INFLUENCE OF WEEDS ON NITROGEN CYCLING IN CORN AGRO-ECOSYSTEMS

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Crop and Soil Sciences

2012

ABSTRACT

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An understanding of nitrogen (N) assimilation and biomass accumulation of weeds and corn (*Zea mays* L.) will help develop N management and weed control strategies to improve crop competitiveness. A field study was established to determine the critical weed removal timing at four preplant N application rates (0, 67, 134, and 202 kg N ha^{-1}). Weed removal timings were based on average weed canopy height (0, 5, 10, and 20 cm). The critical weed removal timings were 3.7-, 11.7-, 10.3-, and 15.9-cm weeds when corn was grown at 0, 67, 134, and 202 kg N ha^{-1}, respectively. Results of this study suggest that weeds need to be removed earlier when N is applied at lower rates. In the same study, the total N concentration in common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), giant foxtail (*Setaria faberi* Herrm.), and corn was measured at several growth stages. A quadratic model significantly described the relationship between total N concentration and growth stage for most treatment combinations. Total N concentration increased from 5 to 10 cm weed heights and decreased as weed height increased from 10 to 20 cm.

Weeds assimilated a large amount of N. A laboratory experiment measured N mineralization from common lambsquarters, common ragweed, and giant foxtail. Weeds were grown in the field at four N rates (0, 67, 134, or 202 kg N ha^{-1}) and collected at two heights (10 or 20 cm). Nitrogen mineralization from weed residue mixed with soil was determined over a 12-week period. Nitrogen mineralization was rapid up to 4 weeks of incubation after which

mineralization plateaued. Across treatments, net N mineralization occurred by week 12 of incubation. However, prior to 12 weeks of incubation, N was immobilized by giant foxtail grown under no N application. Weeds that are controlled by 10 cm height may contribute to the available soil N pool. However, this practice is not recommended due to competition between weeds and crops for other factors such as water and light which may reduce yield.

A greenhouse study was conducted to evaluate the effect of weed density and N application rate on weed growth and N assimilation of common lambsquarters, a C_3 species, and redroot pigweed (*Amaranthus retroflexus* L.), a C_4 species. Study factors included four weed densities (1, 2, 4, and 8 plants pot^{-1}), three N application rates (0, 67, and 134 kg N ha^{-1}). Redroot pigweed shoot biomass was greater than common lambsquarters, indicating that redroot pigweed may be more competitive than common lambsquarters. Weeds grown at low N and low density exhibited greater root biomass compared to weeds grown under higher N application rates and densities. Nitrogen assimilation was greater for redroot pigweed than common lambsquarters.

Common lambsquarters is a highly competitive weed in crop production systems and is considered to be highly responsive to N application. A two-year field study was established to measure N assimilation by common lambsquarters and examine the effect of common lambsquarters on corn grain yield. Study factors included common lambsquarters (presence or absence) and sidedress N application rate (0, 56, 112, 168, or 224 kg N ha^{-1}). In 2009, biomass and total N concentration in common lambsquarters increased with N application rate. In 2010, there was no significant difference in common lambsquarters biomass or total N concentration. In both years, corn grain yield was not influenced by the presence of common lambsquarters.

Dedicated to Alex Lindsey

ACKNOWLEDGEMENTS

I am very thankful for the guidance of my major professor, Dr. Darryl Warncke. I am very privileged that he took me on as his last graduate student, and I have benefitted greatly from his vast experience and knowledge. I would also like to thank Dr. Kurt Steinke for giving me the opportunity to be more involved in soil fertility field studies during my last year of graduate school. I am also very appreciative of his career advice. I also thank Dr. Wesley Everman, Dr. Christy Sprague, and Dr. Dan Brainard for serving on my guidance committee. Thank you for your willingness to help guide my research and my future career.

I would like to extend a special thank you Andy Chomas and Bruce Sackett for helping establish and maintain my field studies. I am also very grateful to my former weed science labmates, Cal Glaspie and John Green, and my current soil fertility labmates, Patrick Ogutu and Luke Thurgood, for all of their help with field and greenhouse projects. Undergraduate research support was also integral to my studies. Thank you, Melissa Huck, Gavan Lienhart, Chris Stump, Cody Ferry, Jim Vincent, and Brian Stiles. I would like to thank my friends and fellow graduate students in Crop and Soil Sciences. I have enjoyed getting to know all of you, and I am thankful for all of your encouragement.

My parents, Bob and Carolyn Bast, have always supported me in my scientific endeavors starting with my 5th grade science fair project, providing me with a great foundation to pursue research. Thank you. I am also very thankful for my labmate/husband Alex Lindsey for his support and advice. He helped collect data, edited manuscripts, and listened to many practice presentations.

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CHAPTER 1

NITROGEN APPLICATION IMPACTS THE CRITICAL WEED REMOVAL TIMING

ABSTRACT

Nitrogen (N) recommendations for corn in the North Central U.S. are based on maximizing economic return. Using the maximum return to N (MRTN) system, N recommendations are often lower compared to the traditional yield-based approach. Lower N application rates may alter the critical weed removal timing (CWRT) in corn grain production. A three-year field study was established in East Lansing, MI to evaluate the impact of N application rate on the CWRT in corn grain production and to determine the correlation between N assimilation by weeds and grain yield. Four N application rates (0, 67, 134, and 202 kg N ha^{-1}) and five weed removal heights based on average weed canopy height (0, 5, 10, 15, and 20 cm) were evaluated. At each weed removal height, weed and corn samples were collected, dry biomass recorded, and total N content measured. The CWRT was determined using regression models to find where grain yield decreased by 5% compared to the weed-free control. There was no correlation between N assimilation by weeds and grain yield. The CWRT was 3.7-, 11.7-, 10.3-, and >20-cm weeds when corn was grown at 0, 67, 134, and 202 kg N ha^{-1}, respectively. Results of this study suggest that weeds need to be removed earlier to maximize grain yield when N is applied at lower rates.

INTRODUCTION

Better understanding of potential nitrogen (N) losses in agro-ecosystems is needed due to increases in the price of N fertilizer. One such potential source of N loss includes N assimilation by weeds. In a mixed population of grass and broadleaf weed species grown with spring wheat (*Triticum aestivum* L.), 32 kg N ha^{-1} was assimilated by weeds at Feekes 11.4 (Kirkland and Beckie 1998). Shattercane (*Sorghum bicolor* L.) assimilated 38 kg N ha^{-1} at a density of 200 plants m^{-2} and 46 cm height (Hans and Johnson 2002). Although N assimilation by weeds has been noted in the greenhouse to increase with N application rate (Blackshaw et al. 2003), previous studies have not examined the influence of N application rate on N assimilation by weeds growing under field conditions and have not examined the correlation between N assimilation by weeds and corn grain yield.

In response to N fertilizer price fluctuations, soil fertility specialists in the North Central U.S. have developed and adopted the maximum return to nitrogen (MRTN) system for making N recommendations for corn (*Zea mays* L.) (Sawyer et al. 2006; Warncke et al. 2009). The MRTN system is based on maximizing economic return whereas the traditional yield-based approach was based on maximizing grain yield (Vitosh et al. 1995). When the cost of N is inexpensive compared to the price of corn (low cost of N: price of grain ratio), N recommendations are greater than when N is relatively expensive compared to the price of corn (high cost of N: price of grain ratio). Because of these economic considerations, N recommendations are often lower using the MRTN system compared to the yield-based approach.

Many studies have evaluated the critical weed removal timing (CWRT), which is defined as the growth stage when weeds need to be removed to avoid a yield reduction from plant competition (Zimdahl 2004). In the North Central U.S., weed removal is recommended prior to the V4 to V6 corn growth stage (Dalley et al. 2006; Gower et al. 2003) or prior to an average weed canopy height of 10 to 15 cm (Carey and Kells 1995; Dalley et al. 2004; Gower et al. 2003; Tapia et al. 1997) to reduce the chance of grain yield loss from weed competition. Most CWRT studies have been conducted under non-limiting conditions, but the CWRT may be influenced by N application rate (Evans et al. 2003; Weaver et al. 1992). Researchers in Ontario, Canada found that corn grain yield losses due to green foxtail [*Setaria viridis* (L.) Beauv.] at higher N application rates were reduced (Cathcart and Swanton 2003). In Nebraska dryland corn grain production, a 5% grain yield reduction occurred when weeds were controlled at the V4 or the V6 growth stage depending if 60 or 120 kg N ha^{-1} was applied, respectively (Evans et al. 2003). The CWRT based on N application rate has not been evaluated in Michigan. Due to the implementation of the MRTN recommendation system, the CWRT in Michigan corn grain production was re-evaluated. The objectives of our study were to i) measure N assimilation by weeds and corn early in the growing season, ii) examine the CWRT based on N application rate, and iii) evaluate the correlation between N assimilation by weeds and corn grain yield.

MATERIALS AND METHODS

A field study was conducted in 2009, 2010, and 2011 at the Michigan State University Crop and Soils Research Farm in East Lansing, MI, to measure N assimilation by weeds and corn, examine the CWRT based on N application rate, and evaluate the correlation between N assimilation by weeds and corn grain yield. Four N rates of 0, 67, 134, and 202 kg N ha^{-1} were examined. Weed populations were controlled at four times based on average weed canopy height (5, 10, 15, and 20 cm), and are described as weed removal height. Weed-free plots were maintained as controls. Weed removal height was replicated four times and randomized within each N rate. In 2009 and 2011, the study was conducted on an Aubbeenaubbee sandy loam (fine-loamy, mixed, active, mesic Aeric Epiaqualfs) and Capac loam (fine-loamy, mixed, active, mesic, Aquic Glossudalfs) complex. In 2010, the study was conducted on Capac loam. Soil physical and chemical properties are shown in Table 1.

Corn ('Pioneer 37Y14') was planted at 71,700 seeds ha^{-1} in 76-cm rows. Plot size was 3 by 11 m and consisted of four rows of corn. The study sites were planted to soybean the previous year, and were chisel-plowed in the fall prior to establishment of the study. The fields were cultivated twice in the spring, with the different rates of urea being applied and incorporated prior to planting. Dates of field operations and weed removal are given in Table 2. With the exception of the weed-free treatment, the natural, mixed population of weeds was allowed to emerge with the corn. Common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), and giant foxtail (*Setaria faberi* Herrm.) were the predominant weed species. At each weed removing height, glyphosate (RoundUp WeatherMax®, Monsanto Co.) was applied at 0.84 kg ae ha^{-1} with ammonium sulfate at 2% (w/w). Glyphosate was applied with a tractor-mounted compressed-air sprayer equipped with flat-fan nozzles (TeeJet® XR 8003, Spraying Systems Co.) and calibrated to deliver 187 L ha^{-1} at a pressure of 207 kPa. Plots were maintained weed-free subsequent to weed removal with additional glyphosate applications and/or by hand weeding. Corn grain yield was determined by harvesting the center two rows of each plot with a mechanical plot harvester (Massey-Ferguson 8XP Harvest Master) and correcting grain yield to 15.5% moisture content. Precipitation and temperature were recorded by Enviro-weather Automated Weather Station Network (Michigan State University, East Lansing, MI). Monthly rainfall and cumulative growing degree days are given in Table 3.

Prior to each weed removal height, the plant density of each weed species was recorded from a 0.25 m^2 quadrat in each plot (Table 4). Twenty to 30 common lambsquarters, common ragweed, and giant foxtail plants were randomly selected and collected from each plot. Shoot fresh biomass was determined at collection and dry biomass was determined after drying in a forced-air dryer for 72 hr at 60°C. Dried samples were finely ground with a Cyclone Sample Mill (Udy Co., Fort Collins, CO). Total N content in the weeds was measured using a Carbon-Nitrogen Combustion Analyzer (Costech Analytical Tech. Inc., Valencia, CA) by the Dumas method (Bremner 1996). Total N assimilation per hectare was calculated by the summation of total N assimilation of each individual weed species. The total N assimilation of each individual weed species was calculated according to [Eq. 1]:

Total N assimilation = (average weed dry weight) x (total %N/100) x (weed density) [Eq. 1]

where, total N assimilation is the total N assimilated for an individual weed species in g N per hectare, the average weed dry weight (g of dry shoot biomass per plant) is the average dry weight of the 20 to 30 randomly selected weed, total %N is the percentage of total N measured in weeds, and weed density is the average weed density in per hectare.

All statistical procedures were conducted using SAS 9.1 (SAS Institute 2003). Nitrogen assimilation and grain yield was modeled over weed and corn growth stages within each N application rate using a quadratic regression models (Proc Reg) (Gower et al. 2003). Critical weed removal timing was calculated within each N application rate and was based on a 5% reduction in corn grain yield compared to the highest grain yield achieved within each N application rate. The correlation between N assimilation by weeds and corn grain yield was determined using Proc Corr. All data were analyzed across the three years due to lack of significant year by treatment interaction.

Table 1. Soil chemical and physical properties for each year of the study.

Property	2009	2010	2011
pH	6.1	6.2	7.2
Sand, %	45.3	39.3	45.3
Silt, %	31.0	34.0	31.0
Clay, %	23.7	26.7	23.7
CEC, cmol kg^{-1}	8.7	9.5	11.1
Total N, g kg^{-1}	0.39	1.09	0.91
NH_4-N, mg kg^{-1}	9.3	2.8	4.7
NO_3-N, mg kg^{-1}	8.8	5.2	5.2
Bray P, mg kg^{-1}	73	37	35
Exchangeable K, mg kg^{-1}	139	105	122
Exchangeable Mg, mg kg^{-1}	166	182	228

Table 2. Dates of field operations and weed removal. Corn growth stages are shown in parenthesis.

	2009	2010	2011
Planting	12 May	5 May	9 May
5 cm weeds	3 June (V2)	1 June (V3)	3 June (V3)
10 cm weeds	8 June (V4)	8 June (V4)	9 June (V4/5)
15 cm weeds	18 June (V6)	11 June (V5)	13 June (V5)
20 cm weeds	20 June (V6)	14 June (V6)	18 June (V6)
Silking	28 July	21 July	22 July
Harvest	28 Oct.	6 Oct.	17 Oct.

Table 3. Cumulative monthly growing degree days (GDD)[a] and precipitation for each year of the study.

	2009	2010	2010	2011	2009	2010	2011	30-year average
	--Monthly cumulative GDD--				---------------precipitation (cm)----------------			
May	153	204		175	10.7	12.7	15	6.8
June	276	309		294	12.4	10.5	4.4	9.0
July	283	395		432	6.0	6.3	17.5	6.7
Aug	317	376		331	10.3	3.4	6.3	8.1
Sept	222	194		187	2.4	9.1	6.6	8.8
Total	1251	1478		1419	41.8	41.9	49.7	39.4

[a]Growing degree days calculated using a base temperature of 10°C.

Table 4. Mean weed densities each year. The standard errors of the means are shown in parenthesis.

	Weed densities			
Year	CHEAL	AMBEL	SETFA	Total
	------------------------weeds m^{-2}---------------------			
2009	540 (43)	64 (5)	260 (32)	865
2010	130 (8)	163 (9)	155 (12)	448
2011	102 (17)	423 (32)	427 (76)	952

RESULTS AND DISCUSSION

Dates of field operations and weed removal are shown in Table 2. Weed removal of 5- and 10-cm weeds occurred at similar times for each year of the study. However, in 2009, weed removal of 15- and 20-cm weeds occurred later in the growing season than in 2010 and 2011. Weed removal occured later in 2009 due to cooler temperatures in 2009 compared to 2010 and 2011 (Table 3). Even though weed removal occurred on different dates, the corn growth stage at weed removal was similar each year.

Biomass Accumulation of Weeds and Corn. Biomass accumulation of weeds increased with increasing weed height (Fig. 1) and a quadratic equation was used to describe biomass accumulation within each N application rate (Table 5). Biomass accumulation of weeds was similar when 67, 134, and 202 kg N ha^{-1} were applied and greater compared to when no N was applied. Weed biomass accumulation was greatest at 3200 kg ha^{-1} while corn biomass accumulation was greatest at 222 kg ha^{-1} (Fig. 2). The greater biomass accumulation on a hectare basis exhibited by weeds compared to corn may be due in part to plant density. Weed density ranged from 448 to 952 plants m^{-2} (Table 4), while corn density was 7 plants m^{-2}.

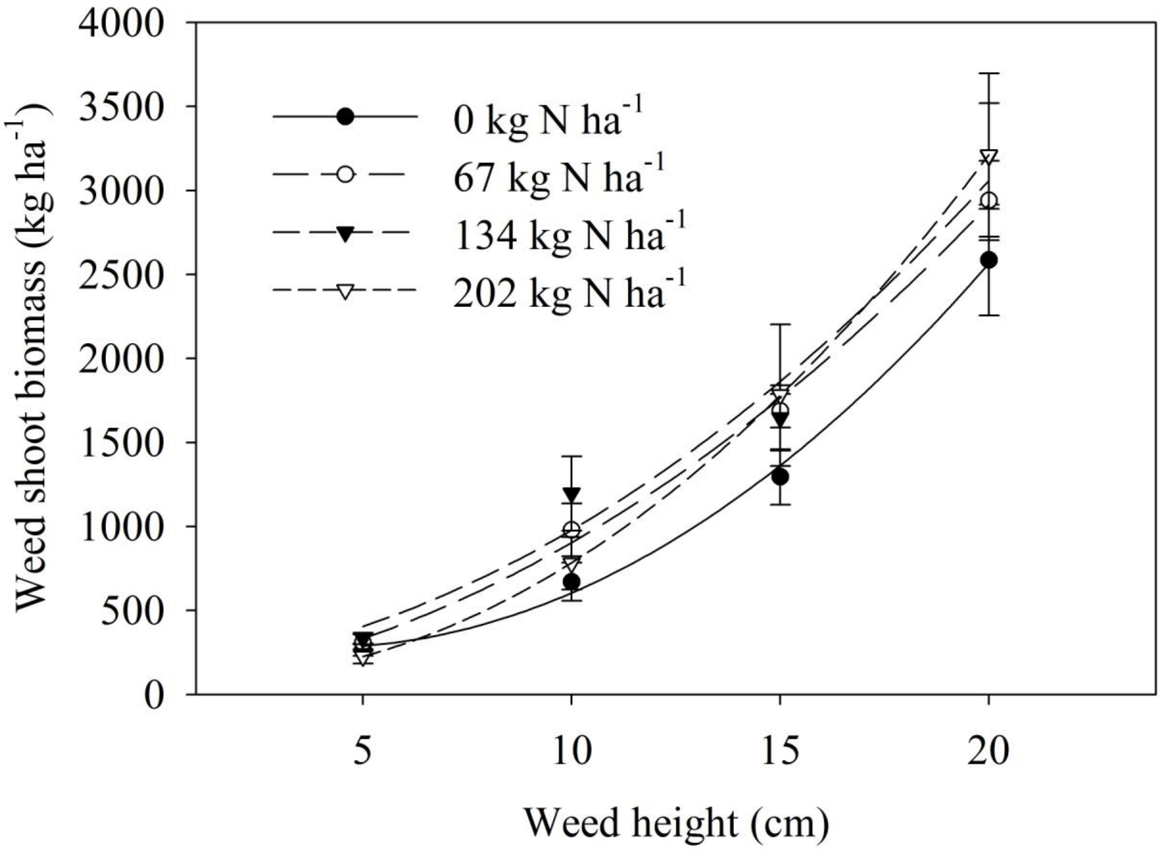

Figure 1. Weed shoot biomass accumulation by weed canopy height within each N application rate. Weed heights of 5, 10, 15, and 20 cm correspond to the V3, V4, V5, and V6 corn growth stages.

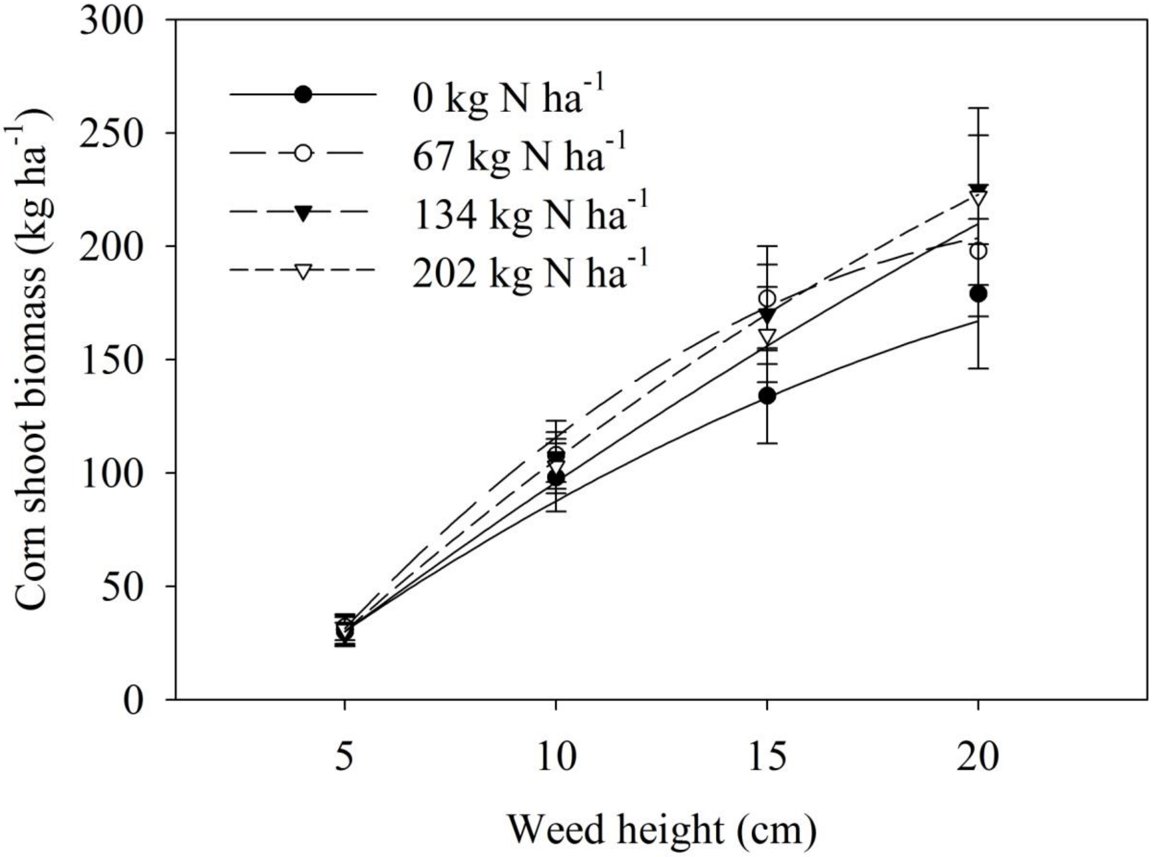

Figure 2. Corn shoot biomass accumulation by weed canopy height within each N application rate. Weed heights of 5, 10, 15, and 20 cm correspond to the V3, V4, V5, and V6 corn growth stages.

