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CORN (*Zea mays* L.) YIELD RESPONSE TO DEFOLIATION AT DIFFERENT ROW WIDTHS

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CORN (*Zea Mays* L.) YIELD RESPONSE TO DEFOLIATION AT DIFFERENT ROW WIDTHS

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Crop Science in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

Martin Leonardo Battaglia

Director: Dr. Chad D. Lee, Associate Professor of Plant and Soil Sciences

Lexington, Kentucky

2014

ABSTRACT OF THESIS

CORN (*Zea Mays* L.) YIELD RESPONSE TO DEFOLIATION AT DIFFERENT ROW WIDTHS

Corn (*Zea mays* L.) defoliation experiments have been conducted for more than 120 years. However, there is limited data on the effect of row width on defoliation in modern hybrids. A two-year experiment was conducted in Lexington, Kentucky with two hybrids (113 relative maturity (RM) and 120 RM), two row widths (38 and 76 cm) and a combination of defoliation timings and severities: 0% defoliation (control), V7-100%, V14-50%, V14-100%, R2-50% and R2-100%. No yield difference among hybrids was observed in 2012. Yields were 26% greater in 38-cm rows than 76-cm rows in 2012. For 2013, corn yield for 38-cm was 10% greater, but hybrid, row width and defoliation interacted. Lowest yields were caused by V14-100% followed by R2-100%. Defoliations of V14-50% and R2-50% reduced yields in some cases. Complete defoliations at V7 did not reduce yields in most comparisons. Light interception below 80% during the critical period was enough to attain maximum yields in defoliated plants. Kernel number and kernel weight were most reduced by V14-100% and R2-100% defoliations, respectively. There is a potential for narrow rows to reduce grain yield losses after a defoliation event, when compared with wide rows.

KEYWORDS: defoliation in corn, row width, grain yield, light interception, yield components.

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CORN (*Zea Mays* L.) YIELD RESPONSE TO DEFOLIATION AT DIFFERENT ROW WIDTHS

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CHAPTER 1

INTRODUCCION: LITERATURE REVIEW

1.1. Hail and crop value

The primary cause of corn defoliation in most of the United States is from hail. Hail is precipitation in the form of irregular ice shapes, created inside convective storms (Changnon et al., 2009). The nation's areas of greatest hail frequency are along and just east of the central Rocky Mountains where point averages vary between 6 and 12 hail days per year. The valleys of the Rocky Mountains have the nation's greatest hail intensity with the largest average stone sizes, while the lowest intensities are found in the eastern U.S. (Florida) and in the Southwest (Arizona and California) with hail storms once every two or three years (Changnon et al., 2009). Long-term trends of hail occurrences show increase in the High Plains and Southeast and decreased in the Midwest and West (Changnon, 2000). However, nationwide trends in crop-hail losses, in property-hail losses, and in number of hail days all show downward trends for the 1950 to 2009 period (Changnon, 1997; Changnon, 2009).

In the U.S., approximately half of all hailstorms occur between March and May (Vorst, 1993; Klein and Shapiro, 2011). These early storms are responsible for only minor corn yield losses because the corn either has not yet been planted or is too small to be damaged significantly. Even when fields are severely damaged early in the growing season, they can often be replanted (Vorst, 1993).

On the other hand, about a third of all hailstorms occur between June and September, where the largest corn loss from hail occurs (Klein and Shapiro, 2011). The average annual frequency of days with crop-damaging hail in the U.S. is 158 days with grain yield losses of corn estimated at $580 million annually (Changnon et al., 2009). Total hail losses for all crops were estimated in the late 1990s by Changnon (1997) at about at $1.3 billion annually, representing between 1 and 2% of the annual crop value. Hail losses vary considerably regionally, representing, for example, 1 to 2% of the crop value in the Midwest, 5 to 6% of the crops produced in the High Plains, and much less elsewhere in the nation (Changnon, 1997).

The record hail event for Kentucky occurred in November 1967 with hail up to 12.7 mm in diameter near Summer Shade in Metcalfe County. The accumulation of hail on the ground was up to 150 mm in some spots (Sander and Conner, 2013). A detailed map of total hail events (>2 cm) by county in Kentucky from the period 1980-1995 can be seen in Figure 1 (Sander and Conner, 2013). Hail in Kentucky occurs more often in western and north-central Kentucky than the south-central and eastern Kentucky. The majority of Kentucky corn acres are in western Kentucky. According to 2012 data from USDA-NASS (2013), Purchase and Midwestern region account for about the 68% total corn acres planted in Kentucky in 2012, while representing the 70% of total production for the state.

From the analysis of original data from USDA Risk Management Agency (Carter, 2014) and USDA-NASS (2014), corn was insured by Kentucky farmers

(GRIP, GRIPH, GRP and YP insurances) representing 81, 80 and 85% of the total corn planted in 2011, 2012 and 2013, respectively. Liabilities insured were approximately equal to $695.6, 794.4 and 811.9-million for 2011, 2012 and 2013, respectively.

According to FAOSTAT (2011), world corn production was approximately 885.3 million metric tons, ranking corn as the second largest crop in the world in 2011, after sugarcane and before rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.). Corn world production is larger than any other cereal, with a total approximate value of $55.5 billion (FAOSTAT, 2011). The United States is, by far, the largest corn producer in the world, with an estimated share of 32% of the total production for the cereal in 2010 (U.S. Environmental Protection Agency, 2013). Corn represents the third most valuable agricultural commodity for the country, with a total value close to $26.4 billion dollars, only surpassed by beef and dairy (FAOSTAT, 2011). Corn is not only important for the world and for United States, but also for Kentucky's economy. According to the 2012 annual report from the Kentucky Corn Growers' Association, corn is the most valuable cash crop in Kentucky, bringing in more money to the Commonwealth than other crops such as soybean, tobacco, hay and wheat (Kentucky Corn Growers Association, 2012). In 2011, corn cash receipts totaled $786.3 million, thus ranking corn the third most valuable Kentucky commodity only behind poultry and horses (Kentucky Corn Growers Association, 2012). In 2012 the situation for corn was even more favorable. In this year, corn was valued at $828.8 million dollars, representing the second most valuable commodity in 2012, or about 16%

of total Kentucky cash receipts for this year (USDA-NASS-Kentucky Department of Agriculture, 2013) (Table A1 in the Appendix). Moreover, Kentucky's corn industry supports about 20,000 jobs and plows hundreds of millions of dollars back into the state's treasuries. It also feeds a number of thriving industries important for healthy and prosperous economic development of Kentucky (Kentucky Corn Growers Association, 2012).

As an example, in 2011 half of the statewide produced corn (about 1.78 million metric tons) was destined for livestock, with a growing poultry industry consuming 1.15 million metric tons alone. About 0.76 million metric tons more were used by Kentucky's food industry. In 2011, the distillery industry utilized around 0.38 million metric tons to produce bourbon and spirits. Finally, about 0.31 million metric tons of corn were converted to fuel ethanol (Kentucky Corn Growers Association, 2012). Table A2 in the Appendix displays data related with total ha harvested, state average yield (Mg ha^{-1}), total production (millions of Mg) and nationwide ranking for each commodity in 2012.

1.2. Defoliation and corn grain yield

Corn plants may be damaged by hail, mechanical injury, insects, or diseases resulting in loss of photosynthetic area of the plants. Much research over the last 120 years has been undertaken to understand the relationship between defoliation timing, defoliation severity and final grain yield in corn. Hail creates grain yield losses most often by shredding leaf blades, resulting in a loss of leaf area (Dungan, 1934; Jenkins, 1941; Hanway, 1969; Vorst, 1993; Klein and Shapiro, 2011). In severe cases, the entire leaf blade is stripped from the midrib. Other damage to corn plants occurs when hail strikes small plants, breaking them at the soil surface and reducing stands (Dungan, 1934; Vorst, 1993; Nielsen, 2012). Hailstones also bruise the stalks of larger plants and that bruising can result in interference with the movement of assimilates within the plant (Dungan, 1934). According to Dungan (1934), the diversity of types and degrees of injury that can be inflicted by natural hailstorms makes almost impossible to duplicate them in experimental research. Even more, the severity of a hail storm may usually vary in different parts of a small field. However, Dungan (1934) points out the importance of the manual defoliations in research as a way to understand the expected grain yield loss following the removal of a given percentage of the leaf area at different moments in the crop cycle.

Grain yield losses to hail damage on young plants is often minimal (Jenkins, 1941), and it increases gradually to a peak at the period just preceding, at or a few days after tasseling (Hume and Franzke, 1929; Dungan, 1930; Eldredge, 1935; Hanway, 1969; Egharevba et al., 1976; Tilahun, 1993; Andrade, 1999; Adee et al., 2005). Defoliation near tasseling can cause grain yield losses as high as 100% for 100% defoliation rate (Dungan, 1930; Dungan, 1934; Hanway, 1969; Crookston and Hicks, 1977; Vasilas and Seif, 1985; Adee et al., 2005). Grain yield losses to defoliation after tasseling decrease as maturity is approached, eventually reaching 0% at maturity (Dungan, 1930; Dungan, 1934; Jenkins, 1941; Adee et al., 2005). The reduction in grain yield from hail is relatively slight when the plants are small because the growing point is below the surface, thus enabling high tolerance to hail damage (Lee, 2007). Dungan (1934) suggested that a) treatments earlier than VT growth stage are not so detrimental to grain yield because some new leaves unroll with the elongation of the tassel-bearing stem, and b) after defoliation, the photosynthetic efficiency of the remaining leaves is increased by the removal of blades, thus preventing the grain yields from falling off in direct proportion to the amount of leaf area destroyed. In relation to defoliation severity, studies consistently showed that greater grain yield losses are attained with 100% defoliation compared to 50% defoliation (Dungan, 1934; Hanway, 1969; Egharevba et al., 1976; Hicks et al., 1977).

Complete or near complete defoliation on plants at V6 or younger resulted in differing results among studies. Removing 75 to 85% of the 21-d old F_1 plants' aboveground portions resulted in about 15 to 33% grain yield losses (Lindstrom, 1935). Similar observations occurred for complete removal of aboveground portions of V3 to V6 (Abendroth et al., 2011) plants, although the yield penalty range was broader in this case, ranging from 5 to 46% (Eldredge 1935; Dungan and Gausman 1951; Cloninger et al., 1974) (see Table 1 for conversions to the leaf collar method). Cutting V7/V8 plants at soil level has the potential to produce almost complete grain yield loss (97%) in some cases (Dungan and Gausman, 1951). Defoliation at or before V5 (Table 1) decreased grain yields in one study (Johnson, 1978) and increased them in another (Crookston and Hicks, 1977).

1.2.1. Highlighted research on defoliation and crop grain yield

Dungan (1934) applied leaf removal of 8, 17, 25, 33, 50, 67, 83 and 100% at tasseling (VT), fresh silking (R1), early blister (R2), milk (R3) and early dent stage (R5). The stage of plant development had little influence on grain yield reduction up to and including 25% leaf removal. For defoliation levels greater than 25%, grain yield loss reached 100% for 100% blade removal at R1 and dropped gradually as the grain developed, reaching 0% at R5. These findings supported results from previous work from late 1800's to beginning of 1930's (Connell, 1890; Tracy and Lloyd, 1895; Hume and Franzke, 1929; Culpepper and Magoon, 1930; Dungan, 1930).

Corn relative maturity (RM) group plays an important role in responses to defoliation. Hybrid maturity responded inconsistently to defoliation across several studies (Hanway, 1969; Crookston and Hicks, 1977). Hanway (1969), working in Iowa found that defoliation caused greater grain yield losses for early than for late maturing hybrids. Defoliation around VT (Table 1) resulted in maximum yield reductions. Defoliation at V10, VT and R2 (Table 1) reduced average grain yield by 15, 25 and 20%, respectively, for 50% defoliation and by 30, 98 and 69%, respectively, for 100% defoliation. In this study, three different plant populations had no significant effect on grain yield losses as a result of defoliation treatments.

Crookston and Hicks (1977) reported that early (V3/V4) (Table 1) defoliation of early maturing hybrids may boost final grain yields. In Minnesota working with 12 different 90-RM hybrids all at the same row width (75-cm), complete defoliations at V3/V4 caused an average significant 13% grain yield increase (range: -14% to +37%). They also reported 48% grain yield increases from V3/V4 defoliations in a three-year study with a 90-RM and 8% grain yield decreases with 115-RM hybrids. Defoliation of both hybrids at later developmental stages (V11, VT, R3 and R5) reduced grain yield (Hicks et all. 1977), with 100% grain yield loss for VT-100% defoliation on both hybrids. The authors hypothesized that a sudden loss of vegetative tissue from a plant that is in the process of developing both vegetatively and reproductively must induce drastic change in source-sink relations, thus stimulating embryonic ear growth at the time of reproductive initiation. Hicks et al. (1977) suggested that a potential may exist for increasing grain yields by planting short-season hybrids in a full-season zone and defoliating plants at an early stage of development. About the same time, Johnson (1978) observed that complete defoliation at V2, V3 and V4 (Table 1) reduced final grain yield by an average of 11% at two Illinois locations, regardless of maturity. Johnson (1978) concluded by saying that a) in this study there was no evidence that early season hybrids grain yields were reduced less by defoliation than were full-season hybrid grain yields, and b) under Illinois conditions defoliation from V2 to V4 did not have a beneficial effect on the grain yield of corn.

Summarizing, with early defoliations during crop cycle, grain yield increases for early maturing hybrids (Crookston and Hicks, 1977) to no change in grain yield among maturities (Johnson, 1978) have been reported. For defoliations close or at the reproductive corn growth, either greater grain yield losses for early maturing hybrids (Hanway, 1969) to similar losses for different maturing hybrids (Hicks et al. 1977) have been reported.

1.2.2. Research on methods and types of leaf removal

Several studies with older hybrids indicated that leaves above and below the ear were equally critical to grain yield (Hanway, 1969; Egharevba et al., 1976). However, Adee et al. (2005) calculated that the upper 8 to 10 leaves contributed 88% of the grain yield in Illinois.

The methods of leaf removal was thought to produce different grain yield responses for a similar total amount of defoliation. Hanway (1969), compared six leaf removal methods (50% removal) at two growth stages (late tasseling-VT- and beginning of R2; see Table 1) using a midseason hybrid. Removing a) alternate pairs of leaves (every other two leaves), b) all leaves from one side of each plant, c) ½ of each leaf (lengthwise), d) all leaves above the uppermost ear, e) all leaves below the uppermost ear or f) terminal ½ of each leaf, resulted in grain yields reductions (range: 17% to 23%) that were not significantly different. Similarly, Egharevba et al. (1976) did not find grain yield difference when comparing defoliations below and above uppermost ear. Egharevba et al. (1976) hypothesized this might be a mixed response resulting from a declined ability to fix CO_2 over the time for the lower leaves, and the fact that mid- and late-season hybrids have approximately 60% of total leaf surface under the main ear. Thereby, larger leaf area below the ear may have compensated for the reduced photosynthetically efficiency associated with leaf age. Completely different results were obtained by Adee et al. (2005) who calculated a lower incidence in final grain yield reductions when all the leaves below the ear were removed (-12%) in comparison with removal of all leaves above the ear at R1 (-88%).

Almost all experiments available in the literature were designed to show the effect of defoliation treatments on the corn grain yield for a specific growth stage. Interestingly, Adee et al. (2005) used the term corn defoliation progress curves (CDPC) in a defoliation experiment in Northern Illinois to describe corn response to progressive defoliation initiated at V14 through R5 (dent stage) caused by plant pathogens or insects. Grain yields declined linearly with defoliation initiated at V14 through R3 (milk stage), but the grain yield loss associated with any level of defoliation did not differ between V14 and R3. Defoliation after the R3 milk stage resulted in a lesser grain yield loss, with no change in yields for R5 defoliations.

1.2.3. Yield components affected by defoliation

The number of kernels set per plant is a parameter that is sensitive to the environment around flowering (Tollenaar et al. 1992), for example, it is highly and positively correlated to the amount of IPAR (Intercepted Photosynthetically Active Radiation) during a 31-d period bracketing flowering (Andrade et al., 1993b). As a result of this, the amount of energy intercepted by the crop at flowering correlated with the allocation of carbohydrates to reproductive structures.

Grain yield losses associated with defoliations around tasseling/silking are mainly explained by fewer kernel number (KN) (Culpepper and Magoon, 1930; Hanway, 1969; Egharevba et al., 1976; Vasilas and Seif, 1985; Severini et al., 2011), while losses for defoliations right before or at grain filling period (R2, blister stage and on) (Abendroth et al., 2011) are largely related to decline in kernel weight (KW) (Dungan, 1934; Hanway, 1969; Egharevba et al., 1976; Hicks et al., 1977; Tollenard and Daynard, 1978; Echarte et al., 2006) without changing the final KN. In some studies, the reduction in KN was as high as 62% with complete defoliations 10 days after 50% silking (R1) (Egharevba et al., 1976).

If the hail occurs at pollination, it may seriously interfere with normal fertilization of the kernels through the destruction of the functioning organs of the tassels and silks (Dungan, 1934). Eventually, complete barrenness may result for 100% defoliation treatments at VT (Hanway, 1969). Storms later in the season may result in direct damage to the developing ears (i.e. ears may be knocked from the plant or the kernels on the cob may be bruised through the husk; Dungan, 1934). Rotting of ears following bruising action was worst with early milk stage (R3) hail treatments (Dungan, 1930, 1934). Test weight (Dungan, 1934; Hicks et al., 1977), shelling percentages (Hicks et al., 1977), ear weight (Hanway, 1969) and grain filling duration (Echarte et al., 2006) may also be negatively affected by defoliation during the grain filling period.

Final KW for corn seems to be sensitive to reductions in assimilate production during seed filling (Borras et al., 2004). Competition for assimilates among kernels takes place during the whole grain-filling period (Borras and Otegui, 2001). Defoliation during seed filling should result in a source-limited crop, since corn is a highly inefficient crop in the use of assimilates stored before flowering (Borras et al., 2004). Kiniry et al. (1992) estimated that only 19 to 24% of the stem dry weight at anthesis represented assimilate available for respiration and growth. Oppositely, Echarte et al. (2006) suggested that an increased remobilization of stem reserves probably contributed to maintaining kernel growth rates in defoliated plants.

Echarte et al., (2006) worked with five Argentinian maize hybrids released in different years [1965 (1), 1978 (1), 1982 (1) and 1993 (2)]. Each of the hybrids was among the three most cultivated hybrids on the Argentinean Pampas for at least 5 years after their release. Under normal growing conditions (untreated control), KW and kernel growth rate were different for hybrids tested, although no clear trend with the year or release was found. However, duration of the effective grain filling period was not different among hybrids (range: 576 to 594 °C d^{-1}; $p > 0.05$). Plant defoliation treatments to decrease assimilate availability during grain filling period were established 27 days after R1 of each hybrid in order to reduce IPAR by 33% with respect to untreated control canopies. Three to four leaves were left in each plant after the defoliation treatment. For all hybrids, defoliation did not affect kernel number per plant (KNP), nor kernel growth rate relative to the control in the hybrids under study, but defoliation reduced mean final KW, and grain filling duration. In this experiment, KW was reduced by 38±0.1% for newer hybrids (released in 1993) and 23±0.7% % for those older hybrids released between 1965 and 1982. Echarte et al. (2006) concluded that a greater ear demand relative to source capacity for newer hybrids may explain their shorter effective grain filling duration to source reductions (i.e. defoliation treatments) during grain filling when compared to older hybrids, which in turn explains a greater KW reduction (lower grain stability) for the newer hybrids.

1.3. Defoliation and its effect on pollen shed and silking delays

Pollen shed and silking might be delayed by defoliation, although the anthesis-silking interval (ASI) is less likely to be changed (Johnson, 1978). Complete or near complete defoliation on plants at V6 or younger delayed the period from planting to pollen shedding (Dungan and Gausman, 1951), silking (Lindstrom, 1935) or both anthesis and silking (Cloninger et al. 1974) by 2 to 8 days (see Table 1 for conversion to Leaf Collar method).

In the case of Dungan and Gausman (1951), the greatest delay in pollen shedding was achieved with close to ground cuttings about V8/V9 (+5 to +8 days). On the other hand, Cloninger et al. (1974) indicated that clipping plants delayed flowering date the most when plants were clipped at or near ground level sometime between V4 and V5 (+8 days to reach both anthesis and silking related to control). In this case, the maximum flowering delayed was accompanied by the highest grain yield reduction. Generally speaking, cutting plants back early (around V3 for Cloninger et al., 1974; around V5 for Dungan and Gausman, 1951) and rather severely gave the greatest delay in flowering and the least relative lowering of grain yield and pollen.

1.4. Defoliation and light interception

The generation and maintenance of leaves as well as the leaf area index (LAI) are the main variables that affect the efficiency of interception (e_i) (Carcova et al., 2003a, b). The generation and maintenance of leaves increases LAI and increases in LAI up to 6-6.5 value increase IPAR to values between 90-95% (Williams et al., 1965; Gallo and Daughtry, 1986).

Many experiments were conducted in Argentina during the last 20 years to elucidate the relationship between light interception and corn grain yield responses to defoliation. Andrade (personal communication, 2012) developed an experiment in 1999-2000 in Balcarce, Argentina, with four levels of defoliation: i) control (0%), ii) mild (33%), iii) moderate (50%) and severe defoliation (100%) at V17, R1 and R4. Control plants reached 95% and 80% radiation interception for irrigated and rainfed conditions, respectively. Mild (33%) and moderate (50%) defoliation was associated with a lower Radiation Interception (RI), close to 80% on average, being always lower for 50% compared with 33% defoliation. With severe defoliation, crops did not exceed 40% RI. In all cases grain yield was reduced by defoliation. The greatest grain yield reductions (94%) occurred with 100% defoliation at R1 and V17, followed by a 42% grain yield reduction at R4-100% defoliation. Mild and moderate defoliation decreased grain yield by 13% with no differences due to timing of treatment.

Andrade et al. (2001) in Balcarce, Argentina, compared three defoliation treatments (untreated control and 100% defoliation at V3 and V5) across two hybrids at both 52- and 70-cm rows. The largest grain yield increase (+13%) to narrow rows occurred at the V5 timing when plants reached a maximum of 73% of RI at flowering in narrow rows versus only 63% in wide rows. Corn plants in both row widths defoliated at V3 reached at least 80% RI at flowering and grain yield differences between row widths were not significant. Untreated plants reached at least 85% RI in both row widths and no grain yield differences between rows were observed.

A summary for the experiments discussed in defoliation literature review occurs in Table A3 in the Appendix.

1.5. Row width

During the first quarter of the 20th century, row spacing was determined by the size of a horse's rump. With the advent of tractors, farmers and agronomists began to narrow the rows. Much research was conducted in the 1960's and 1970's on 76-cm rows. The general consensus was that the corn grain yield could be increased from 5 to 7% by reducing rows from 102- to 76-cm (Nielsen, 1996).

There has been a trend toward narrower row widths for corn production in some US agricultural regions as the northern Corn Belt (Porter et al., 1997). Numerous studies have been conducted to determine if decreasing row width will increase grain yield or not (Lee, 2006; Thelen, 2006). Row width may influence the impact of corn hybrid maturity and plant population on grain yield (Porter et al., 1997).

