Light Quality Effect on Corn Growth as Influenced by Weed Species and Nitrogen Rate

Article *in* Journal of Agricultural Science · December 2016

DOI: 10.5539/jas.v9n1p15

Thomas R. Butts
University of Arkansas
21 PUBLICATIONS **109** CITATIONS

Joshua Miller
University of Nebraska at Lincoln
3 PUBLICATIONS **12** CITATIONS

Maxwel Coura Oliveira
Universidade do Oeste Paulista
31 PUBLICATIONS **127** CITATIONS

John L. Lindquist
University of Nebraska at Lincoln
122 PUBLICATIONS **3,650** CITATIONS

Journal of Agricultural Science; Vol. 9, No. 1; 2017
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Light Quality Effect on Corn Growth as Influenced by Weed Species and Nitrogen Rate

Thomas R. Butts[1], Joshua J. Miller[2], J. Derek Pruitt[3], Bruno C. Vieira[1], Maxwel C. Oliveira[4], Salvador Ramirez II[3], & John L. Lindquist[3]

[1] Department of Agronomy & Horticulture, University of Nebraska-Lincoln, North Platte, NE, USA

[2] Department of Plant Pathology, University of Nebraska-Lincoln, Lincoln, NE, USA

[3] Department of Agronomy & Horticulture, University of Nebraska-Lincoln, Lincoln, NE, USA

[4] Department of Agronomy & Horticulture, University of Nebraska-Lincoln, Concord, NE, USA

Correspondence: Thomas R. Butts, Department of Agronomy & Horticulture, University of Nebraska-Lincoln, North Platte, NE 69101, USA. Tel: 1-608-214-4215. E-mail: tbutts@huskers.unl.edu

Received: October 8, 2016 Accepted: November 3, 2016 Online Published: December 15, 2016
doi:10.5539/jas.v9n1p15 URL: http://dx.doi.org/10.5539/jas.v9n1p15

Abstract

Corn-weed competition has often been characterized as the competition for limited resources such as light quantity, water, and nutrients. However, growing evidence suggests that light quality, specifically the red:far red ratio (R:FR), is a crucial component to corn-weed interactions. Additionally, a reduction in the R:FR has shown to down-regulate plant genes similarly to a nitrogen (N) deficient environment. A greenhouse study was conducted to evaluate the effect of N stress and R:FR from common waterhemp, velvetleaf, and volunteer corn on corn growth and development. The R:FR for all three weed species tended to be similar but lower than a weed-free treatment. However, observations from the spectral response curves demonstrated significant changes in the patterns of light reflected from each weed species. In the N-sufficient environment, early-season (V5 corn growth stage) R:FR from all three weed species reduced corn height, leaf chlorophyll content, and shoot biomass while increasing fibrous root biomass. However, in the N-deficient environment, no effects were observed on corn growth from changes in light quality, indicating N stress was a greater limiting factor. These results highlight the importance of the critical weed-free period and the need for proper early-season weed management.

Keywords: **c**hlorophyll, competition, light quality, red:far red ratio (R:FR)

1. Introduction

Competition between corn (*Zea mays* L.) and weeds presents a significant barrier to crop production worldwide. Traditionally, competition has been viewed from the understanding that weeds compete for limited resources - namely light, water, and nutrients (Kropff & Laar, 1993). Competition for these resources can influence yield, plant height, and leaf area development (Bonifas et al., 2005; McCullough et al., 1994; Zhou et al., 1997). The timing of weed interference also influences the level of competition on corn. Competitive effects of weeds are more important early in the growing season, so early-season weed control is essential to minimize yield loss (Zimdahl, 1988; Swanton et al., 1999). Several studies have identified critical weed free periods for corn that evaluate both the length of time weeds can remain in a crop before interference occurs, and the length of time weed control efforts must be maintained (Hall et al., 1992; Knezevic et al., 1994; Bosnic & Swanton, 1997). One factor that was found to influence the critical weed free period was the application of nitrogen (N) (Evans et al., 2003).

A growing body of evidence suggests that another mechanism for competition is a reduction in the red (670 nm) to far red (730 nm) ratio (R:FR) intercepted by the corn plant due to the presence of neighboring weeds (Rajcan et al., 2004). This mechanism results from two signal-transducing photoreceptors, phytochrome (600-800 nm) and blue-absorbing photoreceptors (300-500 nm), that acquire information on the light environment to modulate cellular processes (Smith, 1982; Smith & Holmes, 1977). Phytochrome has been the primary focus of research investigating the influence of light quality on crop growth and development. The phytochrome molecule can detect both the proximity and distribution of neighboring plants because of reductions in the R:FR ratio (Ballaré, 2009). Particularly in shade-intolerant crops, this can result in a shade avoidance response (Page et al., 2010).

This response can result in several physiological changes in the plant, including stem elongation, reduction in stem diameter, and a reduction in the root and shoot biomass (Afifi & Swanton, 2011). Additionally, Afifi and Swanton (2012) found that in corn subjected to low R:FR light from both biological and nonbiological sources, phytochrome was involved in decreased anthocyanin and increased lignin, increased H_2O_2 content in the first true leaf and crown, increased stomatal closure on the first and second leaves, and changed expression levels of genes involved in auxin transport, ethylene biosynthesis, scavenging enzymes and anthocyanin and lignin biosynthesis pathways.

Three weeds of concern for crop production in the United States are velvetleaf (*Abutilon theophrasti* Medik), common waterhemp (*Amaranthus rudis* Sauer), and volunteer corn. Velvetleaf has been ranked as one of the most troublesome weeds in the United States (Stoller et al., 1993) and is commonly a competitive annual weed in summer crops globally (Loddo et al., 2013). Although yield loss in corn due to velvetleaf competition can be highly variable (Lindquist et al., 1996), research has suggested that grain yields can be decreased by up to 80% depending on field conditions and velvetleaf density (Lindquist et al., 1998). This loss is primarily due to competition for light (Lindquist & Mortensen, 1999). Common waterhemp is a dioecious, indigenous species native to the Great Plains region of the United States (Sauer, 1957). It has spread recently due to several factors, including the adoption of reduced tillage practices, the reduction in soil applied residual herbicides, and the evolution of herbicide-resistant biotypes (Steckel & Sprague, 2004). Previous research has shown when common waterhemp emerges with corn through the V6 growth stage, grain yield can be dramatically reduced (Steckel & Sprague, 2004). Volunteer corn tends to be less of a concern in hybrid corn production, but can still impact yield of neighboring corn plants. Marquardt et al. (2012) observed reductions in hybrid corn grain yield above 20%; however, no reduction in total grain yield was observed when the volunteer corn grain yield was combined with the hybrid corn grain yield.