Table 5. Quadratic regression models used to describe the relationship between shoot biomass accumulation (y) of weeds and corn and weed removal timing (x) within each N application rate, East Lansing, MI.

Biomass accumulation	N application	Regression equation	F-value	p-value[a]
kg ha^{-1}	kg N ha^{-1}			
Weeds	0	$y = 8.87x^2 – 70.01x + 418.09$	41.91	<0.0001
	67	$y = 5.80x^2 + 27.05x + 53.83$	82.08	<0.0001
	134	$y = 6.21x^2 + 21.53x + 143.29$	41.01	<0.0001
	202	$y = 8.74x^2 – 19.47x + 105.35$	24.23	<0.0001
Corn	0	$y = -0.24x^2 + 15.51x – 38.92$	14.79	<0.0001
	67	$y = -0.54x^2 + 24.98x – 80.73$	23.95	<0.0001
	134	$y = -0.23x^2 + 18.59x – 57.00$	34.53	<0.0001
	202	$y = -0.12x^2 + 15.55x – 42.94$	23.90	<0.0001

[a] p-value for regression equation.

Nitrogen Assimilation by Weeds and Corn. Nitrogen assimilation by weeds ranged from 9 to 124 kg N ha^{-1} depending on N application rate and height (Fig. 3). Many summer annual weeds, such as common lambsquarters, redroot pigweed (*Amaranthus retroflexus* L.), and common ragweed, are considered luxury consumers of N (Blackshaw and Brandt 2008; Marten and Andersen 1975; Qasem 1992). High N assimilation by weeds may be attributed to luxury N consumption. Nitrogen assimilation by corn ranged from 1 to 11 kg N ha^{-1} when measured at the V3 to V6 growth stage, which is prior to rapid N assimilation by corn which occurs between the V6 and tasseling growth stages (Abendroth et al. 2011). Nitrogen assimilation by weeds was greater than corn at all weed heights/corn growth stages (Fig. 3 and 4). The greater N assimilation on a hectare basis exhibited by weeds compared to corn may be due in part to plant density. Weed density ranged from 448 to 952 plants m^{-2} (Table 4), while corn density was 7 plants m^{-2}. At high N application rates, tissue N concentration in green foxtail was not affected by density (Cathcart and Swanton 2003), indicating at high weed densities more N will be assimilated on a hectare basis compared to low weed densities.

Nitrogen assimilation by both weeds and corn increased linearly with increasing weed/corn growth stage at all N application rates (Fig. 3 and 4 and Table 6). Within each N application rate, the rate of N assimilation by weeds was at least twelve times greater for weeds compared to corn. The greater rate of N assimilation by weeds may be attributed to the relative growth rate of weeds. Common lambsquarters and giant foxtail (two of the three predominant weed species in our study) have a greater relative growth rate than corn (Berger et al. 2007). Small-seeded weed species tend to have dense, fast-growing root systems that consist of long and thin roots compared to large-seeded crop species (Seibert and Pearce 1993). Dense, long root systems are associated with high underground competitive ability (Andrews et al. 1970), which may explain the early accelerated rate of N assimilation by weeds.

When weeds were 5 cm, N assimilation was similar among N application rates (Fig. 3 and 4). Similarly, when weeds were 5 cm tall/V3 corn growth stage, N assimilation by corn was the same at all N application rates. As weeds grew taller, N assimilation by both weeds and corn increased at all N application rates. The rate of N assimilation for weeds was lowest when no N was applied compared to weeds grown at 67, 134, and 202 kg N ha^{-1}. Nitrogen assimilation by corn increased with increasing N application rates when weeds were 10, 15, and 20 cm tall.

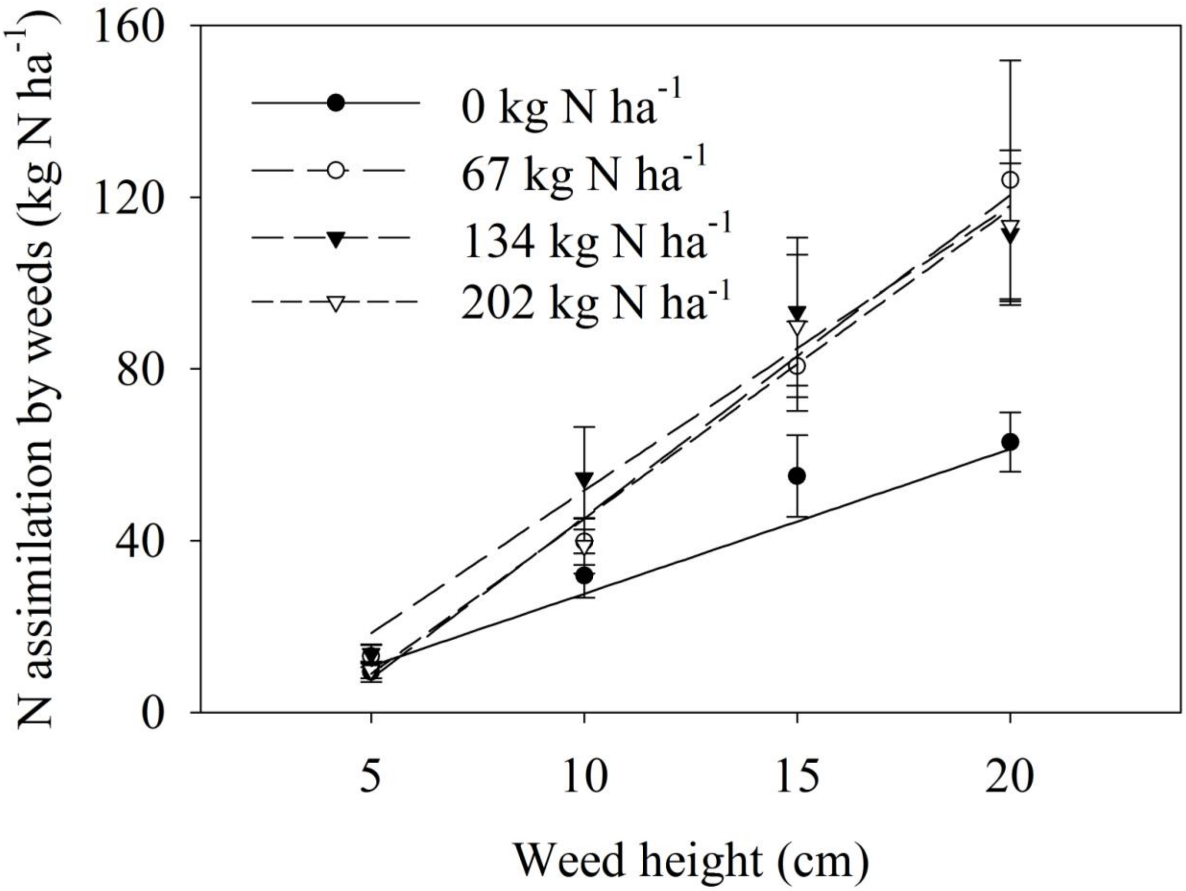

Figure 3. Nitrogen assimilation by weeds by weed canopy height within each N application rate. Weed heights of 5, 10, 15, and 20 cm correspond to the V3, V4, V5, and V6 corn growth stages.

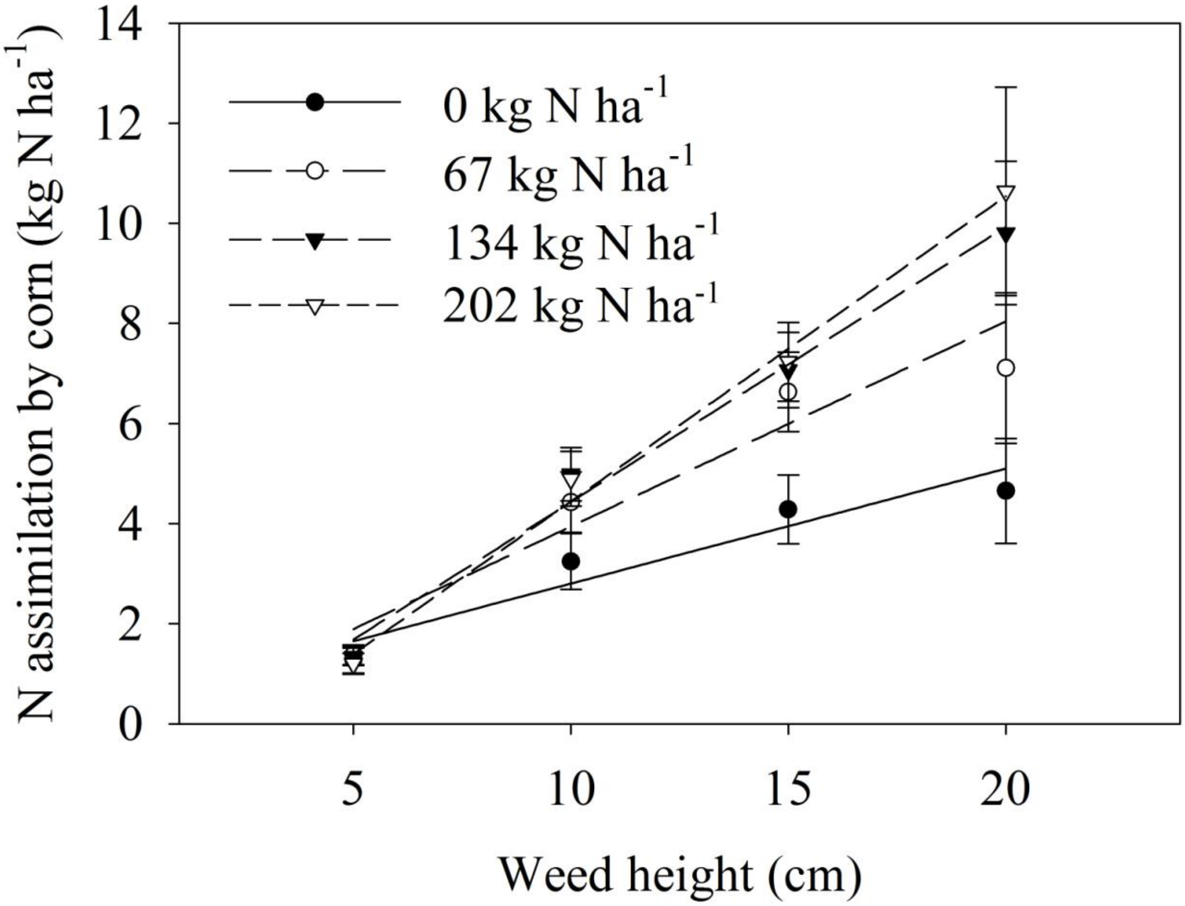

Figure 4. Nitrogen assimilation by corn by weed canopy height within each N application rate. Weed heights of 5, 10, 15, and 20 cm correspond to the V3, V4, V5, and V6 corn growth stages.

Table 6. Linear regression models used to describe the relationship between N assimilation (y) by weeds and corn and weed removal timing (x) within each N application rate, East Lansing, MI.

	N application	Regression equation	F-value	p-value[a]
	kg N ha^{-1}			
N assimilation by weeds	0	y = 3.37x - 6.10	39.92	<0.0001
	67	y = 7.51x - 29.72	30.70	<0.0001
	134	y = 6.64x - 14.80	31.62	<0.0001
	202	y = 7.21x - 27.07	38.25	<0.0001
N assimilation by corn	0	y = 0.23x + 0.50	15.31	0.0003
	67	y = 0.41x - 0.16	31.21	<0.0001
	134	y = 0.55x - 1.07	65.27	<0.0001
	202	y = 0.61x - 1.66	49.26	<0.0001

[a] p-value for regression equation.

Grain Yield. Corn grain yield increased with N application rate and decreased with weed removal timing (Fig. 5). A quadratic regression model was used to describe the relationship between grain yield and weed removal timing within each N application rate (Table 7). When corn was grown at 0, 67, and 134 kg N ha^{-1}, a quadratic regression model significantly fit the data. However, the quadratic regression model did not fit the data when corn was grown at 202 kg N ha^{-1}, indicating that there was no significant decrease in corn grain yield among weed removal heights.

Critical weed removal timing was calculated within each N application rate and was based on a 5% reduction in corn grain yield compared to the highest grain yield achieved within each N application rate (Table 7). The critical weed removal timing was 3.7-, 11.7-, 10.3-, and

>20- cm weeds when corn was grown with 0, 67, 134, and 202 kg N ha^{-1}, respectively. These results indicate that the CWRT was similar when 67 and 134 kg N ha^{-1} was applied. When no N was applied, the CWRT occurred at an earlier weed/corn growth stage, but at 202 kg N ha^{-1}, the CWRT occurred at a later growth stage. In Nebraska dryland corn grain production, Evans et al. (2003) also noted an increase in CWRT at increasing N application rates. In Wisconsin, an additional N application of 22 to 79 kg N ha^{-1} and 69 to 177 kg N ha^{-1} was required to compensate for corn grain yield reductions when weeds were removed at 10- and 30-cm height, respectively (Laboski et al. 2008).

The current MRTN recommendations for Michigan range from 70 to 160 kg N ha^{-1} for corn/soybean rotations (Warncke et al. 2009). The N application rates evaluated in our study were within the range of MRTN recommendations for Michigan corn grain production. When the cost of N is relatively more expensive than the price of grain (high N cost: grain price ratio), low N application rates are recommended. According to our data, when 67 to 134 kg N ha^{-1} is applied, weeds should be controlled prior to 10 cm height. Controlling weeds prior to 10-cm weed height corresponds to previous weed control recommendations for the North Central U.S. (Gower et al. 2003). When 202 kg N ha^{-1} was applied, there was no significant grain yield reduction among the examined weed removal timings. When resources are not limiting (i.e., adequate moisture and N), the CWRT may be >30 cm tall weeds (Dalley et al. 2006; Evans et al. 2003). However, resource-limiting years cannot be predicted, and therefore, we recommend timely weed control, especially when N application rates are reduced.

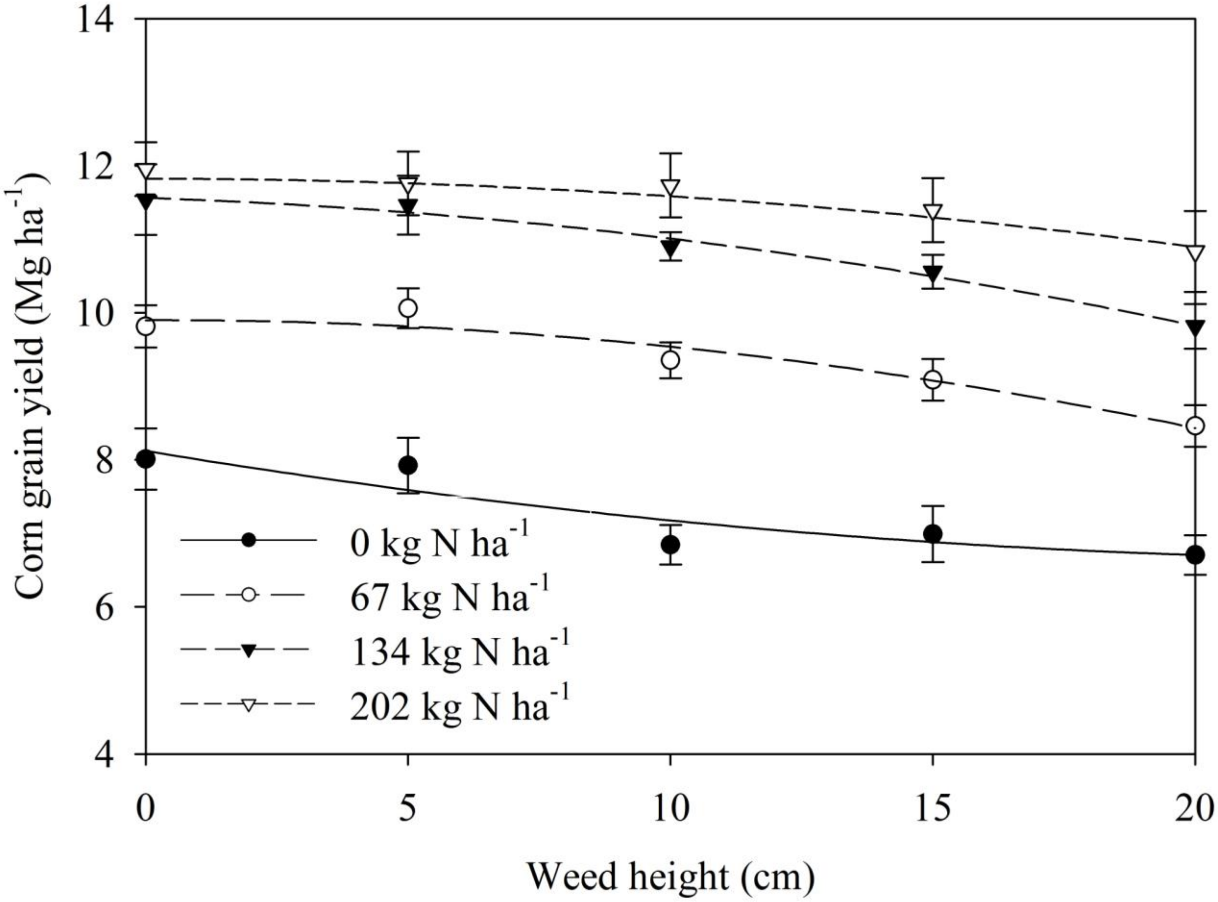

Figure 5. Relationship between corn grain yield and weed height at time of removal within each N application rate. Weed heights of 5, 10, 15, and 20 cm correspond to the V3, V4, V5, and V6 corn growth stages.

Table 7. Quadratic regression models used to describe the relationship between corn grain yield (y) and weed height at time of removal, and critical weed removal timing (CWRT) (x) within each N application rate, East Lansing, MI.

N application	Regression equation	F-value	p-value	CWRT
kg N ha^{-1}				cm
0	$y = 0.002x^2 - 0.118x + 8.12$	5.38	0.0073	3.7
67	$y = -0.004x^2 + 0.001x + 9.91$	9.88	0.0002	11.7
134	$y = -0.003x^2 -0.024x + 11.56$	9.03	0.0004	10.3
202	$y = -0.002x^2 - 0.002x + 11.83$	1.51	0.2296	>20

Relationship Between N Assimilation and Corn Grain Yield. Weeds assimilated up to 125 kg N ha^{-1} (Fig. 3). However, N assimilation by weeds did not correlate with corn grain yield (data not shown) indicating grain yield loss may be attributed to other factors in addition to N competition. Prior to resource dependent competition, resource independent competition such as the red-to-far-red light (R:FR) ratio may impact crop yield. Corn grown with weeds exhibits shade avoidance characteristics including fewer kernels per plant and reduced biomass partitioning to the developing ear (Page et al. 2010). A reduced number of visible corn leaf tips due to low R:FR ratios has been observed as early as 15 days after corn emergence (Page et al. 2009). One possible explanation of the grain yield reductions that occurred in our study may be attributed to a low R:FR ratio caused by the presence of weeds.

The lack of correlation between N assimilation by weeds and corn grain yield may also be attributed to the release of N subsequent to weed control. Nitrogen mineralization of plant material occurs at carbon:nitrogen (C:N) ratios <30 (Fox et al. 1990). Young, vegetative plants, have low C:N ratios compared to mature plants (Müller et al. 1988; Nicolardot et al. 2001).

Early in the growing season, weeds have been found to have a C:N ratio ranging from 7 to 22 (Bast et al. 2012) and there is evidence of significant N mineralization from weeds in field (Vazquez et al. 2003) and in laboratory incubation studies (Bast et al. 2012). Although weeds assimilated a large amount of N early in the growing season (Fig. 3), some of the N may have been released from the weeds back to the soil prior to the rapid N assimilation of corn that occurs between the V6 and tasseling growth stages of corn (Abendroth et al. 2011).

Precipitation was close to the 30-year average from May through September except for June 2011, August 2010, and September 2009 (Table 3). It is unlikely soil moisture was limiting especially early in the growing season, and competition between corn and weeds for water was probably not a yield-limiting factor. Soil phosphorus and potassium also should have not been limiting according to Michigan State University nutrient recommendations (Warncke et al. 2009).

Summary. At high weed densities, the amount and rate of N assimilation by weeds is much greater than N assimilation by corn. Timely weed control is important to reduce N assimilation by weeds. Although a large amount of N was assimilated by weeds, there was no correlation between weed N assimilation and corn grain yield, indicating grain yield may have been more reduced due to other competitive factors rather than N competition. The CWRT was influenced by N application rate. At low N application rates, weeds may need to be removed earlier to reduce the chance of yield loss due to weed competition.

