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Effect of Fertilizer Nitrogen on Weed Emergence and Growth

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The timing of nitrogen (N) fertilizer application may influence germination, emergence, and competitiveness of weeds. Research was conducted to determine the influence of total inorganic soil N (N_{it}) on the germination, emergence, and growth of five weed species. In a greenhouse experiment, seed of five weed species were exposed to four levels of N, and seed germination was measured. In the field, urea ammonium nitrate (UAN 28%) was applied at multiple rates at three spring timings, and N_{it}, weed emergence, and growth were measured for 21 to 35 d after application (DAA). Germination of the four dicotyledonous and single grass species was not stimulated by 450 ppmw of N compared with the untreated control. In the field, N_{it} of 112 or 168 kg N ha^{-1}, measured at 7 and 21 DAA, was always greater than N_{it} in the untreated control. The duration of the available N pulse in the upper 8 cm of soil was dependent on N application rate and timing. At 8 to 16 cm of soil depth, N_{it} was greater when 168 kg N ha^{-1} was applied compared with no N at 21 and 35 DAA in 2004. Emergence of common lambsquarters increased as N application rate increased for each application date in 2003, but not in 2004. Emergence of ladysthumb increased with N application rate for the April 15, 2003, date; emergence of giant foxtail increased with N application rate for the April 6, 2004, date. Weed biomass was always greater when 168 kg N ha^{-1} was applied compared with no N, and at four of six N application dates, when 112 kg N ha^{-1} was applied. This research shows that spring N fertilizer applications increase N_{it} and weed growth, but the influence of N on weed emergence is dependent on the weed species, seed source, and environmental conditions.

Nomenclature: Common lambsquarters, *Chenopodium album* L. CHEAL; ladysthumb, *Polygonum persicaria* L. POLPE.
Key words: Dormancy, integrated weed management, nitrogen fertilizer, nitrogen timing, seed germination, soil fertility, weed growth.

Crop production practices, such as tillage, weed control, and fertilization, influence weed communities in agricultural systems (Barberi et al. 1997; Derksen et al. 1995; DiTomaso 1995; Stevenson et al. 1997). Weeds are difficult to control in sugar beet (*Beta vulgaris* L.) and many other specialty crops because of low crop interference with weeds and limited herbicide options (Dexter 1994; Paolini et al. 1999). POST herbicides in sugar beet are effective only when applied to weeds less than 2 cm in height, and repeated applications are usually needed because weeds continue to emerge until the time of canopy closure in late June or early July (Dale and Renner 2005; Dexter 1994). Strategies that reduce weed emergence early in the season would be beneficial to growers that must manage weeds in noncompetitive crops, such as sugar beet.

Nitrogen (N) is the most important nutrient supplied to most nonlegume crops, including corn (*Zea mays* L.) and sugar beet (Draycott 1993; Hoeft et al. 2000). Corn and sugar beet are planted in April and early May in most production regions of the United States, and the availability of inorganic N in the soil from mineralization and nitrification is minimal at this time of year because of soil temperatures. The N recommendation for corn and sugar beet in Michigan is based on yield goals; for sugar beet, the N application rate is usually 90 to 112 kg ha^{-1}, with up to 78 kg ha^{-1} applied broadcast before, or at, planting, and for corn, 198 kg ha^{-1} is recommended if the yield goal is 9,415 kg ha^{-1} and there are no nitrogen credits (Warncke et al. 2004). Rapid N uptake in corn begins about 30 d after emergence and continues until the R1 stage of growth (Hoeft et al. 2000). In sugar beet, there is a rapid initial phase of N uptake when plants have four to five leaves, and N must be available from this time until the time of canopy closure to meet crop demand (Armstrong et al. 1986; Warncke et al. 2004). Broadcast application of N fertilizer in the spring to these early season crops may stimulate weed seed germination, emergence, and growth.

Weed seed germination is triggered by various factors, including soil temperature, soil moisture, light, and N (Booth et al. 2003). For example, the dormancy of several grass weed species was broken by ammonia, but the gas had no effect on the dormancy of dicotyledonous weed seed (Cairns and de Villiers 1986). Redroot pigweed (*Amaranthus retroflexus* L.) seed germination was stimulated by 10 to 100 ppmv of ammonium nitrate or urea (Sardi and Beres 1996); however, Schimpf and Palmblad (1980) found no evidence of nitrate stimulating redroot pigweed or yellow foxtail [*Setaria glauca* (L.) Beauv.] germination. The dichotomy in these research results may be partially explained by maternal environmental effects on the nitrate concentration in the seed. Germination of common lambsquarters seed from mother plants that received 280 kg ha^{-1} of ammonium nitrate was greater than germination of seed from a mother plant where no N was applied, suggesting that N deficiency increased dormancy in seeds (Baskin and Baskin 1998; Fawcett and Slife 1978).

The chilling or light requirement for seed germination in some species can be replaced with N, particularly nitrate (Cohn et al. 1983; Egley and Duke 1985; Sexsmith and Pittman 1963; Steinbauer and Grigsby 1957). The presence of nitrate during dark incubation and the germination period increased sensitivity to very low red fluence in redroot pigweed seed (Gallagher and Cardina 1998). However, if seed requires both light and nitrate for germination, the use of nitrate fertilizer alone may not always increase weed seed germination (Fawcett and Slife 1978; Hurtt and Taylorson 1986; Schimpf and Palmblad 1980).