In addition to weeds, N stress can significantly affect corn grain yields. Adequate N supply during vegetative stages is essential for achieving optimum yields (Rajcan & Swanton, 2001). Roughly 65-80% of total N uptake by corn plants occurs during the vegetative stages of crop growth (Rajcan & Tollenaar, 1999). Adequate N during the vegetative stages is also important because 50% or more of N found in grain comes from mobilization rather than increased uptake (Pearson & Jacobs, 1987; Ta & Weiland, 1992). Moriles et al. (2012) determined that weed competition and N stress both resulted in the down regulation of genes involved with photosynthesis, auxin signaling, H_2O_2 removal and stomatal movement.

In the current study, changes in R:FR interception by corn due to the presence of velvetleaf, common waterhemp, and volunteer corn plants were evaluated to determine the influence light quality has on corn growth and development. Additionally, because N stress is known to regulate gene expression similarly to weed competition, responses to R:FR changes were evaluated in corn under two N management regimes. The objectives of this study were to 1) determine the differences in reflected R:FR of velvetleaf, common waterhemp, and volunteer corn, 2) evaluate the impact of R:FR from different weed species on corn height, stem diameter, leaf chlorophyll content, and plant biomass, and 3) determine if N stress changes the response of corn to changes in R:FR. From these objectives, we hypothesized the R:FR would vary for each weed species observed and this variance in R:FR would impact the singular corn plant differently: a lower R:FR would decrease corn height, stem diameter, leaf chlorophyll content, and plant biomass more than a higher R:FR. Furthermore, we hypothesized N stress paired with low R:FR would produce an additive negative effect on the corn plant growth characteristics compared with N stressed corn plants alone.

2. Method

2.1 Experimental Design and Maintenance

A greenhouse experiment was conducted in the spring of 2016 at the University of Nebraska-Lincoln East Campus Greenhouse facility. Four weed species (none, common waterhemp, velvetleaf, and volunteer corn) and two N rates [366.5 ppmw (full) and 209.0 ppmw (reduced)] were arranged in a randomized complete block design as a four by two factorial. Treatments were spatially replicated four times. The greenhouse was maintained at 26-30 ^{o}C with 14 hours of light.

The experiment was designed to provide light quality competition between the corn plant and weed species, while eliminating light quantity, nutrient, and root architecture competition. To accomplish this, weed species were sown in 7.6-cm diameter pots, and four of these pots were placed equidistantly apart on the outside rim of a 30.5-cm pot in which the corn was planted directly in the center (Figure 1) (Liu et al., 2009). The growing medium was a 1:1 mixture of perlite:vermiculite specifically chosen to allow for complete control of the nutrient amendments (E. T. Paparozzi, University of Nebraska-Lincoln, personal communication). Weed species were sown and allowed to emerge prior to the corn plant to establish a weedy environment in which the corn plant would emerge. Common waterhemp and velvetleaf were planted on February 10 and were thinned to four plants per 7.6-cm pot after emergence. Volunteer corn was planted on February 17 and thinned to two plants per 7.6-cm pot after emergence to better simulate a corn cropping system scenario. DeKalb DKC62-98VT2RR2 corn variety, a typical hybrid corn used in Nebraska, was planted on February 20 and was thinned to one viable plant per 30.5-cm pot. As the plants grew, weed species were trimmed once per week to maintain no competition for light quantity and avoid shading of the centered corn plant.

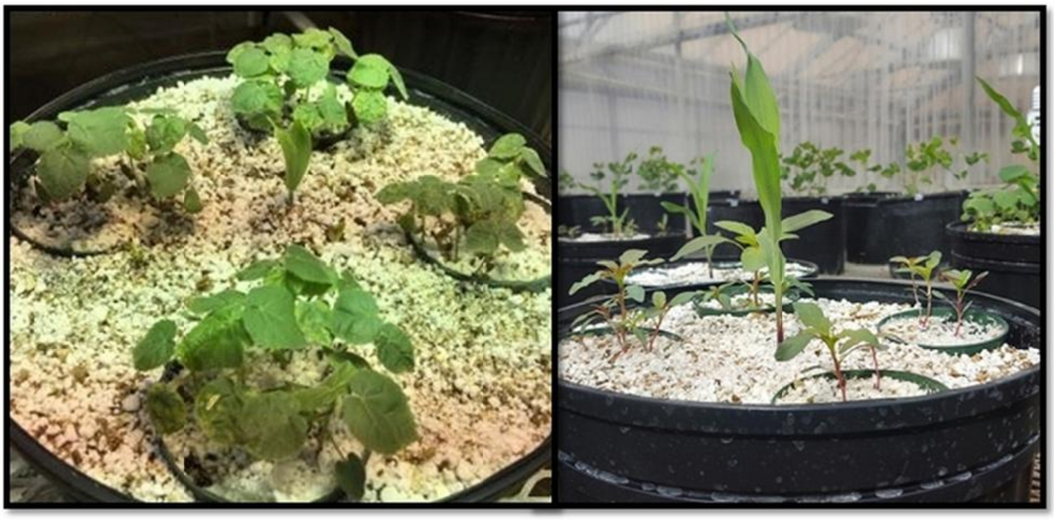

Figure 1. Experiment set-up with weed species sown in 7.6-cm pots placed equidistantly apart on the outside of a 30.5-cm pot in which a corn plant was planted directly in the center and forced to emerge into a weedy environment

Weeds and corn plants were watered and fertilized with Modified Hoagland nutrient solutions (Table 1) developed using a protocol by Clark (Clark, 1982). To determine the amount of nutrient solution needed each fertigation timing, the 7.6- and 30-cm pots were filled to saturation prior to planting to determine the holding capacity of each size pot. Weeds were initially watered by overhead irrigation with tap water until plants emerged. After emergence, the full N solution was used to fertigate the weed species with 100 mL, and the corn plants were fertigated with 1 L of the respective N solution treatment three times per week.

Table 1. Nutrient concentrations and nitrogen (N) treatments supplied at each fertigation

Nutrient	Full N (ppmw)[a]	Low N (ppmw)
Nitrogen (N)	366.5	209.0
Phosphorus (P)	20.4	20.4
Potassium (K)	282.9	282.9
Calcium (Ca)	238.0	238.0
Magnesium (Mg)	35.7	35.7
Sulfur (S)	62.6	62.6
Chlorine (Cl)	71.3	71.3

Note. [a]Abbreviation: ppmw, parts per million by weight.