Numerous grain yield increases have been reported when narrowing rows. In Michigan, row widths of 56- and 38-cm increased grain yield by 2 and 4%, respectively, relative to 76-cm rows (Widdicombe and Thelen, 2001). In Minnesota, grain yield increases were observed for corn in 25- and 51-cm rows relative to 76-cm rows (Porter et al. 1997). While including six hybrids and plant populations ranging from 53,000 to 100,000 pl ha^{-1}, Porter et al. (1997) concluded that some important parameters like grain moisture content can be more influenced by hybrid and the growing season climatic conditions than by row width or plant population. Nielsen (1988) reported a grain yield increase of 3% when narrowing rows from 76- to 38-cm at three locations in central and northwest Indiana, using two hybrids (early and full-season maturity) and four populations ranging from 45,000 to 89,000 plants ha^{-1}. However, these grain yield responses were quite variable from year to year and location to location, ranging from -3.1% to +8.2% for narrow when compared with wider rows (Nielsen, 1996). Finally, Thelen (2006) reported a greater grain yield increase to narrow rows for corn on coarse-textured soils compared with corn in finer-textured clay loams.

While the previous studies reported increases in grain yield in narrow rows, other studies reported decreases to no effect in grain yield. Working in Minnesota in a two-year experiment with a 95-RM dent type hybrid, two row widths (38- and 76-cm) and four plant populations (49 000, 74 000, 99 000 and 124 000 plants ha^{-1}), Westgate et al. (1997) did not find grain yield advantages from narrowing rows, which increased with plant populations up to 99 000 pl ha^{-1}.

Similar to Nielsen (1988), Westgate et al. (1997) pointed out the lack of hybrid by row spacing or row spacing by plant population interactions, "meaning that hybrids yielding well at high plant populations will tend to do the same also do so as row spacings decrease". Moreover, narrow rows did not affect maximum interception of incident PAR neither IPAR. Westgate et al. (1997) concluded that for hybrids adapted to the Northern Corn Belt, rows less than 76-cm will have less impact on grain yield than increases in plant populations beyond the commonly used. In another study, averaged across three years, six locations, and four plant densities, a 102 to 106-RM hybrid grown in 76-cm rows produced greater grain yield (10.5 Mg ha^{-1}) than 38-cm row spacings (10.3 Mg ha^{-1}) in Iowa (Farnham, 2001). Farnham (2001) concluded that plant densities for corn grain production should be similar for either 38-cm or 76-cm row widths. In a second experiment, averaged across three years, with the same six locations and six hybrids, Farnham (2001) did not find grain yield differences between 38- and 76-cm rows spacing for corn grown at a single population of 69 000 pl ha^{-1}. Farnham (2001) also observed a hybrid x row width interaction whereas other studies did not (Nielsen, 1988; Porter et al., 1997; Widdicombe and Thelen, 2001).

Nielsen (1988) observed more stalk lodging in 38-cm rows, but Widdicombe and Thelen (2001) did not. Some other authors suggest that narrow rows may improve weed control (Teasdale, 1995; Nielsen, 1996). In a more recent publication, Nelson and Smoot (2009) compared twin (two 19-cm rows apart planted on 76-cm centers with 57-cm between rows) and single 76-, 57-, and 38-cm rows, in two different Missouri locations and with both no-till and conventional tillage, and four plant populations (62 000, 74 000, 87 000 and 99 000 plants ha^{-1}). Results indicated no grain yield benefit of narrow ($\leq$ 57-cm; $P \leq$ 0.10) over twin or 76-cm single rows across three years. Averaged across populations, grain yields in twin and 76-cm rows moved from no change to 2.0 Mg ha^{-1} greater than narrow rows ($\leq$ 57-cm) depending on the year. Therefore, for claypan soils in northeast Missouri prone to drought conditions, 76-cm rows might be the best option for farmers.

Upon reviewing the literature, Lee (2006) concluded that full season corn grain yields typically did not increase as row width decreased from 76-cm south of 43°N latitude (about the Wisconsin-Iowa border extended east to west). However, narrow rows north of 43°N may increase grain yields in the US. The lack of grain yield increase to narrow rows south of 43°N is likely the result of sufficient light interception in wider rows due to a longer growing season. This hypothesis is supported by research in Argentina (Andrade et al., 2001) and Missouri (Nelson and Smoot, 2009), where corn grain yields were maximized as RI or IPAR approached 85%, independently of the row widths configuration.

A summary for the experiments discussed in row width literature review occurs in Table A4 in the Appendix.

TABLES AND FIGURES CHAPTER 1

Table 1. The Leaf Collar Method compared to Horizontal Leaf staging system. Adapted from Abrendroth et al. (2011).

Study Citation	Growth Stage (as mentioned in study)	Approximate equivalence with the Leaf Collar method†
Cloninger et at. (1974)	4-leaf stage	V3
	6-leaf stage	V4/V5
	8-leaf stage	V6
Crookston and Hicks (1977)	5-leaf stage	V3/V4
	13-leaf stage	V11
Dungan and Gausman (1951)	40-cm plants	V5/V6
	87-cm plants	V8/V9
Eldredge (1935)	4- to 5-leaf stage	V3/V4
Hanway (1969)	Growth stage 2.5	V10
	Growth stage 4‡	Early Tasseling (VT)
	Growth stage 5	Late tasseling (VT) - early R2
	Growth stage 6	R2
Johnson (1978)	5-leaf stage	V3/V4

† For the sake of comparison, equivalences assume no differences in growth stage for a same plant height between old hybrids and modern hybrids described in Abendroth et al. (2011). This assumption might not hold true in all cases.

‡ According to Hanway (1969), growth stage 4 is reached when the tip of the tassel has emerged. Abendroth et al. (2011) describes tasseling (VT) as the stage based solely on whether or not the tassel is completely visible. Strictly speaking, growth stage 4 in Hanway (1969) would occur slightly before the current definition of a crop at VT stage.

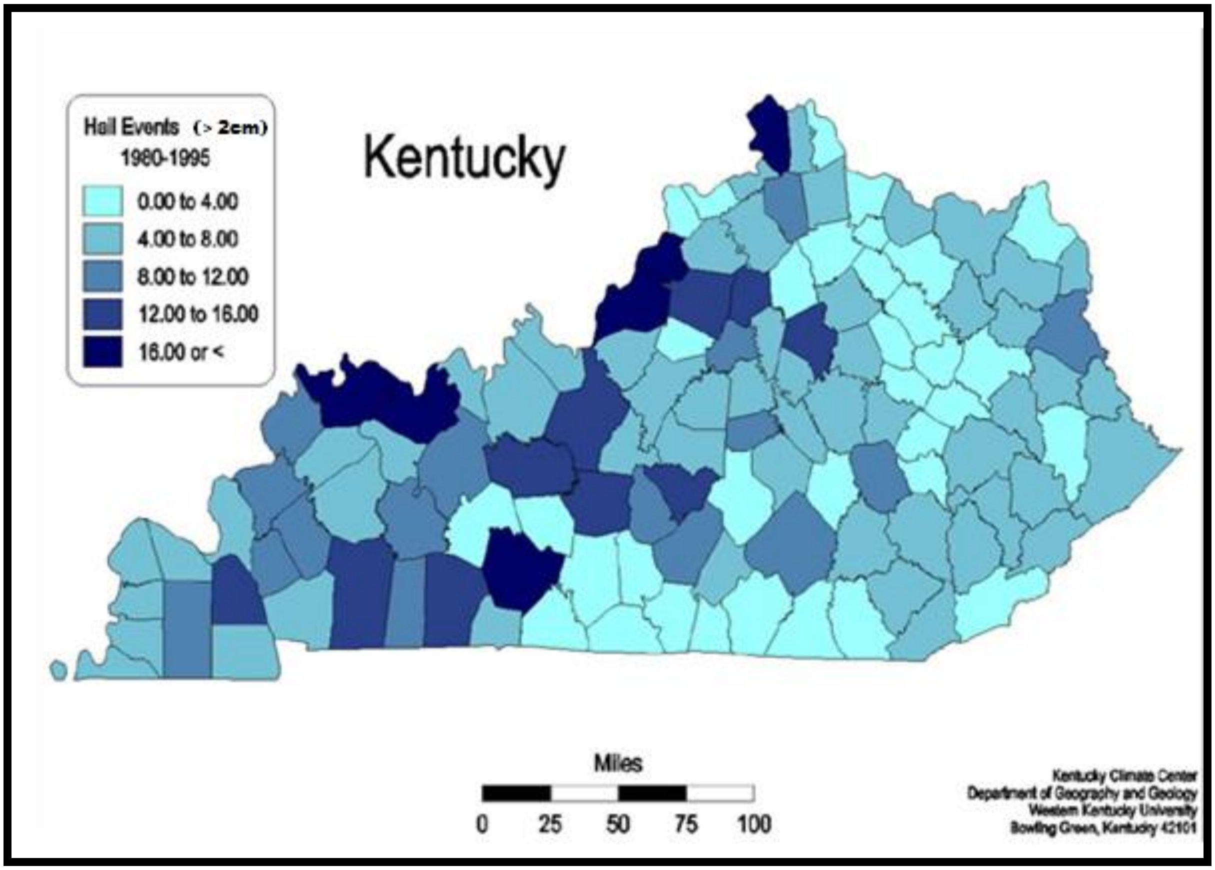


Fig 1. Map of total annual hail events by county in Kentucky.

<u>Source:</u> Kentucky Climate Center (http://www.kyclimate.org/images/hail.jpe).

CHAPTER 2

RATIONALE AND OBJECTIVES

Several fundamental reasons account for the need to design and carry this defoliation study, as follows:

1) Estimates for grain yield loss from hail damage are largely based on research from the 1970’s conducted in the northern Corn Belt on single row spacings (Lee, personal communication, 2014).
2) There are numerous studies investigating corn row width, corn defoliation and hybrid maturity available in the literature, but very few that evaluate those parameters together.
3) Perhaps modern hybrids respond differently to defoliation than those in previous studies.
4) Hybrid maturity responded inconsistently to defoliation (Hanway, 1969; Crookston and Hicks, 1977).

In this study, we hypothesize that corn in narrow rows (38-cm) will yield more than corn in wide rows (76-cm) following defoliation events at vegetative and reproductive phases.

The objectives for this study are as follows:

1. To determine if corn in 38-cm rows will yield more than corn in 76-cm rows after defoliation [three timings (V7, V14, and R2) and two levels (50 and 100%)].

2. To determine if hybrid maturity interacts with row width and/or defoliation.

3. To investigate if the effects of defoliations on grain yield across hybrids and row width can be explained by changes in IPAR.

MATERIALS AND METHODS

Field experiments were conducted during 2012 and 2013 at Spindletop Farm, Lexington, Kentucky (38°01′47″N, 84°29′41″W). Experimental layout was the same each year and consisted on a split-split plot randomized complete block design with hybrids as a main plot (two hybrids, i.e. ‘P1360HR’ and ‘P2088YHR’), row width as a split-plot (two row width, i.e. 38-cm and 76-cm) and defoliation treatments as a split-split plot (six treatments, i.e. untreated control or control hereafter, V7-100%, V14-50%, V14-100%, R2-50%, and R2-100%). Four replications were established each year. Each experimental unit consisted of 8 rows wide for 38-cm and 4 rows wide for 76-cm rows, for a total surface of about 28 m^2 (approximately 9.15 m in length and 3.05 m in width). For final statistical analysis, means were separated using LSMeans procedure in SAS 9.3 (2002-2010 by SAS Institute Inc., Cary, NC, USA) with significances set at $p \leq 0.05$.

Prior to planting, soil fertility was determined from composite samples collected in the field and sent to the University of Kentucky Regulatory Services Soil Testing Laboratory (Lexington, KY) (Table 2). Nitrogen (N) was applied as liquid urea ammonium nitrate (UAN, 28%) at 225 kg N ha^{-1} (April 23, 2012 and May 1, 2013 in excess of university recommendations to avoid the risk of yield limitations from nitrogen deficiencies). Potassium chloride was applied at 135 kg K_2O ha^{-1} (March 15, 2012 and Mar 20, 2013) following University of Kentucky recommendations (University of Kentucky Cooperative Extension Service, 2014).

Application of herbicides was performed a few days before planting. Herbicides used in this study included glyphosate [(N-(phosphonomethyl)glycine; Roundup WeatherMax)] and atrazine + S-metolachlor + mesotrion [(*RS*)-2-Chloro-*N*-(2-ethyl-6-methyl-phenyl)-*N*-(1-methoxypropan-2-yl)acetamide + 1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine + 2-[4-(Methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione), respectively; Lexar] applied preplant burn down on April 19, 2012 and May 1, 2013 (Table 2).

Hybrids P1360HR (113 CRM) and P2088YHR (120 CRM) were no-till seeded on April 26, 2012 and May 2, 2013 following corn at a seeding rate of 94,000 seeds ha^{-1} into a Loradale Silt Loam with 2 to 6% slopes (Table 2). Seed was planted with a modified John Deere MaxEmerge planter, equipped with Precision Planting seed meters, and Martin Row cleaners. The modified planter delivered seeds in 38-cm and 76-cm rows. Final stands averaged 91,000 plants ha^{-1} (97% of target rate) in both years.

Materials for the experiment included two corn hybrids, Pioneer brand ‘P1360HR’ and ‘P2088HYR’. Hybrid P1360HR contains two biotechnology events: 1) HERCULEX I Insect protection against European corn borer (*Ostrinia nubilalis,* Hübner), Western bean cutworm (*Striacosta albicosta*, Smith), Black cutworm (*Agrotis ipsilon*, Hufnagel), Southwestern corn borer (*Diatraea grandiosella,* Dyar), Fall armyworm (*Spodoptera frugiperda*, J.E. Smith), Southern corn stalk borer (*Diatraea crambidoides,* Grote), Lesser cornstalk borer (*Elasmopalpus lignosellus,* Zeller) and Sugarcane borer (*Diatraea saccharalis,* Fabricius). This event also suppresses Corn earworm (*Helicoverpa zea,* Boddie), and 2) Roundup Ready Corn 2, which allows the plant to tolerate applications of glyphosate (N-phosphomethyl glycine) herbicide. Hybrid P2088YHR contains the Herculex I and Roundup Ready 2 Corn traits, plus the YIELDGARD trait for control of the corn borers.

There were different defoliation treatments, resulting from a combination of defoliation timing and levels: 1) control, 2) 100% defoliation at V7 growth stage (V7-100%), 3) 50% defoliation at V14 growth stage (V14-50%), 4) 100% defoliation at V14growth stage (V14-100%), 5) 50% defoliation at R2 growth stage (R2-50%), and 6) 100% defoliation at R2 growth stage (R2-100%) (Figure A1 in Appendix displays pictures on defoliation treatments and plant recovery after defoliation). Table 3 provides information about defoliation timing and levels, and implementation date for each treatment. The six treatments were applied to both row widths and both hybrids. Defoliation events were accomplished either with knives or clippers at each defoliation treatment.

The 50% defoliation was accomplished by cutting off the terminal half part of each unrolled leaf, whereas the 100% defoliation involved complete removal of each unrolled leaf at the collar of the plant. At V7 growth stage (Abendroth et al., 2011), the 100% defoliation was performed by removing the seven fully emerged leaves and then cutting the pseudo stalk (whorl of leaves) at about 10-cm above the seventh leaf insertion. This allowed a quick recovery of plant canopy after this defoliation (see Figure A1 in Appendix, showing defoliated stands 11 d after the defoliation event). Defoliations at V14 growth stage occurred two to three days before tasseling (VT), thereby almost all leaves but one or two top leaves within the plant were completely unrolled. In order to avoid damage to or tassel removal that might have been affected pollination process in the plot, these top unrolled leaves were not removed. At R2 defoliation, all leaves were completely unrolled and thus, defoliation was applied to all leaves. Lower leaves in the plant canopy at different stages into the process of senescence, even if completely dead, were also defoliated at V14 and R2 (both at 50% and 100% levels). The main reason for the defoliation of these leaves was not to avoid any eventual contribution to the photosynthetic capacity of the plant at this moment, but rather to avoid any shadowing during the light bar measurements taken immediately after the defoliation event, in order to obtain non-skewed reliable values.

The plots were irrigated both years with drip-tape irrigation. Irrigation management strategy was defined following the guidelines for irrigation management in corn from University of Nebraska-Lincoln Extension Services (Kranz et al. 2008). Irrigation schedule started earlier and was applied more frequently in 2012 (V11/V12 and 16 days, respectively) than in 2013 (R1/R2 and 4 days, respectively). Time of last irrigation was similar for both years (around R5) (Table 2; Table A5; Figure 2).

Corn grain yields were harvested by hand on September 13 in 2012, and September 20 in 2013 (Table 2; Figure 2) for all four replications in both years. Plots from R2-100% treatment were harvested earlier than the rest of the plots in 2012 (Table 2). For all plots at both years, ears were collected from a 2.33 m^2 area for each experimental unit (approximately 1.5 m long per 1.5 m wide) either from the center two rows (76-cm row width) or the center four rows (38-cm row width) of a plot. Ears collected had at least 10-kernels fully developed to be considered as viable ears. Ears with less kernels were not harvested. Number of plants and number of ears harvested at each plot were recorded at harvesting. With these parameters, viable ears number per plant was calculated. Ears from each plot were weighed in the field (fresh weight, kg) and then dried at 65°C for four to five days until to a constant weight to determine moisture. Ear dry weight (kg), kernel rows per ear (rows per ear hereafter) and missing kernels (%) were determined in the laboratory. Pictures from all plots were also taken for each year (Figure A2 in Appendix shows pictures of some ears harvested for each defoliation event). Missing kernels (%) included both aborted kernels after a successful pollination and ovules that failed to pollinate. The kernels were then shelled from the cobs and weighed to get total sample kernel weight (kg). Finally, a kernel subsample randomly chosen was manually cleaned and five-hundred kernels were counted and weighed to determine one-thousand kernel weight (kg). Data gathered from the recorded parameters were used to calculate kernels per ear, kernels per row, kernel number (kernels m^{-2}), kernel weight (mg $kernel^{-1}$) and kernel number per plant. Hand harvesting was complemented with an additional harvest with a small plot Wintersteiger Delta combine (Salt Lake City, Utah) with a Geringhoff 2-row 76-cm corn head equipped with a HarvestMaster bucket weighing system (Juniper Systems, Salt Lake City, Utah) on both years. But machine harvested grain yields were not analyzed in this thesis. Hand-harvested grain yield values were calculated as Mg ha^{-1}.

Daily weather data (rain in mm; maximum temperature in °C) and irrigation events (mm) for the period April through September in 2012 and 2013 at Spindletop Farm, Lexington, can be found in Figure 2 and in Table A5 in Appendix. Monthly total rainfall (mm) and average temperature (°C) during 2012 and 2013 were compared with the 30-year average value for the period April through September (Figure 3 and 4, respectively). Number of days with extreme temperature events for same period on 2012 and 2013 were plotted (Figure 5). Source: Research Farm Climate Data, UKAg Weather Center, College of Agriculture, Food and Environment, University of Kentucky. Information can be found in: http://wwwagwx.ca.uky.edu/php/farm_www.php

Measurements taken throughout the crop growth cycle:

1) Stand counts within a month after planting (around V3 crop stage) in a 2.33 m^2 area for each experimental unit.

2) Growing stage: visual staging was carried out throughout crop growth and development on both years, two times a week during the vegetative period (Vn stages according to the total number of completely unfolded leaves) and three times a week while on reproductive period (R1 to R6) according to Abendroth et al. (2011) (Tables A6 and A7, Appendix). Since lower leaves slough from the plant as brace root develop, the fifth and then the seventh leaves of three to five plants in each plot were marked with spray as the plant developed, to more accurately determine later crop stages, as suggested by Hicks et al. (1977).

3) Intercepted photosynthetically active radiation (IPAR) readings (Mj m^{-2}) were measured with a line quantum sensor and a LI-1000 datalogger (LI-COR, Inc., Lincoln, Nebraska) at both soil level and dominant ear level.

a. At soil level, the measurements were taken in 2012 and 2013 at two replications and for four crop stages: at V8 (IPAR-V8), VT-R1 growth stage (IPAR-VT), R2 growth stage (IPAR-R2) and R5 (dent stage) (IPAR-R5).

b. In 2012, light measurements were taken in specific comparisons. Light measurements were recorded at V8 for the V7 defoliation and the control. The remaining defoliations had not been performed at that timing. Light measurements were taken for the VT defoliations and control separately from the R2 and control timings.

c. At the dominant ear level, measurements were taken in 2013 at two replications and only for R2 and R5 growth stages.

d. For both years, field work at each experimental unit consisted of three LI readings (either at ground or dominant ear level) measurements inside the plot and one reading outside the plot (alley) by using the LI-COR quantum sensor. All light bar readings were taken after each defoliation event. The V8 measurements were performed after the V7-100% defoliation, while the VT-R1 light measurements were taken after the V14 defoliations, owing to the fact that VT-R1 growth stages occurred 2 to 3 days after V14 growth stage for both hybrids under study. The R2 measurements were taken immediately after the R2 defoliations. The R5 readings were taken around the middle of this stage.

e. For the dominant ear level readings in 2013, the bar was situated slightly aside the main ear leaves of neighboring plants, avoiding situations were readings might have been taken either below or above the natural spatial disposition of those leaves.

f. Maximum intercepted photosynthetic active radiation (IPAR) was then determined for soil-level and ear-level readings, according the formula IPAR=1-(LI row/LI alley), habitually expressed by its functional components as IPAR=1-(I_t/I_0), where I_t is the incident photosynthetic photon flux density (PPFD) at soil level or ear level, and I_0 is the incident PPFD at the top of the canopy.

All measurements were taken between 1100-1400 hours, as suggested and adapted from Andrade et al. (1993b, 2001) and Liu et al. (2012), when sun angles were near the zenith, with cloud-free sky conditions, and when most of the PAR came directly from the sun.

4) Plant height (cm) from the soil to the base of the tassel, and stalk diameter (mm) measured at the height of the third visible internode were measured at R6 (physiological maturity) on 5 plants at each experimental plot over two replications.

TABLES AND FIGURES CHAPTER 2

Table 2. Soil test values and corn management practices in 2012 and 2013 at Spindletop Farm, Lexington, KY.

