Weed Science 2013 61:334–340

Nitrogen Release from Weed Residue

Laura E. Lindsey, Kurt Steinke, Darryl D. Warncke, and Wesley J. Everman*

Weed residues can impact nitrogen (N) cycling in agro-ecosystems that primarily utilize POST weed control. Quantifying this potential N source or sink may influence weed control and fertilization practices. A laboratory experiment measured the rate and quantity of N release 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 weed heights (10 or 20 cm) to give a range of residue chemical composition. Residue chemical composition parameters of carbon : N (C : N) ratio and total N, nitrate-N, acid detergent fiber, and neutral detergent fiber concentration were measured and correlated with N release. Nitrogen release from weed residue mixed with soil was determined over a 12-wk period. Nitrogen was released from all weed residues at 12 wk. Prior to 12 wk, N was immobilized by giant foxtail grown with no N application. Prior to 4 wk, N was immobilized by 20-cm weeds grown with no N application. Nitrogen release from weed residue was negatively correlated with C : N ratio. Weed residue with a C : N ratio of < 19 (weeds grown with N application and 10-cm weeds) released 25 to 45% total N concentration within 2 wk and may contribute N within the growing season. Weed residue with a C : N ratio > 19 (giant foxtail and 20-cm weeds grown with no N) initially immobilized N and may not contribute N within the growing season.

Nomenclature: Common lambsquarters, *Chenopodium album* L. CHEAL; common ragweed *Ambrosia artemisiifolia* L. AMBEL; giant foxtail, *Setaria faberi* Herrm. SETFA; corn, *Zea mays* L.

Key words: Nitrogen immobilization, nitrogen mineralization, postemergence.

Global food demand is expected to double by the year 2050, and sustainable agriculture will rely on nutrient cycling within agro-ecosystems to maximize yield and economic return (Tilman et al. 2002). Nitrogen (N) is often the limiting nutrient in nonleguminous crop production (Joern and Sawyer 2006), but global N use efficiency of cereal production is approximately 30% (Food and Agriculture Organization of the United Nations 2001). To meet the growing food demand while improving agro-ecosystem sustainability, potential N sources and sinks need to be identified. Weeds are a potential N source and sink that have not been thoroughly investigated.

The development of herbicide-resistant crops allows for weed control using the nonselective POST herbicides glyphosate and glufosinate (Culpepper and York 1999; Johnson et al. 2000). To minimize corn grain yield reductions, POST 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; Dalley et al. 2004; Gower et al. 2003). Weeds reduce grain yield by competing with crops for sunlight, water, and nutrients (Dalley et al. 2006; Gower et al. 2003). Some summer annual weeds including common lambsquarters and redroot pigweed (*Amaranthus retroflexus* L.) are considered luxury N consumers and actively compete with corn for soil N (Blackshaw and Brandt 2008; Cathcart and Swanton 2003; DiTomaso 1995; Qasem 1992). 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.) Moench. ssp. arundinaceum (Desv.) de Wef & Harlan] assimilated 38 kg N ha^{-1} at a density of 200 plants m^{-2} and 46 cm height (Hans and Johnson 2002).

Nitrogen assimilation from weeds is well documented, but very little research on N release from weeds subsequent to POST control has been reported. In India, manually removing weeds and retention of the weed biomass in the field conserved up to 20% of soil nutrients (Ramakrishnan 1992). Researchers in Ohio measured a 65% reduction in total N content of common lambsquarters, giant foxtail, 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.) Pers.], 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 (Mikha et al. 2006; Rice and Havlin 1994). Nitrogen release from residues can be examined using laboratory incubation methods to provide baseline comparisons and reduce environmental variability that occurs in field studies. Laboratory and field measurements of N release from crop residue have been correlated (Sanchez et al. 2001). However, N release from weed residue has not been quantified in laboratory studies.

Nitrogen release from plant residue is dependent on plant residue chemical composition, including total N, total carbon (C), hemicellulose, cellulose, and lignin concentration. Net N mineralization of plant residues occurs at C : N ratios < 15 to 44 (Chaves et al. 2004; De Neve and Hofman 1996; Fox et al. 1990). Plant cell wall components, consisting of hemicellulose, cellulose, and lignin, reduce N mineralization with lignin concentration reducing N mineralization more than hemicellulose and cellulose (Haynes 1986; Müller et al. 1988). Total N concentration increases N mineralization (Justes et al. 2009). Young, vegetative plants have narrow C : N ratios and a smaller lignin concentration compared to mature plants (Müller et al. 1988; Nicolardot et al. 2001). As

DOI: 10.1614/WS-D-12-00090.1

* Former Graduate Assistant, Assistant Professor, and Professor Emeritus, Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI 48824; Assistant Professor, Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695. Current address of first author: Department of Horticulture and Crop Science, Ohio State University, 2021 Coffey Road, Columbus, OH 43210. Corresponding author's E-mail: lindsey.233@osu.edu

https://doi.org/10.1614/WS-D-12-00090.1 Published online by Cambridge University Press

plants mature, their C : N ratio and lignin concentration tend to increase (Müller et al. 1988). Subsequent to POST weed control, young summer annual weeds may quickly decompose resulting in N release (Majumder et al. 2008).