2.2 Data Collection

2.2.1 Plant Characteristics

Plant measurements were collected weekly starting seven days after planting (DAP) for six weeks. Plant height was measured from the base of the potting mix to the extended tip of the last collared leaf. Stem diameter was measured with a caliper near the base of the plant. Growth stage of corn plants were recorded each week according to the collar method (Abendroth et al., 2011).

Chlorophyll content was measured using a CCM-300 Chlorophyll Content Meter (Opti-Sciences, Hudson, NH) at 25, 32, and 39 DAP. The device uses a fiber optic probe to detect the emission ratio of red fluorescence (700 nm) to far red fluorescence (735 nm) according to Gitelson et al. (1999). The probe was connected to a leaf clip that was used to secure the probe to the leaf during measurement. Six measurements were recorded on the fifth leaf down from the uppermost collared leaf on each corn plant. The average of the six measurements was calculated and used for further analysis.

Plants were destructively harvested at 45 DAP. Corn plants were cut directly above the uppermost brace roots and the above ground biomass was placed in a paper bag and oven-dried at 55 ^{o}C to constant mass. The remaining plant parts were removed from the potting mix and separated into the crown (remaining aboveground portion of plant and first five cm of roots) and the fibrous roots (roots below five cm). Root components were cleaned and placed in separate paper bags and oven-dried at 55 ^{o}C to constant mass. Once plants reached constant mass, the dry biomass of the shoot and fibrous roots were recorded.

2.2.2 Light Quality (R:FR)

Spectral measurements were taken at the V5, V11, and V14 corn growth stages. Plants were removed from the greenhouse and brought to a staging room for measurements. Four halogen bulbs were used as a light source that was maintained at a constant distance and angle from the corn plants for all measurements. The potting medium was covered with black felt and the plants were placed on a black table with a black backdrop. An Ocean Optics (Dunedin, FL) USB2000+ radiometer was used to collect data in the range of 363 to 1000 nm with a spectral resolution of about 0.35 nm. The radiometer was equipped with a 25^{o} field-of-view optical fiber that was placed at the base of the corn plant approximately 15 cm above the potting mix and pointed into the canopy of the neighboring weeds. Four measurements were collected per pot, one directed at each of the four smaller pots of weeds, and were treated as subsamples. The four subsamples from within the weed species treatment from each N rate were pooled as weeds were only supplied with the full N rate. This provided a total of eight subsamples for each weed species treatment to be averaged for further data analysis. Data were averaged over every 10 nm to construct spectral response curves for every treatment.

2.3 Statistical Analyses

Data were subjected to ANOVA using a mixed effect model in SAS (SAS v9.4, SAS Institute Inc., Cary, NC). Weed species and N rate were designated as fixed effects. Corn stem diameter, height, leaf chlorophyll content, the R:FR light spectrum ratio, and end-of-season corn shoot biomass were the response variables measured. The R:FR light spectrum ratio was calculated by the summation of the reflected light within the 660-680 nm range divided by the summation of the reflected light within the 720-740 nm range (660-680 nm:720-740 nm) as this compared to values measured in previous research that used a R:FR sensor (Liu et al., 2009). Linear regression correlations were developed to determine the influence of the R:FR and timing on corn growth characteristics. All data except for corn shoot biomass were initially analyzed using a repeated measures design. The time factor was significant in all analyses; therefore, response variables were each analyzed separately by date of data collected. Variance and normality assumptions were found to hold true for all data collected. When fixed main effects were significant ($P \leq 0.05$), means were separated using Fisher's protected LSD. When fixed effect interactions were significant ($P \leq 0.1$), means of simple effects were separated using Fisher's protected LSD.

3. Results and Discussion

3.1 Light Quality (R:FR)

Measurements of R:FR decreased from the initial measurement at V5 to the last measurement at V14 within each weed treatment. The weed-free treatment consistently had a greater R:FR than the weed treatments at every measurement (Figure 2). The dicot species (common waterhemp and velvetleaf) R:FR estimates were lower than the monocot species (volunteer corn) at the V5 and V14 corn growth stages, which supports results observed by Cressman et al. (2011); however, the estimates were only statistically different at V14.

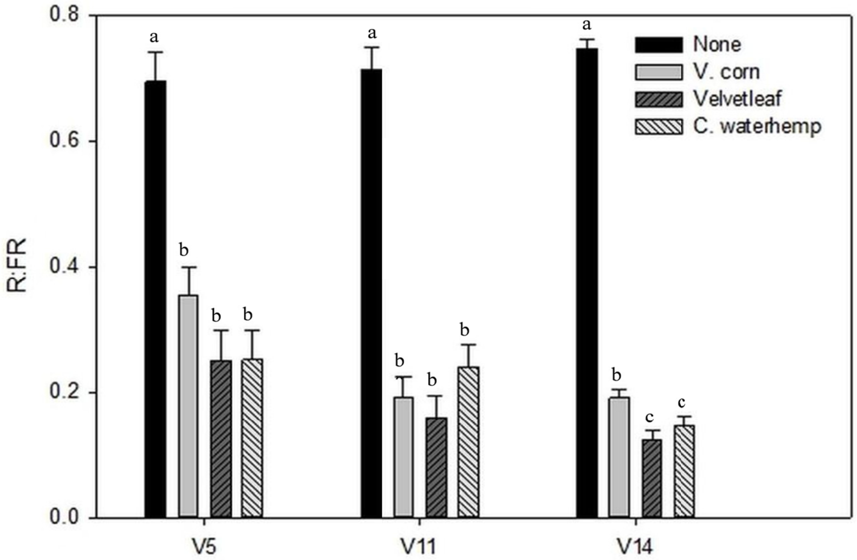

Figure 2. Red to far-red ratio (R:FR) of weed treatments at three corn growth stages

Note. Means within corn growth stage followed by the same letter are not different according to Fisher's protected LSD at α = 0.05.

Differences in the spectral response curves of common waterhemp, velvetleaf, and volunteer corn are shown in Figure 3. Although R:FR was similar for velvetleaf and common waterhemp, the spectral properties of the weeds are markedly different. Reflectance in the red wavebands (660-680 nm) are lowest for velvetleaf, whereas common waterhemp and volunteer corn are similar. Reflectance in the far-red wavebands (720-740 nm) were highest for common waterhemp, whereas velvetleaf and volunteer corn are similar.