Management practice	**2012**	**2013**
Soil test values		
Soil pH, 1 M KCl	5.26	5.44
Calculated soil-water pH†	6.13	6.29
Sikora II Buffer pH†	6.74	6.75
Nutrients (P and Exchangeable) kg ha^{-1} ‡		
P	263	372
K	494	373
Ca	3706	4474
Mg	360	404
Zn	5	7
Fertilizer application date	15-Mar (K_2O); 23-Apr (N)	20-Mar (K_2O);1-May (N)
N–P_2O_5–K_2O, kg ha^{-1} #	225-0-135	225-0-135
Seeding date	26-Apr	2-May
Tillage	No-till	No-till
Hybrids	P1360HR ; P2088YHR	P1360HR ; P2088YHR
Seed rate, seeds ha^{-1}	94 000	94 000
Row width, cm	38 and 76	38 and 76
Burndown date	19-Apr	1-May
Glyphosate (N-(phosphonomethyl)glycine)¶	0.87 kg a.i. ha^{-1}	0.87 kg a.i. ha^{-1}
Lexar (S-Metolachlor + Atrazine + Mesotrione)§	1.46 kg a.i. ha^{-1} ; 1.46 kg a.i. ha^{-1} ; 0.19 kg a.i. ha^{-1}	1.46 kg a.i. ha^{-1} ; 1.46 kg a.i. ha^{-1} ; 0.19 kg a.i. ha^{-1}
Insecticide date	9-May ; 23-May	None
S-Cyano £	0.4 kg a.i. ha^{-1}	None
Irrigation management schedule	Drip irrigation starting at V11-V12 up to R5/R6	Drip irrigation starting at R1-R2 up to R5/R6
Harvest date	30-Aug (R2-100%); 13-Sept	20-Sept (all experiment)

† Water pH is determined in a 1:1 (v/v) ratio of deionized water:soil and provides a measure of active acidity in soil. Soil buffer pH provides a measure of reserve acidity in soil and is determined with the Sikora buffer (Soil Science Society of America Journal 70, 2006). These methods are described in Bulletin 190 of the Southern Cooperative Series (November 1984), *Procedures Used by the State Soil Testing Laboratories in the Southern Region of the United States*.

‡ Nutrients are extracted with Mehlich III-extractant (Mehlich, 1984): 0.2 N acetic acid; 0.25 N NH_4NO_3; 0.015 N NH_4F; 0.013 N HNO_3; 0.001 M EDTA. Nutrient concentrations are shown in units of lbs/acre. To convert to mg/kg soil divide the values by 2.Soil pH in the routine soil test uses 1 M KCl rather than water. For producer reports, University of Kentucky Soil Testing Lab calculates a soil-water pH using the following equation based on analysis of 240 soil samples in March 2009: soil-water pH = 0.91 x 1 M KCl soil pH + 1.34. This equation was used for calculated soil-water pH in this report.

Rates based on AGR-1: 2012-2013 Lime and Nutrients Recommendations. Cooperative Extension Service. University of Kentucky, College of Agriculture, Lexington, KY, 40506.

¶ Active ingredient (a.i.) in the form of the acid, glyphosate.

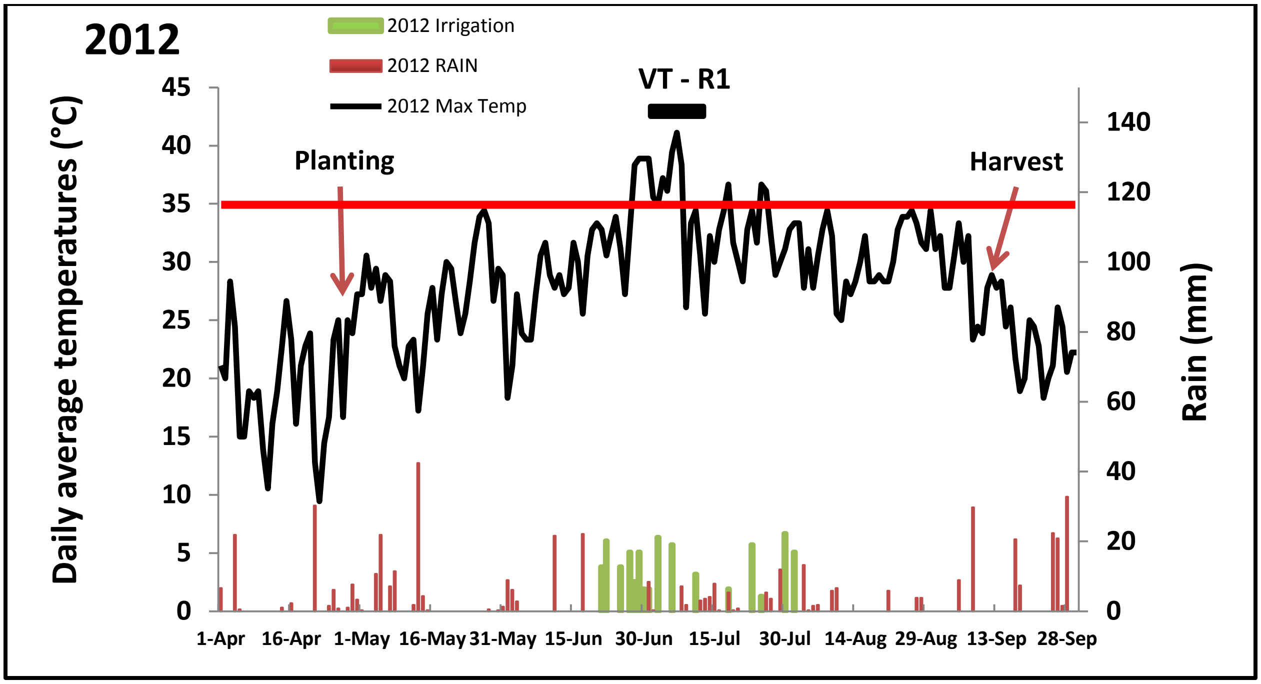
§ S-Metolachlor (19%) (RS)-2-Chloro-N-(2-ethyl-6-methyl-phenyl)-N-(1-methoxypropan-2-yl)acetamide) ; Atrazine (18.61%) 6-chloro-N2-ethyl-N4-(1-methylethyl)-1,3,5-triazine-2,4-diamine; Mesotrione (2.44%) (2-(4-Mesyl-2-nitrobenzoyl)-1,3-cyclohexanedione).

₤ S-Cyano (3-phenoxyphenyl)methyl ± cis/trans 3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropane carboxylate. Cis/trans ratio: Max. 55%(±) cis and min. 45% (±) trans.

Table 3. Detail of the treatments applied to defoliation study at Spindletop farm, Lexington, KY.

Defoliation			Defoliation date	
Timing†	**Rate (%)**	**Denomination**	**2012**	**2013**
Control	0	Check	-	-
V7	100	V7-100%	4-Jun	17-Jun
V14	50	V14-50%	2-Jul	8-Jul
V14	100	V14-100%	2-Jul	8-Jul
R2	50	R2-50%	17-Jul	18 (P1360HR) and 23-Jul (P2088YHR)
R2	100	R2-100%	17-Jul	18 (P1360HR) and 23-Jul (P2088YHR)

† According to Abendroth et al. (2011).



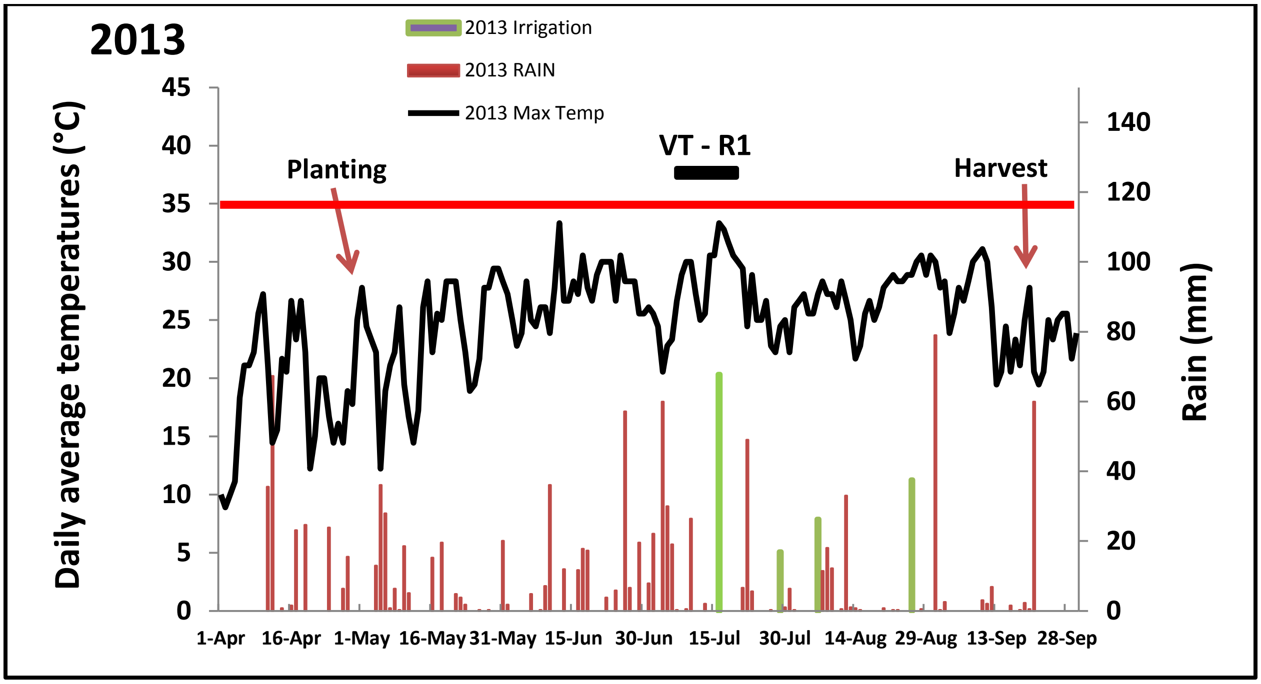


Figure 2. Daily maximum average temperature (°C), rains (mm) and irrigation (mm) for Lexington, KY in 2012 and 2013. Black boxes show occurrence of VT-R1 period. The red horizontal bar is set at 35 C, considered a maximum temperature for corn growth.

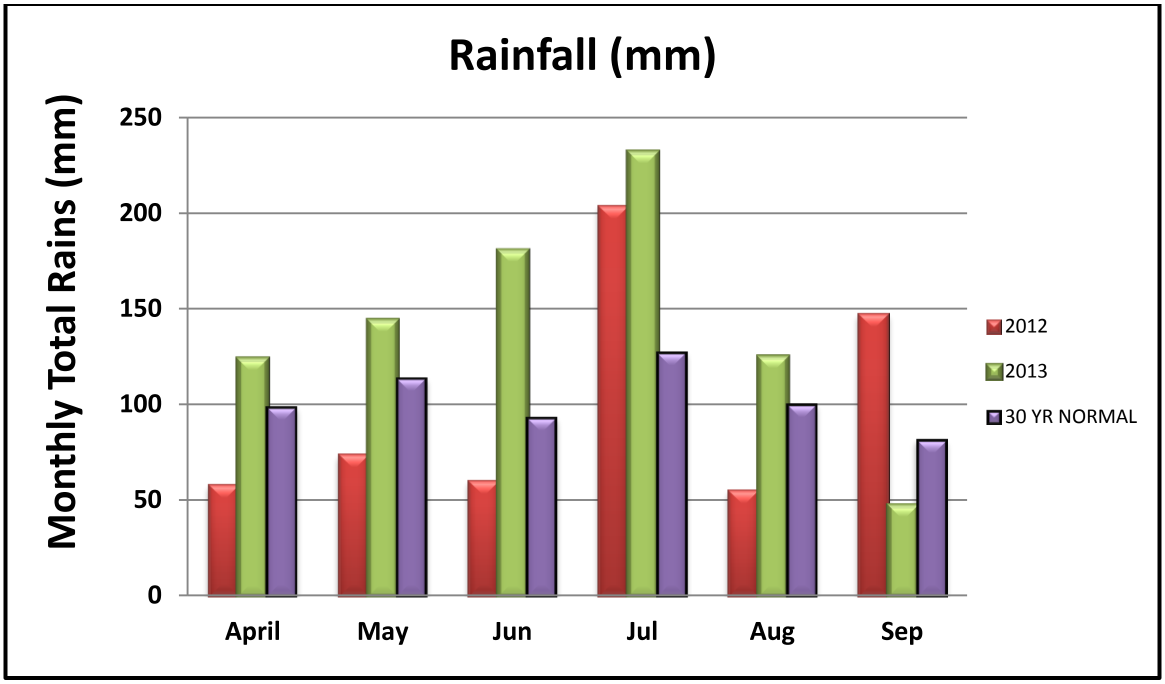


Figure 3. 2012-2013 vs. 30 year rain (mm) for the period April through September at Spindletop farm, Lexington, KY.

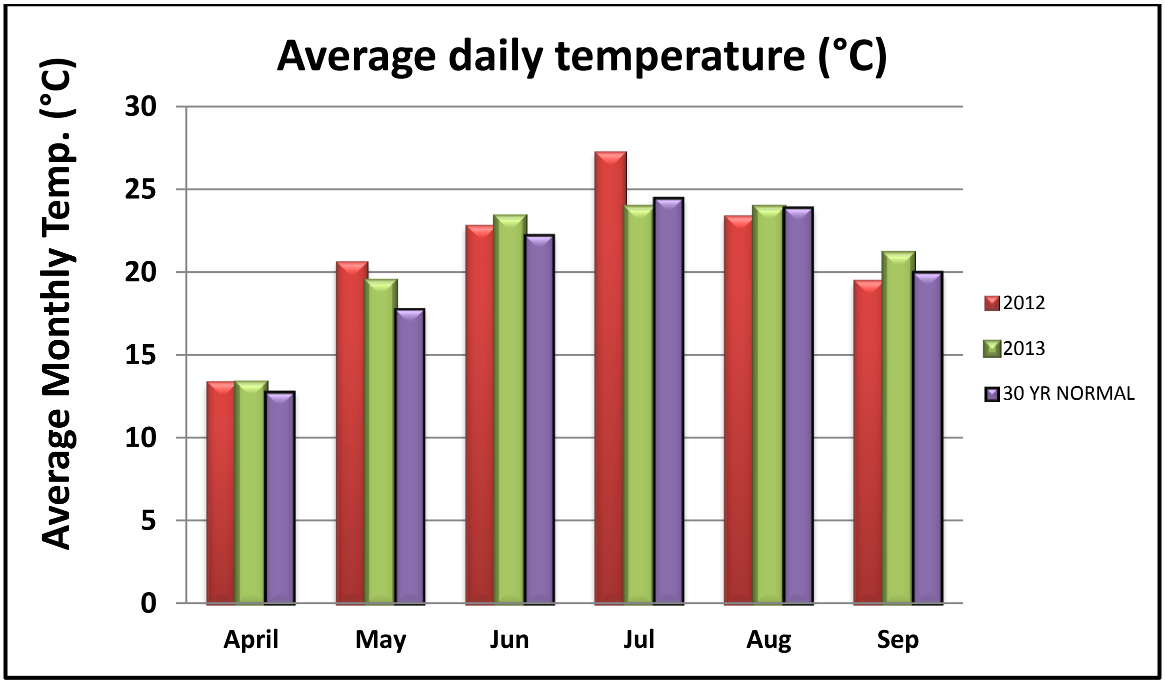
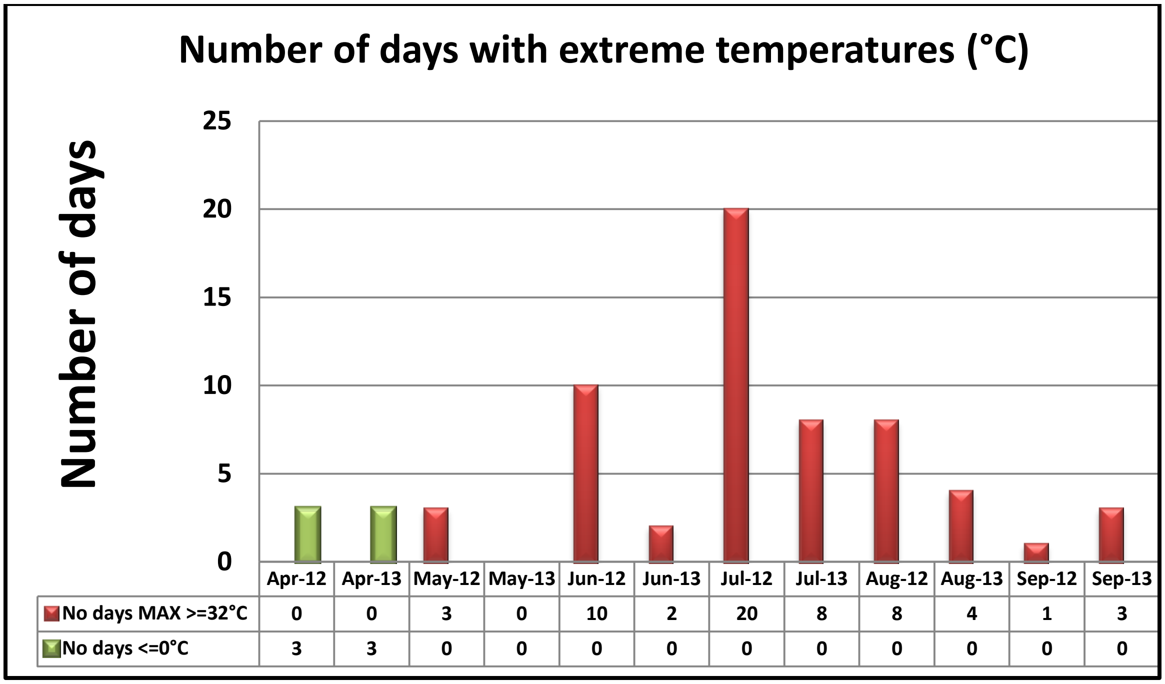


Figure 4. 2012-2013 vs. 30 year average temperature (°C) for the period April through September at Spindletop farm, Lexington, KY.



	Apr-12	Apr-13	May-12	May-13	Jun-12	Jun-13	Jul-12	Jul-13	Aug-12	Aug-13	Sep-12	Sep-13
🟥 No days MAX >=32°C	0	0	3	0	10	2	20	8	8	4	1	3
🟩 No days <=0°C	3	3	0	0	0	0	0	0	0	0	0	0

Figure 5. Number of days with temperature above 32°C or below 0°C in 2012 and 2013 for the period April through September at Spindletop farm, Lexington, KY.

CHAPTER 3

RESULTS

The first year, 2012 was a hot and dry, whereas 2013 was cool and wet. (Figure 2). The horizontal red line is set at 35 °C, which is above the optimum maximum temperatures for normal corn development of about 30°C (Warrington and Kanemasu, 1983; Schlenker and Roberts, 2009). Most of the VT/R1 critical period for yield determination in corn (i.e. +/- 15 to 20 days bracketing VT/R1 stages) in 2012 experienced maximum temperatures at or above 35 °C. On the other hand, maximum daily temperatures for same period in 2013 were around or slightly above 30 °C. Minimum daily temperatures experienced at both years did not represent any harmful situation for the normal crop development, and for the sake of clarity, have not been depicted in Figure 2.

July is a particularly important benchmark in our experiment, as the critical period for grain yield determination in corn took place during this month in 2012 and 2013. Figure 2 show the time of occurrence for the critical period VT-R1 (Abendroth et al., 2011) for both years. Mostly, VT-R1 period in 2012 elapsed with temperatures above 35°C, with days exceeding 40°C. For R2 period, the temperatures were also close to or above 35°C (Figure 2). In 2013, VT-R1 stages occurred with temperatures ranging from 25°C to maximums of 32 to 33°C. For the R2 period, temperatures were always below 30°C in 2013 (Figure 2). Rainfall in June and July 2012 was 67% and 12% lower than rainfall for same months in 2013, respectively (Figure 3). Average monthly air temperatures for July showed the greatest differences between years: 27.2°C in 2012 vs. 23.9°C in 2013, with a 30-year normal temperature of 24.4°C. Another important inter-annual difference was registered for May: 20.6°C in 2012 vs. 19.4°C in 2013, with a 30-year normal temperature of 17.8 °C. Small to none differences were registered for the comparison for the rest of the growing period at both years (Figure 4). Finally, June, July and August 2012 registered 10, 20 and 8 days respectively with average temperatures >32°C, versus only 2, 8 and 4 days for June, July and August 2013, respectively (Figure 5).

Irrigation schedule started earlier, was applied more frequently, and in a greater amount in 2012 (V11/V12, 16 days and approximately 66 mm of water, respectively) than in 2013 (R1/R2, 4 days and approximately 44 mm of water, respectively). Time of last irrigation was similar for both years (around R5). When looking at the distribution of the amount water applied, half applications in 2012 were aimed to the crop at vegetative growth stage, whereas the other half was applied during grain number set and grain filling period. All applications in 2013 took place during reproductive stages to limit water stress during corn critical period for yield determination in corn (Figure 2; Table A5 Appendix).

3.1. ANOVA analysis for defoliation study

Year interacted with defoliation ($p \leq 0.05$) for 9 of the 15 parameters investigated, including grain yield (GY), kernel number (KN), rows per ear (RPE), kernels per ear (KPE), kernel number per plant (KNP) and several others (Table 4). Grain yields in 2013 were 28% greater than in 2012 ($p \leq 0.0001$). Narrow rows (38-cm) increased grain yields 16% when compared with wide rows (76-cm) (averaged across years, hybrids and defoliations; $p=0.001$), but row also interacted with hybrid and defoliation ($p=0.0018$) in the analysis across both years. Year also interacted with defoliation ($p \leq 0.0001$). All defoliation events, except for R2-100%, resulted in greater yields in 2013 ($p \leq 0.0001$) (Table 4), likely a result of the extreme differences in weather at each year (Figure 2, 3, 4 and 5).

The ANOVA was then analyzed by year and those results are presented in Tables 5 and 6.

Additional IPAR readings at ear height ($IPAR_{ear}$) were taken in 2013 and the ANOVA for those measurements are reported in Table 7.

For 2012 no interactions were observed in the main effects for grain yield and the other components (Table 5). Row and defoliation were significant for grain yield ($p=0.0069$; $p \leq 0.0001$, respectively) and several yield components. Row widths did not affect IPAR, while defoliation altered the four IPAR readings in 2012.

Conversely, for 2013 the hybrid, row and defoliation interacted for grain yield (*p=0.0228*), KPE, KPR, stalk diameter, soil IPAR-V8 and soil IPAR-R5 (Table 6). Hybrid and row, hybrid and defoliation, and row and defoliation interacted for several yield components as well.

3.2. Grain yield, yield components and plant architecture-related parameters under study at defoliation study

3.2.1. Grain yield analysis for 2012 and 2013.

Grain yields presented in this section represent hand-harvested yields. Both hand and combine-harvested grain yields for 2012 and 2013 are available in Table A8 of the Appendix. Table A9 in Appendix shows the grain yield raw data for the hand-harvested grain yields in 2012 and 2013.

Averaged across hybrids and defoliation, grain yields were 26% higher for 38-cm rows in 2012 (Table 8) ($p \leq 0.001$). Defoliation also affected GY in 2012 ($p \leq 0.0001$) (Figure 6). In 2012, defoliation at V7-100% across both hybrids and row widths resulted in the greatest numerical grain yield (14.43 Mg ha^{-1}), which was not significantly different from the control (13.21 Mg ha^{-1}). Defoliation at V14 and R2 reduced grain yield compared with V7-100% defoliation. For 2012, R2-50% defoliation yield was not different than the control, but it was 11% lower than V7-100% defoliation. Partial defoliations at V14 reduced grain yields by 22%. V14-100% defoliation resulted in greater grain yield loss (-96%) than R2-

100% defoliation (-76%). For both V14 and R2 defoliation timings, 100% defoliation caused greater grain yield loss than 50%. There was no grain yield difference among hybrids in 2012 (Table 8).