Nitrogen release from weed residue may contribute to the soil N pool within the growing season or release after the growing season which may result in N loss to the environment through leaching and/or denitrification. Common lambsquarters, common ragweed, and giant foxtail were grown in the field at four N application rates and collected at two growth stages to provide a range of weed residue chemical compositions. The objectives were to determine the quantity and rate of N release from weed residue and to examine the relationship between the chemical composition of weed residue and N release.

Materials and Methods

Weed Residue for Laboratory Incubation. Above- and belowground biomass of common lambsquarters, common ragweed, and giant foxtail were collected from a mixed, natural weed population that emerged with corn in the field. The field was at the Michigan State University Crop and Soil Sciences Research Farm in East Lansing, MI, in 2011. Weeds were grown at four preplant N application rates (0, 67, 134, and 202 kg N ha^{-1}) supplied as incorporated urea. Weeds were collected at 10 and 20 cm weed heights on June 9 and June 18, respectively, from three field replications. Approximately 40 plants were randomly collected from the center two rows of corn.

Weeds were dried 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). All weed residue analyses were conducted on dry, finely ground weed residue. Total N and C concentration 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 neutral detergent fiber (NDF) concentration (hemicellulose, cellulose, and lignin) and acid detergent fiber (ADF) concentration (cellulose and lignin) (Undersander and Wolf 2006) using the reflux method (Van Soest et al. 1991). Weed residue chemical composition is shown in Tables 1 and 2.

Soil for Laboratory Incubation. Soil, an Aubbeenaubbee- (fine-loamy, mixed, active, mesic Aeric Epiaqualfs) Capac (fine-loamy, mixed, active, mesic, Aquic Glossudalfs) complex was collected on July 7 from three weed-free plots of the field study where 67 kg N ha^{-1} was applied prior to planting. Plots were kept weed-free with a PRE application of *s*-metolachlor at 0.26 kg ai ha^{-1} and two POST applications of glyphosate at 0.87 kg ae ha^{-1}. Approximately 45 kg of soil was collected to a depth of 0 to 10 cm to use for laboratory incubation. The field-moist soil was homogenized and passed through a 6-mm sieve and stored at 4 C prior to initiating laboratory incubation. The gravimetric soil water content was 0.166 kg water kg^{-1} dry soil (16.6%). Soil pH was 7.2 and cation exchange capacity was 15.1 cmol kg^{-1}. Total N concentration of the soil was 0.91 g kg^{-1} while NH_4–N and NO_3–N concentration was 4.4 and 14.3 mg kg^{-1}, respectively. Bray phosphorus, exchangeable potassium, and exchangeable magnesium were 59, 152, and 207 mg kg^{-1}, respectively. Soil was 50.9% sand, 34.0% silt, and 15.1% clay.

Table 1. Nitrate–nitrogen (NO_3–N) concentration, total N concentration, and carbon : N (C : N) ratio of weed residue by species and field N application rate and by weed height and field N application rate.

Weed species	Field N application	NO_3–N	Total N	C : N
	kg N ha^{-1}	mg g^{-1}	mg g^{-1}	C : N
CHEAL	0	0.255	32.2	13.0
	67	1.389	39.1	11.2
	134	2.582	41.3	9.4
	202	3.264	41.5	10.1
AMBEL	0	0.224	30.6	14.2
	67	2.694	40.9	9.5
	134	4.865	43.1	8.9
	202	5.419	47.2	8.0
SETFA	0	0.094	19.5	21.1
	67	1.035	27.4	15.2
	134	2.925	35.2	11.6
	202	3.421	36.6	10.3
LSD(0.05)		0.865	3.9	2.8
Weed height (cm)				
10	0	0.336	35.6	12.4
	67	2.268	45.3	9.9
	134	3.876	45.4	9.3
	202	3.682	45.4	8.5
20	0	0.046	19.2	19.3
	67	1.143	26.4	14.0
	134	3.039	34.3	10.6
	202	4.387	38.2	10.4
LSD (0.05)		0.875	3.4	2.5
Weed height (cm)				
10	0	0.336	35.6	12.4
	67	2.268	45.3	9.9
	134	3.876	45.4	9.3
	202	3.682	45.4	8.5
20	0	0.046	19.2	19.3
	67	1.143	26.4	14.0
	134	3.039	34.3	10.6
	202	4.387	38.2	10.4
LSD (0.05)		0.875	3.4	2.5

Laboratory Incubation Experiment. Nitrogen release from the dried, ground common lambsquarters, common ragweed, and giant foxtail biomass was evaluated in a laboratory incubation experiment similar to Agehara and Warncke (2005). In 2011, two trials of the laboratory incubation experiment were conducted beginning on July 8 and July 11. The laboratory incubation experiment was arranged in a split-plot, randomized complete block design. Main plot factor was incubation time interval (0, 1, 2, 4, 8, and 12 wk). Subplot factor consisted of the field-collected weed residue.

