were presented with the six methods above and were able to circle as many as desired. Bars display percentage of those who circled the method of extension communication (grey) or did not circle (white).

Chapter 3 - Revisiting the Epidemiology of Common Bunt in Winter Wheat in Kansas

Introduction

Common bunt (caused by the fungal pathogens *Tilletia tritici* and *Tilletia laevis*) is a disease of wheat responsible for global yield losses (Matanguihan et al., 2011). During the grain fill stages of crop development, wheat kernels are replaced with bunt sori containing millions of teliospores. This disease is very difficult to detect prior to harvest due to very subtle pre-harvest symptoms (Mourad et al., 2018). During harvest, infected wheat heads are damaged and bunt sori break open, contaminating harvest equipment, soil, and healthy grain with teliospores. Large, dark clouds of spores can be seen during harvest under severe epidemic conditions, which can be a first indicator of a common bunt. Additionally, the production of trimethylamine within fungal sori results in a fish-like odor that is characteristic of this disease (Mathre et al., 2001). At grain elevators, smutted grain can lead to lots being discounted or rejected—resulting in both yield and quality losses.

Although the pathogens responsible for this disease can survive in the soil for up to two years, in most regions including Kansas, the pathogens are primarily seed-borne (Gaudet & Menzies, 2012). The infection cycle for *T. tritici* and *T. laevis* begins with the sowing of contaminated wheat seed. Teliospores on the seed surface germinate and infect the growing seedling near the soil surface (Mathre et al., 2001). The infection window is limited as the pathogens must colonize and invade the seedling coleoptile prior to emergence (Swinburne, 1963; Goates, 1996; Wegulo, 2009). Successful infection requires the synchronized germination and growth of both the teliospores and wheat seed. Seed treatments have become the key method for management of this disease as they can provide protection through seedling emergence and establishment.

Prior to the 1950s common bunt losses were significant and widespread in wheat growing regions across the world (Mathre, 2000). Although the disease is monocyclic, the disease can evade detection for numerous growing seasons, increasing inoculum levels over subsequent years of saving seed—leading to large outbreaks that appear sudden (Aboukhaddour et al., 2024). However, modern systemic fungicides can result in excellent disease control, leading to an overall decline in prevalence of this disease (Goates, 1996). In the United States, a majority of breeding initiatives have deprioritized common bunt resistance development and resistance gene deployment due to the success of fungicide seed treatments (Matanguihan et al., 2011). In Kansas there are a wide variety of commercially available seed-treatment products that prevent common bunt infection, with recent studies demonstrating the continued effectiveness of these chemistries in controlling the disease (Abshire, 2023). Despite this, common bunt continues to cause losses worldwide. In organic production systems and developing countries, where fungicide seed treatments are unavailable or not allowed, the disease remains economically significant (Lunzer et al., 2023; Matanguihan et al., 2011).

In Kansas, there have been reports in recent years of an increase in discounts and rejections due to common bunt, necessitating re-evaluation of current management recommendations. While current management guidelines recommend the purchase of certified seed and use of a fungicide seed treatment for common bunt control, other recommendations include planting earlier into warmer soil conditions to avoid the optimal infection temperatures previously described in the literature (Gaudet & Puchalski, 1990; Goates, 1996; Holton & Heald, 1941). However, the current literature provides contrasting conclusions on the influence of planting date and environmental conditions such as soil temperature and soil moisture on common bunt infection.

Factors influencing germination and infection of fungal spores can include—but are not limited—to soil temperature, soil moisture, sunlight, pH, and available environmental nutrients (Allen, 1976; Daniels & Trappe, 1980; Guillemette, 1989). Under controlled environmental conditions Purdy and Kendrick (1975) described the fastest teliospore germination of both species to occur within 3-7 days at 15-17°C in soil. Germination was also high at temperatures of 5°C and 10°C after 10 days (Purdy & Kendrick, 1957). Both *T. laevis* and *T. tritici* do not require sunlight to germinate and lack a dormancy period (Hoffman, 1982; Trione, 1972; Zscheile, 1965). Additionally, acidic, clay, or sandy soils may inhibit spore germination (Fischer & Holton, 1957). Despite slight differences in isolate germination rates of *T. tritici* and *T. laevis*, examinations using a single isolate can generally be applied to others (Abshire, 2023; Lowther, 1950; Metzger & Trione, 1962).

Literature on the relationship between environmental conditions and infection are both limited and conflicting. For seedborne spores, Kendrick and Purdy (1959) provided some of the first investigations on the common bunt pathogen's infection requirements. In these studies, investigators evaluated the influence of soil temperature and soil moisture on infection in a controlled environment setting assessing soil temperatures ranging from 5-25 °C and various levels of soil moisture. In these experiments, soil moisture levels of 24% and 10.8% correspond with the 1/3 atmosphere value (soil field capacity) and 15-atmosphere values (permanent wilting point) respectively and levels represent the moisture available for plant growth. Investigators reported the optimum conditions for infection to be 10°C at 13% soil moisture. Infection levels were also high at soil temperatures of 15°C and 5°C, but steeply dropped at 20°C (less than 5%).

Infection did not occur at 25°C. Bunt incidence was high at most moisture levels, but dropped near 10% (wilting point) and was absent at 9%. This study established the importance of soil temperature (Kendrick & Purdy, 1959). However, the methodology used by Kendrick and Purdy to establish soil moisture levels in their experiments did not include efficient soil drying, which may have impacted conclusions. In a study done with spring wheat, susceptible cultivar incidence had a negative association with 35-day average air and soil temperature following sowing (Gaudet & Puchalski, 1990).

In a study conducted in Sweden, Johnsson (1992) examined climate factors influencing infection of common bunt in winter wheat. Field experiments narrowed the optimal air temperature for infection to between 6°C-7°C, with the 10 days following planting having the strongest association with incidence. Additionally, precipitation and snow cover had no correlation with infection (Johnsson, 1992; Lunzer et al., 2023). Liatukas and Ruzgas (2009) investigated the effect of air temperature on common bunt infection in winter wheat by using mean temperature intervals up to 190 days following sowing. They found a significant correlation ($r = 0.6$) between mean air temperature and infection on the 36th day (30 – 190 interval). They described the influence of post-sowing temperatures to be low as similar post-sowing temperatures resulted in vastly different final infection levels when comparing results across years. Additionally, the presence of heavy frosts with thin snow cover led to lower mean infection levels compared to heavy frosts with thicker snow covers which led to high infection levels. In some cases, planting date recommendations may not be sufficient enough to predict infection levels. Gaudet et. al (2013) investigated seeding date and location impacts on winter wheat infection in Kansas. Investigators report that high infection levels were observed in both cases of early and late seeding treatments, despite the notion that an earlier sowing results in decreased infection (Gaudet et al., 2013).

It is important to revisit key conditions that influence common but infection to better optimize management recommendations for the region. Thus, the objectives of this study were to 1) evaluate the influence of planting date on common bunt incidence under natural Kansas field conditions; 2) associate the influence of environmental predictors during critical windows around planting on common bunt incidence, and 3) compare various sources of weather information for informing environmental predictors.

Materials and Methods

Field experiment establishment

A field experiment was conducted to assess the influence of planting date conditions on common bunt establishment under field conditions. This experiment was established at two locations during the 2023 – 24 winter wheat growing seasons; the Rocky Ford Experiment Field Station (39°13’46” N, 96°34’45” W) in Manhattan, KS and the Ashland Bottoms Experiment Station (39°08’25” N, 96°27’54” W) in Manhattan, KS. The trial was carried out as a randomized complete block design with four replications. All treatments were inoculated with the same concentration of spores. Experimental plots were single rows of 0.3 m x 0.3 m (Figure 3.1).

Treatments consisted of 12 planting dates, approximately one week apart. Due to plot availability, the Rocky Ford location was set up a week prior to the Ashland Bottoms location. Planting dates for the Rocky Ford location was: 19 September, 26 September, 3 October, 10 October, 17 October, 24 October, 31 October, 7 November, 14 November, 21 November, 28

November, and 5 December of 2023. The planting dates for the Ashland Bottoms locations were: 26 September, 3 October, 10 October, 17 October, 24 October, 31 October, 7 November, 14 November, 21 November, 28 November, 5 December, and 12 December of 2023.

On the day of the respective treatment, the inoculated seed was hand-sown approximately 3.8 cm - 5 cm deep in a straight line at 23 seeds per plot/treatment. Inoculated seeds were sown 1.25 cm apart. This was done by digging a 30 cm x 3.8 cm - 5 cm in deep furrow and laying a ruler length-wise. Using a forceps, inoculated seeds were placed approximately 1.25 cm apart and then covered gently with soil to prevent compaction. Any remaining inoculated seed not planted in the field was planted in controlled environment settings to validate infection levels in the field as described above.

A TEROS 12 (Meter Group AG, Pullman, WA, USA) soil sensor was installed within the middle of the each of the four blocks. Shallow soil trenches were dug until the sensor was able to fit horizontally at a depth of 5 cm. While digging trenches, it was critical that the surface of one side of the trench remained vertical and flat, while ensuring large objects such as roots or rocks were avoided. Sensors were carefully pressed into the vertical trench side while minimizing disturbance, which prevents air gaps that may result in low soil moisture readings. Soil was carefully added from the bottom up, taking care to add soil under and around the sensor. Once trenches containing the sensors were filled, flags were placed around the burial site to minimize compaction and disturbance from walking. HOBO Micro Station data loggers with external sensors were also installed at the center of each experiment (Figure 3.1).

Inoculum preparation and production

Inoculum concentrations of KS isolate KS0002 were increased using the common bunt susceptible variety cultivar “Apogee”. To produce approximately 28 grams of inoculum, 35 grams of seed were inoculated at approximately a 1% (w/w) rate (Saari & Burnett, 1996). To accomplish this, bunt balls were added to Ziploc bags and carefully crushed to release the teliospore. Seed was added and lightly shaken to evenly coat the seed coat and prevent fracturing of teliospores (Saari & Burnett, 1996). Inoculated seeds were planted in square plastic plant pots (14 cm x 13 cm with 9 cm depth) at a rate of 5 seeds per pot. Soil was added and thoroughly soaked prior to planting. Watering immediately after planting is not recommended as spores may be removed from seed coats if water is added right away. Seeds were planted at a depth of approximately 2.5 cm, with a seed located near each pot corner and one in the middle. Seed holes were closed up by pinching the soil surface to cover. Pots were moved to a 5 °C cold room for approximately two weeks or until emergence occurred. Plants were lightly watered once a week to ensure adequate soil moisture. Following emergence, plants were moved to a greenhouse for the remainder of plant growth. Infected wheat heads were harvested at plant maturity and hand threshed by gently crushing wheat to expose bunt sori. Chaff and awns were separated from bunt sori prior to storage.