Weed emergence and growth in the field can be stimulated by N application rate and timing. In sugar beet, weed emergence from sown seed increased as the N application rate at planting increased from 56 to 224 kg N ha^{-1} (Dotzenko et al. 1969). The competitiveness of wild mustard (*Sinapis arvensis* L.), a winter annual, in sugar beet was favored by early, compared with late, N fertilization (Paolini et al. 1999).

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Ammonium nitrate stimulated emergence of sown redroot pigweed and velvetleaf (*Abutilon theophrasti* Medic.) (Hurtt and Taylorson 1986; Teyker et al. 1991), whereas emergence of ladysthumb and common lambsquarters increased with the addition of 200 kg ha^{-1} of ammonium nitrate applied in early April but not in late May (Freyman et al. 1989). Furthermore, mid-May applications of ammonium nitrate at 112 to 448 kg ha^{-1} had no effect on common lambsquarters, redroot pigweed, velvetleaf, and giant foxtail (*Setaria faberi* Herrm.) emergence from the indigenous seed bank in Illinois research (Fawcett and Slife 1978). Late-spring N applications may not stimulate germination because seed may have responded to other germination cues, or alternatively, rapid mineralization and nitrification under warm, moist conditions may increase the availability of N and saturate any mechanism affecting seed germination (Freyman et al. 1989).

It is important to develop fertilization strategies for crop production that enhance the competitive ability of the crop, minimize weed competition, and reduce the risk of nonpoint source pollution from nitrogen (Cathcart and Swanton 2003; DiTomaso 1995). The timing of N fertilizer application in early planted crops, such as sugar beet and corn, may especially influence the germination, emergence, and competitiveness of weeds that might otherwise remain dormant early in the growing season. If N is broadcast in April at the time of planting, weed germination and emergence may be stimulated. In contrast, N application at the time of planting in May may not influence seed germination and weed emergence because of greater N availability because of mineralization at this time of year or because seed germination has been stimulated by other environmental cues. Regardless of the timing of N applications, weed growth may increase as the N application rate increases, resulting in the need for more frequent POST herbicide applications or cultivation. The first objective of our research was to determine whether total inorganic soil N (N_{it}) increased when N was applied at three dates in the spring compared with the nonfertilized control. In previous research, fertilizer N was applied to determine the influence of N on weed emergence and growth, but N_{it} was not reported (Fawcett and Slife, 1978; Freyman et al., 1989; Sexsmith and Pittman, 1963). Our second objective was to determine the influence of N on the germination, emergence, and growth of weeds from the indigenous seed bank and from weed seed sown following N application at three dates in the spring.

Materials and Methods

N Effects on Weed Germination under Controlled Conditions. A greenhouse experiment was conducted to determine the effect of N on seed germination. Soil was collected from the field in May 2004, passed through a 2-mm sieve, and stored in a 4 C cooler. The soil was a Capac sandy-clay loam (fine-loamy, mixed mesic Aeric Ochraqualf) with a pH of 7.3 and 2.1% organic matter. Seed of common lambsquarters, giant foxtail, ladysthumb, redroot pigweed, and velvetleaf was collected in the fall of 2003 and stored in a 4 C cooler throughout the winter months. In preliminary tests, seed germination was low, so seed was placed in nylon sacks and buried outside at an 8 cm depth from May until August of 2004 for vernalization. Seed was then excavated and stored at 4 C for 1 to 3 wk before use. Thirty seeds of each weed species were placed in a 150-mm-diam by 15-mm-deep petri dish, and 150 g of soil was placed in each dish with the seed. Urea ammonium nitrate (UAN 28%) was applied using a single-tip track sprayer with a TeeJet 8001E nozzle[1] to provide a concentration of 450, 900, and 1,350 ppmv of N in the soil, equivalent to 87, 173, and 260 kg ha^{-1} of N. UAN 28%N was applied to empty petri dishes that were then weighed to ensure application accuracy. Immediately after UAN 28% application, water was added to each petri dish, such that each petri dish received the same total volume of liquid. Petri dishes were then sealed with Parafilm, covered with aluminum foil to reduce bacterial or fungal growth, and placed in the greenhouse under day/night temperatures of 25/20 C. After 7 d, weed seed germination was determined by removing germinated seed (radicle $>$ 2 mm) from the soil. Soil from each treatment was analyzed for total inorganic soil nitrogen (N_{it}); NO_3^--N (Brown 1998), and NH_4^+-N Soil from each treatment was analyzed for total inorganic soil (Keeney and Nelson 1982). The experiment was a randomized complete-block design with three replications and was repeated three times, and data were combined for analysis.

Effect of N Application Date on Weed Emergence and Growth. Research was conducted at the Michigan State University Crop and Soil Sciences Agronomy Farm near East Lansing, MI, in 2003 and 2004. In 2003, the field was a Capac sandy loam soil (fine-loamy, mixed mesic Aeric Ochraqualf) with a pH of 6 and 2.5% organic matter. In 2004, the field was a Capac sandy-clay loam with a pH of 7.3 and 2.1% organic matter. N was applied on April 15, April 29, and May 21, 2003; N application dates in 2004 were April 6, April 20, and May 20. Early to mid-April is the ideal planting date for many early season crops, but wet conditions or replanting of fields because of early season stand loss may delay planting and N application until late April or May. Growing degree days (GDDs), base 1.1 C, of 195, 265, and 575 accumulated before the first, second, and third N application dates, respectively, in 2003; 170, 295, and 685 GDDs accumulated before the first, second, and third N application dates, respectively, in 2004. Rainfall delayed the timing of our third N application in 2004 (Figure 1). Our N application dates were based on GDDs instead of calendar days because of the influence of soil temperature on N mineralization and weed emergence. In previous research, a low GDD base temperature of 1.1 C was important for accurately timing POST herbicide treatments for common lambsquarters and other early emerging weeds in sugar beet (Dale and Renner 2005).