Twenty grams dry weight equivalent moist soil was placed in 118-ml specimen cups. The ground weed biomass from each field treatment was added with the soil at a rate of 60 mg total N kg^{-1} soil. Sufficient cups were set up to allow sampling six cups (one per field replication and laboratory trial) at each specified incubation interval. Following weed residue addition, each cup was capped and 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

https://doi.org/10.1614/WS-D-12-00090.1 Published online by Cambridge University Press

Table 2. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentration of weed residue by species and field N application rate and by weed height and field N application rate.

Weed species	Field N application	NDF	ADF
	kg N ha^{-1}	mg g^{-1}	
CHEAL	0	198	121
	67	179	113
	134	186	125
	202	171	113
AMBEL	0	180	157
	67	178	140
	134	172	145
	202	177	160
SETFA	0	509	233
	67	505	234
	134	471	216
	202	475	210
LSD(0.05)		31	21
Weed height (cm)			
10	0	280	167
	67	272	149
	134	270	158
	202	270	149
20	0	311	174
	67	303	175
	134	283	166
	202	279	173
LSD (0.05)		32	27

matter. The specimen cups were stored in the dark at 25 C. Soil moisture was monitored weekly and maintained at 0.166 kg water kg^{-1} dry soil. If necessary, deionized water was added to the cups.

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 NH_4–N and NO_3–N concentration 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. Initial N release (incubation interval of 0 wk) was attributed to inorganic N (NO_3–N and NH_4–N) concentration in the weed biomass. Nitrogen release at 1, 2, 4, 8, and 12 wk of incubation was attributed to N mineralization from the weed biomass. 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 interval.

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 Equation [1].

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

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

Statistical Analysis. Treatment effects of weed species, weed height, and incubation interval on percent N release from weed biomass were examined using analysis of variance (PROC MIXED) (SAS Institute 2003). Fixed effects included N application rate, weed species, weed height, incubation time, and their interactions. Field replication and laboratory trial were considered the random factor 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. Mean separation of treatments were conducted using Fisher's Protected LSD.

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

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

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 at 12 wk of incubation, exp is the exponential constant with a numerical value approximately 2.718, k_0 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

Nitrogen Release. Nitrogen release from weed residue was influenced by the interaction of weed species and N application rate and the interaction of weed height and N application rate ($\alpha = 0.05$; data not shown). Positive N release values indicate N was released from the weed residue while negative N release values indicate N was immobilized (Figures 1 and 2).

Effect Weed Species and N Application. Nitrogen release from common lambsquarters residue increased from 0 to 4 wk of incubation (Figure 1). At 4 wk of incubation, N release was 13.9, 26.8, 25.0, and 27.0 mg N kg^{-1} soil when common lambsquarters was grown at 0, 67, 134, and 202 kg N ha^{-1}, respectively. After 4 wk of incubation, N release from common lambsquarters slowed. At 1, 2, 4, and 12 wk of incubation, nitrogen release was similar for common lambsquarters grown at 67, 134, and 202 kg N ha^{-1}. Nitrogen release from common lambsquarters grown without N application was less than N release from common lambsquarters grown with N application at every incubation time interval except for 8 wk. At 12 wk of incubation, N release was 24.8, 32.1, 36.2, and 37.1 mg N kg^{-1} soil when common lambsquarters were grown at 0, 67, 134, and 202 kg N ha^{-1}, respectively.

Nitrogen release from common ragweed grown with N fertilizer was rapid during the first four wk of incubation and slowed from 4 to 12 wk of incubation (Figure 1). Common ragweed grown at 67, 134, and 202 kg N ha^{-1} released 21.4, 24.2, and 22.5 mg N kg^{-1} soil, respectively. Nitrogen release from common ragweed grown without N fertilizer was less compared to common ragweed grown with N fertilizer at all incubation intervals except at 12 wk of incubation. By 12 wk

https://doi.org/10.1614/WS-D-12-00090.1 Published online by Cambridge University Press

