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A Vision for Extension: Case Studies on Managing Extreme Weather Challenges in Corn

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A VISION FOR EXTENSION:

CASE STUDIES ON MANAGING EXTREME WEATHER CHALLENGES IN CORN

by

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Global demand for corn is projected to rise in the coming decades to meet the food and fuel requirements of an increasing human population. Technological innovations have significantly improved corn yields over the past few decades; however, corn production is continually limited by unfavorable weather conditions. Extreme weather events put pressure on producers, adjustors, and consultants to make quick management decisions to maintain the highest return on their investment. Proper management decisions require an understanding of plant response and practical ways of applying this knowledge under real world conditions.

The following document was written after completing a six-month internship at the University of Nebraska-Lincoln conducting research and extension activities focused on cropping systems. A number of key issues emerged during the internship and a literature review address those topics (Chapter 1). This internship provided experience on the integration of cover crops in corn, corn hybrid response to greensnap damage, and specifically focused on early-season hail damage and primary ear removal in corn. These last two projects are addressed extensively in this document (Chapters 2-3).

The purpose of this research was to generate experiences in translating scientific information to consultants, educators, industry, crop insurance adjustors, media outlets, and producers. In addition, developing different methods of Extension programming and

interaction with clientele allowed for a better understanding of key barriers in translating scientific information. The combination of research and Extension experiences in this document, as well as the history of the Cooperative Extension Service led to the formation of my future vision for Extension (Chapter 4).

Extension must be strongly centered on issues that are important to its clientele. The technological and intellectual capabilities of today's producers provides Extension with the opportunity to engage them in the problem-solving process through on-farm research. Such strategies allow specialists to understand how solutions interact with producer management strategies. In addition, real world demonstration plots addressing multidisciplinary issues provide a foundation for in depth conversations on underlying causes of key issues in agriculture. Lastly, technologies, such as time-lapse photography and GoPro video cameras, provide an opportunity to overcome key barriers to education.

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CHAPTER 1

Literature Review

Corn Production and Climate Change

Corn (*Zea mays* L.) is one of the most important crops to contribute to global food security (Gaffney et al. 2015). In 2014, global corn production was estimated at 988 million metric tons (MMT) with an annual consumption of 971.2 MMT (USDA-NASS 2015). The United States is the largest producer of corn with approximately 308 MMT, accounting for an estimated 36% of the global food production (Tack and Holt 2015). Global demand for agricultural products is expected to rise in coming decades as a result of an increasing population and shifts in consumer purchasing power towards more resource intensive-diets (Garnett et al. 2013). In the United States, corn is used for animal feed, ethanol fuel, high-fructose corn syrup, sweetners, starch, cereals, and beverages (United States Department of Agriculture – Economic Research Service 2015). Agriculture faces considerable pressure as it is expected to meet these production demands under declining arable land using long-term sustainable management practices.

Technological advancements in plant breeding and management have improved corn yields significantly; however, climate change poses a significant threat to stable food production. Global climate change models predict a mean global warming of 1.5 to 5.8°C by the end of this century as a result of increased atmospheric concentrations of greenhouse gases (Rosenzweig et al. 2001). Increased temperatures are expected to result in greater evapotranspiration, leading to a higher incidence of drought in some regions (Campos et al. 2004). Warmer temperatures are expected to cause changes in rainfall patterns, and an increase in the frequency, probability, and severity of extreme weather events (Wheeler and Braun 2013). In addition, changes in weather patterns can increase crop vulnerability to a range of pests such as weeds, insects, and diseases (Rosenzweig et

al. 2001). Management of crops with changing weather patterns will require a significant amount of research and knowledge on crop response to such events in order to identify management strategies that reduce the likelihood for significant yield losses.

Crop Stress and Yield Components

Corn yield components can be a valuable tool for determining when stress occurred and the potential for yield impact. Yield components of corn develop sequentially at different stages of growth that interact and have compensatory effects (Milander 2015). Fageria et al. (2006) indicated that primary or first order yield components for corn consist of ears m^{-2}, kernels ear^{-1}, and kernel weight. Secondary or second order components are those that have an indirect effect on first order components such as rows ear^{-1} and kernels row^{-1} (Fageria et al. 2006). In the field, ears m^{-2} can be calculated in terms of the number of ears per plant combined with the number of plants per unit area. Figure 1.1 shows a visual representation of the yield components of corn and their period of plasticity throughout the growing season. The number of ears m^{-2} is determined between planting and V6 stage, although some extreme weather events can reduce plant population during later stages of development. Rows per ear is strongly influenced by the genetics of the hybrid (Begna et al. 1997, Abendroth et al. 2011); however; severe environmental stresses occurring between VE and V7 can reduce the number of rows per ear. The number of potential kernels per ear is determined between V7 and V15 (Uribelarrea et al. 2002). Harvestable kernels are first determined during fertilization at the VT stage. A loss of harvestable kernels can occur as a result of stress during the early stages of grain fill with final number of kernels determined during R3

(Abendroth et al. 2011). Stress occurring after R3 usually reduces kernel weight. Field evaluations of yield components at the end of the season can provide insight into the timing of stress, cause of yield impacts, and insights into potential for altering management strategies.

Drought in Corn

Drought can cause significant impact to both rain-fed and irrigated corn. Annual losses from drought in the U.S. have been estimated at $6 to $8 billion dollars (Federal Emergency Management Agency, 1995). Irrigation is fundamental for mitigating yield losses from drought and accounts for 43% of total corn acres in the United States (USDA-NASS 2012); however, area-weighted averages of water levels in the High Plains Aquifer have shown a decline of 15.4 feet between 1950 and 2013 (McGuire 2014). Widespread drought from 2011 – 2013 in the High Plains region resulted in area-weighted decline in the water table of 2.1 feet in this same region (McGuire 2014). Proper water management is fundamental to both irrigated and dryland crops to maintain stable yields in the coming years. The impact of drought on crop productivity will depend on the timing and duration of water deficits, management strategies, and the corn hybrid.

Plant Response to Water Stress

Plants experience water stress whenever soil water availability becomes limited or when transpiration rates are greater than rate of water taken up by plants roots.

An early response of plants to water stress is to close their stomata to reduce transpiration rates. Stomatal closure has been attributed to a loss of turgor pressure (Ludlow 1980), or high vapor pressure deficits (Schulze 1986, Maroco et al. 2002). Some studies suggest that stomatal response is more closely linked with soil moisture content than leaf water status (Gowing et al. 1990, Davies and Zhang 1991). Abscisic acid (ABA), a plant hormone, has also been implicated as an important compound for inducing stomatal closure (Horton 1971, Raschke 1975). Research on ABA has documented the rapid uptake of ^{14}C-ABA by guard cells (Weyers and Hillman 1979) affecting their ionic and metabolic status (Horton and Moran 1972). Studies have documented the role of ABA in closing stomata, its production in dehydrated roots, and circulation within a plant (Chaves et al. 2002). Long-distance signaling of ABA between the roots and leaves, as well as the interaction with other compounds is not well understood (Sauter et al. 2001).

Long term (days) stomatal closure has significant implication for CO_2 diffusion, photosynthesis, nutrient uptake, and growth. When stomata close, gas exchange is limited resulting in reduced diffusion of carbon dioxide from the atmosphere into the plant (Ort et al. 1994). Lower internal CO_2 levels cause a down regulation in the photosynthetic machinery (Ort et al. 1994). Reduced photosynthetic activity over a period of time can lead to reduced growth (Chaves et al. 2002). In addition, nutrient uptake and metabolisms are negatively affected by reduced water intake, and this leads to a decrease in leaf area and an alteration in assimilation partitioning among plant organs (Chaves et al. 2002).

Water Usage and Yield Impact on Corn by Development Stage

Corn water usage and yield impacts from water stress varies according to the development stage of the crop (Table 1.1). Water usage of corn during the first few weeks of development is low (1.5-mm/day) (Shaw 1977, Rhoads and Bennett 1990). After the fourth leaf stage, water use increases to 2.5-mm/day, peaking at 8.4-mm/day just prior to tasseling (Shaw 1977, Rhoads and Bennett 1990). Corn is relatively insensitive to water stress imposed during early vegetative stages due to low water demands (Shaw 1977). Yield losses in late vegetative stages are estimated at 2 – 4% for each day of stress (Rhoads and Bennett 1990). Long-term water deficits prior to pollination were found to reduce leaf area and internode distances with yield losses of 15 – 25% (NeSmith and Ritchie 1992).

Corn is most susceptible to stress during tasseling and silking (Shaw 1983, Rhoads and Bennett 1990). Drought stress during this period can interfere with the overlap of silk emergence and pollination leading to reduced fertilization of potential kernels (Rhoads and Bennett 1990). High temperatures and low humidity can cause desiccation of silks and reduce their ability to receive pollen for fertilization (Shaw 1977). Yield reductions per day of water stress during tasseling and silking is estimated at 3-8% (Rhoads and Bennett 1990). Çakir (2004) evaluated grain yield at various combinations of irrigation for vegetative, tasseling, ear formation, and milk stages and found that a single omission tasseling onward could cause up to 40% yield loss during dry years. Prolonged stress during these sensitive periods caused yield losses of 66-93% (Çakir 2004). Water stress occurring two weeks after pollination can result in kernel abortion, with an estimated 2.5 – 8.0% yield loss for each day of stress (Rhoads and

Bennett 1990). Stress imposed 10 – 31 days after silking caused yield reductions of 40-54%, with kernel number reductions up to 22 days after silking (Grant et al. 1989). NeSmith and Ritchie (1992) found that moderate stress during grain fill reduced kernel number by 8-20% and kernel weight by 21-25%.

Managing Drought in Dryland Cropping Systems

Drought management under rain-fed cropping systems can be mitigated through conservation tillage, planting configuration and population, crop rotation, and drought tolerant hybrids. A study by Norwood and Currie (1996) found that no-till practices increased corn yields by 100% compared to conventional tillage in western Kansas during the driest years of the study. No-till soils have been shown to have higher volumetric water content and reduced evaporation due to an increase in crop residue (Blevins et al. 1971). Baumhardt et al. (2013) found that stubble mulch and no-tillage increased soil water 14 to 50 mm after fallow compared to disk tillage. In addition, the presence of corn stover mulch was found to increase water infiltration rates into soil leading to reduced water runoff and greater water availability (Triplett et al. 1968). Conserving soil moisture through reduced evaporation during early season growth may carry a crop through late season drought periods when water demand is high. Yield increases from conservation tillage were likely due to a reduction in early season evaporation from soil surface with are greater percentage of water being used for plant transpiration (Baumhardt et al. 2013).

The advent of no-till has raised concerns over the potential for increases in plant disease. The use of no-till strategies may indirectly alter the best management practices

for the kind, rate, and time of fertilizer applications, pesticide use, plant spacing and other cultural strategies (Sumner et al. 1981). Changing soil and plant canopy environments could influence the epidemiology of plant pathogens present in crop residues under no-till systems (Sumner et al. 1981). Stalk rot incidence and severity in corn has been shown to increase (Skoglund and Brown 1988) or decrease (Lipps et al. 1991) for no-till compared to conventional tillage systems. Differences between studies have been attributed to soil fungistasis, cropping history, and initial pathogen levels (Sturz et al. 1997). Variations between studies and the potential for increased disease, indicates the importance of utilizing crop rotation and disease resistant hybrids under no-till conditions.

Alterations of planting configurations have been important in areas where yields are expected to be low (< 6,200 kg/hectare) due to limited water. Lyon et al. (2009) found that planting one corn row and skipping a row in western Nebraska increased yields from 2,766 kg/hectare to 8,488 kg/hectare. Yield differences between these two configurations were attributed to corn obtaining water from the skip row location during the later portion of the season when the demand for water is high (Lyon et al. 2009). This concept was discovered by Musick and Dusek (1982) who noted that corn is capable of extracting water 75 cm laterally from the planted row between tasseling and the end of the season.

Planting population of corn under semi-arid conditions can be an important factor for stabilizing corn yields. Norwood and Currie (1996) determined that no-till planted corn planted in mid-May at populations of 44,500 plants/hectare in northwest Kansas had the highest yield potential. In another study, no observable yield increases were found for corn populations from 21,000 through 37,000 plants/hectare in the same region (Havlin and Lamm 1988). Blumenthal et al. (2003) found that grain yield increased by 353 kg/ha

when population was increased from 17,300 to 27,200 plants/hectare; however, plant populations above 27,200 resulted in inconsistent yield. These studies coincide with general recommendations of planting populations, with higher planting populations under irrigated conditions. In addition, research suggests that modern hybrids have been shown to typically have higher tolerance to increased plant populations then older hybrids (Tollenaar 1991).

Long-term yield gains for corn are suspected to be the result of the accumulation of multiple traits that confer tolerance to different stressors such as drought (Duvick 1977, Duvick et al. 2004a). Yield increases in newer hybrids under drought conditions have been attributed to a reduction in water use prior to critical flowering period (Nissanka et al. 1997). In addition, Duvick et al. (2004b) found that tassel dry weight have declined by 36% between 1967 and 1991. Bänziger et al. (2000) indicated that the anthesis silking interval (ASI) has been short in modern hybrids when plants are drought stressed. A long ASI under drought conditions often leafs to barren plants, or few harvestable grains per ear. As a result, the most significant genetic gains occurred during pollination and silking indicating that hybrid selection had reduced the negative impacts of stress during this critical period (Campos et al. 2004). An evaluation of 18 hybrids released between 1953-2001 for water stress tolerance between silking and maturity revealed significant positive genetic gain in terms of yield for stress periods during corn reproduction (Campos et al. 2004).

Commercial and private plant breeders have increased their focus on breeding for specific drought tolerant characteristics in corn. In 2011, Pioneer Hi-bred released several hybrids with drought tolerance under the trade name, AQUAmax™. Drought tolerance

selection and development of AQUAmax™ hybrids was achieved through a QTL-approach known as Accelerated Yield Techology™ (Sebastian et al. 2015). This process is composed of molecular mapping, markers for genetic covariates to highlight genetic hotspots, and multilocation testing (Sebastian et al. 2015). Gaffney et al. (2015) compared 78 drought tolerant hybrids (AQUAmax™) with 4287 industry-leading hybrids across 10,731 locations categorized as water-limited or favorable. Drought tolerant hybrids yielded 6.5% and 1.2% more than industry-leading hybrids under water-limited and favorable environments, respectively (Gaffney et al. 2015). In addition, drought tolerant hybrids had greater yields compared to industry leading hybrids under higher planting populations when water was limited (Gaffney et al. 2015).

The first drought-tolerant hybrid conferred through transgenic introduction was produced by Monsanto in 2013. Hybrid MON 87460 was released under the brand name Droughtgard™ containing a cold-shock protein (*cspB*) that was obtained from the soil-dwelling bacteria *Bacillus subtilis*. Nemali et al. (2015) found that MON 87460 yielded 6% greater than the control under water-limited conditions, but no differences occurred under well-watered conditions. Yield increases in MON 87460 were attributed to high water content at 0.5-m as a result of reduced water uptake (Nemali et al. 2015). Results showed that MON 87460 had decreased leaf area, leaf dry weight, sap flow rate during silking, and increased kernel number and harvest index compared to the control (Nemali et al. 2015).

Current research is identifying new traits to increase maize tolerance to drought. According to Waltz (2014), DuPont Pioneer is developing a new transgenic corn event that down regulates the production of the phytohormone ethylene which may enhance

grain yield after drought. Habben et al. (2014) reported that transgenic gene silencing of ethylene biosynthesis resulted in a 50% reduction in ethylene levels and an increased yield of 584 kg/hectare compared to control hybrids when stress was imposed. Simulation models have also provided insights into other potential targets such as transpiration rates. Messina et al. (2015) assessed the value of a limited transpiration trait in corn as a target for selection and genetic improvement using a simulated study. They postulated that limited transpiration rates during times when vapor pressure deficit (VPD) was high could reduce early season water use, saving water for critical water use periods later in the season. Reduced transpiration could limit early-season growth or yield potentials under well-watered environments. Limited transpiration rates could result in a 24% increase in predicted mean yields under terminal drought stress and a 5% increase in mean yield under drought stress during flowering and grain-fill (Messina et al. 2015). In contrast, limited transpiration rate plants under well-watered conditions showed yield losses of 0% under grain fill stress and 2% when compared to control plants (Messina et al. 2015).

Drought and Irrigation Management

Irrigation has enabled producers to mitigate production risk associated with short-term droughts. Over 300 million hectares of agricultural land is irrigated using groundwater with an estimated global annual output valued at $210-230 billion dollars (Shah et al. 2007). Irrigated acres account for approximately 58% of corn acres in Nebraska and 15% of total annual corn acres in the U.S. (USDA-NASS 2012). Nebraska has approximately 60,000 to 65,000 center pivots and over 110,000 active irrigation wells

(Nebraska DNR 2010). McGuire (2012) found that total water storage in the High Plains Aquifer has declined an estimated 246 million acre-feet from predevelopment of irrigation (1930's) until 2011. Individual wells have ranged from an increase of 85 feet in Nebraska to a decline of 242 feet in Texas. Groundwater depletions and water use restrictions for certain areas within the High Plains Aquifer combined with increasing pumping costs emphasize the need for conservation and efficient use of irrigation water (Eck 1986). In certain parts of the U.S., corn production is only achievable by irrigation derived from the Ogallala Aquifer (Howell 2001). As mentioned earlier, climate change models predict warmer mean temperatures, changes in weather patterns and an increase in extreme summer temperatures (Duffy and Tebaldi 2012). Increased temperatures and low precipitation are likely to continue to reduce water levels in the coming years. Management strategies that limit irrigation will be critical to maintain the viability of irrigation while reducing production risk and maintaining profitability (Hao et al. 2015).

Limiting irrigation without substantial yield losses requires accurate monitoring of soil water status over space and time. In the late 1970's, the Watermark granular matrix sensor was developed as a relatively inexpensive means of proving a continuous indirect estimation of the soil matrix potential (Armstrong et al. 1985, Thomson and Armstrong 1987, McCann et al. 1992, Eldredge et al. 1993, Irmak and Haman 2001). Soil matrix potential is a measure of energy in kilopascals (kPa) needed by a plant to extract water from the soil. Quantifying this energy through the use of Watermark sensors provides information for effective timing of irrigation. Greater water holding capacity soils such as silty-loam soils trigger irrigation at 90 – 110 kPa; whereas, low water-holding capacity (ex. sandy) soils begin irrigation at 30 – 50 kPa (Irmak and Haman

2001). Irrigation thresholds are triggered prior to the standard 50% depletion of available water holding capacity to allow time for a center pivot to make one complete circle (Irmak et al. 2012). Most center pivots can make a complete circle in 3 – 5 days depending on the well capacity, rate applied, and other factors (Irmak et al. 2012). Lower soil water depletion levels (approx. 80 kPa) should be used from 10-days prior through 7-day after silking (Irmak et al. 2012). Large-scale on-farm comparisons of irrigation triggering between producer intuition and watermark sensors resulted in 32-34% less water applied with watermark sensors with no difference in grain yields (Irmak et al. 2012). In addition, irrigation water use efficiency was 30 – 38% greater and net return increased $32 to $74 with watermark sensors compared to convention watering (Irmak et al. 2012).

Hail Damage in Corn

Hail damage can occur at any time during corn development and has the potential to cause significant yield losses. Annual hail losses in corn are estimated at $580 million (Changnon et al. 2009). These losses are not equally distributed across the U.S. with approximately 1 – 2% yield loss in the Midwest, 5 – 6% in the High Plains, and much less elsewhere in the nation (Changnon 1997). Yield loss from hail will depend on timing, severity, and subsequent environmental conditions.

Early-Season Impact and Management

Approximately half of all hail storms in the United States occur during the early part of the growing season when replanting corn remains a viable option (Vorst 1991).

Evaluating corn for replant needs to occur 7 – 10 days after the hail event to allow adequate time for crop regrowth. A replant decision requires an estimation of the existing plant stand, and this is based on live plants in 1/100th of an acre. Plants with abnormal growth (Fig. 1.2; wrapped or tied) are considered dead during this evaluation because their ability to recover is uncertain. Adjustors may delay early-season hail evaluations when a high percentage of plants exhibit abnormal growth froom hail damage. Remaining plant population and the original plant stand are used to determine the percent of potential yield remaining based on corn stand reduction tables (USDA-FCIC 2014). A decision to replant corn should take into account other factors such as calendar date, weed situation, seed availability, crop value, and the cost of equipment and fuel should also be considered when replanting corn (Vorst 1991).

Several studies have documented the yield impact of young corn plants using various methods of artificial defoliation with highly variable results. Crop development stages of these studies were translated to the leaf collar method based on the author’s description or through correlations with related staging methods published in Abendroth et al. (2011). Lindstrom (1935) reported that reducing leaf tissue of plants by 80% prior to V6 resulted in a 15% reduction in total ear weight. In contrast, Eldredge (1935) found that grain production losses were estimated at less than 10% for corn plants between V1 and V7. Clipping V5 at heights between 3 and 18-cm resulted in yield losses ranging from a loss of 44% to a yield increase of 3%, with lower cutting heights resulting in the greatest yield loss (Dungan and Gausman 1951). Complete defoliation of V4 caused yield loss of 1.1% to 25.9% that were primary attributed to reduced ear size as a result of

reduce leaf area and, to a lesser extent, a small change in plant population (Johnson 1978).

Natural hail events often result in variable damage among plants within a row, increasing the likelihood of intra-plant competition. Vasilas et al. (1991) evaluated intra-plant competition by comparing individual plant yield in plots with all plants defoliated and plots with every other plant defoliated. Complete and alternating defoliation plots had whole plot yield reductions of 12.3% and 8.3%, respectively (Vasilas et al. 1991). Undamaged plants next to a damaged plant had increased ear number per plant, increased kernels per ear, and kernel weight (Vasilas et al. 1991). Yield increase of undamaged plants in alternating defoliation plots was 30% greater than plants in plots with no damage applied (Vasilas et al. 1991). In contrast, damaged plants in alternating defoliation plots yielded 63% less than plants in plots with no damage (Vasilas et al. 1991). Plants from plots with defoliation of all plants yielded 16% less than plants from plots with no damage applied. Further studies are needed to determine the impact of overcompensation and intra-competition among plants with varying levels of damage.

Defoliation of plants during early development has also been shown to delay anthesis and silking (Dungan and Gausman 1951, Cloninger et al. 1974, Singh and Nair 1975, Vasilas and Seif 1985a, 1985b), shorten the duration of pollen shed (Vasilas and Seif 1985a, 1985b), and reduce total pollen (Dungan and Gausman 1951). Johnson (1978) also found that complete defoliation of five-leaf stage corn led to delayed pollen shed and silking, but it did not change the pollen-silking interval in nine hybrids.

Early-season defoliation under field conditions has shown variable yield results among corn hybrids. Complete defoliation of full- and short-season hybrids at V4

resulted in a 8% decrease and 48% increase in yields, respectively (Crookston and Hicks 1978). An evaluation of eleven additional short-season hybrids cut with a razor blade below the second collar at V4 ranged from a 37% increase to 14% decrease in yield (Crookston and Hicks 1988). Johnson (1978) cut two early-, mid-, and late-season hybrids at the first leaf collar during V2 and found no consistent relationship between maturity groups and yield loss with losses ranging from 5.1 to 15.8%. Corn plants cut at the first collar during V4 showed similar yield response with an increase of 3.1% to a losses of 24.4% (Johnson 1978). Yield increases of short-season hybrids as a result of early season hail were thought to reduce early season water use leading to reduced water stress during critical periods later in the season, contributing to higher yields (Crookston and Hicks 1988).

