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Simulating Southern Rust Damage in Corn Through Defoliation

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SIMULATING SOUTHERN RUST DAMAGE IN CORN THROUGH DEFOLIATION

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Abstract

The importance of leaf area to corn for grain production beginning at silking is well documented. However, being able to predict yield loss due to defoliators such as foliar plant diseases and insects that progressively increase in defoliation over time has been difficult to quantify. To address this issue, a leaf removal study was conducted at the Dean Lee Research and Extension Center located near Alexandria, Louisiana in 2017 and 2018. Two hybrids, differing in relative maturity were evaluated in this study. An early maturing hybrid (108 days in 2017 and 107 days in 2018) and a later maturing hybrid (118 days) were used. Leaves were removed at one or more of the following corn growth stages: R1 (silking), R2 (blister), R3 (milk), and R5 (dent). All of the lower leaves (leaves below the ear leaf) were removed at the four different reproductive growth stages with the exception of the untreated check. Other treatments included continued removal of the upper leaf area at subsequent growth stages resulting in defoliation ranging from 50 and 78%.

Both hybrids responded similarly to yield loss from the defoliation treatments during both years of this study. Lower leaves are important to yield at the silking, blister, and milk stages of reproductive development. Yields were reduced even more when the upper leaves were incrementally removed beginning at these stages. Even at the dent stage, yields were reduced by over 5% when lower leaves were removed and over 10% when upper leaves were removed. Test weight and dry seed weight were also negatively influenced by defoliation, although the late hybrid was influenced less than the early. The objective of this study was to determine the effect of leaf loss at different reproductive stages of development on yield.

Introduction

The significance of leaf area as it relates to grain production in corn beginning at silk stage has been well documented. While models that measure yield loss in corn as a result of sudden singular events causing defoliation, such as those caused by hail storms are available, models that predict loss due to gradual or incremental defoliation are not as well researched. Examples of these gradual defoliations are foliar plant diseases, such as southern corn rust, and damage that is caused by insects that feed on the plant leaves. These agents cause damage to leaves that increase in severity as time passes and can cause severe yield loss if the plants are not resistant or chemical pesticides are not utilized to reduce or stop the damage.

Puccinia polysora Underwood is the agent that causes the fungal disease southern corn rust. This disease results in the loss of leaf area and ultimately the defoliation of corn plants beginning at the lower leaves. This disease is very common in the tropical regions of the world which include Africa, Latin America, and Hawaii. While less common in subtropical and temperate zones, epidemics and outbreaks in the southern region of the United States have been reported in the past. These outbreaks have caused significant yield losses to grain production in these regions where epidemics can potentially occur. Southern corn rust was identified as a major disease in corn in the United States and Ontario, Canada during the 2012 to 2015 time period. During this same time period, over two million bushels of corn were lost in the state of Louisiana. Consequently, in the southern United States southern corn rust was identified as the fifth most destructive disease.

The amount of leaf area on a corn plant influences grain production by providing more surface area for photosynthesis to occur. Photosynthesis provides energy to the plant throughout the growth process and later provides the energy for grain production after the silk stage and pollination occur. The upper leaves are responsible for having a more significant role in providing energy through photosynthesis to the developing ears of grain than the lower leaves. As foliar diseases progress, more and more leaf area is progressively lost. Southern corn rust is an example of a disease that begins on the plants lower leaves and progresses upwards. If disease progression begins at silk stage and progressively defoliates the corn plant throughout the rest of the growth stages, the impact on yield could be more severe than if the disease begins at a later growth stage such as blister or dent.

The manner in which the loss of photosynthetic tissue reduces yield in corn plants can occur in more than one way. Loss of leaf area at an earlier growth stage can result in a reduced number of grains being produced in an ear of corn. Damage that occurs late in the development of grain simply reduces the weight of the kernels produced in an ear of corn. Whichever type of reduction occurs, the loss of yield can be detrimental to crop production in affected areas.

It has been observed that corn plants can compensate for some leaf loss. Dry matter can be transported to the grain from remaining leaves and leaf stems, and photosynthesis can become more efficient. Some resistance for southern corn rust has been identified. While some selective breeding has been successful and shows promise, further research and improvement is needed for the future.

This study simulated the damage done to corn plants by southern corn rust and similar diseases that cause progressive defoliation in corn. The progressive defoliation was simulated by removing leaves from corn plants at different levels of removal beginning with the lower leaves.

Some treatments only included the lower leaves. Other treatments included the lower leaves and some upper leaves. These treatments were applied at multiple growth stages to simulate varying degrees or severity of damage. For example, some treatments simulated damage due to defoliation beginning at silk stage and not progressing any further. Other treatments simulated damage beginning at silk stage and continuing all the way until dent stage. Plants were hand harvested and yield was measured and compared.