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LITERATURE CITED

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CHAPTER 2

WEED TOTAL NITROGEN CONCENTRATION IN CORN AGRO-ECOSYSTEMS

ABSTRACT

A better understanding of nitrogen (N) assimilation and biomass accumulation of weeds and corn (*Zea mays* L.) will help develop fertilization and weed control strategies to improve crop competitiveness. A three-year field study was established in 2009 in East Lansing, Michigan, to examine the total N concentration of common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), giant foxtail (*Setaria faberi* Herrm.), and corn at several weed/corn growth stages. The effect of soil N on total N was determined. Nitrogen was applied at four rates of 0, 67, 134, and 202 kg N ha^{-1}. Weeds and corn were collected at four growth stages (at weed heights of 5, 10, 15, and 20 cm). At each growth stage, soil nitrate-N and ammonium-N were measured and plant root and shoot dry weights recorded. The total N concentration in shoots was measured. A quadratic model significantly described the relationship between total N concentration and weed/corn growth stage for most year and N application rate combinations. In most instances, total N concentration increased from 5 to 10 cm weed heights and decreased as weed height increased from 10 to 20 cm. A linear-plateau model significantly described the relationship between soil NO_3-N and total N concentration in weeds at all growth stages. At all weed growth stages, the plateau value (maximum total N concentration) was greatest for common ragweed, intermediate for common lambsquarters, and lowest for giant foxtail. To reduce weed competition in corn, weeds should be controlled early in the growing season to reduce N assimilation by weeds.

INTRODUCTION

Weeds actively compete with corn (*Zea mays* L.) for water, light, and nutrients. Nitrogen (N) is often the yield-limiting nutrient in corn grain production, and weed-corn competition for N may reduce corn grain yield. The critical weed removal timing, defined as the point in time when weeds need to be removed to avoid a yield reduction, has been evaluated for corn grain production systems (Zimdahl 2004). The critical weed removal timing in the North Central U.S. is considered to be prior to the V4 to V6 corn growth stage or prior to weeds reaching a height of 10 to 15 cm (Carey and Kells 1995; Dalley et al. 2004; Gower et al. 2003). However, under less competitive conditions (i.e., adequate soil moisture), grain yield losses may be not occur until weeds reach a height of 30 cm (Dalley et al. 2006). Although the critical weed removal timing has been studied thoroughly, studies have not evaluated the total N concentration in weeds at the critical weed removal timing.

Weed shoot and root biomass is influenced by soil N levels (Bonifas et al. 2005). At low soil N levels, shoot growth decreases while root growth increases suggesting that the plant may compete less for light as N becomes limiting (Blackshaw et al. 2003; Bonifas et al. 2005). The decrease in shoot:root ratio is caused by an increase in carbohydrate transport to the root (Hermans et al. 2006) and the resulting dense, long root systems are associated with high underground competitive ability (Andrews and Newman 1970). Weed and corn biomass accumulation and partitioning to shoots and roots needs to be evaluated to better understand weed-corn competition under field conditions and at varying N application rates.

As soil N increases, the total N concentration in weeds increases, but the degree of response is species-dependent (Andreasen et al. 2006; Blackshaw et al. 2003; Blackshaw and Brandt 2008). Differences in N assimilation among weed species may be partly attributed to functional distinctions of C_3 and C_4 metabolic pathways (Abouziena et al. 2007). Plants with C_3 metabolism often have higher shoot N concentrations than plants with C_4 metabolism (Brown 1978, 1985; Sage and Pearcy 1987). When N is limiting, plants with C_3 metabolism increase root growth proportionally more than plants with C_4 metabolism to maintain a sufficient level of tissue N to sustain photosynthetic rates and dry matter accumulation (Bonifas et al. 2005). Plants with C_4 metabolism have higher N use efficiency, producing more biomass per N unit (Brown 1978, 1985; Sage and Pearcy 1987). This study evaluated the growth and N concentration in three common agricultural weed species, common lambsquarters (*Chenopodium album* L.) and common ragweed (*Ambrosia artemisiifolia* L.) which exhibit C_3 plant metabolism and giant foxtail (*Setaria faberi* Herrm.), which exhibits C_4 plant metabolism. Biomass accumulation and N concentration in weeds was compared to corn (C_4 plant metabolism).

Fluctuations in N fertilizer price and increasing concerns surrounding surface- and groundwater N contamination, soil fertility specialists in the North Central U.S. have adopted the maximum return to N (MRTN) system for making N recommendations (Sawyer et al. 2006; Warncke et al. 2009). With the MRTN system, N application rates are based on maximizing economic return whereas the traditional N recommendations were based on maximizing grain yield (Vitosh et al. 1995). Nitrogen recommendations using the MRTN system are often lower than the traditional yield-based approach. The effect of soil N levels on weed and corn biomass and total N concentration needs to be examined in response to implementing the MRTN system.

A better understanding of N assimilation and biomass accumulation of weeds and corn will help develop fertilization strategies to improve crop competitiveness (Di Tomaso 1995). Biomass accumulation, total N concentration, and N use efficiency of common agricultural weeds needs to be examined to help develop fertilization strategies to improve crop competitiveness (Di Tomaso 1995). Study objectives were to evaluate the effect of weed/corn growth stage on the total N concentration in common lambsquarters, common ragweed, giant foxtail, and corn and determine the relationship between soil N and total N concentration in weeds and corn.

MATERIAL AND METHODS

A field study was conducted in 2009, 2010, and 2011 at the Michigan State University Crop and Soils Research Farm in East Lansing, MI. Four N rates of 0, 67, 134, and 202 kg N ha^{-1} were examined. Common lambsquarters, common ragweed, giant foxtail, and corn samples were collected at four growth stages based on average weed canopy height (5, 10, 15, and 20 cm). Plant collection growth stages were replicated four times and randomized within each N rate. In 2009 and 2011, the study was conducted on Aubbeenaubbee sandy loam (fine-loamy, mixed, active, mesic Aeric Epiaqualfs) and Capac loam (fine-loamy, mixed, active, mesic, Aquic Glossudalfs). In 2010, the study was conducted on Capac loam. Soil physical and chemical properties are shown in Table 8.

Corn (‘Pioneer 37Y14’) was planted at 71,700 seeds ha^{-1} in 76-cm rows. Plot size was 3 by 11 m and consisted of four rows of corn. The study sites were planted to soybeans the previous year, and were chisel-plowed in the fall prior to establishment of study. The fields were cultivated twice in the spring with urea being applied and incorporated prior to planting. Dates of field operations and weed collection are given in Table 9. The natural, mixed population of weeds was allowed to emerge with the corn. Common lambsquarters, common ragweed, and giant foxtail were the predominant weed species. Precipitation and temperature were recorded by the Enviro-weather Automated Weather Station Network (Michigan State University, East Lansing, MI). Cumulative growing degree days and monthly rainfall are given in Table 10.

When the weed growth stages were 5, 10, 15, and 20 cm in height, 10 to 20 common lambsquarters, common ragweed, and giant foxtail plants and four corn plants were randomly selected and collected. Weeds were removed from the soil using a small spade and corn was dug using a shovel to keep roots intact. At collection, shoot and root portions were separated. Roots were gently washed to remove adhering soil. Shoots and roots were dried in a forced-air dryer for 72 hr at 60°C and weights recorded. Dried shoot samples were finely ground with a Cyclone Sample Mill (Udy Co., Fort Collins, CO). Total N concentration in each weed species was measured using a Carbon-Nitrogen Combustion Analyzer (Costech Analytical Tech. Inc., Valencia, CA) by the Dumas method (Bremner 1996).

Six soil samples per plot (0 to 15 cm deep) were collected at each growth stage. The soil was air-dried and ground to pass a 1.00 mm sieve. Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) content were determined by the ammonia-salicylate method and cadmium reduction method, respectively, with a Lachat rapid flow injector autoanalyzer following extraction with 1 *M* KCl (Mulvaney 1996).

All statistical procedures were conducted using SAS 9.1 (SAS Institute 2003). The total N concentration in each weed species and corn was modeled over time (weed/corn growth stage) within each N application rate and year using a quadratic model (Proc Reg). Correlations between soil N and plant biomass accumulation were evaluated using Proc Corr. To evaluate the relationship between soil NO_3-N level and total plant N concentration, several regression models were evaluated, including linear, quadratic, linear-plateau, and quadratic-plateau. The linear-plateau model most adequately described the data based on p-values. The linear-plateau model is defined by Eq. [1] and [2]:

$$y = b + ax, \text{ if } x < j \quad [1]$$

$$y = P, \text{ if } x \geq j \quad [2]$$

where, y is the total plant N concentration (%), x is the soil NO_3-N (mg NO_3-N kg^{-1} soil), b is the y-intercept, a is the linear coefficient, j is where the two functions join (soil NO_3-N critical value), and P is the point at which the tangent line has a slope equal to zero and any larger x values are equal to that value (total N concentration plateau).

Table 8. Soil chemical and physical properties for each year of the study.

Property	2009	2010	2011
pH	6.1	6.2	7.2
Sand, %	45.3	39.3	45.3
Silt, %	31.0	34.0	31.0
Clay, %	23.7	26.7	23.7
CEC, cmol kg^{-1}	8.7	9.5	11.1
Total N, g kg^{-1}	0.39	1.09	0.91
NH_4-N, mg kg^{-1}	9.3	2.8	4.7
NO_3-N, mg kg^{-1}	8.8	5.2	5.2
Bray P, mg kg^{-1}	73	37	35
Exchangeable K, mg kg^{-1}	139	105	122
Exchangeable Mg, mg kg^{-1}	166	182	228

Table 9. Dates of field operations and weed removal timings. Corn growth stages are shown in parenthesis.

	2009	2010	2011
Planting	12 May	5 May	9 May
5 cm weeds	3 June (V2)	1 June (V3)	3 June (V3)
10 cm weeds	8 June (V4)	8 June (V4)	9 June (V4)
15 cm weeds	18 June (V6)	11 June (V5)	13 June (V5)
20 cm weeds	20 June (V6)	14 June (V6)	18 June (V6)
Silking	28 July	21 July	22 July
Harvest	28 Oct.	6 Oct.	17 Oct.

Table 10. Cumulative monthly growing degree days (GDD) and precipitation for each year of the study.

	2009	2010	2011	2009	2010	2011
	----------Monthly cumulative GDD[a]---------			------Precipitation (cm)------		
May	153	204	175	10.7	12.7	15.0
June	276	309	294	12.4	10.5	4.4
July	283	395	432	6.0	6.3	17.5
Aug	317	376	331	10.3	3.4	6.3
Sept	222	194	187	2.4	9.1	6.6
Total	1251	1478	1419	41.8	41.9	49.7

[a]Growing degree days calculated using a base temperature of 10°C.

RESULTS AND DISCUSSION

Total N Concentration. The total N concentration in weeds and corn was influenced by a significant year and weed height interaction ($p \leq 0.01$), so data is presented separately for each year of the study. Analysis of variance for total N concentration within N application rate for each year of the study is shown in Table 11.

A quadratic model was used to describe the relationship between total N concentration and weed/corn growth stage for each year, species, and N application rate (Fig. 6 to 8). A quadratic model significantly described the relationship ($\alpha = 0.05$) between total N concentration and weed/corn growth stage for most years and at most N application rates. There were 4, 1, 3, and 9 instances out of 18 where the quadratic model did not describe the data at 0, 67, 134, and 202 kg N ha^{-1}, respectively. A higher number of instances where the quadratic model did not fit the data occurred at the highest N application rate, indicating that weeds and corn tended to maintain high levels of total N concentration at high N application rates. Maintaining high levels of total N concentration as weeds grow from a height of 5 to 20 cm may result in a decrease in N available to corn. Controlling weeds at the suggested critical weed removal timing prior to weeds reaching 10 to 15 cm height (Gower et al. 2003) should reduce N assimilation by weeds.

Total N concentration in weeds and corn was influenced by weed/corn growth stage (Fig. 6 to 8). In most instances, the total N concentration in weeds and corn increased from 5 to 10 cm weed height, but total N concentration decreased as weeds grew from 10 to 20 cm. The increase in plant biomass that occurred when weeds grew from 10 to 20 cm may have caused a “dilution effect” on the total N concentration in the plant, which resulted in lower total N concentrations for plants with greater biomass (Blackshaw et al. 2003). The “dilution effect” was more likely to occur at low N application rates. At low N application rates, the total N concentration in weeds and corn tended to decrease with increasing weed/corn growth stage. In 2009 when 0 and 67 kg N ha^{-1} was applied, the total N concentration in corn decreased with weed/corn growth stage (Fig. 6). In 2010 when no N was applied, the total N concentration in all weed species and corn decreased with weed/corn growth stage (Fig. 7). In 2011, there was a decrease in total N concentration in corn and giant foxtail at later weed/corn growth stages at 0, 67, and 134 kg N ha^{-1}, but not for common lambsquarters and common ragweed (Fig. 8).

In 2009 at 0 and 134 kg N ha^{-1}, there were no significant differences in total N concentration among weed species and corn (Table 11 and Fig. 6). However, at 67 kg N ha^{-1}, there were significant differences in total N concentration among weed species and corn. When 67 kg N ha^{-1} was applied, the total N concentration in common lambsquarters and common ragweed was greater than giant foxtail and corn. In 2009, there was a significant weed height by species interaction when 202 kg N ha^{-1} was applied. At 202 kg N ha^{-1} and 5 cm height, total N concentration was lowest for common ragweed. When weeds were 10 cm, there was no difference in total N concentration among species, but at 15 cm height, total N concentration was greatest for common lambsquarters and giant foxtail. At 20 cm height, the total N concentration in all weed species was greater than corn.

In 2010 at 0 and 134 kg N ha^{-1}, total N concentration was influenced by the main effect of weed species (Table 11). The total N concentration was generally greatest for common ragweed at 0 and 134 kg N ha^{-1} (Fig. 7). At 202 kg N ha^{-1}, there were no differences in total N concentration among weed species and corn. In 2011, total N concentration was influenced by the interaction of weed species and weed/corn growth stage at 0, 67, and 134 kg N ha^{-1} (Table 11). When 0 to 134 kg N ha^{-1} was applied, common ragweed and common lambsquarters tended to have the greatest total N concentration at each weed height (Fig. 8). In 2011, at 202 kg N ha^{-1}, total N concentration was only influenced by species. The total N concentration in common ragweed was greater than common lambsquarters, giant foxtail, and corn.

Across all N rates, common ragweed and common lambsquarters often times had a greater total N concentration compared to giant foxtail and corn (Fig. 6 to 8). Common lambsquarters roots have a rapid growth rate (Qasem 1993) and can assimilate a large amount of N resulting in luxury N consumption (Andreasen et al. 2006). Differences in total N concentration among weed species and corn may also be attributed to the functional differences in C_3 and C_4 plant metabolism pathways (Abouziena et al. 2007). Plants with C_3 metabolism (i.e., common lambsquarters and common ragweed) often have higher shoot N concentrations compared to plants with C_4 metabolism (i.e., giant foxtail and corn). Plants with C_4 metabolism tend to have greater N use efficiency, producing more biomass per unit of N compared to C_3 species (Brown 1978, 1985; Sage and Pearcy 1987).

Table 11. Analysis of variance for total N concentration by N application rate for each year of the study.

N rate	Source	F-value	Pr > F	F-value	Pr > F	F-value	Pr > F
kg N ha^{-1}		2009		2010		2011	
0	Height	7.44	0.0007	56.30	<0.0001	30.92	<0.0001
	Species	2.02	0.1812	6.00	0.0157	33.76	<0.0001
	Height*species	1.29	0.2839	1.02	0.4433	3.50	0.0039
67	Height	11.22	<0.0001	25.05	<0.0001	63.40	<0.0001
	Species	4.04	0.0450	0.82	0.5134	54.87	<0.0001
	Height*species	1.74	0.1292	0.86	0.5713	2.74	0.0152
134	Height	0.79	0.5078	21.55	<0.0001	10.70	<0.0001
	Species	1.13	0.3888	4.26	0.0394	23.82	0.0001
	Height*species	0.89	0.5371	0.93	0.5151	4.47	0.0006
202	Height	19.62	<0.0001	1.00	0.4043	2.73	0.0592
	Species	2.50	0.1256	1.00	0.4369	14.65	0.0008
	Height*species	3.24	0.0085	1.00	0.4565	0.61	0.7837

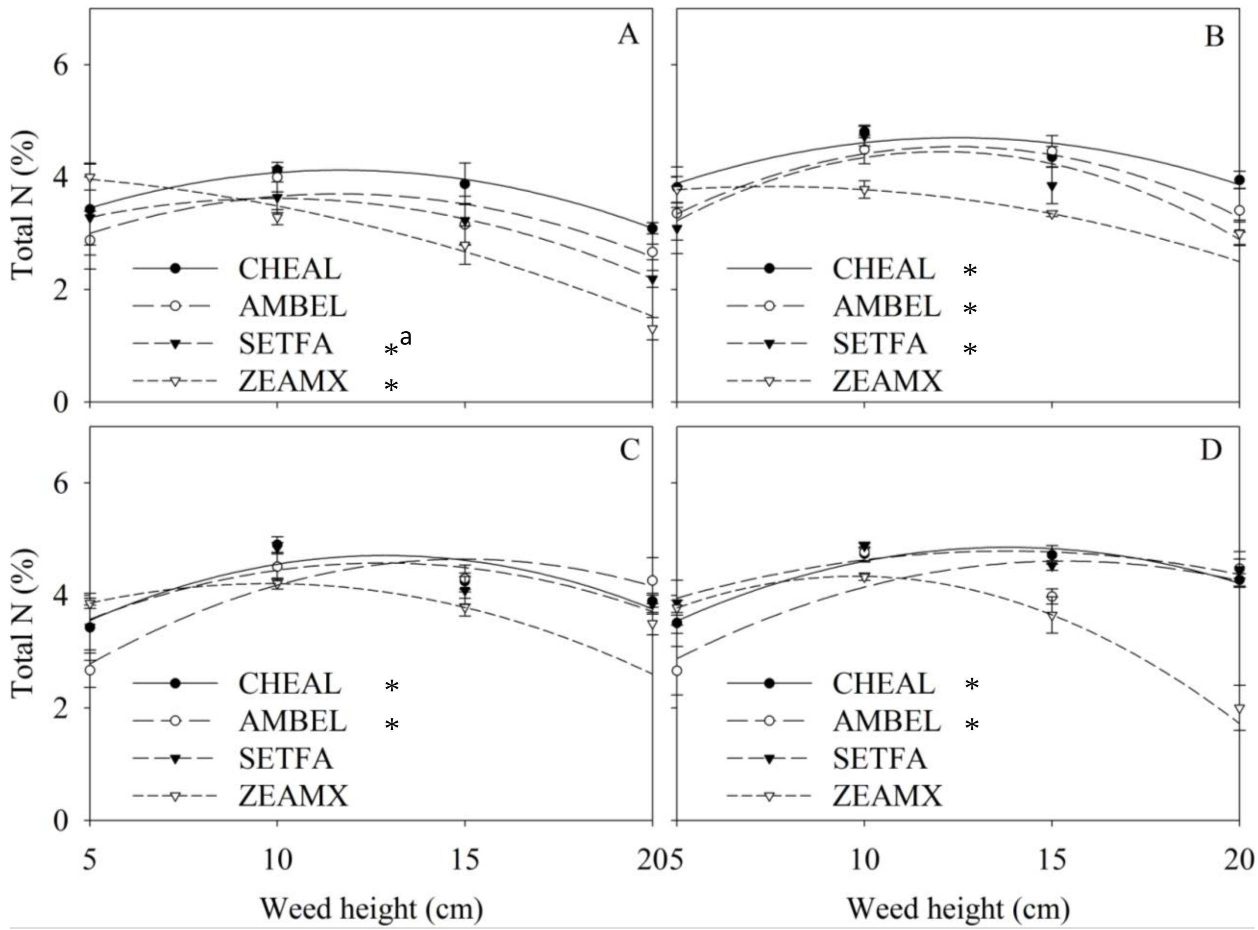

Figure 6. Total N concentration in common lambsquarters (CHEAL), common ragweed (AMBEL), giant foxtail (SETFA), and corn (ZEAMX) by weed growth stage in 2009 when grown at 0 (A), 67, (B), 134 (C), and 202 (D) kg N ha^{-1} at East Lansing, MI. Weed growth stages of 5, 10, 15, and 20 cm height correspond to corn at the V2, V4, V6, and V6 growth stage, respectively.

[a] Quadratic model fits data at $\alpha = 0.05$.