The physiological response of damaged corn plants indicates a complex interaction between plant damage and environmental conditions following hail. Detailed studies of damaged plants grown in a lysimeter showed that plants had elevated temperatures of 2-4°C relative to air temperature that gradually declined to 0.5-1°C difference over the course of 8 days following hail (Anda et al. 2002). Field studies showed that evapotranspiration levels varied according to environmental conditions. Compared to undamaged plants, damaged plants had higher evaporation levels when conditions were warm and dry and lower evaporation levels when cool and wet (Anda et al. 2002).

Late-Season Impact and Management

Yield loss potential increases as the growing point moves above ground during the V6 stage. Cutting plants at the soil level during V7/V8 can result in almost complete loss (97%) of the crop (Dungan and Gausman 1951). Such extreme losses are likely due to the removal of the growing point through cutting. Cutting corn 6 cm above the growing point resulted in a decrease in yield from 12.3% to 40.5% between V6 and V9 (Shapiro et al. 1986). Hanway (1969) determined that leaf defoliation of 50% and 100% at the V10 stage resulted in a 15% and 30% reduction in grain yield, respectively.

Crop hail adjustors use a combination of remaining plant stand and leaf loss charts to estimate payments for insurance (USDA-FCIC 2014). Leaf loss charts indicate the percentage of production lost in 5% increments from 10 to 100% leaf area destroyed (USDA-FCIC 2014). Leaf loss charts show that total loss of leaf area produced 9%, 13%, 22%, 34%, and 51% production loss for V6, V7, V9, V11, and V14, respectively (USDA-FCIC 2014). Leaf loss charts are not available from V1 to V6 because leaf loss is expected to have minimal impacts.

Maximum yield reduction for 100% defoliation occurs around VT when all corn leaves are fully expanded (Hanway 1969). Removal of leaves below the ear leaf at silking resulted in only an 11% yield loss (Adee et al. 2005) because interception of photosynthetically active radiation is reduced in the lower canopy. Dungan (1934) removed 100% of leaf tissue during the reproductive stages of corn and found a 75%, 50% and 4.5% reduction for R2, R3, and R5 stage corn, respectively. These yield reductions don't take into account direct loss of kernels as a result of hail impacting corn

ears. In addition, ear damage increases the likelihood for further loss from insects and diseases.

Hail interactions with Insects and Disease

Physical damage to plants incurred during hailstorms can result in the infestation of secondary insect pests and the inoculation of secondary pathogens. The presence of these organisms can increase yield losses and, in some cases, make grain unmarketable. Limited research has been conducted on the specific role and potential of these organisms in hailed corn fields. The following focuses on a few organisms that are typically found in hail damaged cornfields.

Goss's wilt (*Clavibacter michiganensis* subsp. *nebraskensis* (Vidaver and Mandel)) is a bacterial plant pathogen that is most common and severe following hailstorms (Jackson et al. 2007). Inoculum of Goss's wilt can remain viable on corn residue for up to 10 months (Schuster 1975). Infection occurs as a result of rain splash from crop-infected residue onto open plant wounds during a hailstorm (Claflin 1999). Rapid disease development occurs under warm and moist environments (Martin et al. 1975). The optimal growth for Goss's wilt is between 24°C and 28°C, with arrested pathogen development and death occurring by 38°C (Vidaver and Mandel 1974, Smidt and Vidaver 1986). Symptoms first appear as water soaked lesions parallel to leaf veins with bacterial exudates that appear shiny (Schuster 1975). These symptoms are similar to other plant pathogens, such as Stewart's bacterial wilt (*Erwinia stewartii* (E. F. Smith) Dye) (Schuster 1975). Yield losses of susceptible hybrids typically range from 44% to 63% when comparing resistant and susceptible hybrids (Claflin 1999, Jackson et al.

2007). Preventative management strategies, such as crop rotation and resistant hybrids, are the most effective means of reducing the impact from this pathogen.

Fields impacted by hail during ear development need to be monitored closely for the secondary pathogens and mycotoxins. Robertson et al. (2011) documented the potential impact on disease development and mycotoxin levels following a widespread natural hail event. Mycotoxins are of considerable concern as contaminated grain or feed can result in livestock illness or death, and pose a potential threat to human health (Robertson et al. 2011). During the 2009 growing season, a severe storm affected more than 400,000 hectares of corn in Iowa ranging from R1 to R3 stage (Robertson et al. 2011). The study found that *Fusarium, Gibberella*, and *Cladosporium* ear rots were most prevalent in hail damaged fields. Mycotoxin levels were highest for deoxynivalenol (2.63 mg/kg), followed by zearalenone (0.53 mg/kg) and fumonisin (0.49 mg/kg). Deoxynivalenol and zearalenone levels were four- and ten-fold higher in hail-damaged fields compared to undamaged fields (Robertson et al. 2011).

Scouting fields prior to harvest will provide an estimation of disease potential. Under high disease pressure, heavily infected fields should be harvested first and the grain dried below 15% moisture as soon as possible to arrest mycotoxin development. Producers should avoid mixing clean and infected grain and sell infected grains as soon as possible.

Severe, late season hail storms can bruise corn stalks and increase the likelihood of yield losses due to lodging at harvest. Severe bruising of stalks can interrupt the flow of assimilates in the plant and provide an entry point for plant pathogens. Weakening of stalks increases the likelihood of breaking prior to harvest as a result of high winds.

Scouting fields prior to harvest and assessing plants by pinching the lowest node of the stalks on 100 random plants will determine the number of stalks that have been compromised. A second method involves pushing on plants to 45° of normal to determine lodging risk. Fields should be prioritized for earliest harvest based on those with the highest percentage of weakened or broken stalks.

Hail damaged ears are commonly infested with sap beetles (Nitidulidae). The four-spotted fungus beetle (*Glischrochilus quadrisignatus* Say) is attracted to ripe, damaged or decomposing plant material (McCoy and Brindley 1961). The beetles undergo two generations per year with adults from the second generation occurring during the reproductive growth stages of corn (McCoy and Brindley 1961). Sap beetles alone cause little secondary yield losses to corn, and they are typically only controlled in higher value crops such as sweet corn and seed corn (Steffey et al. 1999). Increased risk of sap beetles in field corn is due to the beetles ability to vector toxigenic fungi, such as *Aspergillus, Penicillium,* and *Fusarium* (Dowd 1995). Several aspects of these beetles make them well suited as a vector of mycotoxin producing fungi. Kaminski et al. (1974) reported that sap beetles were attracted to volatiles produced by *Aspergillus* and *Penicillium* in addition to their attraction for plant-derived esters and alcohols (Dowd 1991). Also, the hair on the sap beetle is ideal for collecting powdery conidia (Juzwik and French 1986, Lussenhop and Wicklow 1991). Toxicology studies show that the sap beetles can tolerate 10- to 100-fold the mycotoxin levels relative to caterpillars, *Heliothus zea* (Boddie) and *Spodoptera frugiperda* (JE Smith) (Dowd and Van Middlesworth 1989). Limited information is available on the management of sap beetles because of their minor importance in corn. Insecticides have been used to effectively control sap

beetles in sweet corn (Dowd 1995). Effective control is field corn requires multiple applications, making this management economically unfeasible (Dowd 1995).

Freeze Damage in Corn

The extent of freeze damage in corn will depend on the low temperature, duration of exposure at that low temperature, corn development stage, water status of the plant, and the environmental conditions that follow the event. Dry corn seeds can withstand -5 to -10°C for two days, but seeds are killed if germination is initiated through exposure to moist conditions at 20°C for one to two days prior to cold treatment (Harper 1956). Young seedlings are easily damaged by freezing temperatures, but plants remain viable as long as the growing point is unaffected (Harper 1956). Buican (1969) found that killing temperatures varied relative to the duration of exposure. Data from Buican (1969) showed that 50% of plants were killed when exposed to -6°C for 2 hr, -5°C for 3 hr, -4°C for 3-6 hr, -3°C for 24-36 hr, and -2°C for 48 hr. The severity of frost damage decreased slightly when plants were 'hardened' at 5-10°C prior to the exposure of colder temperatures (Buican 1969).

Early season freeze damage has a range of potential yield impacts. Severe damage is usually limited to lowlying areas within the a field (Arny and Upper 1973) because cool air is heavier than warm air (de Long 2001). As a result, frost damage to plants can range from slight to severe in a single field (Carter 1990, Elmore and Doupnik 1995). Early season survival of corn plants in the field is attributed to growing-point protection below the soil surface, however, a hard frost or temperatures below -4°C for at least four hours can penetrate the ground and kill plants (Carter 1990). Regrowth of corn following

freeze damage is often impeded by dead leaf tissue causing new leaves to become trapped leading to abnormal growth commonly known as ‘buggy whipping’. Plants significantly impacted by frost have been shown to have silking delayed by 7 to 10 days (Arny and Upper 1973, Carter 1995).

Producers have a limited number of management options following a major freeze event (Elmore and Doupnik 1995). Depending on the level of damage, they may decide to leave the crop, replant, or clip the dead plant tissue to prevent plants from becoming wrapped or tied. Replanting corn affected by frost will depend on numerous factors such as frequency of plant death, replant cost, and seed availability. Clipping frost-damaged plants has led to highly variable results. Clipping heights greater than 1 inch were found to increase grain yields by 40% compared to nonclipped plants (Carter 1990). In contrast, Carter (1995) found that post frost clipping corn plants reduced yields by 15 – 34% at three sites and were comparable to unmanaged corn plants. A fourth site showed a 10% increase as a result of clipping (Carter 1995). Elmore and Doupnik (1995) evaluated three fields at V3-V4 with varying levels of defoliation (100%, 70%, and 55%) from frost for replant, clipping, and no treatment. Replanted corn yielded 22-90% greater with 100% defoliation, no differences were observed with 70% defoliation, and a yield loss was observed when compared to 55% defoliation (Elmore and Doupnik 1995). Clipping plants was not significantly change yields at 55% defoliation; however, yields were reduced by 37% when plants were defoliated 100% (Elmore and Doupnik 1995).

The variability of corn response to clipping could be due to numerous factors. Temperature during clipping can have a significant impact on corn plants. Johnson (1978) found that clipping corn plants under high temperatures (30-32°C) reduced stands

by more than 90%. None of the previous studies noted temperature at time of cutting, but it is possible that this could influence the yield potential of cut plants. Elmore and Doupnik (1995) indicated that cool conditions following frost could lead to continued plant mortality as a result of *Pseudomonas fluorescens*. Cutting could provide a means of widespread dissemination of bacterial pathogens in the field leading to increased yield losses (Elmore and Doupnik 1995).

Chilling temperatures don't have to be lethal to leaf tissue to cause yield losses. Lejeune and Bernier (1996) demonstrated that significant primary ear abortion was achieved by chilling corn plants, but this occurred only when it was applied at the V6 growth stage (Lejeune and Bernier 1996). Chilling treatments applied at V3 only caused abortion of ear shoots below the primary ear (Lejeune and Bernier 1996). This corresponds with McMaster et al. (2005) finding that ear shoot initiation began during the V3 growth stage. Chilling temperature of 5°C were slightly less inhibitory compared with 10°C (Lejeune and Bernier 1996). Duration of chilling ranging from three to seven days resulted in similar levels of abortion (Lejeune and Bernier 1996). Primary ear loss has been associated with the presence of 'double' and 'bouquet' ears under field conditions (Elmore and Abendroth 2006). Yield potentials for double ears did not appear to cause significant yield losses; however, fields with a higher percentage of 'bouquet' ears yielded significantly less (Elmore and Abendroth 2006).

Replanting corn is highly dependent on both the calendar date and prevailing environmental conditions. Nafziger (1994) found that yield losses were 18% between 9 May and 29 May planting dates in central Illinois. Planting in mid-June caused yields to decline rapidly with losses as high as 50% (Nafziger 1994). Lauer et al. (1999) found

similar losses; with grain yields declined at a rate of 0.5 to 1.1%, 1.3 to 1.9%, and 2.0 to 2.8% per day for 0-2, 2-4, and 4-6 weeks after 9 May in Wisconsin. Yield losses with later planting dates increases the importance of properly evaluating the yield potential of the existing crop. These evaluations should only be made after the crop has had adequate time for regrowth. Replant decisions should also consider the weed situation, seed availability, and the cost of equipment and field conditions.

Drought, hail and chilling temperatures have numerous biological and economical implications for corn. The information in this chapter provides some insights into the potential for knowledge and information to mitigate losses under a changing climate. Continued research will be needed to provide agricultural clientele with the most accurate information available to assist in the making difficult management decisions.

References

Abendroth, L. J., R. W. Elmore, M. J. Boyer, and S. K. Marlay. **2011**. Corn growth and development. PMR 1009. Iowa State University Extension, Ames, Iowa.

Adee, E. A., L. E. Paul, E. D. Nafziger, and G. Bollero. **2005**. Yield loss of corn hybrids to incremental defoliation. Crop Manag. 4: 1–9.

Anda, A., Z. Burucs, Z. Lõke, and É. K. Decsi. **2002**. Effects of hail on evapotranspiration and plant temperature of maize. J. Agron. Crop Sci. 188: 335–341.

Armstrong, C. F., J. T. Ligon, and S. J. Thomson. **1985**. Calibration of Watermark model 200 soil moisture sensor. Pap.-Am. Soc. Agric. Eng. USA.

Arny, D. C., and C. D. Upper. **1973**. Example of the effects of early season frost damage on yield of corn. Crop Sci. 13: 760–761.

Bänziger, M., G. O. Edmeades, D. L. Beck, and M. R. Bellon. **2000**. Breeding for drought and nitrogen stress tolerance in maize: from theory to practice. CIMMYT, Mexico.

Baumhardt, R. L., R. Schwartz, T. Howell, S. R. Evett, and P. Colaizzi. **2013**. Residue Management Effects on Water Use and Yield of Deficit Irrigated Corn. Agron. J. 105: 1035.

Begna, S. H., R. I. Hamilton, L. M. Dwyer, D. W. Stewart, and D. L. Smith. **1997**. Effects of population density and planting pattern on the yield and yield components of leafy reduced-stature maize in a short-season area. J. Agron. Crop Sci. 179: 9–17.

Blevins, R. L., D. Cook, S. H. Phillips, and R. E. Phillips. **1971**. Influence of no-tillage on soil moisture. Agron. J. 63: 593–596.

Blumenthal, J. M., D. J. Lyon, and W. W. Stroup. **2003**. Optimal plant population and nitrogen fertility for dryland corn in western Nebraska. Agron. J. 95: 878–883.

Buican, D. 1969. Researches sur la transmission de la resistance aux basses temperatures· chez les hybrides de Zea mays. Ann. Physiol. Veg. 11: 431–440.

Çakir, R. 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Res. 89: 1–16.

Campos, H., M. Cooper, J. E. Habben, G. O. Edmeades, and J. R. Schussler. **2004**. Improving drought tolerance in maize: a view from industry. Field Crops Res. 90: 19–34.

Carter, P. R. 1990. Clipping corn following early-season frost. J. Prod. Agric. 3: 394–398.

Carter, P. R. 1995. Late spring frost and post-frost clipping effect on corn growth and yield. J. Prod. Agric. 8: 203–209.

Changnon, S. A. 1997. Trends in hail in the United States. *In* Workshop Soc. Econ. Impacts Weather. Boulder, Colorado, U.S.

Changnon, S. A., D. Changnon, and S. D. Hilberg. **2009**. Hailstorms across the nation: an atlas about hail and its damages. Illinois State Water Survey, Chapaign, Illinois.

Chaves, M. M., J. S. Pereira, J. Maroco, M. L. Rodrigues, C. P. P. Ricardo, M. L. Osório, I. Carvalho, T. Faria, and C. Pinheiro. **2002**. How plants cope with water stress in the field? Photosynthesis and growth. Ann. Bot. 89: 907–916.

Claflin, L. E. 1999. Goss's bacterial wilt and blight., pp. 4–5. *In* Compend. Corn Dis. American Phytopathological Society, St. Paul, MN.

Cloninger, F. D., M. S. Zuber, and R. D. Horrocks. **1974**. Synchronization of flowering in corn (Zea mays L.) by clipping young plants. Agron. J. 66: 270–272.

Crookston, R. K., and D. R. Hicks. **1978**. Early defoliation affects corn grain yields. Crop Sci. 18: 485–489.

Crookston, R. K., and D. R. Hicks. **1988**. Effect of early defoliation on maize growth and yield: an eleven-year perspective. Crop Sci. 28: 371.

Davies, W. J., and J. Zhang. **1991**. Root signals and the regulation of growth and development of plants in drying soil. Annu. Rev. Plant Biol. 42: 55–76.

Dowd, P. F. 1991. Nitidulids as vectors of mycotoxin-producing fungi. Res. Bull.-Iowa State Univ. Agric. Home Econ. Exp. Stn. USA.

Dowd, P. F. 1995. Sap beetles and mycotoxins in maize. Food Addit. Contam. 12: 497–508.

Dowd, P. F., and F. L. Van Middlesworth. **1989**. In vitro metabolism of the trichothecene 4-monoacetoxyscirpenol by fungus-and non-fungus-feeding insects. Experientia. 45: 393–395.

Duffy, P. B., and C. Tebaldi. **2012**. Increasing prevalence of extreme summer temperatures in the U.S. Clim. Change. 111: 487–495.

Dungan, G. H. 1934. Losses to the corn crop caused by leaf injury. Plant Physiol. 9: 749–766.

Dungan, G. H., and H. W. Gausman. **1951**. Clipping corn plants to delay their development. Agron. J. 43: 90–93.

Duvick, D. N. 1977. Genetic rates of gain in hybrid maize yields during the past 40 years. Maydica. 50: 193–202.

Duvick, D. N., J. S. C. Smith, and M. Cooper. **2004a**. Long-term selection on a commercial hybrid maize breeding program. Plant Breed. Rev. 24: 109–151.

Duvick, D. N., J. S. C. Smith, and M. Cooper. **2004b**. Changes in performance, parentage, and genetic diversity of successful corn hybrid, 1930-2000., pp. 65–99. *In* Corn Orig. Hist. Technol. Prod. John Wiley & Sons.

Eck, H. V. 1986. Effects of water deficits on yield, yield components, and water use efficiency of irrigated corn. Agron. J. 78: 1035–1040.

Eldredge, E. P., C. C. Shock, and T. D. Stieber. **1993**. Calibration of granular matrix sensors for irrigation management. Agron. J. 85: 1228–1232.

Eldredge, J. C. 1935. Effect of injury in imitation of hail damage on the development of the corn plant. Agric. Exp. Stn. Iowa State Coll. Agric. Mech. Arts. 185: 61 pp.

Elmore, R., and L. Abendroth. **2006**. A response to phenomenon in 2006: Multiple ears per node. Integr. Crop Manag. News. Paper 1358: 3 pp.

Elmore, R. W., and B. Doupnik. **1995**. Corn Recovery from Early-Season Frost. J. Prod. Agric. 8: 199–202.

Fageria, N. K., V. C. Baligar, and R. Clark. **2006**. Physiology of crop production. CRC Press.

Gaffney, J., J. Schussler, C. Löffler, W. Cai, S. Paszkiewicz, C. Messina, J. Groeteke, J. Keaschall, and M. Cooper. **2015**. Industry-scale evaluation of maize hybrids selected for increased yield in drought-stress conditions of the us corn belt. Crop Sci. 55: 1608–1618.

Garnett, T., M. C. Appleby, A. Balmford, I. J. Bateman, T. G. Benton, P. Bloomer, B. Burlingame, M. Dawkins, L. Dolan, D. Fraser, and others. **2013**. Sustainable intensification in agriculture: premises and policies. Science. 341: 33–34.

Gowing, D. J. G., W. J. Davies, and H. G. Jones. **1990**. A positive root-sourced signal as an indicator of soil drying in apple, Malus x domestica Borkh. J. Exp. Bot. 41: 1535–1540.

Grant, R. F., B. S. Jackson, J. R. Kiniry, and G. F. Arkin. **1989**. Water deficit timing effects on yield components in maize. Agron. J. 81: 61–65.

Habben, J. E., X. Bao, N. J. Bate, J. L. DeBruin, D. Dolan, D. Hasegawa, T. G. Helentjaris, R. H. Lafitte, N. Lovan, H. Mo, K. Reimann, and J. R. Schussler. **2014**. Transgenic alteration of ethylene biosynthesis increases grain yield in maize under field drought-stress conditions. Plant Biotechnol. J. 12: 685–693.

Hanway, J. J. 1969. Defoliation effects on different corn (Zea mays L.) hybrids as influenced by plant population and stage of development. Agron. J. 61: 534–538.

Hao, B., Q. Xue, T. H. Marek, K. E. Jessup, J. Becker, X. Hou, W. Xu, E. D. Bynum, B. W. Bean, P. D. Colaizzi, and others. **2015**. Water use and grain yield in drought-tolerant corn in the Texas High Plains. Agron. J. 107: 1922–1930.

Harper, J. L. 1956. Studies in seed and seedling mortality. New Phytol. 55: 35–44.

Havlin, J. L., and F. R. Lamm. **1988**. Management of dryland corn for the central Great Plains. *In* Chall. Dryland Agric. - Glob. Perspect. Proc. Int. Conf. on Dryland Farming, Amarillo, TX.

Horton, R. F. 1971. Stomatal opening: the role of abscisic acid. Can. J. Bot. 49: 583–585.

Horton, R. F., and L. Moran. **1972**. Abscisic acid inhibition of potassium influx into stomatal guard cells. Z. Für Pflanzenphysiol. 66: 193–196.

Howell, T. A. 2001. Enhancing water use efficiency in irrigated agriculture. Agron. J. 93: 281–289.

Irmak, S., M. J. Burgert, H. S. Yang, K. G. Cassman, D. T. Walters, W. R. Rathje, J. O. Payero, P. Grassini, M. S. Kuzila, K. J. Brunkhorst, and others. **2012**. Large-scale on-farm implementation of soil moisture-based irrigation management strategies for increasing maize water productivity. Trans. ASABE. 55: 881–894.

Irmak, S., and D. Z. Haman. **2001**. Performance of the watermark granular matrix sensor in sandy soils. Appl. Eng. Agric. 17: 787–795.

Jackson, T. A., R. M. Harveson, and A. K. Vidaver. **2007**. Reemergence of Goss's wilt and blight of corn to the central High Plains. Plant Health Prog. (doi:10.1094/PHP-2007-0919-01-BR.).

Johnson, R. R. 1978. Growth and yield of maize as affected by early-season defoliation. Agron. J. 70: 995–998.

Juzwik, J., and D. W. French. **1986**. Relationship between nitidulids and Ceratocystis fagacearum during late summer and autumn in Minnesota. Plant Dis. 70: 424–426.

Kaminski, E., S. Stawicki, and E. Wasowicz. **1974**. Volatile flavor compounds produced by molds of Aspergillus, Penicillium, and Fungi imperfecti. Appl. Microbiol. 27: 1001–1004.

Lauer, J. G., P. R. Carter, T. M. Wood, G. Diezel, D. W. Wiersma, R. E. Rand, and M. J. Mlynarek. **1999**. Corn hybrid response to planting date in the northern corn belt. Agron. J. 91: 834–839.

Lejeune, P., and G. Bernier. **1996**. Effect of environment on the early steps of ear initiation in maize (Zea mays L.). Plant Cell Environ. 19: 217–224.