Seed inoculation

Untreated winter wheat seed of the common bunt susceptible variety cultivar “SY Wolf” was inoculated and prepared on the day if its respective planting date. “SY Wolf” was selected due to its known susceptibility to common bunt and historical availability in Kansas over the last decade (USDA NASS, 2023). Approximately 5 grams of seed were inoculated per planting date treatment (per location) at a 1% (w/w) rate as described by Saari and Burnett (Saari & Burnett, 1996). Bunt balls were weighed and added to plastic Ziploc bags and crushed to release teliospores. Seeds were combined with teliospores and lightly shaken until the seed coat was visibly covered. Shaking vigorously fractures teliospores and reduces viability (Saari & Burnett, 1996).

To ensure inoculum viability, a 1g allocation of the inoculated seed from each planting date was planted in square plastic plant pots (14 cm x 13 cm with 9 cm depth) at a rate of 5 seeds per pot, in the same manner described above for inoculum production. Soil was added and thoroughly soaked prior to planting. Seeds were planted at a depth of approximately 2.5 cm, with a seed located near each pot corner and one in the middle. Pots were moved to a 5°C cold room for approximately 8 weeks to ensure vernalization requirements for the host were met. Plants were lightly watered once a week to ensure adequate soil moisture. After the 8 week vernalization period, plants were moved to a greenhouse until maturity. Infected wheat heads were harvested at plant maturity and evaluated for the presence of common bunt to validate spore viability on the respective planting date.

Measures of environmental variables and soil meter installation

TEROS 12 (Meter Group AG, Pullman, WA, USA) soil sensors were utilized to accurately monitor hourly soil temperature, soil moisture, and electrical conductivity throughout the duration of the experiment. Data was recorded on ZL6 Basic Data Loggers (Meter Group AG, Pullman, WA, USA). Hourly air temperature readings for the surrounding areas were provided by two different sources. First, HOBO Micro Station data loggers with external sensors (Onset Computer Corporation, Bourne, MA USA) were placed in each experimental location, within the experimental plots. Second, we evaluated the data collected by the Kansas State

University Mesonet weather stations which were located on the experimental farms, but not within the experiments. HOBO Micro Station Data loggers also collected data on leaf wetness, light intensity, precipitation, and relative humidity. Mesonet data also included data on average relative humidity (2 m), average soil temperature (10 m), average soil temperature (5 m), wind direction, and wind speed. Air temperature from the Mesonet was recorded at 2 m.

Field and disease evaluations

Emergence was assessed for each plot on a weekly basis until emergence was complete by conducting a stand count for each plot (number of plants per row emerged). Average height measurements were collected on 14 May, 2024 by taking a measurement from the soil to the tip of awns from the center of each 30 cm plot. The plots at the Rocky Ford Experiment Field Station and Ashland Bottoms Experiment Station were harvested on 23 June, 2024 and 24 June, 2024 respectively. Each treatment was hand harvested by individually collecting every wheat head and transporting back to the lab to rate incidence. Each individual wheat head was gently hand-threshed and evaluated for the presence of common bunt. Heads were scored as either healthy or infected based on the presence of bunt sori (incomplete infection of a head is rare). Incidence was evaluated as the total number of heads per plot with bunt infection.

Effect of planting date on disease incidence and height

All data analysis was conducted in the R programming software (R Core Team, 2024). Initially, an analysis of variance using the function “aov” from the base R package “stats” was used to evaluate the influence of planting date on disease incidence for each location independently. Both planting date and block were treated as a categorical fixed effects in this initial analysis. Treatment means were compared using Fisher's Least Significant Difference (LSD). A similar analysis was run for plant height, for each location. To understand the influence of disease incidence on plant height, a linear mixed effect model was fit for each location with disease incidence treated as a fixed effect and rep as a random effect.

Meteorological data and predictor summaries

In addition to understanding the influence of planting date on common bunt incidence, we were also interested in assessing the potential influence of environmental conditions on disease development. To do this, epidemiologically relevant predictors were summarized across the three previously described data sources. As an overall goal of this study was to identify key environmental variables to help inform disease risk at planting, we made the decision to summarize weather variables for four fixed-length time windows around planting date, including 14- and 7-days pre-planting and 7- and 14-days after planting. Summarized weather predictors for each time window did not include the day of planting but rather the first day before or after each treatment date. In total, the dataset included 108 predictors (Table 3.1).

Due to normal delays in field and seedbed preparation, soil sensor and HOBO Micro Stations were installed the day prior to the beginning of the first planting date. This resulted in missing data for the pre-planting time windows for some predictors in the earliest planting dates. Additionally, for average soil moisture recorded from soil sensors, it was advised that readings prior to the first precipitation event should be discarded as precipitation is required to establish soil saturation and drying. Therefore, precipitation was evaluated beginning on 22 September, 2023 for Rocky Ford and 3 October, 2023 for Ashland Bottoms.

Influence of environmental predictors on disease incidence

To assess the relationship between weather predictors and disease incidence we fit a linear mixed effects regression model to the data assuming a Gaussian distribution, where block was treated as random effects and the weather predictor was treated as a continuous fixed effect. Location was removed to improve parsimony after preliminary model assessment revealed that it was not resulting in a significant reduction in the likelihood ratio. The model was fit using the package "lme4" and function *lmer* (Bates et al., 2015).

Historic summaries of air temperature

Historical weather data from Kansas was explored to evaluate the frequency of the conditions identified in previous part of the analysis. To accomplish this, 10 years of weather data was obtained from the Kansas Mesonet weather stations (2015-2025). Data consisted of hourly air temperature (2m) observations for all Mesonet stations located across Kansas. In total, 14 Mesonet stations were retained due to data completeness: Tribune and Tribune 6NE in Western Kansas, McPherson and Washington in Central Kansas, and Haskell, Ottawa 2SE, Overbrook, Sedan, Sheridan, Sherman, Spearville, Stanton, Wallace, and Woodson in Eastern Kansas. Conditions matching the best identified predictors were summarized for all days in the fall when winter wheat planting could take place (September – December).

Results

Summary of weather across locations

The highest average daily soil temperatures at the Rocky Ford and Ashland Bottoms locations were recorded on 30 September 2023, at 29.2°C and 28.1°C, respectively. The lowest average daily soil temperature was recorded on 25 November 2023, at 1.23°C and 0.48°C for Rocky Ford and Ashland Bottoms, respectively (Figure 3.2). It should be noted that the soil moisture sensors can fail at below freezing temperatures and thus moisture and temperature conditions under sub-zero soil temps were not captured. Weather from the K-State Mesonet weather stations indicated that the highest average daily air temperatures at the Rocky Ford and Ashland Bottoms farms were 28.2°C and 28.0°C, recorded on 30 September, 2023, respectively. The lowest average daily air temperature at both locations was recorded on 25 November 2023 and was -3.03°C for Rocky Ford and -3.12°C for Ashland Bottoms (Figure 3.4). Similar air temperatures were recorded from the HOBO Micro Station data loggers which were installed within the experiments (Figure 3.5).

For precipitation, the first precipitation event recorded by soil sensors for Rocky Ford occurred on 22 September, 2023. For Ashland Bottoms, the first precipitation event recorded by soil sensors occurred on 3 October, 2023. The date with the highest amount of precipitation occurred on 19 November, 2023 at 25 mm and 28.2 mm for the Rocky Ford and Ashland Bottoms locations respectively (Figure 3.6). The date with the highest average soil moisture for both locations occurred on 1 December, 2023 and was 0.304 m^3/m^3 and 0.345 m^3/m^3 for Rocky Ford and Ashland Bottoms respectively. The date with the lowest average soil moisture for both locations occurred on 3 October, 2023 and was 0.122 m^3/m^3 and 0.078 m^3/m^3 for Rocky Ford and Ashland Bottoms respectively (Figure 3.3).

Pairwise correlations of soil temperature, air temperature measured within the experimental plots, and air temperature from the Mesonet (Figure 3.7) show strong consistency between all three sources. Mesonet and weather air temperatures demonstrated a near 1:1 strong positive linear relationship (R^2 = 0.993, r = 0.997). The relationships between air and soil temperatures are strong, but demonstrated greater variation, with soil temperature increasing at a slower rate compared to air temperature. This may be attributed to the capacity of the soil to buffer temperatures.

Influence of planting date on disease incidence

Two treatments at Rocky ford (19 September & 3 October, 2025) and one treatment at Ashland (3 October, 2025) died due to an unknown cause. In late February these treatments appeared to have extreme necrosis on a majority of leaf blades that originated from tips. These plants did not survive. These planting dates were removed from analysis. For each location, there was a significant effect of planting date on disease incidence ($P < 0.0001$, Table 3.2). The dates with the highest average disease incidence were recorded for the Rocky Ford location were 14 November and 7 November, resulting in 88.44% and 83.9% incidence respectively. The highest average disease incidence recorded for the Ashland Bottoms locations also occurred on the 14 November planting date, and was 87.15%. For both locations, the lowest average disease incidence recorded occurred on the 13 September planting date and was 13.71% and 5.56% for Rocky Ford and Ashland Bottoms, respectively (Table 3.2). Generally, disease incidence increased from 01 September to 15 November, 2023, then decreased 15 November to 5 December, 2023 (Figure 3.8).

Plant height

Planting date also significantly influenced plant height ($p < 0.0001$, Table 3.2). For the Ashland Bottoms location, average plant height appeared to decrease from 26 September to 21 November. After 21 November, average plant height appeared to increase through 12 December, 2023. For the Rocky Ford location, plant height also generally followed a similar pattern. From 17 October to 7 November, 2023 plant height decreased. Between 7 November and 21 November, 2023 average height did not vary greatly. Following 21 November, average plant height appeared to increase (Figure 3.9). The greatest average height at the Rocky Ford and Ashland Bottoms locations were planted on 17 October and 26 September respectively, at 87.38 cm and 82.37 cm. The lowest average height at the Rocky Ford and Ashland Bottoms locations were planted on 7 November and 21 November, 2023 respectively, at 65.41 cm and 63.80 cm (Figure 3.9).

Additionally, the effect of disease incidence on plant height was highly significant for both Rocky Ford ($p<0.0001$, R^2) and Ashland Bottoms ($p< 0.001$, R^2) (Figure 3.10). However, this result may be confounded by the agronomic influence of late planting on height.