In 2013, a significant hybrid*row width*defoliation interaction ($p = 0.0228$) required a separate analysis (Figure 7). For hybrid P1360HR in 38-cm rows, only V14-100% and R2-100% reduced grain yield. In 76-cm rows, all defoliations events reduced grain yield relative to the control. For P2088YHR in 38-cm rows, all defoliation events reduced grain yields relative to the control (21.76 Mg ha^{-1}). Remarkably, control yield for this hybrid was the largest numerical yield for the both years of the experiment, but it was not different than the 2013 control grain yield for P1360HR at 76-cm rows (20 Mg ha^{-1}). For P2088YHR in 76-cm rows, V14-100%, R2-50% and R2-100% reduced grain yields. For both hybrids and row width, greatest grain yield losses (range: 85-97%) occurred for V14-100% and R2-100%, which were not different from each other for all comparisons in 2013 (Figure 7). When grain yield reductions occurred for 50% defoliations at V14 or R2 in 2013, losses ranged from 16% to 34%.

When comparing defoliation events across row widths, when grain yield differences were significant ($p \leq 0.05$), grain yields were greater in 38-cm rows (+20, +21 and +28% yields for V7-100%, V14-50% and R2-50%, respectively for P1360HR; +19% for control for P2088YHR) (Figure 7).

3.2.2. Grain moisture analysis for 2012 and 2013.

Grain moisture information was only collected for the machine-harvested grain (Table A10 and A11, in Appendix).

3.2.3. Kernels number (KN) and Kernel weight (KW) analysis for 2012 and 2013.

Kernel number (kernels m^{-2}, KN) and kernel weight (mg $kernel^{-1}$, KW) are presented together (Table 9 and 10), as they are the main yield components in corn. The rest of the secondary-yield components analyzed are presented separately.

Narrow rows increased KN in 2012 (+33%) (*p=0.0063)* and 2013 (+12%) (*p=0.0375)* (Table 9). Narrow rows decreased KW in 2012 (-7%) (*p=0.0109*) but had no effect in 2013 (Table 9). However, the greater KW in wide rows in 2012 did not compensate the lower KN in 76-cm, and finally, grain yield was greater for 38-cm rows (+26%) (Table 8).

In 2012, there was a defoliation effect on KN ($p\leq0.0001$) and KW ($p\leq0.0001$) (Table 9). Kernel number was reduced most by V14-100% (-95%), followed by R2-100% (-35%) and V14-50% (-20%). Kernel weight was only reduced by R2-100% defoliation (-61%) (Table 9).

In 2013, hybrid and defoliation interacted for KN and KW ($p\leq0.0001$) (Table 10). For P1360HR, KN was reduced by defoliations at V14-50%, V14-100%, R2-50% and R2-100%, with greatest reductions (close to 90%) at V14-100% and R2-100%, followed by R2-50% (-23%) and V14-50% (-13%). For

P2088YHR, KN was reduced by defoliation at V14-100%, R2-50% and R2-100%, with greatest reductions for V14-100% (-90%), followed by R2-100% (-48%) and R2-50% (-14%). For both hybrids, KN was greatest for the control and V7-100%. Kernel weight was reduced most by R2-100% defoliation for both P1360HR and P2088YHR (-25% and -71%, respectively). The V14-100% defoliation also reduced KW for P2088YHR (-18%). When comparing hybrids across defoliations, R2-100% reduced KN more for P130HR than P2088YHR. The R2-100% defoliation reduced KW more for P2088YHR (Table 10).

3.2.4. Rows per ear (RPE) analysis for 2012 and 2013.

For RPE, a significant hybrid ($p= 0.0069$; $p= 0.0008$), row spacing ($p=0.0036$; $p= 0.0207$) and defoliation effect ($p\leq 0.0001$; $p\leq 0.0001$) occurred in both 2012 and 2013, respectively (Table 11). For both years, RPE was greater for P1360HR than P2088YHR and greater for 38-cm than 76-cm rows, but by only one kernel row in all cases.

The V14-100% defoliation reduced RPE greatest in 2012 and 2013. This reduction is in the order of 2 to 3 rows of kernels per ear when compared with the control. In 2013, R2-100% reduced RPE by approximately 1 row (table 11).

3.2.5. Kernels per ear (KPE) analysis for 2012 and 2013.

For KPE, hybrid, row and defoliation main effects were significant in 2012 (*p= 0.042; p= 0.0082 and p≤ 0.0001*, respectively) (Table 11). Hybrid P1360HR and 38-cm rows had more KPE (+13% and +21%, respectively). Defoliations at V14-50%, V14-100% and R2-100% reduced KPE, with greatest reductions at V14-100% (-77%), followed by defoliations at R2-100% (-27%) and V14-50% (-22%) (Table 11).

In 2013, the hybrid*row*defoliation interaction was significant (*p= 0.050*) (Table 12). Complete defoliations at V14 and R2 greatly reduced KPE for both hybrids and row widths (range: -36 to -87%). Defoliations at R2-50% also reduced KPE for P1360HR (-23%). When differences among rows occurred, KPE was always greater in 38-cm (V14-100% and R2-50% for P1360HR; V14-100% for P2088YHR) (Table 12).

3.2.6. Kernels per row (KPR) analysis for 2012 and 2013.

Significant main effects of row width (*p= 0.0164*) and defoliation (*p≤ 0.0001*) occurred in 2012, while hybrid was not significant for KPR, with both hybrids having approximately 24 KPR (Table 11). Narrow rows increased KPR by 17% compared with 76-cm rows. Defoliations at V14-50%, V-14-100% and R2-100% reduced KPR, with maximum losses at V14-100% defoliation (-71%) and losses ranging from 23 to 28% for the other treatments (Table 11).

In 2013, a significant interaction hybrid*row*defoliation (*p*= *0.0243*) occurred (Table 12). For P1360HR at both row widths, KPR was most reduced by R2-100% (range: -81 to -87%), followed by V14-100% (range: -50 to -63%). Defoliations at R2-50% only reduced KPR at 76-cm. For P2088YHR, V14-100% and R2-100% reduced KPR similarly in 38-cm rows (range: -31 to -36%), while V14-100% caused greatest reductions at 76-cm rows (-84%), followed by defoliations at R2-100% (-34%). When differences in KPR across row widths occurred, KPR was always greater at 38-cm (R2-50% on hybrid P1360HR and V14-100% on hybrid P2088YHR) (Table 12).

3.2.7. Kernels number per plant (KNP) analysis for 2012 and 2013.

In 2012, hybrid (*p*= *0.0454*), row width (*p*= *0.0086*) and defoliation (*p*≤ *0.0001*) were significant for KNP (Table 11). Hybrid P1360HR produced more KNP (+12%) than hybrid P2088YHR in this year. Defoliations treatments V14-50%, V14-100% and R2-100% reduced KNP, with greatest reductions achieved at V14-100% (-95%) and reductions ranging from 22 to 30% for the other treatments (Table 11).

In 2013, row width (*p*= *0.050*) (Table 11) and the hybrid*defoliation interaction were significant (*p*≤ *0.0001*) (Table 13). All defoliations events reduced KNP for P1360HR, while only V14-100% and R2-100% reduced KNP for P2088YHR. Greatest KNP decreases were a result of the V14-100% and R2-100% treatments for P1360HR and V14-100% for P2088YHR, with reductions close to 90% in all cases. Reductions for the R2-100% defoliation for P2088YHR were smaller (-40%). Partial defoliations at V14 and R2 for P1360HR reduced KNP between 15 to 21%. When differences in KNP across hybrids occurred, KNP was greater at control P1360HR and at R2-100% treatment for P2088YHR (Table 13).

In 2012 and 2013, narrow rows increased KNP by 26 and 9%, respectively (Table 11).

3.2.8. Viable ears number per plant (ENP) analysis for 2012 and 2013.

For ENP in 2012, row and defoliation were significant for ENP ($p= 0.0017$; $p \leq 0.0001$, respectively), while the ENP value for both hybrids was similar (around 0.83) (Table 11). Rows at 38-cm resulted in 4% greater ENP than 76-cm rows in 2012. Defoliations of V14-100% decreased ENP the greatest (-83% or about one viable ear every 6 plants at harvesting) while R2-100% defoliations reduced ENP by 8%. The rest of the treatments produced almost one viable ear per plant in all cases (range: 0.95 to 0.99) (Table 11).

In 2013, hybrid*defoliation ($p= 0.0259$) (Table 13) and row width*defoliation interactions were significant ($p= 0.0006$) (Table 14). For both hybrids and row width, final ENP was reduced most by V14-100% (range: 64 to 85%) followed by R2-100% defoliations (range: 10 to 32%). When differences among hybrids and rows occurred, ENP reductions were greater for P1360HR and for 76-cm rows at R2-100% defoliations, and at 38-cm rows for V14-100% defoliations (Table 13 and 14).

3.2.9. Missing kernels (%) analysis for 2012 and 2013.

In 2012, hybrid and defoliation effects on missing kernels (%) were significant ($p= 0.0082$; $p\leq 0.0001$, respectively) (Table 15). Hybrid P2088YHR produced 36% more missing kernels (%). Complete defoliations at V14 and R2 significantly increased missing kernels (%), with increase at R2-100% (+285%) greater than at V14-100% defoliations (+156%).

In 2013, hybrid*defoliation interaction was significant ($p= 0.0004$) (Table 16). Defoliation at R2-100% increased missing kernels (%) in P1360HR by 645%, while V14-100% and R2-100% treatments increased missing kernels (%) for P2088YHR by 388 and 288%, respectively). When differences between hybrids occurred, P1360HR resulted in greater missing kernels (%) at R2-100% defoliations, while P2088YHR had greater missing kernels (%) with V14-100% defoliations (Table 16).

Row widths did not affect the occurrence of missing kernels (%) in either year (Table 15).

3.2.10. Plant height (cm) analysis for 2012 and 2013.

In 2012, row width effect on plant height was significant ($p= 0.0395$), with narrow rows increasing plant height by 5% (Table 15). In 2013, defoliation effect was significant ($p=0.0321$). No difference in plant height between hybrids was found in either year. The shortest plants in 2013 occurred in the V7-100% treatment, with a significant height reduction of approximately 10%. Overall, across hybrids, row width and defoliations, plants in 2013 were approximately 12% taller than in 2012 (Table 15).

3.2.11. Stalk diameter (mm) analysis for 2012 and 2013.

In 2012, row width and defoliation effects on stalk diameter were significant ($p= 0.0201$ and $p\leq 0.0001$, respectively) (Table 15). Stalk diameters were 6% smaller in 76-cm rows in 2012. In this year, defoliation at V7-100% was the only treatment that significantly reduced stalk diameter (-13%). There was no difference in stalk diameter between the hybrids used in this experiment.

In 2013, the hybrid*row width*defoliation interaction was significant ($p= 0.0349$) (Table 17). In 38-cm rows, V7-100%, V14-100% and R2-100% decreased stalk diameter for P1360HR, while the V7-100% and R2-100% decreased diameter for P2088YHR. In 76-cm rows, the stalk diameter in both hybrids was only reduced at V7-100% defoliation. In four of five situations where differences across row width appeared, plants in 38-cm rows had greater stalk diameter than plants grown in 76-cm (Table 17).

3.3. Light interception relations at defoliation study

3.3.1. Intercepted Photosynthetically Active Radiation at soil level (Soil IPAR, %) at V8, VT, R2 and R5 stages for 2012 and 2013.

In 2012, IPAR at soil level at R2 growth stage (IPAR-R2) was 9% greater for P2088YHR than P1498 (*p= 0.0212*) (Table 18). No differences in IPAR among the two hybrids were observed at other growth stages in 2012. Row spacing did not affect IPAR in 2012 at any growth stage, and did not affect IPAR-VT or IPAR-R2 in 2013 (Table 18). In 2012, IPAR-R5 was reduced for all defoliation events relative to the control (Table 18). In 2013, IPAR-R5 was reduced by both V14-100% and R-100% treatments for each hybrid and row width (Table 19

Observations about IPAR values for each reading are included below:

i. **V8 readings**: Defoliation at V7-100% reduced IPAR-V8 by 47% compared to the control in 2012 (Table 18). Even though IPAR differences were not significant, IPAR-V8 in 2012 for 38-cm were almost 22% greater than for 76-cm rows (Table 18). In 2013, across hybrids, V7-100% reduced IPAR-V8 75% and 67% for 38- and 76-cm rows, respectively (Table 19). It is worthy to remark that maximum IPAR-V8 values to make the comparisons were substantially higher in 38-cm than in 76-cm, something that can help to explain the greater reductions in 2012 when compared with 2013. For the rest of the untreated plots at V8 growth stage, IPAR-

V8 values ranged from 60 to 68% in 2012 (Table 18) and from 57 to 84% in 2013 (Table 19). In 2013, when differences between row spacings occurred, IPAR-V8 was always greater in 38-cm rows (range: +18 to 34%) (Table 19).

ii. **<u>VT readings</u>:** For IPAR-VT, all defoliations prior to VT reduced IPAR in both years with greatest reduction as a result of V14-100% defoliation (range: -72 to -74%), followed by defoliations at V14-50% and V7-100% (range: -17 to -21%) (Table 18). Overall, the V14-100% defoliation reduced light interception about 3.5 times more than V14-50% defoliation. Remarkably, in 2013 the plots defoliated at V7-100% increased IPAR from 23% at IPAR-V8 (4-6 days post-defoliation) to 75% at IPAR-VT, approximately 25 days post-defoliation (Table A7, Appendix). This recovery from the plots defoliated at V7-100% was noticeable even earlier, as shown in Figure A1 in Appendix. The untreated plots at IPAR-VT readings (i.e. control, R2-50% and R2-100%) ranged from 83 to 91% (Table 18).

iii. **<u>R2 readings</u>:** at this growth stage, all defoliation treatments had been applied. The IPAR-R2 readings were reduced most by R2-100% defoliations in 2012, and by V14-100% and R2-100% defoliations in 2013 (range: -60 to -67%), followed by R2-50% defoliations in 2012, and by V14-50% and R2-50% defoliations in 2013 (range: -15 to -17%) (Table 18). Across both years, R2-100% defoliation reduced light interception 4 to 4.5 times the reduction after R2-50% defoliation. In 2013, V7-100% plots increased light interception from 75% at IPAR-VT to

86% at IPAR-R2 readings, thus reaching a maximum IPAR-R2 value similar to the control) (Table 18).

iv. **<u>R5 readings</u>:** in 2012, all defoliation treatments reduced IPAR-R5 (%) relative to the control, with the greatest reductions for the V14-100% and R2-100% treatments (range: -55 to -60%), followed by V7-100%, V14-50% and R2-50% treatments (range: -9 to -15%). In 2012, IPAR of the V7-100% treatment increased from 36% at IPAR-V8 to 74% at IPAR-R2, a period of 60 days (Table 18) (Table A6, Appendix). Recovery for the VT and R2 defoliated plots was less evident at IPAR-R5 (Table 18). In 2013, across hybrids and row widths, IPARR5 (%) was reduced 43 to 69% but only by V14-100% and R2-100% treatments in this year, respectively (Table 19). When differences between rows occurred in 2013 (V14-100% for both hybrids), responses were mixed, with greater IPAR-R5 at 38-cm for hybrid P1360HR and at 76-cm row width for hybrid P2088YHR.

3.3.2. Soil IPAR at V8, VT, R2 and R5 stages and grain yield relationship for 2012 and 2013.

The raw data for the relationship IPAR at the soil level and grain yield for 2012 and 2013 is available in Tables A12 and A13 in Appendix, respectively.

In general, IPAR readings at the soil surface taken at VT growth stage or later were positively related to grain yield in 2012 (Figure 8) and 2013 (Figure 9).

As pointed out before, IPAR-V8 values were significantly reduced by V7-100% defoliations (47% in 2012; average 75% and 67% for 38- and 76-cm across hybrids in 2013, respectively) (Table 18 and 19). However, these declines in IPAR-V8 were not related with final grain yield in all situations. In 2012, these reductions did not affect yields for V7-100% plots related to control (Figure 6; Table A12). In 2013, IPAR-V8 reductions in 38-cm rows only reduced grain yields for P2088YHR, by approximately 20%, while IPAR-V8 reductions in 76-cm rows only reduced grain yields for P1360HR when compared with control (Figure 7; Table A13). For the untreated treatments at IPAR-V8 readings (all but V7-100% plots), when differences across rows occurred in 2013, IPAR-V8 at 38-cm were always greater than at 76-cm rows (Table 19). In most cases, these positive early differences in light interception were translated in greater grain yields for narrow rows (i.e. V14-50% and R2-50% for P1360HR, and control for P2088YHR) but not in all (V14-100% for P2088YHR) (Figure 7; Table A13).

Soil IPAR-VT and IPAR-R2 show an asymptotic relationship with grain yield in 2012, with a clearer saturation response for IPAR-R2. In the case of IPAR-R5, the relationship with grain yield can be defined as linear. IPAR values around 85% were needed at VT and R2 growth stages to maximize grain yields in the control treatment. Soil IPAR-R5 close to 75% were enough to maximized grain yields in 2012 (i.e. V7-100% plots) (Figure 6 and 8).

In 2013, V14-50% and V7-100% significantly reduced IPAR-VT values to 72 and 75% in 38-cm rows, respectively. However, yield loss did not occur from V14-50% and V7-100% in 38-cm rows in 2013 (Figure 7 and 9).

Conversely, similar reductions in IPAR-VT for V14-50% defoliation in 2012 reduced grain yield (Figure 6 and 8). Same maximum grain yield was only achieved with IPAR-VT values of 90% in 76-cm rows for hybrid P1360HR. For hybrid P2088YHR, IPAR-VT values between 72 and 75% were enough to maximize grain yields in 76-cm rows, but those yields were not maximum for the hybrid. In this case, hybrid P2088YHR only attained maximum grain yields with IPAR-VT values around 90% in 38-cm rows (Figure 7 and 9). For both years, hybrids and row widths, the greatest reduction in IPAR-VT (related to control) occurred with the V14-100% defoliation (around 74%) which also reduced grain yield the most (Figure 6, 7, 8 and 9). The V4-50% and V7-100% also reduced IPAR-VT (17% to 21%) and these reductions are associated to grain yield penalties in some cases (i.e. P1360HR in 76-cm in 2013) but not in others (i.e. P1360HR at 38-cm in 2013).

Related to control, IPAR-R2 was greatly reduced by V14-100% and R2-100% defoliation (range: -60 to -67%), followed by R2-50% and V14-50% treatment (range: -15 to -17%) in both years (Table 18). As a result, highest grain yield decline occurred with V14-100% at both years, and with R2-100% defoliations in 2013 (Figure 6, 7, 8 and 9). In 2012, R2-100% defoliation resulted in the second lowest overall grain yield. For partial defoliations at V14 and R2, grain yield losses were achieved in some cases (i.e. R2-50% in 2012; V14-50% and R2-50% for P1360HR at 76-cm and P2088YHR at 38-cm in 2013) but did not in others (i.e. V14-50% and R2-50% for P1360HR at 38-cm in 2013). In 2013, effects of IPAR-R2 values on grain yield were similar to the effects of IPAR-VT values. For P1360HR, a minimum IPAR-R2 of 79% achieved with 38-cm rows, was enough to attain overall maximum grain yields for this hybrid (Figure 7 and 9). Same yields were only achieved with IPAR-R2 above 90% in 76-cm rows. For P2088YHR, IPAR-R2 around 80% was enough for maximum grain yields in 76-cm, but overall grain yields for the hybrid were only achieved with IPAR-R2 values of 93% at 38-cm rows (Figure 7 and 9).

In 2012, at the R5 growth stage, minimum IPAR-R5 values of 74% were needed to achieve maximum grain yields (V7-100% defoliation). However, values not different than this, reduced grain yields in some other cases (V14-50% and R2-50%) (Figure 6 and 8). In 2013, across row width, IPAR-R5 near 80 to 85% were sufficient for maximum grain yields for P1360HR, while P2088HYR required IPAR-R5 values above 90% for maximum grain yields (Figure 7 and 9). IPAR-R5 was greatly reduced by V14-100% and R2-100% defoliations at both years (range: 43 to 69%).

3.3.3. Intercepted Photosynthetically Active Radiation at ear level (Ear IPAR, %) at R2 and R5 stages and grain yield relationship for 2013.

In 2013, no differences between row width for ear IPAR-R2 were observed (*p=0.5723*) (Table 20). The hybrid by defoliation interaction was significant for ear IPAR-R2 (*p=0.0131*) (Table 21). All defoliation events reduced earIPAR-R2 for both hybrids, with greatest reductions at V14-100% and R2-100% (range: -74 to -87%). When differences between hybrids across defoliation events occurred, responses were mixed. Both V7-100% and V14-50% treatment resulted in greater earIPAR-R2 for P2088YHR while R2-100% resulted in a greater earIPAR-R2 for P1360HR. At the control, earIPAR-R2 values between 85-90% were achieved (Table 21). Values as low as 54% earIPAR-R2 for R2-50% treatment (36% lower than for control) were needed to achieve maximum grain yields for P1360HR, while values of 90% (control) were needed to maximize grain yields in P2088YHR.

At the R5 growth stage, defoliation effect on earIPAR-R5 values was significant ($p \leq 0.0001$). The V14-100% and R2-100% reduced earIPAR-R5 the most (range: -59 to -64%) ($p \leq 0.05$) (Table 20). The hybrid by row width interaction was significant for earIPAR-R5 ($p = 0.0015$) (Table 22). Hybrid P2088YHR resulted in a greater earIPAR-R5 ($p \leq 0.05$) in both row width than the other hybrid. Row width effect on earIPAR-R5 was mixed, with narrow rows resulting in greater light interception for P1360HR, but wide rows resulted in greater light interception for P2088YHR ($p \leq 0.05$) (Table 22).

TABLES AND FIGURES CHAPTER 3

Table 4. ANOVA table summary for the defoliation study in Lexington, KY for the period 2012-2013.