Lindstrom, E. W. 1935. Genetic experiments on hybrid vigor in maize. Am. Nat. 69: 311–322.

Lipps, P. E., I. W. Deep, and others. **1991**. Influence of tillage and crop rotation on yield, stalk rot, and recovery of Fusarium and Trichoderma spp. from corn. Plant Dis. 75: 828–833.

de Long, E. 2001. Understanding frost. Cornell Coop. Ext. Chemung Cty. (http://gardening.cce.cornell.edu/).

Ludlow, M. M. 1980. Adaptive significance of stomatal response to water stress. *In* Adapt. Plants Water High Temp. Stress. Wiley, New York, NY.

Lussenhop, J. L., and D. T. Wicklow. **1991**. Nitidulid beetles as a source of Aspergillus flavus infective inoculum. Trans. Jpn. Mycol. Soc. 31: 63–74.

Lyon, D. J., A. D. Pavlista, G. W. Hergert, R. N. Klein, C. A. Shapiro, S. Knezevic, S. C. Mason, L. A. Nelson, D. D. Baltensperger, R. W. Elmore, M. F. Vigil, A. J. Schlegel, B. L. Olson, and R. M. Aiken. **2009**. Skip-row planting patterns stabilize corn grain yields in the central Great Plains. Crop Manag. 8: 8 pp.

Maroco, J. P., M. L. Rodrigues, C. Lopes, and M. M. Chaves. **2002**. Limitations to leaf photosynthesis in field-grown grapevine under drought—metabolic and modelling approaches. Funct. Plant Biol. 29: 451–459.

Martin, P. R., C. O. Gardner, A. G. Calub, and M. L. Schuster. **1975**. Inheritance of susceptibility and tolerance to leaf freckles and wilt (Corynebacterium nebraskense) of corn. Maize Genet Coop Newsl. 49: 137–138.

McCann, I. R., D. C. Kincaid, and D. Wang. **1992**. Operational characteristics of the watermark model 200 soil water potential sensor for irrigation management. Appl. Eng. Agric. 8: 603–609.

McCoy, C. E., and T. A. Brindley. **1961**. Biology of the four-spotted fungus beetle, Glischrochilus q. quadrisignatus and its effect on European corn borer populations. J. Econ. Entomol. 54: 713–717.

McGuire, V. 2012. Water-level and storage changes in the High Plains Aquifer, predevelopment to 2011 and 2009–11. U.S. Geological Survey Scientific Investigation Reports 2012-5291.

McGuire, V. L. 2014. Water-level changes and change in water in storage in the High Plains aquifer, predevelopment to 2013 and 2011-13. U.S. Geological Survey Scientific Investigations Report 2014–5218.

McMaster, G. S., W. W. Wilhelm, and A. B. Frank. **2005**. Developmental sequences for simulating crop phenology for water-limiting conditions. Crop Pasture Sci. 56: 1277–1288.

Messina, C. D., T. R. Sinclair, G. L. Hammer, D. Curan, J. Thompson, Z. Oler, C. Gho, and M. Cooper. **2015**. Limited-Transpiration Trait May Increase Maize Drought Tolerance in the US Corn Belt. Agron. J. 107: 1978–1986.

Miedema, P. 1982. The effect of low temperature on Zea mays. *In* Adv. Agron. Vol. 35. Academic Press, Inc., New York.

Milander, J. 2015. Maize yield and components as influenced by environment and agronomic management. Theses Diss. Stud. Res. Agron. Hortic.

Musick, J. T., and D. A. Dusek. **1982**. Skip-row planting and irrigation of graded furrows. Trans. ASAE. 25: 82–87.

Nafziger, E. D. 1994. Corn planting date and plant population. J. Prod. Agric. 7: 59–62.

Nebraska DNR. **2010**. Registered groundwater wells by natural resources district. Lincoln, Neb.: Nebraska Department of Natural Resources. (http://dnrdata.dnr.ne.gov/wellssql/Summary.asp?type=nrd.).

Nemali, K. S., C. Bonin, F. G. Dohleman, M. Stephens, W. R. Reeves, D. E. Nelson, P. Castiglioni, J. E. Whitsel, B. Sammons, R. A. Silady, D. Anstrom, R. E. Sharp, O. R. Patharkar, D. Clay, M. Coffin, M. A. Nemeth, M. E. Leibman, M. Luethy, and M. Lawson. **2015**. Physiological responses related to increased grain yield under drought in the first biotechnology-derived drought-tolerant maize. Plant Cell Environ. 38: 1866–1880.

NeSmith, D. S., and J. T. Ritchie. **1992**. Short-and long-term responses of corn to a pre-anthesis soil water deficit. Agron. J. 84: 107–113.

Nissanka, S. P., M. A. Dixon, and M. Tollenaar. **1997**. Canopy gas exchange response to moisture stress in old and new maize hybrid. Crop Sci. 37: 172–181.

Norwood, C. A., and R. S. Currie. **1996**. Tillage, planting date, and plant population effects on dryland corn. J. Prod. Agric. 9: 119.

Ort, D. R., K. Oxborough, and R. R. Wise. **1994**. Depressions of photosynthesis in crops with water deficits. Photoinhibition Photosynth. Mol. Mech. Field. 315–329.

Raschke, K. 1975. Stomatal action. Annu. Rev. Plant Physiol. 26: 309–340.

Rhoads, F. M., and J. M. Bennett. **1990**. Corn. 569–596.

Robertson, A. E., G. P. Munkvold, C. R. Hurburgh, and S. Ensley. **2011**. Effects of natural hail damage on ear rots, mycotoxins, and grain quality characteristics of corn. Agron. J. 103: 193–199.

Rosenzweig, C., A. Iglesias, X. B. Yang, P. R. Epstein, and E. Chivian. **2001**. Climate change and extreme weather events; implications for food production, plant diseases, and pests. Glob. Change Hum. Health. 2: 90–104.

Sauter, A., W. J. Davies, and W. Hartung. **2001**. The long-distance abscisic acid signal in the droughted plant: the fate of the hormone on its way from root to shoot. J. Exp. Bot. 52: 1991–1997.

Schulze, E. 1986. Carbon-Dioxide and Water-Vapor Exchange in Response to Drought in the Atmosphere and in the Soil. Annu. Rev. Plant Physiol. Plant Mol. Biol. 37: 247–274.

Schuster, M. L. 1975. Leaf freckles and wilt of corn incited by corynebacterium nebraskense. Agric. Exp. Stn. IANR Univ. Neb. Res. Bull. 270: 40 pp.

Sebastian, S. A., L. Feng, and L. C. Kuhlman. **2015**. Accelerated Yield Technology™: a platform for marker assisted selection of simple and complex traits. Des. Soybeans 21st Century Mark. 297.

Shah, T., J. Burke, K. Villholth, M. Angelica, E. Custodio, F. Daibes, J. Hoogesteger, M. Giordano, J. Girman, and J. Van Der Gun. **2007**. Groundwater: a global assessment of scale and significance. International Water Management Institute.

Shapiro, C. A., T. A. Peterson, and A. D. Flowerday. **1986**. Yield loss due to simulated hail damage on corn: A comparison of actual and predicted values. Agron. J. 78: 585–589.

Shaw, R. H. 1977. Climatic requirements, pp. 315–341. *In* Corn Corn Improv. ASA, CSSA, and SSSA, Madison, WI.

Shaw, R. H. 1983. Estimates of yield reductions in corn caused by water and temperature stress. Crop React. Water Temp. Stress. Humid Temp. Clim. 49–65.

Singh, R. P., and K. P. P. Nair. **1975**. Defoliation studies in hybrid maize: I. Grain yield, quality and leaf chemical composition. J. Agric. Sci. 85: 241–245.

Skoglund, L. G., and W. M. Brown. **1988**. Effects of tillage regimes and herbicides on Fusarium species associated with corn stalk rot. Can. J. Plant Pathol. 10: 332–338.

Smidt, M. L., and A. K. Vidaver. **1986**. Differential effects of lithium chloride on in vitro growth of Clavibacter michiganense subsp. nebraskense depending upon inoculum source. Appl. Environ. Microbiol. 52: 591–593.

Steffey, K. L., M. E. Rice, J. All, D. A. Andow, M. E. Gray, J. W. van Duy, and others. **1999**. Handbook of corn insects. Entomological society of America.

Sturz, A. V., M. R. Carter, and H. W. Johnston. **1997**. A review of plant disease, pathogen interactions and microbial antagonism under conservation tillage in temperate humid agriculture. Soil Tillage Res., Soil Biology and Tillage. 41: 169–189.

Sumner, D. R., B. Doupnik Jr, and M. G. Boosalis. **1981**. Effects of reduced tillage and multiple cropping on plant diseases. Annu. Rev. Phytopathol. 19: 167–187.

Tack, J. B., and M. T. Holt. **2015**. The influence of weather extremes on the spatial correlation of corn yields. Clim. Change. 134: 299–309.

Thomson, S. J., and C. F. Armstrong. **1987**. Calibration of the Watermark model 200 soil moisture sensor. Appl. Eng. Agric. 3: 186–189.

Tollenaar, M. 1991. Physiological basis of genetic improvement of maize hybrids in Ontario from 1959 to 1988. Crop Sci. 31: 119–124.

Triplett, G. B., D. M. VanDoren, and B. L. Schmidt. **1968**. Effect of corn (Zea mays L.) stover mulch on no-tillage corn yields and water infiltration. Agron. J. 60: 236–239.

Uribelarrea, M., J. Carcova, M. E. Otegui, and M. E. Westgate. **2002**. Pollen production, pollination dynamics, and kernel set in maize. Crop Sci. 42: 1910–1918.

USDA-FCIC, (United States Department of Agriculture - Federal Crop Insurance Corporation). **2014**. Corn Loss Adjustment Standards Handbook. Risk Manag. Agency. 25080: 1–104.

Vasilas, B. L., J. J. Fuhrmann, and R. W. Taylor. **1991**. Response of three corn hybrids to defoliation of neighboring plants. Can. J. Plant Sci. 71: 311–315.

Vasilas, B. L., and R. D. Seif. **1985a**. Defoliation effects on two corn inbreds and their single-cross hybrid. Agron. J. 77: 816–820.

Vasilas, B. L., and R. D. Seif. **1985b**. Pre-anthesis defoliation effects on six corn inbreds. Agron. J. 77: 831.

Vidaver, A. K., and M. Mandel. **1974**. Corynebacterium nebraskense, a new, orange-pigmented phytopathogenic species. Int. J. Syst. Evol. Microbiol. 24: 482–485.

Vorst, J. J. 1991. Assessing hail damage to corn. Natl. Corn Handb. Clim. Weather Iowa State Univ. Ext. NCH 1.

Waltz, E. 2014. Beating the heat. Nat. Biotechnol. 32: 610–613.

Weyers, J. D. B., and J. R. Hillman. **1979**. Uptake and distribution of abscisic acid in Commelina leaf epidermis. Planta. 144: 167–172.

Wheeler, T., and J. von Braun. **2013**. Climate change impacts on global food security. Science. 341: 508–513.

Tables

Table 1.1: Estimated evapotranspiration from corn and loss per day during various stages of development.

Development Stage	Evapotranspiration mm/day	% Yield Loss / Day of Stress (min – ave – max)
Seedling to 4 leaf	1.5	.
4 leaf to 8 leaf	2.5	.
8 leaf to 12 leaf	4.6	.
12 leaf to 16 leaf	5.3	2.1 - 3.0 - 3.7
16 leaf to tasseling	8.4	2.5 - 3.2 - 4.0
Pollination (R1)	8.4	3.0 - 6.8 - 8.0
Blister (R2)	8.4	3.0 - 4.2 - 6.0
Milk (R3)	6.6	3.0 - 4.2 - 5.8
Dough (R4)	6.6	3.0 - 4.0 - 5.0
Dent (R5)	6.6	2.5 - 3.0 - 4.0
Maturity (R6)	5.8	0

Adapted from Rhoads and Bennett (1990) and Shaw (1988)

Table 1.2: Low temperature range to cause visible response in corn plants and the impact on genetic variation and significance on growth for different metrics at different times during development.

Timing and metrics	Temperature range (°C)	Genetic variation	Significance for growth
Damage before emergence			
Chilling injury to seeds	0 - 5	+[α]	?
Chilling injury to seedlings	0 - 5	++	+ ?
Seedling malformations	ca. 10	+	±
Reduced vigor	5 - 12	+	+
Seed rot	8 - 12	+	+
Seedling blight	8 - 12	?	+
Rate limitations before emergence			
Germination	6 - 10	+	-
Shoot growth (rate of emergence)	8 - 15	+	?
Root growth	8 - 15	+	+
Damage after emergence			
Frost injury	< -2	±	±
Chilling-induced cross bands	< 10	±	±
Chilling injury at high light levels	10 - 13	?	?
Chlorosis	10 - 15	++	++
Rate limitations after emergence			
Water uptake	< 12	?	?
Net photosynthesis	10 - 15	?	-
Translocation of carbohydrates	5 - 10	?	?
Root growth (P deficiency)	8 - 15	++	+
Shoot growth, leaf extension	8 - 15	++	+++

[α] -, ±, +, ++ and +++ represent a scale of impact of metric from zero to large
Adapted from (Miedema 1982)

Figures

Figure 1.1: Corn development stage and period of development for determination of yield components.

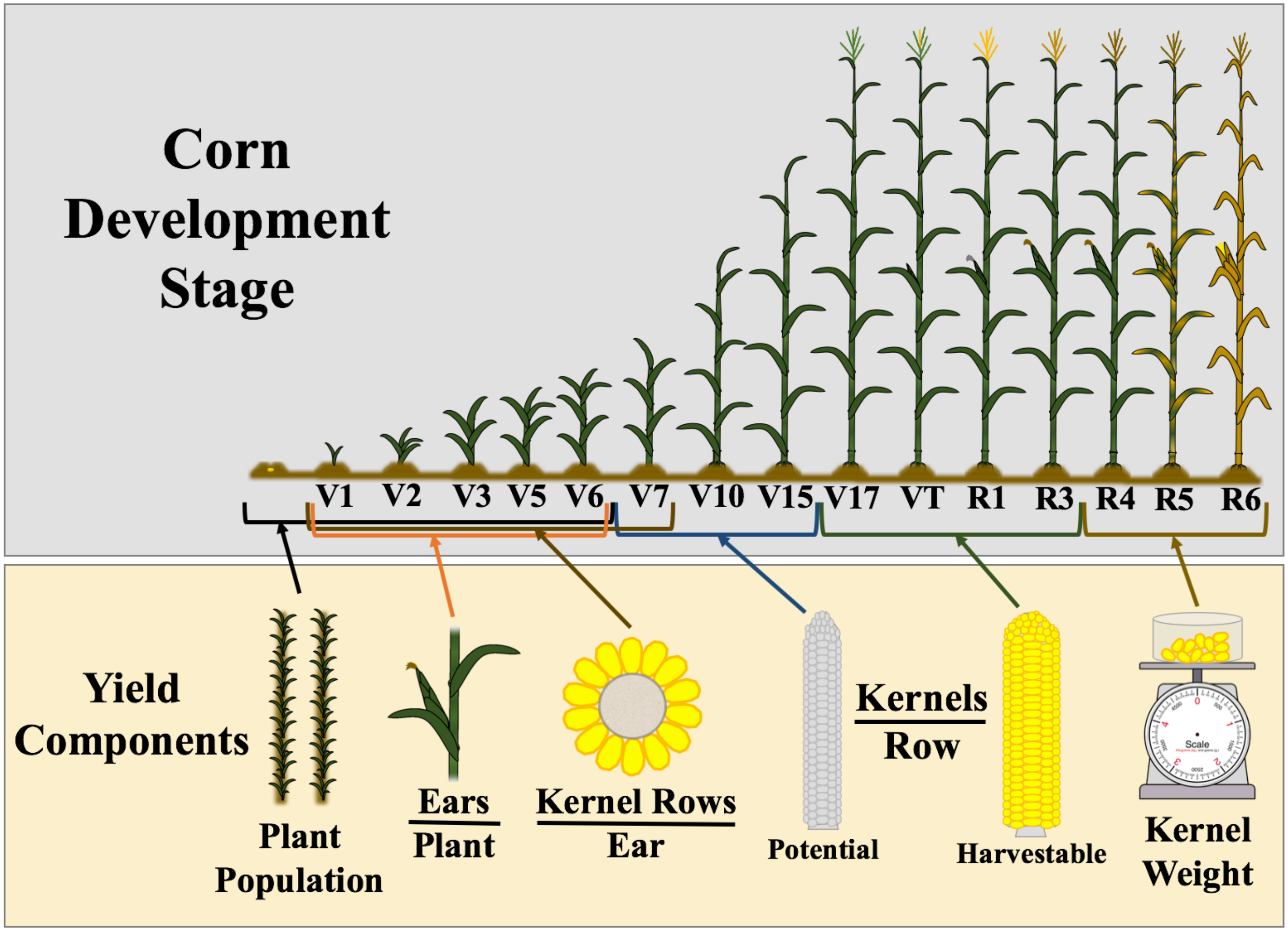


Figure 1.2: Examples of plants with abnormal growth (a) wrapped (b) poor growth (c) late season wrapped (d) non-competitive responses following a major hail event.

CHAPTER 2

Evaluating early-season hail damage in corn and its interaction with Goss's Wilt

Introduction

Approximately half of all hail storms in the United States occur during the early part of the growing season when replanting corn remains a viable option (Vorst 1991). To properly assess fields for replant, producers should wait 7 – 10 days after a hail event. Early-season hail damage evaluations by crop adjustors are based on the remaining live plant population and typically assume that corn plants hailed prior to V6 (Abendroth et al. 2011) will produce similar grain yields regardless of the range in damage among plants.

Yield potential of surviving plants has been estimated through artificial defoliation. Complete defoliation of V2 to V5 corn resulted in yield losses from 8.7 to 23%, respectively (Eldredge 1935). In contrast, shredding or removing up to two-thirds of corn leaves from V2 to V5 plants resulted in less than 4% yield loss (Eldredge 1935). Lindstrom (1935) found that harvest biomass was reduced by 30% when plants were defoliated by 75-85% prior to V6. Damage from hail can vary significantly between neighboring corn plants increasing the likelihood of unequal intra-plant competition. Vasilas et al. (1991) evaluated the potential yield impact of intra-plant competiton by comparing plots with defoliation of every other corn plant to those with all plants defoliated during the early stages of plant development (~V4). Average grain yield was reduced by 12.3% for complete defoliation and 8.3% yield loss was observed when only half of the plants were defoliated (Vasilas et al. 1991). Undamaged plants from the half-defoliated plots yielded 30% more than plants in the control plots as a result of increased ear number per plant, kernels per ear, and kernel weight (Vasilas et al. 1991). In contrast, damaged plants in the half-defoliated plots yielded 63% less (Vasilas et al. 1991). These

results suggest that undamaged or lightly damaged plants may be able to compensate for some of the yield losses incurred by adjacent plants with more severe hail damage.

Corn hybrids vary in their response to artificial hail. Complete defoliation of full-season hybrids at V4 resulted in an 8% yield loss; whereas, short-season hybrids hailed at the same stage increased yields by 48% (Crookston and Hicks 1978). An evaluation of eleven additional short-season hybrids showed yields ranging from a 37% increase to 14% decrease (Crookston and Hicks 1988). Johnson (1978) cut two early-, mid-, and late-season hybrids at the first leaf collar during V2 and found no consistent relationship between maturity groups and yield loss with losses ranging from 5.1 to 15.8%. Corn plants cut at the first collar during the V4 showed similar yield response with increases of 3.1% to a losses of 24.4% (Johnson 1978). Yield increases from early-season defoliation have been attributed to situations where soil water was limited. Early-season defoliation was thought to reduce water uptake, leaving more water available during the later half of the growing season when water demand was high (Crookston and Hicks 1988).

Yield reductions from early-season damage have been attributed to reduced leaf area and changes in anthesis-silking intervals. Yield losses from complete defoliation of V3 corn plants were attributed to reduced ear size as a result of reduce leaf area and to a lesser extent, reduced plant population (Johnson 1978). Defoliation of plants during early development has also been shown to delay anthesis and silking (Dungan and Gausman 1951, Cloninger et al. 1974, Singh and Nair 1975, Vasilas and Seif 1985a, 1985b), reduce pollen shed period (Vasilas and Seif 1985a, 1985b), and reduce total pollen (Dungan and Gausman 1951).

Physical damage to plants incurred during hailstorms can increase the potential for secondary disease development from bacterial pathogens. Goss's wilt (*Clavibacter michiganensis* subsp. *nebraskensis* (Vidaver and Mandel 1974)) is a bacterial plant pathogen that is most common and severe following hailstorms (Jackson et al. 2007). Infection occurs as a result of rain splash from crop-infected residue onto open plant wounds during a hailstorm (Claflin 1999). Inoculum of Goss's wilt can remain viable on corn residue for up to 10 months (Schuster 1975). Rapid disease development occurs under warm and moist environments (Martin et al. 1975). The optimal growth for Goss's wilt is between 24°C and 28°C, with arrested development and death occurring at 38°C (Vidaver and Mandel 1974, Smidt and Vidaver 1986). Symptoms appear as water soaked lesions parallel with leaf veins with bacterial exudates that appear shiny (Schuster 1975). Yield losses for susceptible hybrids typically range between 44% and 63% compared to resistant hybrids (Claflin 1999, Jackson et al. 2007). Preventative management strategies such as crop rotation and resistant hybrids are the most effective means of reducing the impact from this pathogen.

Yield impact of early-season defoliation of corn are highly variable. Studies addressing early-season defoliation used precise methods and didn't take into account plant regrowth following defoliation treatment. This study was designed to assess yield impacts based on short-term response of corn to early-season hail damage using a hail machine. The first objective was to test the assumption of the National Crop Insurance Service that surviving plants hailed prior to V6 will have no yield impacts compared to undamaged plants. To test this, we use of a novel plant damage scoring system to provide a graded evaluation of damage severity. The second objective was to compare this novel

damage scoring system with the current hail-industry evaluation method, i.e. counting the remaining plant stand, to determine its value in predicting final grain yield. In addition, the study evaluates whether the timing of evaluation could alter the final grain yield estimates. The last objective was to address the interaction between early-season hail and a bacterial plant pathogen, Goss's wilt, on the yield potential and impact on predicting yield losses with plant damage score or remaining plant population evaluation methods.

Materials and Methods

This field study was conducted as a randomized complete block, split-split plot design with six replications at the Agricultural Research and Development Center near Mead, NE during the summer of 2015. The field that was planted to corn in 2014. Main plot treatments were four planting dates (11 May, 28 May, 11 June and 23 June) to represent potentially different growing conditions following a major hail event. Split-plot treatments consisted of two corn hybrids with different tolerance to Goss's wilt. DeKalb 65-66 (115-day), a Goss's wilt tolerant hybrid and DeKalb 61-88 (111-day), a Goss's wilt susceptible hybrid, were each planted in two adjacent 13.5-m rows with 0.76-m row spacing at a seeding rate of approximately 34,000 plants per acre. Split-split plot treatments consisted of an unhailed check, simulated hail, and simulated hail with Goss's wilt inoculation. Each hail treatment consisted of two, 4.5-m rows for both corn hybrids. Planting date plots were separated by two rows of DeKalb 65-66, planted on 11 May to reduce the spread of Goss's wilt among planting dates.