Emergence data summary

Generally, time to emergence varied from approximately 7 to 14 days from 26 September to 31 October, 2023. From 7 November to 21 November, 2023 emergence appeared to occur between 14 and 21 days. After 21 November, emergence consistently occurred around approximately 21 days (Figure 3.11). Stand counts following emergence for 05 and 12 December were not taken. It is possible stand counts may have increased past 21 days.

Influence of environmental predictors on disease incidence

Single predictor models were compared within each of the four time windows and the top performing models were retained based on fit statistics including conditional R^2, marginal R^2, AIC, and log likelihood (Table 3.3). Interestingly, the best pre-planting predictors were the accumulation of hours where the soil temperature was between 5 and 10 ℃ and 5 and 15 ℃. The highest marginal R^2 and lowest AIC observed for the accumulation of hours where soil moisture was between 5 ℃ and 10 ℃ in the 14 days weeks prior to planting (R^2_{m}. = 0.38, AIC = 604, Table 3.2). The accumulation of hours where soil temperatures were between 5 and 10 ℃ was the best fitting predictor for the 7 days after planting (R^2_{m}.= 0.40, AIC = 600). The accumulation of hours where the air temperature was between 5 ℃ and 10 ℃ was the best fitting model for the 14-day window after planting (R^2_{m}. = 0.41, AIC = 600) (Figure 3.12).

Summary of historical weather data from Kansas

Cumulative hours where air temperatures were between 5-10℃ was consistently an important predictor. Therefore, we selected these conditions to summarize across historical Kansas weather data (Figure 3.13). Generally, over the 10 years summarized, the number of average daily hours where temperatures were between 5-10°C increased and remained consistently high in October (Figure 3.13). For the weather stations in Eastern Kansas, the range of dates with the highest average number of hours where temperatures were between 5-10°C ranged from 24 October to 21 November. For the two stations in Western Kansas, the dates were 24 September (9.12 hours) and 7 October (8.38 hours). For the two stations in Central Kansas, the dates were 4 November (10 hours) and 5 November (11.1 hours) (Table 3.4).

Similarly, the number of average cumulative hours in the 14 days following each calendar date where temperatures were between 5-10°C also generally increased and remained consistently higher began in October (Figure 3.14). For the stations in Eastern Kansas, the dates with the highest average hours where temperatures were between 5-10°C (during the 14 days after each date) ranged between 11 October and 28 November. For the two stations in Central Kansas, the dates were 23 October (97.9 hours) and 30 October (98.4 hours). For the two stations in Western Kansas, the dates were 11 October (86.2 hours) and 17 October (84.9 hours) (Table 3.5).

Discussion

There have been relatively few studies examining the influence of planting date and weather on common bunt incidence, particularly in Kansas, despite the fact that this disease remains important regionally. In this study we found that disease incidence appeared to increase into mid-November, then decrease later into December across both locations. There is evidence that disease incidence differed across the planting dates considered in this study. This suggests that environmental conditions at or around planting likely influenced the infection process and subsequent disease development. Interestingly, predictors that summarized soil or air temperature between 5-10℃ before or after planting appeared to have the strongest association with incidence. These results are reasonably consistent with the literature as temperatures between 5-10℃ were found to be optimal temperature for infection in controlled environmental studies (Kendrick & Purdy, 1959). Historically, these results have influenced planting date recommendations, as a general consensus was that cool soil temperatures increase disease incidence (Gaudet & Puchalski, 1990).

Interestingly, weather variables that included moisture and precipitation were generally less important than temperature across models and time-windows. These results suggest that either moisture did not play a significant role in influencing disease incidence in these experiments, that moisture was not limited in these locations and a broader range of conditions needs to be explored in the future, or that our summaries of soil moisture variables were insufficient to capture any trends. These findings are supported by those of Kendrick and Purdy (1959), who reported high disease incidence for all levels of moisture that were above the soil's permanent wilting point (Kendrick & Purdy, 1959). Similarly, Johnnsson (1992) also reported that precipitation had no influence on disease incidence (Johnsson, 1992).

Our results suggest increased disease incidence is associated a reduction in plant height. However, we acknowledge that our data is confounded with planting date effects since these can also impact plant height; thus, we cannot conclude a cause-effect relationship between disease incidence and plant height. Previous literature has described a negative relationship between common bunt infection and plant height (Dumalasová & BarToš, 2007), but that it can vary widely across different cultivars (Gaudet et al., 1991). Stunting or reductions in plant height are more commonly reported for dwarf bunt, a disease caused by the close relative *Tilletia controversa* Kuhn (Goates, 1996; Muhae-Ud-Din et al., 2020). Plant stunting caused by common bunt may cause diseased plants to lie lower in the plant canopy, which complicates scouting efforts.

A producer's decision to plant is influenced by a variety of factors including environmental conditions and agronomic considerations. In Kansas, the current recommendations for planting are based on geographical location in four distinct climate zones. Planting date recommendations range from September 10th to October 25th, with the Northwest

Kansas recommended end date being September 13th and the Southeast Kansas recommended end date being October 25th (Shroyer et al., 1996). Planting during these optimal windows ensures optimal tillering occurs in the spring that minimizes inter-tiller competition and maximizes grain yield (Thirty et al., 2002). An optimum planting date also suggests that yield reductions are expected when planting earlier or later than the optimum peak (Jaenisch et al., 2021; Munaro et al., 2020). Across several years in the Midwest, delayed planting past late-September decreased kernel weight and yield (Dahlke et al., 1993). However, these recommendations are a suggestion and adjustments to planting date may be made due to other pest and disease considerations. For example, planting too early increases the risk of viral wheat diseases, such as wheat streak mosaic virus (WSMV), barley yellow dwarf virus (BYDV), high plains virus (HPWMoV), and Triticum mosaic virus (TriMV), as well as insect pests such as Hessian fly (*Mayetiola destructor*). Additionally, early seeding can leave seedlings at an increased risk for root diseases such as take-all or dryland root rot (Lollato et al., 2024).

Recommendations to avoid early planting conflict with the current recommendation of planting early in warm soils to minimize infection by the common bunt pathogens. Based on historical air temperature data collected from K-State Mesonet weather stations over ten years, temperatures between 5-10°C generally increased and remained higher the beginning of October. Planting dates that occur past 1 October may be at an increased risk for common bunt development. However, additional work is needed to operationalize the results from these studies to inform planting decisions for Kansas farmers.

Overall, our results support the importance of previously described temperatures for infection. However, low marginal R^2 values suggests model improvement is possible. There may be select environmental variables that were left unexplored, or predictors we created did not summarize effectively. The window for infection is brief; it requires simultaneous conditions that promote spore germination and wheat seed germination. Future work should prioritize additional data and factors such as wheat germination requirements or growing degree days until emergence to better describe this critical infection period. Improved models will help further refine management recommendations in the region.

Table 3.1. List of environmental predictors used in data analysis.

Environmental variables	Measurement source	7 days before planting	14 days before planting	7 days after planting	14 days after planting
Average moisture (m3/m3)	TEROS 12 Soil Sensor	avg_moisture_7_days_before	avg_moisture_14_days_before	avg_moisture_7_days_after	avg_moisture_14_days_after
Number of hours soil temperature was between 5 - 10°C	TEROS 12 Soil Sensor	5_10C_7_days_before	5_10C_14_days_before	5_10C_7_days_after	5_10C_14_days_after
Number of hours soil temperature was between 5 - 15°C	TEROS 12 Soil Sensor	5_15C_7_days_before	5_15C_14_days_before	5_15C_7_days_after	5_15C_14_days_after
Number of hours soil temperature was between 5 - 20°C	TEROS 12 Soil Sensor	5_20C_7_days_before	5_20C_14_days_before	5_20C_7_days_after	5_20C_14_days_after
Number of hours soil temperature was between 5 - 25°C	TEROS 12 Soil Sensor	5_25C_7_days_before	5_25C_14_days_before	5_25C_7_days_after	5_25C_14_days_after
Number of hours soil temperature was below 25 °C	TEROS 12 Soil Sensor	below_25C_7_days_before	below_25C_14_days_before	below_25C_7_days_after	below_25C_14_days_after
Number of hours soil temperature was below 20 °C	TEROS 12 Soil Sensor	below_20C_7_days_before	below_20C_14_days_before	below_20C_7_days_after	below_20C_14_days_after
Number of hours soil temperature was below 15 °C	TEROS 12 Soil Sensor	below_15C_7_days_before	below_15C_14_days_before	below_15C_7_days_after	below_15C_14_days_after

Number of hours soil temperature was below 10 °C	TEROS 12 Soil Sensor	below_10C_7_days_before	below_10C_14_days_before	below_10C_7_days_after	below_10C_14_days_after
Number of hours soil temperature was below 5 °C	TEROS 12 Soil Sensor	below_5C_7_days_before	below_5C_14_days_before	below_5C_7_days_after	below_5C_14_days_after
Maximum soil temperature °C	TEROS 12 Soil Sensor	max_temp_7_days_before	max_temp_14_days_before	max_temp_7_days_after	max_temp_14_days_after
Minimum soil temperature °C	TEROS 12 Soil Sensor	min_temp_7_days_before	min_temp_14_days_before	min_temp_7_days_after	min_temp_14_days_after
Maximum soil moisture (m3/m3)	TEROS 12 Soil Sensor	max_moisture_7_days_before	max_moisture_14_days_before	max_moisture_7_days_after	max_moisture_14_days_after
Minimum soil moisture (m3/m3)	TEROS 12 Soil Sensor	min_moisture_7_days_before	min_moisture_14_days_before	min_moisture_7_days_after	min_moisture_14_days_after
Number of hours air temperature was between 5 - 10°C	HOBO Micro Station	5_10C_air_7_days_before	5_10C_air_14_days_before	5_10C_air_7_days_after	5_10C_air_14_days_after
Number of hours air temperature was between 5 - 15°C	HOBO Micro Station	5_15C_air_7_days_before	5_15C_air_14_days_before	5_15C_air_7_days_after	5_15C_air_14_days_after
Number of hours air temperature was between 5 - 20°C	HOBO Micro Station	5_20C_air_7_days_before	5_20C_air_14_days_before	5_20C_air_7_days_after	5_20C_air_14_days_after
Number of hours air temperature was between 5 - 25°C	HOBO Micro Station	5_25C_air_7_days_before	5_25C_air_14_days_before	5_25C_air_7_days_after	5_25C_air_14_days_after

Number of hours air temperature was below 25 °C	HOBO Micro Station	below_25C_air_7_days_before	below_25C_air_14_days_before	below_25C_air_7_days_after	below_25C_air_14_days_after
Number of hours air temperature was below 20 °C	HOBO Micro Station	below_20C_air_7_days_before	below_20C_air_14_days_before	below_20C_air_7_days_after	below_20C_air_14_days_after
Number of hours air temperature was below 15 °C	HOBO Micro Station	below_15C_air_7_days_before	below_15C_air_14_days_before	below_15C_air_7_days_after	below_15C_air_14_days_after
Number of hours air temperature was below 10 °C	HOBO Micro Station	below_10C_air_7_days_before	below_10C_air_14_days_before	below_10C_air_7_days_after	below_10C_air_14_days_after
Number of hours air temperature was below 5 °C	HOBO Micro Station	below_5C_air_7_days_before	below_5C_air_14_days_before	below_5C_air_7_days_after	below_5C_air_14_days_after
Maximum air temperature °C	HOBO Micro Station	max_air_temp_7_days_before	max_air_temp_14_days_before	max_air_temp_7_days_after	max_air_temp_14_days_after
Minimum air temperature °C	HOBO Micro Station	min_air_temp_7_days_before	min_air_temp_14_days_before	min_air_temp_7_days_after	min_air_temp_14_days_after
Number of hours air temperature was between 5 - 10°C	K-State Mesonet	5_10C_mesonet_air_7_days_before	5_10C_mesonet_air_14_days_before	5_10C_mesonet_air_7_days_after	5_10C_mesonet_air_14_days_after
Cumulative precipitation	K-State Mesonet	cum_precip_7_days_before	cum_precip_14_days_before	cum_precip_7_days_after	cum_precip_14_days_after

Four predicators were created for each environmental variable by looking at conditions 7 days before, 14 days before, 7 days after, and 14 days after planting. In total, there were 108 predictors examined.