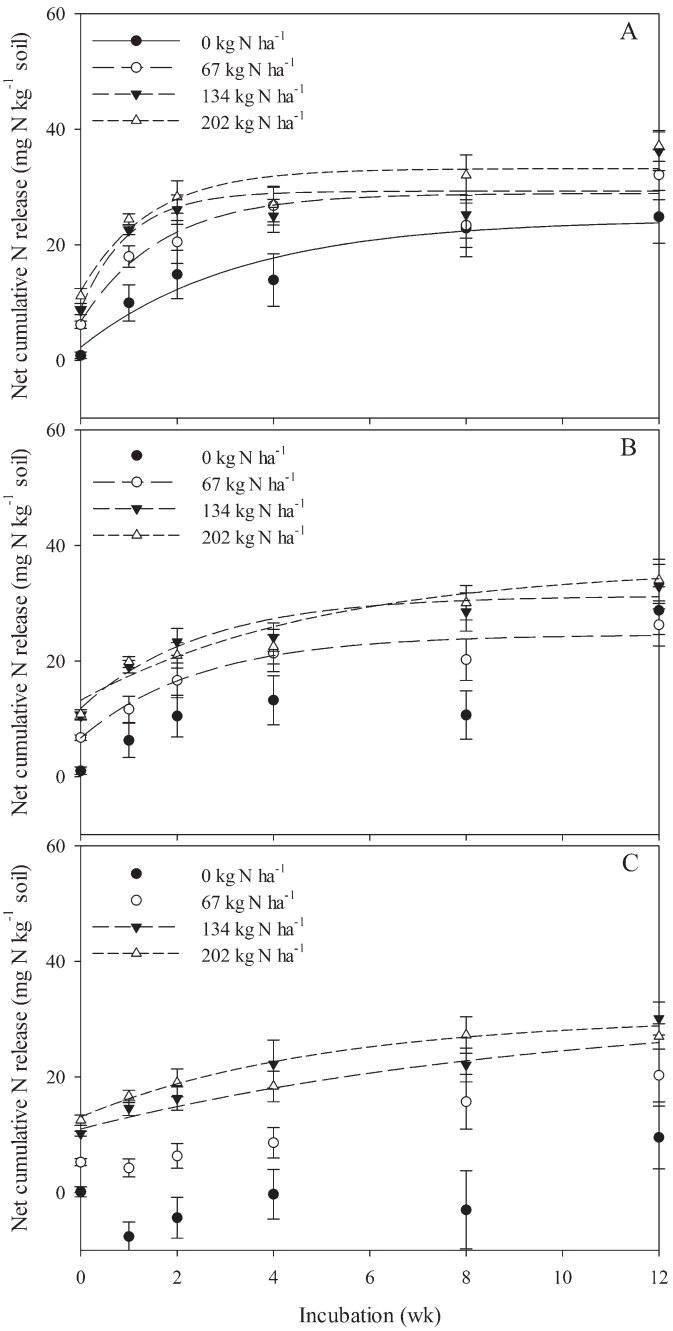


Figure 1. Cumulative nitrogen (N) release from weed residue at each incubation interval by weed species and field N application rate averaged across weed height.

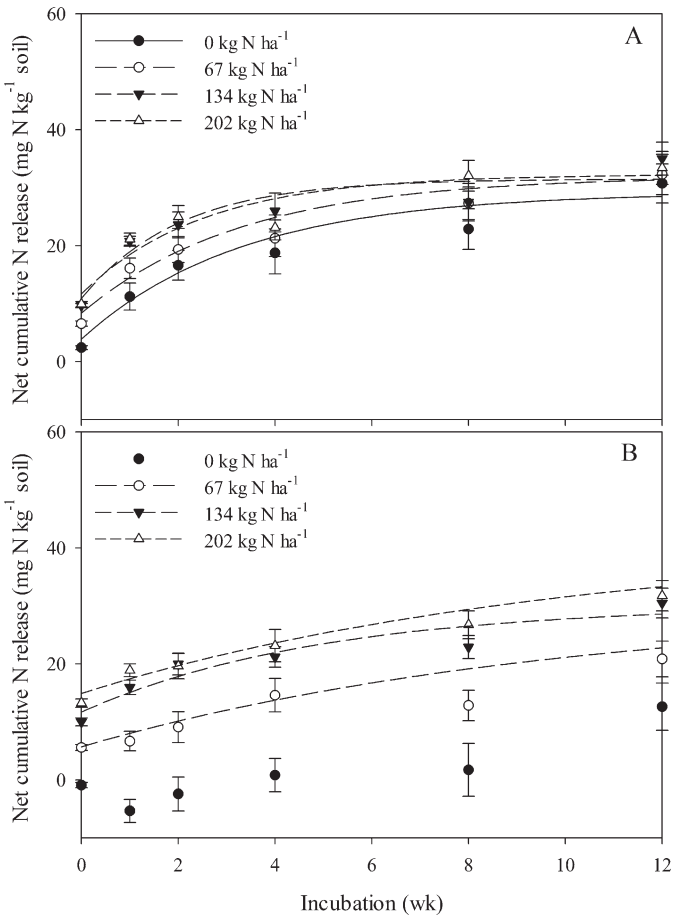


Figure 2. Cumulative nitrogen (N) release from weed residue at each incubation interval by weed height and field N application rate averaged across weed species.

of incubation, N release from common ragweed was similar among N application rates ranging from 26.3 to 34.0 mg N kg^{-1} soil.