The experimental design was a split plot with four replications. The main plot was the time of N application, and the subplot was the N application rate. Subplot size each year was 3 m by 9.1 m. The previous crop each year was soybean [*Glycine max* (L.) Merr.], and weeds were controlled with glyphosate. The field sites were chisel plowed in the fall of each year and then tilled on April 15, 2003, and on April 6, 2004, to a 10 cm depth with a field cultivator before the first N application. Plots receiving N applications at the later April and May application timings were tilled again just before the N application to control emerged weeds. Nitrogen in the form of liquid urea ammonium nitrate (UAN 28%) was broadcast at rates of 0 (control), 56, 112, and 168 kg N ha^{-1} and

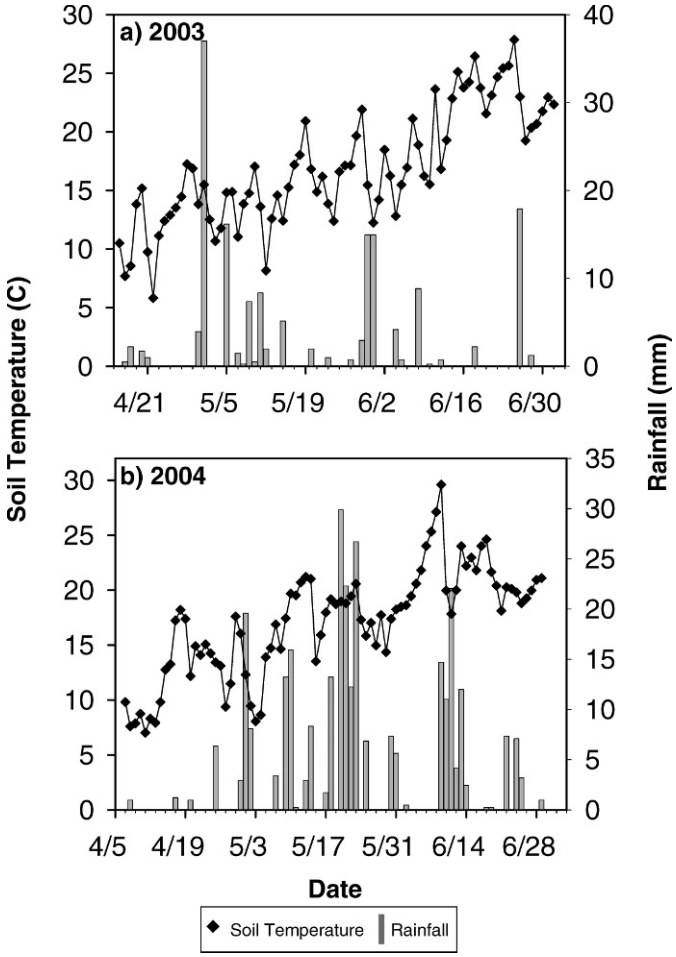

Figure 1. Mean daily soil temperature at a 2.5 cm depth and rainfall during the time of study at the Michigan State University Crop and Soil Sciences Agronomy Farm near East Lansing, MI, in (a) 2003 and (b) 2004.

immediately incorporated to a 5 cm depth with a field cultivator that had four rows of 6.4-cm sweeps and rolling baskets. Urea ammonium nitrate was chosen because previous researchers have shown weeds to be more responsive to UAN 28% than other fertilizer sources (Freyman et al. 1989; Pyšek and Lepš 1991). Soil temperature and precipitation were monitored daily (Figure 1). Soil temperature data was collected using HOBO temperature probes[2] that were buried 2.5 cm deep in each plot. Rainfall was collected with rain gauges placed in the field.

Total Soil Inorganic Nitrogen (N_{it}). Fifteen to 20 soil cores, measuring 2.5 cm in diameter, were taken randomly from each experimental unit to measure N_{it}. Soil samples were collected to a depth of 8 cm before N application in the spring, 7, 14, and 21 d after application (DAA) in 2003, and 7, 21, and 35 DAA in 2004. An 8 cm depth was chosen because we were interested in determining N availability in the weed seed germination and early rooting depth zone. Soil samples were also collected from the 8 to 16 cm depth in 2004 to determine whether N_{it} at this soil depth increased following N application; a sign of potential N leaching (Cathcart and Swanton 2003). Individual cores were combined as one sample and kept in a cooler at 4 C until analysis. Samples were then air-dried, ground, sieved through a 2-mm sieve, mixed thoroughly to ensure homogeneity, and analyzed to determine N_{it}, $NO_3^- - N$ (Brown 1998), and $NH_4^+ - N$ (Keeney and Nelson 1982).

Weed Emergence and Growth. Four hundred seeds each of redroot pigweed, common lambsquarters, ladysthumb, and giant foxtail, and 300 seeds of velvetleaf were sown at a 0.5 cm depth in individual circular areas 20 cm in diameter within each plot the day after N application. Sowing rates in 2004 were increased to 600 seeds of redroot pigweed, ladysthumb, and giant foxtail based on germination tests and the desired emergence of 100 seedlings per circular area. Seed sown in 2003 was collected from soybean and fallow fields adjacent to the field site in 2001; seed sown in 2004 was collected from soybean and fallow fields adjacent to the field site in 2003. Seed was stored in a cooler at 4 C and 40% relative humidity until sown in the field the following spring. Weed emergence was measured every 7 d until 42 d after sowing. Weed emergence was also measured in two 0.25-m^2 quadrats in the nonseeded area of each plot to determine the influence of N on the emergence of weeds from the indigenous seed bank. At 42 d after sowing, weeds in the sown areas were harvested and dried to constant weight to determine biomass.