Table 3.2. Average disease incidence and standard deviation for different planting date treatments at the Rocky Ford and Ashland Bottoms locations. Means followed by the same letter are not significantly different from one another based on Fisher's LSD.

	Rocky Ford		**Ashland Bottoms**	
Planting date	**Average disease incidence (%)**	**Average plant height (cm)**	**Average disease incidence (%)**	**Average plant height (cm)**
9/26/2023	13.71 d	82.7 abc	5.56 f	82.37 a
10/10/2023	32.29 c	87.0 ab	24.61 e	80.31 ab
10/17/2023	22.02 cd	87.47 a	42.39 cd	77.47 abc
10/24/2023	59.23 b	81.43 bc	43.12 cd	73.33 bcd
10/31/2023	30.09 cd	81.28 c	40.76 cde	69.22 de
11/7/2023	83.92 a	65.41 d	68.29 b	65.41 e
11/14/2023	88.44 a	66.34 d	87.16 a	66.52 de
11/21/2023	61.39 b	66.82 d	64.5 b	63.83 e
12/5/2023	33.93 c	70.18 d	55.88 bc	69.22 de
12/12/2023	-	-	27.31 de	72.69 cd
p-value	< 0.0001	< 0.0001	<0.0001	<0.0001

Table 3.3. Summary of results from linear mixed effect regression models.

Time window	Predictor	Intercept	Slope	R_m^2	R_c^2	AIC	LogLik	Slope p-value
14 days before	5_10C_14_days_before	30.67	0.30	0.38	0.39	604.22	-298.11	1.68E-08
	5_15C_14_days_before	21.66	0.20	0.34	0.35	609.07	-300.53	1.37E-07
	below_20C_14_days_before	3.24	0.17	0.24	0.25	618.58	-305.29	1.92E-05
7 days before	5_15C_7_days_before	23.24	0.34	0.28	0.29	613.50	-302.75	2.55E-06
	5_10C_7_days_before	33.40	0.45	0.28	0.29	613.22	-302.61	3.00E-06
	below_20C_7_days_before	-18.70	0.47	0.22	0.23	617.88	-304.94	3.97E-05
7 days after	5_10C_7_days_after	22.89	0.61	0.41	0.42	601.20	-296.19	3.50E-09
	5_10C_air_7_days_after	17.13	0.42	0.26	0.27	614.74	-303.37	6.32E-06
	5_10C_mesonet_air_7_days_after	19.72	0.74	0.24	0.25	615.45	-303.73	1.71E-05
14 days after	5_10C_air_14_days_after	-8.06	0.37	0.42	0.43	599.50	-295.91	1.50E-09
	5_10C_mesonet_air_14_days_after	10.45	0.49	0.29	0.30	612.18	-302.09	1.87E-06
	below_20C_14_days_after	-62.28	0.36	0.22	0.23	618.80	-305.40	4.86E-05

Akaike Information Criterion (AIC) provides information on model fit using Goodness of fit while penalizing for complexity when adding parameters. Lower AIC values suggests good model prediction without compromising model complexity. Log-Likelihood (LogLik) quantifies probability of the observed data given the parameters of the model. Higher LogLik values suggest greater consistency with the observed data. The marginal coefficient of determination (R_m^2) represents the proportion of the variance explained by the model's fixed effects. The conditional coefficient of determination (R_c^2) represents the proportion of variance explained by both fixed and random effects.

Table 3.4. Peak dates for average daily hours in which air temperatures were between 5-10°C based on historical data from Kansas Mesonet weather stations over ten years (2015-2025).

Region	County	Latitude	Longitude	Station	Day of year	Average hours
Eastern KS	Woodson	37.8612	-95.7836	Woodson	21-Nov	10.5
	Wallace	38.8198	-101.85299	Wallace	24-Oct	8.62
	Stanton	37.61393	-101.72704	Stanton	30-Oct	9.25
	Ford	37.90245	-99.869524	Spearville	30-Oct	8.75
	Sherman	39.28125	-101.81936	Sherman	1-Oct	7.88
	Sheridan	39.35745	-100.6082	Sheridan	24-Oct	9.88
	Chautauqua	37.165	-96.228	Sedan	21-Nov	10
	Osage	38.71658	-95.516262	Overbrook	21-Nov	12.6
	Franklin	38.54268	-95.24647	Ottawa 2SE	21-Nov	12.6
	Haskell	37.65916	-101.0267	Haskell	30-Oct	9.86
Central KS	Washington	39.78121	-97.05976	Washington	4-Nov	10
	McPherson	38.34503	-97.66311	McPherson 1S	5-Nov	11.1
Western KS	Greeley	38.53041	-101.66434	Tribune 6NE	7-Oct	8.38
	Greely	38.46625	-101.77522	Tribune	24-Oct	9.12

Table 3.5. Peak dates for average cumulative hours in which air temperatures were between 5-10°C during the 14 days following each calendar date based on historical data from Kansas Mesonet weather stations over ten years (2015-2025).

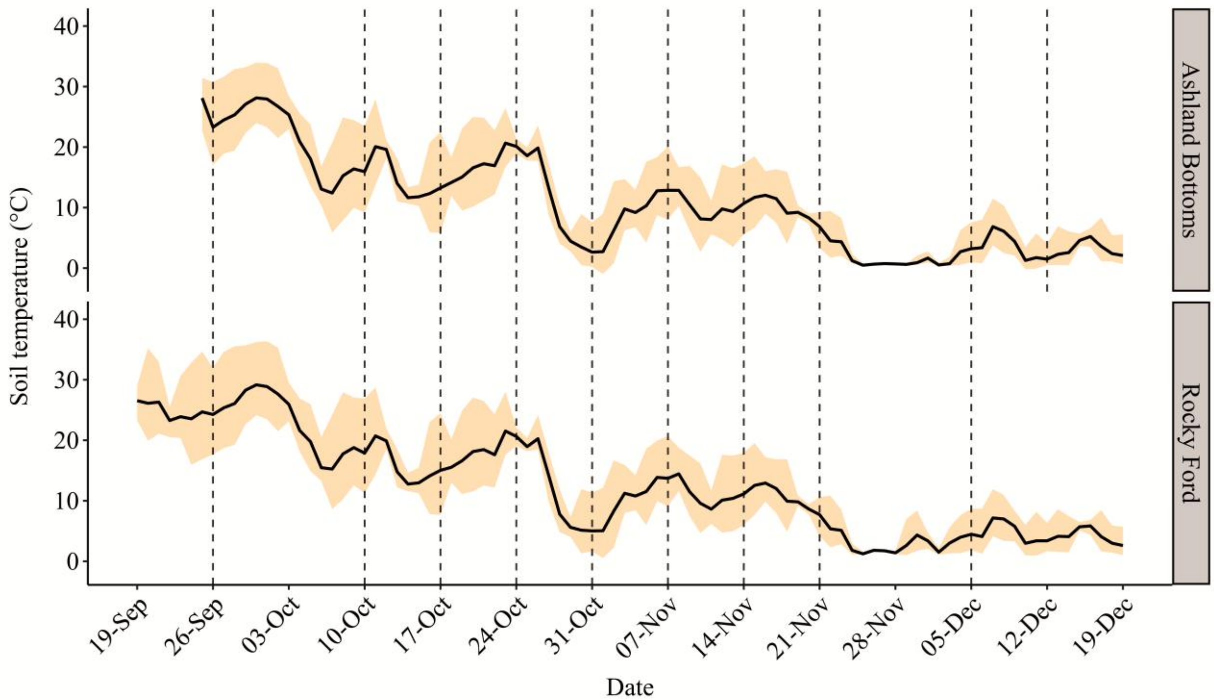
Region	County	Latitude	Longitude	Station	Day of year	Average hours
Eastern KS	Woodson	37.8612	-95.7836	Woodson	19-Nov	93.9
	Wallace	38.8198	-101.85299	Wallace	11-Oct	83.8
	Stanton	37.61393	-101.72704	Stanton	23-Oct	82.5
	Ford	37.90245	-99.869524	Spearville	23-Oct	78.9
	Sherman	39.28125	-101.81936	Sherman	17-Oct	81.8
	Sheridan	39.35745	-100.6082	Sheridan	23-Oct	90.9
	Chautauqua	37.165	-96.228	Sedan	28-Nov	94.9
	Osage	38.71658	-95.516262	Overbrook	24-Oct	97.5
	Franklin	38.54268	-95.24647	Ottawa 2SE	24-Oct	91.4
	Haskell	37.65916	-101.0267	Haskell	23-Oct	85.4
Central KS	Washington	39.78121	-97.05976	Washington	23-Oct	97.9
	McPherson	38.34503	-97.66311	McPherson 1S	30-Oct	98.4
Western KS	Greeley	38.53041	-101.66434	Tribune 6NE	17-Oct	84.9
	Greely	38.46625	-101.77522	Tribune	11-Oct	86.2

Figure 3.1. Experimental plot map containing plot, TEROS 12 soil sensor, and HOBO Micro Station locations.