Source†	DF	GY	KN	KW	RPE	KPE	KPR	KNP	ENP	Missing kernels (%)	DF	Plant Height	Stalk Diam	DF	Soil IPAR-VT	Soil IPAR-R2	DF	Soil IPAR-V8	Soil IPAR-R5
							P > F						*P > F*			*P > F*			*P > F*
Replication	3	**	*	ns	ns	*	ns	**	ns	ns	2	ns	**	1	ns	***	1	ns	***
Year (Y)	1	***	***	ns	ns	***	***	***	ns	***	1	***	***	1	***	***	1	**	***
Hybrid (H)	1	ns	ns	ns	***	ns	ns	ns	ns	ns	1	ns	ns	1	ns	ns	1	**	ns
Y*H	1	ns	*	ns	ns	*	*	*	ns	ns	1	ns	ns	1	ns	ns	1	ns	ns
Row (R)	1	***	***	**	***	***	***	***	ns	ns	1	*	**	1	ns	ns	1	ns	*
Y*R	1	ns	ns	ns	ns	ns	ns	ns	**	ns	1	ns	ns	1	ns	ns	1	ns	ns
H*R	1	ns	ns	ns	ns	ns	ns	ns	*	ns	1	ns	ns	1	ns	ns	1	ns	**
Y*H*R	1	ns	ns	ns	ns	ns	ns	ns	ns	*	1	ns	*	1	ns	ns	1	ns	**
Defoliation (D)	5	***	***	***	***	***	***	***	***	***	5	*	***	5	***	***	5	***	***
Y*D	5	***	***	ns	**	***	***	***	**	ns	5	*	ns	2	ns	ns	5	***	ns
H*D	5	ns	***	**	ns	***	***	***	*	***	5	ns	ns	5	ns	ns	5	ns	ns
Y*H*D	5	ns	ns	ns	ns	**	*	*	ns	**	5	ns	ns	2	ns	ns	5	ns	ns
R*D	5	*	ns	*	ns	ns	ns	ns	***	ns	5	ns	ns	5	ns	ns	5	ns	ns
Y*R*D	5	ns	ns	ns	ns	**	*	ns	*	ns	5	ns	ns	2	ns	ns	5	ns	ns
H*R*D	5	**	ns	ns	ns	ns	ns	ns	ns	ns	5	ns	ns	5	ns	ns	5	ns	*
Y*H*R*D	5	ns	ns	ns	ns	*	*	ns	ns	ns	5	ns	*	2	ns	ns	5	ns	ns

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

***Significant at 0.001 probability level.

†Abbreviations: GY= grain yield (harvested by hand) in Mg ha^{-1}; RY = relative yield related to control (%); KN = kernel number (Kernels m-^{2}); KW = kernel weight (mg seed-^{1}); RPE= kernel rows per ear; KPE= kernels per ear; KPR= kernels per row; KNP= kernel number per plant; ENP = viable ear number per plant; Missing kernels (% or ear with non-pollinated + aborted kernels); Plant Height= plant height, in cm; Stalk Diam= stalk diameter, in mm; Soil IPARV8, VT, R2, R5= Intercepted Photosynthetically Active Radiation (IPAR, %) taken at ground level at V8, VT, R2 and R5 stages.

Table 5. ANOVA summary for the defoliation study in Lexington, KY in 2012.

Source†	DF	GY	KN	KW	RPE	KPE	KPR	KNP	ENP	Missing kernels (%)	DF	Plant Height	Stalk Diam	DF	Soil IPAR-VT	Soil IPAR-R2	DF	Soil IPAR-V8	Soil IPAR-R5
							P > *F*						*P* > *F*			*P* > *F*			*P* > *F*
Replication	3	**	ns	ns	ns	ns	ns	ns	ns	ns	2	***	ns	1	ns	ns	1	ns	ns
Hybrid (H)	1	ns	ns	ns	**	*	ns	*	ns	**	1	ns	ns	1	ns	*	1	ns	ns
Row (R)	1	**	**	*	**	**	*	**	**	ns	1	*	*	1	ns	ns	1	ns	ns
H*R	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	1	ns	ns	1	ns	ns	1	ns	ns
Defoliation (D)	5	***	***	***	***	***	***	***	***	***	5	ns	***	2	***	***	5	***	***
H*D	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	5	ns	ns	2	ns	ns	5	ns	ns
R*D	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	5	ns	ns	2	ns	ns	5	ns	ns
H*R*D	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	5	ns	ns	2	ns	ns	5	ns	ns

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

***Significant at 0.001 probability level.

†Abbreviations: GY= grain yield (harvested by hand) in Mg ha^{-1}; KN = kernel number (Kernels m-^{2}); KW = kernel weight (mg seed-^{1}); RPE= kernel rows per ear; KPE= kernels per ear; KPR= kernels per row; KNP= kernel number per plant; ENP = viable ear number per plant; Missing kernels (% or ear with non-pollinated + aborted kernels); Plant Height= plant height, in cm; Stalk Diam= stalk diameter, in mm; Soil IPARV8, VT, R2, R5= Intercepted Photosynthetically Active Radiation (IPAR, %) taken at ground level at V8, VT, R2 and R5 stages.

Table 6. ANOVA for the defoliation study in Lexington, KY in 2013.

Source†	DF	GY	KN	KW	RPE	KPE	KPR	KNP	ENP	Missing kernels (%)	DF	Plant Height	Stalk Diam	DF	Soil IPAR-VT	Soil IPAR-R2	DF	Soil IPAR-V8	Soil IPAR-R5
							$P > F$						$P > F$			$P > F$			$P > F$
Replication	3	ns	*	*	ns	*	ns	**	ns	ns	1	*	ns	1	ns	***	1	ns	***
Hybrid (H)	1	ns	ns	ns	***	ns	ns	ns	ns	ns	1	ns	ns	1	ns	ns	1	ns	ns
Row (R)	1	**	*	ns	*	***	*	*	ns	ns	1	ns	ns	1	ns	ns	1	ns	ns
H*R	1	ns	ns	ns	ns	ns	ns	ns	*	ns	1	ns	ns	1	ns	ns	1	ns	*
Defoliation (D)	5	***	***	***	***	***	***	***	***	***	5	*	***	5	***	***	5	***	***
H*D	5	ns	***	***	ns	***	***	***	*	***	5	ns	ns	5	ns	ns	5	ns	ns
R*D	5	ns	ns	ns	ns	**	**	ns	***	ns	5	ns	ns	5	ns	ns	5	ns	ns
H*R*D	5	*	ns	ns	ns	*	*	ns	ns	ns	5	ns	*	5	ns	ns	5	*	*

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
***Significant at 0.001 probability level.

†Abbreviations: GY= grain yield (harvested by hand) in Mg ha^{-1}; KN = kernel number (Kernels m-^{2}); KW = kernel weight (mg seed-^{1}); RPE= kernel rows per ear; KPE= kernels per ear; KPR= kernels per row; KNP= kernel number per plant; ENP = viable ear number per plant; Missing kernels (% or ear with non-pollinated + aborted kernels); Plant Height= plant height, in cm; Stalk Diam= stalk diameter, in mm; Soil IPARV8, VT, R2, R5= Intercepted Photosynthetically Active Radiation (IPAR, %) taken at ground level at V8, VT, R2 and R5 stages.

Table 7. ANOVA summary for the defoliation study for ear IPAR (%) at R2 and R5 in Lexington, KY in 2013.

Source†	DF	EarIPAR-R2	EarIPAR-R5
		P > F	
Replication	1	**	**
Hybrid (H)	1	ns	ns
Row (R)	1	ns	ns
H*R	1	ns	**
Defoliation (D)	5	***	***
H*D	5	*	ns
R*D	5	ns	ns
H*R*D	5	ns	ns

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
***Significant at 0.001 probability level.

[†] EarIPAR-R2 and EarIPAR-R5 = intercepted photosynthetically active radiation (IPAR, %) taken at ear level at R2 and R5 stage, respectively.

Table 8. Main effects on grain yield in Lexington, KY in 2012 and 2013.

	Year			
Main effect	**2012**		**2013†**	
Hybrid	**Yield, Mg ha^{-1}**			
P1360HR	8.87	ns	11.66	ns
P2088YHR	9.75		12.11	
Row (cm)				
38	10.37	a	12.44	a
76	8.26	b	11.33	b

† For 2013, hybrid*row*defoliation was significant.

‡For mains effect, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table 9. Main effects on kernel number and kernel weight in Lexington, KY in 2012 and 2013.

	Year							
Main effect	**2012**				**2013†**			
Hybrid	**Kernels m^{-2}**		**Mg $kernel^{-1}$**		**Kernels m^{-2}**		**Mg $kernel^{-1}$**	
P1360HR	3050	ns	252	ns	3620	ns	269	ns
P2088YHR	2870		299		3742		268	
Row (cm)								
38	3383	a	265	b	3883	a	261	ns
76	2538	b	285	a	3479	b	276	
Defoliation								
Control	3694	ab	311	a	5491	a	309	a
V7-100%	4116	a	309	a	4993	b	292	ab
V14-50%	3277	b	302	a	4864	bc	290	ab
V14-100%	219	d	308	a	599	e	263	b
R2-50%	3756	ab	302	a	4488	c	300	a
R2-100%	2698	c	120	b	1650	d	158	c

† For 2013, Hybrid*Defoliation was significant for Kernel number (KN, kernels m^{-2}) and Kernel Weight (KW, mg $kernel^{-1}$).

‡For main effects, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table 10. Kernel number and kernel weight for hybrid and defoliation in Lexington, KY in 2013.

Defoliation	Hybrid								
	P1360HR		**P2088YHR**		**P1360HR vs P2088YHR**	**P1360HR**		**P2088YHR**		**P1360HR vs P2088YHR**
	Kernels m^{-2}					**mg $kernel^{-1}$**				
Control	5744	a	5239	a	ns	288	a	331	a	ns
V7-100%	5286	ab	4700	ab	ns	276	a	309	ab	ns
V14-50%	5036	bc	4693	ab	ns	278	a	303	ab	ns
V14-100%	658	d	541	c	ns	255	ab	271	b	ns
R2-50%	4446	c	4531	b	ns	295	a	304	ab	ns
R2-100%	554	d	2746	d	*	221	b	95	c	*

‡For hybrids, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among hybrids are indicated by a star. No significant differences are indicated by ns.

Table 11. Main effects on rows per ear (RPE), kernels per ear (KPE), kernels per row (KPR), kernel number per plant (KNP) and viable ear number per plant (ENP) in Lexington, KY in 2012 and 2013.

Main effects	**2012**		**2013**		**2012**		**2013†**		**2012**		**2013†**		**2012**		**2013‡**		**2012**		**2013‡¶**	
Hybrid	**rows per ear**				**kernels per ear**				**kernels per row**				**kernels per plant**				**ears per plant#**			
P1360HR	16.4	a	16.2	a	395	a	410	ns	23.6	ns	24.9	ns	364	A	371	ns	0.83	ns	0.81	ns
P2088YHR	14.6	b	14.7	b	350	b	435		23.6		29.2		326	B	394		0.83		0.84	
Row (cm)																				
38	15.8	a	15.7	a	408	a	452	a	25.4	a	28.7	a	384	a	400	a	0.85	a	0.82	ns
76	15.1	b	15.3	b	336	b	392	b	21.8	b	25.4	b	306	b	366	b	0.81	b	0.83	
Defoliation																				
Control	16.1	a	16.0	a	454	a	568	a	28.1	a	35.5	a	449	a	560	a	0.99	a	0.98	a
V7-100%	15.7	a	15.9	a	486	a	531	ab	30.9	a	33.4	ab	473	a	512	b	0.98	a	0.96	a
V14-50%	15.8	a	15.7	a	381	b	502	b	24.0	b	32.1	b	367	b	497	b	0.95	ab	0.98	a
V14-100%	13.1	b	14.0	c	114	c	219	c	8.9	c	15.5	c	23	c	61	d	0.17	c	0.26	c
R2-50%	16.0	a	16.1	a	442	a	499	b	27.6	a	31.1	b	430	a	479	b	0.97	a	0.97	a
R2-100%	16.2	a	15.0	b	357	b	215	c	22.2	b	14.7	c	330	b	188	c	0.91	b	0.79	b

Viable ears are ears with at least 10 kernels fully developed.

† For 2013, hybrid*row*defoliation was significant.

‡ For 2013, hybrid*defoliation was significant.

¶ For 2013, row*defoliation was significant.

‡For main effects, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table 12. Kernels per ear and kernel per row for hybrid, row and defoliation in Lexington, KY in 2013.

	Row width									
P1360HR	**38-cm**		**76-cm**		**38- vs 76-cm**	**38-cm**		**76-cm**		**38- vs 76-cm**
Defoliation	**kernels per ear**					**kernels per row**				
Control	600	A	569	a	ns	36	A	34	a	ns
V7-100%	580	A	516	ab	ns	34	A	31	ab	ns
V14-50%	531	A	494	ab	ns	31	A	30	ab	ns
V14-100%	272	B	180	c	*	18	B	13	c	ns
R2-50%	559	A	441	b	*	33	A	27	b	*
R2-100%	106	C	70	d	ns	7	C	4	d	ns
P2088YHR										
Defoliation										
Control	545	A	558	a	ns	35	A	37	a	ns
V7-100%	548	A	481	a	ns	36	A	32	a	ns
V14-50%	492	A	490	a	ns	33	A	33	a	ns
V14-100%	350	B	72	c	*	25	BC	6	c	*
R2-50%	509	A	485	a	ns	32	AB	33	a	ns
R2-100%	333	B	352	b	ns	23	C	24	b	ns

‡For each hybrid, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among row widths are indicated by a star. No significant differences are indicated by ns.

Table 13. Kernel number per plant and viable ears number per plant for hybrid and defoliation in Lexington, KY in 2013.

	Hybrid									
Defoliation	**P1360HR**		**P2088YHR**		**P1360HR vs P2088YHR**	**P1360HR**		**P2088YHR**		**P1360HR vs P2088YHR**
	Kernel number per plant					**Viable ears per plant**				
Control	594	A	525	a	*	1.02	A	0.95	a	ns
V7-100%	528	B	495	a	ns	0.96	A	0.96	a	ns
V14-50%	504	B	490	a	ns	0.98	A	0.98	a	ns
V14-100%	70	C	51	c	ns	0.26	C	0.25	b	ns
R2-50%	467	B	491	a	ns	0.95	A	1.00	a	ns
R2-100%	63	C	314	b	*	0.69	B	0.90	a	*

‡For hybrid, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among hybrids are indicated by a star. No significant differences are indicated by ns.

Table 14. Viable ears number per plant for row width and defoliation in Lexington, KY in 2013.

	Row width				
Defoliation	**38-cm**		**76-cm**		**38- vs 76-cm**
	viable ears per plant				
Control	0.97	A	1.00	a	ns
V7-100%	0.98	A	0.94	a	ns
V14-50%	1.00	A	0.96	a	ns
V14-100%	0.15	B	0.36	c	*
R2-50%	0.95	A	1.00	a	ns
R2-100%	0.89	A	0.70	b	*

‡For row widths, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among row widths are indicated by a star. No significant differences are indicated by ns.

Table 15. Main effects on missing kernels, plant height and stalk diameter in Lexington, KY in 2012 and 2013.

Main effects	2012		2013†		2012		2013		2012		2013‡	
Hybrid	**Missing kernels (%)**				**Plant height (cm)**				**Stalk diameter (mm)**			
P1360HR	16	b	13	ns	226	ns	248	ns	19.8	ns	18.5	ns
P2088YHR	22	a	13		231		263		20.4		19.4	
Row (cm)												
38	18	ns	11	ns	234	a	259	ns	20.7	a	19.5	ns
76	20		14		222	b	252		19.5	b	18.3	
Defoliation												
Control	11	a	5	a	233	ns	264	a	20.8	a	19.7	a
V7-100%	13	a	10	a	225		241	b	18.1	b	16.7	b
V14-50%	13	a	7	a	233		251	ab	20.7	a	19.6	a
V14-100%	27	b	16	b	229		249	ab	20.5	a	19.5	a
R2-50%	11	a	7	a	231		263	a	20.2	a	19.4	a
R2-100%	41	c	31	c	221		265	a	20.0	a	18.6	a

† For 2013, hybrid*defoliation was significant.

‡ For 2013, hybrid*row*defoliation was significant.

‡For main effects, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table 16. Missing kernels for hybrid and defoliation in Lexington, KY in 2013.

	Hybrid				
Defoliation	**P1360HR**		**P2088YHR**		**P1360HR vs P2088YHR**
	Missing kernels (%)				
Control	6	A	5	a	ns
V7-100%	8	A	13	ab	ns
V14-50%	6	A	8	a	ns
V14-100%	7	A	24	b	*
R2-50%	8	A	6	a	ns
R2-100%	42	B	19	b	*

‡For hybrid, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among hybrids are indicated by a star. No significant differences are indicated by ns.

Table 17. Stalk diameter for hybrid, row and defoliation in Lexington, KY in 2013.

	Row width				
P1360HR	**38-cm**		**76-cm**		**38- vs 76-cm**
Defoliation	**Stalk diameter (mm)**				
Control	18.9	AB	18.9	a	ns
V7-100%	17.0	B	15.3	b	ns
V14-50%	20.7	A	18.5	a	ns
V14-100%	17.5	B	19.6	a	ns
R2-50%	20.5	A	17.6	ab	*
R2-100%	17.1	B	19.9	a	*
P2088YHR					
Defoliation					
Control	21.9	A	19.3	a	*
V7-100%	18.8	B	15.6	b	*
V14-50%	19.9	AB	19.1	a	ns
V14-100%	22.0	A	19.1	a	*
R2-50%	20.2	AB	19.2	a	ns
R2-100%	19.4	B	18.0	a	ns

‡For each hybrid, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among row widths are indicated by a star. No significant differences are indicated by ns.

Table 18. Main effects on IPAR at soil level for V8, VT, R2 and R5 growth stages in Lexington, KY, in 2012 and 2013.

	2012								2013							
Main effects	**V8**		**VT**		**R2**		**R5**		**V8‡**		**VT**		**R2**		**R5‡**	
Hybrid	**Soil IPAR (%)**								**Soil IPAR (%)**							
P1360HR	57	ns	55	ns	59	b	59	ns	59	ns	71	ns	69	ns	68	ns
P2088YHR	61		59		64	a	62		67		77		66		72	
Row (cm)																
38	65	ns	60	ns	63	ns	62	ns	66	ns	75	ns	68	ns	71	ns
76	53		54		61		59		60		72		67		69	
Defoliation																
Control	63	a†	83	a	86	a	81	a	68	b	90	a	93	a	91	A
V7-100%	36	b					74	b	23	c	75	b	86	a	84	B
V14-50%	65	a	65	b			71	b	74	a	72	b	79	b	82	B
V14-100%	68	a	23	c			37	c	71	ab	24	c	37	c	41	C
R2-50%	63	a			72	b	69	b	70	ab	91	a	79	b	84	B
R2-100%	60	a			28	c	32	c	74	a	91	a	31	c	40	C

‡ For 2013, hybrid*row*defoliation was significant at V8 and R5 soil IPAR readings.

† For main effects, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table 19. The Intercepted Photosynthetically Active Radiation at the soil level at V8 and R5 (soil IPAR-V8 and soil IPAR-R5, respectively) for each hybrid, row width and defoliation in Lexington, KY in 2013.

	Row Width									
P1360HR	**38-cm**		**76-cm**		**38- vs 76-cm**	**38-cm**		**76-cm**		**38- vs 76-cm**
Defoliation	**Soil IPAR-V8 (%)**					**Soil IPAR-R5 (%)**				
Control	62	b†	64	a	ns	91	a	84	a	ns
V7-100%	22	c	17	b	ns	83	a	76	a	ns
V14-50%	82	a	61	a	*	83	a	74	a	ns
V14-100%	73	ab	65	a	ns	52	b	30	b	*
R2-50%	74	ab	57	a	*	82	a	77	a	ns
R2-100%	73	ab	62	a	ns	42	b	40	b	ns
P2088YHR										
Defoliation										
Control	79	a	67	A	*	93	a	95	a	ns
V7-100%	20	b	31	B	ns	86	a	90	a	ns
V14-50%	76	a	77	A	ns	82	a	88	a	ns
V14-100%	79	a	66	A	*	29	b	52	b	*
R2-50%	73	a	77	A	ns	90	a	88	a	ns
R2-100%	84	a	78	A	ns	39	b	39	c	ns

† For each hybrid, means in the same column followed by different letter are significantly different at the 0.05 probability level. Significant differences among row widths are indicated by a star. No significant differences are indicated by ns.

Table 20. Main effects on Intercepted Photosynthetically Active Radiation at R2 and R5 growth stages (earIPAR-R2 and earIPAR-R5, respectively) in Lexington, KY in 2013.

Hybrid	EarIPAR-R2†		EarIPAR-R5‡	
	%		%	
P1360HR	50	ns	54	ns
P2088YHR	56		60	
Row (cm)				
38	52	ns	57	ns
76	53		57	
Defoliation				
Control	87	a	82	a
V7-100%	74	b	76	ab
V14-50%	62	c	71	bc
V14-100%	20	d	24	d
R2-50%	57	c	70	c
R2-100%	16	d	19	d

† For 2013, hybrid*defoliation was significant.

‡ For 2013, hybrid*row was significant.

† For main effects, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table 21. Intercepted Photosynthetically Active Radiation at R2 growth stage at ear level (earIPAR-R2) for hybrid and defoliation in Lexington, KY in 2013.

	Hybrid				
Defoliation	P1360HR		P2088YHR		P1360HR vs P2088YHR
	EarIPAR-R2 (%)				
Control	84	A	90	a	ns
V7-100%	68	B	80	b	*
V14-50%	57	C	68	c	*
V14-100%	17	D	24	d	ns
R2-50%	54	C	60	c	ns
R2-100%	21	D	12	e	*

‡For hybrid, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among hybrids are indicated by a star. No significant differences are indicated by ns.

Table 22. Intercepted Photosynthetically Active Radiation at R5 growth stage at ear level (earIPAR-R5) for hybrid and row in Lexington, KY in 2013.

Hybrid	Row Width				
	38-cm		76-cm		38- vs 76-cm
	EarIPAR-R5 (%)				
P1360HR	57	B	51	b	*
P2088YHR	58	A	62	a	*

‡For rows, means in the same column followed by different letters are significantly different at the 0.05 probability level. Significant differences among row widths are indicated by a star.

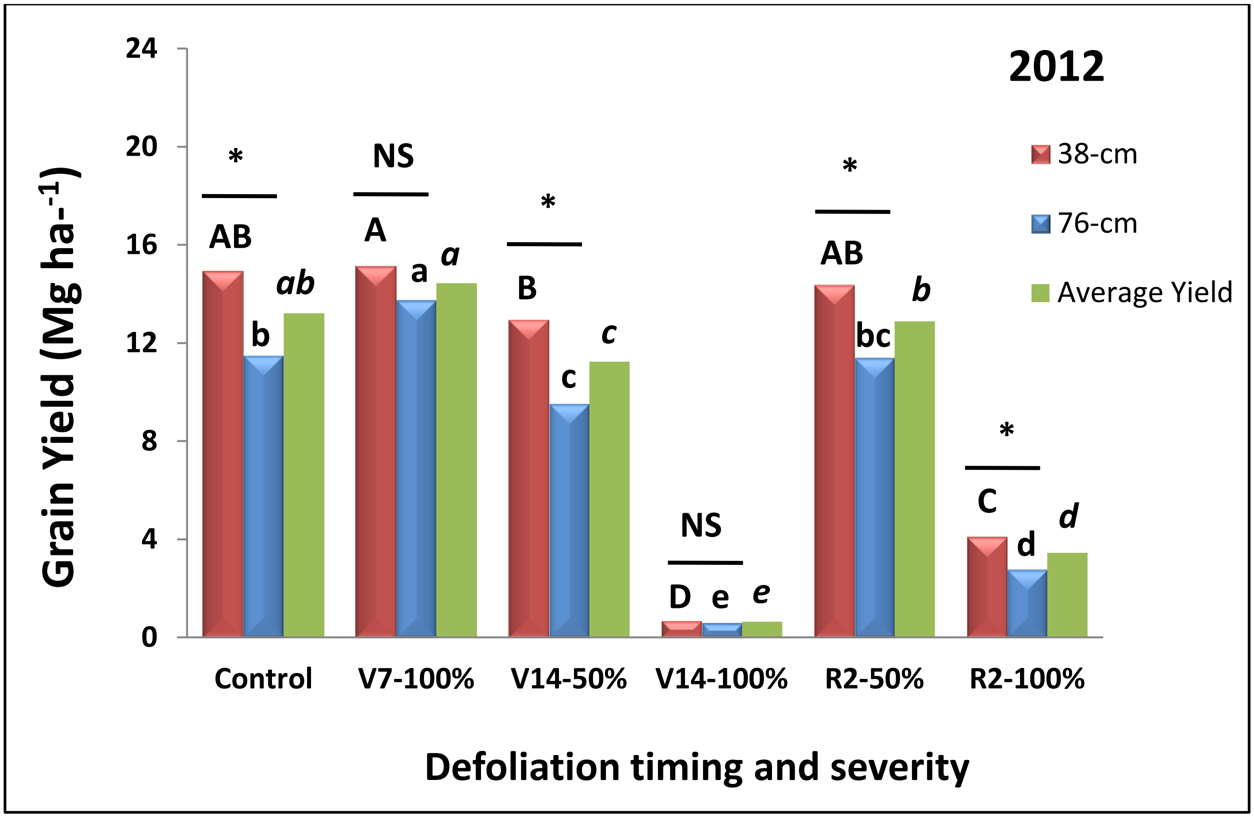


Figure 6. Defoliation effect on grain yield in Lexington, KY in 2012 for each row width and averaged across row widths. Different letters over the bars indicate significant differences *(p ≤0.05)* among comparisons. Capital letters are for comparisons within 38-cm rows. Lower case letters are for comparisons within 76-cm rows. Italic lower case letter are for comparisons among averaged defoliation treatments. An asterisk (*) above two bars represents a significant difference among row widths for a defoliation event. NS indicates no significant difference.