Statistical Analysis. For the seed germination experiment, germination and nitrogen recovery data were analyzed using PROC GLM in SAS[3] to determine significant differences between N treatments using Fisher's Protected LSD at the 95% confidence level. Correlations between applied nitrogen and nitrogen recovery were analyzed using Pearson's Correlation Coefficient with PROC CORR in SAS. In the seed germination and field studies, SigmaPlot[4] was used to determine whether the N applied in the experiments was correlated to the total inorganic N ($N0_3^- - N + NH_4^+ - N$) from soil analysis represented as N_{it}. Determination of significant relationships between weed emergence or growth and the N treatment, time of N application, or the interaction between N and time of N application for the field experiment were made by using PROC MIXED in SAS. Regression analyses were performed by fitting linear models with Sigma Plot.

Results and Discussion

N Effects on Weed Germination under Controlled Conditions. *Soil Analysis.* Application rates of N fertilizer to petri dishes were highly correlated ($P < 0.0001$) to N_{it} concentrations measured 7 DAA ($r = 0.922$). Only 20% of the applied N was recovered as N_{it} 7 DAA (Table 1). The

Table 1. $NO_3^- - N$, $NH_4^+ - N$, and total inorganic soil N (N_{it})[a] recovered from soil in petri dishes 7 d after application of urea ammonium nitrate (28% UAN) at 0, 450, 900, and 1,350 mg N kg^{-1}.

N rate applied	$NO_3^- - N$	$NH_4^+ - N$	N_{it}[a]
	mg N kg^{-1}		
0	18	3	21
450	60	39	99
900	86	103	189
1,350	109	183	292
LSD (0.05)	11	28	38

[a] $N_{it} = NO_3^- - N + NH_4^+ - N$

Table 2. Germination of velvetleaf (ABUTH), redroot pigweed (AMARE), common lambsquarters (CHEAL), ladysthumb (POLPE), and giant foxtail (SETFA) 7 d after application of urea ammonium nitrate (UAN 28%) at 0, 450, 900, and 1,350 mg N kg^{-1} in petri dishes.

N rate	Germination				
	ABUTH	AMARE	CHEAL	POLPE	SETFA
mg N kg^{-1}	%				
0	45	90	48	14	66
450	37	68	53	4	56
900	23	29	16	3	30
1,350	11	8	10	2	14
LSD (0.05)	9	11	9	4	8

difference between the amount of N applied and the amount measured as nitrate plus ammonium may be due to volatility of the urea portion of the UAN 28%–N solution, and some of the urea may not have been converted to ammonium or nitrate in 7 d under the imposed conditions. Nitrogen could not leach from the system, and therefore, significant volatilization or denitrification may have reduced the inorganic N in the soil.

Seed Germination. Nitrogen did not stimulate germination of the four dicotyledonous or single grass species in vitro (Table 2). Germination of redroot pigweed, ladysthumb, and giant foxtail decreased with applications of 450 ppmw N compared with the untreated control, and germination of all species decreased at 900 ppmw N (Table 2). In research by Sardi and Beres (1996), ammonium nitrate fertilizer concentrations of 100 ppmv of N stimulated, and 1,000 ppmv of N inhibited weed seed germination. N at 100 ppmw is equivalent to 19 kg N ha^{-1} under field conditions. Higher concentrations of fertilizer in the soil solution may reduce weed seed germination because of osmotic stress or salt toxicity, similar to the injury to corn seedlings when fertilizer is placed directly on, or too close to, the seed (Hoeft et al. 2000).

Field Study. *Soil Analysis*. Correlation coefficients for the relationship between N_{it} and N application rate were highly significant ($P < 0.01$) and ranged from 0.626 to 0.938 across years, treatments, and sampling depths (data not shown). N_{it} did not consistently follow a linear or quadratic trend across application dates and years (data not presented). Data are therefore presented for each year, application date, and sample time, and LSD values show differences in N_{it} among fertilizer N treatments (Figure 2).

In 2003 and 2004, field plots that were not fertilized had 20 kg ha^{-1} or less of N_{it} in the 0 to 8 cm depth throughout the duration of the experiment (Figure 2). Total inorganic N at 7 and 21 DAA in the 112 or 168 kg N ha^{-1} treatment was always greater than N_{it} in the untreated control in 2003 and 2004 (Figure 2). By 35 DAA in 2004, N_{it} in the 112 kg N ha^{-1} treatment was similar to N_{it} in the untreated control, whereas N_{it} was greater in plots where 168 kg N ha^{-1} was applied on April 6 or May 20 compared with the untreated control (Figure 2).