	1 ft	1 ft	3 ft	1 ft	1 ft	3 ft	1 ft	1 ft	3 ft	1 ft	1 ft
1 ft	201	204		207	210		301	304		307	310
1 ft											
1 ft	202	205	X	208	211		302	305	X	308	311
1 ft											
1 ft	203	206		209	212		303	306		309	312
3 ft						Weather station					
1 ft	101	104		107	110		401	404		407	410
1 ft											
1 ft	102	105	X	108	111		402	405	X	408	411
1 ft											
1 ft	103	106		109	112		403	406		409	412

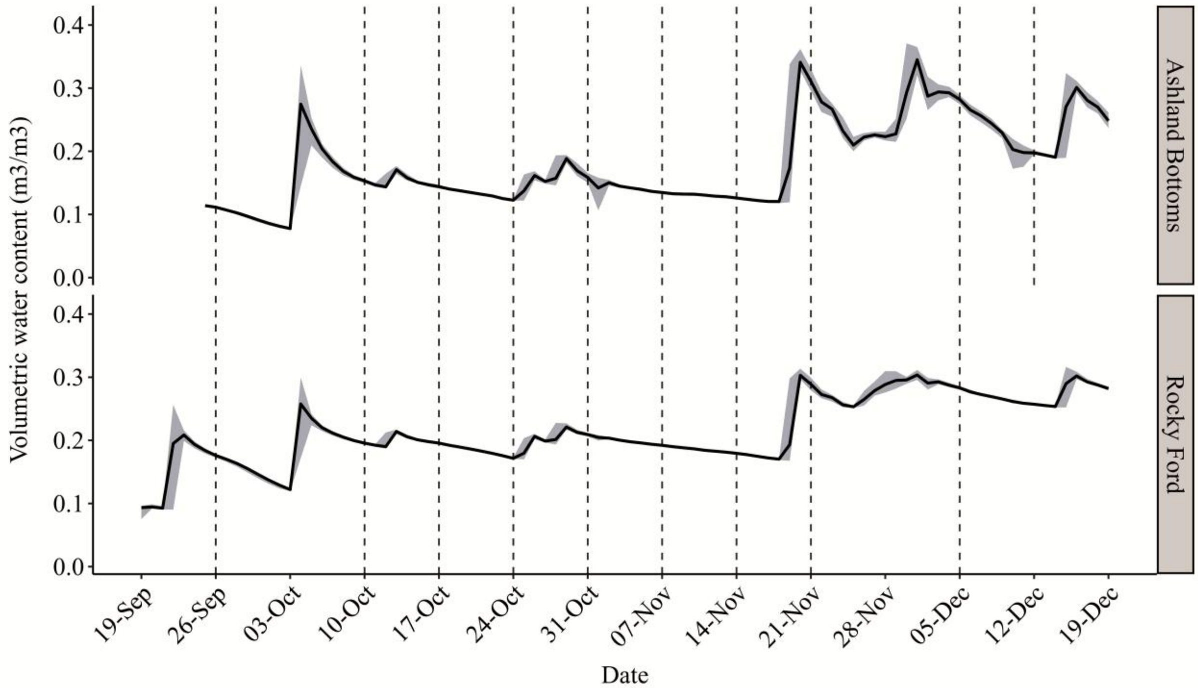
Experimental set up including soil sensors (marked with X) and the HOBO Micro Station (center). Experimental set up was consistent across both Rocky Ford and Ashland locations. Weather stations were set in the middle of the experiment and also housed the datalogger that collected data from soil sensors.

Figure 3.2. Daily average soil temperature and ranges from soil sensors at the Ashland Bottoms and Rocky Ford locations from September to December.



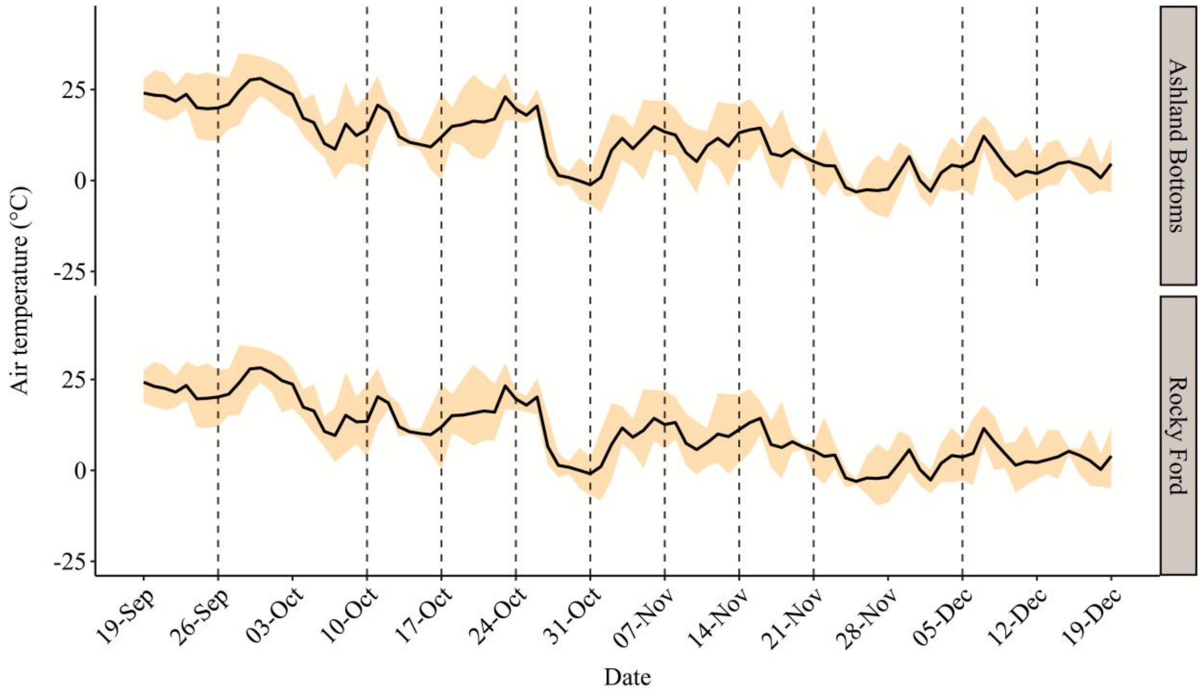
Daily average soil temperature (°C) taken from soil sensors located at both Ashland Bottoms and Rocky Ford locations. Thick dark lines indicate average daily soil temperature while yellow shaded area represents daily soil temperature ranges between the minimum and maximum temperatures. Black dashed lines indicate respective planting dates for each location.

Figure 3.3. Daily average soil moisture and ranges from soil sensors at the Ashland Bottoms and Rocky Ford locations from September to February.



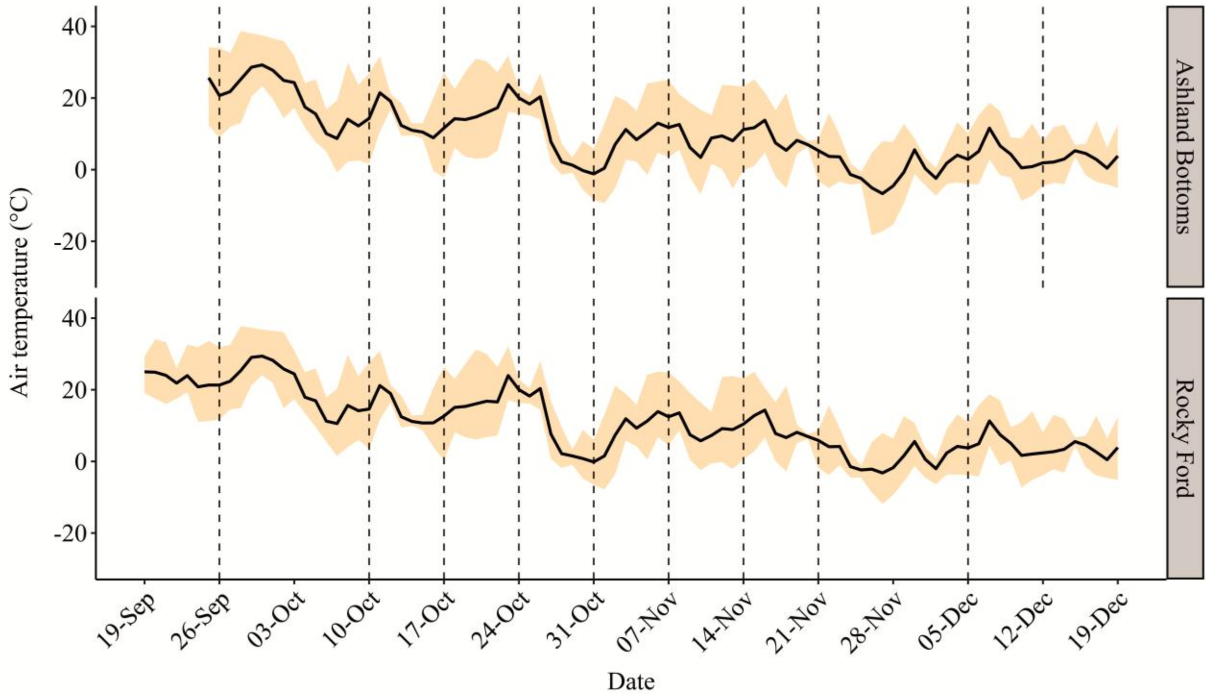
Daily average soil volumetric water content (m^3/m^3) taken from soil sensors located at both Ashland Bottoms and Rocky Ford locations. Thick dark lines indicate average daily soil volumetric water content while shaded area represents daily soil volumetric water content ranges between maximum and minimum volumetric water contents. Black dashed lines indicate planting date treatments. For volumetric water content, it was advised that readings prior to the first precipitation event should be ignored due to the soil sensors requiring a precipitation event to accurately begin recording declining volumetric water content. The first precipitation event occurred on 22 September, 2023 for Rocky Ford and 3 October, 2023 for Ashland Bottoms.

Figure 3.4. Daily average air temperature and ranges from K-State Mesonet weather stations at the Ashland Bottoms and Rocky Ford locations from September to February.