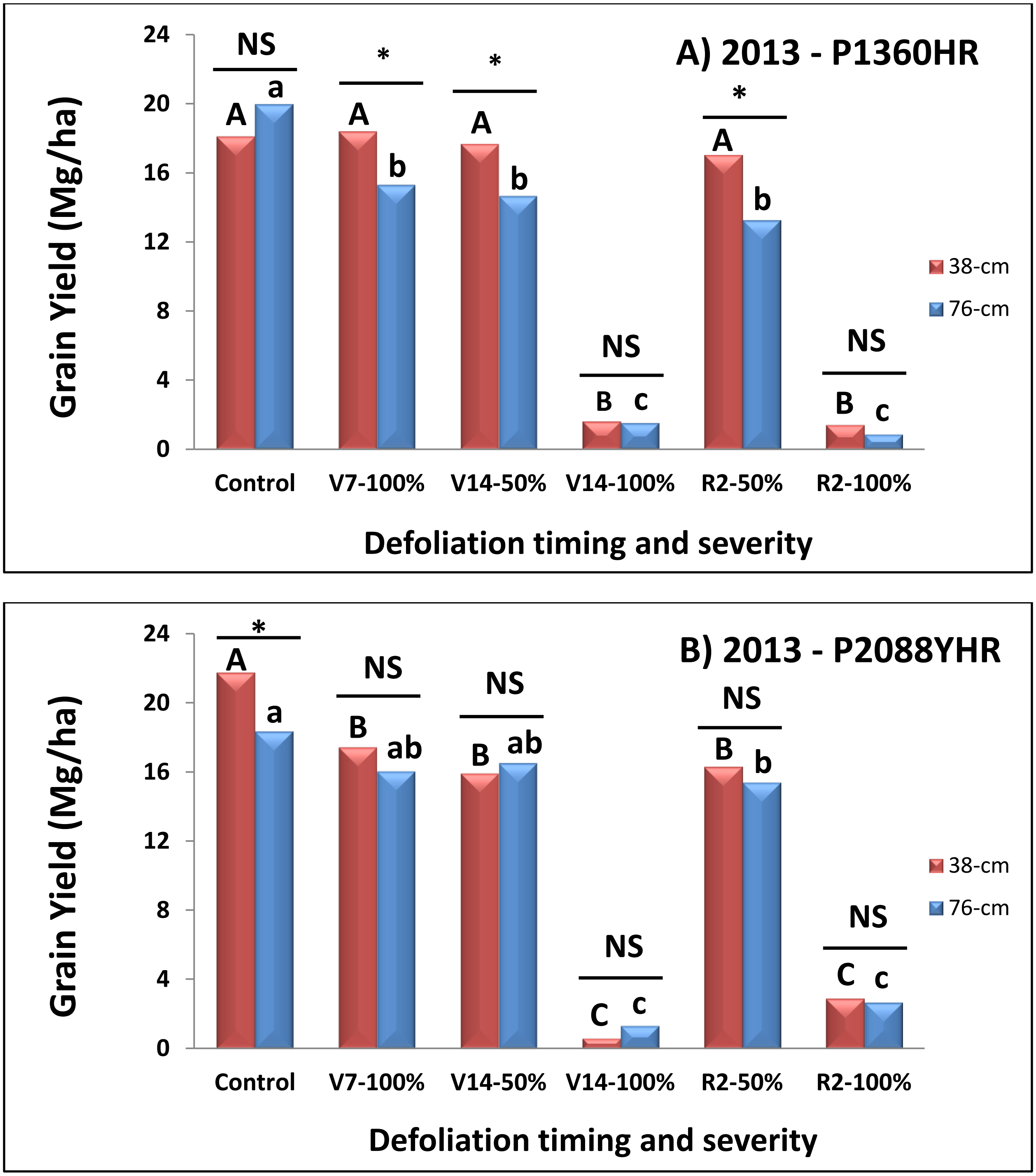


Figure 7. Defoliation effect on yield in Lexington, KY in 2013 for A) P1360HR and B) P2088YHR. Different letters over the bars indicate significant differences ($P < 0.05$) among defoliation treatments. Capital letters are for comparisons within 38-cm rows. Lower case letters are for comparisons in 76-cm rows. An asterisk (*) above two bars represents a significant difference among row widths for a defoliation event. NS indicates no significant difference.

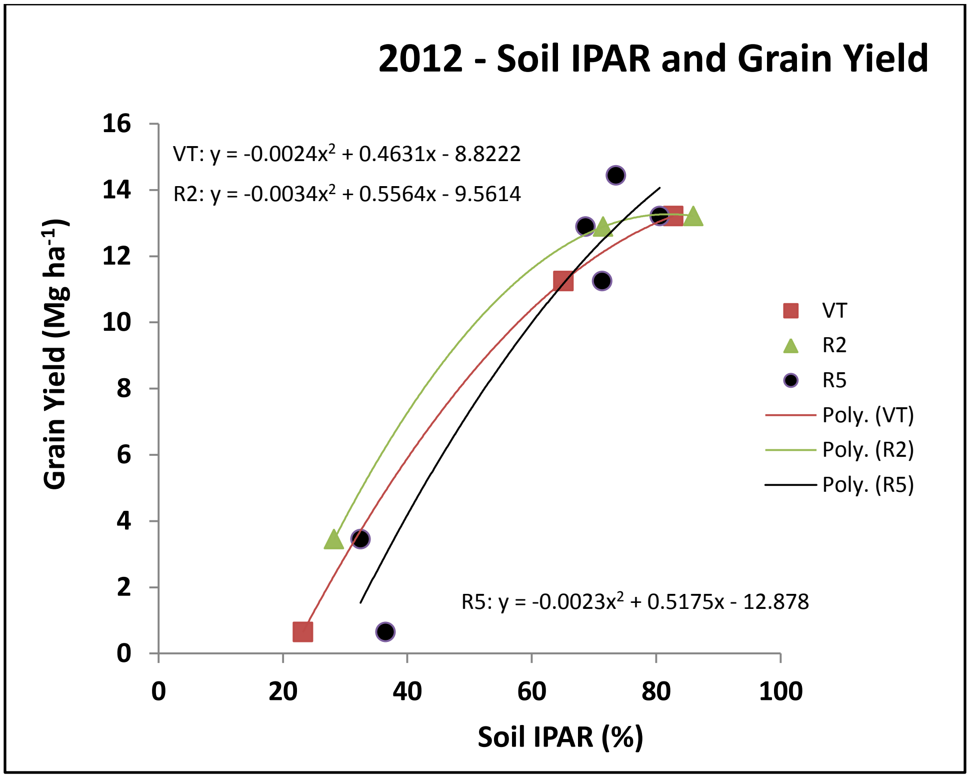
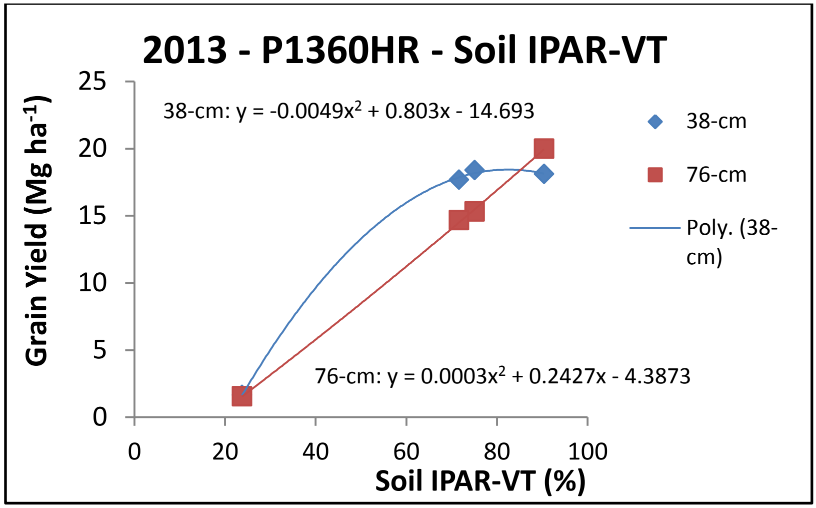
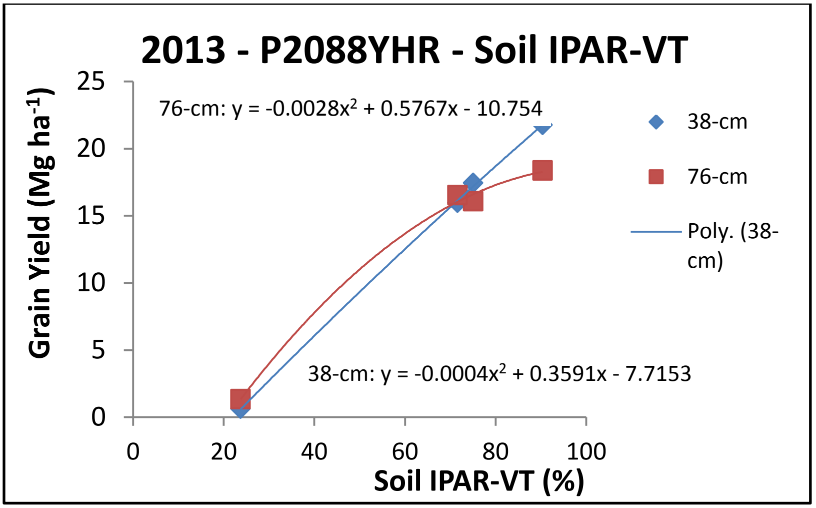


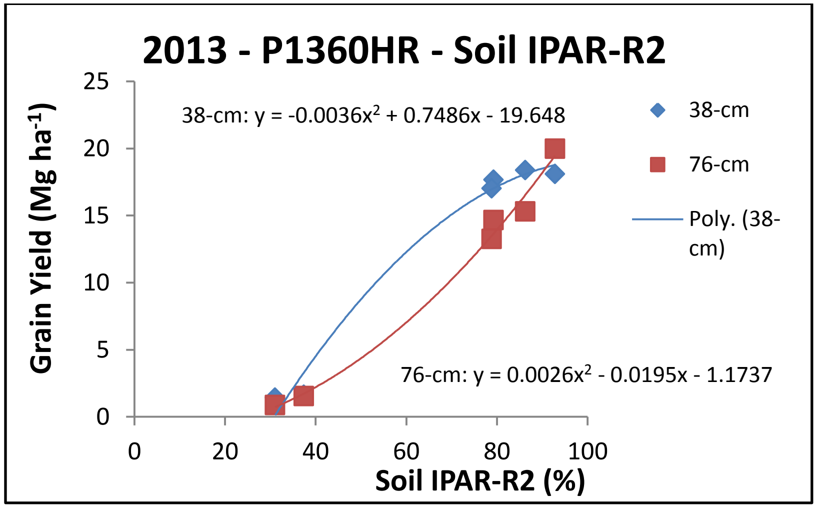
Figure 8. Soil IPAR (%) at VT, R2 and R5 (averaged across hybrids and rows) and grain yield relationship in Lexington, KY in 2012.



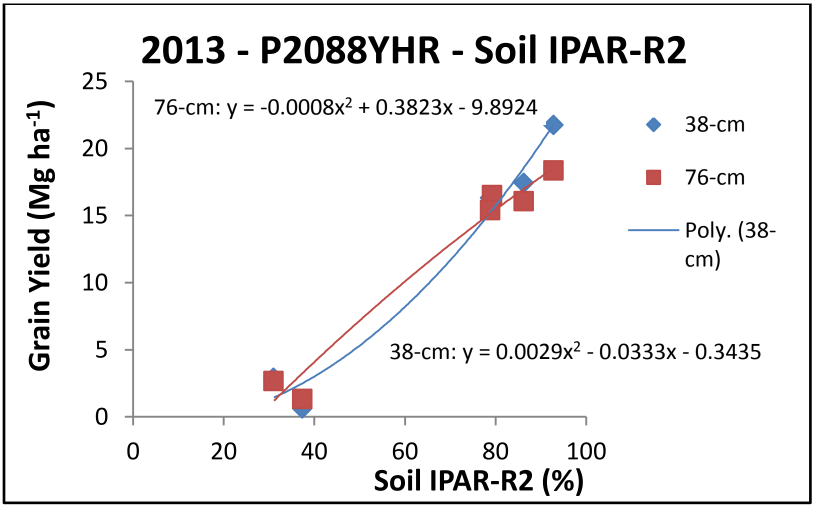
2013 - P1360HR - Soil IPAR-VT



2013 - P2088YHR - Soil IPAR-VT



2013 - P1360HR - Soil IPAR-R2



2013 - P2088YHR - Soil IPAR-R2

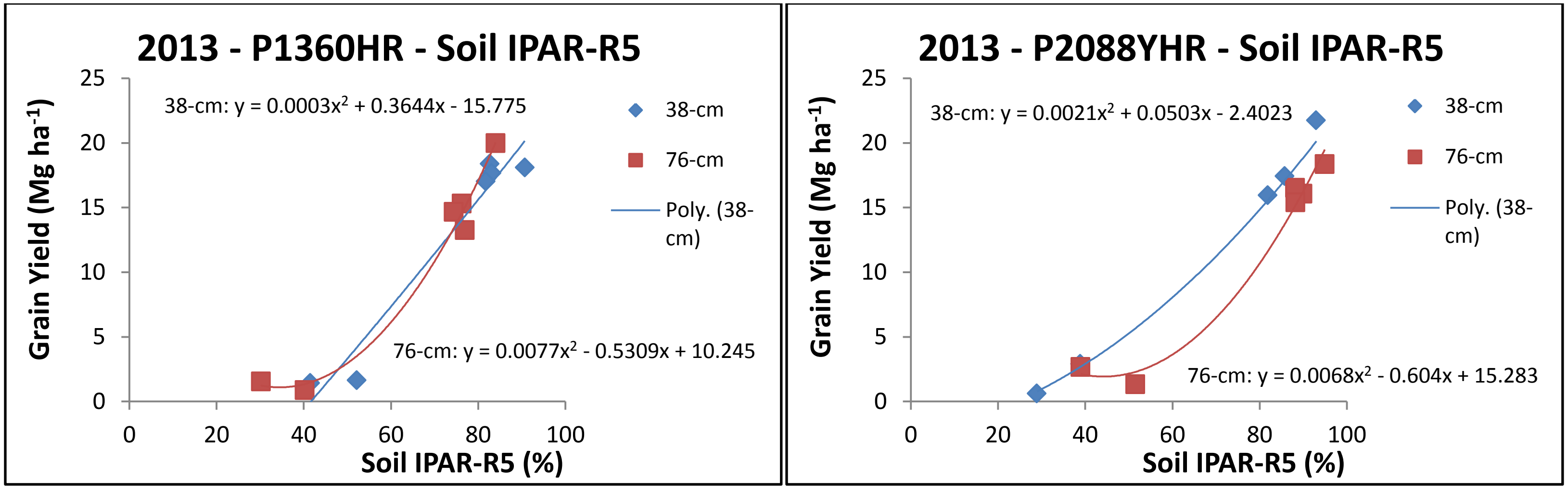


Figure 9. Soil IPAR (%) at VT, R2 and R5 for hybrid P1360HR and P2088YHR and grain yield relationship in Lexington, KY in 2013.

CHAPTER 4

DISCUSSION

4.1. Grain yields in 2012 and 2013

The contrasting weather conditions for 2012 and 2013 at our experimental site affected crop response to defoliation. The length of the corn growing period was very similar both years (late April-early May to mid-September), but the temperatures were higher and the rainfall amount was lower and less evenly distributed for 2012.

The stressful weather scenario for corn in 2012 might have eliminated the genotype differences between hybrids in this experiment. In this year, the hot, dry weather compressed tassel and silk emergence such that both hybrids approximately reached VT-R1 stage on the same day, although both hybrids were rated as 6 days apart for relative maturity. Duration of R2 growth stage in 2012 was approximately 4 days shorter than in 2013 (i.e. 5 vs. 9 days) (Table A6 and A7, Appendix). Grain filling-period (from R2 to R6) was shortened due to excessively high temperatures in 2012 with an approximate length of 42 days in contrast with the 51 days in 2013. Tollenaar and Bruulsema, (1988) in corn and Egli and Wardlaw (1980) in soybean observed that higher temperatures correlate with shorter seed-filling period. Problems associated with environmental stresses like severe heat and low humidity in corn can desiccate emerged silks and make them no longer receptive to pollen grain germination (Nielsen, 2009), reduce pollen viability (Herrero and Johnson, 1980) and affect silk receptivity (Basetti and Westgate, 1993). In our experiments in 2012, a considerable proportion of corn tassels did not fully emerge from the final leaves of the upper whorl. Furthermore, this pattern was rather seen in the whole experiment than in particular treatments. In these cases, pollen shed within the whorl of the leaves, instead of into the open air. This failure can lead to unsuccessful pollination (Nielsen, 2012), causing asynchronous flowering so that the pollen is shed when no viable silks are present or, if present, the spatial constraint for pollen complicates or even make pollination impossible, as most likely occurred in defoliation study in 2012. The result of this phenomenon was an increase of 53% in the total missing kernels (aborted kernels + ovules that failed to pollinate) in 2012 in comparison with 2013. All these responses highlight the importance that pollination and fertilization have in corn (Egli, 1998). Short delays in both anthesis and silking occurrence where evident in V7-100% defoliated plants at both years, as previously reported by Cloninger et al. (1974) and Johnson (1978). Same as in 2012, hybrids reached VT-R1 stage approximately at the same day in 2013, but R1 stage was 3-4 days longer for hybrid P2088YHR. This difference in the Anthesis-Silking interval (ASI) may partly explain different responses to row width and defoliation in 2013.

The expressed differences in weather at each year likely explain several interactions that occurred when comparing grain yield and yield components across years. Overall, grain yields (across hybrids, rows and defoliations) were 28% higher in 2013.

Data on the effect of row widths on the response of corn grain yield response to defoliation is scarce. In our study, when grain yield differences occurred among row widths in 2012, grain yields were 26% greater in 38-cm rows. When differences between row widths across defoliation treatments were found in 2013, 38-cm rows performed better in all situations. Andrade et al. (2001) working in Argentina with 100% defoliation at V3 and V5 also found grain yield increases in 52-cm vs. 70-cm rows. In the US, others also documented grain yield increases when narrowing rows in Michigan (Widdicombe and Thelen, 2001; Thelen, 2006), Minnesota (Porter et al. 1997) and Indiana (Nielsen, 1988). In 2013, the effect of complete defoliation at V14 and R2 were not affected by row widths, as they were in 2012, where R2-100% defoliation performed better than V14-100%. In this year, hybrid P1360HR responded to defoliation better in 38-cm rows while P2088YHR responded to defoliation better in wide rows. However, caution has to be exercised at this point. This last response might suppose the consequence of the overall highest grain yield for the experiment at the control for P2088YHR at 38-cm rows, significantly greater than that for 76-cm. As a result of this highest grain yield ceiling, all grain yields after defoliation treatments were reduced. A much lower grain yield for 76-cm might in part explain the better performance to defoliation events for this hybrid at wide rows (i.e. some defoliation treatments yielded the same than its control). The study of two factors separated from the three used in our study (i.e. hybrid, row width and defoliation) reveals some inconsistencies. Nielsen (1988), Porter et al. (1997) and Widdicombre and Thelen (2001), did not find an interaction between hybrids and row widths, while Farnham (2001) found one. Inconsistency in hybrid maturity response to defoliation was also identified by others (Hanway, 1969; Crookston and Hicks, 1977), although these studies only used one row width (102- and 75-cm rows, respectively). Perhaps corn maturity is important for investigating row width when defoliation is present. In 2013, a three-way interaction among hybrids, rows and defoliation was present.

Regarding defoliation, the untreated control was among the greatest grain yields in all comparisons. Grain yield losses to hail damage on young plants are often minimal (Jenkins, 1941) or null, as evidenced in our experiment for V7 growth stage defoliation. In one comparison (P1360HR in 76-cm rows in 2013), V7-100% reduced grain yield which is similar to the observation by Johnson (1978) in Illinois. In all other comparisons, early defoliation did not increase grain yields, contrary to reports by Crookston and Hicks (1977), who found grain yield increases of 48% after early defoliations in an early maturing hybrid working in Minnesota.

Grain yield responses to 50% defoliations during corn critical period for yield determination (V14, a few days prior to anthesis, and R2), were mixed, with reductions ranging from 10 to 22% in 2012 and from 25 to 27% in P2088YHR in 2013, to no differences from maximum grain yields in P1360HR in 2013. Clearly, complete defoliation during the critical period were the most detrimental for yield in all comparisons, with grain yield losses ranging 91 to 97% for V14-100%, and 76 to 95% for R2-100% defoliation. These findings are in agreement with a large body of literature produced in the last 130 years (Hume and Franzke, 1929;

Culpepper and Magoon, 1930; Dungan, 1930; Dungan, 1934; Eldredge, 1935; Jenkins, 1941; Hanway, 1969; Egharevba et al., 1976; Tilahun, 1993; Andrade, 1999; Adee et al., 2005).

4.2. Grain yield and its relationship with primary and secondary yield components and plant architecture parameters

4.2.1. Primary yield components

There is a widespread scientific agreement in the use of kernel number per surface unit area and kernel weight as the main yield components for grain crops. Egli (1998) gave an exhaustive and interesting explanation on the historical use and misuse of yield components. He expressed that the yield component approach was hindered by the tendency of some researchers to create too many components. The simple use of the equation yield = number of seeds per area x weight per seed contains the primary grain yield components (seed number and seed size) that determine yield. More important, this equation applies to all crops (Egli, 1998).