Only a portion of the N applied was detected in the 0 to 8 cm soil analysis as N_{it} at 7 DAA (Figure 2). For example, less than 100 kg ha^{-1} of N_{it} was recovered from the 0 to 8 cm depth when 168 kg N ha^{-1} was applied April 29 and May 21 in 2003, and at each N application date in 2004 (Figure 2). Available N in the nitrate form could have leached to the 8 to 16 cm soil depth in our research because of rainfall in mid-May and mid-June of 2004 (Figure 1). In the 8- to 16-cm zone, N_{it} was greater in plots treated with 168 kg N ha^{-1} compared with the untreated control, 7 d after each of the N application dates in 2004 (Figure 3). By 35 DAA, N_{it} recovered from the 112 and 168 kg N ha^{-1} plots was greater than N_{it} in the untreated control for each of the application dates (Figure 3). The soil type and percentage of organic matter in our research was similar to that reported by Cathcart and Swanton (2003); unaccounted N in their research was suggested to be due to N leaching. At the 8 to 16 cm soil depth, nitrogen can be taken up by weed and crop roots and stimulate plant growth. If N stimulated weed seed germination at an 8 cm or greater soil depth, it would most likely result in fatal germination (Benvenuti et al. 2001).

The low N_{it} levels at the 0 to 8 cm soil depth relative to the N application rates may also be a reflection of volatilization, mineralization, immobilization, and denitrification (Hoeft et al. 2000). The loss of N to volatilization was probably minimal in this experiment because UAN 28% was incorporated with tillage immediately following application. The field soil in early April was cooler and drier than at the later application dates (Figure 1), which would lower the risk of N volatilization at this time. Microbial degradation of soybean residues may have resulted in immobilization of the applied N in later April and May, once soil temperatures attained 13 C. Warmer temperatures and precipitation were also suitable for denitrification following N application on April 29, 2003, and April 20, 2004 (Carter et al. 1974; Hoeft et al. 2000, Figure 1). The risk of N loss to denitrification was minimal at the early N application dates in 2003 and 2004 because of cool and dry soil conditions. The average daily soil temperature was below 13 C for 5 d in 2003 and 10 d in 2004, and precipitation was less than 1 cm for the 7 d following N application in both years (Figure 1).

Weed Emergence and Growth. Common lambsquarters and ladysthumb are typically early emerging weeds, and common lambsquarters has a longer period of emergence than other small-seeded broadleaf weeds (Myers et al. 2004). In 2003, common lambsquarters emergence in the sown quadrats was greater following the late May compared with the earlier N application dates (Figure 4). Most of the common lambsquarters emerged within the first 3 wk following N application and sowing of the seed (data not shown). In the nonseeded area, emergence of common lambsquarters from