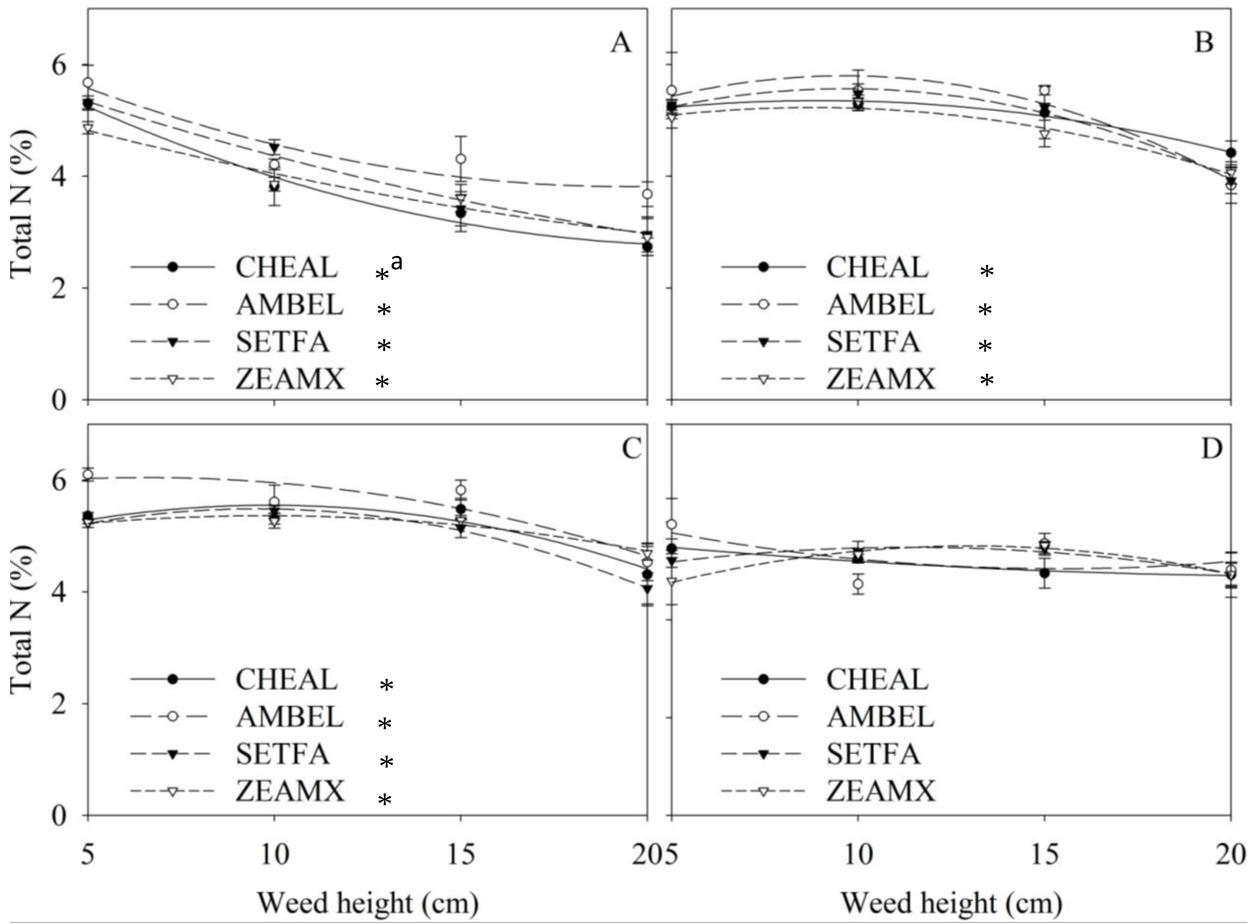

Figure 7. Total N concentration in common lambsquarters (CHEAL), common ragweed (AMBEL), giant foxtail (SETFA), and corn (ZEAMX) by weed growth stage in 2010 when grown at 0 (A), 67, (B), 134 (C), and 202 (D) kg N ha^{-1} at East Lansing, MI. Weed growth stages of 5, 10, 15, and 20 cm height correspond to corn at the V3, V4, V5, and V6 growth stage, respectively.

[a] Quadratic model fits data at $\alpha = 0.05$.

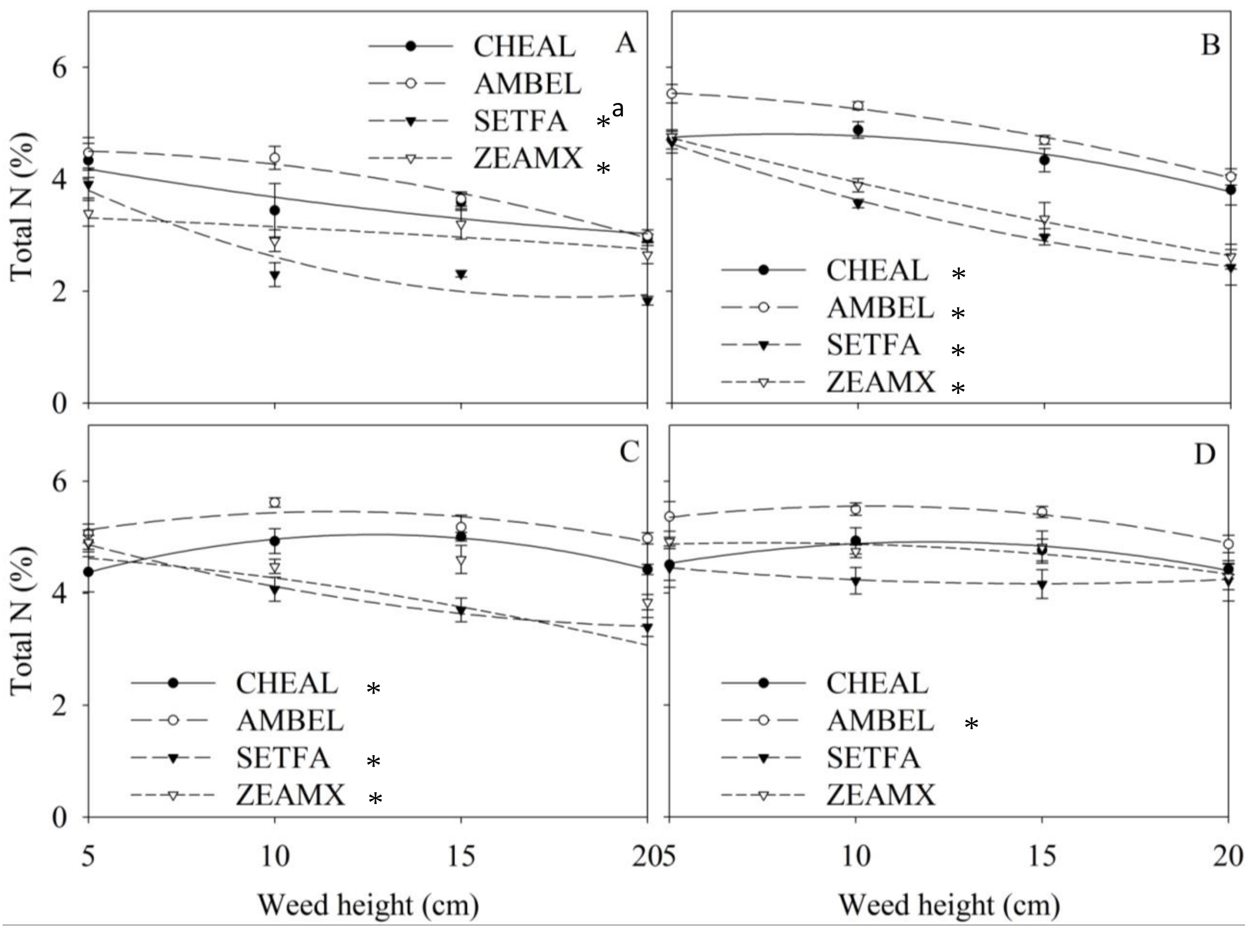

Figure 8. Total N concentration in common lambsquarters (CHEAL), common ragweed (AMBEL), giant foxtail (SETFA), and corn (ZEAMX) by weed growth stage in 2011 when grown at 0 (A), 67, (B), 134 (C), and 202 (D) kg N ha^{-1} at East Lansing, MI. Weed growth stages of 5, 10, 15, and 20 cm height correspond to corn at the V3, V4, V6, and V6 growth stage, respectively.

[a] Quadratic model fits data at $\alpha = 0.05$.

Effect of Soil N on Total Plant N Concentration. A linear-plateau model significantly described the relationship between soil NO_3-N and total N concentration in weeds at all weed growth stages (Table 12). When corn was at the V5 and V6 growth stage (15 and 20 cm tall weeds), a linear-plateau model significantly fit the data. However, when corn was at the V3 and V4 growth stage (5 and 10 cm tall weeds), a linear-plateau model did not fit the data. Rapid N assimilation by corn begins at the V5/V6 growth stage (Abendroth et al. 2011), which may explain why the linear-plateau model did not adequately describe the data until corn was at the V5 growth stage. Weeds tend to be very responsive to N application rate, increasing total N concentration with increasing rates of N fertilizer (Andreasen et al. 2006; Blackshaw et al. 2003), which may occur before corn is responsive to fertilizer N application.

The x-axis value where the linear component of the model meets the plateau component of the model is referred to as the soil NO_3-N critical value. Critical values ranged from 8.6 to 39.3 mg N kg^{-1} soil (Table 12). At 5-, 10-, and 15- cm weed heights, the critical value for common ragweed was greater compared to common lambsquarters and giant foxtail. At 20-cm height, the critical value for common lambsquarters was greater compared to common ragweed and giant foxtail. Higher critical values indicate that total N concentration will increase at higher soil NO_3-N levels. Low critical values indicate that the total N concentration will remain constant even though soil NO_3-N may increase.

Plateau values indicate the total N concentration where the linear component of the model meets the plateau component of the model. At the plateau, the maximum total N concentration in the plant has been achieved. At all weed growth stages, the plateau value was greatest for common ragweed, intermediate for common lambsquarters, and lowest for giant foxtail (Table 12). Plants exhibiting C_3 metabolism, such as common ragweed and common lambsquarters, tend to have a higher total N concentration than plants with C_4 metabolism, such as giant foxtail (Brown 1978, 1985; Sage and Pearcy 1987). Common ragweed and common lambsquarters may be more competitive for N than giant foxtail. The total N plateau value for corn was less than weeds at the 5 cm weeds/V3 corn growth stages, but the total N plateau value for corn was greater than weeds at the 10 cm weeds/V4 corn growth stages. At 15 and 20 cm weeds/V5 and V6 corn growth stages, the total N plateau value of corn was similar to the plateau value of giant foxtail. Corn exhibits C_4 metabolism, which may explain the similarity in total N plateau values with giant foxtail.

Table 12. Linear-plateau regression model[a] coefficients describing the effect of soil nitrate-N on the total N concentration in weeds and corn by weed height and corn growth stage (shown in parenthesis) at East Lansing, MI.

Weed height	Species[a]	a	b	Critical value	Plateau	R^2	p-value
cm				mg N kg^{-1} soil	%N		
5 (V3)	CHEAL	0.04	3.49	35.6	4.99	0.24	0.003
	AMBEL	0.06	3.23	39.3	5.51	0.28	0.001
	SETFA	0.09	3.11	19.7	4.9	0.41	<0.001
	CORN	-0.14	6.89	14.8	4.74	0.02	0.59
10 (V4)	CHEAL	0.23	2.95	8.6	4.98	0.51	<0.001
	AMBEL	0.05	4.27	19.5	5.16	0.19	0.009
	SETFA	0.34	2.11	7.7	4.74	0.36	<0.001
	CORN	0.48	1.71	10	6.49	0.02	0.72
15 (V5)	CHEAL	0.07	3.68	18	4.99	0.41	<0.001
	AMBEL	0.05	4	25.8	5.26	0.29	<0.001
	SETFA	0.26	2.25	8.7	4.54	0.47	<0.001
	CORN	0.07	3.1	24.3	4.82	0.48	<0.001
20 (V6)	CHEAL	0.06	3.18	20.7	4.58	0.37	<0.001
	AMBEL	0.15	2.96	12.4	4.84	0.62	<0.001
	SETFA	0.11	2.47	17.8	4.35	0.49	<0.001
	CORN	0.16	2.27	13.5	4.5	0.7	<0.001

[a] $y = b + ax$, if $x < j$ [1]

$y = P$, if $x \geq j$ [2]

where, y is the total plant N concentration (%), x is the soil NO_3-N, b is the y-intercept, a is the linear coefficient, j is the critical value, and P is the total N concentration plateau.

[b] Abbreviations: CHEAL, common lambsquarters; AMBEL, common ragweed; SETFA, giant foxtail.

Management Implications. A better understanding of N assimilation and biomass accumulation of weeds and corn will help develop fertilizer management strategies that improve crop competitiveness (Di Tomaso 1995). Controlling weeds prior to an average weed canopy height of 10 to 15 cm (Gower et al. 2003) should reduce N losses from weeds. Total N concentration (and weed biomass) was lowest when weeds are 5 cm (Fig. 3 to 5). Total N concentration increases rapidly as weeds grow from 5 to 10 cm, which can result in greater N loss. Early in the season, the total N concentration in weeds was more responsive to soil N levels compared to corn. Nitrogen management strategies that minimize early season soil N availability, such as a split-N application or use of slow-release N fertilizers, may reduce N assimilation by weeds.

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LITERATURE CITED

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CHAPTER 3

NITROGEN MINERALIZATION FROM WEED RESIDUES IN CORN AGRO-ECOSYSTEMS

ABSTRACT

Weed residues can impact nitrogen (N) cycling in agro-ecosystems. QuantifyingCorrelation between chlorophyll meter reading and N concentration in common lambsquarters. this potential N source may influence fertilization practices for corn (*Zea mays* L.) grain production. A laboratory experiment measured the rate and quantity of N mineralization from common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), and giant foxtail (*Setaria faberi* Herrm.). Weeds were grown in the field at four N rates (0, 67, 134, or 202 kg N ha^{-1}) and collected at two weed heights (10 or 20 cm). The nitrate-N and total N concentration, carbon:N (C:N) ratio, and cell wall components of the weed residue were measured. Nitrogen mineralization from weed residue mixed with soil was determined over a 12 week period. Cell wall components and the C:N ratio of the weed residues tended to be greatest for giant foxtail residue followed by common lambsquarters and common ragweed residues. Weeds grown at high N rates had increased nitrate-N content, increased total N concentration, and decreased C:N ratio. Nitrogen mineralization from the weed residues was rapid up to 4 weeks of incubation after which the rate of N mineralization slowed. Across treatments, net N mineralization occurred by week 12 of incubation except for giant foxtail grown with no N application. However, prior to 12 weeks of incubation, N was immobilized by giant foxtail grown under no N application. Nitrogen mineralized was strongly correlated with C:N ratio, while rate of N mineralization was strongly correlated with cell wall

components (cellulose and lignin). Nitrogen mineralization was also influenced by the chemical composition of the weed residue which varied by N application rate, weed height, and weed species.

INTRODUCTION

Nitrogen (N) is often the yield-limiting nutrient in corn (*Zea mays* L.) grain production and identifying potential N sources is essential for maximizing grain yield. In order to minimize environmental impact, N availability should correspond to rapid N assimilation by corn which begins at the V6 growth stage (i.e., six fully emerged leaves) (Mengel 1995). Prior to the V6 growth stage, early-season N losses may contribute to surface- and groundwater pollution (Bernot et al. 2006). However, delayed N availability may reduce corn grain yield (Binder et al. 2000).

Weeds reduce crop yield by competing with corn for sunlight, water, and nutrients (Dalley et al. 2006; Gower et al. 2003). Corn and weeds actively compete for soil N (DiTomaso 1995; Cathcart and Swanton 2003). Annual weeds, such as common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and wild oat (*Avena fatua* L.), are considered luxury consumers of N (Qasem 1992; Blackshaw and Brandt 2008) and can assimilate large amounts of N. In a mixed population of grass and broadleaf weed species grown with spring wheat (*Triticum aestivum* L.), 32 kg N ha^{-1} was assimilated by weeds at Feekes 11.4 (Kirkland and Beckie 1998). Shattercane (*Sorghum bicolor* L.) assimilated 38 kg N ha^{-1} at a density of 200 plants m^{-2} and 46 cm height (Hans and Johnson 2002). Weed biomass and N assimilation increases with N application rate (Salas et al. 1997; Blackshaw et al. 2003), indicating that weeds have the potential to remove a large amount of N from agro-ecosystems. To avoid corn grain yield reductions, weed control is recommended in the North Central U.S. prior to the V4 to V6 corn growth stage or prior to weeds reaching a height of 10 to 15 cm (Carey and Kells 1995; Gower et al. 2003; Dalley et al. 2004). However, few data are available concerning N release from weed residues subsequent to weed control.

The weed residue chemical components of NO_3-N, total N, C:N ratio, neutral detergent fiber (NDF), and acid detergent fiber (ADF) were measured in this study. Neutral detergent fiber consists of the plant cell wall components of cellulose, hemi-cellulose, and lignin, while ADF consist of the plant cell wall components of cellulose and lignin (Undersander and Wolf 2006). Hemi-cellulose, cellulose, and lignin are recalcitrant to decomposition (Van Kessel et al. 2000). Previous studies have measured chemical components in plant residues (Fox et al. 1990; Chaves et al. 2004). A few studies have measured extractable NO_3-N, ADF, and NDF in weeds to measure digestibility by livestock (Jones et al. 1971; Marten and Andersen 1975). Few studies have measured and related these parameters in the context of N mineralization (Sakonnakhon et al. 2006).

Net N mineralization of plant residues occurs at carbon:N (C:N) ratios < 15 to 44 (Fox et al. 1990; De Neve and Hofman 1996; Chaves et al. 2004). Plant cell wall components consisting of hemi-cellulose, cellulose, and lignin reduce N mineralization (Haynes 1986), while total N concentration increases N mineralization (Justes et al. 2009). Plant residues vary widely in their chemical composition (Poorter and Villar 1997). Young, vegetative plants have decreased C:N ratios and lignin and cellulose contents compared to mature plants (Müller et al. 1988; Nicolardot et al. 2001). As plants mature, their C:N ratio, cellulose, and lignin content tend to increase (Müller et al. 1988). Subsequent to postemergence weed control, young summer annual weeds may decompose quickly resulting in net N mineralization (Majumder et al. 2008).

Studies have shown the mineralization of crop residues to be a potential source of N to cropping systems (e.g., Liebig et al. 2002; Njunie et al. 2004). Estimates of potential N mineralization from crop residues have been measured *in situ* and in laboratory incubation studies (Stanford and Smith 1972; Green and Blackmer 1995; Recous et al. 1995; Burgess et al. 2002), but very few studies have examined N mineralization from weed residues. In India, manually removing weeds and retention of the weed biomass in the field conserved up to 20% of soil nutrients (Ramakrishnan 1992). Two litterbag studies have been conducted to measure N loss and mineralization of weed residues. Researchers in Ohio measured a 65% reduction in total N content in common lambsquarters, giant foxtail (*Setaria faberi* Herrm.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), and smooth pigweed (*Amaranthus hybridus* L.) residues from December to July (Vazquez et al. 2003). A second study conducted in Georgia revealed 7, 17, and 16 kg N ha^{-1} was mineralized from redroot pigweed, sicklepod (*Cassia obtusifolia* L.), and Johnsongrass (*Sorghum halepense* L.), respectively, during November to April (Parmelee et al. 1989). Field mineralization studies are influenced by environmental conditions such as moisture (Agehara and Warncke 2005), temperature (Saint-Fort et al. 1990), and tillage (Rice and Havlin 1994; Mikha et al. 2006). Laboratory incubation methods can be used to reduce environmental variability and have been correlated to N mineralization under field conditions (Sanchez et al. 2001).

Although weed N assimilation increases with increasing N application rate and N mineralization occurs at C:N ratios <15 to 44 (Stevenson 1986; Vigil and Kissel 1991; De Neve and Hofman 1996; Chaves et al. 2004), information regarding the fate of weed residues subsequent to postemergence weed control is limited. Nitrogen mineralization from weed residues may either contribute to soil N pools just prior to corn N demand or mineralize later in the growing season resulting in N losses to the environment. Our objectives were to i) compare the effects of weed species, weed height, and N application rate on the chemical composition of weed residues, ii) determine the quantity and rate of N mineralization from weed residues, and iii) examine the relationship between the chemical composition of weed residue and the rate of N mineralization.

MATERIALS AND METHODS

Weed Residues. Weed residues were collected from a field study established at the Michigan State University Crop and Soil Sciences Research Farm in East Lansing, MI, in 2011. The field study was a randomized complete block design consisting of four N preplant application rates (0, 67, 134, and 202 kg N ha^{-1}) of incorporated urea and two weed collection heights (10 and 20 cm) across three replications. Corn (‘Pioneer 37Y14’) was planted on 9 May 2011. Mixed, natural populations of weeds were allowed to emerge with the corn. Weed species consisted of common lambsquarters, common ragweed (*Ambrosia artemisiifolia* L.), and giant foxtail. Root and shoot portions of common lambsquarters, common ragweed, and giant foxtail were collected when the average weed canopy height was 10 and 20 cm on 9 June and 18 June, respectively. Approximately 40 plants were randomly collected from the center two rows of corn. Plant fresh biomass was determined at collection and dry biomass was determined after drying in a forced-air dryer for 72 hr at 60°C. Dried samples were finely ground with a Cyclone Sample Mill (Udy Co., Fort Collins, CO). Total N and carbon (C) content of the weed residues were measured using a Carbon-Nitrogen Combustion Analyzer (Costech Analytical Tech. Inc., Valencia, CA) by the Dumas method (Bremner 1996). Extractable nitrate-N (NO_3-N) from the weed residues was determined by the cadmium reduction method using a Lachat rapid flow injection autoanalyzer (Hach Co., Loveland, CO) subsequent to extraction with 1 *M* KCl. The extracts were filtered through #2 Whatman filter paper previously washed with 1 *M* KCl. Weeds were analyzed for NDF (hemi-cellulose, cellulose, and lignin) and ADF (cellulose and lignin) concentration (Undersander and Wolf 2006). Acid detergent fiber and NDF content were determined using the reflux method (Van Soest et al. 1991).

Soil for Laboratory Incubation. Soil chemical and physical properties are displayed in Table 13. Approximately 45 kg of soil was collected to a depth of 0 to 10 cm from the field to use for the laboratory incubation. Soil, an Aubbeenaubbee- (fine-loamy, mixed, active, mesic Aeric Epiaqualfs) Capac (fine-loamy, mixed, active, mesic, Aquic Glossudalfs) complex collected on 7 July from plots where 67 kg N ha^{-1} was applied prior to planting. Soil was homogenized and passed through a 6 mm sieve and stored at 4°C prior to initiating the laboratory incubation experiment. The gravimetric soil water content was 0.166 kg water kg^{-1} dry soil (16.6%).

Table 13. Chemical and physical properties of soil used in this study.