For both years, both KN and KW affected grain yield and defoliation treatments appeared to have greater impact on KN. In both years, grain yields reductions with V14-100% defoliations were explained by reductions of 90-95% in KN. Reductions in KW (about 18%) for V14-100% defoliations only occurred for some comparisons in 2013, but not in 2012. For R2-100% defoliations, grain yield reductions were always a function of reduction in both KN (-35% to -90%) and KW (-25% to -71%). Grain yield reductions after 50% defoliations at V14 and R2 are only explained by KN reduction (12 to 23%). The lack of reductions in KW for partial defoliations at the beginning of grain filling period (R2 stage) in our experiments, is in disagreement with Borras et al. (2004) findings, who stated that KW for corn seems to be highly sensitive to reductions in assimilate production during seed filling in all cases. Conceivably, an increased remobilization of stem reserves probably contributed to maintain kernel growth rates in partial defoliated plants in our experiments, as stated by Echarte et al. (2006). Different from Echarte et al. (2006), however, duration of the grain-filling period for a particular year was not reduced in our experiments by either combination of defoliation timing and severity (Table A6 and A7, Appendix). The reduction in grain filling period that we found in R2-100% defoliation in 2012 was most likely a result of the high temperatures during the last part of the filling period in that year, and contrary to the general temperature effect in pollination rates, this “grain-filling length” effect only affected R2-100% treatments. Admittedly, this reduction in grain-filling period might have also been expected for V14-100% treatment, since even higher temperatures occurred at the VT-R1 critical period in 2012. Nonetheless, the lack of viable ears with fully-develop kernels in most plants for this treatment, the lowest yielding in 2012, prevented any meaningful evaluation of the grain-filling process. Reduction in R2 growth stage at R2-100% in 2012 it mainly explains the concomitant total reduction of about 9 days between total grain-filling periods between years. Besides, the range in KN decline for our experiment (12 to 95%) was wider than the range (23 to 38%) obtained by Echarte et al. (2006). In the case of Echarte et al. (2006) defoliations were less intense and only applied 27 days after R1 (later than our last defoliation at R2), which most likely explains the differences between comparisons. Finally, our findings agreed with others in that grain yield losses associated with defoliations around tasseling/silking are mainly explained by fewer final KN (Culpepper and Magoon, 1930; Hanway, 1969; Egharevba et al., 1976; Severini et al., 2011). However, our data in both 2012 and 2013 suggest that KN can also be largely modified by partial and complete defoliation during grain-filling period (R2, blister stage and on), contrary to other reports (Hanway 1969; Egharevba et al. 1976; Hicks et al. 1977; Echarte et al. 2006). The concept of thermal time (TT) can be used in order to clarify this important discrepancy with findings from other authors. It is important first to elucidate the beginning of the effective grain-filling period for corn. This phase takes place immediately after the end of the "lag" phase, a formative period in which biomass accumulation is very slow. During the effective grain-filling period, more than 80% of the final weight is deposited in the kernel (Carcova et al., 2003b). Indeed, when we (and in most research) referred as grain-filling, we are basically talking about this effective filling period. The "lag" phase extends approximately 150 to 235 °C day^{-1} post-silking (R1) (Maddonni et al., 1998; Otegui et al., 2000 cited by Carcova et al., 2003b). Taking a base temperature of 8 °C as a reference for corn in template regions (Cirilo, 1994; Ritchie and Nesmith, 1991) we found that:

- In 2012, from July 4th (approximately beginning of R1 stage for both hybrids; Table A6) until July 17th (R2 defoliation; Table 3), the corn accumulated 273 °C day^{-1}.
- In 2013, hybrid P1360HR accumulated 147 °C day^{-1} from July 10th to July 18th, and hybrid P2088YHR accumulated 231 °C day^{-1} from July 10th to July 23th (beginning of R1 and R2 defoliation for each hybrid, respectively; Table A7 and Table 3).

The case of hybrid P1360HR is in the low limit for the duration of the "lag" phase. In the other two comparisons, the TT for the period beginning of R1 stage-R2 defoliation timing is either close to the upper limit (P2088YHR in 2013) or above (both hybrids in 2012) the length of "lag" phase measured from R1. In other words, we may hypothesize that the defoliation treatments we imposed at R2 stage in both years were, at least for these two last examples, at the onset of "lag" phase and the beginning of the effective grain-filling period. This supports our idea that KN can potentially be reduced by partial and complete defoliation that occur, at least, at the beginning of the grain-filling period (R2 stage).

4.2.2. Secondary yield components

Grain yield reductions can be explained by changes in several of the secondary yield components. For instance, P1360HR had greater RPE, KPE and KNP than P2088YHR in 2012. However, final grain yield for both hybrids was the same. A greater, but still not significantly different, KW for P2088YHR might have adjusted differences here.

Grain yield increases for 38-cm rows in 2012 and in most comparisons in 2013, were a function of greater RPE, KPE, KPR, KNP, ENP, stalk diameter and plant height. Greatest reductions in RPE, KPE, KPR, KNP and ENP were a result of V14-100% defoliations in most comparisons, followed by R2-100% defoliations. Significant yield losses from 50% defoliations atV14 and R2 were a function of reductions in KPE, KPR or KNP, but never due to reductions in the number of viable ears produced per plant (ENP). Complete defoliations well before the critical period for yield determination (i.e. V7-100%) did not change secondary yield components in most comparisons, which also explain the lack of grain yield reductions for this treatment in most comparisons.

Particularly important among secondary yield components is KNP (Tollenaar, 1992). In our experiments, this parameter was considerably affected by complete defoliations around flowering (V14 and R2), which reduced KNP by about 90 to 95%, similar to observations by Tollenaar (1992). Partial defoliations at V14 and R2 also reduced KNP in the order of 15-30%. Echarte et al. (2006) did not observe any defoliation effect on KNP for hybrids defoliated after R1 stage.

4.3. Grain yield and IPAR (%) at soil and ear level.

Light interception is important to grain yield. The two treatments resulting in the least IPAR values at R5 growth stage also resulted in the least grain yield. Increased IPAR generally correlated with increasing yield up to a certain threshold and those thresholds differed for certain comparisons. The defoliations timings and severities affected IPAR values throughout the remaining development of the corn plants. Plants defoliated at V7 recovered to 75 and 86% IPAR by R1 and R5, respectively, and achieved yields similar to the control. Plants completely defoliated at V14 or R2 recovered to about 40% IPAR by R5 but lost yield. In 38-cm rows, P1360 needed about 72-79% IPAR for maximum yield while P2088 required 90-93% IPAR to maximize yield. Both hybrids needed about 80% IPAR in 76-cm rows to maximize yield. When significant differences in IPAR occurred, 38-cm rows resulted in greater IPAR values.

Our findings indicate that leaves above and below the ear were both critical for final grain yield determinations, as stated before by Hanway (1969) and Egharevba et al. (1976).

SUMMARY

Defoliation and grain yield

- There was no yield difference among hybrids under study in 2012. In 2013, hybrids were involved in a three way interaction with row width and defoliation.
- Yields for 38-cm rows were 26% greater in 2012. In 2013, yields for different rows and defoliations were hybrid-dependent. Across defoliations, earlier-maturing hybrid P1360HR performed better in 38-cm, while later maturing-hybrid P2088YHR did better in 76-cm rows. However, this last response might suppose the consequence of the overall highest grain yield for the experiment at the control for P2088YHR at 38-cm rows, significantly greater than that for 76-cm. When differences between rows occurred, 38-cm performed better in most situations.
- Untreated control and V7-100% were among greatest yields in all comparisons.
- Complete defoliations at V14 and R2 (during critical period for yield determination in hybrids under study) reduced yield by the most. Partial defoliations at V14 and R2 reduced yields in some, but not all cases.

Grain yield and yield components

- In 2012, KN was greater for 38-cm rows. KW was greater for 76-cm rows. In 2013, when differences in yield among row widths occurred, a greater KN component explained greater yields for 38-cm.
- KN was reduced most by V14-100% defoliation in both years.
- KW was reduced most by R2-100% defoliation in both years.
- Grain yield reductions for V14-100% defoliation were always explained by reductions in KN. Grain yield reductions for R2-100%, were always a function of both KN and KW decline. Grain yields reductions for partial defoliation at V14 and R2 were always explained by reductions in KN.
- KN and KW main components were better to explain grain yield differences in our experiment.
- Grain yield differences were not always satisfactorily explained by changes in secondary yield components.
- Yield increases at 38-cm, when occurring, were a function of greater KPR, KPE, KNP, ENP, stalk diameter and plant height.
- Defoliations at V14-100% and R2-100% affected all secondary yield components.

Grain yield and IPAR (%)

- At the VT growth stage, IPAR was 90% or greater for the untreated plants.
- Hybrid P1360HR maximized grain yields in defoliated plants with lower IPAR (ranging 72 to 79%) at VT and R2 for 38-cm than in 76-cm rows. Maximum grain yields in hybrid P2088YHR were only attained with soil IPAR values at or above 90% at 38-cm rows for the period VT-R2.
- Changes in the light interception patterns after defoliation event for partial defoliations at V14 and R2 did not change yields in all cases.

CONCLUSION

In summary, at the beginning of our experiment, we hypothesized that corn grain yield reduction from defoliation events would be less in 38-cm than in 76-cm rows. Our findings suggest that grain yield loss in narrow rows may be less after a defoliation event. Similar to other studies, greatest yield losses occurred for severe defoliation events slightly before or after tassel and silking (V14 and R2 in this case). Partial defoliations during this part of the corn growth period reduced yields in some cases, but not in all. Early defoliations in the crop growth period, even when severe, did not reduce grain yields in most cases, due to a satisfactory post-defoliation crop recovery that increased leaf area index, allowing corn plant to achieve maximum soil and ear IPAR values by the critical period for yield determination. In 2012, with a hot and dry season, soil IPAR values around 85% at the critical period were needed to maximize grain yields. In 2013, a year with better overall growing conditions, IPAR between 72 to 79% in narrow rows during the critical period were enough for maximum grain yields in defoliated plants for the 113-RM hybrid. However, for the 120-RM hybrid, only IPAR values at or above 90% in narrow rows attained maximum grain yields. This response may indicate that some hybrids are better adapted to varying losses in their photosynthetically active canopy than others. Finally, there was a significant interaction effect on grain yield involving hybrids, rows and defoliations in 2013. The three-way interaction on grain yield and the hybrid effect on IPAR and grain yield relationship implied that hybrids may respond differently to defoliation at different row widths. More studies on the effect of different row widths to corn yield response after defoliation are needed to strengthen the evidence found in this study.

APPENDIX DEFOLIATION STUDY

Table A1. 2012 Kentucky cash receipts.

RANK	COMMODITY	MILLION DOLLARS	% OF TOTAL
1	Broilers	866.6	16.4
2	Corn	828.8	15.7
3	Horses	810.0	15.3
4	Soybeans	741.3	14.0
5	Cattle and calves	656.7	12.4
6	Tobacco	384.9	7.3
7	Dairy products, Milk	219.6	4.2
8	Wheat	201.3	3.8
9	Hay	142.4	2.7
10	Chicken eggs	116.1	2.2
11	Hogs	115.4	2.2
	All Other Commodities	201.0	3.8

Source: “USDA-NASS-Kentucky Department of Agriculture. 2013. A quick guide: Agricultural Facts. Kentucky Agriculture 2013. At: *http://www.nass.usda.gov/Statistics_by_State/Kentucky/Publications/Pamphlets/KYataGlance2013.pdf*

Table A2. Kentucky value of crop production, 2012.

CROP	Hectares harvested	Yield (Mg ha^{-1})	Production (Mg)	US rank
CORN				
For Grain	619,169	4.27	2,642,836	18
For silage	36,422	13.00	473,482	-
TOBACCO				
All	35,208	2.52	88,593	
Burley	29,947	2.30	68,810	1
Dark Fire-Cured	3,642	3.92	14,288	1
Dark Air-Cured	1,619	3.36	5,443	1
WHEAT, WINTER	190,202	4.17	793,048	17
SOYBEANS	594,888	2.69	1,600,248	16
HAY				
All	963,152	2.00	1,926,304	4
Alfalfa	72,843	3.00	218,530	25
All other	890,308	2.00	1,780,617	3

Adapted from: "USDA-NASS-Kentucky Department of Agriculture.2013. A quick guide: Agricultural Facts. Kentucky Agriculture 2013. Source: *http://www.nass.usda.gov/Statistics_by_State/Kentucky/Publications/Pamphlets/KYataGlance2013.pdf*

Table A3. Summary for relevant defoliation studies.

Reference	Study	Hybrids / inbred lines †	Maturity ‡	Defoliation timing ∏	Defoliation intensity ¶	Final yield ψ	Yield component affected ₳
Dungan (1934) (Illinois)	1925-1929	1925-1928: uniform strain of open-pollinated Reid Yellow Dent	-	VT , R1 , R2 , R3 and R5	8.3 , 16.7 , 25 , 33.3 , 50 , 66.7 , 83.3 and 100%	About 100% loss for 100% def. at VT and R1; then decreasing till reach 0% at maturity. Little effect of def. up to and below 25% at any stage other than VT.	No reference about KN. KW most reduced by R2 def.
		1929: F $_1$365	-				
Lindstrom (1935) (Iowa)	1933	6 lots of F$_1$ inbreed progenies	-	From +9 to +21 days after planting	75% to 85% top plant aerial portion	15% to 33% yield loss from early to late cutting, respectively.	-
Dungan and Gausman (1951) (Illinois)	1945-1948	1945-1947: double cross-hybrids U.S. 13, Illinois 201 and Illinois 972	-	V6 and V7/V8	Cutting at soil level and 5-cm above soil level at each stage	V6: 44% and 26%; V7/V8: 97% and 54% yield losses for ground and +5-cm level respect.	-
		1948: eight adapted single crosses and eight standard inbreds	-	V5/V6 and V8/V9	Cutting at soil level and 6-cm above soil level	From 18% (V5/V6, soil level) to 48% (V8/V9, 6-cm above soil) yield reduction	-
Hanway (1969) (Iowa)	1965	3 hybrids: early (B8xW153R), midseason (Wf9xB37) and late (B14xC131A)	-	V10 , VT and R2	50% and 100%	15, 25, 20% for 50% def. and 30, 98, 69% for 100% def. at V10, VT and R2 respect.	KN and KW for all treatments except VT-100% (complete barrenness)
Cloninger et al. (1974) (Missouri)	1969-1970	28 single crosses among 8 inbreds lines (Va35, H49, B57, B37, B14A, Mo17, Mo5, N38A)	74 to 88 days to VT	V3 - V4/V5 - V6	Ground level cutting	Average 11%, 38% and 46% yield reduction for V3, V4/V5 and V6 respectively.	-
						Yield increase in five singles crosses clipped at V3 and one cross clipped at V4/V5	

Egharevba et al (1976) (Missouri)	1971-1972	P3773, P3306 and P3149	Early-, mid- and late-season, respectively	Starting 10 days after R1 (50%) and continued at 10-day intervals for the next 40 days	All leaves below ear, all leaves under ear and all leaves	Complete def more detrimental (6 to 82% losses) than partial def. (2 to 33% losses).	KN most reduced with 100% def. from +0 to +10 days after 50% R1. KW most important from +20 days and more from 50% R1 and/or partial def.
Hicks et al (1977) (Minnesota)	1973-1975	Short-season (Trojan TXS 85) and full-season DeKalb XL45a	90 and 115 RM	V3/V4, V11, VT, R3 and R5	100% at V3/V4; 50% and 100% for the rest	100% yield loss for VT-100% def. Slightly greater yield losses at R2 (range: +4 to -47%) than V11 def timing (range: -3.5 to -31%); 100% rates always produced greater losses than 50% rates.	KN nor recorded. KW not affected before VT. After VT, KW was greatly reduced only at 100% def. rates.
Crookston and Hicks (1977) (Minnesota)	1973-1975	Short-season (Trojan TXS 85) and full-season DeKalb XL45a	90 and 115 RM	V3/V4	100%	8% yield loss for full-season hybrid; 48% average increase for short season.	KW not affected; authors hypothesized KN was comp affected
	1975	12 short-season hybrids (one location)	Ranging from 70 to 95 RM			Average yield increase of 13% (range: +37% to -14%).	-
	1976	12 short-season hybrids (three locations)				Average yield response ranged from 0 to-22% from southern to northern locations (Minnesota)	-
Johnson (1978) (Illinois)	1976-1977	9 hybrids (Funks 5048, Trojan TXS85, Sokota SK36, Pioneer 3976, Jacques JX62, DeKalb XL12, DeKalb XL310, Minhybrid 7301, DeKalb XL43a) (loc. 1)	8 early-season hybrids ; DeKalb XL43a full-season	V3/V4	100%	11.2% yield decrease (averaged across both years and 9 hybrids)	Smaller ears
	1976	4 early-season and one full-season hybrids (loc. 2)	-			13% yield decrease (averaged across 5 hybrids)	
	1977	2 early-, 2 mid- and 2 full-season hybrids (loc. 2)	-	V2, V3 and V4		10% yield decrease (average across 6 hybrids)	

Adee et al (2005) (Illinois)	1997-1999	P3394, P3489 and P33Y18	2660, 2630 and 2710 GDD	V14, R1, R2, R3 and R5	20% of the leaf area at one or more corn growth stages	Yield declined linearly with def. initiated at V14 through R3. Losses associated with any level of def. did not differ between V14 and R3. After R3 yield losses diminished. Def. at R5 did not affect final yield.	-
Echarte et al (2006) (Argentina)	2000-2001	DKF880, M400, DK4F36, DK664 and DK752	120-, 128-, 127-, 116- and 125-RM	27 days (≈330 growing degree days) after R1 of each hybrid	Aiming at reducing canopy photosynthetically active radiation (PAR) interception by 1/3 with respect to intact canopies	-	Defoliation 27 days after R1 reduced KW and grain filling period for all hybrids. No effect on KN not Kernel growth rate.

† As quoted in the original work.

‡ Either days to 50% pollen shedding or to physiological maturity.

∏ Vn: number of leaves completely unfolded; TS: Tasseling or anthesis; R1: Silking; R2: Blister-stage; R3: milk-stage; R5: dent-stage.

¶ Percentage of blades removed if nothing else stated.

ψ As a function of the control no defoliated treatment.

₳ Kernel Number (KN) and/or Kernel Weight (KW).

Table A4. Summary of defoliation and row width literature.

Reference	Study	Location	Hybrids †	Row widths	Yield (Mg ha-$^{-1}$)	Notes
Nielsen (1988)	1984-1986	Three locations in West-central and Northwest Indiana	Early (1) and full-season (1)	38- and 76-cm	Average yield increase 2.7% ($P \leq 0.01$) when narrowing rows from 76- (9.23 Mg ha^{-1}) to 38-cm (9.45 Mg ha^{-1}). Yield for 38-cm rows ranging from -3.1% to +8.2% when compared to 76-cm rows	Plant populations (4) from 45,000 to 89,000 pl ha^{-1}. Significant ($P \leq 0.01$) year-by-location-by-row interaction. No hybrid x row interaction
Nielsen (1996); Compilation of data	1960's - 1970's	US Corn Belt	-	76- and 102-cm	General consensus: +5-7% yield by switching from 102- to 76-cm	-
	Mid-80's to early 1990's	Central and Northern US Corn Belt	-	Narrow rows (≤57-cm) vs 76-cm	Narrow rows (≤57-cm) increased yields as much as 10% compared to 76-cm rows.	Magnitude of yield increase varied greatly from year to year.
	1989-1991	Michigan	-	56- and 76-cm	A +8.8% yield for 56- (10.05 Mg ha^{-1}) vs. 76-cm rows (9.23 Mg ha^{-1}).	-
	1992-1993	Minnesota	-	51- and 76-cm	A +10% yield for 51- (7.66 Mg ha^{-1}) vs 76-cm rows (6.97 Mg ha^{-1}).	-
	-	Illinois	-	51- and 76-cm	A +3% yield for 51- (8.54 Mg ha^{-1}) vs 76-cm rows (8.29 Mg ha^{-1}).	-
	1995	Iowa	-	38- and 76-cm	Yields in 38-cm rows (range: 7.47-to 10.23 Mg ha^{-1}) were up to 3% greater than yields in 76-cm rows (range: 7.28-to 9.98 Mg ha^{-1}).	-
Porter et al. (1997)	1992-1994	Lamberton, Morris and Waseca (Minnesota)	G4372, DK421, DK512, P3563, P3751 and N3624.	25-, 51- and 76-cm	Yield advantage when narrowing from 76- to 51- or 25-cm. For Lamberton and Waseca, +7.2% yield for 25- and 51-cm vs. 76-cm. For Morris, +8.5% yield for 25- and 51-cm vs. 76-cm.	Overall plant populations ranging from 53 000 to 100 000 pl ha^{-1}. Lower populations for Morris site. No hybrid x row interaction

Farnham (2001)	1997-1999	Six locations across Iowa (Sutherland, Kanawha, Nashua, Ames, Lewis and Crawsfordsville)	N4640Bt	38- and 76-cm	Averaged across years, locations and populations, yields greater (*$P \leq 0.05$*) for 76-cm (10.50 Mg ha^{-1}) than for 38-cm rows (10.30 Mg ha^{-1}).	Plant pop (4) ranging from 59,000 to 89,000 pl ha^{-1}. Optimum pop should be similar for either 38- or 76-cm rows.
			MAX23, MAX21, MAX454, N4242Bt, N4640Bt and N6800Bt		Averaged across years, locations and hybrids, corn grain yields did not differ between row spacings.	Single population of 69 000 pl ha^{-1}. Significant hybrid x row interaction.
Widdicombre and Thelen (2001)	1998-1999	Six locations across Michigan (Calhoun, Huron, Ingham, Kalamazoo, Monroe and Saginaw counties)	2 early- (Max86, RK552), 2 mid- (GL4758, PIO3573) and 2 full-season (GL5715, RK775)	38-, 56- and 76-cm	Row width was inversely correlated with grain yield. Yield increased 2% (*$P \leq 0.05$*) when narrowing from 76- to 56-cm (11.13 vs 11.35 Mg ha^{-1}) and 4% (*$P \leq 0.05$*) when moving from 76- to 38-cm rows (11.13 vs 11.55 Mg ha^{-1}).	Plant populations (5) ranging from 56,000 to 90,000 pl ha^{-1}. No hybrid x row interaction.
Andrade (2001)	1999	Pergamino (33°56'S lat) and Balcarce (37°45' S lat), Argentina	DK 688, P37P73	52- and 70-cm	1) Control: 10.68 - and 10.75 Mg ha^{-1} for 52- and 70-cm rows, respectively.	The greater the RI for wide rows, the lower the yield increase (%) when reducing row width
					2) Defoliation (all exposed leaf blades) at V3: 10.86- and 10.35 Mg ha^{-1} for 52- and 70-cm rows	
					3) Defoliation (all exposed leaf blades) at V5: 9.74- and 8.60 Mg ha^{-1} for 52- and 70-cm rows. Significant difference at *$P \leq 0.05$*	
Lee (2006); Compilation of data	1992 to 2004	Illinois, Iowa, Kentucky, Michigan, Minnesota, Missouri, Pennsylvania, South Carolina, Texas and Wisconsin	-	Twin-rows, 25-, 38-, 48-, 51-,56-, 76-, 97-, 102-cm	Corn yields tend to increase in narrow rows north of latitude 43°N, but these increases did not occur in every comparison. Full-season corn hybrids south of 43°N in row widths less than 76 cm typically did not yield more than hybrids in 76-cm rows.	-

Nelson and Smoot (2009)	2001-2003	Novelty (40° 01’N, 92°11’W) and Bethel (39° 56’N, 92°3’W) (Missouri)	P34B24, Garst8342IT, Garst8464IT, BurrusBX65	Twin-rows, 38-, 57- and 76-cm	No yield benefit of narrow (≤ 57-cm; *$P \leq 0.10$*) over twin or 76-cm single rows. Twin row yields were similar to 76-cm rows. Averaged across populations, yields in twin and 76-cm rows ranged from no change to 2.0 Mg ha^{-1} > than narrow rows (≤ 57-cm).	No-till and conventional tillage, with 4 final populations (62 000, 74 000, 87 000 and 99 000 pl ha^{-1})

† As quoted in the original work.