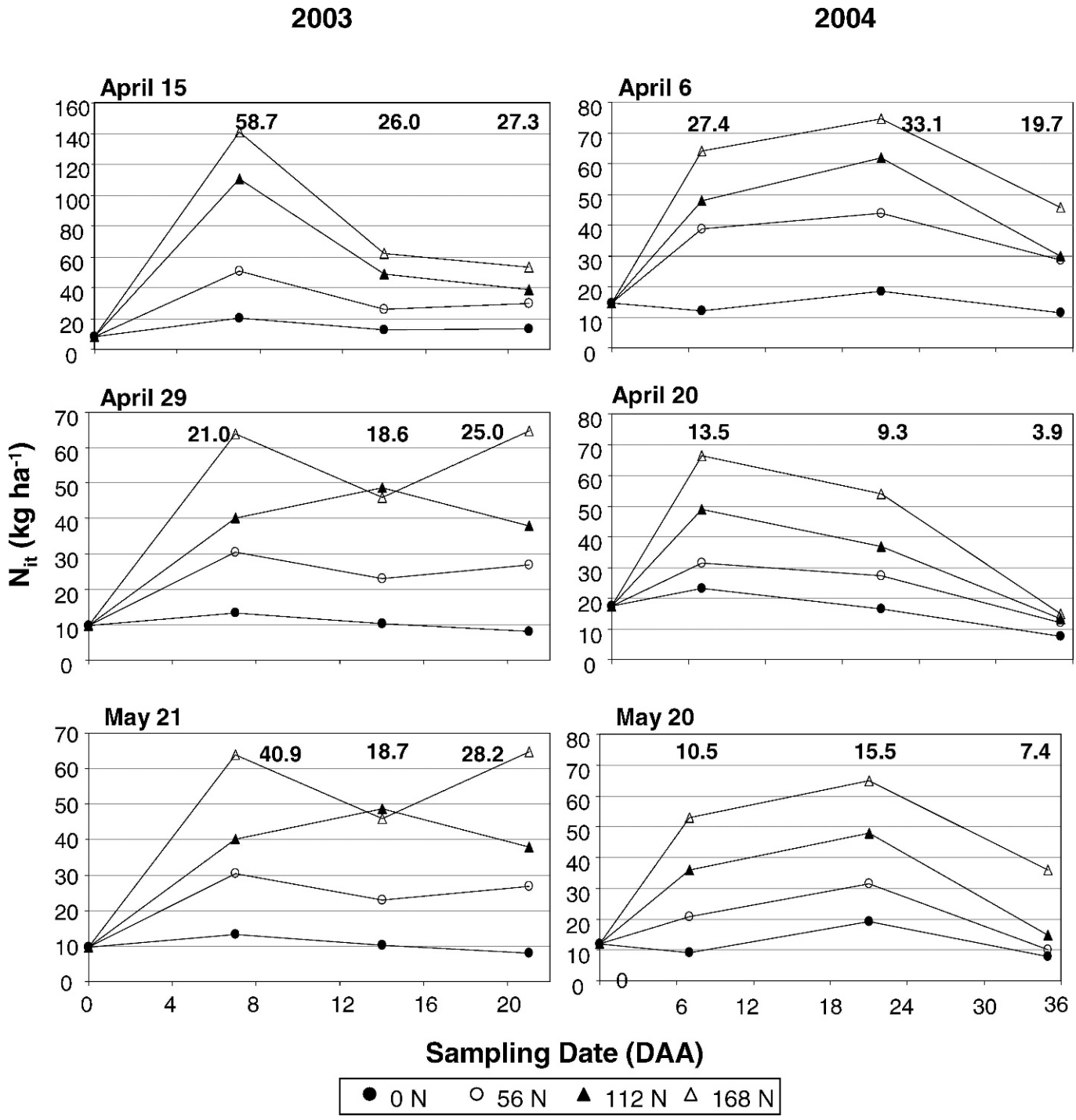

Figure 2. Total inorganic nitrogen (N_{it}) ($NO_3^- + NH_4^+ - N$) at the 0 to 8 cm depth when sampled 7, 14, and 21 d after nitrogen application (DAA) in 2003, and 7, 21, and 35 DAA in 2004. $LSD_{(0.05)}$ values are displayed at the top of the graph to show differences in N_{it} at each sampling date.

the indigenous seed bank was greater for the early April, compared with the later N application dates, in 2003; average emergence for the early, mid, and late N application dates was 130, 50, and 60 plants m^{-2}, respectively. In 2004, fewer than 10 plants m^{-2} emerged in either the sown or nonseeded plot area (data not shown). Soil temperature in April and May of 2003 and 2004 were similar (Figure 1), suggesting that other factors, such as the relative dormancy of the seed source, may have reduced emergence in 2004 (Baskin and Baskin 1998).

Common lambsquarters emergence increased as the N application rate increased for all N application dates in 2003 ($P < 0.05$ for all dates; Figure 4). For the early, mid, and late N application dates, respectively, *r* values were 0.52, 0.54, and 0.61, indicating a weak positive linear relationship between these two variables. N_{it} at the 0 to 8 cm depth increased with N application rate at 7 and 21 DAA in 2003 (Figure 2), further supporting the association between fertilizer N and enhanced germination of sown common lambsquarters in 2003. In contrast, common lambsquarters emergence from

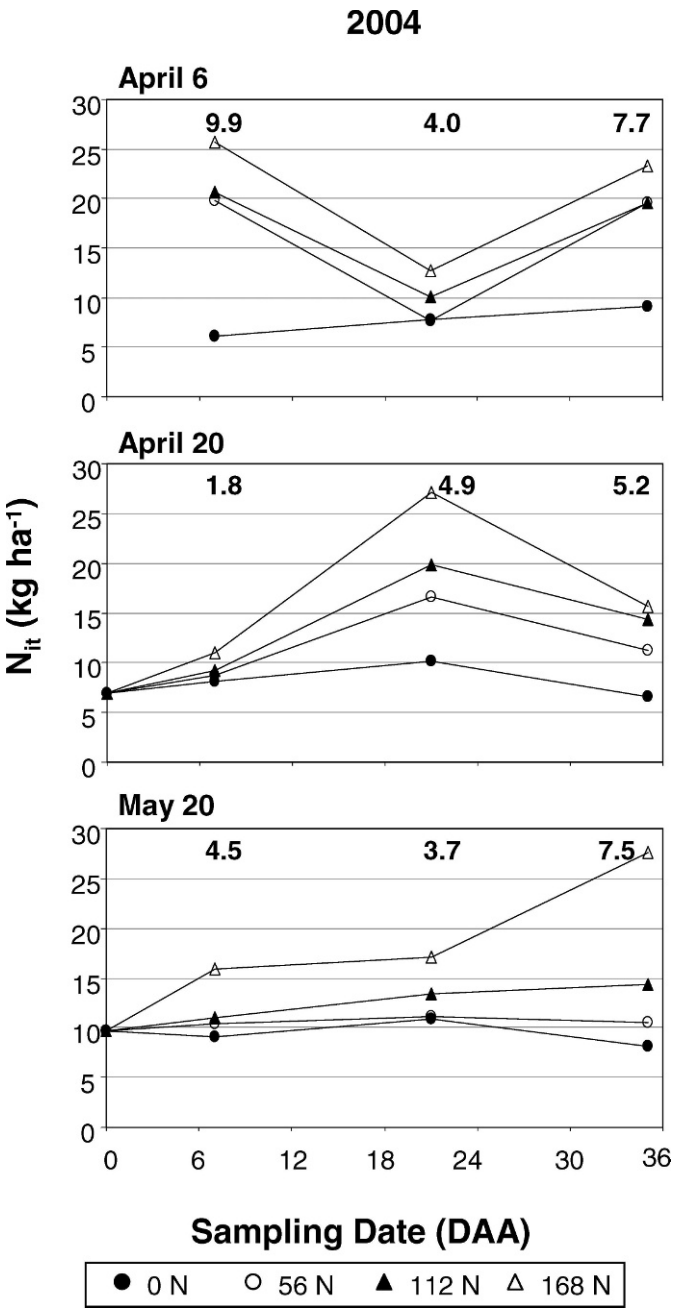

Figure 3. Total inorganic nitrogen (N_{it}) ($NO_3^- + NH_4^+ - N$) at the 8- to 16-cm depth when sampled 7, 21, and 35 d after application in 2004. $LSD_{(0.05)}$ values are displayed at the top of the graph to show differences in N_{it} at each sampling date.

the indigenous seed bank in the quadrats did not increase as the N application rate increased (data not shown). The spatial variability in the natural seed bank may increase the difficulty in assessing weed response to N_{it}. Coefficients of variation in weed seed bank emergence across the Corn Belt ranged from 65 to 111% for the five weed species in our research (Forcella et al. 1997). Increasing sampling frequency or a more uniform weed seed bank would improve the ability to detect differences in weed emergence of indigenous seed banks following application of N, but it may be that the indigenous seed bank is too heterogeneous for reliable detection of N stimulation of seedling emergence (Benech-Arnold et al. 2000; Hurtt and Taylorson 1986).