Property	
pH	7.2
Sand, %	50.9
Silt, %	34.0
Clay, %	15.1
CEC, cmol kg^{-1}	8.3
Total N, g kg^{-1}	3.5
NH_4-N, mg kg^{-1}	4.4
NO_3-N, mg kg^{-1}	14.3
Bray P, mg kg^{-1}	59
Exchangeable K, mg kg^{-1}	152
Exchangeable Mg, mg kg^{-1}	207

Laboratory Incubation Experiment. Mineralization of the dried, ground weed residues consisting of common lambsquarters, common ragweed, and giant foxtail, grown under four preplant N application rates and collected at two heights was evaluated at six incubation time intervals (0, 1, 2, 4, 8, and 12 wk). The laboratory incubation experiment was conducted twice. Soil incubation procedures were similar to that of Agehara and Warncke (2005). Twenty grams dry weight equivalent moist soil was placed in 118 mL specimen cups. The ground weed residue from each field treatment was added with the soil at a constant rate of 60 mg total N kg^{-1} soil. Sufficient cups were set up to allow sampling three cups (one per replication) at each specified incubation interval. Following weed residue addition, each cup was inverted several times to uniformly mix the soil and residues. Controls for each incubation time consisted of soil without residue addition to account for N mineralization from soil organic matter. The containers were stored in the dark at 25°C. At each incubation time interval, soil was removed from specimen cups and dried at 40°C in a forced-air dryer for 48 h. After drying, soil was ground to pass through a 1-mm sieve. Soil was analyzed for ammonium-N (NH_4-N) and NO_3-N content by the ammonium-salicylate method and cadmium reduction method, respectively, using a Lachat rapid flow injection autoanalyzer (Hach Co., Loveland, CO) subsequent to extraction with 1 *M* KCl. The extracts were filtered through #2 Whatman filter paper previously washed with 1 *M* KCl. Extracts were frozen until processed.

Nitrogen Release Determination. Nitrogen release (N_{total}) from both soil organic matter and weed residue was considered to be the sum of NH_4-N and NO_3-N at each incubation time. Background N release (N_{soil}) from soil organic matter was determined for each incubation time from the control (soil with no plant residue added). Nitrogen release from weed residue ($N_{residue}$) is calculated from Eq. [1].

$$N_{residue} = N_{total} - N_{soil} \qquad [1]$$

where $N_{residue}$ is the N released from the weed residue addition, N_{total} is N release from both soil organic matter and weed residue addition, and N_{soil} is N released from soil organic matter.

Statistical Analysis. Treatment effects of weed species and weed height on chemical composition of weed residues were examined within each N application rate using analysis of variance in the MIXED procedure of SAS (SAS Institute 2003). Fixed effects included N application rate, weed species, weed height, incubation time, and their interactions. The three field replications, two laboratory trials, and their interactions were considered random factors in the model. Data were normally distributed and equal variance assumptions were checked using Levene's procedure (Schultz 1985). When the unequal variance assumption was not met, treatments were grouped by similar variances.

Nitrogen release from the weed residues over the twelve weeks of incubation time period was fit to a first-order model (Stanford and Smith 1972; Chaves et al. 2004) using the non-linear regression procedure (NLIN). Nitrogen release was modeled as follows:

$$N_{rel} = N_{12}[1-\exp(-k_0 t)] + b \qquad [2]$$

where N_{rel} (mg N kg^{-1}) is the cumulative N released from the weed residue at time t, N_{12} (mg N kg^{-1}) is N released from weed residue after 12 wk of incubation, exp is the exponential constant with a numerical value approximately 2.718, K_0 (wk^{-1}) is the first-order rate constant, and b is the y-intercept. The N_{12} and k_0 values were deemed significantly different ($\alpha = 0.05$) if the 95% confidence intervals did not overlap. Pearson's correlation coefficient (r) was used to evaluate relationships between the chemical composition of weed residue and N_{12} and k_0 using the CORR procedure.

RESULTS AND DISCUSSION

Weed Residue Chemical Components. Analysis of variance results for NO_3-N, total N, C:N ratio, NDF, and ADF concentration in weed residues are shown in Tables 14 and 15. When weeds were grown at 0 kg N ha^{-1}, there were no significant differences in NO_3-N among the three weed species (Table 16). However, when weeds were grown at 67, 134, and 202 kg N ha^{-1}, NO_3-N content was greater for common ragweed compared to common lambsquarters and giant foxtail. Marten and Andersen (1975) also measured a greater NO_3-N concentration in common ragweed compared to common lambsquarters and giant foxtail. Within each N application rate, total N concentration was greatest for common lambsquarters and common ragweed. The C:N ratio of the weed residue ranged between 8.0 and 21.1 and decreased with N application rate. Giant foxtail had a greater C:N ratio than the other two weed species when grown at 0 and 67 kg N ha^{-1}. When weeds were grown at 134 and 202 kg N ha^{-1}, there was no significant difference in the C:N ratio among the three weed species. The C:N ratio was negatively correlated with NO_3-N (r=-0.63, p<0.0001) and total N concentration (r=-0.84, p<0.0001), indicating NO_3-N and total N concentration influences the C:N ratio of weed residue.

Common lambsquarters and common ragweed had greater NO_3-N content, greater total N concentration, and smaller C:N ratio compared to giant foxtail. Differences in NO_3-N, total N, and C:N ratio among weed species may be partly attributed to the functional differences in C_3 and C_4 plant metabolism pathways (Abouziena et al. 2007). Plants with C_3 metabolism (i.e., common lambsquarters and common ragweed) often have higher shoot N concentrations compared to plants with C_4 metabolism (i.e., giant foxtail). Plants with C_4 metabolism tend to have greater N use efficiency, producing more biomass per unit of N compared to C_3 species (Brown 1978, 1985; Sage and Pearcy 1987). High N use efficiency leads to a large C:N ratio.

Nitrate-N and total N concentration in weed residues increased with increasing N application rates (Table 16). At low soil N levels, many plant species show a decrease in shoot growth and an increase in root growth (Blackshaw et al. 2003; Bonifas et al. 2005). A decrease in shoot:root ratio is caused by an increase in carbohydrate transport to the root (Hermans et al. 2006), which may explain the observed decrease in C:N ratio under low N application in our study.

The interaction of N application rate and weed height influenced NO_3-N, total N, and C:N ratio of the weed residues (Table 14). When weeds were grown at 67 kg N ha^{-1}, NO_3-N content was greater for 10-cm tall weeds than 20-cm tall weeds (Table 16). At 0, 134, 202 kg N ha^{-1}, there were no differences in NO_3-N content between weed heights. Total N concentration was greatest for 10-cm tall weeds grown at 67, 134, and 202 kg N ha^{-1}. The 20-cm tall weeds tended to have low total N concentration compared to the 10-cm tall weeds. The increase in plant biomass that occurred when weeds grew from 10 to 20 cm tall may have had a “dilution effect” on N taken up by the plant resulting in lower total N concentrations for plants with greater biomass (Blackshaw et al. 2003). In addition to low total N concentrations, 20-cm tall weeds also had a greater C:N ratio than 10-cm tall weeds when grown at 0 and 67 kg N ha^{-1}. At 134 and 202 kg N ha^{-1}, there was no difference in C:N ratio between 10- and 20-cm tall weeds.

Analysis of variance results for NDF and ADF concentration in weed residue is shown in Table 15. Within each N application rate, NDF content was greater for giant foxtail compared to common lambsquarters and common ragweed (Table 17). Neutral detergent fiber content in giant foxtail residue decreased with increasing N application rate. Within each N application rate, ADF was lowest for common lambsquarters and greatest for giant foxtail. Grass weed species with C_4 metabolism often have a higher lignin content and consequently higher ADF content compared to C_3 species (Marten and Andersen 1975; Jung and Vogel 1986). Neutral detergent fiber was influenced by the interaction of weed height and N application rate (Table 15). Neutral detergent fiber of 10-cm tall weeds grown at 67 to 202 kg N ha^{-1} was less than 20-cm tall weeds grown at 0 kg N ha^{-1} (Table 17). Acid detergent fiber in weed residues was not influenced by weed height or N application rate.

Table 14. Analysis of variance for NO_3-N, Total N, and C:N ratio of weed residue for N application rate, weed height, weed species, and interaction as sources of variation.

Source	F-value	Pr > F	F-value	Pr > F	F-value	Pr > F
	NO_3-N		Total N		C:N	
N Rate	64.79	<0.0001	78.72	<0.0001	32.68	0.0004
Height	7.12	0.0285	350.71	<0.0001	48.53	0.0001
Species	58.31	<0.0001	91.63	<0.0001	28.04	<0.0001
N rate*height	7.67	0.0097	13.48	0.0017	6.92	0.0130
N rate*species	6.98	0.0001	3.09	0.0189	3.65	0.0084
Height*species	10.94	0.0003	20.17	<0.0001	0.20	0.8237
N rate*height*species	2.35	0.0556	1.74	0.1476	1.40	0.2497

Table 15. Analysis of variance for neutral detergent fiber (NDF) and acid detergent fiber (ADF) of weed residue for N application rate, weed height, weed species, and interactions as sources of variation.

Source	F-value	Pr > F	F-value	Pr > F
	NDF		ADF	
N Rate	1.67	0.2716	0.61	0.6352
Height	12.31	0.0080	8.00	0.0222
Species	1943.27	<0.0001	345.25	<0.0001
N rate*height	0.88	0.4921	0.85	0.5028
N rate*species	1.72	0.1528	3.21	0.0149
Height*species	17.68	<0.0001	4.94	0.0140
N rate*height*species	1.25	0.3097	1.05	0.4116

Table 16. Interaction between field N application rate and weed species for nitrate-N content (NO_3-N), total N content, and C:N ratio of weed residues, East Lansing, MI.

Weed species[1]	Field N application	NO_3-N	Total N	C:N
	kg N ha^{-1}	mg kg^{-1}	%	
CHEAL	0	255	3.22	13.0
	67	1389	3.91	11.2
	134	2582	4.13	9.4
	202	3264	4.15	10.1
AMBEL	0	224	3.06	14.2
	67	2694	4.09	9.5
	134	4865	4.31	8.9
	202	5419	4.72	8.0
SETFA	0	94	1.95	21.1
	67	1035	2.74	15.2
	134	2925	3.52	11.6
	202	3421	3.66	10.3
LSD(0.05)		865	0.39	2.8
Weed height (cm)				
10	0	336	3.56	12.4
	67	2268	4.53	9.9
	134	3876	4.54	9.3
	202	3682	4.54	8.5
20	0	46	1.92	19.3
	67	1143	2.64	14.0
	134	3039	3.43	10.6
	202	4387	3.82	10.4
LSD (0.05)		875	0.34	2.5

[1]CHEAL, common lambsquarters; AMBEL, common ragweed; SETFA, giant foxtail.

Table 17. Interaction between field N application rate and weed height for neutral detergent fiber (NDF) and acid detergent fiber (ADF) content in weed residues, East Lansing, MI.

Weed species[a]	Field N application	NDF	ADF
	kg N ha^{-1}	----------%----------	
CHEAL	0	19.8	12.1
	67	17.9	11.3
	134	18.6	12.5
	202	17.1	11.3
AMBEL	0	18.0	15.7
	67	17.8	14.0
	134	17.2	14.5
	202	17.7	16.0
SETFA	0	50.9	23.3
	67	50.5	23.4
	134	47.1	21.6
	202	47.5	21.0
LSD(0.05)		3.1	2.1
Weed height (cm)			
10	0	28.0	16.7
	67	27.2	14.9
	134	27.0	15.8
	202	27.0	14.9
20	0	31.1	17.4
	67	30.3	17.5
	134	28.3	16.6
	202	27.9	17.3
LSD (0.05)		3.2	2.7

[a]CHEAL, common lambsquarters; AMBEL, common ragweed; SETFA, giant foxtail.

Percentage of N Release. The percentage of total N mineralized from weed residue was influenced by weed species and N application rate (Table 18). Giant foxtail grown at 0 kg N ha^{-1} immobilized N during the first 8 weeks of incubation (Table 19). By week 12, N was mineralized. When no N was applied, giant foxtail residue had a 21.1 C:N ratio whereas the ratio was ≤ 15.2 when giant foxtail was grown at 67, 134, and 202 kg N ha^{-1} (Table 16). The high C:N ratio of giant foxtail when no N was applied may explain the initial N immobilization, which has been noted at C:N ratios as low as 16 (Jensen 1994).

Percentage of N mineralized from weed residue increased with increasing N application rate after 1 to 2 weeks of incubation for common lambsquarters and common ragweed and at all incubation intervals for giant foxtail (Table 19). Nitrogen release exceeded 25% for common lambsquarters after 1 week of incubation when grown at 67 to 202 kg N ha^{-1}, while mineralization did not exceed 25% until 2 weeks of incubation when grown at 0 kg N ha^{-1}. When common ragweed was grown at 134 and 202 kg N ha^{-1}, N release exceeded 25% after 1 week of incubation. Common ragweed grown at 67 kg N ha^{-1} exceeded 25% N release by week 2, while 25% N release did not occur until after 12 weeks of incubation when grown at 0 kg N ha^{-1}. Nitrogen release from giant foxtail exceeded 25% after 1 and 2 weeks of incubation when grown at 202 and 134 kg N ha^{-1}, respectively. After 12 weeks of incubation, 25% N was released from giant foxtail grown at 67 kg N ha^{-1}. For giant foxtail grown at 0 kg N ha^{-1}, N release was never greater than 13%, which occurred at 12 weeks of incubation. Grass plant species have been noted to have a larger C:N ratio (due to high N use efficiency) and ADF content (due to high lignin content) than broadleaf plant species (Marten and Andersen 1975; Brown 1978, 1985; Jung and Vogel 1986; Sage and Pearcy 1987; Creamer and Baldwin 2000). In field studies grass weed species have also been found to immobilize N (Sakonnakhon et al. 2006). The high C:N ratio and ADF content of giant foxtail grown at 0 kg N ha^{-1} (Tables 16 and 17) may explain the slower rate and smaller amount of N release from giant foxtail residue.

Percentage of total N mineralized from weed residue was also influenced by the interaction of weed height and N application rate (Table 18). Nitrogen was mineralized from all weed residues except 20-cm tall weeds grown at 0 kg N ha^{-1} after 1 and 2 weeks of incubation (Table 20). After 12 weeks of incubation, 51.3% of the N was mineralized from 10 cm-tall weeds grown at 0 kg N ha^{-1} whereas only 19.0% was mineralized from 20 cm-tall weeds. Nitrogen mineralization was greater for 10 cm-tall weeds compared to 20 cm-tall weeds when grown at 0 and 67 kg N ha^{-1}. When weeds were grown at higher N application rates, N mineralization from 10 and 20 cm- tall weeds was not different. The C:N ratio, cellulose, and lignin content of plants increase with plant age, whereas the soluble materials decrease (Nicolardot et al. 2001). Young plant materials tend to decompose more rapidly than mature plant residues. The difference in N mineralization from 10- and 20-cm tall weeds was most apparent when weeds were grown at low N application rates. At low N application rates, a decrease in NO_3-N and total N concentration and an increase in C:N ratio, NDF, and ADF content was observed (Tables 16 and 17).

Table 18. Analysis of variance for N released from weed residue by main effects of N application rate, weed height, and weed species at each incubation time interval.

Source	F-value					
	0 wk	1 wk	2 wk	4 wk	8 wk	12 wk
N Rate	106.74**[1]	106.74**	56.67**	13.83**	24.15**	5.75*
Height	135.21**	135.21**	90.95**	27.23**	38.29**	50.54**
Species	103.95**	103.95**	66.39**	18.02**	17.17**	29.62**
N rate*height	23.24**	23.24**	16.23**	5.54*	5.76*	8.14**
N rate*species	6.93**	6.93**	3.50**	2.31	4.01**	3.86**
Height*species	2.39	2.39	0.22	1.51	0.25	0.05
N rate*height*species	0.34	0.34	0.41	0.49	0.61	0.81

[1] **denotes F-value significant at $\alpha \leq 0.01$; *denotes F-value significant at $\alpha \leq 0.05$.

Table 19. Percentage of total N released (positive values) or immobilized (negative values) from weed residue at each incubation time by weed species and N application rate averaged across weed height.

Weed species[1]	Field N application	Incubation time (wk) 1	2	4	8	12
	kg N ha^{-1}	%				
CHEAL	0	19.8	26.3	28.8	38.8	44.7
	67	31.7	34.7	42.4	38.4	60.3
	134	36.8	44.2	39.6	40.3	57.2
	202	40.5	46.8	44.2	53.0	60.1
AMBEL	0	10.5	17.5	23.1	22.1	47.5
	67	20.6	26.4	34.5	31.1	43.8
	134	31.7	38.9	40.3	46.7	54.8
	202	33.1	35.0	37.5	46.4	56.7
SETFA	0	-12.7	-7.3	-0.5	-3.8	13.3
	67	6.3	10.5	14.4	22.7	33.7
	134	24.4	26.7	37.1	34.4	50.2
	202	27.7	31.6	30.6	43.7	42.7
LSD (0.05)		6.5	16.1	23.2	23.3	32.5
CV		0.49	0.48	0.49	0.42	0.39

[1]CHEAL, common lambsquarters; AMBEL, common ragweed; SETFA, giant foxtail.

Table 20. Percentage of total N released (positive values) or immobilized (negative values) from weed residue at each incubation time by weed height and N application rate averaged across weed species.

Weed height	Field N application	Incubation time (wk) 1	2	4	8	12
cm	kg N ha^{-1}	---------------------------%---------------------------				
10	0	20.6	28.4	32.9	35.2	51.3
	67	28.4	32.8	36.7	40.0	56.6
	134	34.6	38.4	43.3	44.3	58.4
	202	35.2	41.6	38.6	50.8	54.6
20	0	-8.9	-4.1	1.4	2.9	19.0
	67	10.7	14.9	24.2	21.5	35.3
	134	27.3	34.8	34.6	36.6	49.8
	202	32.4	34.0	36.3	44.7	51.8
LSD (0.05)		5.9	17.1	23.7	23.7	35.5
CV		0.49	0.48	0.49	0.42	0.39

Patterns of N Release. Patterns of N release from weed residue are shown in Figures 6 through 10 and N_{12} and k_0 values are shown in Table 21. Available N initially (0 week of incubation) was > 0 mg N kg^{-1} soil due to N release of readily extractable NO_3-N and NH_4-N. Nitrogen release from weed residue was rapid until after 4 weeks of incubation. After 4 weeks of incubation, N release from weed residue slowed. Decomposition rate of fresh, organic material tends to be most rapid during the first weeks after addition to the soil (Sorensen 1981). Nitrogen mineralized after 12 weeks of incubation and k_0 are given for each N application rate weeds were grown at when the model significantly fit the data. Higher k_0 values indicate higher rates of N mineralization. When the model significantly fit the data, there was no significant difference in N_{12} and k_0 values among N application rates (Table 21). Weed residues were collected from the field and chemical composition was variable, which may explain the lack of significant differences in N_{12} and k_0 values.

Net cumulative N release from weed residue was influenced by the interaction of weed species and N application rate. Nitrogen mineralization from common lambsquarters was rapid for the first 2 weeks of incubation (Fig. 6), indicating the weed residue contained unstable organic N forms (Sorensen 1981; Agehara and Warncke 2005). After 2 weeks of incubation, N mineralization from common lambsquarters plateaued possibly due to stable organic N forms that are more resistant to mineralization. There was no significant difference in N_{12} and k_0 values among common lambsquarters grown at varying N application rates. The C:N ratio of common lambsquarters was narrow, ranging from 10.1 to 13.0 (Table 15) and may explain the lack of significant differences in N_{12} and k_0 values. High total N concentration at all N application rates (Table 15) resulted in net N mineralization of common lambsquarters residue and no significant differences in N_{12} and k_0 values.

When common ragweed was grown at 67 to 202 kg N ha^{-1}, the k_0 was 0.37 to 0.74 (Fig. 7). At the 0 kg N ha^{-1}, the model did not significantly fit the data. The C:N ratio of common ragweed grown at 0 kg N ha^{-1} was 14.2 and was 8.9 and 8.0 for common ragweed grown at 134 and 202 kg N ha^{-1}, respectively. Giant ragweed (*Ambrosia trifida* L.) has been found to assimilate as much as 16 kg N ha^{-1} when 40-cm tall plants were grown at a density of 0.5 plants m^{-2} (Johnson et al. 2007). The ability of *Ambrosia* spp. to assimilate a large quantity of N may contribute to the low C:N ratio measured in this study when weeds were grown at 134 and 202 kg N ha^{-1}.

When giant foxtail was grown at 0 and 67 kg N ha^{-1}, the net cumulative N release from its residue did not fit the first-order model (Fig. 8). The C:N ratio of giant foxtail grown at 0 and 67 kg N ha^{-1} was 21.1 and 15.2, respectively, and the C:N ratio of giant foxtail grown at 134 and 202 kg N ha^{-1} was 11.6 and 10.3, respectively (Table 15). Acid detergent fiber was also greater in giant foxtail residue grown at 0 and 67 kg N ha^{-1} compared to 202 kg N ha^{-1} (Table 15). The model did not fit the data when weeds were grown at 0 and 67 kg N ha^{-1} due to the high C:N ratio and high ADF in the giant foxtail residue.

Net cumulative N released from 10-cm tall weeds by N application rate is shown in Figure 9. When 10-cm tall weeds were grown at 0 kg N ha^{-1}, the model did not fit the data and N_{12} and k_0 values could not be calculated. When 10-cm tall weeds were grown at 67 to 202 kg N ha^{-1}, N_{12} and k_0 were not significantly different. The C:N ratio of 10-cm tall weeds grown at 0 kg N ha^{-1} was 12.4 while the C:N ratio of the same height of weeds grow at 202 kg N ha^{-1} was 8.5 (Table 15). Additionally, the extractable NO_3-N content of 10-cm tall weeds grown at 0 kg N ha^{-1} was 336 mg NO_3-N kg^{-1} and extractable NO_3-N content of 10-cm tall weeds grown at 67 to 202 kg N ha^{-1} was 2268 to 3682 mg NO_3-N kg^{-1} (Table 15). When 20-cm tall weeds were grown at 0 kg N ha^{-1}, the first-order model did not significantly fit the data and N release was negative at 1 and 2 weeks indicating N was immobilized (Fig. 10). When 67 to 202 kg N ha^{-1} was applied, there was a net release of N from 20-cm tall weeds. There was no significant difference in N_{12} and k_0 values for 20-cm tall weeds when 67, 134, and 202 kg N ha^{-1} were applied. The C:N ratio of 20-cm tall weeds grown at 67, 134, and 202 kg N ha^{-1} ranged from 10.4 to 14.0 (Table 15). The narrow range in C:N ratio may explain the lack of significant differences in N_{12} or k_0 values for 20-cm tall weeds grown at 67, 134, and 202 kg N ha^{-1} (Table 21).