Literature Review

Corn is a very important crop that has multiple uses. As a food for humans it is a source of protein, carbohydrates, fiber, and oil. It is also a primary source of animal feed (Alvanagh et al, 2009). Corn stover is also utilized in the production of biofuels (Blanco-Canqui and Lal, 2007). Therefore, the loss of yield in corn crops can have major impacts on both commodities and food sources. One major cause of yield loss in corn crops is defoliation due to diseases.

Southern corn rust, caused by the agent *Puccinia polysora* Underwood, is a major disease of corn. This disease is known to cause significant losses to corn yields. Epidemics have occurred throughout the tropics over the years (Brewbaker et al., 2011). An epidemic also occurred in the 1970s across the southern United States. Another series of infections by the pathogen occurred in 2010 when spores entered the United States from Latin America. Incidence of southern rust in corn crops is related to temperature and rainfall. Temperatures above 20 degrees Celsius coupled with high rainfall results in higher incidence of infection. Long periods of dew can also contribute to infection (Brewbaker et al., 2011). A cumulative estimated total loss of 273,247,781 bushels of corn to southern rust infections across the United States and Ontario, Canada for the period 2012-2015. The state of Louisiana was reported to have lost a total of 2,824,942 bushels of corn to above-ground and foliar diseases, including southern corn rust, in that time period. Southern corn rust was determined to be the fifth most destructive disease of corn in the southern region of the United States from 2012 to 2015 (Mueller et al., 2016).

Southern corn rust and similar diseases reduce yield by reducing leaf area via progressive defoliation which occurs as the disease advances (Adee et al, 2005). Southern rust causes

defoliation in corn plants by producing uredinia both under the husks and on the surface of the leaves. These uredinia are bright orange-red and circular, and lighter in color than other rust diseases (Brewbaker et al., 2011). Infections of this and other similar foliar diseases typically begin in the lower leaves of the plant and progress upwards. Yield losses from such diseases are due to the loss of photosynthetic tissue, which provides the primary source of energy for the development of the grain. Defoliation and loss of photosynthetic tissue reduces yield in one of two ways. First, yield can be reduced by the reduction in the number of kernels produced in each ear of corn. Second, yield can be reduced due to the decreased weight and size of the kernels of corn produced. The loss of leaves can also reduce photosynthate from being channeled into the roots and stalks which may result in lodging (Ward et al., 1999).

Information on the effects of leaf area on corn production has been evident for many years (Adee et al., 2005). Models do exist to assess yield loss caused by defoliation from sudden loss of leaf area from a singular event such as a hail storm. However, it is more difficult to predict yield loss from defoliation that is progressive, such as defoliation that is caused by a disease. Current yield loss models are more accurate for predicting losses when the damage occurs at only one growth stage. Progressive diseases, such as southern corn rust, however, can occur throughout the growth process. These diseases reduce the leaf area gradually across multiple growth stages (Adee et al, 2005).

Research on the effects of defoliation on the yield of corn has been conducted in the United States for more than 130 years (Battaglia et al., 2019). Dungan (1930) conducted research in which a procedure similar to the one used for our study was used to simulate defoliation in corn due to hail damage. This study was conducted to create a formula to calculate yield losses due to defoliation. It has been suggested by prior research that defoliation prior to VT (Table 1)

growth stage does not have an impact as negative as defoliation at later growth stages (Battaglia et al., 2018). In fact, it has been reported that early-season corn hybrids defoliated completely at V5 have been reported to yield more than the control group. Similar treatments on full-season hybrids yielded grain loss by as much as 13% (Johnson, 1978). However, early defoliation can cause a delay in silking and anthesis in corn plants (Mangen et al., 2005).

Table 1. Corn Growth Stage Terms.

Growth Stage	Abbreviation	Days after Emergence
nth Leaf Collar	V(n)	Up to 63
Tasseling	VT	60-67
Silking	R1	63-68
Blister	R2	73-78
Milk	R3	83-88
Dough	R4	89-94
Dent	R5	99-104
Maturity	R6	118-123

Yield losses in corn defoliated at the R2 growth stage have reduced yield by as much as 97%. The growth period just prior to tasseling (VT) to R2 is identified as the critical period for grain production. Defoliation during this period can have a devastating impact on grain yield. This is especially true when defoliation is above 50% (Battaglia et al., 2019). Amount of leaf area removed is not the only factor to consider when predicting yield loss. While the amount of yield loss is dependent on the amount of leaf area that is removed via defoliation, the stage of growth at which the damage occurs is also highly influential on yield loss due to the defoliation (Vasilas and Seif, 1985a). Defoliation that occurs near or during flowering has been documented

to cause the greatest loss of yield. Loss of leaf area at this point in plant growth has been found to reduce yield in excess of 95% in some studies (Thomison and Nafziger, 2003).