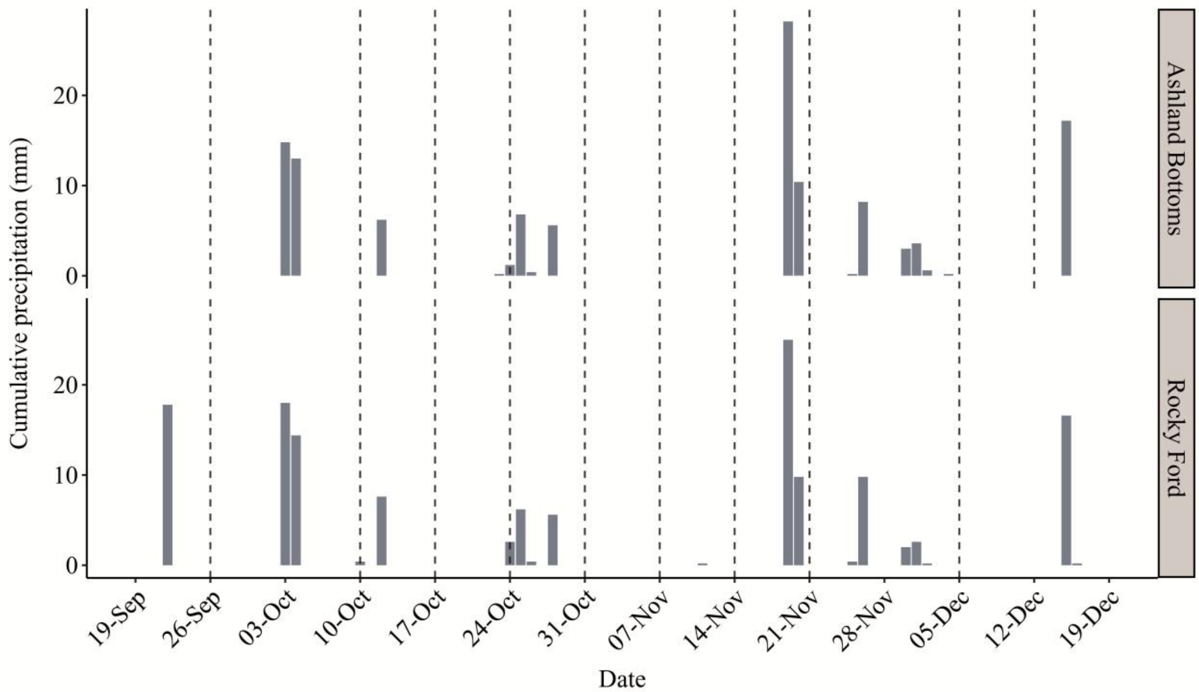
Daily average air temperature (at 2m) collected from the K-State Mesonet weather stations located at both Ashland Bottoms and Rocky Ford locations. Thick dark lines indicate average daily air temperature while shaded area represents daily air temperature ranges between maximum and minimum temperatures. Black dashed lines indicate planting date treatments.

Figure 3.5. Daily average air temperature and ranges from HOBO Micro Stations at the Ashland Bottoms and Rocky Ford locations from September to February.



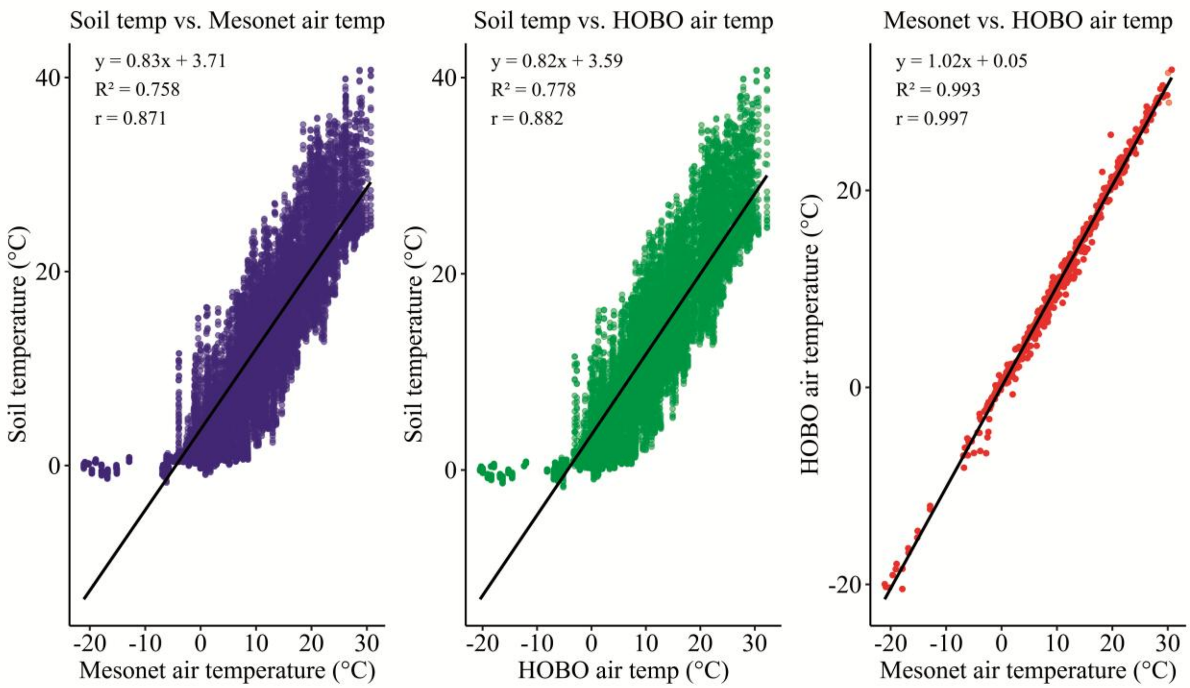
Daily average air temperature collected from HOBO Micro Stations located at both Ashland Bottoms and Rocky Ford locations. Thick dark lines indicate average daily air temperature while shaded area represents daily air temperature ranges between maximum and minimum temperatures. Black dashed lines indicate planting date treatments.

Figure 3.6. Daily cumulative precipitation from HOBO Micro Stations at the Ashland Bottoms and Rocky Ford locations from September to February.



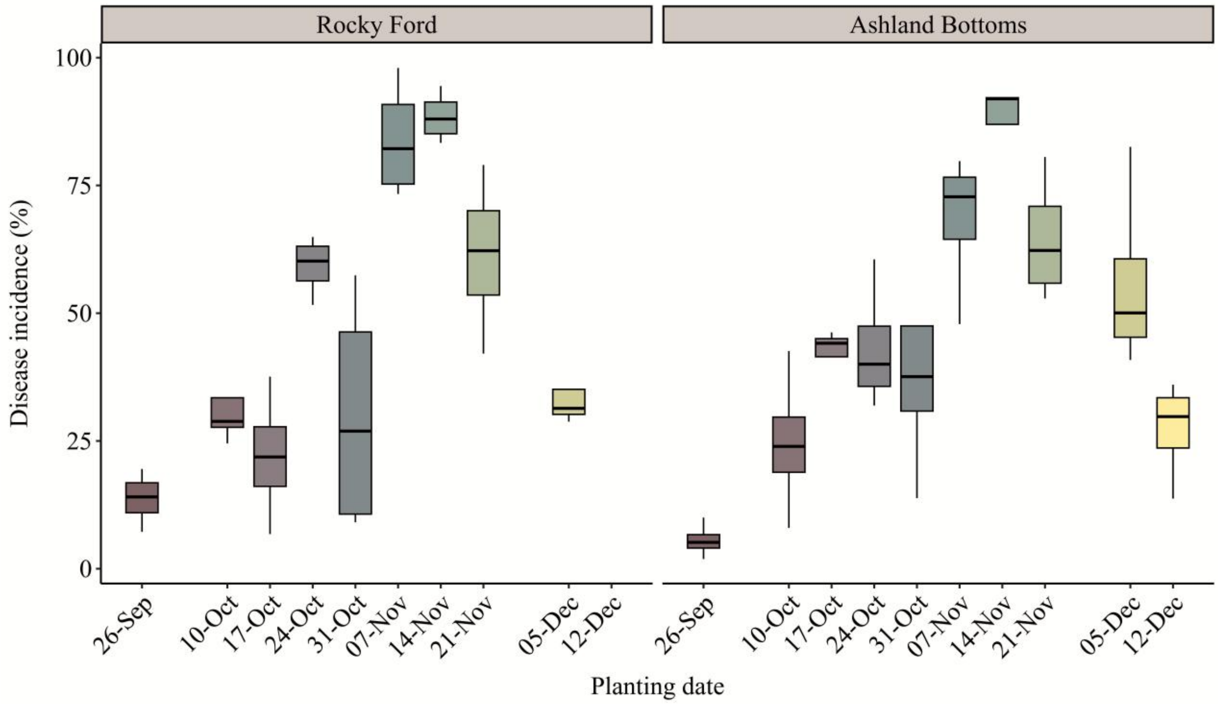
Daily cumulative precipitation (mm) collected from HOBO Micro Stations at the Ashland Bottoms and Rocky Ford locations. Blue bars indicate cumulative precipitation. Black dashed lines indicate planting date treatments.

Figure 3.7. Scatterplots showing pairwise correlation between soil temperature and air temperature (Mesonet and HOBO Microstation).



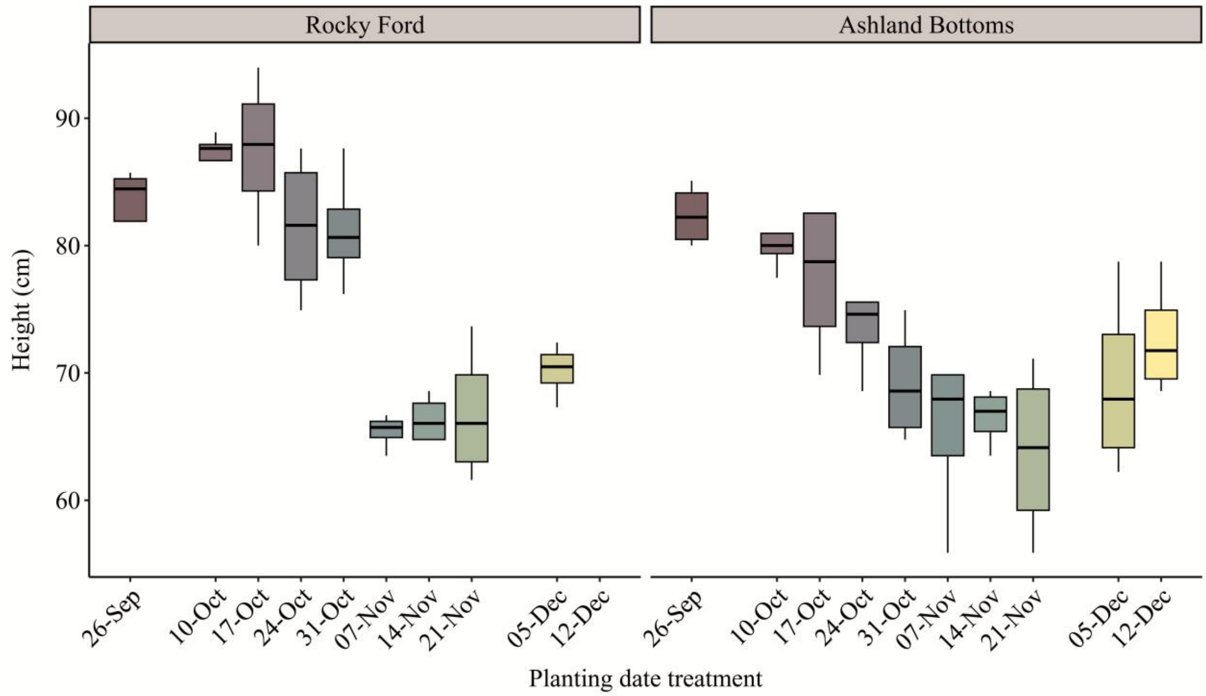
Plots display pairwise comparisons between soil temperature, air temperature (Mesonet), and air temperature (HOBO Micro Station). Black lines represent fitted linear regression models for each comparison. Panels contain regression equations, coefficient of determinations (R^2), and Pearson's correlation coefficients (r). As temperature approaches 0 °C, soil sensors are unable to make observations due to freezing temperatures which is observed in the two leftmost plots.