Individual corn plant locations and development stages were recorded prior to each hail treatment using a GoPro Hero 4 camera (GoPro Inc. San Mateo, California, USA), FeiyuTech 3-Axis gimbal (GuiLi FeiYu Electronic Technology Co., Ltd. Guilin, China) and a field tape measure. To record an individual row, the tape measure was stretched out the entire length of the plot for an individual planting date. The GoPro camera was attached to the gimbal and oriented to record the plant location and development stage. Pre-hail recordings were taken within 48-hours of the simulated hail treatment.

Ice was applied with a hail simulator attached to and powered by a tractor at the V3-V4 stage. Five, 9-kg ice bags were placed in a hopper at the top of the machine and fed into a vertical feeder housing containing a rotating horizontal cylinder with spikes that crushed the ice into 3-5 cm pieces. Ice stones were propelled from the machine via a hydraulic air seeder fan at approximately 280 km/h at the nozzle opening through a 20-cm diameter flexible hose. Air speed declines rapidly upon exiting the hose with speeds of approximately 80 – 120 km/hr a few feet from the nozzle The hose was held at a height of 1.7-m and directed at a 45-degree angle across the entire corn plot in a continuous motion to provide a uniform application of ice within each plot. Corn plants were V3-V4 stage at the time of the hail events.

Bacterial applications were made to plots immediately following the simulated hail treatment. Goss's wilt inoculum consisted of five isolates from various geographic regions in Nebraska collected during the summer of 2011. Bacterial isolates were taken from porous beads stored at -80°C. A single bead was spread in a T-streak pattern onto nutrient broth-yeast extract (NBY) agar as previously decribed by Vidaver (1967). Pure colonies were streaked onto new NBY plates every 3-4 days. Virulence test for each isolate were performed on corn plants in the greenhouse after the fourth successive plate transfer. Goss's wilt was re-isolated from greenhouse corn leaves and plated onto NBY for subsequent plate transfers to maintain virulence (Schuster 1975). Goss's wilt inoculum for field application was prepared by streaking three plates per bacterial isolate approximately 3-4 days prior to field use (Schuster 1975). A disposable L-shaped cell spreader was used to scrape bacterial cells from each plate into a 1 L beaker containing 600-mL of 10% Tryptic Soy Broth suspension. The beaker was hand mixed between

isolates to disperse the bacterial cells in the suspension. Bacterial suspension samples (1 mL) were evaluated in a Genesys 20 Spectrophotometer (Thermo Fisher Scientific Inc., Waltham, MA, USA) at 620 nm to estimate the number of colony forming units (CFU) based on absorbance values (Langemeier 2012). Additional 10% Tryptic Soy Broth was added until absorbance values read between 0.4 – 0.5, the equivalent to approximately 10^6 colony forming units per milliliter (Langemeier 2012). Bacterial suspension was applied using a one-gallon Flo-Master hand pump sprayer calibrated to apply approximately 10 gal/A at 25 psi. Applications were made at a height of 0.6-m directly above a single corn row.

Plant damage was recorded at 7 and 14 days after the hail event with the GoPro camera using the same methods for recording development and location. Damage scores were assigned to each plant within the plot through visual evaluation of video data. Damage scores were based on a novel scoring system (Fig 2.2) that categorized plants based on the level of plant damage after a period of regrowth.

Harvest consisted of two separate data collections to isolate individual plant and whole plot yield responses. For each treatment, a maximum of three individual plants were randomly selected and harvested for each damage score. Kernels per row, rows per ear, grain weight per 100 seeds, and total grain weight were recorded for individual plant samples. The remaining ears from each plot were hand harvested for the whole plot analysis. Grain was separated from individual ears by using a hand-operated corn sheller; whereas, whole plot samples were processed using an electric corn sheller. Individual grain weights from individual plant samples were added to whole plot grain weights prior

to analysis. Total grain weight per plot was recorded in grams and converted to kg/hectare prior to the analysis.

Data were analyzed by using SAS software version 9.3 (SAS Institute Inc. Cary, NC). Individual plant sample yield components were analyzed as a randomized complete block, split-split plot design by using PROC GLIMMIX for the 7-day evaluations to compare planting date, hybrid, score, and their interactions. Least significant differences were used to establish differences between treatments. Damage scores (0 – 5) for 7 and 14 day evaluations were transformed to ranks ranging from 3.5 - 48.5 using PROC RANK to evaluate their relationship with grain weight per plant (Conover and Iman 1981) using PROC CORR and PROC REG.

Whole plot yields were analyzed using the same methods as the individual plant samples. An analysis of variance was used to compare main plot (planting date), split-plot (corn hybrid) and split-split plot (hail treatments), and their interactions. Least significant differences were used to establish differences between treatment means. For the whole plot data, regression analysis was used to determine the relationship between yield and % yield loss with non-transformed average damage scores per plot and remaining plant stand using PROC CORR, PROC REG and PROC GLM. Percent yield loss was calculated as a measure of the difference between hail treatments and check plots within each planting date and replication combination. Environmental data were obtained from the High Plains Regional Climate Center (hprcc.unl.edu; University of Nebraska-Lincoln). Weather data originated from an established weather station located less than 2 km from the plot site.

Results

Environmental Conditions

Average temperature, humidity, cumulative growing degree days, and total precipitation varied for the seven days following each hail event (Table 2.1). No consistent trends occurred across planting dates for average temperature with 25.9°C, 29.4°C, 27.8°C, and 30.7°C for planting dates one, two, three, and four, respectively. Similar observations were made for average humidity which varied by approximately 10% between planting dates with highest levels in planting date one (82.6%) and lowest in planting date two (72%). Total precipitation varied considerably for the seven days following each hail event with 83.3, 11.4, 34.0 and 8.9-mm for planting dates one, two, three and four, respectively. Cumulative growing degree days (GDD; base temperature: 10°C) accumulation showed no noticeable trends with planting dates ranging from 73.6 to 104.3 GDD.

Individual Plant Samples

Grain yield per plant decreased significantly across planting dates ($F_{3,15} = 24.96$; $P < .0001$) at 126.3 g, 110.3 g, 100.9 g, and 82.8 g for the first, second, third, and fourth planting dates, respectively. Yields were significantly different between planting dates with the exception of the second and third planting dates ($t_{15} = 3.10$; $P = 0.0866$). Larger differences in damage score ($F_{4,159} = 613.22$; $P < .0001$) were observed with plant damage scores of zero (184.7 g) and one (189.8 g) having greater yields than plants with a score two (114.4 g), followed by three (35.2 g), and five (1.3 g). The interaction between planting date and damage score was also significant ($F_{12,159} = 4.27$; $P < .0001$;

Fig. 2.2a). This interaction was due to an increase from 183.8g to 211.4 g between damage score of zero and one for the second planting date compared to no differences occurring for other planting dates for these same damage scores. In addition, interaction was due to plants with a damage score of three having different yields between the first (70.6 g), second (36.5 g), third (17.7 g), and fourth (16.1 g) planting dates and similar yields for all planting dates for a damage score of five. No differences occurred between hybrids ($F_{1,20}$ = 0.16; P = 0.6928) or in their interaction with planting date ($F_{3,20}$ = 0.16; P = 0.9235), damage score ($F_{4,159}$ = 0.09; P = 0. 9846). The interaction between planting date, hybrid, and score was also not significant ($F_{12,159}$ = 0.75; P = 0.7007).

Rows per ear differed significantly between planting dates ($F_{3,15}$ = 9.27; P = 0.0010) with the first planting date (11.5) having more rows per ear than the second (9.8), third (9.7) or fourth (9.4) planting dates. Damage scores had the largest impact of rows per ear ($F_{4,159}$ = 413.72; P < .0001) with a damage scores of zero (15.7) and one (15.8) having greater number of rows per ear than plants with score of two (12.7) followed by score three (6.1) and lastly, score five (0.23). A significant interaction occurred between planting date and damage score ($F_{12,159}$ = 2.09; P = 0.0200; Fig. 2.2b). This interaction was due to a decrease in the number of rows per ear between damage scores one and two for planting dates two (15.9 vs. 11.9), three (15.0 vs. 11.6) and four (16.0 vs. 12.4); whereas, no differences occurred across these scores for first planting date (16.3 vs. 14.8). In addition, plants with damage score three had greater number of rows per ear in first planting date (9.6) compared to the second (5.5), third (4.8), and fourth (4.6) planting dates with no differences in between planting dates with a damage score of five. No differences were observed between planting date and hybrid ($F_{3,20}$ = 0.48; P = 0.6974),

hybrid and score ($F_{4,159}$ = 0.50; P = 0.7373), and planting date, hybrid, and score ($F_{12,159}$ = 0.18; P = 0.9990)

Kernels per row differed between hybrids ($F_{3,15}$ = 4.61; P = 0.0442) with DeKalb 65-66 (25.5) having more rows than DeKalb 61-88 (23.9). Large differences were observed between damage scores ($F_{12,159}$ = 620.10; P < .0001) with zero (40.8) and one (41.3) have more kernels than score two (29.7) followed by three (11.2) and then five (0.4). Differences between planting dates were approaching significance ($F_{3,15}$ = 2.78; df = 3, 15; P = 0.0773) as a result of greater number of kernels in first planting date (26.6) compared to the second (24.2), third (24.1) and fourth (23.9) planting dates. A significant interaction occurred between planting date and damage score ($F_{12,159}$ = 3.72; P < .0001; Fig. 2.3a) due to a greater number of kernels for damage scores two and three in the first planting date compared to a similar number of kernels for all planting dates in damage score five. No interactions occurred between planting date and hybrid ($F_{3,20}$ = 0.52; P = 0.6708), hybrid and score ($F_{4,159}$ = 1.11; P = 0.3536), or planting date, hybrid, and score ($F_{12,159}$ = 0.65; P = 0.7964).

Grain weight per 100 seeds decreased significantly across planting dates ($F_{3,15}$ = 32.40; P <.0001) at 24.3 g, 20.3 g, 18.5 g, and 16.1 g for the first, second, third, and fourth planting dates, respectively. Greater differences were observed across damage scores ($F_{4,159}$ = 393.56; P < .0001) with zero (31.1 g) and one (29.8 g) having greater grain weights than damage score two (24.3 g) followed by three (13.3 g), and lastly, damage score five (0.5 g). No differences were observed between hybrids ($F_{1,20}$ = 0.36; df = 1, 20; P = 0.5547). A significant interaction between planting date and damage score occurred ($F_{12,159}$ = 4.45; P < .0001; Fig. 2.3b) with declining grain weights of 23.5

g, 12.4 g, 9.3 g, and 8.0 g at damage score three compared to no differences (1.3 g, 0.5 g, 0.3 g, and 0.3 g) at damage score five for planting dates one, two, three, and four, respectively. Interactions were not significant for planting date and hybrid ($F_{3,20}$ = 0.37; df = 3, 20; P = 0.7778), hybrid and score ($F_{4,159}$ = 0.49; P = 0.7402), or planting date, hybrid, and score ($F_{12,159}$ = 0.28; P = 0.9922).

The relationship between plant damage from hail (damage score ranks) and grain yield per plant was assessed at both 7 and 14-day evaluations. A strong negative correlation was found between score rank and yield for day 7 (-0.91) and day 14 (-0.92). The correlation between day 7 and 14 scores was a very strong negative relationship (0.98). To further understand this relationship a regression analysis was run for each evaluation day (Fig. 2.4). Parameter estimates and R^2-values indicate a linear decline in yield per plant with increasing damage score rank with a strong fit between observed and predicted data for both 7 day (R^2 = 0.82) and 14-day (R^2 = 0.84) evaluations. Slopes and intercepts between day 7 and 14 equations were nearly identical.

Whole Plot Samples

Whole plot grain yield decreased across planting date ($F_{3,15}$ = 34.96; P <.0001) at 12661 kg/hectare, 11657 kg/hectare, 9590 kg/hectare, 8155 kg/hectare for the first, second, third and fourth planting dates, respectively. Differences were also observed for hail treatments ($F_{2,80}$ = 70.81; P < .0001) with significant differences occurring between controls (12353 kg/hectare), hail (9919 kg/hectare) and hail with Goss's wilt (9275 kg/hectare). No differences were observed between hybrids ($F_{1,20}$ = 1.37; P = 0.2557). The planting date by treatment interaction was significant ($F_{6,80}$ = 5.61; P < .0001; Fig.

2.5) due to a lack of differences between control (13351 kg/hectare) and hail (12513 kg/hectare) treatments (t_{80} = 1.54; P = 0.1284) in planting date one compared to highly significant differences between control (10855 kg/hectare) and hail (6747 kg/hectare) treatments (t_{80} = 7.53; P <.0001) in planting date four. In addition, Goss's wilt treatments were significantly lower than hail alone in planting dates two (t_{80} = 2.18; P = 0.0322) and three (t_{80} = 2.08; P = 0.0408) but not one (t_{80} = 0.72; P = 0.4734) and four (t_{80} = -0.21; P = 0.8359). No interactions occurred between hybrid and planting date ($F_{3,20}$ = 0.27; P = 0.8491), hybrid and treatment ($F_{2,80}$ = 0.57; P = 0.5687), or hybrid, planting date, and treatment ($F_{6,80}$ = 1.13; P = 0.3504). Similar results were obtained when yield data were analyzed as the percentage of yield loss relative to the check plot (Fig. 2.5b). The only exception was that unlike the grain yield data, percent yield loss data had no differences between control and hail + Goss's wilt treatments in planting date one.

To evaluate the value of damage score as a method of predicting grain yield, we correlated average damage score per plot with yield and percent yield loss across all planting dates (Table 2.2). Average damage scores were 1.6, 2.0, 2.3, and 2.4 for planting dates one, two, three and four, respectively. Hail alone and hail with Goss's wilt were evaluated separately to determine how disease presence might impact this evaluation method. Correlations between average damage score and yield differed between hail treatments with hail only (-0.85) having higher correlations than hail with Goss's wilt (-0.76). Correlations were further reduced when average damage score was compared with percent yield loss at -0.77 and -0.73 for hail and hail with Goss's wilt, respectively. Current evaluations of early-season hail are based on remaining plant stand, and thus, correlations were run on these same variables to determine differences between these two

evaluation methods. Remaining plant stand had good correlations for grain yield but was always marginally lower than average damage score for hail only (0.82) and hail with Goss's wilt (0.73). Similar differences occurred between these evaluation methods when correlated with percent yield loss with hail only plots having (0.73 vs. -0.77). However, correlations for remaining plant stand (0.72) and average damage score (-0.73) were nearly identical when percent yield loss was evaluated for hail with Goss's wilt.

To further understand these relationships, regression equations were run for each evaluation method, hail treatment, and yield measurement. No significant differences occurred for intercepts or slopes of average damage score (Fig. 2.6a; 2.6b) and remaining plant stand (Fig 2.7a; 2.7b) when comparing hail only and hail with Goss's wilt for both grain yield and yield loss. R^2-values for grain yield were higher for average damage score (0.72 and 0.58) compared to remaining plant population (0.67 and 0.52) for hail only and hail with Goss's wilt, respectively. In contrast, R^2-values were only greater for damage score (0.60) compared to remaining plant population (0.52) when hail was applied without bacterial disease. Average damage score (0.52) and remaining plant population (0.52) has nearly identical R^2-values for the hail with Goss's wilt treatment.

Discussion

Simulated hail damage occurring prior to V6 reduced grain yields from 5% to 38% with increasing yield losses for each subsequent planting date. Additional yield losses from hail in later planting dates coincided with an increase in average plant damage score per plot. Greater damage scores in later planting dates would be unexpected unless environmental conditions between hail and the evaluation date were less conducive for plant growth or response. If similar environmental conditions occurred following each hail event, we would expect a similar range of damage scores between planting dates with a reduction in yield at the same damage score due to yield losses associated with later planting dates in the absence of hail. Environmental conditions such as temperature, relative humidity, solar radiation, growing degree days, and precipitation varied by planting date (Table 2.1); however, these factors did not show trends that would coincide with increased plant damage scores or a reduction in plant response between the hail and evaluation dates. A second possible explanation is that increased average damage score could be attributed to enhanced proficiency of the use of simulated hail equipment with each subsequent use which would coincide with later planting date. Lastly, plant health status in terms of nutrient or water availability prior to simulated hail could potentially alter the plants response resulting in poor regrowth or death when combined with hail damage. Such inferences cannot be concluded from the current data and further studies will be needed to isolate which of these factors might be responsible for increasing plant damage scores with planting date.

A strong linear decline in the relationship between grain yield and damage score per plant contradicts the assumption that surviving plants hailed prior to V6 will have no

impact on grain yield. This result is supported by previous research using various means of artificial defoliation that showed similar but less extensive yield losses with early-season defoliation (Eldredge 1935, Lindstrom 1935). Greater yield losses from hail in this study compared to previous research could be attributed to the evaluation method, calendar date of hail application, or the defoliation technique. Previous studies have evaluated hail treatments based on the percentage of defoliation at the time of application, whereas, this study allowed for a period of plant growth between the hail treatment and evaluation. As mentioned previously, yield losses in this study increased with planting date and may be responsible for greater yield loss than in previous studies. For previous studies, defoliation techniques varied not only in terms of equipment but also in the spatial distribution and variation in damaged plants. Unlike the simulated hail used in this study, artificial defoliation in previous studies was applied uniformly across an entire plot, reducing the likelihood for increased yield losses due to unequal competition between adjacent plants. Unequal defoliation of adjacent plants was evaluated by Vasilas et al. (1991) with yield compensations of 30% for undamaged plants next to damage plants when compared with control plants. The current study found that only the second planting date showed an increase in yield (15%) with damage score of one when compared to control plants. The lack of yield increases in other planting dates could be attributed to the random distribution of plant damage with different damage scores or the presence of dead tissue causing abnormal growth patterns in plants with limited damage.

Yield reductions of individual plants with increasing damage score appears to be attributed to season-long stress following hail as evident by differences in several yield components across damage scores. The yield components of corn develop sequentially at

different stages of plant development (Fig. 1.1). Development of the yield components for corn begins with rows per ear (V1-V7), followed by kernels per row (V7-R3), and lastly, kernel weight (R4-R6) (Abendroth et al. 2011). Plants with mainstems cut (damage score two and three) by hail showed consistent and significant reductions in all yield components with the exception of planting date one for rows per ear and grain weight. Our current assumption is that season-long stress occurred as a result of competition with adjacent plants; however, studies are needed to determine if early-season damage in the absence of apparent plant-to-plant competition could reduce yield components that occur after hail damage.

The two corn hybrids used in this study had little impact on plant response to hail damage. Such results are not entirely unexpected given the range of response among hybrids in previous studies (Crookston and Hicks 1978, 1988, Johnson 1978). The selection of these hybrids was to determine hybrid value in the managing yield losses associated with Goss's wilt and early season hail. We found no hybrid by treatment interactions with whole plot samples. The lack of differences between these hybrids in terms of disease protection could be due to reduced tolerance when plants are subject to high levels of mechanical damage or a lack of pressure from Goss's wilt. An overall difference in yield between hail only and hail with Goss's wilt suggests that disease pressure would have been great enough to detect differences between these hybrids.

The presence of the bacterial disease, Goss's wilt increased yield losses relative to hail in two of the four planting dates. Differences in the effectiveness of the pathogen could be attributed to a wide range of factors. Timing of bacterial application following plant damage is fundamental to successful infection as plants can heal within minutes of

damage. In addition, Goss's wilt is heavily temperature dependent with arrested development of the disease at higher temperatures. Hail treatments with Goss's wilt had reductions in the relationship between plant damage score and remaining plant population. A reduction in the relationship between evaluation methods and yield is likely a result in a loss in yield of plants that would have received low damage score or a loss in productivity of live plants in the remaining plant population. This study clearly demonstrates that yield predictions of either evaluation method can be hindered by Goss's wilt. Studies are needed to address other bacterial plant pathogens, such as *Pectobacterium caratovorum*, a disease that is commonly isolated from dying corn plants in hailed fields.

This is the first study to document the use of a novel damage scoring system and use the average damage score from this system as a predictor for final grain yield. Under simulated hail, the plant damage score method was a better predictor of grain yield than remaining plant stand. However, it is important to note the time requirements between these two methods vary considerably with assessing remaining plant stand requiring less time compared to assessing plants for damage score. The increased value of the plant damage score system may become more apparent in fields where a greater frequency of plants that have had their mainstems destroyed by hail. Studies are needed to address the grain yield predictions of these evaluation systems under such situations.

Correlations between yield and day 7 and 14 evaluations showed almost no differences. Future studies addressing the relationship with earlier evaluations (3 and 5 days post hail) may provide insights into the potential for earlier evaluations. Such

results would reinforce the need to wait or provide producers with a reduced time to wait for making sound replant decisions.

Differences among planting dates in this study provide an opportunity to estimate the economic value of replanting corn. We found a yield loss of only 9% when comparing corn planted between 11 May and 11 June and a 19% decrease in yield when comparing 11 May and 23 June. Such results are atypical of previous literature on planting dates and could be due to an unseasonably warm fall in 2015. A study by Nafziger (1994) found that yield losses were 18% between 9 May and 29 May planting dates in central Illinois. Planting in mid-June causes yields to decline rapidly with losses as high as 50% (Nafziger 1994). Lauer et al. (1999) found that the optimum planting date was between 24 April and 9 May with grain yields declined at a rate of 0.5 to 1.1%, 1.3 to 1.9%, and 2.0 to 2.8% per day for 0-2, 2-4, and 4-6 weeks after 9 May in Wisconsin.

Proper evaluation for replant decisions cannot not be made immediately following the hail event as plants need time for regrowth to allow for a proper assessment of existing yield potential. Producers should consider the calendar date, weed situation, seed availability, and the cost of equipment and field conditions when making a replant decision (Vorst 1991). This study, as well as previous studies, demonstrates the high degree of variability in yield of corn when damaged by hail during its early stages of plant growth. Continued research is needed to better understand what factors contribute to the variability among damaged plants. Quantifying and simplifying those variables will provide growers and consultants with the tools necessary to make good management decisions when evaluating corn fields for replant.

Tables

Table 2.1: Average temperature, humidity, cumulateive growing degree days and total precipitation for seven days following hail event for each planting date (PD).

Planting Date	Temperature (°C)	Humidity (%)	Growing Degree Days	Precipitation (mm)
1	25.9 ± 1.9	82.6 ± 4.4	73.6	83.3
2	29.4 ± 1.3	72.0 ± 2.9	89.7	11.4
3	27.8 ± 1.3	78.3 ± 3.0	84.2	34.0
4	30.7 ± 1.4	77.0 ± 2.7	103.4	8.9

Table 2.2: Whole plot correlations for hail treatments (hail only and hail with Goss's wilt), early-season hail evaluation method (average damage score and remaining plant stand), and yield measurement (grain yield and % yield loss) across four planting dates.

Treatments	Loss Assessment	Yield (kg/hectare)	% Yield Loss
Hail Only	Average Damage Score	-0.85	-0.77
	Remaining Plant Stand[1]	0.82	0.73
Hail + Goss's wilt	Average Damage Score	-0.76	-0.73
	Remaining Plant Stand	0.72	0.72

[1] Current method of evaluating predicted yield losses from early-season hail damage (USDA-FCIC 2014).,

Figures

Figure 2.1: Visual representation, damage score number, and description of damage scores for novel damage scoring system for evaluation of hail damaged plants.