Defoliation following the R3 stage shows decreased yield loss compared to the preceding stages of growth while defoliation at the R5 growth stage shows even less loss in yield, or no loss in yield at all (Battaglia et al., 2019). The most severe reductions in yield due to defoliation typically occur when defoliation occurs during the R1 (silking) stage of growth. The final yield of corn defoliated at R1 has consistently shown the greatest reduction in yield when compared to other growth stages (Crookston and Hicks, 1978).

Yield loss resulting from defoliation during the VT and R1 growth period can be attributed to a reduction in the number of kernels produced on the ears. Conversely, losses from R2 to R5 are not typically due to a reduction in the number of kernels produced on the ear but a reduction in the size of the individual kernels, thus reducing grain weight (Battaglia et al., 2019). Tollenaar and Daynard (1978) reported that loss of leaf area up to 10 days after mid-silk results in a reduction in the number of kernels each plant produces, thereby reducing yield. That same report also stated that defoliation at and up to 20 days after mid-silk resulted in the reduction of the weight of the kernels the corn plants produce.

In addition to the reduction of kernel weight, defoliation has also been shown to be accompanied by a reduced test weight (a measure of grain density) and a reduced shelling percentage (Pomeranz et al., 1986). This contributes to the overall reduction in grain yield (Hicks et al., 1977). Defoliation has also been found to influence the development of second ears on plants. The stress caused by defoliation can significantly reduce the number of second ears that exert silks and successfully develop (Vasilas and Seif, 1985b).

Defoliation also results in the reduction of organic nutrients within corn plants. The loss of nutrients in these cases results in an uneven distribution of the available nutrients to the developing kernels. Some kernels may abort while others manage to receive sufficient nutrients for development (Helm et al., 1967). Defoliation also has an impact on corn grown for silage for livestock. While forage quality is not as easily affected as grain yield by loss of leaf area, it has been documented in some studies that forage quality can be reduced as a result of defoliation. For example, reduction in forage quality has been observed following defoliation from the R1 to the R4 growth stage (Roth and Lauer, 2008).

The specific leaves on the plant which are affected by a progressive defoliation have different degrees of impact on grain production as well. Historical research conducted on corn defoliation has suggested that the leaves below the ear are just as important for grain yield as the leaves above the ear (Battaglia et al., 2019). However, it has been determined that the majority of the dry matter produced by a corn plant is influenced more by the upper leaves than the lower leaves of the plant (Allison and Watson, 1966). Although the majority of research now supports the notion that the upper leaves are more critical to development of grain production than the lower leaves some studies have found that, when provided with adequate light and nutrition, lower leaves can have as much effect on grain production as the upper leaves (Thomison and Geyer, 2009). Again, the timing of the defoliation plays a significant role with regards to dry matter. It was observed that defoliation up to 10 days after 50% silk stage resulted in a reduction of kernel numbers while defoliation damage 20 or more days after 50% silk stage results in a reduction in kernel weight (Egharevba et al., 1976).

Plants do have the ability to compensate for the loss of leaf area, at least to a degree. Dry matter previously stored in stems and remaining leaves can transfer to the grain to reduce the

amount of weight that would be lost due to the defoliation. The remaining leaves were also found to have an increased efficiency in photosynthesis to compensate for the loss of photosynthetic tissue due to defoliation (Allison and Watson, 1966). The husk leaves, if present, can also contribute to dry matter production. In fact, the rate of photosynthesis of husk leaves has been shown to increase or compensate for the loss of other leaves due to defoliation (Fujita et al., 1995). Corn plant population has not been observed to influence the effect on dry matter accumulation in plants in relation to a response to defoliation (Hanway, 1969).

The application of fungicides on corn crops can reduce the amount of yield loss inflicted by foliar diseases. Timing, rate, and proper application methods are extremely important to effectively preserve yield (Wise, 2017). Application at tasseling has been shown to result in as much as a 10% yield preservation. However, application of fungicide before tasseling has not been shown to increase yield. Likewise, application at later growth stages, such as R5, has also been shown to have no effect in yield due to the yield potential of the corn already having been determined. Therefore, the timing of the fungicide application related to the growth stage of the corn is a major factor in preventing yield loss (Adee and Duncan, 2016). Fungicide applications has also been found to preserve moisture and stalk integrity in corn compared to untreated corn infected with southern rust (Habour and Jackson-Ziems, 2016), Table 2 displays several fungicides, as well as their respective rates and prices, that were shown to be effective against southern corn rust in Wise (2017).