Nitrogen was released from giant foxtail grown with N application at all incubation time intervals (Figure 1). Giant foxtail grown at 67 kg N ha^{-1} released 20.3 mg N kg^{-1} soil at 12 wk of incubation while giant foxtail grown at 134 and 202 kg N ha^{-1} released 30.1 and 27.0 mg N kg^{-1} soil, respectively. Giant foxtail grown with no N application was the only weed residue that immobilized N. All other weed species and N application rate combinations resulted in N release. 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 1). Immobilization has been found to occur at C : N ratios as low as 16 (Jensen 1994). The ADF concentration of giant foxtail was greater than common lambsquarters and common ragweed (Table 2). Grassy 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 (Brown 1978, 1985; Creamer and Baldwin 2000; Jung and Vogel 1986; Marten and Andersen 1975; Sage and Pearcy 1987). The initial immobilization of giant foxtail grown where no N was applied may be explained by the C : N ratio and ADF concentration of its biomass.

Effect of Weed Height and N Application. At 1 wk of incubation, N release was greatest for10-cm weeds grown at 134 and 202 kg N ha^{-1} (Figure 2). Following 2, 4, 8, and 12 wk of incubation, N release of 10-cm weeds was similar among all N application rates. When weeds were 20 cm tall, N was immobilized at 1 and 2 wk of incubation from weeds that were grown without N. Nitrogen was released from 20 cm tall weeds at all incubation time intervals when weeds were grown at 67, 134, and 202 kg N ha^{-1}. The C : N ratio and ADF concentration of plants increase with plant maturity, whereas the soluble materials decrease (Nicolardot et al. 2001). Immature plant residues tend to decompose more rapidly than mature plant residues. The difference in N mineralization from 10- and 20-cm tall weeds was most

https://doi.org/10.1614/WS-D-12-00090.1 Published online by Cambridge University Press

Table 3. Nitrogen release at 12 wk (N_{12}), first-order rate constant (k_0), and y-intercept (b) values and standard error (SE) describing N release from weed residue by species and field N application rate.[a]

Weed species	Field N application	N_{12}	N_{12} SE	k_0	k_0 SE	*b*	*b* SE
	kg N ha^{-1}						
CHEAL	0	22.1 a[b]	4.6	0.3 a	0.1	2.3 b	3.4
	67	22.2 a	3.6	0.6 a	0.2	6.7 ab	3.1
	134	20.4 a	3.2	1.0 a	0.4	8.9 ab	2.7
	202	21.2 a	2.9	0.7 a	0.2	12.0 ab	2.5
AMBEL	0		Model could not be fit to data[c]				
	67	17.9 a	3.3	0.4 a	0.2	6.7 ab	2.6
	134	19.5 a	3.0	0.4 a	0.1	11.8 ab	2.4
	202	23.2 a	5.5	0.2 a	0.1	13.2 ab	2.2
SETFA	0		Model could not be fit to data				
	67		Model could not be fit to data				
	134	21.4 a	7.3	0.1 a	0.1	11.0 ab	2.1
	202	17.3 a	5.8	0.2 a	0.1	13.1 a	1.8

[a] Nonlinear regression equation: $N_{rel} = N_{12}[1-\exp(-k_0 t)] + b$, 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 at 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.

[b] The N_{12}, k_0, and *b* values were deemed significantly different if the 95% confidence intervals did not overlap.

[c] Model could not be fit to data and N_{12}, k_0, and b values were unable to be calculated.

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 concentration was measured (Tables 1 and 2).

Nitrogen Release Model. Nitrogen release from weed residue was modeled over a 12-wk period (Equation 2) and is shown in Figures 1 and 2. When the model significantly fit the data, N_{12}, k_0, and *b* values were calculated. The nonlinear model significantly fit all weed species and field N application rate combinations except common ragweed grown at 0 kg N ha^{-1} and giant foxtail grown at 0 and 67 kg N ha^{-1} (Table 3). There was no significant difference in calculated N_{12} and k_0 values among all weed species and field N application rate combinations. The C : N ratio of common lambsquarters at all N application rates, common ragweed grown at 67 to 202 kg N ha^{-1}, and giant foxtail grown at 134 and 202 kg N ha^{-1} was narrow ranging from 8.0 to 13.0 (Table 1). The narrow C : N ratio of weed residue may explain the lack of significant differences among N_{12} and k_0 values. When the data did not significantly fit the model, the C : N ratio of the weed residue ranged from 14.2 to 21.1. Acid detergent fiber of giant foxtail grown at 0 and 67 kg N ha^{-1} was also greater compared to giant foxtail grown at 134 and 202 kg N ha^{-1} which may also explain why the N release model may have not fit the data (Table 2). The value of *b* in the model is the y-intercept, which is the initial N release from the weed residue. Initial N release is attributed to inorganic N (NH_4–N and NO_3–N) concentration in the weed residue. Common lambsquarters grown with no N application had a significantly lower *b* value compared to giant foxtail grown at 202 kg N ha^{-1} (Table 3). More N was initially available from giant foxtail grown at 202 kg N ha^{-1} than common lambsquarters grown with no N application.