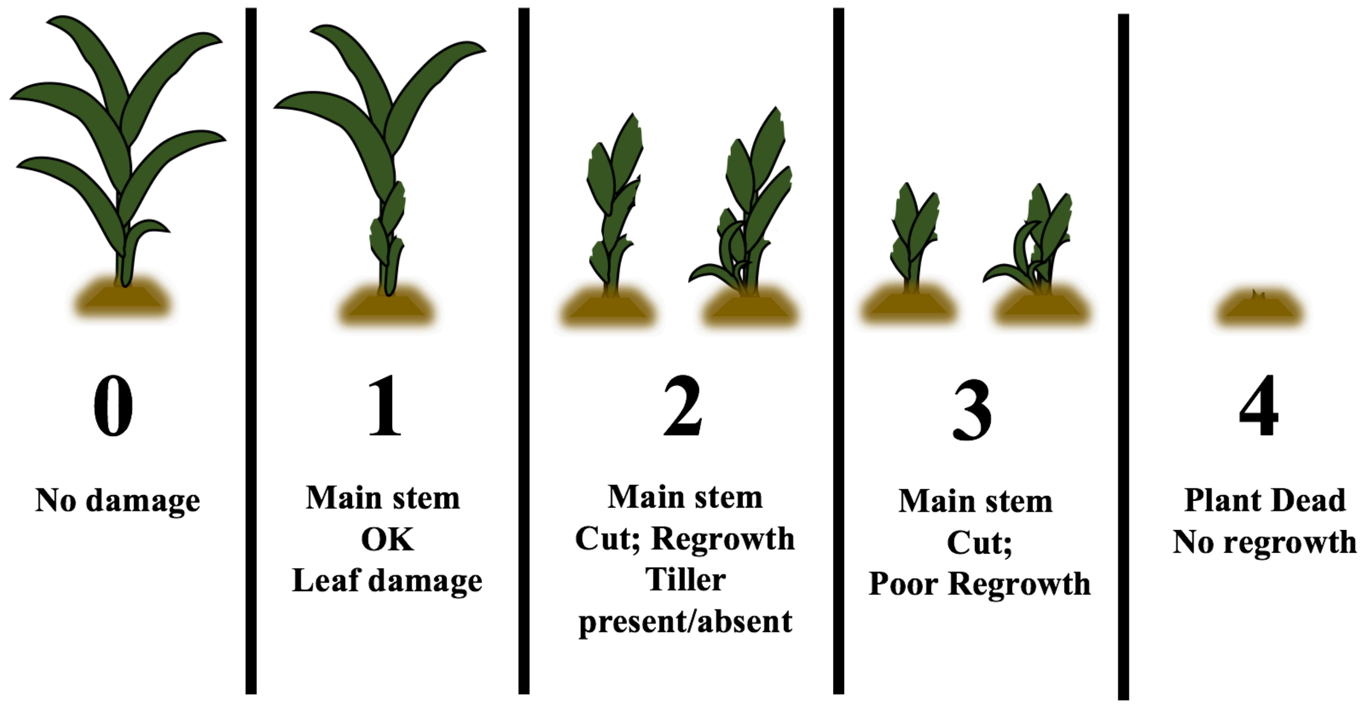


Figure 2.2: Individual plant yield (a) and rows per ear (b) across damage scores (0 = no damage, 1 = leaf damage, 2 = mainstem cut, regrowth, 3 = mainstem cut, poor regrowth, 5 = dead) for each planting date (PD1, PD2, PD3, and PD4). Letters indicate significant difference at P < 0.05 across planting dates and damage scores.

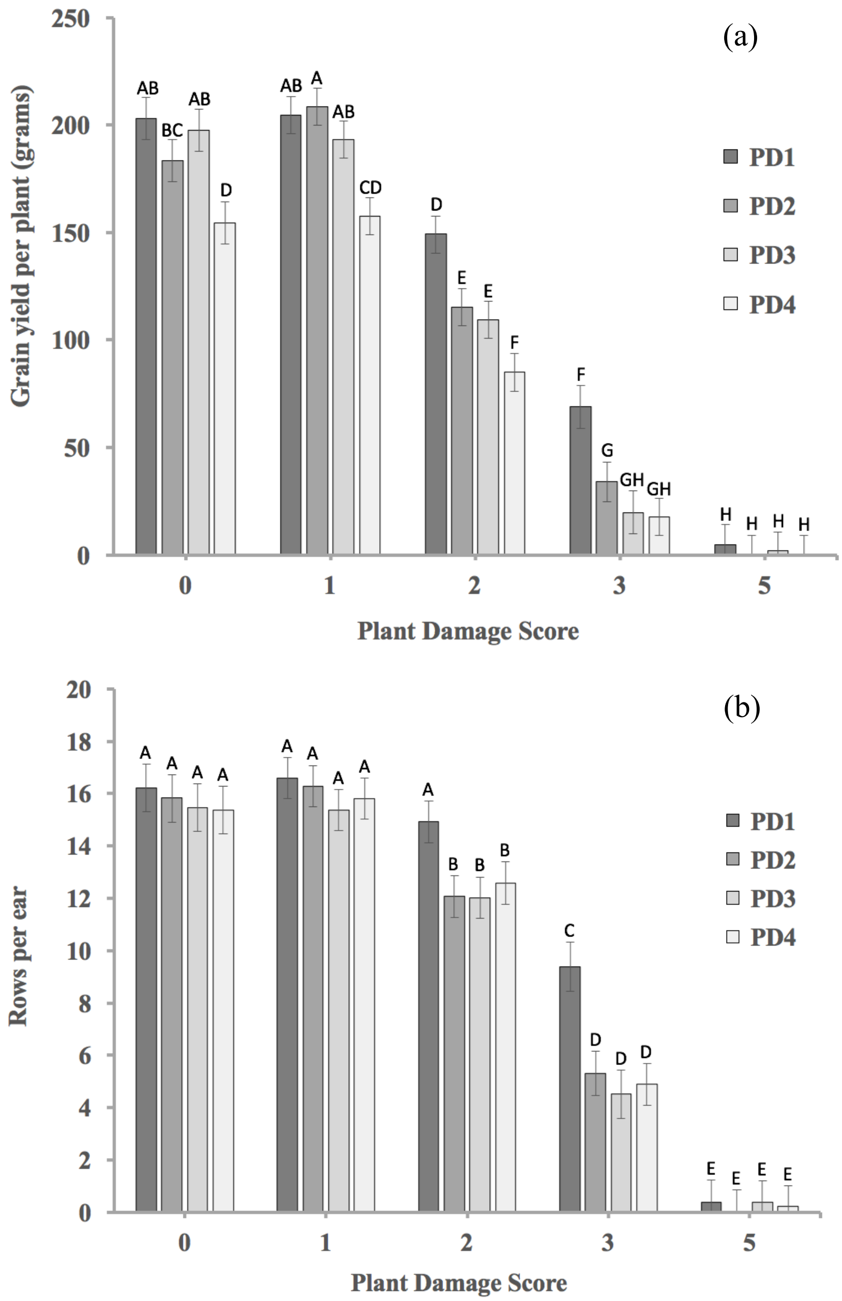


Figure 2.3: Individual kernels per row (a) and kernel weight per 100 seeds (b) across damage scores (0 = no damage, 1 = leaf damage, 2 = mainstem cut, regrowth, 3 = mainstem cut, poor regrowth, 5 = dead) for each planting date (PD1, PD2, PD3, and PD4). Letters indicate significant difference at P < 0.05 across planting dates and damage scores

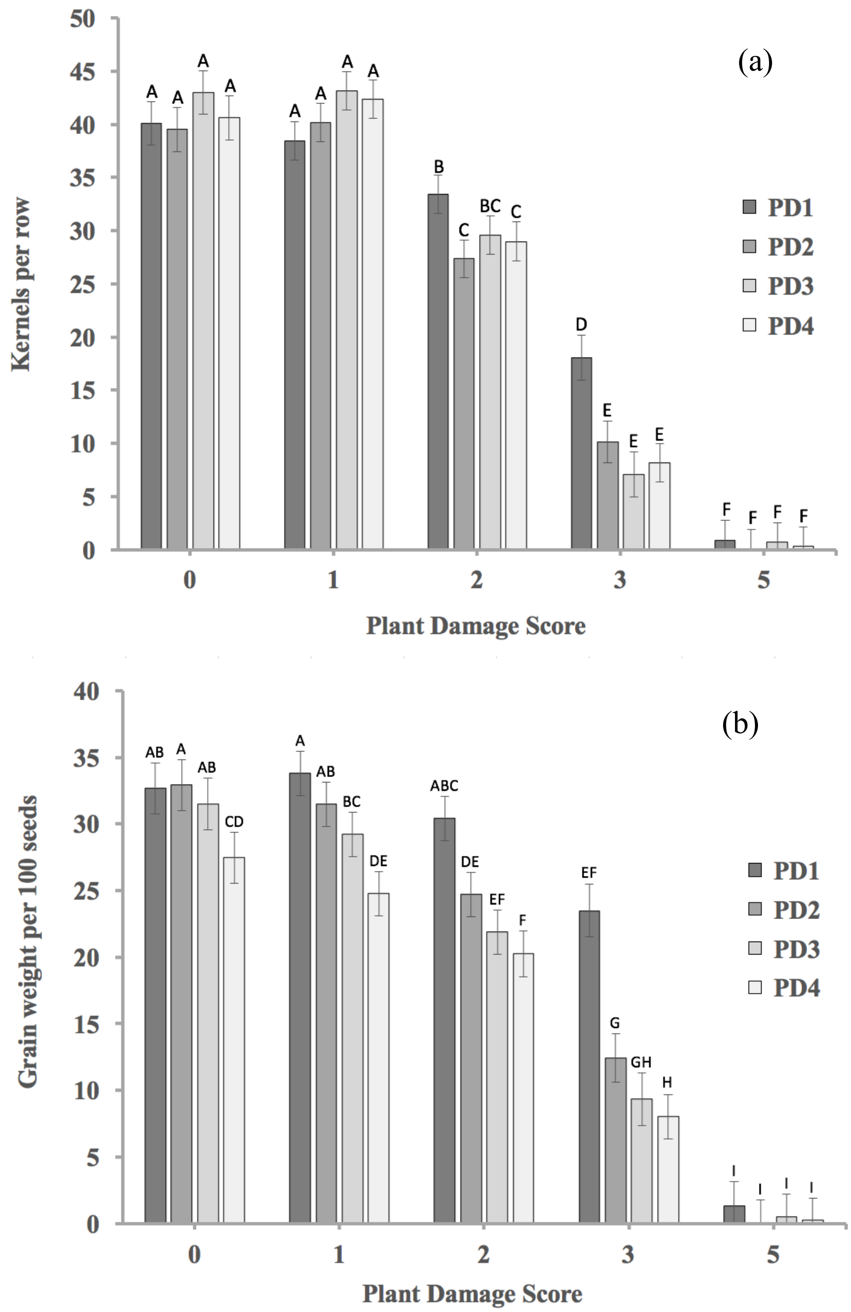
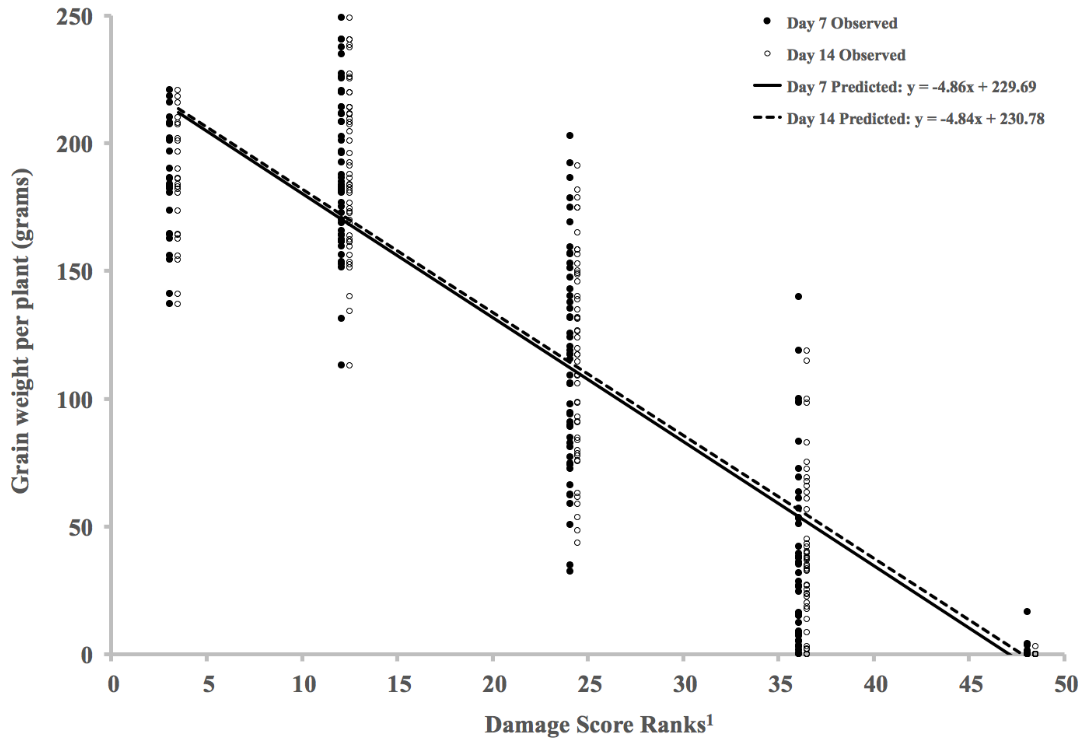


Figure 2.4: Linear regression of individual plant samples comparing grain yield with damage score ranks for evaluations at 7 and 14 days after hail event across all treatments, hybrids, and planting dates (n=215).



[1] Damage scores were transformed to damage score ranks using PROC RANK prior to regression analysis as described by Conover and Iman (1981).

Figure 2.5: Whole plot grain yield (a) and percent yield loss (b) by planting date (PD1, PD2, PD3, and PD4) and treatment (Control, Hail, and Hail+GW). GW = Goss's Wilt. Letters indicated significant difference across planting dates and treaments at P<0.05; yield loss, (b) letters with A were not different than control plots.

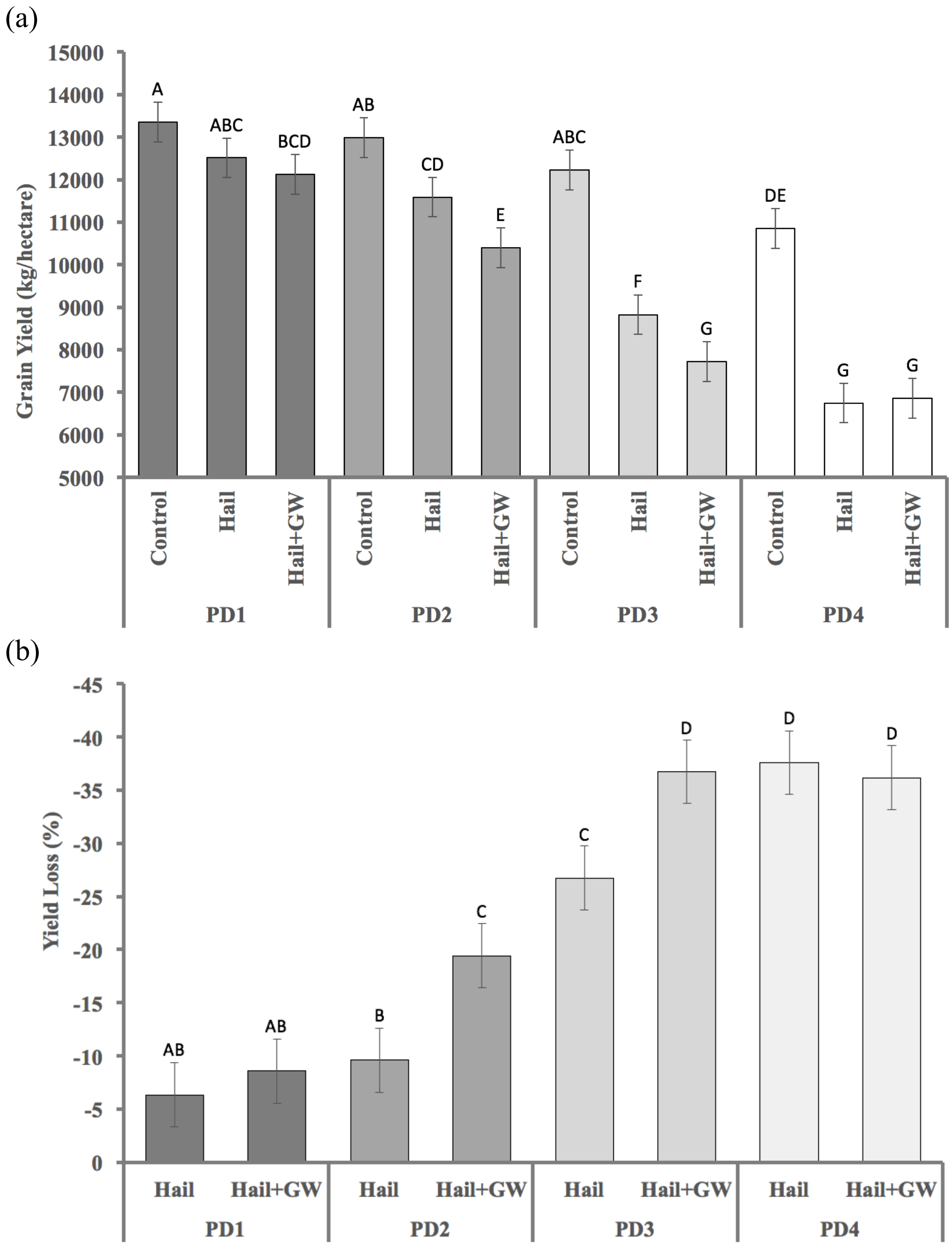
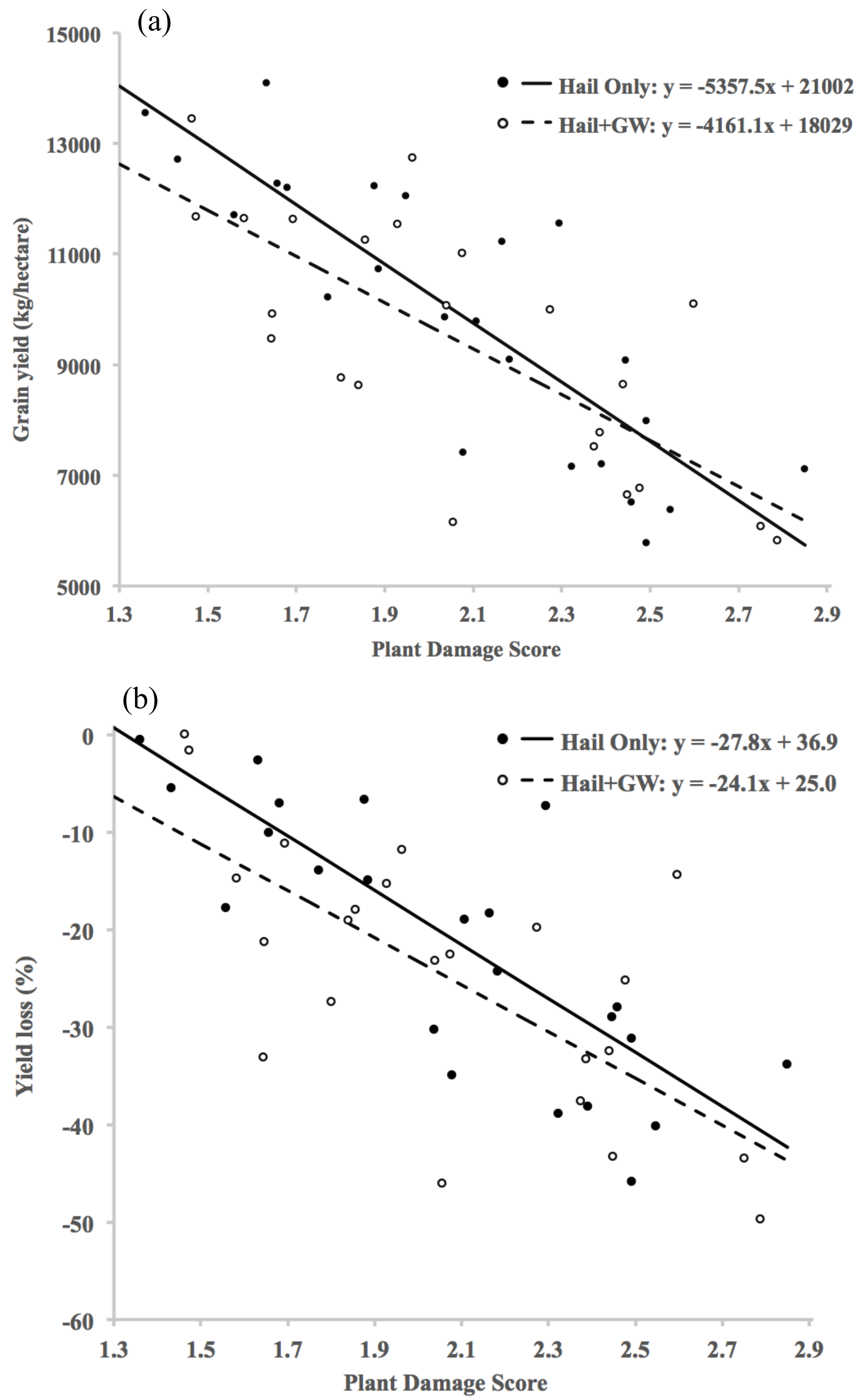
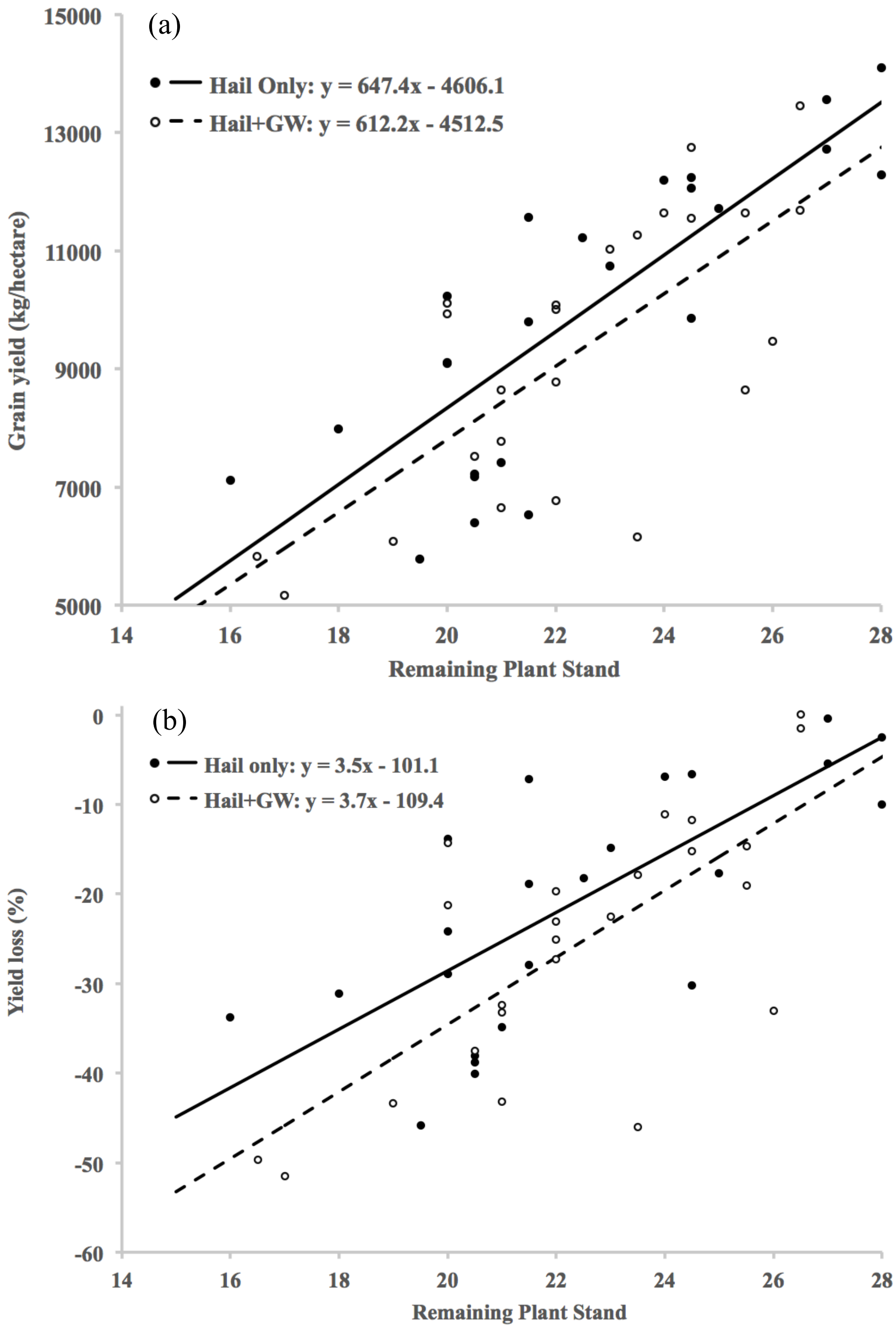


Figure 2.6: Average damage score regression relationship for hail treatments (Hail only and hail with Goss's wilt) for grain yield (a) and % yield loss (b) across all planting dates and hybrids (n=24).