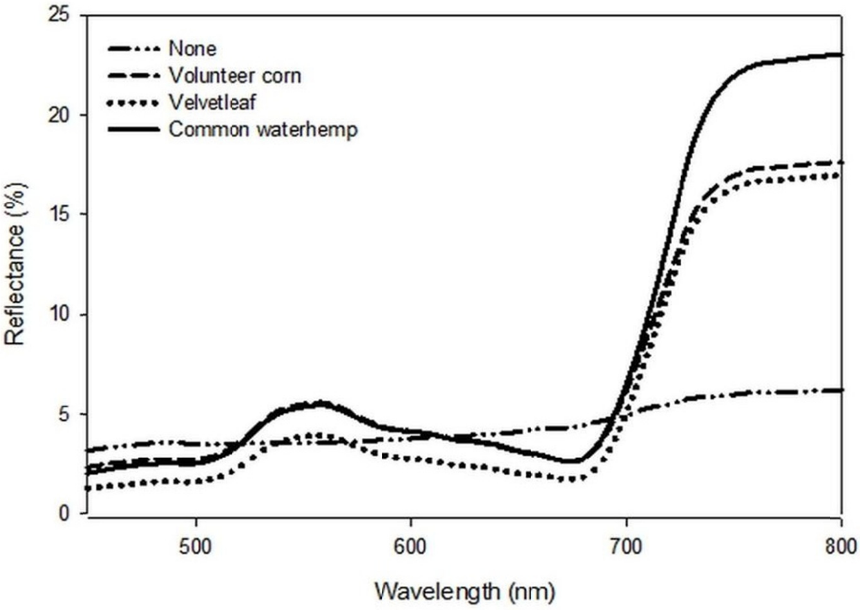

Figure 3. Spectral response curves for weed species at the V14 corn growth stage

3.2 Corn Height and Stem Diameter

Measurements of corn height and stem diameter were recorded and analyzed for six dates (Table 2). The relationship over time is shown for corn stem diameter (Figure 4) and height (Figure 5) in response to weed species and N rate. Both corn growth measurements were not different across treatments when compared at the V1 growth stage. At the V3 and V5 growth stages, the full N rate increased corn height by 6.4 ($P < 0.0001$) and 14.8 cm ($P < 0.0001$), respectively, and increased corn stem diameter by 0.1 ($P = 0.0002$) and 0.5 cm ($P < 0.0001$), respectively, compared to the reduced N rate. Data collected from the V8 and V11 growth stages resulted in a significant weed*N rate interaction for both corn height ($P = 0.0194$ and $P = 0.0210$, respectively) and stem diameter ($P = 0.0557$ and $P = 0.0918$, respectively). The full N rate and weed-free treatment produced the tallest corn and largest stem diameters at the V8, V11, and V14 growth stages. This leads to the conclusion that N rate was more critical for influencing early season growth of corn than changes in light quality; however, with full season exposure to weed presence, light quality additionally impacted late-season growth of corn in corroboration with N rate. Furthermore, two general trends appear for each response variable. In the full N rate treatments, all three weed species decreased corn height and stem diameter compared to the weed-free treatment at the V8, V11, and V14 corn growth stages. However, in the reduced N rate treatments, weed species buffered the impact of the reduced N rate and the corn plant tended to be taller with larger stem diameters than the weed-free treatment. We hypothesize this can be explained through two means. First, there is potential for experimental error as the full N rate supplied to weed species may have leached from the pots and provided extra N compared to the weed-free treatment. However, this effect is likely minor as the saturation capacity of the pots measured prior to the experiment was used to determine the total amount of solution added at each fertigation. Secondly, the N-deficient environment may be a greater limiting factor on corn growth than changes in light quality by neighboring weeds. At the V14 growth stage, corn height was impacted similarly as the previous significant weed species*N rate interaction. However, corn stem diameter was no longer impacted by weed species, but the full N rate increased the corn stem diameter by 0.3 cm compared with the reduced N rate.

Table 2. Corn growth stage corresponding to date of data collected for each response variable[a]

Date	Corn growth stage[b]	Corn height	Corn diameter	Corn leaf chlorophyll content	R:FR[c]	Corn shoot biomass
1	V1	Y	Y	N	N	N
2	V3	Y	Y	N	N	N
3	V5	Y	Y	N	Y	N
4	V8	Y	Y	Y	N	N
5	V11	Y	Y	Y	Y	N
6	V14	Y	Y	Y	Y	Y

Note. [a] Y = Data were collected; N = No data collected; [b] Average vegetative growth stage of corn plants based on number of collared leaves; [c]Red:far red light spectrum ratio (660-680 nm:720-740 nm).