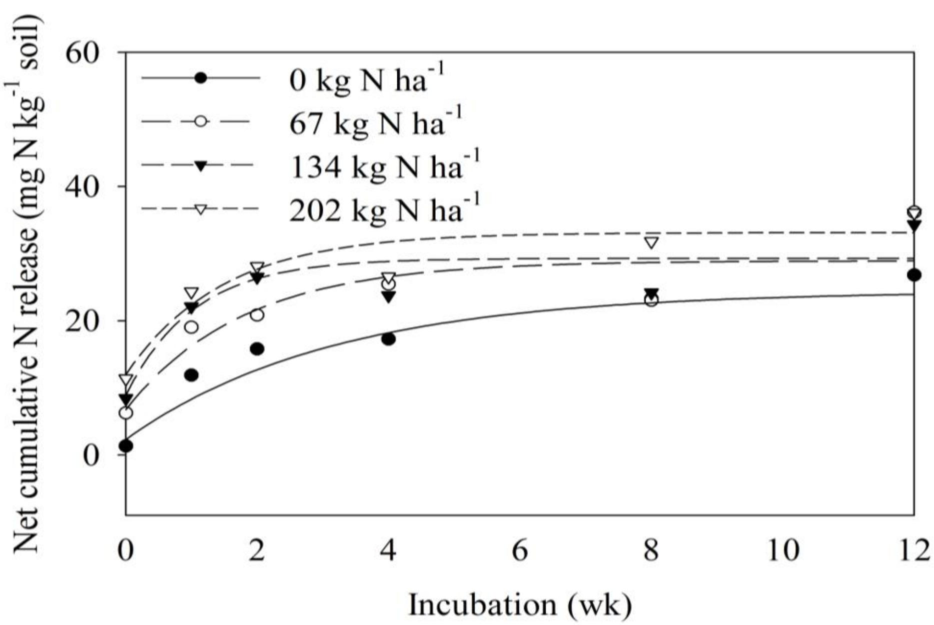

Figure 9. Net cumulative N released from common lambsquarters weed residue (averaged across weed height) by N application rate.

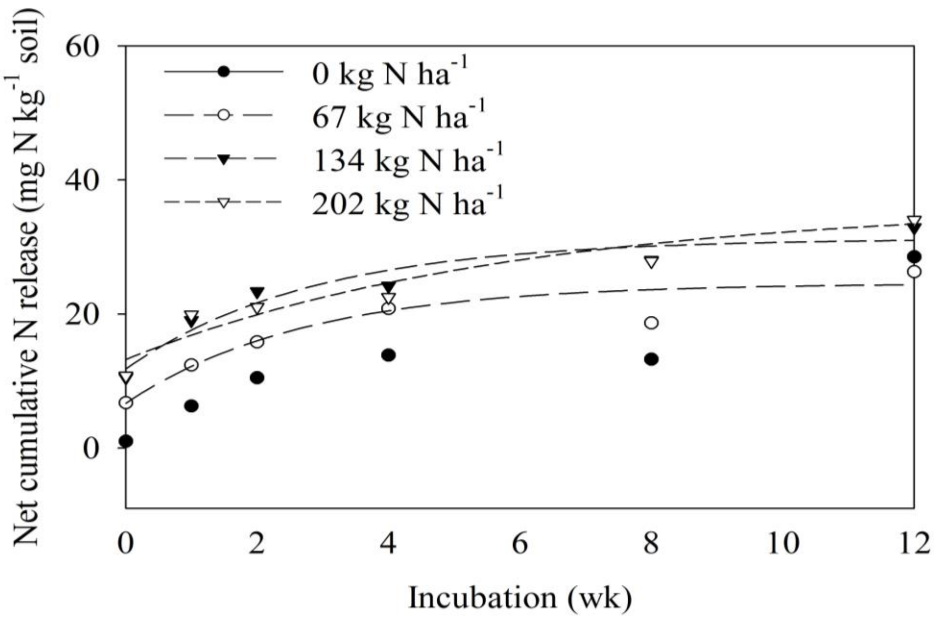

Figure 10. Net cumulative N released from common ragweed weed residue (averaged across weed height) by N application rate.

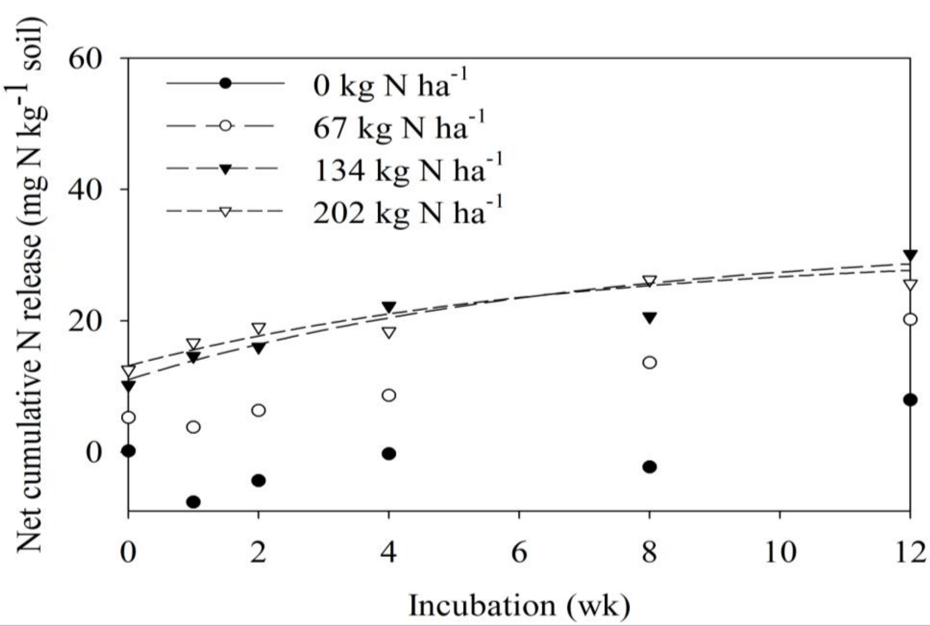

Figure 11. Net cumulative N released from giant foxtail weed residue (averaged across weed height) by N application rate.

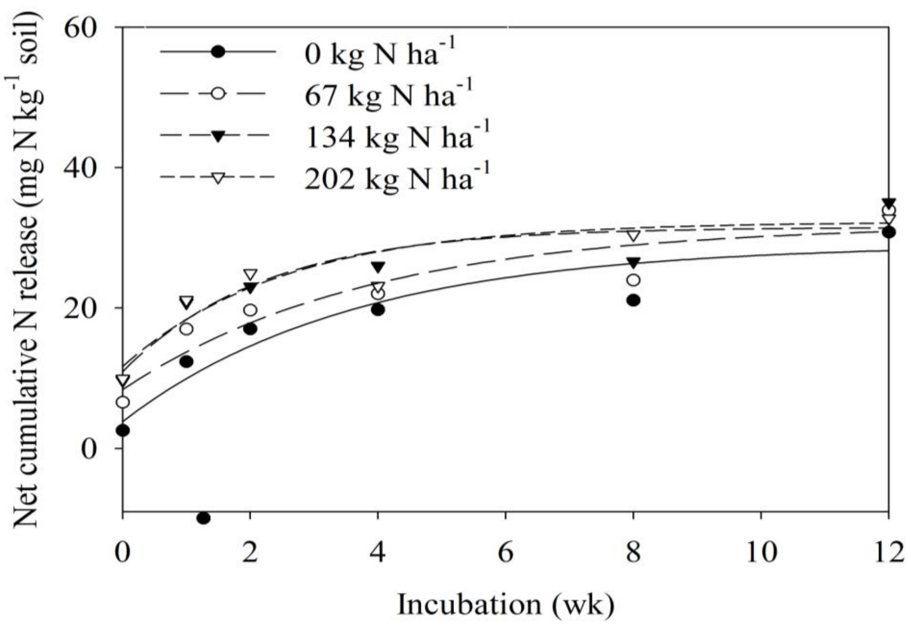

Figure 12. Net cumulative N released from 10-cm tall weeds (averaged across weed species) by N application rate.

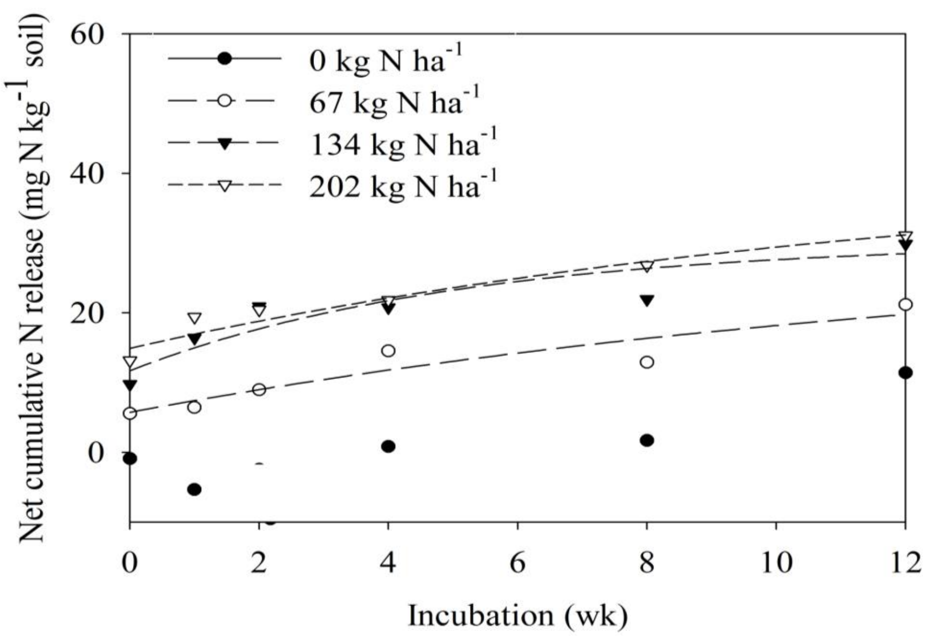

Figure 13. Net cumulative N released from 20-cm tall weeds (averaged across weed species) by N application rate.

Table 21. Net cumulative N release at 12 weeks of incubation (N_{12}) and the first-order rate constant for N mineralization (k_0) by weed species, N application rate, and weed height.

Weed species[1]	Field N application	N_{12}	k_0
	kg N ha^{-1}		
CHEAL	0	22.1 a[2]	0.3 a
	67	22.2 a	0.6 a
	134	20.4 a	1.0 a
	202	21.2 a	0.7 a
AMBEL	0	ns[3]	ns
	67	17.9 a	0.4 a
	134	19.5 a	0.4 a
	202	23.2 a	0.4 a
SETFA	0	ns	ns
	67	ns	ns
	134	21.4 a	0.1 a
	202	17.3 a	0.2 a
Weed height (cm)			
10	0	ns	ns
	67	23.6 a	0.3 a
	134	20.6 a	0.5 a
	202	20.6 a	0.4 a
20	0	ns	ns
	67	24.4 a	0.1 a
	134	18.6 a	0.2 a
	202	26.4 a	0.1 a

[1]CHEAL, common lambsquarters; AMBEL, common ragweed; SETFA, giant foxtail.

[2] Nitrogen mineralized by week 12 (N_{12}) and the first-order rate constant (k_0) values followed by the same letter are not significantly different according to 95% confidence interval.

[3] Model did not significantly fit the dataset.

Factors Influencing Quantity and Rate of N Mineralization. Studies have cited a large range of C:N ratios (15 to 44) where net immobilization begins to occur (Stevenson 1986; De Neve and Hofman 1996; Vigil and Kissel 1991; Chaves et al. 2004), indicating other factors of plant residue chemical composition may also influence N_{12} and k_0 (Fox et al. 1990; De Neve and Hofman 1996; Chaves et al. 2004).

Nitrogen release after 12 weeks of incubation was positively correlated with extractable NO_3-N (r=0.52, $p<0.05$) and total N concentration (r=0.67, $p<0.01$) in the weed residue, and was negatively correlated with C:N ratio (r=-0.74, $p<0.001$) and ADF content (r=-0.47, $p<0.05$). Neutral detergent fiber was not significantly correlated with N_{12} values. Chaves et al. (2004) and De Neve and Hofman (1996) also found a significant correlation between N_{12} and C:N ratio of 21 vegetable crop residues, but the plant residues had a wider range of C:N ratio (2.9 to 58.2) than in our study (8.0 to 21.1).

The first-order rate constant was negatively correlated with C:N (r=-0.56, $p<0.01$), NDF (r=-0.54, $p<0.01$), and ADF (r=-0.71, $p<0.001$). Other studies have also found that the decomposition rate of plant residues was related to C:N ratio, and NDF, and ADF content (De Neve and Hofman 1996; Trinsoutrot et al. 2000; Van Kessel et al. 2000). Total N concentration of the weed residue was positively correlated with k_0 (r=0.59, $p<0.01$). Previous studies have found that decomposition rate of plant residues was related to N content (Parmelee et al. 1989; De Neve and Hofman 1996; Trinsoutrot et al. 2000). The NO_3-N content of the weed residues was not correlated with k_0.

CONCLUSIONS

The current study increases the understanding of the quantity and rate of N mineralization of weed residue under controlled laboratory conditions. Quantity and rate of N mineralization may differ in the field due to uncontrolled environmental conditions and soil management (Sanchez et al. 2001; Agehara and Warncke 2005; Mikha et al. 2006). Additionally, environmental conditions influence the chemical components of plants (Deinum et al. 1968; Van Soest et al. 1978). However, laboratory and *in situ* N mineralization measurements have been found to be comparable to field measurements (Sanchez et al. 2001). The laboratory incubation measurements of N mineralization from weed residue in this study are not intended to represent actual field mineralization, but to further examine chemical composition of several weed species grown at varying N application rates and quantify the rate of N mineralization under controlled conditions. Nitrogen release from giant foxtail residue tended to be slower compared to common lambsquarters and common ragweed, especially when grown without N application. Weeds should be controlled prior to reaching 20 cm height to avoid N immobilization from weed residue. Weeds that are controlled by 10 cm height may contribute to the available soil N pool. However, the practice of purposefully delaying weed control to 10-cm height is not recommended.

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CHAPTER 4

IMPACT OF NITROGEN AND WEED DENSITY ON GROWTH AND NITROGEN ASSIMILATION OF COMMON LAMBSQUARTERS AND REDROOT PIGWEED

ABSTRACT

Weeds compete with crops for water, nutrients, and light. Competition is dependent on several factors, including weed density, weed species, and soil nitrogen (N) supply. A controlled environment study was established in 2011 in East Lansing, Michigan, to evaluate the effect of weed density and N application rate on weed growth and N assimilation of common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.). Study factors included four weed densities (1, 2, 4, and 8 plants pot^{-1}), three N application rates (0, 67, and 134 kg N ha^{-1}), and two weed species (redroot pigweed and common lambsquarters). Weeds were destructively harvested 3 and 5 weeks after emergence (WAE), and shoot height, shoot and root biomass, and total N concentration were measured. Redroot pigweed shoot biomass was greater than common lambsquarters 3 WAE. By 5 WAE, both weed species were equally competitive in terms of biomass accumulation. Shoot and root biomass increased for both species with increasing N application rate. Three WAE, weeds grown at low N and low density exhibited greater root biomass compared to weeds grown at higher N application rates and densities, but differences were not evident 5 WAE. Nitrogen assimilation was greater for redroot pigweed than common lambsquarters 3 WAE, but by 5 WAE N assimilation was greater for common lambsquarters than redroot pigweed. At 67 and 134 kg N ha^{-1}, N assimilated by weeds increased with density 3 WAE. At 5 WAE, N assimilation increased with N application

rate, but was not influenced by weed density. The results of this study demonstrate that weed biomass accumulation and N assimilation are influenced by weed species, weed density, and N application rate. Differences in biomass accumulation and N assimilation were more evident 3 WAE compared to 5 WAE. Nitrogen management and weed control strategies that limit N assimilation by weeds and weed density may be beneficial in reducing weed-crop competition.

INTRODUCTION

Weeds actively compete with crops for water, nutrients, and light and competition can reduce crop yield (Gower et al. 2003; Dalley et al. 2006). Nitrogen (N) is often a limiting nutrient in non-leguminous crop production (Joern and Sawyer 2006) and weeds may be equally responsive or more responsive than crops to N (Blackshaw et al. 2004; Teyker et al. 1991). Due to weed responsiveness to N and recent increases in N fertilizer cost, the effect of N application rate, weed species, and weed density on growth and N assimilation of weeds was examined.

Weed growth positively responds to N application. In a study examining the response of 23 agricultural weeds to N addition, common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) were amongst the most responsive weeds, with a high rate of shoot and root biomass accumulation with increasing N application rates (Blackshaw et al. 2003). An increase in weed shoot biomass due to N application has been noted in other studies (Barker et al. 2006; Iqbal and Wright 1997; Teyker et al. 1991). Many species show an increase in shoot biomass more than root biomass with increasing N levels because plants usually have less need to increase root growth when N supply is adequate (Blackshaw et al. 2003). Under N limiting conditions, velvetleaf root biomass increased while shoot biomass decreased, suggesting that the species may compete less for light as N becomes limiting (Bonifas et al. 2005).

Nitrogen concentration of weeds increases with N application rate (Blackshaw and Brandt 2008; Iqbal and Wright 1997). However, the degree of response is species-specific (Blackshaw et al. 2003), which may be partly attributed to the functional differences in C_3 and C_4 plant metabolism pathways (Abouziena et al. 2007). Plants with C_3 metabolism often have high shoot N concentrations whereas plants with C_4 metabolism tend to produce more dry matter per unit N (Brown 1978, 1985; Sage and Pearcy 1987). When N is limiting, plants with C_3 metabolism increase root growth proportionally more than C_4 plants to maintain a sufficient level of tissue N to sustain photosynthetic rates and dry matter accumulation (Bonifas et al. 2005).

At high weed densities, weed interference and competition increases reducing crop yield (Harrison et al. 2001; Kempenaar et al. 1996; Myers et al. 2005; Werner et al. 2004). Crop reduction due to weeds is also influenced by N application rate (Evans et al. 2003). A reduction in N fertilizer application led to a decrease in the weed density thresholds of green foxtail in corn (Cathcart and Swanton 2003). Several controlled environment studies have examined the impact of N application and weed species on biomass accumulation and N assimilation; however, these studies have not included weed density as a factor (Blackshaw and Brandt 2008; Blackshaw et al. 2003; Iqbal and Wright 1997; Teyker et al. 1991). The effect of weed density on weed biomass accumulation and N assimilation will give researchers a better understanding of intra-specific weed interference in a controlled environment. The objectives of our study were to quantify biomass accumulation and total N assimilation of common lambsquarters, a C_3 species, and redroot pigweed, a C_4 species, grown at varying N supplies and at several weed densities.

MATERIALS AND METHODS

The study was conducted under controlled-environment conditions in the Michigan State University research greenhouses, East Lansing, MI in 2011. The study was a split, split-plot randomized complete block design with five replications and two trials of the experiment. The first trial began on 25 February 2011, and the second trial began 8 March 2011. Factors included two weed species (common lambsquarters and redroot pigweed), four weed densities (1, 2, 4, and 8 weeds pot^{-1}), and three N application rates (0, 67, and 134 kg N ha^{-1}). Weeds were harvested at 3 and 5 weeks after emergence (WAE). Within a replication, treatments were blocked first by species and then by harvest date. Weed density and N rate were randomized within each block.

Weed seeds were planted into 20 cm deep and 100 cm^2 pots containing 1000 g of steam-sterilized Spinks loamy sand (sandy, mixed, mesic Lamellic Hapludalfs). Soil chemical and physical properties are shown in Table 22. A 0.06% N solution was made by dissolving urea in deionized water and applied to the soil surface the same day as planting to supply appropriate N rates. Nitrogen was incorporated by adding 100 mL of water to the soil surface. Weeds were thinned to the desired density at the cotyledon stage. To ensure water was not a growth limiting factor, weeds were watered at least once daily. An additional set of pots containing field soil with N applied at the three rates with no plants was used as a control. The same watering regime was used for these pots. Pots were rotated by replication every week. Natural light was supplemented with artificial light at 400 µmol m^{-2} s^{-1} photosynthetic photon flux in a 16-h day to approximate summer light intensity and photoperiod. Conditions in the greenhouse were maintained at a day/night temperature of 27/24°C. Plant height was recorded every 3 to 5 d.

At weed harvest, shoot and root portions were separated and shoot fresh weight recorded. Roots were gently washed to remove adhering soil. Shoots and roots were dried in a forced-air dryer at 65°C for 72 hr and dry weights recorded. Shoot tissue was ground to pass a 0.178 mm sieve. Total N content was determined by the micro-Kjeldahl digestion (Jung et al. 2003) and colorimetric analysis through a Lachat rapid flow injector autoanalyzer. Weed N use efficiency (NUE) was evaluated by dividing weed biomass by unit N assimilated.

Treatment effects of weed species, plant density, and N application rate on N assimilation and NUE were examined using analysis of variance in the PROC MIXED procedure of SAS (SAS Institute 2003) at $\alpha = 0.05$. Normality and equal variance assumptions were checked using Levene's procedure (Schultz 1985). Shoot biomass data was log-transformed to meet normality assumption; however, untransformed data are presented for readability with statistical analysis based on transformed data. When the unequal variance assumption was not met, treatments were grouped by similar variances. If treatment effects were found significant, means were separated using a paired *t*-test ($\alpha = 0.05$) using the LSMEANS option in SAS. Regression models were determined by using the PROC REG procedure. Models were considered significant at $\alpha = 0.05$.

Table 22. Chemical and physical properties of soil used in the study.