The N release model was fit to all weed height and field N application rate combinations except 20-cm weeds grown with no N application (Table 4). When 10-cm tall weeds were grown at all N application rates and 20-cm weeds grown at 67 to 202 kg N ha^{-1}, there were no differences in N_{12} and k_0 values. The C : N of 20-cm weeds grown with no N application was 19.3 while the C : N ratio of all other weed height and N application rate combinations was 8.5 to 14.0 (Table 1). The narrow range in C : N ratio may explain the lack of significant differences in N_{12} or k_0. The value of *b* was greater for 20-cm weeds grown at 202 kg N ha^{-1} compared to 10-cm weeds grown with no N application and 20-cm weeds grown at 67 kg N ha^{-1}. The extractable NO_3–N concentration of 20-cm weeds grown at 202 kg N ha^{-1} was 4,387 mg kg^{-1} while the extractable NO_3–N concentration was 336 and 1,143 for 10-cm weeds grown at 0 kg N ha^{-1} and 20-cm weeds

Table 4. Nitrogen release at 12 wk (N_{12}), first-order rate constant (k_0), and y-intercept (*b*) values and standard error (SE) describing N release from weed residue by height and field N application rate.[a]

Weed height	Field N application	N_{12}	N_{12} SE	k_0	k_0 SE	*b*	*b* SE
cm	kg N ha^{-1}						
10	0	25.3 a[b]	3.5	0.3 a	0.1	3.9 b	2.3
	67	23.6 a	3.3	0.3 a	0.1	8.4 ab	2.2
	134	20.6 a	2.7	0.5 a	0.1	10.9 ab	2.2
	202	20.6 a	2.3	0.4 a	0.1	11.7 ab	1.9
20	0		Model could not be fit to data[c]				
	67	24.4 a	28.0	0.1 a	0.1	5.7 b	1.9
	134	18.6 a	32.0	0.2 a	0.1	11.7ab	1.6
	202	26.4 a	18.9	0.1 a	0.1	14.9 a	1.7

[a] Nonlinear regression equation: $N_{rel} = N_{12}[1-\exp(-k_0 t)] + b$, 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 at 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.

[b] The N_{12}, k_0, and *b* values were deemed significantly different if the 95% confidence intervals did not overlap.

[c] Model could not be fit to data and N_{12}, k_0, and *b* values were unable to be calculated.

https://doi.org/10.1614/WS-D-12-00090.1 Published online by Cambridge University Press

grown at 67 kg N ha^{-1} (Table 1). Initial N release was greatest for 20-cm giant foxtail grown at 202 kg N ha^{-1}.

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

Nitrogen release after 12 wk 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 concentration ($r = -0.47$, $p < 0.05$). 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.

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 (De Neve and Hofman 1996; Parmelee et al. 1989; Trinsoutrot et al. 2000). The NO_3–N concentration of the weed residues was not correlated with k_0.

Management Implications. The current study increases the understanding of the quantity and rate of N mineralization of weed residue under controlled laboratory conditions. Nitrogen was released from all weed residues at 12 wk. Prior to 12 wk, N was immobilized by giant foxtail grown with no N application. Prior to 4 wk, N was immobilized by 20-cm weeds grown with no N application. Nitrogen release from weed residue was negatively correlated with C : N ratio. Weed residue with a C : N ratio of < 19 (weeds grown with N application and 10-cm weeds) released 15 to 27 mg N kg^{-1} soil within 2 wk and may contribute N within the growing season. Weed residue with a C : N ratio > 19 (giant foxtail and 20-cm weeds grown with no N) initially immobilized N and may not contribute N within the growing season.

Weeds, especially giant foxtail, 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 due to competition between weeds and crops for other factors such as water and light which may reduce yield (Dalley et al. 2006). Furthermore, laboratory N mineralization measurements are usually greater than *in situ* N mineralization measurements (Sanchez et al. 2001). The quantity and rate of N mineralization may differ in the field due to uncontrolled environmental conditions and soil management (Agehara and Warncke 2005; Deinum et al. 1968; Mikha et al. 2006; Sanchez et al. 2001; Van Soest et al. 1978).

Acknowledgments

We thank Pioneer Hi-Bred, a DuPont Company, for the Pioneer Graduate Fellowship in Plant Sciences for assisting in graduate student support. This material is based upon work supported by Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and the Regents of the University of Minnesota, under Cooperative Agreement No. 2010-38640-21425.

Literature Cited

Agehara, S. and D. D. Warncke. 2005. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. Soil Sci. Soc. Am. J. 69:1844–1855.

Blackshaw, R. E. and R. N. Brandt. 2008. Nitrogen fertilizer rate effects on weed competitiveness is species dependent. Weed Sci. 56:743–747.

Bremner, J. M. 1996. Nitrogen-total. Pages 1085–1121 *in* D. L. Sparks, ed. Methods of soil analysis. Part 3. Madison, WI: Soil Science Society of America, Inc.