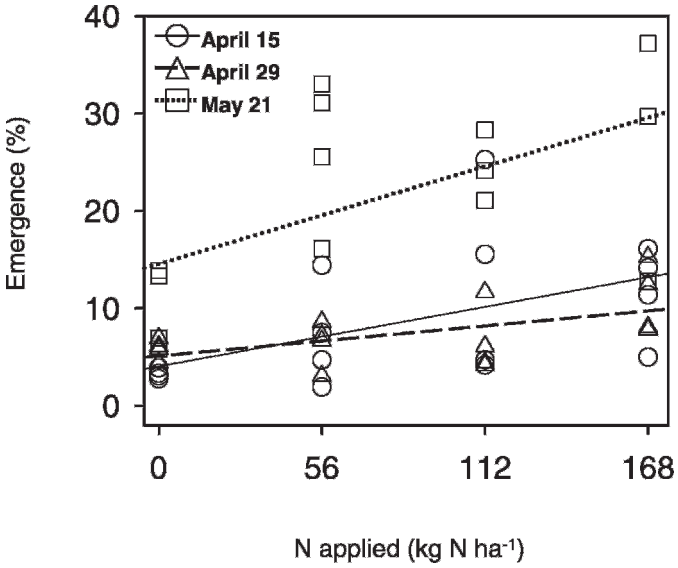

Figure 4. Effect of nitrogen (N) application rate and date on common lambsquarters (CHEAL) cumulative emergence in 2003. Symbols represent observed means of four replications. The r and P values for the April 15, April 29, and May 21 N application and sowing dates are $r = 0.52$, $P = 0.0375$; $r = 0.54$, $P = 0.0298$; $r = 0.61$, $P = 0.0129$, respectively.

Ladysthumb seedling emergence following the April N application dates was less than 10% in 2003 and 2004 (Figure 5). Lack of ladysthumb emergence may be due to storage conditions enforcing dormancy, although emergence of ladysthumb is thought to be triggered by low winter temperatures similar to our storage conditions (Benech-Arnold et al. 2000). Fertilizer N was associated with increased emergence of ladysthumb at the early April N application date in one of two years ($P = 0.0018$ in 2003, $P = 0.0592$ in 2004; Figure 5). In previous research by Freyman et al. (1989), applying N fertilizer increased emergence of ladysthumb.

Giant foxtail and velvetleaf emerge somewhat later in the growing season than common lambsquarters or ladysthumb, followed by redroot pigweed (Myers et al. 2004). Giant foxtail emergence from the sown quadrats was greater in the late May N application (80% emergence) compared with the earlier N application dates (60% emergence) in 2003; however, in 2004, emergence of giant foxtail from the sown quadrats was greater at the early compared with later N application dates (data not shown). Giant foxtail emergence from seed sown in April increased as the N application rate increased in 1 of 2 yr ($P = 0.0897$ in 2003, $P = 0.0018$ in 2004; Figure 5). In contrast, emergence of giant foxtail from the indigenous seed bank was not influenced by N application in either year; an average of 15 and 95 plants m^{-2} emerged in 2003 and 2004, respectively. Fawcett and Slife (1978) also found no effect of N on giant foxtail emergence from the indigenous seed bank. N_{it} may not always influence the germination of giant foxtail seeds; however, as giant foxtail seeds pass from dormancy to conditional dormancy to nondormancy in early spring (Benech-Arnold et al. 2000), N_{it} may trigger germination of some giant foxtail seed.

Velvetleaf and redroot pigweed emergence were unrelated to N application rate in both years (data not shown). In previous research, nitrogen stimulated pigweed (Teyker et al.