Table 2. Fungicides Rates and Application Cost per acre

Fungicide	Rate (fl oz/a)	[1]Fungicide Cost ($/acre)
Quilt Xcel 2.2SE®	10.5-14.0	$11.03-$14.70
Fortix 3.22SC®	4.0 -6.0	$8.76-$13.14
Stratego YLD 4.18SC®	4.0-5.0	$8.60-$10.75
Headline 2.09EC/SC®	6.0-12.0	$9.84-$19.68

[1]Prices found at http://www.agchemicalsolutions.com/pesticides (verified 3/13/20)

Research has also been done on developing host plant resistance to southern corn rust. This is made more difficult by the fact that the disease is a global issue and different races of the pathogen exist. For example, even if African corn crops are bred for resistance to the southern rust that is currently present in the region and if that same race of the pathogen appears in the United States the corn crops in that region may not be resistant. As of 2011, over 295 inbreds have been analyzed for resistance from all over the world (Brewbaker et al., 2011). These corn inbreds feature a variety of levels of tolerance to the southern corn rust pathogen. However, more research is necessary on these forms of resistance for future management of the disease to be successful (Brewbaker et al., 2011).

Objectives

This study will have three objectives. First, it will seek to determine the effect that loss of leaf area at different stages of reproductive growth will have on yield. Second, to determine if yield losses due to defoliation are consistent among different corn hybrids with different maturities. Third, this study will seek to determine if the leaves below the upper ear leaf are important regarding to yield.

Materials and Methods

This study was conducted at the Dean Lee Research Station and Extension Center Located near Alexandria, LA in 2017 and 2018. The experiment was arranged in a split-plot design and was replicated four times in a randomized complete block design. Main plots were the differing corn hybrids and subplots were the defoliation treatments Main plots were the differing corn hybrids and subplots were the defoliation treatments Each plot was four rows (row centers 96.52 centimeters) wide and 13.716 meters in length. Ten sequential plants that developed harvestable ears on the second and third row of each plot were selected to undergo the defoliation treatments, making it a total of twenty treated plants per plot. These plants were located near the center of each plot to prevent edge effect. Two corn hybrids of differing relative maturity provided by Terral Seed Inc. (Rayville, LA) were chosen for this test. The hybrids used in 2017 were 1884AM (early) and 28HR20 (late). The late hybrid (28HR20) was also used in 2018, but 17BHR98 was used as the early hybrid that year. Both hybrids were planted at a population of 34,000 seeds per acre for both years of the study.

This study was designed to simulate the damage done to corn plants by southern corn rust and similar diseases that cause progressive defoliation in corn. Defoliation treatments were applied by physically removing leaves at one or more of the following reproductive growth stages: R1 (silking), R2 (blister), R3 (milk), and R5 (dent). The pattern of defoliation treatments is shown in Table 3. Except for the check plots, all the lower leaves (the leaves located below the upper ear) were removed for each stage of growth (Figure 1). Removing the lower leaves on all the treated plots was meant to determine how significant the lower leaves contribute to yield. Also, removing the lower leaves reduced the variability of those leaves contributing to yield between the two corn hybrids, and reduced the variability of leaves that may or may not be

healthy. Other treatments included the removal of upper leaves as growth stages progressed toward R5, ultimately resulting in defoliation percentages ranging from 50% to 78%. Removal of the upper leaves began at the upper ear leaf and progressed upward in order to simulate the progression of foliar disease. Each leaf removed represented 7% of the total leaves on each plant. Leaves were cut perpendicularly across the blade of the leaf, while leaving the leaf sheath intact, to achieve defoliation. The total number of leaves for each treated plant, as well as the check plants, were counted prior to the application of defoliation treatments. No fungicide applications were needed during the growing season in either year as there was no need for it.

Table 3. Defoliation Treatments.

Defoliation	Treatment Stage	Crop growth stage when leaves were removed					Total % defoliation
		LL[1]	R1[2]	R2[3]	R3[4]	R5[5]	
R1UTC	Silk						0
R1LL	Silk	X					50
R1	Silk	X	X				57
R12	Silk-Blister	X	X	X			64
R123	Silk-Blister-Milk	X	X	X	X		71
R1235	Silk-Blister-Milk-Dent	X	X	X	X	X	78
R2UTC	Blister						0
R2LL	Blister	X					50
R2	Blister	X		X			57
R23	Blister-Milk	X		X	X		64
R235	Blister-Milk-Dent	X		X	X	X	71
R3UTC	Milk						0
R3LL	Milk	X					50
R3	Milk	X			X		57
R35	Milk-Dent	X			X	X	64
R5UTC	Dent						0
R5LL	Dent	X					50
R5	Dent	X				X	57