Brown, R. H. 1978. A difference in N use efficiency in C_3 and C_4 plants and its implications in adaptation and evolution. Crop Sci. 18:93–98.

Brown, R. H. 1985. Growth of C_3 and C_4 grasses under low N levels. Crop Sci. 25:954–957.

Carey, J. B. and J. J. Kells. 1995. Timing of total postemergence herbicide applications to maximize weed control and corn (*Zea mays*) yield. Weed Technol. 9:356–361.

Cathcart, R. J. and C. J. Swanton. 2003. Nitrogen management will influence threshold values of green foxtail (*Setaria viridis*) in corn. Weed Sci. 51:975–986.

Chaves, B., S. De Neve, G. Hofman, P. Boeckx, and O. Van Cleemput. 2004. Nitrogen mineralization of vegetable root residues and green manures to their (bio)chemical composition. Euro. J. of Agron. 21:161–170.

Creamer, N. G. and K. R. Baldwin. 2000. An evaluation of summer cover crops for use in vegetable production systems in North Carolina. Hort. Sci. 35: 600–603.

Culpepper, A. S. and A. C. York. 1999. Weed management in glufosinate-resistant corn (*Zea mays*). Weed Technol. 13:324–333.

Dalley, C. D., M. L. Bernards, and J. J. Kells. 2006. Effect of weed removal and row spacing on soil moisture in corn (*Zea mays*). Weed Technol. 20:399–409.

Dalley, C. D., J. J. Kells, and K. A. Renner. 2004. Effect of glyphosate application timing and row spacing on corn (*Zea mays*) and soybean (*Glycine max*). Weed Technol. 18:165–176.

Deinum, B., A.J.H. van Es, and P. J. Van Soest. 1968. Climate, nitrogen and grass. II. The influence of light intensity, temperature and nitrogen on *in vivo* digestibility of grass and the prediction of these effects from some chemical procedures. Neth. J. Agr. Sci. 16:217.

De Neve, S. and G. Hofman. 1996. Modelling N mineralization of vegetable crop residues during laboratory incubations. Soil Biol. Biochem. 28:1451–1457.

DiTomaso, J. M. 1995. Approaches for improving crop competitiveness through the manipulation of fertilization strategies. Weed Sci. 43:491–497.

Food and Agriculture Organization of the United Nations. 2001. FAO Statistical Databases. http://www.fao.org/corp/statistics/en/. Accessed: October 3, 2012.

Fox, R. H., R.J.K. Myers, and I. Vallis. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin, and nitrogen contents. Plant Soil 129:251–259.

Gower, S. A., M. M. Loux, J. Cardina, S. K. Harrison, P. L. Sprankle, N. J. Probst, T. T. Bauman, W. Bugg, W. S. Curran, R. S. Currie, R. G. Harvey, W. G. Johnson, J. J. Kells, M.D.K. Owen, D. L. Regehr, C. H. Slack, M. Spaur, C. L. Sprague, M. VanGessel, and B. G. Young. 2003. Effect of postemergence glyphosate application timing on weed control and grain yield in glyphosate-resistant corn: results of a 2-yr multistate study. Weed Technol. 17:821–828.

Hans, S. R. and W. G. Johnson. 2002. Influence of shattercane [*Sorghum bicolor* (L.) Moench.] interference on corn (*Zea mays* L.) yield and nitrogen accumulation. Weed Technol. 16:787–791.

Haynes, R. J. 1986. The decomposition process: Mineralization, immobilization, humus formation and degradation. Pages 52–76 *in* Mineral Nitrogen in the Plant-Soil System. Ed. R. J. Haynes. Pp. 52–176, Orlando, FL: Academic.

Jensen, E. S. 1994. Mineralization-immobilization of nitrogen in soil amended with low C:N ratio plant residues with different particle size. Soil Biol. Biochem 26:519–521.

Joern, B. and J. Sawyer. 2006. Nitrogen and corn use. Pages 6–8 *in* Concepts and rationale for regional nitrogen rate guidelines for corn. Ames, IA: Iowa State University Extension.

https://doi.org/10.1614/WS-D-12-00090.1 Published online by Cambridge University Press