Table A5. Rain and irrigation totals (mm) every 2 weeks in 2012 and 2013 at Spindletop Farm, Lexington, KY.

	2012		**2013**	
	Rain	**Irrig.**	**Rain**	**Irrig.**
	---------------------------**mm**		-------------------------	
26 Apr-9 May	64.0	0.0	106.2	0.0
10 May-23 May	48.8	0.0	68.8	0.0
24 May-6 June	19.8	0.0	27.2	0.0
7 Jun-20 June	43.7	0.0	102.1	0.0
21 June-4 July	8.6	36.5	182.9	0.0
5 July-18 July	33.0	10.8	78.2	20.3
19 July-1 Aug	21.8	18.7	69.1	5.1
2 Aug-15 Aug	29.2	0.0	77.2	7.9
16 Aug-29 Aug	13.5	0.0	1.8	11.3
30 Aug-12 Sept	38.6	0.0	93.7	0.0
12 Sept-25 Sept	50.3	0.0	71.4	0.0
Total (mm)	371.3	66.0	878.6	44.5

Source: UK Research Farm Climate Data, Agricultural Weather Center. At:

http://wwwagwx.ca.uky.edu/php/farm_www.php

Table A6. Defoliation study growth stages in Lexington, KY in 2012.

Hybrid	Row (cm)	Defoliation	7-17 May	25-31 May	4-15 Jun	22-28 Jun	3-Jul	6-Jul	9-Jul	11-Jul	16-Jul	19-30 Jul	6-29 Aug
P1360HR	38	Control	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P1360HR	38	R2-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT/R1	VT/R1	VT/R1	R2	R2/R3	R3-R4	R5-R6
P1360HR	38	R2-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT/R1	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P1360HR	38	V14-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	V14	VT/R1	VT/R1	R2	R2/R3	R3-R4	R5-R6
P1360HR	38	V14-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	V14	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P1360HR	38	V7-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14/VT	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P1360HR	76	Control	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT/R1	VT/R1	VT/R1	R2	R3-R4	R5-R6
P1360HR	76	R2-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14/VT	VT/R1	VT/R1	VT/R1	R2	R3-R4	R5-R6
P1360HR	76	R2-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT	VT/R1	VT/R1	R2	R3-R4	R5-R6
P1360HR	76	V14-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT/R1	VT/R1	VT/R1	R2	R3-R4	R5-R6
P1360HR	76	V14-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT	VT/R1	R2	R2	R3-R4	R5-R6
P1360HR	76	V7-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	13	VT	VT/R1	VT/R1	R2	R3-R4	R5-R6
P2088YHR	38	Control	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT	VT/R1	VT/R1	R2	R2/R3	R3-R4	R5-R6
P2088YHR	38	R2-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT	VT/R1	VT/R1	R2	R3	R3-R4	R5-R6
P2088YHR	38	R2-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT/R1	VT/R1	VT/R1	R2	R3	R3-R4	R5-R6
P2088YHR	38	V14-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT/R1	R1	R2	R2	R3-R4	R5-R6
P2088YHR	38	V14-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P2088YHR	38	V7-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P2088YHR	76	Control	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P2088YHR	76	R2-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT/R1	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P2088YHR	76	R2-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P2088YHR	76	V14-50%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6
P2088YHR	76	V14-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	14	VT/R1	VT/R1	R1/R2	R2	R3-R4	R5-R6
P2088YHR	76	V7-100%	V1-V3	V4.5-V6	V7-V9	V11.5-V13	VT	VT/R1	VT/R1	R2	R2	R3-R4	R5-R6

Table A7. Defoliation study growth stages in Lexington, KY in 2013.

Hybrid	Row (cm)	Defoliation	13-28 May	5-20 Jun	20-26 Jun	1-3 Jul	8-Jul	12-15 Jul	17-19 Jul	26-Jul	2-9 Aug	14-31 Aug	9-Sep
P1360HR	38	Control	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R2	R3	R4-R5	R6
P1360HR	38	R2-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R3	R3	R4-R5	R6
P1360HR	38	R2-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R3	R3	R4-R5	R6
P1360HR	38	V14-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R3	R3	R4-R5	R6
P1360HR	38	V14-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R2	R3	R4-R5	R6
P1360HR	38	V7-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R2/R3	R3	R4-R5	R6
P1360HR	76	Control	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R3	R3	R4-R5	R6
P1360HR	76	R2-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R2	R3	R4-R5	R6
P1360HR	76	R2-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R3	R3	R4-R5	R6
P1360HR	76	V14-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R3	R3	R4-R5	R6
P1360HR	76	V14-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R2/R3	R3	R4-R5	R6
P1360HR	76	V7-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R2	R2	R3	R4-R5	R6
P2088YHR	38	Control	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R3	R3	R4-R5	R6
P2088YHR	38	R2-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R2	R3	R4-R5	R6
P2088YHR	38	R2-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R3	R3	R4-R5	R6
P2088YHR	38	V14-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R2	R3	R4-R5	R6
P2088YHR	38	V14-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R2	R3	R4-R5	R6
P2088YHR	38	V7-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R2	R3	R4-R5	R6
P2088YHR	76	Control	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R3	R3	R4-R5	R6
P2088YHR	76	R2-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R3	R3	R4-R5	R6
P2088YHR	76	R2-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R3	R3	R4-R5	R6
P2088YHR	76	V14-50%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R3	R3	R4-R5	R6
P2088YHR	76	V14-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R2	R3	R4-R5	R6
P2088YHR	76	V7-100%	VE-V3	V5-V7	V8-V10	V12-V13	V14	VT/R1	R1-R2	R2	R3	R4-R5	R6

Table A8. Main effects on grain yield (Mg ha^{-1}) in Lexington, KY in 2012 and 2013. Hand and combine harvested experiment.

	Hand harvest				Combine harvest			
Main effects	**2012**		**2013†**		**2012**		**2013**	
Hybrid	**Yield (Mg ha^{-1})**							
P1360HR	8.87	ns	11.66	ns	7.97	ns	10.43	ns
P2088YHR	9.75		12.11		8.35		10.6	
Row (cm)								
38	10.37	a	12.44	a	8.62	ns	10.52	ns
76	8.26	b	11.33	b	7.7		10.5	
Defoliation								
Control	13.21	ab	19.55	a	11.65	b	17.29	a
V7-100%	14.43	a	16.8	b	12.94	a	14.78	b
V14-50%	11.25	c	16.2	b	10.39	c	14.65	b
V14-100%	0.65	e	1.28	c	0.43	e	0.64	d
R2-50%	12.89	b	15.51	b	11.27	bc	14.32	b
R2-100%	3.45	d	1.97	c	2.27	d	1.4	c

† For 2013, hybrid*row*defoliation was significant for hand harvested grain yields.

‡ For main effects, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table A9. Hand harvested grain yield raw data in Lexington, KY in 2012 and 2013.

	2012				**2013**			
	P1360HR		**P2088YHR**		**P1360HR**		**P2088YHR**	
	38-cm	**76-cm**	**38-cm**	**76-cm**	**38-cm**	**76-cm**	**38-cm**	**76-cm**
Defoliation	Yield, Mg ha^{-1}				Yield, g ha^{-1}			
Control	13.32	11.95	16.55	11.03	18.11	19.98	21.76	18.36
V7-100%	15.33	13.04	14.93	14.44	18.38	15.31	17.44	16.06
V14-50%	13.26	9.46	12.66	9.6	17.68	14.66	15.94	16.53
V14-100%	0.64	0.54	0.75	0.66	1.63	1.54	0.61	1.33
R2-50%	13.84	9.44	14.92	13.36	17.03	13.27	16.32	15.41
R2-100%	3.39	2.26	4.85	3.31	1.43	0.87	2.91	2.68

Table A10. Main effects on grain moisture (%) in Lexington, KY in 2012 and 2013. Combine harvested experiment.

Main effects	2012		2013†	
Hybrid	**Harvest moisture (%)**			
P1360HR	15.0	b	19.0	b
P2088YHR	17.1	a	20.8	a
Row (cm)				
38	15.7	ns	19.7	ns
76	16.4		20.0	
Defoliation				
Control	18.7	a	20.7	b
V7-100%	18.9	a	21.3	ab
V14-50%	19.1	a	21.2	ab
V14-100%	7.3	c	20.7	b
R2-50%	18.7	a	21.5	a
R2-100%	13.7	b	13.8	c

† For 2013, hybrid*defoliation was significant.

‡ For main effects, means in the same column followed by different letters are significantly different at the 0.05 probability level. No significant differences are indicated by ns.

Table A11. Grain moisture for hybrid and defoliation in Lexington, KY in 2013. Combine harvested experiment.

Defoliation	Hybrid			
	P1360HR		P2088YHR	
	Harvest moisture (%)			
Control	19.6	b	21.8	b
V7-100%	19.8	b	22.8	a
V14-50%	19.9	ab	22.4	ab
V14-100%	20.7	a	20.7	c
R2-50%	20.0	ab	23.0	a
R2-100%	13.8	c	13.8	d

‡ For hybrid, means in the same column followed by different letters are significantly different at the 0.05 probability level.

Table A12. IPAR (%) at V8, VT, R2 and R5 at soil level and grain yield relationship in Lexington, KY in 2012.

Defoliation			V8		VT		R2		R5	
	Yield, Mg ha^{-1}		Soil IPAR (%)							
Control	13.21	ab	63	a	83	a	86	a	81	a
V7-100%	14.43	a	36	b					74	b
V14-50%	11.25	c	65	a	65	b			71	b
V14-100%	0.65	e	68	a	23	c			37	c
R2-50%	12.89	b	63	a			72	b	69	b
R2-100%	3.45	d	60	a			28	c	32	c

‡ For each growth stage and grain yield, means in the same column followed by different letters are significantly different at the 0.05 probability level.

Table A13. IPAR (%) at V8, VT, R2 and R5 at soil level and grain yield relationship in Lexington, KY in 2013.

2013 - P1360HR	**38-cm**		**76-cm**		**38-cm**		**76-cm**						**38-cm**		**76-cm**	
Defoliation	**Yield, Mg ha^{-1}**				**Soil IPAR-V8 (%)**				**Soil IPAR-VT**		**Soil IPAR-R2**		**Soil IPAR-R5 (%)**			
Control	18.1	a	20.0	a	62	b	64	a	90	a	93	a	91	a	84	a
V7-100%	18.4	a	15.3	b	22	c	17	b	75	b	86	a	83	a	76	a
V14-50%	17.7	a	14.7	b	82	a	61	a	72	b	79	b	83	a	74	a
V14-100%	1.6	b	1.5	c	73	ab	65	a	24	c	37	c	52	b	30	b
R2-50%	17.0	a	13.3	b	74	ab	57	a	91	a	79	b	82	a	77	a
R2-100%	1.4	b	0.9	c	73	ab	62	a	91	a	31	c	42	b	40	b

2013 - P2088YHR	**38-cm**		**76-cm**		**38-cm**		**76-cm**						**38-cm**		**76-cm**	
Defoliation	**Yield, Mg ha^{-1}**				**Soil IPAR-V8 (%)**				**Soil IPAR-VT**		**Soil IPAR-R2**		**Soil IPAR-R5 (%)**			
Control	21.8	a	18.4	a	79	a	67	a	90	a	93	a	93	a	95	a
V7-100%	17.4	b	16.1	ab	20	b	31	b	75	b	86	a	86	a	90	a
V14-50%	15.9	b	16.5	ab	76	a	77	a	72	b	79	b	82	a	88	a
V14-100%	0.6	c	1.3	c	79	a	66	a	24	c	37	c	29	b	52	b
R2-50%	16.3	b	15.4	b	73	a	77	a	91	a	79	b	90	a	88	a
R2-100%	2.9	c	2.7	c	84	a	78	a	91	a	31	c	39	b	39	c

‡ For each growth stage and grain yield, means in the same column followed by different letters are significantly different at the 0.05 probability level.

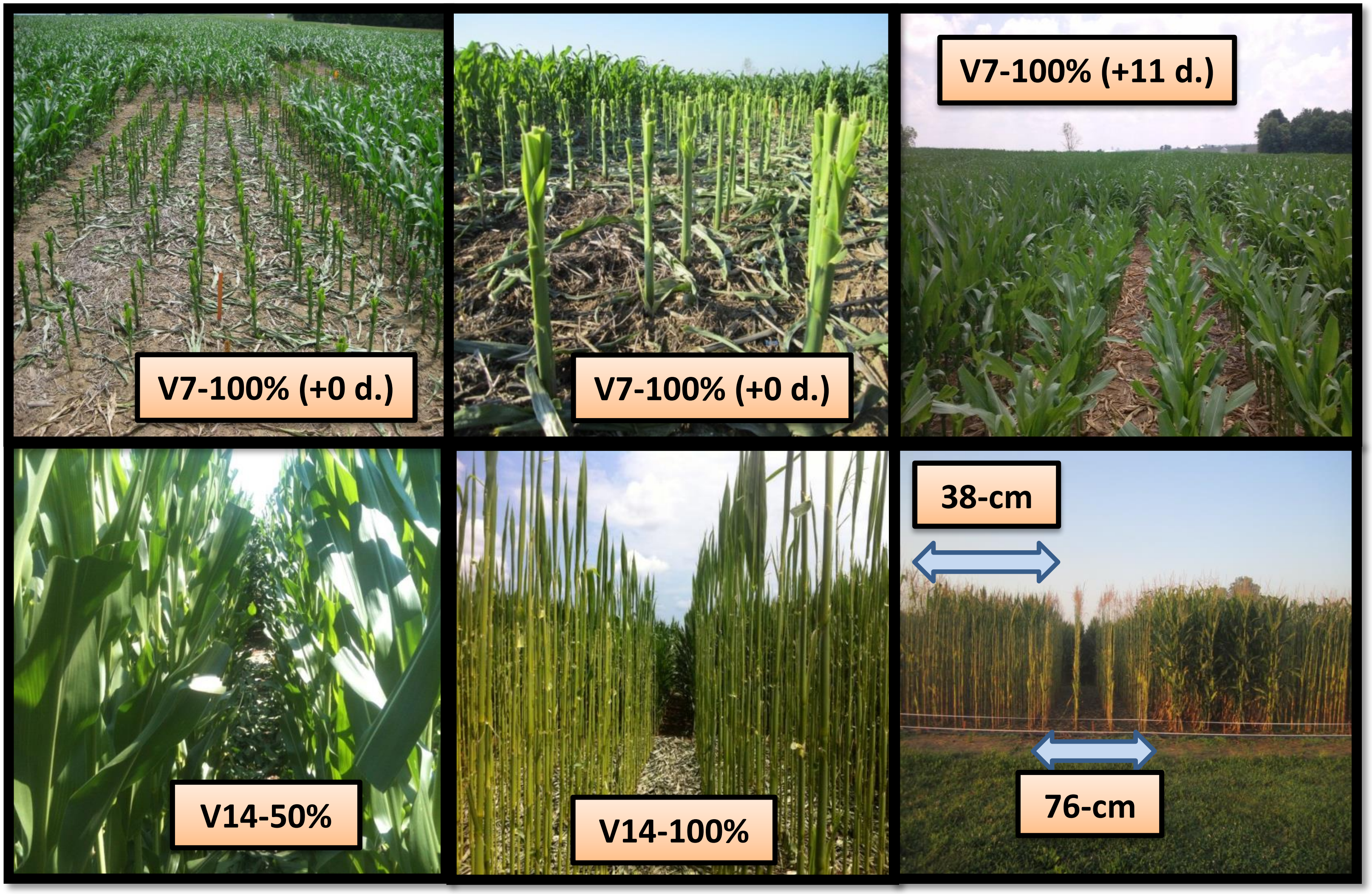
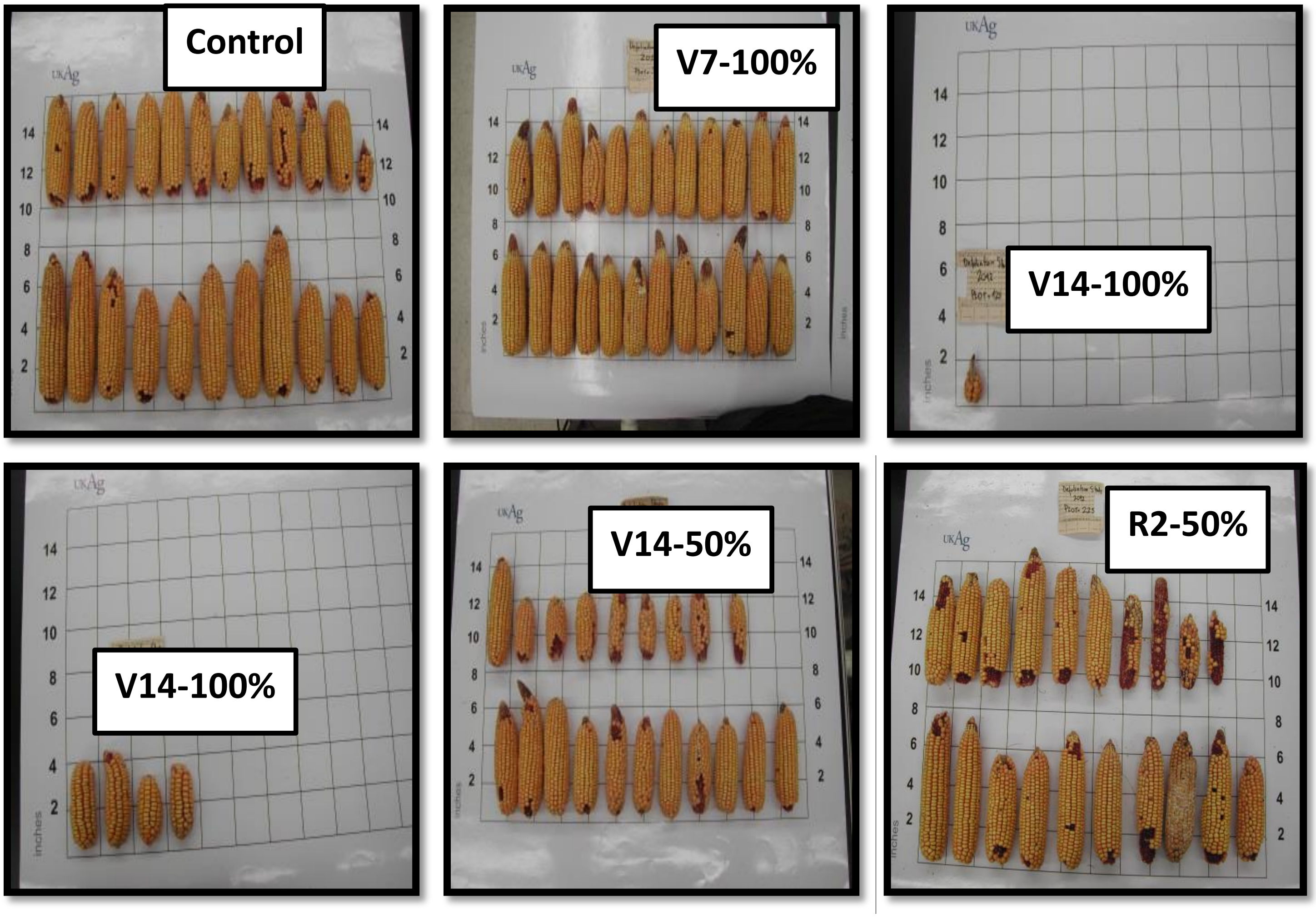


Figure A1. Images of defoliation treatments and crop recovery after defoliation



FigureA2. Images of ears harvested for different defoliation treatments.

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VITA

Martin Leonardo Battaglia

1. Place of birth: Pergamino, Buenos Aires, Argentina.
2. Educational institutions attended and degrees already awarded:
    - A.A. Technical Agronomist. Agricultural Education School Nº 1. Pergamino. Argentina. 1999.
    - B.S Agronomy Department. College of Agriculture. University of Buenos Aires. Argentina. 2010 (Honor Diploma). Undergraduate thesis title: "Performance of early corn hybrids in the sequence corn-soybean in the north of Buenos Aires province".
    - Graduate Research Assistant (Master Science candidate). Plant and Soil Sciences. College of Agriculture. University of Kentucky. Spring 2014. GPA: 4.0 (from 1 to 4 scale).

During this time in the graduate school, I was mainly involved in corn research related to a) understanding the corn yield response to defoliation at different row widths, and b) testing drought-tolerance hybrids in different environments, row widths and plant populations. I was also actively involved in research related to fertirrigation, crop water supply and demand, laboratory calibrations for soil water sensing probes, corn fertilization and soybean field management.

3. Professional positions held:

   -Technician, Production Research. Dow Agro Sciences. 2009-2010.

   -During my time as an undergraduate student, I worked as a part-time employee in several other places, mostly during the summer (scholar break in Argentina): a) Collaborator, fertilization trials management. Fertilization Section. INTA Pergamino. 2008; b) Operative soybean section. Pioneer Pergamino. 2006-2007; c) Corn fields inspector. Monsanto Pergamino. 2005-2006; d) Freelance soybean scouting. 2004-2008.

4. Scholastic and professional honors:

   - 1998-1999. Cargill Foundation Scholarship. Buenos Aires, Argentina.
   - 2002. Monsanto Argentina Scholarship. Pergamino, Argentina.
   - 2007. Spinetto Foundation Scholarship. University of Buenos Aires. Argentina.
   - 2010. Honor Diploma. College of Agriculture. University of Buenos Aires. Argentina.
   - 2012. The Honor Society of Agriculture, Gamma Sigma Delta chapter. Membership in recognition of high scholarship achieved.
   - 2013. Crop Science Society of America. Second place poster for Graduate Student Poster Contest. Division C-3 Crop Ecology, Management and Quality. ASA-CSSA-SSSA International Annual Meetings, Tampa, Fl, US.

- 2014. 2014 Gerald O. Mott Meritorious Graduate Student Award in Crop Science. Department of Plant and Soil Science. College of Agriculture. University of Kentucky.
- 2014-present. ASA Graduate Student Committee member (appointment by ASA president).
- 2014. College of Agriculture and Life Sciences (CALS) Graduate Student Committee. Virginia Tech (appointment by Crop and Soil Environmental Sciences head).
- 2014. Graduate Extension Scholar. College of Agriculture and Life Sciences (CALS). Virginia Tech.

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