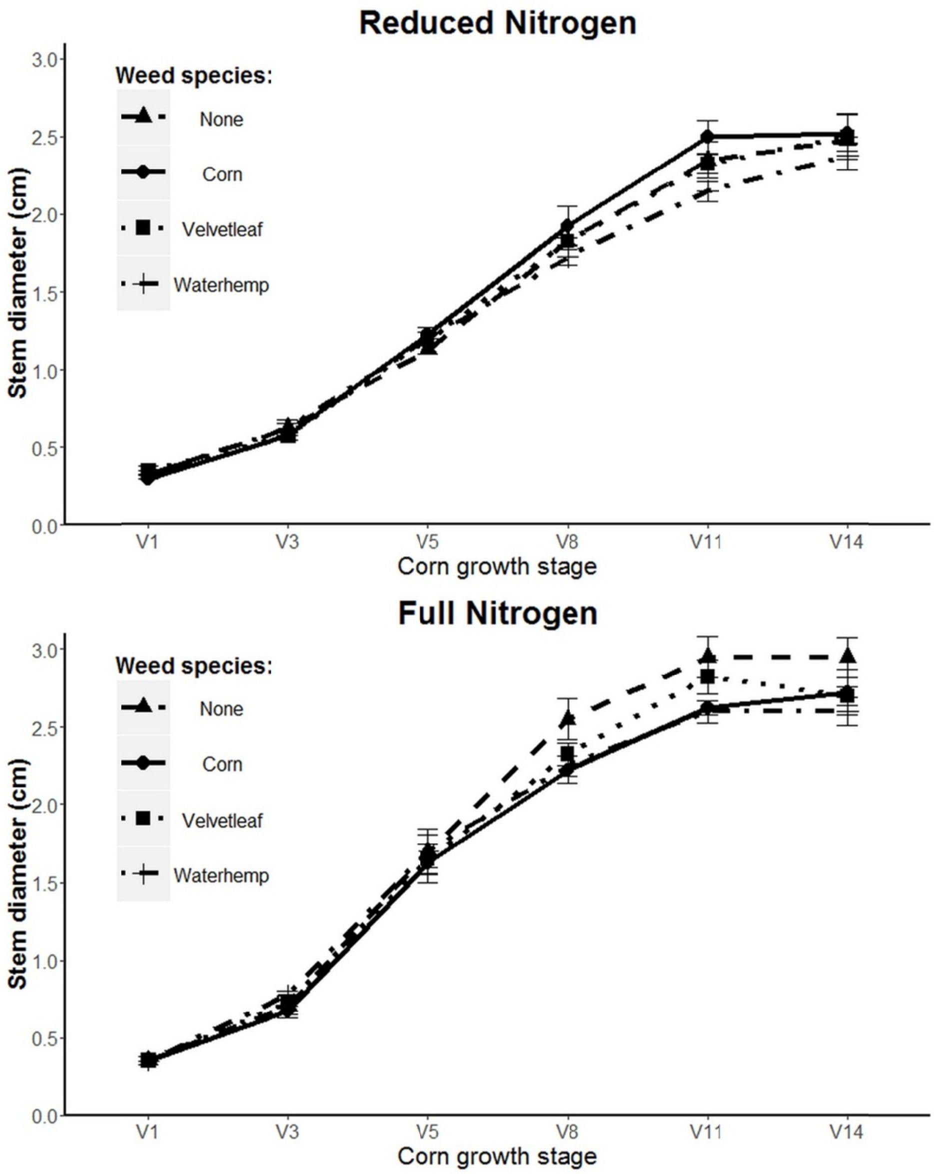

Figure 4. Measured corn stem diameter (cm) for four weed species treatments across six dates with reduced nitrogen (N) (top) or full N (bottom)

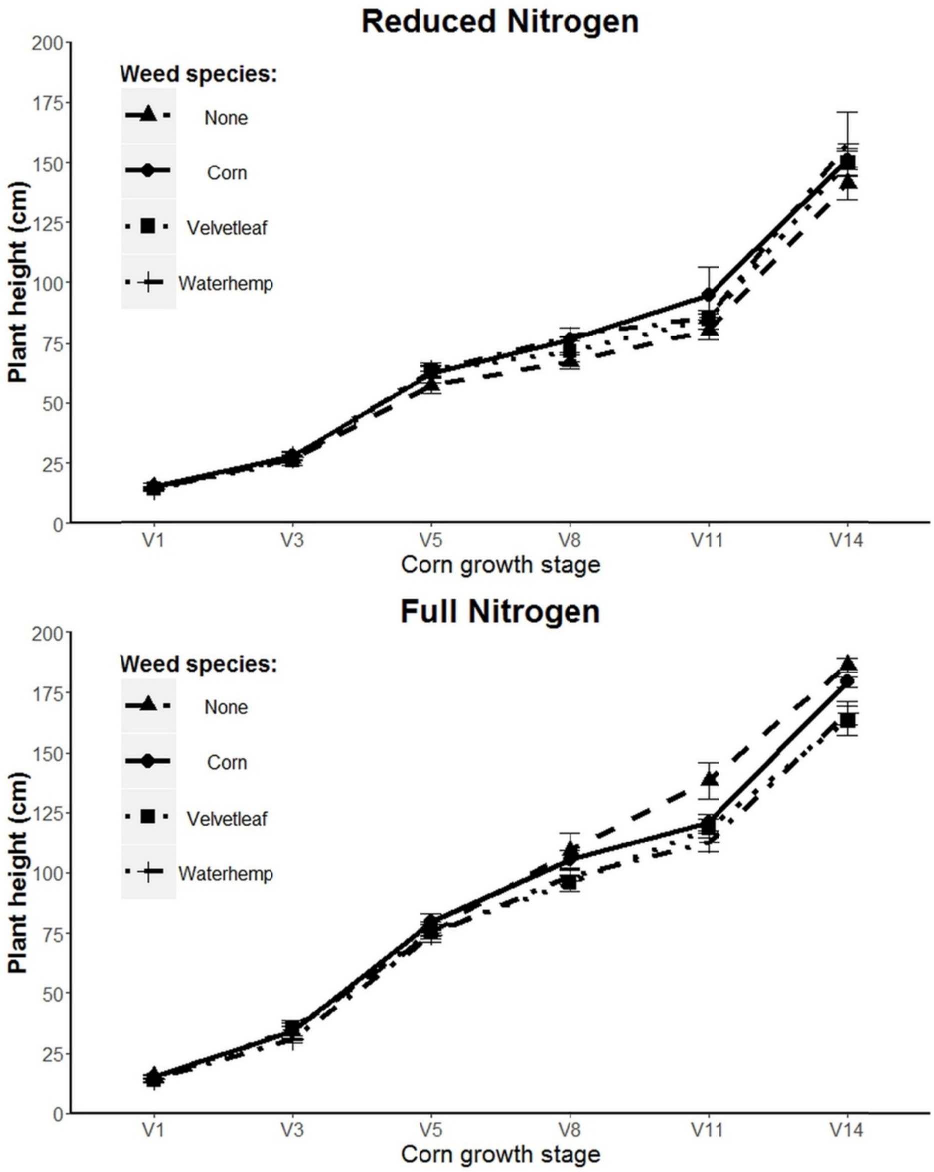

Figure 5. Measured corn height (cm) for four weed species treatments across six dates with reduced nitrogen (N) (top) or full N (bottom)

From the linear regression correlations, significant relationships were observed between late-season corn height and early-season R:FR measurements (data not shown). Lower R:FR at the V5 growth stage was correlated with reduced corn height at the V8, V11, and V14 growth stages in the full N rate treatments. No correlations were observed between R:FR and corn height in the reduced N rate treatments (data not shown), which further illustrated the greater influence of N rate as the limiting factor when compared to light quality.

3.3 Corn Leaf Chlorophyll Content

The weed species*N rate interaction influenced chlorophyll content in corn leaves at the V8 growth stage (Table 3). The full N rate and weed-free treatment resulted in the highest chlorophyll content (770.0 mg m^{-2}); however, it was not different than the common waterhemp (740.8 mg m^{-2}) and volunteer corn (740.0 mg m^{-2}) treatments. The chlorophyll content of the velvetleaf (720.0 mg m^{-2}) treatment was 6.5% less than the weed-free treatment but was similar to the common waterhemp and volunteer corn treatments. The influence of light quality on leaf chlorophyll content is not well understood. There is evidence that *PIF1*, a transcription factor in the phytochrome interaction factor protein family, inhibits protochlorophyllide, a precursor of chlorophyll (Jiao et al., 2007). Therefore, further studies investigating the molecular mechanisms involved are needed.