Johnson, W. G., P. R. Bradley, S. E. Hart, M. L. Buesinger, and R. E. Massey. 2000. Efficacy and economics of weed management in glyphosate-resistant corn (*Zea mays*). Weed Technol. 14:57–65.
Jung, H. G. and K. P. Vogel. 1986. Influence of lignin on digestibility of forage cell wall material. J. Anim. Sci. 62:1703–1712.
Justes, E., B. Mary, and B. Nicolardot. 2009. Quantifying and modeling C and N mineralization kinetics of catch crop residues in soil: parameterization of the residue decomposition module of STICS model for mature and non mature residues. Plant Soil 325:171–185.
Kirkland, K. J. and H. J. Beckie. 1998. Contribution of nitrogen fertilizer placement to weed management in spring wheat (*Triticum aestivum*). Weed Technol. 12:507–514.
Majumder, M., A. K. Skukla, and A. Arunachalam. 2008. Nutrient release and fungal succession during decomposition of weed residues in a shifting cultivation system. Comm. Biometry Crop Sci. 3:45–59.
Marten, G. C. and R. N. Andersen. 1975. Forage nutritive value and palatability of 12 common annual weeds. Crop Sci. 15:821–827.
Mikha, M. M., C. W. Rice, and J. G. Benjamin. 2006. Estimating soil mineralizable nitrogen under different management practices. Soil Soc. Am. J. 70:1522–1531.
Müller, M. M., V. Sundman, O. Soininvaara, and A. Meriläinen. 1988. Effect of chemical composition on release of nitrogen from agricultural plant materials decomposing in soil under field conditions. Biol. Fertil. Soils 6:78–83.
Nicolardot, B., S. Recous, and B. Mary. 2001. Simulation of C and N mineralization during crop residue decomposition: a simple dynamic model based on the C:N ratio of the residues. Plant Soil 228:83–103.
Parmelee, R. W., M. H. Beare, and J. M. Blair. 1989. Decomposition and nitrogen dynamics of surface weed residues in no-tillage agroecosystems under drought conditions: Influence of resource quality on the decomposer community. Soil. Biol. Biochem. 21:97–103.
Qasem, J. R. 1992. Root growth, development and nutrient uptake of tomato (*Lycopersicon esculentum*) and *Chenopodium album*. Weed Res. 33:35–42.
Ramakrishnan, P. S. 1992. Shifting agriculture and sustainable development. Pages 154–155 *in* Man and the biosphere series. Paris: Parthenon.
Rice, C. W. and J. L. Havlin. 1994. Integrating mineralizable nitrogen indices into fertilizer nitrogen recommendations. P 1–3. *In* J. L. Havlin, ed. Soil testing: prospects for improving nutrient recommendations. SSSA Spec. Publ. No. 40. SSSA Madison, WI.
Sage, R. F. and R. W. Pearcy. 1987. The nitrogen use efficiency of C_3 and C_4 plants. Plant Physiol. 84:954–958.
Saint-Fort, R., K. D. Frank, and J. S. Schepers. 1990. Role of nitrogen mineralization in fertilizer recommendations. Commun. Soil Sci. Plant Anal. 21:13–16.
Sanchez, J. E., T. C. Wilson, K. Kizilkaya, E. Parker, and R. R. Harwood. 2001. Enhancing the mineralizable nitrogen pool through substrate diversity in long term cropping systems. Soil Sci. Soc. Am. J. 65:1442–1447.
SAS Institute. 2003. The MIXED Procedure. Pages 2664–2844 *in* SAS/STAT User's Guide, Ver. 9.1. Cary, NC: SAS Institute.
Schultz, B. B. 1985. Levene's test for relative variation. Syst. Zool. 34:449–456.
Stanford, G. and S. J. Smith. 1972. Nitrogen mineralization potentials of soil. Soil Sci. Soc. Am. Proc. 36:465–472.
Stevenson, F. J. and M. A. Cole. 1986. Cycles of Soil Carbon, Nitrogen, Phosphorous, Sulfur, Micronutrients. New York: Wiley. 449 p.
Tilman, D., K. G. Cassman, P. A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. Nature 418:671–677.
Trinsoutrot, I., S. Recous, B. Bentz, M. Lineres, D. Cheneby, and B. Nicolardot. 2000. Biochemical quality of crop residues and carbon and nitrogen mineralization kinetics under nonlimiting nitrogen conditions. Soil Sci. Soc. Am. J. 64:918–926.
Undersander, D. and M. Wolf. 2006. Determination of Acid Detergent Fiber by Refluxing. National Forage Testing Association Reference Method. National Forage Testing Association. http://foragetesting.org/files/NFTAReference MethodADF-09-18-06.pdf. Accessed: November 8, 2012.
Van Kessel, J. S., J. B. Reeves, III, and J. J. Meisinger. 2000. Nitrogen and carbon mineralization of potential manure components. J. Environ. Qual. 29:1669–1677.
Van Soest, P. J., D. R. Mertens, and B. Deinum. 1978. Preharvest factors influencing quality of conserved forage. J. Animal Sci. 47:712–721.
Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.
Vazquez, R. I., B. R. Stinner, and D. A. McCartney. 2003. Corn and weed residue decomposition in northeast Ohio organic and conventional dairy farms. Agriculture, Ecosystems and Environment 95:559–565.
Vigil, M. F. and D. E. Kissel. 1991. Equations for estimating the amount of nitrogen mineralized from crop residues. Soil Sci. Soc. Am. J. 55:757–761.

Received June 19, 2012, and approved October 19, 2012.

https://doi.org/10.1614/WS-D-12-00090.1 Published online by Cambridge University Press