[1]All lower leaves were removed, [2,3,4,5]Upper most leaf was removed each time.
UTC=Untreated Check, LL=Lower Leaves

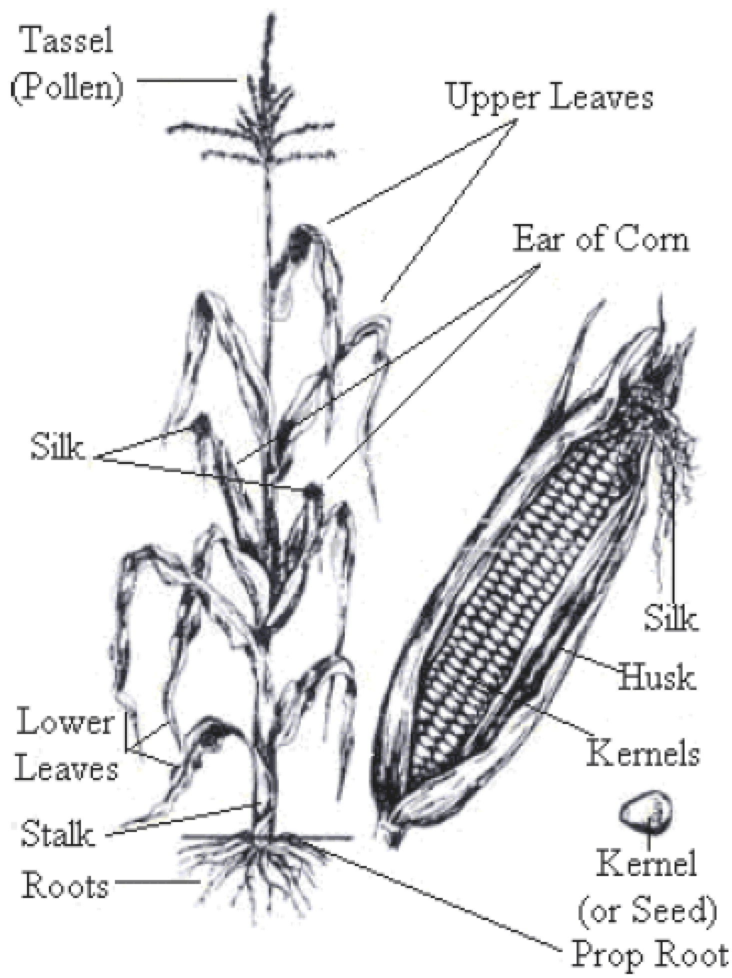

Figure 1. Anatomy of a Corn Plant (Young et al., 2007).

The corn ears were harvested by hand and an Almaco model 97001 motorized corn sheller was used to shell the corn. Grain weight was recorded in grams for each plot to calculate yield. Also, grain test weight (bu/ac) and percent moisture for each plot was measured. Moisture was adjusted to 15.5% during analysis of yield. Dry seed weight was determined by drying three hundred seeds from each plot to 5% moisture in a Despatch LBB Series oven model LBB 2-27-1 and then weighed in grams.

Data were subjected to ANOVA with PROC GLIMMIX in SAS release 9.4 (SAS Institute, Cary, NC). Defoliation, hybrid, and their interaction were fixed effects. Random effects were years and replications within those years. Least square means were calculated and effects were separated using Tukey's honest significant difference test at $P \leq 0.05$.

Results

The study in 2017 received in excess of 50% more rainfall than the 2018 test (Table 4). The rainfall amounts were recorded by the LSU Agcenter weather station located at the Dean Lee Research Station. The higher amounts in overall rainfall resulted in slightly higher yields in 2017 as compared to 2018.

Table 4. Rainfall (in) during growing seasons.

Year	March	April	May	June	July	Total
2017	2.48	12.91	6.49	7.66	4.09	33.63
2018	7.2	5.17	0.41	2.03	5.25	20.06

The late hybrid had more total leaves on average than the early hybrid. The early hybrid averaged 7.08 lower leaves and 6.53 upper leaves and late hybrid averaged 7.23 lower leaves 7.13 upper leaves plant. Each leaf removed represents 7% of total leaves (data not shown).

Moisture was adjusted to 15.5% when yield was analyzed. However, there was no statistical difference in harvest moisture (see Appendix). The late maturing hybrid yielded slightly higher than the early maturing hybrid both years. The difference in yield was not statistically significant, however. Data from both hybrids is pooled by defoliation treatment (Table 5). Both hybrids responded similarly to defoliation treatments in both years (supplemental data in Appendix).