Table 3. The weed species*nitrogen (N) rate interaction effect on leaf chlorophyll content of corn plants at the V8 growth stage[a]

Weed species*N rate	Chlorophyll (mg m^{-2})
None*Full	770.0 a
Volunteer corn*Full	740.0 ab
Velvetleaf*Full	720.0 b
Common waterhemp*Full	740.8 ab
None*Reduced	668.0 c
Volunteer corn*Reduced	712.5 bc
Velvetleaf*Reduced	704.3 bc
Common waterhemp*Reduced	721.0 b
ANOVA	P-value
N rate	0.001
Weed species	0.666
Weed species*N rate	0.044

Note. [a] Means within a column with the same letter are not significantly different ($P \leq 0.1$).

At the reduced N rate, the corn leaf chlorophyll content of the weed-free treatment was 53.0 mg m^{-2} lower than the common waterhemp treatment (Table 3). These results demonstrate that neighboring weeds variably affect corn leaf chlorophyll content. In a resource dependent weed removal study in corn, Cordes et al. (2004) showed that corn leaf chlorophyll content was similar in weed-free and weedy treatments at low common waterhemp densities (35-82 plants m^{-2}), however, at higher common waterhemp densities (> 369 plants m^{-2}), chlorophyll content was reduced by direct competition. Therefore, it appears that corn leaf chlorophyll content may be weed density dependent.

The weed species*N rate interaction was not significant for later corn growth stages (Table 4). The full N rate resulted in higher corn leaf chlorophyll content than the reduced N rate. The full N rate resulted in a 56.5 and 45.6 mg m^{-2} increase in corn leaf chlorophyll content over the reduced N rate at the V11 and V14 growth stages, respectively. Our results are consistent with previous studies that have demonstrated the positive correlation between corn leaf chlorophyll content and N application rates (Lindquist et al., 2010; Ziadi et al., 2008; Scharf et al., 2006). Additionally, lower R:FR at the V5 growth stage correlated with lower corn leaf chlorophyll content at the V8 and V14 growth stages in the full N rate treatments (data not shown).

Table 4. Nitrogen (N) rate effect on leaf chlorophyll contents of corn plants at the V11 and V14 growth stages[a]

N rate	V11	V14
	mg m^{-2}	
Full	743.4 a	627.4 a
Reduced	686.9 b	581.8 b
ANOVA	P-value	P-value
N rate	0.027	0.014
Weed species	0.576	0.845
Weed species*N rate	0.970	0.365

Note. [a] Means within a column with the same letter are not significantly different ($P \leq 0.05$).

3.4 Corn Biomass

Corn shoot biomass varied as a function of weed species ($P = 0.0491$) and nitrogen rate ($P < 0.0001$), although no significant interaction was detected between factors ($P = 0.1365$). Therefore, nitrogen rate and weed species main effects were analyzed individually. As expected, corn plants that were supplied with the full N rate had greater shoot biomass when compared to the reduced N rate treatments (Table 5). Corn shoot biomass for the common waterhemp treatment was lower than the volunteer corn and velvetleaf treatments by 9.0 and 6.6 g, respectively. No differences were detected among the velvetleaf, volunteer corn, and weed-free treatments.

Table 5. Influence of weed species and nitrogen (N) rate on corn shoot biomass and root:shoot ratio[a]

Factor	Shoot biomass (g)	Root:shoot (g:g)
N rate		
Full	90.18 a	0.84 a
Reduced	70.29 b	0.89 a
Weed species		
None	80.23 ab	0.64 b
Volunteer corn	84.03 a	0.83 ab
Velvetleaf	81.65 a	0.92 ab
Common waterhemp	75.03 b	1.06 a
ANOVA	P-value	P-value
N rate	< 0.0001	0.5823
Weed species	0.0491	0.0468
Weed species*N rate	0.1365	0.1636

Note. [a] Means within a column and factor with the same letter are not significantly different ($P \leq 0.05$).

A significant weed species*N rate interaction (P = 0.0937) influencing corn root biomass was observed, thus simple effects of both factors were investigated. For the full N rate, the common waterhemp treatment resulted in a greater corn root biomass when compared with the corn and weed-free treatments (Table 6). No differences were detected among the velvetleaf, volunteer corn, and weed-free treatments. Corn root biomass did not vary across weed species at the reduced N rate.

Table 6. Influence of weed species and nitrogen (N) rate interaction on corn root biomass[a]

Factor	Root biomass (g)
Weed species*N rate	
None*Full	60.41 b
Volunteer corn*Full	60.42 b
Velvetleaf*Full	72.73 ab
Common waterhemp*Full	104.74 a
None*Reduced	41.96 b
Volunteer corn*Reduced	76.57 ab
Velvetleaf*Reduced	75.04 ab
Common waterhemp*Reduced	60.79 b
ANOVA	P-value
N rate	0.2047
Weed species	0.0863
Weed species*N rate	0.0937

Note. [a] Means within a column with the same letter are not significantly different ($P \leq 0.1$).

Corn root:shoot ratio varied as a function of weed species (P = 0.0468), whereas N rate had no effect (P = 0.5823) (Table 5). The common waterhemp treatment had a greater root:shoot ratio when compared to the weed-free treatment (P = 0.0069), but no differences were observed among velvetleaf, volunteer corn, and weed-free treatments.

The results suggest that the presence of common waterhemp influenced biomass partitioning of corn plants, where plants tended to accumulate more biomass in the roots. Similar results were reported by Liu et al. (2009), where corn plants in the presence of neighboring redroot pigweed had an increase in the root:shoot biomass partitioning at early growth stages. The authors associated that result with lower R:FR interception by the corn plants. However, the same study reported a decrease in the root:shoot ratio at the 9-leaf tip stage, whereas no differences were observed at later growth stages. Croster et al. (2003) reported that the total biomass production of nightshade species (*Solanum* spp.) was not influenced by the R:FR ratio, although the stem biomass was greater at the lower R:FR treatment. Contrary to the results reported in this research, Rajcan et al. (2004) reported that total corn biomass was not affected by upwardly reflected R:FR radiation treatments, whereas root:shoot ratio was greater in the higher R:FR radiation treatments. Kasperbauer and Hunt (1992) reported an increase in soybean root:shoot ratio when they were exposed to higher R:FR radiation when compared to plants exposed to lower R:FR radiation. Similar results were reported in corn seedlings, where lower R:FR radiation resulted in lower root:shoot ratios (Kasperbauer & Karlen, 1994). In the current study, lower early-season R:FR (V5 growth stage) correlated with lower shoot biomass and increased root biomass and root:shoot ratio in the full N rate treatments.