R^2-values: Grain yield (a): 0.72 (Hail), 0.58 (Hail+GW); Yield loss (b): 0.60 (Hail), 0.52 (Hail+GW)

Figure 2.7: Remaining plant population regression relationship for hail treatments (hail only and hail with Goss's wilt) for grain yield (a) and % yield loss (b) across all planting dates and hybrids (n=24).



R^2-values: Grain yield (a): 0.67 (Hail), 0.52 (Hail+GW); Yield loss (b): 0.52 (Hail), 0.52 (Hail+GW)

References

Abendroth, L. J., R. W. Elmore, M. J. Boyer, and S. K. Marlay. **2011**. Corn growth and development. PMR 1009. Iowa State University Extension, Ames, Iowa.

Claflin, L. E. 1999. Goss's bacterial wilt and blight., pp. 4–5. *In* Compend. Corn Dis. American Phytopathological Society, St. Paul, MN.

Cloninger, F. D., M. S. Zuber, and R. D. Horrocks. **1974**. Synchronization of flowering in corn (*Zea mays* L.) by clipping young plants. Agron. J. 66: 270.

Conover, W. J., and R. L. Iman. **1981**. Rank transformations as a bridge between parametric and nonparametric statistics. Am. Stat. 35: 124–129.

Crookston, R. K., and D. R. Hicks. **1978**. Early defoliation affects corn grain yields. Crop Sci. 18: 485–489.

Crookston, R. K., and D. R. Hicks. **1988**. Effect of early defoliation on maize growth and yield: an eleven-year perspective. Crop Sci. 28: 371.

Dungan, G. H., and H. W. Gausman. **1951**. Clipping corn plants to delay their development. Agron. J. 43: 90–93.

Eldredge, J. C. 1935. Effect of injury in imitation of hail damage on the development of the corn plant. Agric. Exp. Stn. Iowa State Coll. Agric. Mech. Arts. 185: 61 pp.

Jackson, T. A., R. M. Harveson, and A. K. Vidaver. **2007**. Reemergence of Goss's wilt and blight of corn to the central High Plains. Plant Health Prog. (doi:10.1094/PHP-2007-0919-01-BR.).

Johnson, R. R. 1978. Growth and yield of maize as affected by early-season defoliation. Agron. J. 70: 995–998.

Langemeier, C. 2012. Improved understanding of factors influencing the re-emergence of goss's bacterial wilt and blight of corn. Thesis University of Nebraska-Lincoln Digital Commons. 130 pp.

Lauer, J. G., P. R. Carter, T. M. Wood, G. Diezel, D. W. Wiersma, R. E. Rand, and M. J. Mlynarek. **1999**. Corn hybrid response to planting date in the northern corn belt. Agron. J. 91: 834–839.

Lindstrom, E. W. 1935. Genetic experiments on hybrid vigor in maize. Am. Nat. 311–322.

Martin, P. R., C. O. Gardner, A. G. Calub, and M. L. Schuster. **1975**. Inheritance of susceptibility and tolerance to leaf freckles and wilt (*Corynebacterium nebraskense*) of corn. Maize Genet Coop Newsl. 49: 137–138.

Nafziger, E. D. 1994. Corn Planting Date and Plant Population. J. Prod. Agric. 7: 59.

Schuster, M. L. 1975. Leaf freckles and wilt of corn incited by corynebacterium nebraskense. Agric. Exp. Stn. IANR Univ. Neb. Res. Bull. 270: 40 pp.

Singh, R. P., and K. P. P. Nair. **1975**. Defoliation studies in hybrid maize: I. Grain yield, quality and leaf chemical composition. J. Agric. Sci. 85: 241–245.

Smidt, M. L., and A. K. Vidaver. **1986**. Differential effects of lithium chloride on in vitro growth of *Clavibacter michiganense* subsp. *nebraskense* depending upon inoculum source. Appl. Environ. Microbiol. 52: 591–593.

Vasilas, B. L., J. J. Fuhrmann, and R. W. Taylor. **1991**. Response of three corn hybrids to defoliation of neighboring plants. Can. J. Plant Sci. 71: 311–315.

Vasilas, B. L., and R. D. Seif. **1985a**. Defoliation effects on two corn inbreds and their single-cross hybrid. Agron. J. 77: 816–820.

Vasilas, B. L., and R. D. Seif. **1985b**. Pre-anthesis defoliation effects on six corn inbreds. Agron. J. 77: 831.

Vidaver, A. K. 1967. Synthetic and complex media for the rapid detection of fluorescence of phytopathogenic pseudomonads: effect of the carbon source. Appl. Microbiol. 15: 1523–1524.

Vidaver, A. K., and M. Mandel. **1974**. Corynebacterium nebraskense, a new, orange-pigmented phytopathogenic species. Int. J. Syst. Evol. Microbiol. 24: 482–485.

Vorst, J. J. 1991. Assessing hail damage to corn. Natl. Corn Handb. Clim. Weather Iowa State Univ. Ext. NCH 1.

CHAPTER 3

Multi-Ear Development in Corn and its Impact on Yield

Introduction

The occurrence of multiple corn ears originating from separate stalk nodes on an individual corn plant is not uncommon. These plants typically occur along field edges or under reduced plant populations. Certain "prolific" hybrids exhibit a greater tendency for multiple ear development under these conditions. In 2006, researchers observed widespread multiple-ear development; however, in these situations multiple corn ears originated from the same stalk node (Elmore and Abendroth 2006). Two distinct types of multi-ear development were classified based on ear location and number. In most cases, plants developed "double ears" where two ears were produced from a single stalk node (Fig. 1b). These consisted of one full-sized ear and the other ear significantly smaller (Elmore and Abendroth 2006). Other plants produced "bouquet" ears where a single node bore up to eight ears (Fig. 1c), and little to no seed was present on these ears (Elmore and Abendroth 2006). No significant yield impacts were observed for "double ear" plants; however, fields with a high number of "bouquet" ears yielded significantly less (Elmore and Abendroth 2006). This unusual ear development occurred at varying levels across a range of corn hybrids from different seed companies from Iowa to Indiana (Elmore and Abendroth 2006). The cause of this phenomenon was unclear, but it is unlikely that it originated from a single management tactic.

Previous research has documented atypical multi-ear development. Bonnett (1966) indicated that some varieties of corn are capable of initiating additional ear axils in the husk of an ear shoot; however, these additional shoots seldom produced seed. The 2006 report visually documented the presence of an aborted primary ear on plants exhibiting multi-ear development (Elmore and Abendroth 2006). Bonnet (1966) made no

mention of the loss of primary ears in cases where additional ears were initiated. A greater understanding of the causes for primary ear abortion and its yield imacts may shed light on the causes of multi-ear development.

Historical literature suggests that primary ear abortion and subsequent secondary ear development could be a combination of environmental stress, plant hormone imbalance, and/or genetics. Lejeune and Bernier (1996) conducted the only known study to demonstrate the impact of environmental conditions on primary ear abortion during the early stages of ear initiation by using a scanning electron microscope and binocular microscope examination. Significant primary ear abortion was achieved by chilling corn plants at 5 to 10°C, but this occurred only when it was applied at the V6 growth stage (Lejeune and Bernier 1996). Chilling treatments applied at V3 only caused abortion of ear shoots below the primary ear (Lejeune and Bernier 1996). This corresponds with McMaster et al. (2005) finding that ear shoot initiation began during the V3 growth stage. Chilling temperature of 5°C were slightly less inhibitory compared with 10°C (Lejeune and Bernier 1996). Duration of chilling ranging from three to seven days resulted in similar levels of abortion (Lejeune and Bernier 1996). Flooding alone had little impact on aborted ears with 0-5% increase in abortion over control plants; however, significantly higher ear abortion (60 – 65% increase) occurred when combined with chilling treatment of 10°C for 3 days compared to same chilling treatment alone (15-35% increase) (Lejeune and Bernier 1996). Mature plants that received both the chilling and flooding treatments exhibited symptoms very similar to “double ” and “bouquet” ears produced in 2006.

Plant hormones regulate bud initiation and secondary ear formation. The ratio of auxins and cytokinins, rather than the absolute level of either hormone, was critical for bud intiation (Klee and Estelle 1991). An analysis of hormones of plants exposed to chilling treatments revealed moderate decreases in indoleacetic acid (auxin) in apical shoots (Lejeune et al. 1998). In contrast, zeatin-type cytokinins decreased at a higher relative ratio of 5- to 8-fold (Lejeune et al. 1998). Differences in these hormones could be important in initiation of multiple ears due to a loss in apical dominance as a result of primary ear loss. The results from the Lejeune and Bernier (1996) and Lejeune et al. (1998) studies were observed for only a single inbred line (B22), indicating the interaction between an environmental stress and the genetics of the plant may be necessary for multi-ear development. Other inbred lines (C33, F2) were tested in the initial stages of these experiments with less pronouced lateral bud formation (Lejeune and Bernier 1996).

The genetic factors for multi-ear development are not well understood; however, some potential candidates have been indentified. In 1995, researchers identified the transciption gene, *teosinte branched1 (tb1),* responsible for apical dominance in corn (Doebley et al. 1995). The *tb1* gene functions in the apical dominance of the plant, repressing the growth of axillary organs, but it also enables the formation of the female inflorescence (Hubbard et al. 2002). Corn plants with the *tb1* mutant exhibited complete loss of apical dominance, resulting in unrestrained growth of axillary buds with tassels (Doebley et al. 1995). Irish and Nelson (1993) found that the *tassel seed2* (*ts2*) gene is important for suppressing the formation of pistillate florets. Double-mutants of *tb1* and *ts2* revealed the formation of visible silks on lateral axillary buds (Doebley et al. 1995);

however, visual documentation of this response did not resemble the bouquet ears observed in 2006. These studies demonstrate the potential for genetics to alter lateral bud development, although further studies would be needed to explain the morphology of the "bouquet" ears.

Previous literature indicates that under certain environmental conditions a corn plant could abort the primary ear, leading to the potential development of multiple ears. Field observations and greenhouse studies suggest that a loss of apical dominance in corn plants could result in the development of secondary ears. The incidence and type (double vs. bouquet) of multi-ear development has strong implications for the yield potential of a corn plant (Elmore and Abendroth 2006). Research is needed to validate that the loss of the primary ear leads to secondary ear development in current hybrids. In addition, research is needed to determine if the frequency and type of multi-ear development varies by corn hybrid. A study was designed to evaluate three hybrids and their response to primary ear removal.

Materials and Methods

This field study was conducted at the South Central Agricultural Lab near Harvard, NE at three sites within the same field with one hybrid per site. Corn hybrids DKC-30-19 RIB VT Double Pro (80-day), Pioneer P1151A (111-day), and Mycogen 2v717d (112-day) were chosen based on varying maturity levels and potential for differences in genetic backgrounds. Hybrids were planted on 5 May 2015 at each of the locations with 0.76-m row spacing and seeding rate of 86,000 plants per hectare. Experimental description for each hybrid consisted of a randomized complete block design with six replications across three different treatments. Three treatments to simulate and isolate the effect of primary ear removal were applied to each of the six reps within each hybrid. Treatments consisted of (1) primary ear and leaf removal, (2) leaf removal from primary ear location, and an (3) undamaged check. Leaf removal from the primary ear location was added as a treatment because primary ears couldn't be removed without affect the primary ear leaf. Each plot consisted of a single, 9-m length of row. All treatments were applied for each hybrid within a few days of silks emerging, which varied by hybrid. The primary ear and leaf treatment was administered by physically tearing the primary ear and leaf from the plant. Removal of primary leaf was achieved by tearing the leaf away from the primary ear. Leaf removal treatments often left the sheath attached to the primary ear. Plants were evaluated three weeks after applying treatments to document plants where the treatment was not applied properly.

At harvest, five individual plants were from each plot sampled by cutting them off at ground level for dissection. All leaves were removed from plants to identify ear location. Ear location was recorded for each treatment with 1A representing the primary

ear location. Secondary ears originating from the primary ear shank were designated 1B; whereas, ears originating at lower stalk nodes (axillary meristems) were designated as 2A, 3A, etc. (Figure 1c). Each ear was categorized as productive (produced seed) or non-productive (no seed present). Whole plots were harvested to determine the total number of ears per plot, grain weight per plot, and 100 seed/weight. Due to varying ear sizes, kernels were separated from ears using a mechanical separator and hand removal.

Individually sampled plants were analyzed for differences in total, productive, and non-productive ears per plant using PROC GLIMMIX with a Poisson distribution to evaluate treatment (primary ear and leaf removed, primary leaf removed, and undamaged check) as a fixed effect, and replication and individual plant were considered random effects. Individually sampled ears were combined with whole plot samples to analyze the total number of ears, grain weight per plot, grain weight per ear, and 100 seed weight using PROC GLIMMIX with normal distributions. An analysis of variance was used to determine differences in fixed effects of treatments, and T-test were used to determine differences between treatments. Replication was considered as a random effect. Grain weight per plot was converted from grams/plot to kg/hectare prior to the analysis.

Results

Application of the primary ear removal treatment resulted in a high percentage of broken stalks (Fig. 3.2) in 111-day and 112-day hybrids as a result of weakened stems, averaging 21% and 50% breakage, respectively. Due to the high percentage of broken stalks, the 111-day and 112-day hybrids were excluded from all analyses. Broken stalks were also observed in the 80-day hybrid, but the occurrence was less than 10% across all treatments. A proliferation in secondary ear development was observed in individual plant samples when comparing the check and primary ear and leaf removal treatment (Fig. 3.3).

Individual plant sample data showed differences in treatments for total ears (Fig. 3.4) ($F_{2,58}$ = 48.49; P < .0001), productive ears (Fig. 3.5) ($F_{2,58}$ =12.18; P <.0001), and non-productive ears (Fig. 3.6) ($F_{2,58}$ =12.18; P <.0001). The leaf removal and check treatments did not differ for total ears (t_{58} = -0.33; P = 0.7410), productive ears (t_{58} = 0.12; df = 58; P = 0.9017), or non-productive ears (t_{58} = -0.99; P = 0.3267). In contrast, primary ear and leaf removal increased the number of total ears (t_{58} = 9.85; P < .0001), productive ears (t_{58} = 4.94; P <.0001), and non-productive ears (t_{58} = 8.35; P < .0001) when compared with the leaf removal and check treatments.

Number of ears per plot was different between treatments ($F_{2,10}$ =43.09; P < .0001) indicating increased secondary ear development. Ear and leaf removal (84.5) resulted in a greater number of ears per plot than the check (49) (t_{10} = -7.45; P < .0001) and leaf removal (47) (t_{10} = -7.87; P < .0001). There was no difference between the check and leaf removal (t_{10} =0.46; df = 10, P = 0.6579).

Yield per plot was different between treatments ($F = 50.3$; $P < .0001$). Primary ear and leaf removal (5129.5 kg/hectare) had lower yields than primary leaf removal (8685.4 kg/hectare) ($t_{10} = 8.11$; $P < 0.0001$) and the check (9123.5 kg/hectare) ($t_{10} = 9.13$; $P < 0.0001$). No differences were observed between primary leaf removal and check ($t_{10} = 1.02$; df = 10; $P = 0.3330$).

Treatment differences occurred for average grain weight per ear ($F_{2,10} = 93.73$; $P <.0001$) as a result of reduced ear weights in the primary ear and leaf removal (67.18 g/ear) compared to primary leaf removal (183.02 g/ear) ($t_{10} =-11.73$; $P < 0.0001$) and the check (185.43 g/ear) ($t_{10} =-11.98$; $P < 0.0001$). Primary leaf removal and the check were not different for average grain weight per ear ($t_{10} = 0.24$; $P = 0.8116$). No differences were observed for seed weights between treatments ($F_{2,10} = 0.79$; $P = 0.4806$).

Discussion

Unexpected broken stalks in 111-day and 112-day hybrids, as a result of primary ear removal, excluded the interpretation of differences in secondary ear development across hybrids. However, this study confirms that the removal of the primary ear during early-silking stage (R1) of corn leads to multi-ear development for DKC-30-19 RIB VT Double Pro (80-day). In addition, individual plant samples showed a high percentage of "bouquet" ears. Only 10% (3 of 30) of individual plants produced a single secondary ear at the node below the primary ear node when the primary ear and leaf were removed. "Double" ears were prevalent in 2006 (Elmore and Abendroth 2006); however, this study indicates that secondary ear development primarily resulted in proliferation of secondary ears on a single corn plant (Fig. 3.4). The differences between these two studies could be an artifact of the hybrid, method, or timing of primary ear removal.

The position of secondary ears appears to be in a set sequence from the primary ear location. The presence of ears on lower stalk nodes was always preceded by the presence of ears at the next higher stalk node. For example, ears present of lowest node (5) had ears present at stalk nodes 4, 3, and 2 (Fig 3.1c). This suggests that the removal of the primary ear initiates axillary buds and secondary ear development in a sequence from the primary ear location. This sequence begins with the node below the primary ear node and proceeded downward.

Additional ears were also present in the primary leaf removal and undamaged check treatments (37% and 23%, respectively), but these were mostly unproductive (only 7% productive ears) and usually located on the next node below the ear node (Fig. 3.4

and 3.5). The presence of ears on separate stalk nodes is common and could be an indication that the 80-day hybrid is somewhat “prolific” in ear development.

Yield losses from primary ear removal in the 80-day hybrid correspond with observations made by Elmore and Abendroth (2006). A high frequency of bouquet ears resulted in poor yields (44% yield loss) at the whole plot level. Individual plant samples show that primary ear removal resulted in an increase in the number of productive, non-productive, and total ears. In this study, ears were classified as productive based on the presence of an individual kernel. Whole plot yields show that although there was an increase in productive ears they lack pollination with a limited number of fertilized kernels. Average grain weight per ear indicates that many ears produce little to no kernels. The lack of kernels on secondary ears is likely the result of poor fertilization resulting from silks emerging after pollen shed. This study may represent higher than normal yields from primary ear loss due to the presence of pollen from other later maturing hybrids planted nearby.

Additional studies are needed to determine if ear removal at early silking corresponds with impacts that would occur if the primary ear loss was during the early stages of vegetative growth. Study comparisons may provide a means of screening hybrids for multi-ear development to reduce the likelihood of significant yield losses from ‘bouquet’ ears on current corn hybrids. The proliferation of multiple ears and yield losses for the 80-day hybrid may or may not correspond with other commercial hybrids. Typically, 80-day hybrids are grown for silage production and could differ significantly from corn hybrids that are intended for seed production.

Figures

Figure 3.1: Corn plant indicating the presence of the primary ear (a) compared with multi-ear development for double-ear (b) and bouquet ears (c) with letter designation for ears originating from the same stalk node.

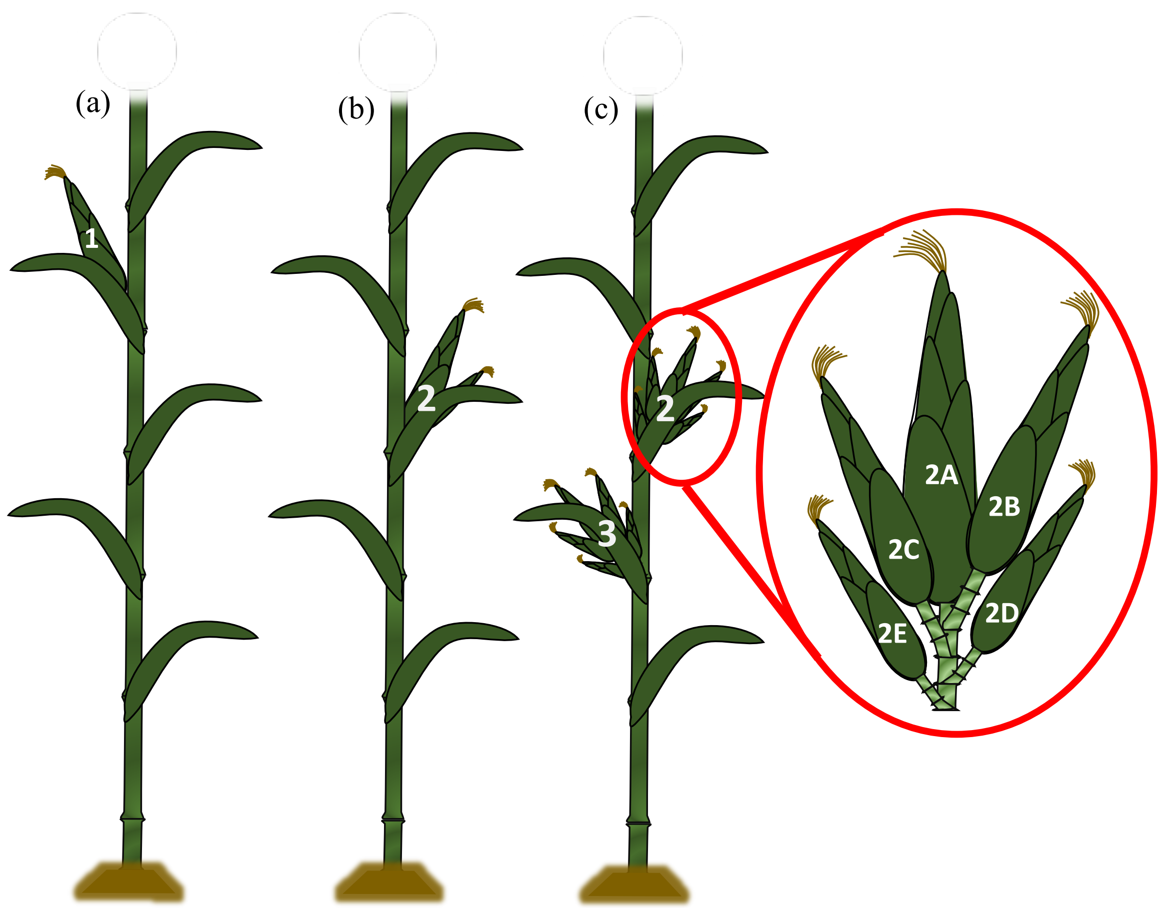


Figure 3.2: Example of intact (a) and broken stalks (b) (greensnap) damage as a result of primary ear removal on 111-day corn hybrid.