Table 5. Yield Comparison (g) in 2017, 2018.

2017				2018			
Defoliation	%Defoliation	Yield (g)	Group	Defoliation	%Defoliation	Yield (g)	Group
R1UTC	0	3085	a	R1UTC	0	2617	ab
R1LL	50	2278	cd	R1LL	50	2123	bcde
R1	57	1974	def	R1	57	1658	efg
R12	64	1503	gh	R12	64	1511	fgh
R123	71	1148	h	R123	71	1246	gh
R1235	78	1141	h	R1235	78	1081	h
R2UTC	0	2977	ab	R2UTC	0	2689	a
R2LL	50	2341	cd	R2LL	50	2082	cde
R2	57	2015	de	R2	57	2040	de
R23	64	1649	efg	R23	64	1778	ef
R235	71	1578	fg	R235	71	1618	efg
R3UTC	0	3168	a	R3UTC	0	2574	abc
R3LL	50	2308	cd	R3LL	50	2419	abcd
R3	67	2097	d	R3	67	2055	de
R35	64	1929	defg	R35	64	1800	ef
R5UTC	0	3220	a	R5UTC	0	2709	a
R5LL	50	2939	ab	R5LL	50	2480	abcd
R5	57	2608	bc	R5	57	2452	abcd

The effects of defoliation treatments were most severe at the earlier stages of growth (R1, R2). Treatments applied at R1 resulted in the most dramatic reductions in yield compared to the untreated check plots. Yields continued to decline within each growth stage as the percentage of defoliation was increased. Corn plants defoliated at 50% at R1 yielded significantly higher than the plants that received the higher rates of defoliation, such as the maximum rate of 78%.

Defoliation at 50% also yielded significantly lower than the untreated check plots at every growth stage except for R5. This pattern of declining yield with increasing percentage of defoliation was reflected among all growth stages with the impact of defoliation decreasing as the growth stages progressed. Each successive defoliation treatment resulted in further reduction of grain yield. This impact becomes less significant as the growth stages progress from R1 to R5. Defoliation of 50% at R1 results in a yield reduction of 23%. Defoliation of 78% of leaves at R1 results in a loss of 61% of grain yield. Dent stage (R5) shows the least significant reduction in yield in response to the defoliation treatments. However, a treatment of 57% defoliation at R5 still reduces yield by 15%. Yield losses in the R2 and R3 stages of growth follow the same pattern of progressive yield loss at higher defoliation rates.

Yield results from the 2017 study were comparable to the results from 2018. Table 6 displays yield data with year set as a random effect for analysis. The pattern of yield loss shown in Table 6 is reflected in Graph 1. The error that is associated with the year in this analysis procedure was 15.13% (see Appendix for supplemental data). Table 7 displays yield data converted to bushels per acre based on the plant population of 34,000, percent yield loss compared to respective untreated checks, and the economic value of each treatment. Economic value is based on the average corn price of $3.79 per bushel from January 2020 ("USDA - National Agricultural Statistics Service - Charts and Maps - Prices Received: Corn Prices Received by Month, US", 2020). The highest yielding untreated check was 176 bushels/acre. The most severe defoliation, beginning at R1 and continuing through R5, displayed a yield of only 66 bushels/acre. The data displayed in Table 7 is very similar to yield loss in corn caused by defoliation as a result of hail damage with nearly identical yield loss with respect to percent of defoliation based on the table found in Klein and Shapiro (2011).

Table 6. Yield (g) with Year Set as a Random Effect.

Treatment	Defoliation	%Defoliation	Yield (g)	Group
1	R1UTC	0	2851	ab
2	R1LL	50	2201	def
3	R1	57	1816	ghij
4	R12	64	1507	jk
5	R123	71	1197	kl
6	R1235	78	1111	l
7	R2UTC	0	2833	ab
8	R2LL	50	2211	def
9	R2	57	2028	efgh
10	R23	64	1714	hij
11	R235	71	1598	ij
12	R3UTC	0	2871	ab
13	R3LL	50	2364	cde
14	R3	67	2076	efg
15	R35	64	1864	fghi
16	R5UTC	0	2965	a
17	R5LL	50	2710	abc
18	R5	57	2530	bcd

Graph 1. Pattern of Yield Loss (g).