Figure 3.8. Disease incidence for each planting date treatment at the Rocky Ford and Ashland Bottoms locations.



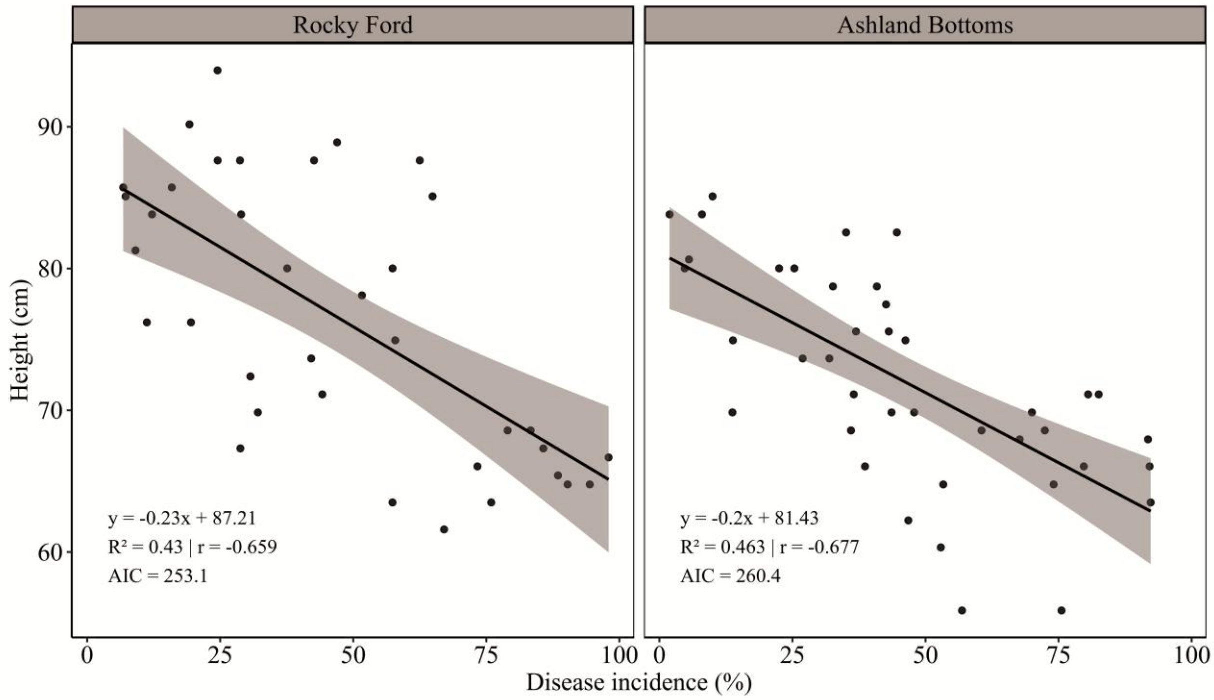
Boxplots of the distribution of disease incidence (%) for each planting date at each location is shown above. Boxplots show the median, interquartile range (IQR), and variability of disease incidence for each planting date. Colors represent planting dates that were the same across both locations.

Figure 3.9. Plant height for each planting date treatment at the Rocky Ford and Ashland Bottoms locations.



Boxplots of the distribution of plant height for each planting date at the Rocky Ford and Ashland Bottoms locations. Boxplots show the median, interquartile range (IQR), and variability of height for each planting date. Plant height was recorded at approximately wheat Feekes growth stage 11.2. Colors represent planting dates that were the same across both treatments.

Figure 3.10. Linear mixed effect regression models fit for height and disease incidence at Rocky Ford and Ashland Bottoms locations.



Linear mixed effect models fit with height and disease incidence for both locations. Points represent individual observations. Black lines indicate fitted regression lines and shaded regions indicated 95% confidence interval. Regression equations, marginal R^2 values, AIC values, and Pearson's correlation coefficients are displayed for each location.

Figure 3.11. Average stand count taken following emergence for the Rocky Ford and Ashland Bottoms locations.

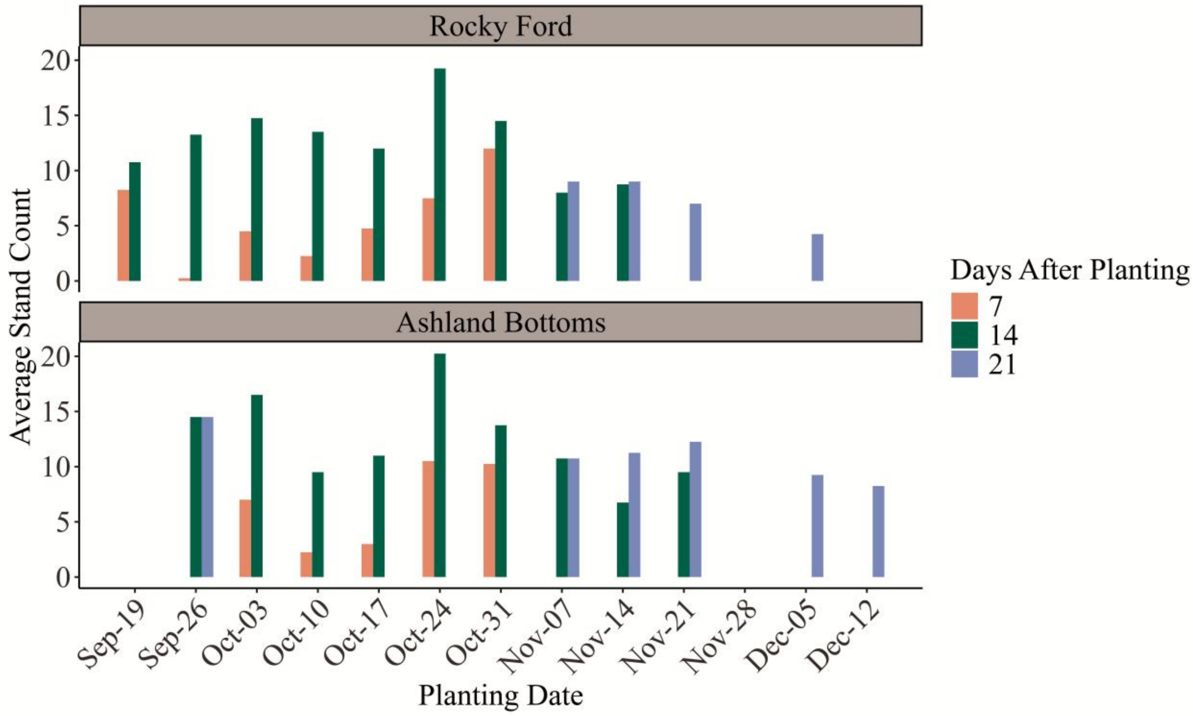
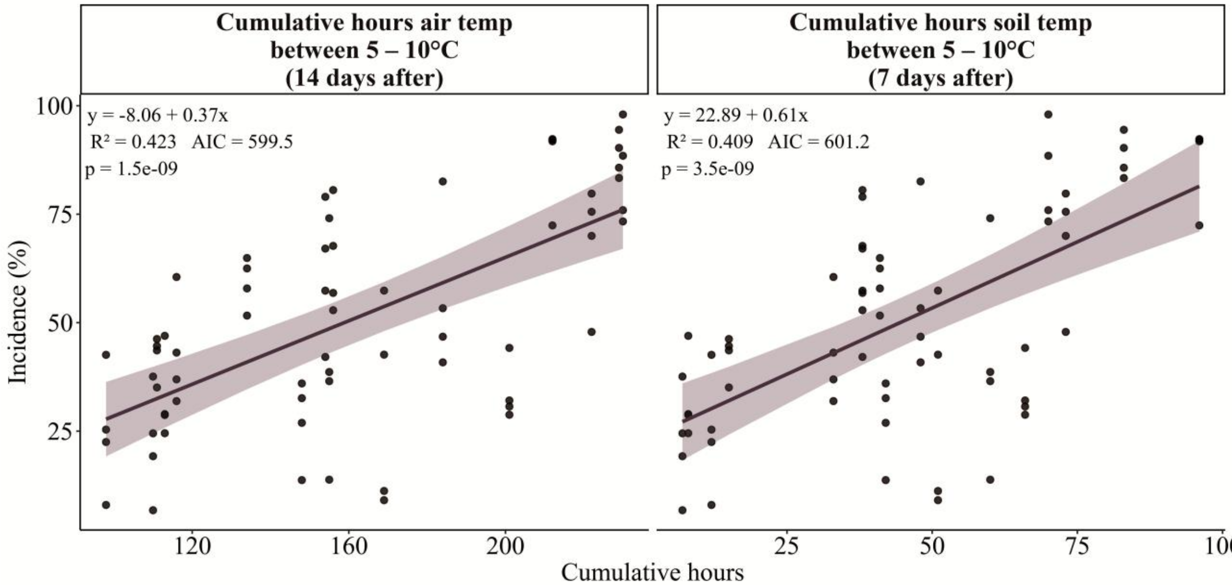