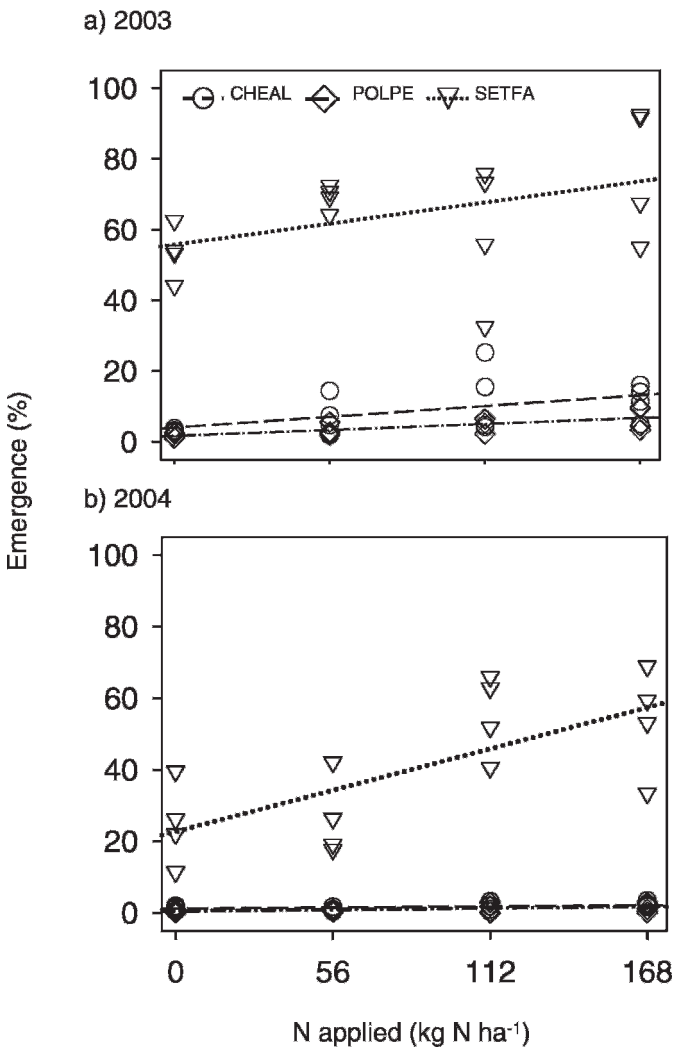

Figure 5. Common lambsquarters (CHEAL), giant foxtail (SETFA), and ladysthumb (POLPE) cumulative emergence following N application on (a) April 15, 2003, and (b) April 6, 2004. Symbols represent observed means of four replications. The r and p values for CHEAL, SETFA, and POLPE in 2003 are $r = 0.52$, $P = 0.0375$; $r = 0.44$, $P = 0.0897$; $r = 0.72$, $P = 0.0018$, respectively. The r and P values for CHEAL, SETFA, and POLPE in 2004 are $r = 0.43$, $P = 0.0928$; $r = 0.72$, $P = 0.0018$; $r = 0.48$, $P = 0.0592$, respectively.

1991) and velvetleaf emergence when applied in early May (Hurtt and Taylorson 1986) but had no effect on emergence of velvetleaf or redroot pigweed from the indigenous seed bank when 0 to 448 kg N ha^{-1} was applied in late May (Fawcett and Slife 1978). As with giant foxtail, it is possible that other seed dormancy factors or germination cues may have been met such that N had no effect on velvetleaf and redroot pigweed emergence.

Weed biomass at all N application dates was greater when 168 kg N ha^{-1} was applied compared with no N in 2003 and 2004 (Table 3). Weed biomass in the sown quadrats was also greater when 56 kg N ha^{-1} was applied on April 29, 2003, and on April 20, 2004, compared with no N. There was no difference in N_{it} in the 0 to 8 cm depth between the 0 and 56 kg N ha^{-1} N treatments at any sample date in either year. However, N_{it} in the 8 to 16 cm depth was greater where 56 kg N ha^{-1} was applied, compared with the untreated control, when measured 21 DAA in 2004 (Figure 3), indicating that weeds were able to make use of fertilizer N that had leached rapidly from the upper 8 cm of the soil profile. Weed biomass in the late May N application dates was greater than weed biomass in the earlier N application treatments, regardless of N application rate. GDDs of 462, 514, and 672 accumulated in the 6 wk following the early, mid, and late N application dates, respectively, in 2003, and 472, 534, and 702 GDDs accumulated in the 6 wk following the early, mid, and late N application dates, respectively, in 2004. GDDs usually accumulate more rapidly in late May and June compared with April and early May, which makes it more difficult to manage weeds that grow rapidly when fields are planted in later spring (Dale and Renner 2005).

Applying UAN 28%–N at 112 or 168 kg ha^{-1} increased N_{it} compared with N_{it} in the untreated control for 21 d or more after application. Emergence of sown common lambsquarters, ladysthumb, giant foxtail, and velvetleaf increased as N application rate increased in some instances, particularly at the early N application date. Interestingly, weed emergence from the indigenous seed bank did not increase with N fertilizer application. A wider variety of dormancy states exists in the indigenous seed bank compared with our sown seed sources, and seed exposure to light from tillage before and immediately following N application may have elicited a response in the small-seeded broadleaf weeds that overrode the effect of applied N on germination (Baskin and Baskin 1998; Benech-Arnold 2000; Gallagher and Cardina 1998; Hartmann et al. 2003).

Weed community composition and competition with crops can be affected by application timing and placement of N fertilizer (Anderson et al. 1998; Andersson et al. 1998; Barberi et al. 1997). More research is needed to understand how seed age and maternal development influence dormancy, and how temperature, N, light, and moisture release seed from dormancy and subsequent germination. Delaying N applications, applying slow-release N fertilizers, or placing N below the weed seed germination zone could be potential strategies for reducing early season weed establishment in integrated cropping systems.

Table 3. Nitrogen (N) application rate and sowing date effects on weed biomass in 2003 and 2004. Aboveground biomass was harvested 42 d after sowing.

	2003				2004			
N rate	April 15	April 29	May 21		April 6	April 20	May 20	
kg N ha^{-1}	g m^{-2}			LSD (0.05)	g m^{-2}			LSD (0.05)
0	25	85	988	194	34	31	125	44
56	65	167	1,445	397	42	54	208	56
112	86	123	1,471	390	51	40	240	72
168	102	196	1,572	133	67	52	304	29
LSD (0.05)	43	46	500		17	21	84	

Sources of Materials

[1] Teejet even fan tips. Spraying Systems Co., North Ave. and Schmale Rd., Wheaton, IL 60188.

[2] HOBO data loggers. Onset Computer, 470 MacArthur Blvd., Bourne, MA 02532.

[3] SAS ver. 8.0, SAS Institute, SAS Campus Dr., Cary, NC 27513.

[4] SigmaPlot 2001 ver.7.101, SPSS, 233 S. Wacker Dr., Chicago, IL 60606.

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