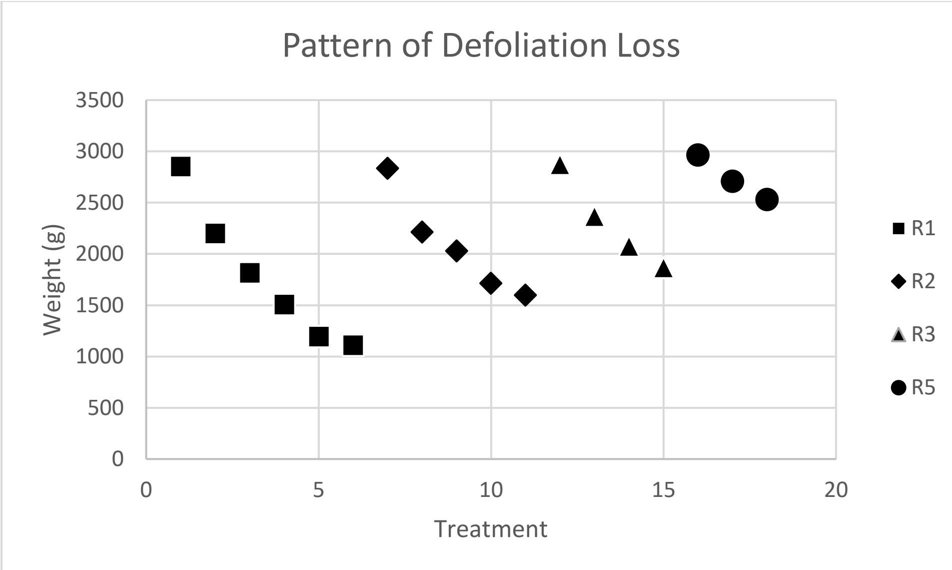

Table 7. Yield Displayed as bushel/acre with Economic Value.

Treatment	Defoliation	%Defoliation	Yield(bu/ac)	[1]%Loss From UTC	[2]Price per Acre
1	R1UTC	0	178	0%	$674.62
2	R1LL	50	138	22.47%	$523.02
3	R1	57	113	36.53%	$428.27
4	R12	64	94	47.19%	$356.26
5	R123	71	75	57.87%	$284.25
6	R1235	78	69	61.24%	$261.51
7	R2UTC	0	177	0%	$670.83
8	R2LL	50	138	22.03%	$523.02
9	R2	57	127	28.25%	$481.33
10	R23	64	107	39.55%	$405.53
11	R235	71	100	43.50%	$379.00
12	R3UTC	0	179	0%	$678.41
13	R3LL	50	148	17.32%	$560.92
14	R3	67	130	27.37%	$492.70

(table cont’d)

Treatment	Defoliation	%Defoliation	Yield(bu/ac)	[1]%Loss From UTC	[2]Price per Acre
16	R5UTC	0	185	0%	$701.15
17	R5LL	50	169	8.65%	$640.51
18	R5	57	158	14.59%	$598.82

[1]% Yield loss is compared to each respective untreated check (UTC)
[2]Prices are based on the January 2020 average corn price of $3.79 per bushel

The dry weight of the grain was also analyzed with data from both years averaged together (Table 8). A total of 300 seeds from each plot was dried to 5% moisture and the weights measured. Effects of defoliation were also observed in the dry seed weight. However, this effect on dry seed weight is not as obvious or pronounced as the effect on yield. Similarly, dry seed weight is most noticeably impacted at earlier growth stages, with R1 being the most vulnerable and R5 being the least. Defoliation impacted the two hybrids differently in the case of dry seed weight. The early hybrid was observed a more pronounced loss in seed weight across all plots than the late hybrid observed (supplemental data in Appendix).

Table 8. Dry Seed Weight (g) Comparison.

Early Hybrid			Late Hybrid		
Defoliation	Estimate	Group	Defoliation	Estimate	Group
R1UTC	90.77	defghijk	R1UTC	103.25	abc
R1LL	83.42	jklm	R1LL	100.95	abcd
R1	81.13	klmn	R1	100.07	abcde
R12	76.52	lmno	R12	96.32	bcdefghi
R123	74.70	mnop	R123	87.58	ghijk
R1235	62.12	q	R1235	86.16	ijkl
R2UTC	92.80	defghij	R2UTC	106.59	ab
R2LL	84.16	jklm	R2LL	96.88	bcdefg
R2	72.40	nopq	R2	92.58	defghij
R23	64.40	pq	R23	88.99	ghijk
R235	63.80	q	R235	86.53	hijkl
R3UTC	92.05	defghij	R3UTC	109.39	a
R3LL	80.79	klmn	R3LL	96.50	bcdefgh

(table cont'd)

Early Hybrid			Late Hybrid		
Defoliation	Estimate	Group	Defoliation	Estimate	Group
R35	67.23	opq	R35	87.49	ghijk
R5UTC	89.48	fghijk	R5UTC	103.71	abc
R5LL	85.44	jkl	R5LL	99.44	abcdef
R5	83.30	jklm	R5	95.92	cdefghi

Test weight was also similarly impacted by defoliation. As with dry seed weight, the data from both years was averaged together (Table 9). The test weight of grain decreased as defoliation rate increased. Likewise, the earlier growth stages were more severely impacted by plant defoliation than the later stages of growth. The early hybrid, however, was more affected by defoliation than the late hybrid. All test weights for the late hybrid were not significantly different from one another (see Appendix for supplemental data).