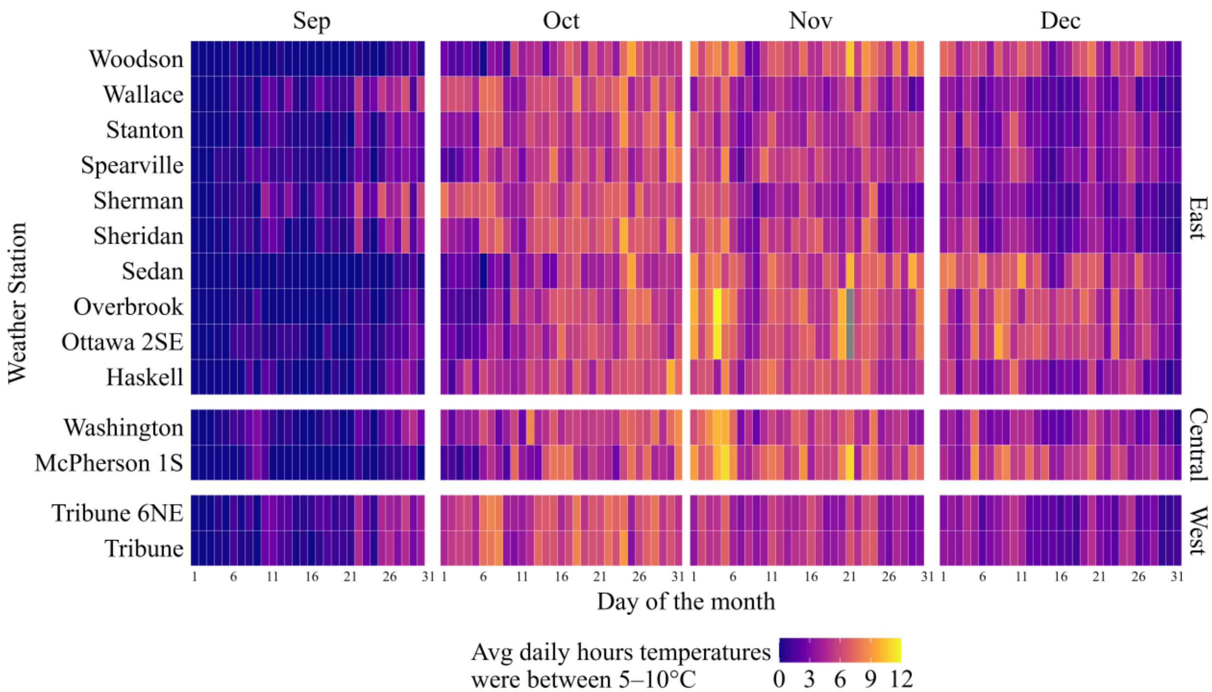
Figure above represents the average stand count for each planting date treatment. Orange bars represents stand counts if plants were found at 7 days after planting, Green bars represent stand counts if plants were found 14 days after planting. Blue bars represent stand counts if plants were found 21 days after planting. Treatments for planting dates that did not survive until harvest are also included. These are 19 September and 3 October for Rocky Ford and 3 October for Ashland Bottoms.

Figure 3.12. Relationship between disease incidence (%) and the two best fitting predictors from the linear mixed effect regression model.



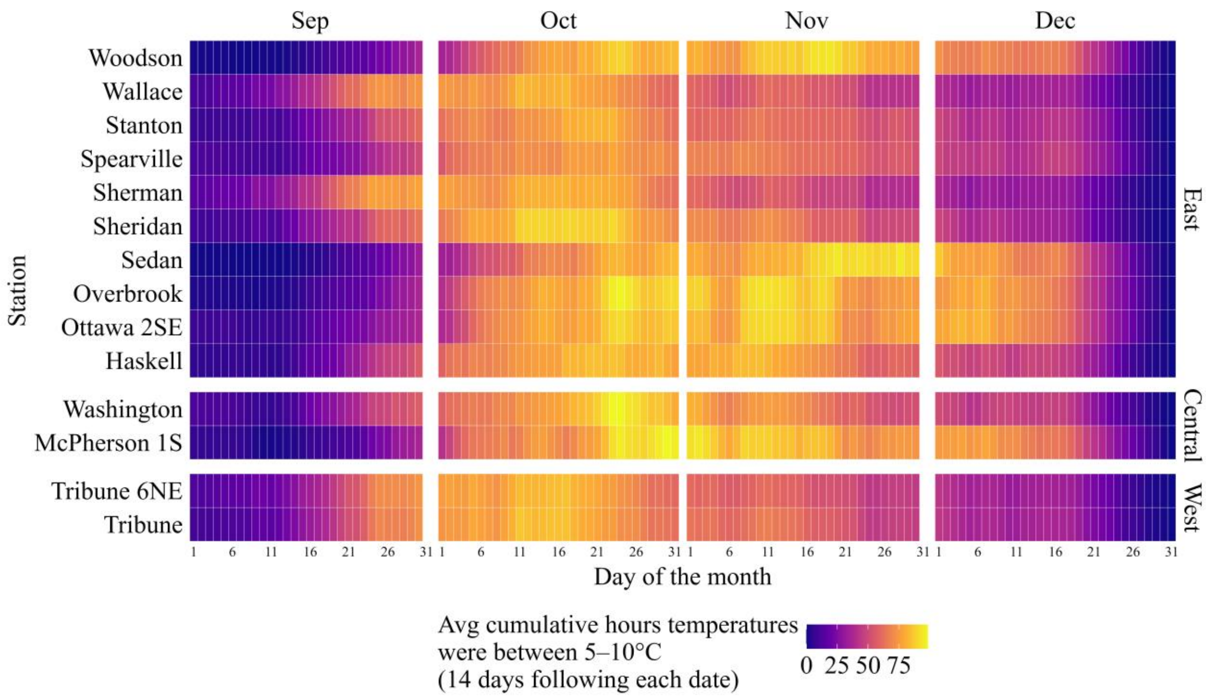
Relationship between disease incidence (%) and cumulative hours the air temperature from the HOBO Micro Station was between 5 - 10°C 14 days after planting (left). Relationship between disease incidence (%) and cumulative hours the soil temperature was between 5 - 10°C 7 days after planting (left). Each point represents individual plot observations. Solid lines represent fitted linear mixed effect regression models. Shaded areas represent 95% confidence intervals. Marginal R^2 values, AIC, and slope p-values are labeled.

Figure 3.13. Average daily hours in which air temperatures were between 5 – 10°C based on historical data from Kansas Mesonet weather stations from September to December over ten years (2015-2025).



Heatmap displays daily average hours where temperatures were between 5 – 10°C based on historical data from Kansas Mesonet weather stations from September to December. Data are aggregated by station and day of the month, faceted by region (rows) and month (columns). Higher values (yellow) indicate higher hours where conditions were favorable for infection. Values represent the daily average across 2015-2025. For Overbrook and Ottawa, data was missing on 21 November for one of the years, indicated by grey boxes.

Figure 3.14. Average cumulative hours in which air temperatures were between 5 – 10°C during the 14 days following each calendar date based on historical data from Kansas Mesonet weather stations from September to December over ten years (2015-2025).



Heatmap displays cumulative hours where temperatures were between 5 – 10°C during the 14 days following each calendar date across Kansas Mesonet weather stations from September to December. Data are aggregated by station and day of the month, faceted by region (rows) and month (columns). Higher values (yellow) indicate higher hours where conditions were favorable for infection for the common bunt pathogens 14 days following each planting date. Values represent the daily average across 2015-2025.

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Appendix A - Supplementary Material

Figure A – 1. Common bunt management survey distributed to wheat growers in Kansas

COMMON BUNT MANAGEMENT SURVEY

This survey is being conducted by researchers at Kansas State University. This information is being collected for the purpose of improving management recommendations for wheat diseases and wheat production in Kansas. Results of this survey will not influence seed policy. Your participation is voluntary. All survey responses will be kept confidential and any summaries will omit identifying information of respondents. After removal of identifying information, this data may be used by future researchers or other investigators at Kansas State University. We very much appreciate your time. If you have questions, please contact the project director (andersenk@ksu.edu), the Kansas State University IRB Chair (Lisa Rubin, rubin@k-state.edu), or the Associate Vice President for Research Compliance (Brad Woods, brwoods@k-state.edu).

Name_____________________________ Phone Number________________

County (or counties) of farm operations______________________________

(1) How many acres total do you farm? ______________________________

(2) What is your typical seeding rate? __________________seeds/A or lbs / A (circle one)

(3) What is your typical your row spacing? ☐ 7.5 in ☐ 10 in ☐ 12 in Other _______

(4) What percentage of your wheat operation is typically irrigated?

☐ 0 % ☐ 1-5 % ☐ 6-15 % ☐ 16-30% ☐ 31-50 % ☐ 51-75% ☐ 76% or more

(5) What is your typical tillage method?

☐ No-till ☐ Reduced-till ☐ Conventional till

Common bunt, sometimes called "stinking smut", is a disease that infects wheat grain. It can be difficult to detect because there are few symptoms before the grain fill stage of development. Infected grain will be filled with black spores and can have a strong fishy odor. These spore-filled grains are sometimes called "bunt balls" and can break open during harvest, contaminating healthy grains. The following images show what stinking smut looks like at/after harvest:

(6) Have you ever noticed common bunt (stinking smut) on your farm? ☐ Yes ☐ No

If yes to (6), what years was common bunt a problem (list all that can be recalled)

____

(7) Have you ever received a price discount or rejection for common bunt? ☐ Yes ☐ No

If yes, what was the discount ________________________________

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COMMON BUNT MANAGEMENT SURVEY

For this next series of questions, please consider your practices ***over the last two years***:

Question	Season 2023 - 2024	Season 2022 - 2023
8. Total area of wheat planted		
9. What was/were your planting date (or dates) across your operation?		
10. Did you purchase certified seed?	Y N (circle one)	Y N (circle one)
11. What % of your operation was planted with certified seed?		
12. Did you use a seed treatment that included a fungicide?	Y N (circle one)	Y N (circle one)
13. What percentage of your seed received a fungicide seed treatment?		
14. Did you use any of these components in your seed treatments?	(circle all that apply) Insecticide Growth regulator Nutrient supplement	(circle all that apply) Insecticide Growth regulator Nutrient supplement
15. Please list the seed treatment product or products used, if known.		
16. What was the approximate price paid per acre for seed treatment?		
17. What percentage of your seed was saved on-farm from a previous season?		
18. Was saved seed treated with a fungicide and/or cleaned?	Treated Cleaned Both Neither (circle one)	Treated Cleaned Both Neither (circle one)
19. Is any portion of your wheat production organic? If yes, what percentage?	Y N (circle one) ________%	Y N (circle one) ________%

(20) What factors influence your decision to use a seed treatment? (Circle all that apply)

Cost of treatment	Grain price	Number of years seed has been saved	Seed germination results
Insect pressure	Disease pressure	Planting date	Recommendations from crop consultant

(21) Would you be open to being contacted for clarification or further information regarding your responses to this survey?

☐ Yes, I am open to being contacted. ☐ No, I prefer not to be contacted.

☐ Maybe (please specify): ______________________________

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