Property	Soil
pH	7.5
Sand, %	69.3
Silt, %	20.2
Clay, %	10.5
CEC, c mol kg^{-1}	7.5
Total N, g kg^{-1}	2.15
NH_4-N, mg kg^{-1}	15.8
NO_3-N, mg kg^{-1}	10.4
Bray P, mg kg^{-1}	94
Exchangeable K, mg kg^{-1}	82
Exchangeable Mg, mg kg^{-1}	127

RESULTS AND DISCUSSION

Weed Biomass. Shoot biomass was influenced by weed species 3 WAE (Table 23). At 0 and 67 kg N ha^{-1}, shoot biomass 3 WAE was greater for redroot pigweed than common lambsquarters, but at 134 kg N ha^{-1} there was no difference in shoot biomass between common lambsquarters and redroot pigweed. Root biomass 3 WAE was also influenced by weed species and N application rate (Table 23). Root biomass was greater for common lambsquarters than redroot pigweed at all N application rates. Common lambsquarters roots tend to exhibit a rapid growth rate (Qasem 1993). Root biomass of both weed species decreased with N application. Under the controlled environment conditions of this study, these results imply that redroot pigweed may exhibit more above-ground competition than common lambsquarters, especially at low N application rates. Due to its greater root biomass, common lambsquarters may be more competitive for below-ground resources than redroot pigweed. Differences in above-ground biomass accumulation of redroot pigweed and common lambsquarters may have been temperature-dependent. Day/night temperatures of 29/24°C favor redroot pigweed shoot growth compared to common lambsquarters (Chu et al. 1978). At a day/night temperature of 17/14°C, common lambsquarters has a greater relative growth rate than redroot pigweed (Pearcy et al. 1981).

Both weed species were equally competitive in terms of shoot and root biomass accumulation 5 WAE. There were no differences in shoot and root biomass between species within an N application rate (Table 23). Shoot biomass increased with increasing N application rate. Root biomass was not influenced by weed species and N application rate. Five WAE, weeds were beginning to enter the reproduction stage and root growth may have been restricted by pot size, which may explain lack of differences among treatments. At a 16-h daylength, common lambsquarters and redroot pigweed have been found to begin flowering 4 to 6 WAE (Nakatani et al. 2009; Rajcan et al. 2002).

Shoot biomass 3 WAE was influenced by weed density and N application rate (Table 24). Within each N application rate, shoot biomass 3 WAE was greatest when there were 8 plants pot^{-1}. Root biomass was also influenced by N application rate and weed density 3 WAE (Table 24). At 0 kg N ha^{-1}, there was no difference in root biomass among weed densities, while at 67 and 134 kg N ha^{-1}, root biomass increased with weed density. The root biomass increase was greater at 67 kg N ha^{-1}, indicating more root biomass at lower N application rates. Velvetleaf also tends to produce more root biomass under N limiting conditions (Bonifas et al. 2005), suggesting that weeds may compete more for below-ground resources as N becomes limiting.

Table 23. Shoot height, shoot biomass, and root biomass of common lambsquarters (CHEAL) and redroot pigweed (AMARE) by weed species and N application rate (averaged across weed density) collected 3 and 5 weeks after emergence (WAE).

Species	N rate[a]	Shoot height[b]		Shoot biomass		Root biomass	
		3 WAE	5 WAE	3 WAE	5 WAE	3 WAE	5 WAE
	kg N ha^{-1}	---------cm-------		---------------------mg pot^{-1}--------------------			
CHEAL	0	7.2 B	17.3 B	550 BC	2070 ABC	190 B	560 A
	67	6.7 B	18.4 B	500 C	2470 ABC	210 A	580 A
	134	6.8 B	18.8 B	520 BC	2720 A	170 C	700 A
AMARE	0	9.4 A	21.0 AB	770 A	1960 C	130 D	520 A
	67	9.0 A	23.7 A	920 A	2630 AB	100 DE	560 A
	134	8.7 A	21.0 AB	590 AB	2560 ABC	90 E	620 A

[a]Nitrogen application rate applied at planting of weed seeds.

[b]Means within a column followed by the same letter are not significantly different according all pair-wise comparisons among the treatments conducted using a *t*-test at the 0.05 level of significance.

Table 24. Shoot height, shoot biomass, and root biomass of weeds by N application rate and plant density (averaged across weed species) collected 3 and 5 weeks after emergence (WAE).

N rate[a]	Density	Shoot height[b]		Shoot biomass		Root biomass	
		3 WAE	5 WAE	3 WAE	5 WAE	3 WAE	5 WAE
kg N ha^{-1}	plants pot^{-1}	---------cm---------		---------------------mg pot^{-1}--------------------			
0	1	8.3 AB	19.7 ABCD	620 C	1740 C	170 B	440 B
	2	7.8 BC	21.0 ABCD	550 E	2060 BC	140 B	550 AB
	4	8.0 ABC	18.6 BCD	680 BC	2090 BC	190 AB	580 AB
	8	9.2 A	17.4 D	830 AB	2290 ABC	250 AB	530 AB
67	1	7.3 BC	21.8 AB	610 D	2290 ABC	80 C	600 AB
	2	7.4 BC	22.8 A	510 E	2600 AB	100 B	610 AB
	4	8.4 AB	19.6 ABCD	790 AB	2420 ABC	190 AB	530 AB
	8	8.4 AB	19.9 ABCD	960 A	2970 AB	760 A	760 A
134	1	7.4 BC	20.9 ABCD	310 F	2210 BC	50 D	570 AB
	2	7.0 C	21.1 ABC	440 E	2630 AB	80 C	630 AB
	4	8.4 AB	17.9 CD	730 AB	2790 AB	80 C	620 AB
	8	8.1 ABC	18.3 BCD	840 AB	3130 A	590 AB	590 AB

[a]Nitrogen application rate applied at planting of weed seeds.

[b]Means within a column followed by the same letter are not significantly different according all pair-wise comparisons among the treatments conducted using a *t*-test at the 0.05 level of significance.

Weed Height. At 3 WAE, redroot pigweed height ranged from 8.7 to 9.4 cm while common lambsquarters height was 6.7 to 7.2 cm (Table 23). By 5 WAE, redroot pigweed at 67 kg N ha^{-1} was significantly taller than common lambsquarters at all N application rates. Shoot height was influenced by weed density 3 WAE. When nitrogen was applied, weeds were the tallest when there was 4 and 8 plants pot^{-1} (Table 24). Weeds may have been taller at higher densities due to shade avoidance strategies which includes accelerated stem extension growth (Morgan and Smith 1976). This has been observed for *Amaranthus* spp. and common lambsquarters (Brainard et al. 2005; Gramig and Stoltenberg 2009; Rajcan et al. 2002). By 5 WAE, there were no differences in weed height among N application rates and weed densities (Table 24).

Nitrogen Assimilation. Nitrogen assimilation was influenced by weed species and N application rate (Table 25). Three WAE when 0 kg N ha^{-1} was applied, N assimilation was similar for common lambsquarters and redroot pigweed. When 67 and 134 kg N ha^{-1} was applied, N assimilation was greater for redroot pigweed compared to common lambsquarters. Five WAE when 0 kg N ha^{-1} was applied, N assimilation was similar across species. However, when 67 to 134 kg N ha^{-1} was applied, N assimilation was greater for common lambsquarters than redroot pigweed. Nitrogen concentration in shoots of C_3 plants tends to be greater than C_4 plants (Brown 1985), but in this study this only occurred 5 WAE. Additionally, differences in N assimilation between common lambsquarters and redroot pigweed only occurred at 67 and 134 kg N ha^{-1}, indicating when N is limiting, N assimilation may be similar for the two weed species. Nitrogen assimilation by weeds collected 3 WAE was significantly influenced by the interaction of N application rate and weed density (Fig. 14). Nitrogen assimilated by weeds was greatest when weeds were grown under 134 kg N ha^{-1} and least when weeds were grown under 0 kg N ha^{-1}. When no N was applied to weeds, N assimilation by weeds did not increase with weed density. However, when weeds were grown at 67 and 134 kg N ha^{-1}, N assimilated by weeds increased linearly with density, indicating that when N is applied, a higher density of weeds may remove more N than a lower density of weeds. Five WAE, N assimilated by weeds was influenced by N application rate, but not weed density (Fig. 14). This may have been because plants were initiating the reproductive stage or due to root growth restrictions.

Table 25. Nitrogen assimilation and nitrogen use efficiency (NUE) of common lambsquarters (CHEAL) and redroot pigweed (AMARE) by weed species and N application rate (averaged across weed density) collected 3 and 5 weeks after emergence (WAE).

Species	N rate[a]	N assimilation[b]		NUE	
		3 WAE	5 WAE	3 WAE	5 WAE
	kg N ha^{-1}	----mg N pot^{-1}---		--mg biomass mg^{-1} N--	
CHEAL	0	25 D	34 D	29.61 BC	62.10 AB
	67	29 C	47 B	23.39 CD	53.39 C
	134	30 BC	62 A	19.22 D	44.52 C
AMARE	0	22 D	30 D	43.45 A	63.83 A
	67	33 B	38 C	32.86 B	69.51 A
	134	39 A	50 B	29.12 BC	55.38 BC

[a]Nitrogen application rate applied at planting of weed seeds.

[b]Means within a column followed by the same letter are not significantly different according all pair-wise comparisons among the treatments conducted using a *t*-test at the 0.05 level of significance.

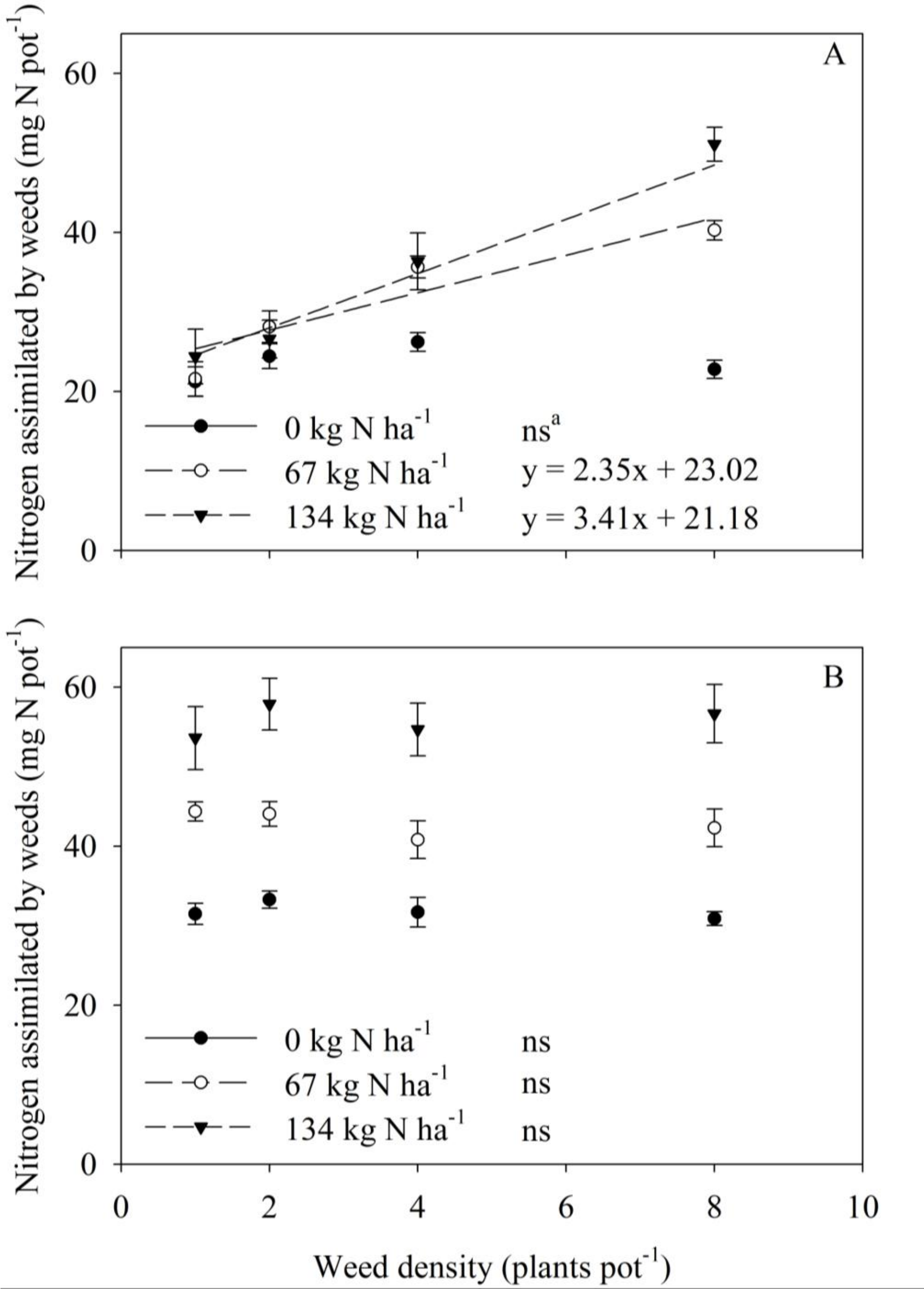

Figure 14. Regression equations for nitrogen assimilated by weeds three (A) and five (B) weeks after emergnece by plant density (averaged across weed species) for weeds grown at three N application rates.

[a]ns, non-significant.

Nitrogen Use Efficiency. Nitrogen use efficiency was influenced by weed species and N application rate (Table 25). Within each N application rate, NUE was greater for redroot pigweed than common lambsquarters 3 and 5 WAE. Plants with C_4 metabolism tend to have a higher NUE than plants with C_3 metabolism (Brown 1985). At low N, common lambsquarters has been found to exhibit a greater NUE than redroot pigweed (Sage and Pearcy 1987), but this did not occur in our study possibly due to temperature settings that may have favored redroot pigweed growth over common lambsquarters growth (Chu et al. 1978). Nitrogen use efficiency of common lambsquarters and redroot pigweed decreased with increasing N application at both 3 and 5 WAE.

There was a positive, linear relationship between NUE and weed density 3 WAE at 0 and 67 kg N ha^{-1} (Fig. 15). Nitrogen use efficiency increased with increasing density more rapidly at 0 kg N ha^{-1} than 67 kg N ha^{-1}. At 134 kg N ha^{-1}, there was no significant correlation between NUE and weed density. Nitrogen use efficiency was also influenced by N application rate. Nitrogen use efficiency was greatest at 0 kg N ha^{-1} and lowest at 134 kg N ha^{-1} (Fig. 15). Five weeks after emergence, there was a positive linear relationship between NUE and weed density at all N application rates (Fig. 15). Nitrogen use efficiency increases in situations when N is limiting, such as at low N application rates, high plant density, and later in the weed life cycle. An increase in NUE indicates that the weeds absorbed N in excess of that required for immediate growth (Ampong-Nyarko and De Datta 1993) as demonstrated by a decrease in N stored in vacuoles under N limiting conditions (Chapin 1980).

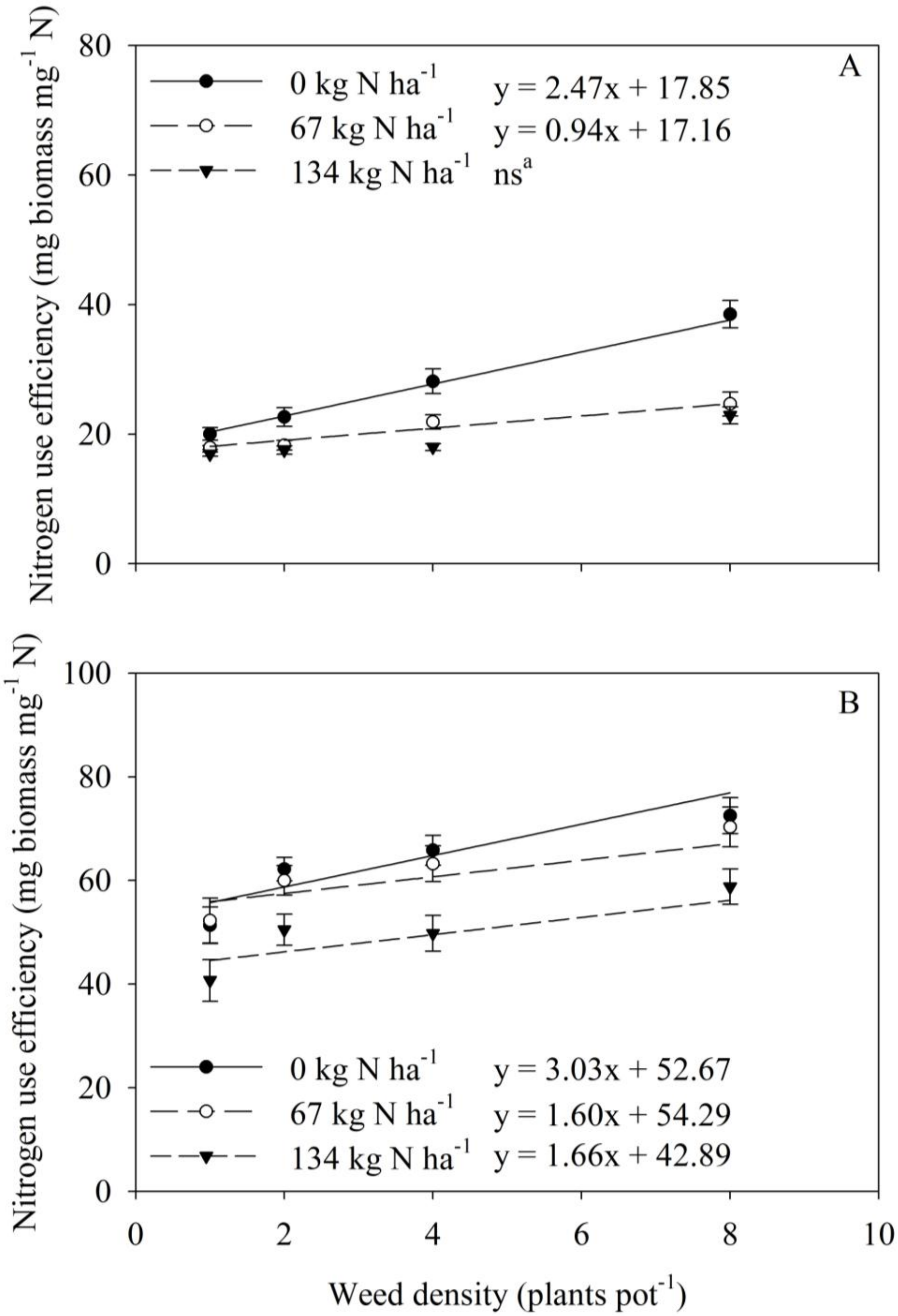

Figure 15. Regression equations for nitrogen use efficiency of weeds three (A) and five (B) weeks after emergnece by plant density (averaged across weed species) for weeds grown at three N application rates.

[a]ns, non-significant.

Management Implications. Three weeks after emergence, redroot pigweed was taller, produced more shoot biomass, and assimilated more N than common lambsquarters (Tables 23 and 25). With environmental conditions similar to this study, redroot pigweed may be more competitive than common lambsquarters early in the growing season. At 5 WAE, shoot and root biomass accumulation was similar for both weed species (Table 23), but N assimilation was greater for common lambsquarters than redroot pigweed when 67 and 134 kg N ha^{-1} was applied (Table 25). At 0 kg N ha^{-1}, there was no difference in N assimilation between weed species. Both shoot and root biomass as well as N assimilation increased with N application rate regardless of weed species. Nitrogen management strategies that limit N assimilation by weeds and favor crop growth may be beneficial to reduce crop-weed competition (Di Tomaso 1995). Weed interference with crops has been reduced by placing fertilizer in a band instead of broadcasting (Blackshaw et al. 2004; Mesbah and Miller 1999). Timing fertilizer applications when crop assimilation is rapid also can reduce weed interference (Davidson 1984). High weed densities resulted in more N assimilation than low weed densities early in the growing season (Fig. 14). Weed management strategies that reduce the weed seed bank and subsequently weed density should reduce N loss to weeds early in the growing season. Two-pass herbicide programs may reduce early-season weed competition and late-emerging weeds (Bradley et al. 2000; Gower et al. 2002), reducing the weed seed bank. Nitrogen management and weed control strategies that limit N assimilation by weeds and reduce weed density should be employed.

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CHAPTER 5

NITROGEN ASSIMILATION BY COMMON LAMBSQUARTERS AND IMPACT ON CORN GRAIN YIELD

ABSTRACT

Common lambsquarters is a highly competitive weed in crop production systems and is considered to be highly responsive to nitrogen (N) application. A field study was established in 2009 and 2010 in Entrican, Michigan to measure N assimilation by common lambsquarters and examine the effect of common lambsquarters on corn grain yield. The study was a randomized complete block design with two factors including common lambsquarters (presence or absence) and N application rate (0, 56, 112, 168, or 224 kg N ha^{-1}). Common lambsquarters were transplanted from an adjacent field when they were approximately 5 to 10 cm tall at a density of 5 plants m^{-1} of corn row when corn was at V6/V7 growth stage. After transplanting common lambsquarters, N was applied as topdressed urea and watered in with irrigation. At corn silking, total N concentration in corn ear leaves and chlorophyll measurements for common lambsquarters were collected. Prior to weed senescence (R5 corn growth stage), common lambsquarters were collected, dry weight recorded, and total N concentration measured. In 2009, biomass and total N concentration in common lambsquarters increased with N application rate. In 2010, there was no significant difference in common lambsquarters biomass or total N concentration. In both years, corn grain yield was not influenced by the presence of common lambsquarters.

INTRODUCTION

Nitrogen (N) fertilizer is one of the most costly inputs of corn grain production and is often a yield-limiting nutrient. Corn requires N throughout the growing season, but demand is greatest between the V6 (six fully-emerged leaves with visible collars) and VT (tasseling) growth stages (Abendroth et al. 2011; Mengel 1995). To reduce the potential of early season N losses from leaching and/or denitrification, producers can apply a split application of N where a small amount of N is applied prior to planting or at planting and the remaining N after corn is emerged. Weed seedlings contain a high concentration of N (Vengris et al. 1953) and postponing N application until demand is greatest by corn may also reduce N loss to weeds.