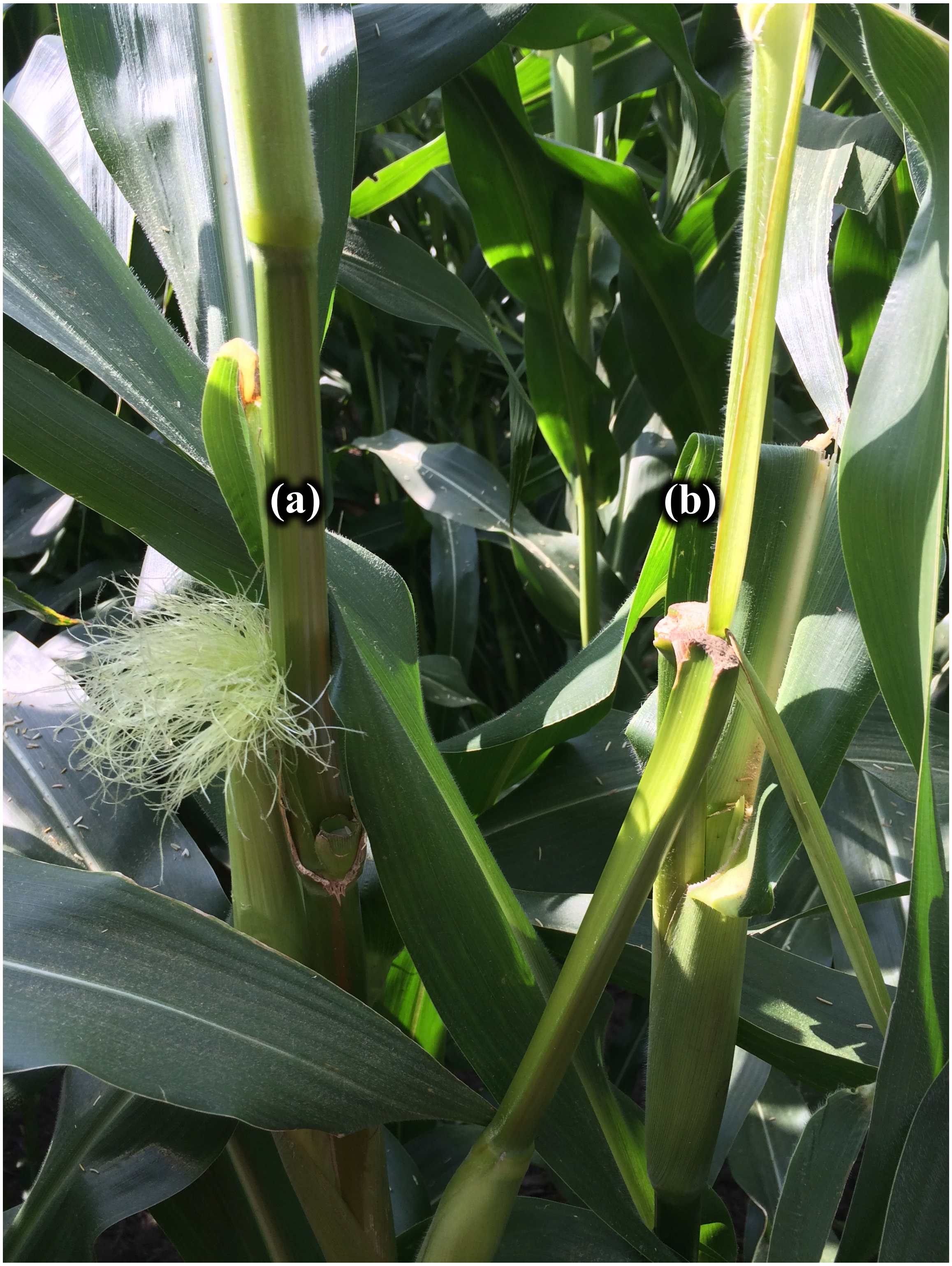


Figure 3.3: Photos of individual plant samples from check (a), and primary ear and leaf removal (b) with arrows indicated primary ear location on the 80-day hybrid

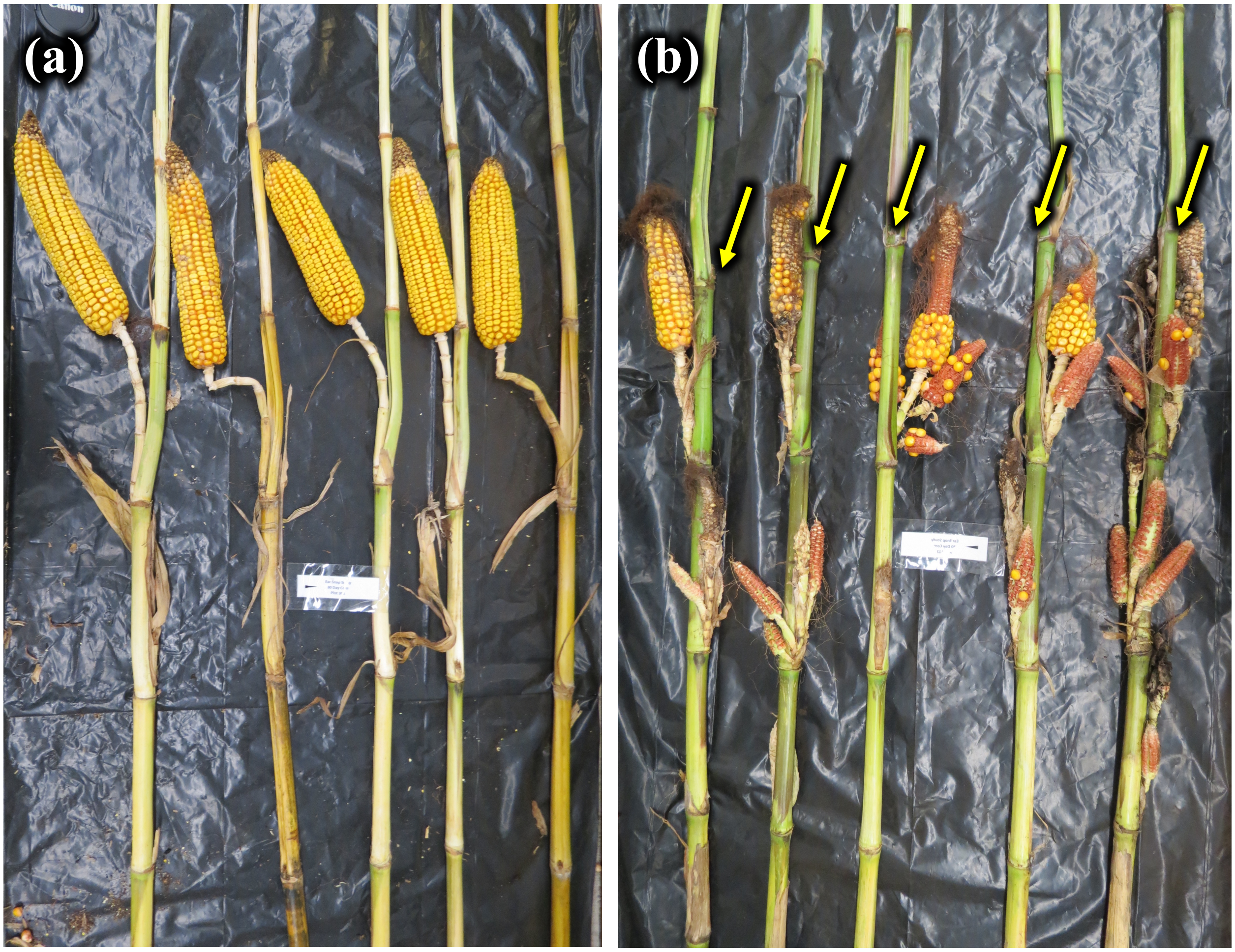


Figure 3.4: Distribution of all ears on corn plants by treatment (primary ear and leaf removal, primary leaf removal and undamaged check) from individual plant samples for the 80-day corn hybrid.

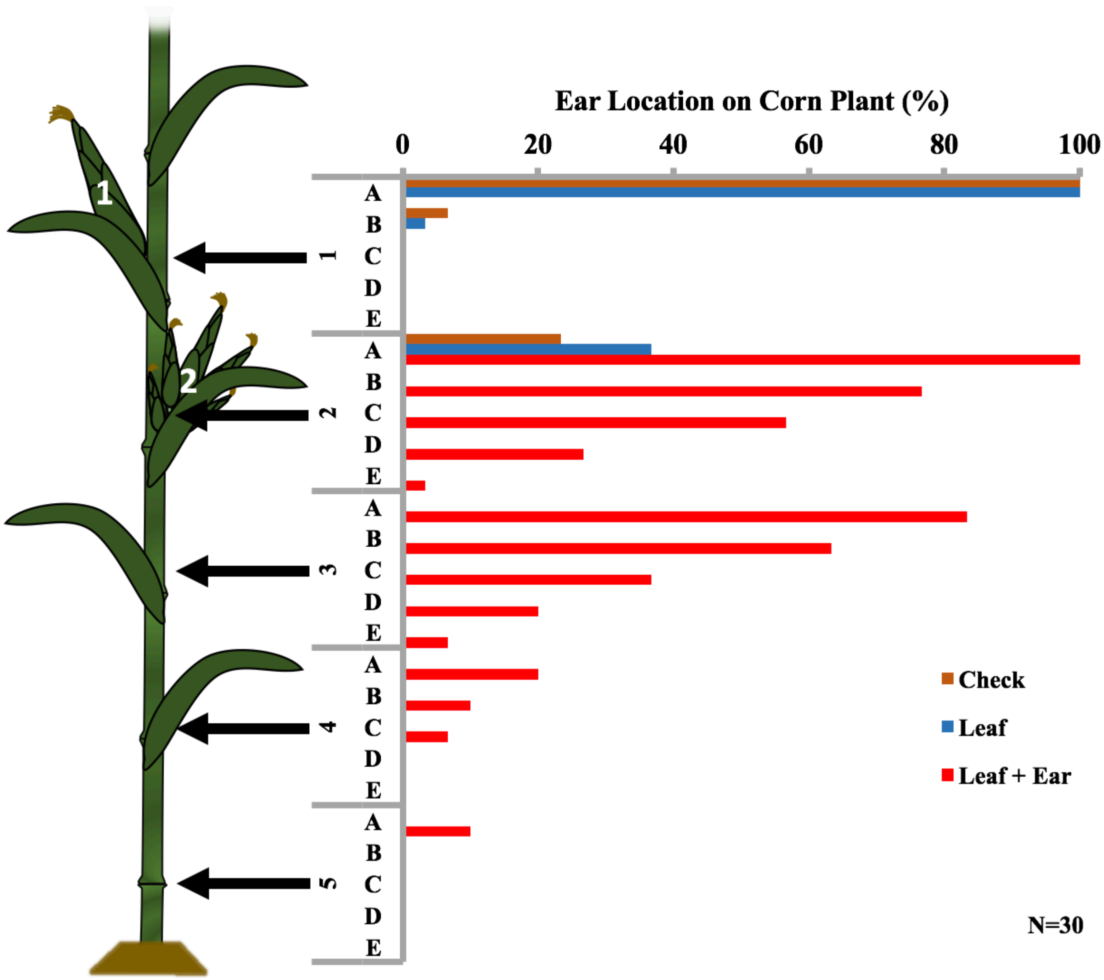


Figure 3.5: Distribution of productive ears (any harvestable kernels present) on corn plants by treatment (primary ear and leaf removal, primary leaf removal and undamaged check) from individual plant samples for the 80-day corn hybrid.

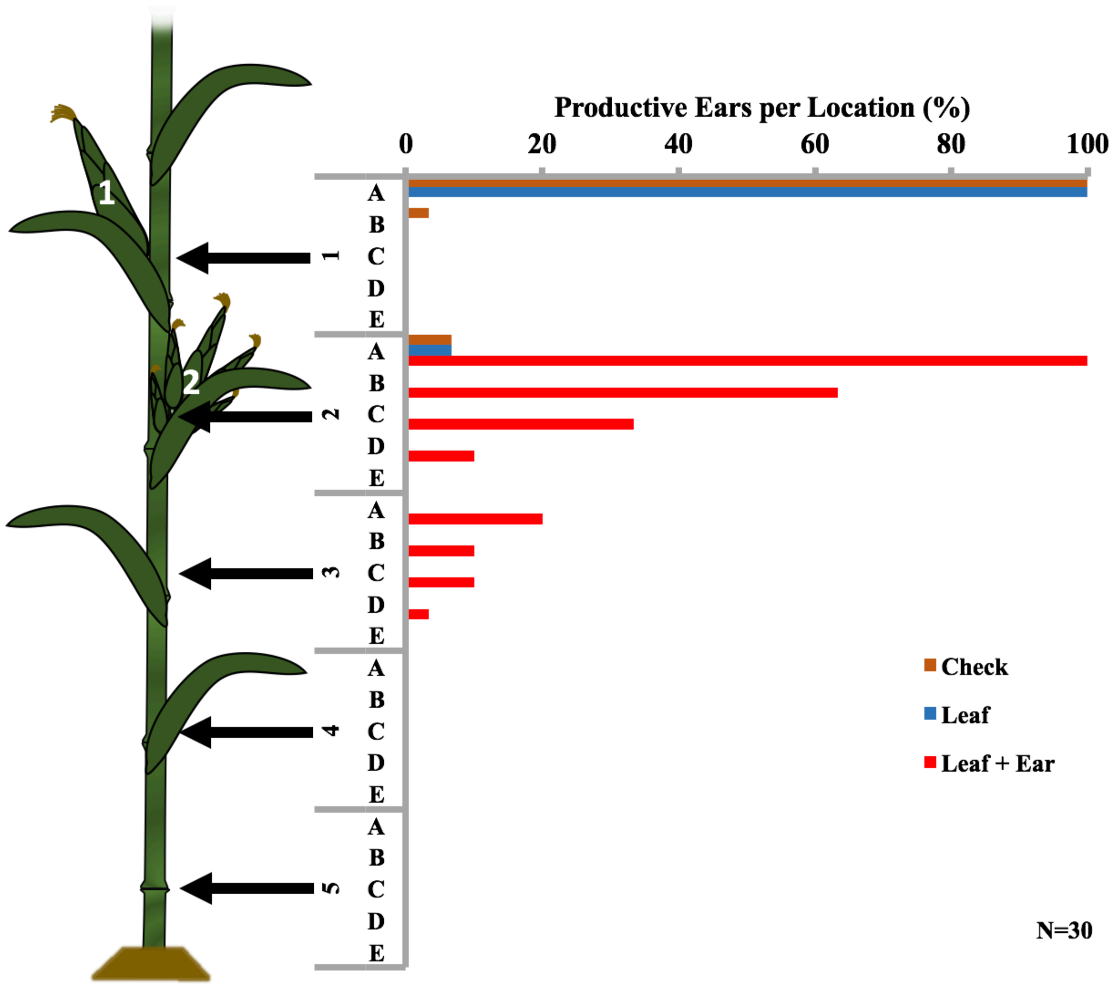
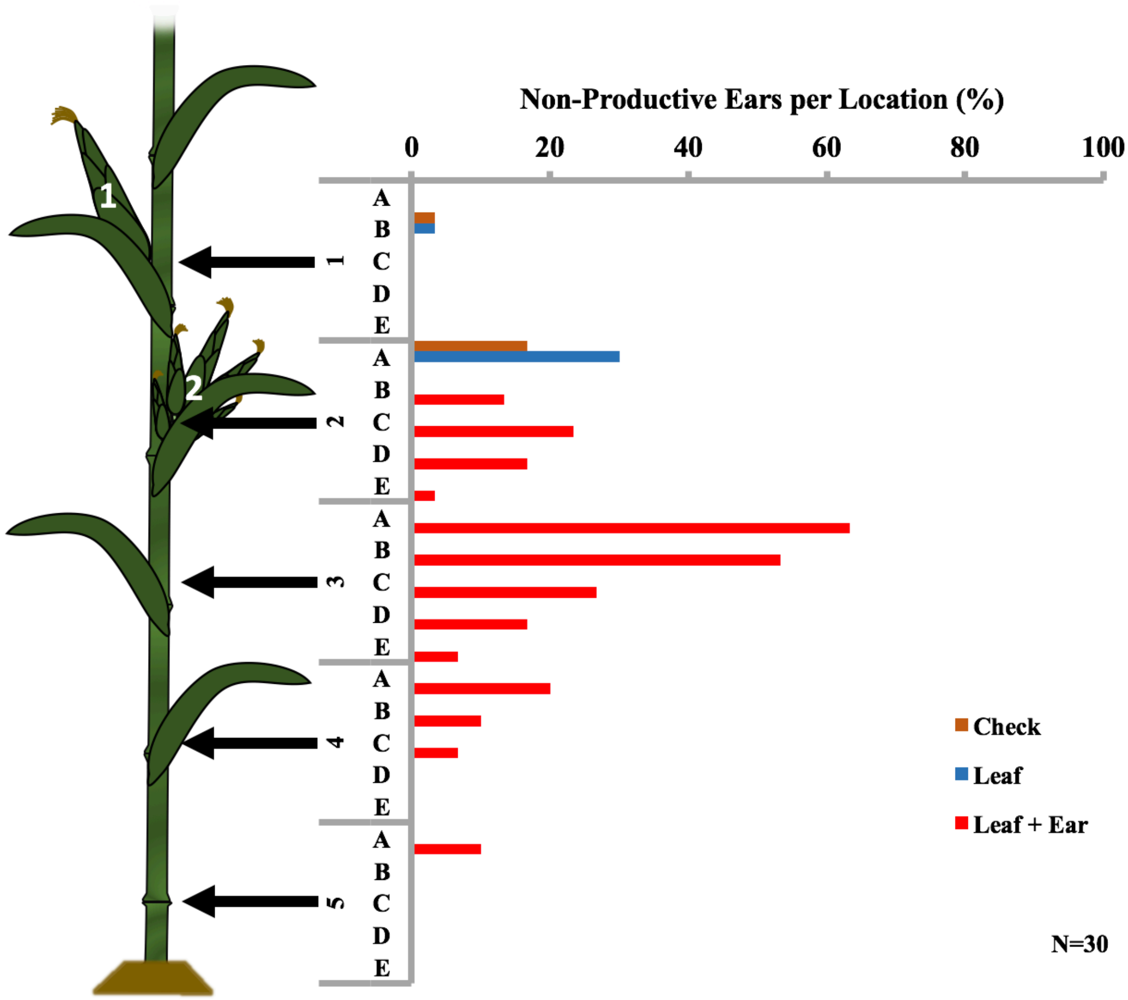


Figure 3.6: Distribution of non-productive (any harvestable kernels absent) ears on corn plants by treatment (primary ear and leaf removal, primary leaf removal and undamaged check) from individual plant samples for the 80-day corn hybrid.



References

Bonnett, O. T. 1966. Inflorescence of maize, wheat, rye, barley and oats: their initiation and development. University of illinois College of Agriculture. Bull. 721. 121 pp.

Doebley, J., A. Stec, and C. Gustus. **1995**. Teosinte branched1 and the origin of maize: evidence for epistasis and the evolution of dominance. Genetics. 141: 333–346.

Elmore, R., and L. Abendroth. **2006**. A response to phenomenon in 2006: Multiple ears per node. Integr. Crop Manag. News. Paper 1358: 3 pp.

Elmore, R. W., and L. Abendroth. **2009**. Hail Injury on Corn. Integr. Crop Manag. News. Paper 631. (http://lib.dr.iastate.edu/cropnews/631/).

Hubbard, L., P. McSteen, J. Doebley, and S. Hake. **2002**. Expression patterns and mutant phenotype of teosinte branched1 correlate with growth suppression in maize and teosinte. Genetics. 162: 1927–1935.

Irish, E. E., and T. M. Nelson. **1993**. Development of tassel seed 2 inflorescences in maize. Am. J. Bot. 80: 292–299.

Klee, H., and M. Estelle. **1991**. Molecular genetic approaches to plant hormone biology. Annu. Rev. Plant Biol. 42: 529–551.

Lejeune, P., and G. Bernier. **1996**. Effect of environment on the early steps of ear initiation in maize (*Zea mays* L.). Plant Cell Environ. 19: 217–224.

Lejeune, P., E. Prinsen, H. V. Onckelen, and G. Bernier. **1998**. Hormonal control of ear abortion in a stress-sensitive maize (*Zea mays*) inbred. Funct. Plant Biol. 25: 481–488.

McMaster, G. S., W. W. Wilhelm, and A. B. Frank. **2005**. Developmental sequences for simulating crop phenology for water-limiting conditions. Crop Pasture Sci. 56: 1277–1288.

CHAPTER 4

Historical origins and future vision of extension in agriculture

The United States agricultural extension service is considered to be one of the most widely recognized systems in the world for disseminating technological innovations (Rogers 1988). This system has been so effective that it has become nearly synonymous with the word diffusion in the agricultural community. To quote Eveland (1986), "It is impossible for anyone to speak 10 words about diffusion without two of them being 'agricultural extension' ". In part, the success of extension has been its ability to adapt to the changing needs of the agricultural community.

The future holds numerous challenges for agriculture. As a result, scientists are continually developing a range of technologies aimed at decreasing environmental impacts and increasing productivity and resiliency under a rapidly changing climate. These new technologies are set to take the stage in an agricultural system that is already mechanically and biologically complex. Successful incorporation of future technologies will require a new type of dialogue and interaction between extensionists and their clientele. Defining this new role of extension requires an understanding of its origin and evolution. This chapter will discuss the history, development, and importance of extension, its current vision and speculations about its future direction and interaction with the agricultural community.

Brief History of Extension

Today's modern agricultural extension service can be linked to events occurring during the last half of the 19th century; however, the concept of 'extension' in terms of advising others on agricultural practices has existed for thousands of years in places all around the world (Leeuwis 2004). The earliest physical evidence of exchange or advice

on agricultural practices dates back nearly 4000 years (Anandajaysekeram et al. 2008). Archeologists uncovered clay tablets believed to be created around 1800 B.C. that were inscribed with information on watering crops and killing rats in Mesopotamia (present-day Iraq) (Ahmed 1982). Early evidence also existed in the form of hieroglyphs on Egyptian columns describing ways to avoid crop damage and loss of life from floods occurring in the Nile (Jones and Garforth 1997).

Agricultural writing documenting farming practices are thought to have first emerged with Phoenician and Greek civilizations (Laet and Herrmann 1996). Few of these writings survived; however, some were later translated by Roman writers who passed the information on to Roman landowners as a way to improve their estates (Laet and Herrmann 1996). A large part of the history of advising in agriculture existed in the form of agricultural writings. Some notable landmarks throughout the early history are the Chinese treatise, “Essentials Techniques for the Peasantry” produced in 535 A.D. which is thought to be the oldest fully intact agricultural writing of its time (Needham and Bray 1984). In addition, Thomas Tusser’s, “Five hundred pointes of good husbandrie” published in 1573 served as a best seller in Tudor England and has been reprinted numerous times in the centuries that followed (Tusser 1812). These writings serve as evidence of the exchange in knowledge of farming practices; however, it is not clear if there were any means of active dissemination of information at that time.