Spectral characteristics of common waterhemp, velvetleaf, and volunteer corn varied in the red and far-red waveband regions and the R:FR was consistently lower in the dicot species than volunteer corn. The effect of reduced early-season R:FR from neighboring weeds impacted corn growth characteristics under an optimal N regime. When the corn plants were not stressed from inadequate N, lower R:FR at the V5 growth stage reduced corn height and corn leaf chlorophyll content and increased fibrous root biomass. Changes in R:FR did not have an impact on these growth characteristics under reduced N treatments, indicating N stress was a greater limiting factor to corn growth than light quality. Therefore, this supports that competition for resources is still more important than the effect of light quality on the outcome of interplant competition. Results highlight the importance of the critical weed-free period and the need for proper early-season weed management.

Acknowledgements

The authors would like to thank Dr. Ellen Paparozzi, Dr. Timothy Arkebauer, and Dr. Bryan Leavitt for their technical expertise with experimental design, maintenance, and data collection techniques.

References

Abendroth, L. J., Elmore, R. W., Boyer, M. J., & Marlay, S. K. (2011). *Corn growth and development*. Iowa State Univ. Extension Publication #PMR-1009. Retrieved April 15, 2016, from https://store.extension.iastate.edu/Product/Corn-Growth-and-Development

Afifi, M., & Swanton, C. J. (2011). Maize seed and stem roots differ in response to neighboring weeds. *Weed Research, 51*, 442-450. http://dx.doi.org/10.1111/j.1365-3180.2011.00865.x

Afifi, M., & Swanton, C. J. (2012). Early physiological mechanisms of weed competition. *Weed Science, 60*, 542-551. http://dx.doi.org/10.1614/WS-D-12-00013.1

Ballaré, C. L. (2009). Illuminated behavior: Phytochrome as a key regulator of light forging and plant anti-herbivore defence. *Plant Cell Environment, 32*, 713-725. http://dx.doi.org/10.1111/j.1365-3040.2009.01958.x

Bonifas, K. D., Walters, D. T., Cassman, K. G., & Lindquist, J. L. (2005). Nitrogen supply affects root:shoot ratio in corn and velvetleaf (*Abutilon theophrasti*). *Weed Science, 53*, 670-675. http://dx.doi.org/10.1614/WS-05-002R.1

Bosnic, C. A., & Swanton, C. J. (1997). Influence of barnyardgrass (*Echinochloa crus-galli*) time of emergence and density on corn (*Zea mays*). *Weed Science, 45*, 276-282.

Clark, R. B. (1982). Nutrient solution growth of sorghum and corn in mineral nutrition studies. *Journal of Plant Nutrition, 5*, 1039-1057. http://dx.doi.org/10.1080/01904168209363037

Cordes, J. C., Johnson, W. G., Scharf, P., & Smeda, R. J. (2004). Late-emerging common waterhemp (*Amaranthus rudis*) interference in conventional tillage corn. *Weed Technology, 18*, 999-1005. http://dx.doi.org/10.1614/WT-03-185R

Cressman, S. T., Page, E. R., & Swanton, C. J. (2011). Weeds and the red to far-red ratio of reflected light: Characterizing the Influence of herbicide selection, dose, and weed species. *Weed Science, 59*, 424-430. http://dx.doi.org/10.1614/WS-D-10-00166.1

Croster, M. P., Witt, W. W., & Spomer, L. A. (2003). Neutral density shading and far-red radiation influence black nightshade (*Solanum nigrum*) and eastern black nightshade (*Solanum ptycanthum*) growth. *Weed Science, 51*, 208-213. http://dx.doi.org/10.1614/0043-1745(2003)051[0208:NDSAFR]2.0.CO;2

Evans, S. P., Knezevic, S. Z., Lindquist, J. L., Shapiro, C. A., & Blankenship, E. E. (2003). Nitrogen application influences the critical period for weed control in corn. *Weed Science, 51*, 408-417. http://dx.doi.org/10.1614/0043-1745(2003)051[0408:NAITCP]2.0.CO;2

Gitelson, A. A., Buschmann, C., & Lichtenhaler, H. K. (1999). The chlorophyll fluorescence ratio F735/F700 as an accurate measure of chlorophyll content in plants. *Remote Sensing of Environment, 69*, 296-302. http://dx.doi.org/10.1016/S0034-4257(99)00023-1

Hall, M. R., Swanton, C. J., & Anderson, G. W. (1992). The critical period of weed control in grain corn (*Zea mays*). *Weed Science, 40*, 441-447.

Jiao, Y., Lau, S., & Deng, X. W. (2007). Light-regulated transcriptional networks in higher plants. *Nature Reviews Genetics, 8*, 217-230. http://dx.doi.org/10.1038/nrg2049

Kasperbauer, M. J., & Hunt, P. G. (1992). Root size and shoot root ratio as influenced by light environment of the shoot. *Journal of Plant Nutrition, 15*, 685-697. http://dx.doi.org/10.1080/01904169209364355

Kasperbauer, M. J., & Karlen, D. L. (1994). Plant spacing and reflected far-red light effects on phytochrome-regulated photosynthate allocation in corn seedlings. *Crop Science, 34*, 1564-1569. http://dx.doi.org/10.2135/cropsci1994.0011183X003400060027x

Knezevic, S. Z., Weise, S. F., & Swanton, C. J. (1994). Interference of redroot pigweed (*Amaranthus retroflexus* L.) in corn (*Zea mays* L.). *Weed Science, 42*, 568-573.

Kropff, M. J., & van Laar, H. H. (1993). *Modelling crop-weed interactions*. Wallingford, U.K.: CAB International and Manila, Philippines: International Rice Research Institute.