Weed interference may limit N available to corn and limit grain yield, especially at low N application rates (Evans et al. 2003). Nitrogen assimilation of weeds in competition with corn has been measured in several field studies. Grass weeds at a density of 300 plants m^{-2} assimilated up to 71 kg N ha^{-1} when they were 31 cm tall (Hellwig et al. 2002). Shattercane at a density of 200 plants m^{-2} assimilated up to 38 kg N ha^{-1} when they were 46 cm tall (Hans and Johnson 2002). At a density of 0.5 plants m^{-2}, 40-cm giant ragweed assimilated up to 16 kg N ha^{-1} (Johnson et al. 2007). These studies examined N assimilation when weeds emerged with corn. Weeds that emerge with corn tend to be more competitive than late-emerging weeds (Swanton et al. 1999). Fewer studies have examined N assimilation of late-emerging weeds; however, 30-cm common waterhemp at 369 plants m^{-2} assimilated up to 12 kg N ha^{-1} when it emerged 20 days after planting corn (Cordes et al. 2004).

Common lambsquarters is one of the most widely distributed weeds in the world (Holm et al. 1977). Nitrogen assimilation and aboveground biomass production of common lambsquarters increases with N supply (Blackshaw et al. 2003), making it highly competitive in agricultural production systems. Season-long interference of 4.9 common lambsquarters m^{-1} row has resulted in as much as a 12% corn grain yield loss (Beckett et al. 1988). Another study reported a 9% grain yield loss at a density of 6.6 common lambsquarters m^{-1} row (Sibuga and Bandeen 1980).

Due to competition for resources, weed control before weeds are 10 cm tall is recommended in the North Central region to avoid corn grain yield reductions (Dalley et al. 2004; Gower et al. 2003). However, preemergence and early postemergence herbicide applications may result in weed re-infestations (Gower et al. 2002). Common lambsquarters is an early emerging species (Forcella et al. 1992), but emergence has been documented from April through September (Ogg and Dawson et al. 1984). Yield reductions from late-emerging common lambsquarters have been noted in tomato cropping systems (Friesen 1979). Yields are more likely to be reduced due to late-emerging weeds in circumstances when the crop is less competitive (i.e., incomplete stand, reduced crop vigor, or limiting soil moisture) (Dawson 1977; Dalley et al. 2006). This study was designed to simulate a common lambsquarters re-infestation. Our objectives were to measure N assimilation by common lambsquarters grown under various N application rates and examine the effect of common lambsquarters on corn grain yield.

MATERIALS AND METHODS

A field study was established in 2009 and 2010 at the Montcalm Research Farm in Entrican, Michigan in irrigated corn. Soil consisted of a Montcalm (coarse-loamy, mixed, semiactive, frigid Alfic Haplorthods) and McBride (coarse-loamy, mixed, semiactive, frigid, Alfic Fragiorthods) complex. Soil physical and chemical properties are shown in Table 26. The previous crop was corn.

The study was a randomized complete block design with four replications. The two study factors included common lambsquarters (presence or absence) and N application rate (0, 56, 122, 168, and 224 kg N ha^{-1}). Plots were 3 by 8 m, consisting of four rows of corn. Dates of field operations are listed in Table 27. At planting, 78 kg N ha^{-1} was banded 5 cm below and 5 cm to the side of the corn seed. Corn hybrid was of 'Golden Harvest H7149GT' in 2009 and 'Dekalb 4661' in 2010. Seeding rate was 79,000 plants ha^{-1}. Four to five weeks after planting weeds were controlled using glyphosate (0.87 kg ae ha^{-1}) and *s*-metolachlor (0.26 kg ai ha^{-1}). Common lambsquarters were transplanted from an adjacent field when corn was at the V6/V7 corn growth stage. Transplanting occurred 14 and 5 days after herbicide application in 2009 and 2010, respectively. Glyphosate is a non-residual herbicide (Smith and Oehme 1992) and *s*-metolachlor is considered to be a seedling shoot inhibitor (Fuerst 1987); therefore, transplanted weeds were not affected by the herbicide application. At the time of transplanting, common lambsquarters were 5 to 10 cm tall and placed 10 to 15 cm to the right of the center two corn rows at a density of 5 plants m^{-1} row (6.5 plants m^{-2}). If necessary, weeds were re-transplanted three days after initial transplanting to maintain density. Nitrogen was applied the same day by topdressing urea by hand. Urea was watered in with 1.25 cm of irrigation water to prevent volatile N losses.

At R1 corn growth stage (silking), chlorophyll measurements (Minolta SPAD 502) of twenty newest fully emerged leaves of common lambsquarters near the center two rows of corn were recorded. At the R1 corn growth stage, the average common lambsquarters height was 17 cm. Nitrogen sufficiency index (SI) was calculated by dividing SPAD meter reading by non-N limiting treatment (225 kg N ha^{-1}) (Schepers et al. 1992). At R1 growth stage, twenty corn ear leaves were collected, dried at 65°C for 72 hr, and ground to pass a 1.178 mm sieve. Total N concentration in ear leaves was measured using the micro-Kjeldahl method (Bremner 1996). Prior to weed senescence (R5 corn growth stage), weeds were counted and collected along 1.5 m of each of the center two rows of corn. Common lambsquarters biomass was dried at 65°C for 72 hr and weight recorded. Biomass was ground to pass 1.178 mm sieve and total N measured using the micro-Kjeldahl method (Bremner 1996). The center two rows of corn were harvested using a plot harvester and grain yield determined at 15.5% moisture content. Growing degree days (GDD) were calculated using daily temperature measurements recorded by the Michigan State University Enviro-weather Automated Weather Station Network in Entrican, Michigan. Growing degree days were calculated using a base temperature of 10°C.

Treatment effects were examined for each year of the study separately using analysis of variance in the Mixed procedure of SAS (SAS Institute 2003). Normality and equal variance assumptions were checked using Levene’s procedure (Schultz 1985). The regression procedure (Proc Reg) and correlation (Proc Corr) procedure was used to evaluate the relationship between common lambsquarters chlorophyll meter readings and total N concentration.

Table 26. Soil physical and chemical properties in 2009 and 2010.

Property	2009	2010
pH	6.9	6.1
Sand, %	79.6	70.5
Silt, %	17	23.5
Clay, %	3.4	6.0
CEC, c mol kg^{-1}	3.8	9.3
Total N, g kg^{-1}	1.44	0.8
NH_4-N, mg kg^{-1}	3.3	2.9
NO_3-N, mg kg^{-1}	5.0	5.3
Bray P, mg kg^{-1}	168	163
Exchangeable K, mg kg^{-1}	217	191
Exchangeable Mg, m kg^{-1}	78	103

Table 27. Dates of field operations in 2009 and 2010.

	2009	2010
Corn planted	16 May	28 April
Herbicide applied	12 June	9 June
Weeds transplanted/fertilizer applied	26 June	16 June
Corn ear leaves collected/SPAD measurements	5 Aug.	19 July
Weeds collected	18 Sept.	16 Sept.
Corn at blacklayer	19 Oct.	21 Sept.
Corn harvested	23 Nov.	11 Oct.

RESULTS AND DISCUSSION

Weather. Weather conditions were very different in 2009 and 2010. Monthly cumulative growing degree days (GDD), precipitation, and irrigation are given in Table 28. There were 316 more GDD in 2010 than in 2009 from May through August. Due to variable weather conditions in 2009 and 2010, the results are presented separately for each year of the study.

Table 28. Cumulative monthly growing degree days (GDD) for 2009 and 2010.

	2009	2010	2009	2010	2009	2010
	--Monthly cumulative GDD[a]--		-Precipitation (cm)-		--Irrigation (cm)--	
May	133	196	5.5	9.3	0	0
June	258	280	6.2	8.2	1.9	2.5
July	241	391	5.3	5.4	9.0	6.8
Aug	275	356	12.0	6.8	4.8	3.9
Total	907	1223	28.9	29.7	15.7	13.2

[a]Growing degree days calculated using a base temperature of 10°C.

Nitrogen Assimilation by Common Lambsquarters. Chlorophyll meter readings were collected from the uppermost fully-emerged common lambsquarters leaves when corn was at the R1 corn growth stage. At the R1 corn growth stage, common lambsquarters average height was 17 cm. Chlorophyll meter readings were used to calculate the SI of each treatment. The SI was used as an indicator of the N status of the common lambsquarters (Varvel et al. 1997; Bozic et al. 2008). The SI for common lambsquarters was influenced by N application rate in 2009, but not in 2010 (Table 29). In 2009, SI increased with N application rate when 0 to 112 kg N ha^{-1} was applied. There was no significant difference in SI when 112 to 224 kg N ha^{-1} was applied. This indicates that common lambsquarters assimilated the maximum amount of N when 112 kg N ha^{-1} or more was applied.

Total N concentration in common lambsquarters was measured prior to weed senescence, which occured at the R5 corn growth stage (Table 30). In 2010, there was no significant difference in total N concentration among treatments. In 2009, total N concentration in common lambsquarters was greatest (1.50 to 1.82%) when 112 to 224 kg N ha^{-1} was applied. When 0 to 56 kg N ha^{-1} was applied, total N was 1.02 to 1.04%. In a greenhouse study, Blackshaw et al. (2003) also found that N concentration in common lambsquarters increased with N application rate. To our knowledge, the effect of N application rate on N concentration in common lambsquarters has not been evaluated under field conditions when grown with corn.

Chlorophyll measurements are rarely used to evaluate the N status of weeds (Bozic et al. 2008). Quick, non-destructive measurements can be collected using a chlorophyll meter whereas tissue sampling for N concentration is destructive and time consuming. We examined the use of a chlorophyll meter to evaluate the N status of the plant by correlating the chlorophyll meter readings at the R1 corn growth stage and total N concentration in weeds just prior to senescence (R5 corn growth stage). There was a significant ($p \leq 0.0001$; $r = 0.68$), positive correlation between chlorophyll meter reading and N concentration (Fig. 16). This indicates that chlorophyll measurements may be an alternative method to measure the N status of weeds.

Table 29. Nitrogen sufficiency index from uppermost fully developed common lambsquarters (average height of 17 cm) leaves at the R1 corn growth stage by N application rate in 2009 and 2010.

N application rate (kg N ha^{-1})	2009	2010
	---sufficiency index[a]---	
0	0.85 c[b]	0.93 a
56	0.95 ab	0.97 a
112	0.95 ab	0.95 a
168	0.95 ab	0.98 a
224	1.00 a	1.00 a

[a]Sufficiency index calculated by dividing chlorophyll meter reading of each treatment by non-N limiting treatment (244 kg N ha^{-1}).

[b]Same letters indicate no significant differences in chlorophyll meter readings at $\alpha = 0.05$ within an individual year.

Table 30. Total N concentration in common lambsquarters prior to senescence in 2009 and 2010.

N application rate (kg N ha^{-1})	2009	2010
	------------% N[a]------------	
0	1.02 b[b]	1.17 a
56	1.04 b	1.04 a
112	1.87 a	1.37 a
168	1.50 ab	1.66 a
224	1.82 a	1.09 a

[a]Total N concentration measured as percentage N in dry biomass.

[b]Same letters indicate no significant differences in total N concentration at $\alpha = 0.05$ within an individual year.

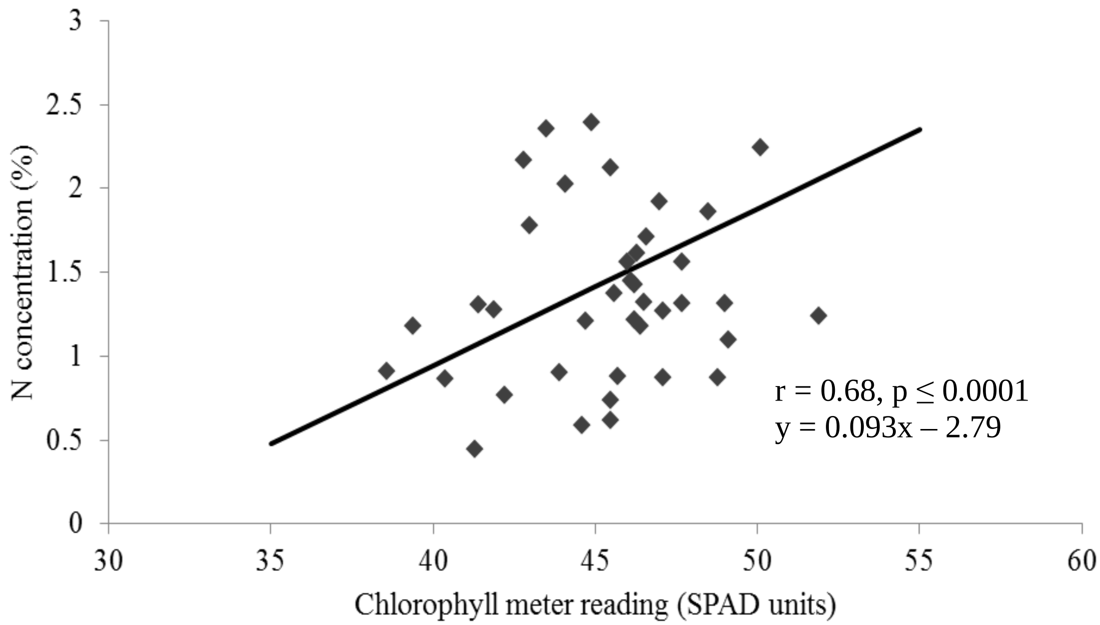

Figure 16. Correlation between chlorophyll meter reading and N concentration in common lambsquarters.

Common Lambsquarters Biomass. Common lambsquarters were collected prior to weed senescence which occured at the R5 corn growth stage. The dry-weight biomass of common lambsquarters is shown in Table 31. Common lambsquarters biomass was significantly influenced by N application rate in 2009. In 2009, common lambsquarters biomass was greatest when 168 and 224 kg N ha^{-1} was applied. When plants are shaded and grown at high N, plants adapt by growing taller, increasing biomass allocation to leaves, and producing more leaf area (Mahoney and Swanton 2008). However, in 2010, there was no difference in common lambsquarters among N application rates. Cumulative growing degree days were greater in 2010 than in 2009 (Tables 28). A competitive crop has been found to reduce weed biomass (Anderson et al. 1998). In 2009, corn may have been less competitive due to cooler temperatures and resulted in more weed biomass than in 2010 when crops were more competitive. Additionally, in 2009, corn stand establishment was poor compared to 2010. The poor corn establishment in 2009 may have resulted in more light being transmitted to the lower part of the corn canopy and allowing weeds to received more light and accumulate more biomass. Different corn hybrids were used in 2009 and 2010, which may also explain differences in common lambsquarters biomass accumulation between the two years of the study.

Nitrogen removed by common lambsquarters on an area basis was calculated using dry weight and total N concentration in common lambsquarters. Nitrogen removed was not significant by N application rate (data not shown). Nitrogen removed by common lambsquarters was <4 kg N ha^{-1} for all treatments. Johnson et al. (2007) reported that 40-cm tall giant ragweed growing at a density of 0.5 plants m^{-2} assimilated 16 kg N ha^{-1} when giant ragweed emerged with corn. The amount of nitrogen removed by common lambsquarters in this study may have been small because common lambsquarters were transplanted into corn at the V6/V7 growth stage.

Table 31. Common lambsquarters biomass and final weed density prior to weed senescence (R5 corn growth stage) on 18 September 2009 and 17 September 2010.

	2009	2010	2009	2010
N application rate (kg N ha^{-1})	Biomass		Density	
	------------g m^{-2}-----------		---plants m^{-1} row--	
0	6.15 c[a]	4.37 a	5.5	5.5
56	15.39 bc	3.46 a	5.9	4.8
112	9.08 c	4.86 a	5.6	4.9
168	27.38 a	4.63 a	6.2	4.9
224	20.93 ab	3.61 a	6.6	5.1

[a]Same letters indicate no significant differences in biomass at $\alpha = 0.05$ within an individual year.

Nitrogen Assimilation by Corn. Corn ear leaves were collected at the R1 growth stage (silking) and analyzed for total N concentration. Nitrogen deficiencies in corn are most apparent in leaves and leaf sheaths at corn silking (Hanway 1962). A total N concentration of 2.90 to 3.50% in ear leaves collected at initial silking are considered within the N sufficiency range, while total N of 2.44 to 2.89% is considered marginal (Vitosh et al. 1995). Total N concentration was influenced by N application rate in 2010, but not in 2009 (Table 32). In 2009, total N concentration was considered to be in the below to marginal range. In 2010, the concentration of total N in ear leaves increased with N application rate; however, total N concentration was also considered to be in the below to marginal range. At the same corn growth stage, chlorophyll measurements collected from common lambsquarters was non-significant in 2009, but in 2010, chlorophyll measurements increased with N application rate (Table 29). This indicates that the weeds were more responsive to N in 2009, while the corn was more responsive to N in 2010. This suggests the corn was less competitive in 2009 compared to

2010. In both years, the presence of common lambsquarters did not influence total N concentration in corn ear leaves (data not shown).

Table 32. Percentage of total N in corn ear leaves at R1 growth stage by N application rate in 2009 and 2010.

N application rate (kg N ha^{-1})	2009	2010
	------------%N-----------	
0	2.20 a[a]	2.04 d
56	2.14 a	2.40 c
112	2.70 a	2.52 bc
168	2.77 a	2.84 a
224	2.32 a	2.70 ab

[a]Same letters indicate no significant differences in percentage of total N at $\alpha = 0.05$ within an individual year.

Grain Yield. Corn grain yield was influenced by N application rate (Table 33). In 2009 and 2010, grain yield increased from 0 to 56 kg N ha^{-1}, but there was no difference in grain yield when 56 to 224 kg N ha^{-1} was applied. Corn grain yield was not influenced by the presence of common lambsquarters (data not shown). Grain yield reduction from weeds has primarily been evaluated when weeds emerge with the crop. In our study, common lambsquarters were transplanted into corn rows when corn was at V6/V7 growth stage when yield reduction due to weed competition is less likely (Connolly and Wayne 1996; Swanton et al. 1999). A yield loss due to the presence of weeds may have occurred at higher weed densities or at lower N application rates (Johnson et al. 2007).

Table 33. Corn grain yield at 15.5% moisture content in 2009 and 2010.

N application rate (kg N ha^{-1})	2009	2010
	--------Mg ha^{-1}-------	
0	10.88 b[a]	13.85 b
56	13.08 a	15.57 a
112	12.84 a	16.11 a
168	13.91 a	16.19 a
224	13.47 a	15.89 a

[a]Same letters indicate no significant differences in corn grain yield at $\alpha = 0.05$ within an individual year.

Management Implications. The presence of common lambsquarters transplanted at 5 plants m^{-1} of row into corn at V6/V7 did not affect corn grain yield. Researchers have reported a 12% corn grain yield reduction at densities of 4.9 common lambsquarters m^{-1} row when weeds emerge with the crop (Beckett et al. 1988). Weeds emerging at later stages of development tend to impact corn grain yield less than when weeds emerge with the crop (Swanton et al. 1999). Although there was no yield reduction due to common lambsquarters, it may be beneficial to control late emerging weeds to decrease the weed seed bank (Sattin et al. 1992).

In 2009, there was a significant difference in total N concentration and weed biomass at the end of the season among N application rates (Tables 30 and 31). However, in 2010, there were no significant differences. In 2009, the cool growing season (Table 28) and poor stand may indicate that the corn was less competitive in 2009 than in 2010. These results indicate that weed interference may increase in situations where the crop is less competitive due to a poor stand (causing more light to reach the weeds under the crop canopy) and unfavorable weather conditions.

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LITERATURE CITED

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APPENDIX

Table 34. Soil nitrate-nitrogen (NO_3-N) concentration for each year of the field study by N application rate in East Lansing, MI.

N rate	Weed control	Soil NO_3-N					
		29 June 2009	13 July 2009	28 June 2010	15 July 2010	29 June 2011	14 July 2011
kg N ha^{-1}	cm	mg N kg^{-1} soil					
0	0	4.3	1.3	18.7	6.2	7.7	3.4
	5	4.1	1.2	11.9	9.4	5.5	2.2
	10	5.2	1.2	10.7	6.7	6.3	4.9
	15	5.6	2.4	10.2	7.2	5.7	6.9
	20	5.5	1.4	6.6	5.8	4.5	7.3
	none	2.4	0.6	3.1	5.7	0.9	1.4
	LSD(0.05)	2.7	2.0	9.9	5.6	4.2	5.4
67	0	7.7	1.5	22.8	19.2	21.3	15.5
	5	7.7	1.9	36.7	26.0	13.8	13.4
	10	6.5	2.3	12.9	14.9	18.4	8.8
	15	6.5	2.7	20.7	8.6	17.9	5.6
	20	5.6	2.3	15.5	12.4	7.9	3.8
	none	1.7	0.8	3.2	4.8	1.8	0.7
	LSD(0.05)	3.7	1.7	21.8	16.2	22.1	11.0
134	0	12.8	2.2	38.8	98.5	58.5	28.9
	5	12.3	4.5	70.0	72.5	47.1	25.3
	10	9.8	3.9	57.5	72.9	33.3	24.0
	15	9.2	2.9	44.6	27.4	29.3	25.1
	20	6.5	3.6	25.0	31.9	23.8	12.8
	none	1.8	0.7	7.3	8.6	3.7	0.7
	LSD(0.05)	9.2	4.0	34.0	36.6	27.8	30.4
202	0	17.0	3.7	88.2	109.6	59.0	44.8
	5	23.2	4.6	58.6	59.6	39.8	53.0
	10	26.1	7.7	106.5	109.9	64.9	33.4
	15	13.9	4.0	55.2	103.6	57.4	24.9
	20	15.8	10.3	45.1	41.0	31.6	23.8
	none	1.2	2.4	22.8	29.6	8.8	3.1
	LSD(0.05)	14.2	8.8	44.1	77.2	32.2	39.9