Table 9. Comparison of Test Weights (lbs/bu).

Early Hybrid			Late Hybrid		
Defoliation	Estimate	Group	Defoliation	Estimate	Group
R1UTC	55.93	bcdefghi	R1UTC	58.70	a
R1LL	55.77	cdefghi	R1LL	57.89	abcdef
R1	55.71	defghij	R1	58.83	a
R12	55.46	ghij	R12	58.59	a
R123	53.75	ijkl	R123	59.15	a
R1235	52.24	kl	R1235	59.00	a
R2UTC	55.30	hij	R2UTC	58.17	abc
R2LL	54.68	ij	R2LL	57.71	abcdefgh
R2	54.32	ijk	R2	58.68	a
R23	51.55	l	R23	58.16	abc
R235	51.47	l	R235	57.87	abcdefg
R3UTC	55.67	efghij	R3UTC	58.22	ab
R3LL	54.11	ijk	R3LL	58.17	abc
R3	53.41	jkl	R3	57.94	abcde
R35	52.23	kl	R35	58.54	a
R5UTC	55.51	fghij	R5UTC	58.18	abc
R5LL	54.96	ij	R5LL	58.73	a
R5	54.43	ijk	R5	58.13	abcd

Discussion

The results of the study are similar to previous studies, including older studies, such as the study by Crookston and Hicks (1978). More recent studies, such as Battaglia et al., (2019), also yielded similar findings. Our findings tend to support the historical theory that lower leaves do play a vital role in grain production as suggested in Thomison and Geyer (2009). These illustrate the importance field scouting by grain producers. Corn growers should routinely check their fields for any indication of southern corn rust presence. The rate at which the disease is spreading up the plant should be monitored. If the disease is discovered early in the corn growth cycle, and is advancing up the plant at a rapid rate a fungicide should be applied to avoid dramatic yield loss. However, if the disease is discovered at a later stage the decision to treat the diseased fields can be up to the producer's discretion. The producer should take into account the growth stage of corn, weather, corn prices, and cost of fungicide application.

Conclusions

Defoliation at earlier reproductive stages resulted in much lower yields than defoliation at later growth stages when compared to the untreated check plots. Both the early and late maturing corn hybrids responded to defoliation in a similar fashion. While the late hybrid yielded slightly higher in both years of the study, the statistical difference was not significant. The data showed a statistically significant difference in yield between the untreated check and 50% defoliation at every reproductive stage except for R5. This suggests that lower leaves play a role in grain production through the R3 stage. Test weight and dry seed weight were also negatively impacted by defoliation. However, the early hybrid experienced a greater reduction when compared to the untreated check with regard to both test weight and dry seed weight.

Appendix. Supplemental Statistics

Test of Fixed Effects for Moisture

Effect	Num DF	Den DF	F Value	Pr > F
HYB	1	7	2.38	0.1666
DEF	17	238	3.07	<.0001
HYB*DEF	17	238	3.39	<.0001

Tests of Fixed Effects for 2017 Yield (Table 5)

Effect	Num DF	Den DF	F Value	Pr > F
HYB	1	105	72.72	<.0001
DEF	17	105	63.31	<.0001
HYB*DEF	17	105	0.87	0.6053

Tests of Fixed Effects for 2018 Yield (Table 5)

Effect	Num DF	Den DF	F Value	Pr > F
HYB	1	105	16.4	<.0001
DEF	17	105	24.88	<.0001
HYB*DEF	17	105	1.57	0.0856

Test of Fixed Effects for Yield with Year Set as Random (Table 6)

Effect	Num DF	Den DF	F Value	Pr > F
HYB	1	7	43.09	0.0003
DEF	17	238	69.41	<.0001
HYB*DEF	17	238	1.56	0.0746

Tests of Fixed Effects for Dry Seed Weight (Table 8)

Effect	Num DF	Den DF	F Value	Pr > F
HYB	1	7	397.01	<.0001
DEF	17	238	6.76	<.0001
HYB*DEF	17	238	6.52	<.0001

Tests of Fixed Effects for Test Weight (Table 9)

Effect	Num DF	Den DF	F Value	Pr > F
HYB	1	245	768.29	<.0001
DEF	17	245	40.84	<.0001
HYB*DEF	17	245	2.3	0.003

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