Formal extension services began in most countries during mid- to late-19th century (Anandajaysekeram et al. 2008), usually as a response to an agriculture crisis. The potato famine of 1845 in Europe was a landmark in the concept of an agricultural extension service (Swanson et al. 1997). Two-years after the famine began, the newly

appointed Earl of Clarendon recognized the need to act on the situation (Jones 1982). He wrote a letter to the Royal Agricultural Improvement Society urging them to send lecturers to distressed districts and explain in simple terms the ways that peasants could improve their operations through the use of cultivation or alternative root crops (Caird 1890). The Society of Dublin appointed, positioned, and paid the lectures that were expected to report their findings and progress to the society on a weekly basis (Jones 1981).

The success of lecturers soon caught the attention of several states in western Germany that later appointed traveling agricultural teachers. The concept continued to build momentum over the course of the next decade as a result of the devastation of phylloxera in vine orchards (Jones 1981). Western Germany's nomadic agricultural teachers spent their summers travelling to districts giving talks and advice to producers. In the winter, they taught the sons of farmers at winter agricultural schools (Jones 1981). The program later became an integral part of the civil service due to its recognition and appropriation of state funds (Maier-Bode 1910). In 1879, France would be the first nation to pass a law to have a completely state-funded agricultural extension service (Jones and Garforth 1997). Professors were appointed under the new law and instructed to train primary school teachers (Jones and Garforth 1997). In addition, they were to be nomadic in their education to keep farmers informed of modern discoveries that could be applied to their agricultural system (Jones 1981).

The movement in Europe soon gained the attention of delegates travelling from North America (Jones 1981). In North America, the exchange of agricultural knowledge had already begun with the emergence of agricultural societies and clubs in the wake of

the American Revolution (Jones and Garforth 1997). In 1819, these societies along with the help of J. S. Skinner would found one of the most successful early farm papers, "American Farmer" (Sands 1848). Each issue was typically composed of eight pages of news on agriculture, horticulture, livestock, market prices, and the activities of the agricultural societies (Library of Congress).

Extension in the United States

The cooperative extension services in the United States began indirectly with the formation of land-grant institutions as a result of the Morrill Act, passed in 1862. Several attempts had been made prior to 1862, but bills were either rejected by state senators or vetoed by President James Buchanan (Mayberry 1977). In 1861, the Civil War broke out and those that were opposed to the bill were absent from U.S. Congress allowing the bill to pass, and be signed into law by President Abraham Lincoln on July 2nd, 1862. The law dictated that each state set aside federal land (30,000 acres) and that the income from that land be used to support the university in teaching agricultural and mechanical arts. In 1890, a second Morrill Act was passed that required land-grant institutions at each state to show that race was not a requirement for student enrollment or form separate land-grant colleges for blacks. These schools were later known as the 1890's land-grants (Mayberry 1977). The early land-grant institutions were considered a radical innovation for their time compared to the classical, liberal arts, and scientific education given at the private universities within the U.S and Europe.

The newly formed land-grant institutions faced numerous challenges in the early stages of their development as they suffered from a lack of qualified teachers, scientific

information, and a near absence of contact with farmers (Scott 1962). Experiment stations were later formed as a result of the Hatch Act in 1887 that allowed for the development of critical agricultural knowledge. However, the issue remained on how information could be effectively transferred to producers (Edwards 1941). Despite the effort and expectations, college officials came to realize that many farmers were not attending educational venues on college campuses because of cost, time ability, or inclination (Scott 1962).

University faculty realized that alternative action was needed and began the process of bringing their scientific information to the producers themselves (Scott 1962). Although the education movement met with hostility by some farmers, it expanded rapidly through the 1880's and onward (Bailey 1899). In 1904, the land-grant institutions initiated a cooperative effort with the railroad that would drastically alter its influence on the agricultural community (Scott 1962). The concept "education" or "demonstration" trains emerged first with Perry G. Holden, a staff member at State College who would later become the head of the state's extension service (Scott 1962). The first trains, called 'seed-corn specials' were initiated in response to concerns over seed corn germination issues occurring throughout the state (Rogers 1988). The demonstration trains exceeded all expectations as professors from the college connected with an estimated 17,600 people representing 1.5 million acres over the course of eight days and 1,321 miles within Iowa. Burlington train company quickly expanded the operation into Nebraska the following year, and within two-years, the trains were running educational stops at stations in 21 states (True 1928). The education trains reached their peak in 1911 with 62 trains covering 35,705 miles connecting with 939,120 people through a total of

740 lectures (True 1928). Lectures on the trains were tailored to match the location, the available time at each stop, and the inclination of the presenter. The excitement of trains declined shortly after their peak in 1911 (Scott 1962). Within two-years, the number of trains had been reduced by more than 50% (Eddy 1957) with a complete loss of interest by 1917 (Scott 1962). The education trains reemerged again in 1920, but their efforts were directed towards specific agricultural issues (Scott 1962).

The early 1900's saw a wide range of new ideas in communicating information to producers, but none of them would rival the innovations of Seaman A. Knapp. Widely considered as the Father of Extension, Knapp revolutionized the dissemination of agricultural information with the introduction of the County Demonstration Agent System (Westwood 1973). Knapp, was hired as federal agricultural specialist to Texas in response to devastation of the boll weevil in cotton (Bull et al. 2004). Shortly after his arrival, Knapp connected with a local farmer, Walter Porter, and the two initiated test plots on the Porter Farm in Kaufman County, Texas in 1903 (Bull et al. 2004). Knapp's plan was simple but effective. He would contact a farmer and ask them to devote a few of his acres to management as Knapp instructed. Knapp would make frequent visits throughout the growing season to insure that things were done correctly. At the end of the season, cotton yields would indicate the success of the Knapp's education, and the lessons were not likely to be forgotten (Bordelon 1985). After completing his first year of demonstration plots, Walter Porter would reported a $700 net increase after expenses from the demonstration works (Martin 1921).

Knapp's philosophy on his interaction with growers can be summed up in this quote, "What a man hears, he may doubt; what he sees, he may possibly doubt; but what

he does himself, he cannot doubt" (Texas A.M. Cooperative Extension 2003). Knapp furthered his progress with farmers through field trips and home visits to demonstrate new technologies and techniques (Gould et al. 2014). In the fall of 1903, Secretary Wilson and Chief Galloway would travel from Washington to Texas to observe the progress of the demonstration works (Martin 1921). Knapp would later be given $40,000 in congressional appropriations to continue his work in Texas (Martin 1921). By 1905, the demonstration works would spread to Oklahoma, Arkansas, Louisiana, and Mississippi (Martin 1921).

Dr. Seaman Knapp would pass away in 1911 at the age of 78; however, the success of the demonstration works would continue to live on. By 1914, the demonstration works would be active in 16 southern states with a total of 781 farm agents and 351 home agents (Martin 1921). Senator Smith of Georgia and senator Lever of South Carolina would become heavily invested in the concept of the demonstration works and made rounds with county agents to learn more about the use of the newly developing system (Martin 1921). These senators would use the information from Knapp's demonstration works concept to merge it with legislation for what would later become known as the Smith-Lever Act of 1914. Five years prior, the McLaughlin Bill had been proposed; however, the bill had failed to gain ground because of disagreements about federal and state control (Hansen and County 2014). In 1914, James Houston, the Secretary of Agriculture and a former president of a land-grant college, would enter the debate with senators Lever and Smith and bring the United States Department of Agriculture and land-grant systems together. The plan for the bill hinged on Knapp's

work with demonstration plots, the field agent concept, and the appropriation of federal funds. The final result was the formal introduction of the cooperative extension service.

The mission of the cooperative extension service in the Smith-Lever Act was to diffuse practical information to the people of the United States on subjects relating to agriculture and home economics. World War I became the first big test for the extension service. Extension agents were a fundamental component for increasing the countries food production efforts, aiding in food preservation practices and helping address the farm labor shortages by organizing the Women's Land Army and Boy's Working Reserve (Schwieder 1990). The Great Depression brought a new set of challenges, and extension adjusted its efforts to aid farmers with marketing by helping to organize buying and selling cooperatives (Egolf 2008). Extension home economists taught the importance of good nutrition, gardening, home poultry production, and other skills that helped the farm family survive the economic depression and drought (Egolf 2008).

In the 1930's, extension became involved with several federal programs such as the Agricultural Adjustment Administration, which subsidized farmers to not plant crops on parts of their land and reduce livestock numbers (Egolf 2008). In 1935, the Soil Conservation Service Act was passed, and extension worked closely with soil scientists to set up demonstrations on different methods of fertility, terracing, contouring, and tree planting in sloughs (Egolf 2008). Extension pushed the soil conservation concept into teaching at rural schools to prepare the next farming generation.

World War II saw a drastic shift towards increased food production for the wartime effort. Extension worked closely with farm families to increase production each year for the five years during the war (Hansen and County 2014). By 1944, food

production was 38% greater than the average production from 1935-1939 (USDA-NIFA). Agricultural extension agents also helped implement the Victory Garden Program by providing seeds, fertilizer, and gardening supplies to communities (Rasmussen 1989). An estimated 20 million victory gardens were planted in 1943, producing more than 40% of the fresh vegetables for consumption that year (Rasmussen 1989). Mechanical, chemical, and biological technologies flourished in the years after World War II, and extension agents placed a strong focus on translating the use of these technologies to producers (Rasmussen 1989). As a result, farm production soared from the 1950's through the 1980's for both corn and wheat (Rasmussen 1989). This increased production also coincided with a decline in the number of farms from 5.4 million to 1.9 million farms (USDA-NIFA). The farm crisis of the 1980's restructured farmers goals, and county agents worked with farmers to cut input costs, shift to different crops, and find new markets in order to improve farm income (Rasmussen 1989).

Today's agricultural issues are complex as producers are asked to meet the increasing global demand for food by using economically and environmentally friendly management practices. A reduction in agricultural farms and increased consumer awareness of environmental impacts, combined with a myriad of potential technological solutions will make cooperative extension's role in the future more important than it has ever been.

Future Vision of Extension

The future of extension exists in its ability to rapidly identify key issues and actively engage its clientele with research-based information. In 2015, Nebraska

Extension continued this initiative by evolving its approach from an action team to an issue team concept. The new issue team concept strongly embraces my core philosophy of extension. As a result, this section will focus on the components of the issue team concept and my vision for the future of extension.

At the core of the issue team concept is a strong effort by extension to identify what is important to its clientele. I believe that identifying clientele's key issues should be a regular effort among extension faculty and staff. Today's rapid-paced agricultural systems reinforce this need and allow extension to take a proactive approach to addressing new and emerging issues. Extension regularly faces more issues than what it can reasonably manage, and a survey provides an opportunity to rank these issues based on stakeholder responses. In addition, a survey could identify what areas of the state share similar concerns and coordinate those efforts among faculty and staff. The process of engaging clientele in identifying key issues also allows them to think critically about their system. This approach provides greater opportunity for clientele to participate in active learning because the key issues are important to their future.

Another core component of the issue team concept is its limited lifespan, with the expectation that teams dissolve after an issue is considered resolved. Evaluating the progress of teams at three- to five-year intervals allows extension to recognize what progress has been made and what additional steps remain. I believe that an active and open dialogue between extension and clientele can provide an opportunity to determine the value of addressing current issues or shifting focus to address other important issues.

It is my belief that the extension educator's role in detection of emerging issues and the discovery of innovative solutions will be increasingly important in the future.

Extension has placed a strong emphasis on identification of emerging issues and I believe that this approach could be expanded. Proactive educators working with their network of clientele could determine the extent and impact of an emerging issue in the early phases of its development. Early documentation of these issues could help concentrate efforts of specialists and add critical knowledge needed for the future direction of research-based solutions. An extension educator's network and connection with their clientele serves as the primary means of making early detection and documentation successful. Specialists also serve a fundamental role in early detection because their network of clientele is typically consultant and educators. Broad and early dissemination of information regarding an emerging issue will help to accurately document the issues spread and impact. This approach would also allow for a strong connection between extension specialists, educators, and clientele. The collective approach also provides a stronger dialogue and exchange of practical and applied knowledge for all those involved. Increasing the dialogue and understanding of the situation through this approach will lead to more sustainable, practical, and economical solutions.

My second vision for extension is the role of educators in the discovery of innovative solutions. I believe that significant progress can be made through extension educators actively engaging innovative producers in conducting experiments aimed at addressing local solutions through on-farm research trials. Nebraska Extension has placed a growing effort on on-farm research since its inception during the 1990's. Directing these efforts towards potential solutions generated by specialists on experiment stations would allow for feedback on the interactions between a potential solution and producer management practices. Conducting this type of on-farm research across a range

of different management practices would provide information on the durability and practicality of a solution. In addition, round table discussions with specialists, educators, and producers provide an opportunity to brainstorm possible solutions or changes in management strategies to address key issues. Skeptics may suggest that this approach may be overly optimistic in terms of producer commitment, but I believe that a new era of producers are emerging. The adoption of technological innovations over the last couple of decades has allowed a portion of the agricultural population to shift their mindset towards a more proactive approach to solving problems. Open dialogue about these opportunities will allow for progression toward this approach.

I believe that the on-farm research approach to innovative solutions can extend its impact through the identification and discussion of common goals among a group of producers. The variation in farming practices would provide an opportunity to evaluate how a producer's management practices affect a potential solution. Such information would indicate that the solution could either be widely disseminated or limited based on certain management strategies. This type of progression towards a solution from both the research stations and on-farm research sites would provide opportunities to refine goals and redirect efforts. Expanding these projects over several counties would provide an opportunity to identify regional differences in solutions that specialists could use as a starting point for future research questions. It's my opinion that successful on-farm research programs occur when extension actively engages producers with updates and reminds them of the goals and value of the information obtained. Utilizing technology and being proactive about the status of these projects is essential to their success.

Research-based solutions are only relevant and important if they can be translated to clientele and put into practice. I believe that the integration of educators and producers into the development of potential solutions provides an opportunity for clientele to recognize the relevance of research objectives. Specialists would also benefit from this activity as they are likely to encounter clientele that are already engaged in problem solving, allowing for productive and insightful conversation when presenting research findings. Dialogues focused on problem solving will result in more practical and sustainable options that can be readily adopted.

I think it is important to recognize that the majority of the agricultural community consists of clientele that are not early adopters and perhaps unwilling to try new solutions. By identifying those that are willing to conduct research on their farms, we can present findings from research stations and producer farms that allows the more passive and pessimistic adopters to recognize the relevance of current research, its application, and some potential similarities with the farming practices of early adopters in their area. A large part of extension is trust, and inclusion of producers into the innovative solution system provides an opportunity to recognize them as equals in problem solving process. My philosophy on this approach stems from Seaman Knapp approach more than 100 years ago. I believe that by working with producers to "do" problem solving, we present an opportunity to have them engage more fully in the conversation about future innovations.

I believe that increased expectations on future extension educators will require change in their range of expertise. Early diagnosis of emerging issues and on-farm research expectations suggest that educators will need a broad background in the field of

agricultural sciences combined with a research-based approach to achieve and coordinate productive conversations between specialists and producers. Greater knowledge of plant, weeds, disease, insects, and soil sciences allows educators to effectively communicate with specialists and provides a greater level of expertise for detection and interpretation in the field. A research-based background is also important, as it allows educators to conduct, analyze and interpret data useful for discussions with clientele and specialists. I believe that courses directed at the statistical approach to on-farm studies are needed and that this information would be of value to a wide range of people in the field of agriculture.

The issues team concept also provides a chance for increased interactions between specialists and educators of different disciplines or backgrounds. Nebraska Extension's action teams regularly engaged in interdisciplinary projects and their research-based results that have been very beneficial for their clientele. I believe that having teams form based on interests to specific issues allows for the increased development of new partnerships and connections with other disciplines. Through those interactions, specialists can gain an appreciation of the impact of other disciplines and the knowledge of their impact on the system. This type of information would translate well to producers during extension events by improving their trust in extension. The ability of faculty to carry conversation with producers across disciplines will lead to more engaging interactions and deeper understanding of barriers to solutions.

Demonstration plots provide an opportunity to further the interaction with clientele. I strongly believe that clientele engage and ask new questions when these plots are developed in a way that reflects real world problems. Nebraska Extension has made

tremendous strides with demonstration plots by intentionally creating real world scenarios and allowing clientele to determine what the problems and solutions are. The crop management diagnostic clinics held at the Agricultural Research and Development Center near Ithaca, NE serve as an example of innovative work in demonstration plots. Its fundamental that this effort continue with increasing focus on interdisciplinary issues allowing clientele to identify the problem, determine if action is needed, and interpret the factors that influence their decision. For example, splitting a demonstration plot with hail alone and the presence of a pathogen would allow clientele to generate a understanding of the replant decision process and develop an awareness of additional issues in a field. Surveying extension faculty and staff on potential interdisciplinary ideas for demonstration plots. Also, such practices would help recruit speakers for field days and disseminate information on the event to clientele. I believe this approach would provide clientele with the tools necessary to make those decisions, and it will increase their willingness to engage in active conversations about management options.

Advances in technology over the course of the past decade have provided extension with numerous opportunities to translate complex issues to producers. In my experience, subtle changes that occur over time have become a fundamental barrier for education of key issues in agriculture. The slow progression of problems makes it difficult to tie together the source of a problem that occurred earlier in the season to its eventual result later in the season. Time-lapse photography is a cheap and effective tool to bridge issues that extended over long periods of time. In the case of early-season hail damage, growers want their crop adjustors to make decision to replant the crop immediately after a hail event. Time lapse allows for opportunity to collapse 10-days of

plant response following hail damage over the course of a minute. This provides growers with an opportunity to visualize the value of waiting to make a management decision. The development of these provides adjustors and consultants with a tool that they can use to mediate the conversation with growers when contention appears over the need to delay an evaluation. Utilizing this type of technology to break these barriers could allow for an understanding of a true risk level and allow producers to engage in new questions about the system in which they work.

Interactive technologies also provide clientele with an opportunity to set their own pace and explore a range of possibilities through the learning process. I believe that significant advances in the dissemination of information can be made through collaborations with software development specialists, and this can provide an opportunity to incorporate complex learning objectives into simple-to-use interactive software packages. The interactive component allows the user to have some control over the outcome or settings of the agricultural situation, and by changing these options, they can learn more about how the system changes under different scenarios.

Extension has made tremendous advancements in its use and integration of technologies. The quality and diversity of apps produced by the Nebraska Extension provides a glimpse to the future potential of incorporating new innovations into these platforms. Adding such innovations of early detection and innovative on-farm research approaches will help inform, advance, collect, and integrate new innovative solutions for agriculture in the years to come.

References

Ahmed, A. 1982. The role of the information system in development. Baghdad Iraq Minist. Cult. Inf. Studies Series, No. 314.

Anandajaysekeram, P., R. Puskur, W. Sindu, and D. Hoekstra. **2008**. Concepts and practices in agricultural extension in developing countries: a source book. International Food Policy Research Institute, Washington, DC, USA and International Livestock Research Institute, Nairobi, Kenya.

Bailey, L. H. 1899. Farmers' reading courses. United States. Office of Experiment Stations, Washington : U.S. G.P.O.

Bordelon, K. B. 1985. Seaman A. Knapp Collection. Archives and Special Collections Department, Frazer Memorial Library, McNeese State University.

Bull, N. H., L. S. Cote, P. D. Warner, and M. R. McKinnie. **2004**. Is extension relevant for the 21st century? J. Ext. 42 (6): 6COM2.

Caird, J. 1890. Fifty years' progress of british agriculture, p. 889. *In* J. R. Agric. Soc. Englad, 3. Spottiswoode and Co., London, England.

Eddy, E. D. 1957. Colleges for our land and time: the land-grant idea in american education. Harper. 360 pp.

Edwards, E. E. 1941. American agriculture: the first 300 years, pp. 171 – 262. *In* Yearb. Agric. 1940. U.S. Department of Agriculture.

Egolf, J. A. 2008. "Keep America American": great depression, government intervention, and conservative response in Somerset county, Pennsylvania, 1920s--1940.

Eveland, J. D. 1986. Diffusion, technology transfer, and implementation thinking and talking about change. Sci. Commun. 8: 303–322.

Gould, F. I., D. Steele, and W. J. Woodrum. **2014**. Cooperative extension: a century of innovation. J. Ext. 52(1): 1COM1.

Hansen, A., and H. County. **2014**. A century of science and service. Calif. Agric. 68.

Jones, G. E. 1981. The origins of agricultural advisory services in the nineteenth century. Soc. Biol. Hum. Aff. 46: 89–106.

Jones, G. E. 1982. The Clarendon letter., pp. 11–19. *In* Prog. Rural Ext. Community Dev. Ext. Relat. Advant. Rural Dev. John Wiley & Sons, Chichester.

Jones, G. E., and C. Garforth. **1997**. The history, development, and future of agricultural extension. *In* B E Swanson R P Bentz J Sofranko Improv. Agric. Ext. Ref. Man.

Laet, S. J. de, and J. Herrmann. **1996**. History of humanity: from the seventh century b.c. to the seventh century a.d. UNESCO. 696 pp.

Leeuwis, C. 2004. Communication for rural innovation: rethinking agricultural extension. 3rd EditionBlackwell Publishers. 428 pp.

Library of Congress. About American farmer [microform]. Baltimore, Md., 1819-1834. http://chroniclingamerica.loc.gov/lccn/sf88091326/

Maier-Bode, F. 1910. Die organization und die erfolge des landwirtschaftlichen wanderunterrichts im konigreich bayern. Landsberg am Lech. George Verza.

Martin, O. B. 1921. The demonstration work: Dr. Seaman A. Knapp's Contribution to civilization. The Stratford Co. Boston, Mass. 328 pp.

Mayberry, B. D. 1977. Development of research at historically black land-grant institutions. Assoc. Res. Coord. Land Grant 1890 Coll. Univ. Jefferson City MO.

Needham, J., and F. Bray. **1984**. Science and civilization in china: Volume 6, Biology and biological technology, Part 2, Agriculture. Cambridge University Press.

Rasmussen, W. D. 1989. Taking the university to the people: seventy-five years of cooperative extension. Iowa State Univ. Press. Ames, IA. 300 pp.

Rogers, E. M. 1988. The intellectual foundation and history of the agricultural extension model. Sci. Commun. 9: 492–510.

Sands, S. 1848. The American farmer, and spirit of the agricultural journals of the day. Volume 4. 426 pp.

Schwieder, D. 1990. The Iowa State college cooperative extension service through two world wars. Agric. Hist. 64: 219–230.

Scott, R. V. 1962. Railroads and farmers: educational trains in Missouri, 1902-1914. Agric. Hist. 36: 3–15.

Swanson, B. E., R. P. Bentz, and A. J. Sofranko. **1997**. Improving agricultural extension: a reference manual, 3rd ed. Food and Agriculture Organization of the United Nations, Rome, Italy. 229 pp.

Texas A.M. Cooperative Extension. **2003**. To make a great people (DVD-R). College Station, TX: Texas A.M. University.

True, A. C. 1928. A history of agricultural extension work in the united states, 1785-1923. U.S. Government Printing Office.

Tusser, T. 1812. Five hundred points of good husbandry. Lackington, Allen, and Company. 364 pp.

Westwood, G. R. 1973. Seaman A. Knapp: Won't you please come home? J. Ext. 11: 35–41.