Lindquist, J. L., & Mortensen, D. A. (1999). Ecophysiological characteristics of four maize hybrids and Abutilon theophrasti. *Weed Research, 39*, 271-285. http://dx.doi.org/10.1046/j.1365-3180.1999.00143.x

Lindquist, J. L., Evans, S. P., Shapiro, C. A., & Knezevic, S. Z. (2010). Effect of nitrogen addition and weed management interference on soil nitrogen and corn nitrogen status. *Weed Technology, 24*, 50-58. http://dx.doi.org/10.1614/WT-09-070.1

Lindquist, J. L., Mortensen, D. A., & Johnson, B. E. (1998). Mechanisms of corn tolerance and velvetleaf suppressive ability. *Agronomy Journal, 90*, 787-792. http://dx.doi.org/10.2134/agronj1998.00021962009000060012x

Lindquist, J. L., Mortensen, D. A., Clay, S. A., Schmenk, R., Kells, J. J., Howatt, K., & Westra, P. (1996). Stability of corn (*Zea mays*)-velvetleaf (*Abutilon theophrasti*) interference relationships. *Weed Science, 44*, 309-313.

Liu, J. G., Mahoney, K. J., Sikkema, P. H., & Swanton, C. J. (2009). The importance of light quality in crop-weed competition. *Weed Research, 49*, 217-224. http://dx.doi.org/10.1111/j.1365-3180.2008.00687.x

Loddo, D., Sousa, E., Masin, R., Calha, I., Zanin, G., Fernández-Quintanilla, C., & Dorado, J. (2013). Estimation and comparison of base temperatures for germination of European populations of velvetleaf (Abutilon theophrasti) and jimsonweed (*Datura stramonium*). *Weed Science, 61*, 443-451. http://dx.doi.org/10.1614/WS-D-12-00162.1

Marquardt, P. T., Terry, R., Krupke, C. H., & Johnson, W. G. (2012). Competitive effects of volunteer corn on hybrid corn growth and yield. *Weed Science, 60*, 537-541. http://dx.doi.org/10.1614/WS-D-11-00219.1

McCullough, D. E., Aguilera, A., & Tollenaar, M. (1994). N uptake, N partitioning, and photosynthetic N-use efficiency of an old and a new maize hybrid. *Canadian Journal of Plant Science, 74*, 479-484. http://dx.doi.org/10.4141/cjps94-088

Moriles, J., Hansen, S., Horvath, D. P., Reicks, G., Clay, D. E., & Clay, S. A. (2012). Microarray and growth analyses identify differences and similarities of early corn response to weeds, shade, and nitrogen stress. *Weed Science, 60*, 158-166. http://dx.doi.org/10.1614/WS-D-11-00090.1

Page, E. R., Tollenaar, M., Lee, E. A., Lukens, L., & Swanton, C. J. (2010). Shade avoidance: An integral component of crop weed competition. *Weed Research, 50*, 281-288. http://dx.doi.org/10.1111/j.1365-3180.2010.00781.x

Pearson, C., & Jacobs, B. (1987). Yield components and nitrogen partitioning of maize in response to nitrogen before and after anthesis. *Australian Journal of Agricultural Research, 38*, 1001-1009. http://dx.doi.org/10.1071/AR9871001

Rajcan, I., & Swanton, C. J. (2001). Understanding maize-weed competition: Resource competition, light quality and the whole plant. *Field Crop Research, 71*, 139-150. http://dx.doi.org/10.1016/S0378-4290(01)00159-9

Rajcan, I., & Tollenaar, M. (1999). Source : Sink ratio and leaf senescence in maize: II. Nitrogen metabolism during grain filling. *Field Crop Research, 60*, 255-265. http://dx.doi.org/10.1016/S0378-4290(98)00143-9

Rajcan, I., Chandler, K., & Swanton, C. J. (2004). Red-far-red ratio of reflected light: A hypothesis of why early-season weed control is important in corn. *Weed Science, 52*, 774-778. http://dx.doi.org/10.1614/WS-03-158R

Sauer, J. (1957). Recent migration and evolution of the dioecious Amaranths. *Evolution, 11*, 11-31. http://dx.doi.org/10.2307/2405808

Scharf, P. C., Brouder, S. M., & Hoeft, R. G. (2006). Chlorophyll meter readings can predict nitrogen need and yield response of corn in the North-Central USA. *Agronomy Journal, 98*, 655-665. http://dx.doi.org/10.2134/agronj2005.0070

Smith, H. (1982). Light quality, photoperception, and plant strategy. *Annual Review of Plant Physiology and Plant Molecular Biology, 33*, 481-518. http://dx.doi.org/10.1146/annurev.pp.33.060182.002405

Smith, H., & Holmes, M. G. (1977). The function of phytochrome in the natural environment. III. Measurement and calculation of phytochrome photoequilibrium. *Photochemistry and Photobiology, 25*, 547-550. http://dx.doi.org/10.1111/j.1751-1097.1977.tb09126.x

Steckel, L. E., & Sprague, C. L. (2004). Common waterhemp (*Amaranthus rudis*) interference in corn. *Weed Science, 52*, 359-364. http://dx.doi.org/10.1614/WS-03-066R1

Stoller, E. W., Wax, L. M., & Alm, D. M. (1993). Survey results on environmental issues and weed science research priorities within the corn belt. *Weed Technology, 7*, 763-770.

Swanton, C. J., Shrestha, A., Roy, R. C., Ball-Coelho, B. R., & Knezevic, S. Z. (1999). Effect of tillage systems N, and cover crop on the composition of weed flora. *Weed Science, 47*, 454-461.

Ta, C. T., & Weiland, R. T. (1992). Nitrogen partitioning in maize during ear development. *Crop Science, 32*, 443-451. http://dx.doi.org/10.2135/cropsci1992.0011183X003200020032x

Zhou, X. M., Madramootoo, C. A., MacKenzie, A. F., & Smith, D. L. (1997). Biomass production and nitrogen uptake in corn-ryegrass systems. *Agronomy Journal, 89*, 749-756. http://dx.doi.org/10.2134/agronj1997.00021962008900050007x

Ziadi, N., Brassard, B. M., Bélanger, G., Claessens, A., Tremblay, N., Cambourins, A. N., … Parent, L. (2008). Chlorophyll measurements and nitrogen nutrition index for the evaluation of corn nitrogen status. *Agronomy Journal, 100*, 1264-1273. http://dx.doi.org/10.2134/agronj2008.0016

Zimdahl, R. L. (1988). The concept and application of the critical weed-free period. In M. A. Altieri & M. Liebman (Eds.), *Weed Management in Agroecosystems: Ecological Approaches* (pp. 145-155). CRC Press, Boca Raton, FL.

Copyrights