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Differences in yields, residue composition and N mineralization dynamics of Bt and non-Bt maize

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Abstract

Cultivation of genetically modified crops may have several direct and indirect effects on soil ecosystem processes, such as soil nitrogen (N) transformations. Field studies were initiated in Northeast Missouri in 2002 and 2003 to determine grain and biomass yields and the effects of application of crop residues from five Bt maize hybrids and their respective non-Bt isolines on soil inorganic N under tilled and no-till conditions in a maize-soybean rotation. A separate aerobic incubation study examined soil N mineralization from residue components (leaves, stems, roots) of one Bt maize hybrid and its non-Bt isoline in soils of varying soil textural class. Three Bt maize hybrids produced 13–23% greater grain yields than the non-Bt isolines. Generally no differences in leaf and stem tissues composition and biomass was observed between Bt and non-Bt maize varieties. Additionally, no differences were observed in cumulative N mineralization from Bt and non-Bt maize residues, except for non-Bt maize roots that mineralized 2.7 times more N than Bt maize roots in silt loam soil. Incorporation of Bt residues in the field did not significantly affect soil inorganic N under tilled or no-till conditions. Overall Bt and non-Bt maize residues did not differ in their effect on N dynamics in laboratory and field studies.

Introduction

Increased use of Bt maize (*Zea mays* L.) with resistance to European maize borer (EMB), *Ostrinia nubilalis* (Hübner), has generated public concerns as to the possible effects of transgenic crops on soil ecosystem processes such as nutrient cycling. Bt maize may influence nutrient cycling by increasing the amount of residues returned to the soil, altering plant residue composition, and releasing Bt endotoxin that may affect soil decomposer organisms (Motavalli et al. 2004). Folmer et al. (2002) reported that two Bt varieties produced higher grain and silage yields than their respective non-Bt isolines. Similarly, Russell et al. (2001) reported greater amounts of maize residue from Bt maize in one year but observed no differences in residue amounts between Bt and non-Bt maize the following year. Both studies concluded that Bt maize silage or residues had feed values similar to non-Bt maize.

Comparisons of Bt and non-Bt maize residue composition have generated variable results. Folmer et al. (2002) observed no differences in chemical composition between Bt and non-Bt maize tissues, and Jung and Sheaffer (2004) suggested that the cry1 Ab transgene in 12 Bt maize hybrids did not alter lignin concentration in maize stover. In contrast, Saxena and Stotzky (2001) reported higher lignin content in the stem tissue of 11 Bt maize hybrids compared to their corresponding non-Bt isolines. Similarly, Masoero et al. (1999) observed that two Bt maize hybrids had higher lignin and lower soluble N contents compared with non-Bt maize. Elevated concentrations of structural compounds, such as lignin in Bt maize residues, coupled with low N content may reduce soil C and N mineralization rates, which would enhance soil C sequestration (Paustian et al. 1997) and reduce N availability (Prescott et al. 2000). Some authors have reported lower CO_2 evolution from soil amended with Bt maize residues than soil amended with unmodified, isogenic maize residues (Stotzky 2000), while others report no difference in CO_2 evolution between Bt and non-Bt maize residue-amended soils (Hopkins and Gregorich 2003). Information on the effect of Bt maize residues on N mineralization is limited. Devare et al. (2004) reported no differences in anaerobic N mineralization potential for soils collected from fields planted to either Bt or non-Bt maize.

Soil properties can influence N mineralization directly or indirectly. For example, clay-sized particles alter N mineralization by binding with organic matter to form soil aggregates that physically protect soil N from heterotrophic soil organisms (Christensen, 1996). Indirectly, soil texture may alter factors that influence conditions for decomposer organisms involved in N mineralization such as soil water availability, pore size distribution, nutrient availability and surface area.

Management practices, such as tillage, cause a substantial decrease in soil organic matter content and N mineralization, leading to lower soil inorganic N content (Six et al. 1999). Tillage tends to promote faster release of residue N by mixing and incorporating crop residues in the soil compared to surface-placed residues in no-till systems (Varco et al. 1993). However, residue composition and soil properties may interact with tillage effects.

Bt toxins from transgenic maize may enter the soil through root exudates (Saxena and Stotzky 2000) or by plant residues (Zwahlen et al. 2003). Accumulation of the insecticidal activity of the toxin especially by being adsorbed on surface-active particles (Saxena and Stotzky 2000) can cause harmful effect on non-target organisms in the soil such as nitrifiers. The objectives of this research were: (i) to determine differences in the composition and quantity of Bt maize residues grown under field conditions, (ii) to evaluate the effect of Bt maize residues on N mineralization in soils of varying texture and (iii) to assess the effects of Bt residues on soil inorganic N under different tillage systems.

Materials and methods

Field study

A two-year study was initiated in 2002 at the University of Missouri Greenley Memorial Research Center (40°02′ N, 92°14′ W) in Northeast Missouri. Five Bt maize hybrids Merschman ‘M00112Bt’, ‘M9114Bt’ (Merschman Seeds Inc., West Point, IA, USA), Golden Harvest ‘H9247Bt’ (Golden Harvest Seeds Inc., Bloomington, IL, USA), Garst ‘G8484Bt’ (Garst Seeds Company, Slater, IA, USA) and ‘33P67’ (Pioneer Hi-Bred International Inc., Johnston, IA, USA) with their respective non-transgenic isolines (M00110, M6114, H9229, G8464 and 33P66) were no-till planted in April in a RCB design with four replications in plots of 3.0 m width by 10.6 m length. A separate adjoining field site was used for repeating the study in 2003. The soil at both sites is classified as a Putnam silt loam (fine, montmorillonitic, mesic mollic Albaqualfs). The field was fertilized with 21 kg N ha^{-1}, 24 kg P ha^{-1} and 93 kg K ha^{-1} in fall 2001 and fall 2002. Additional N was applied as anhydrous ammonia in the spring of 2002 at 202 kg N ha^{-1} and in fall, 2002 at 196 kg N ha^{-1} (with N-serve 24). Plots were maintained weed-free with pre-emergence atrazine (6-Chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine)/metolachlor(2-Chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide) at 3.9 kg ha^{-1} plus simazine (1-Chloro-3,5-Bisethylamino-2,4,6-Triazine; 2,4-bis(ethylamino)-6-chloro-s-triazine) at 560 g ha^{-1} followed by bromoxynil (3,5-Dibromo-4-hydroxybenzonitrile) applied post-emergence at 280 g ha^{-1}.

Fifteen whole maize plants were harvested per plot in September 2002 and October 2003 and weighed to determine total aboveground biomass on a dry weight basis. The harvested plants were separated to determine stem and leaf weights of remaining aboveground plant material that would be returned to the surface of each plot as crop residues after grain harvest. Root material was also collected from five plants per plot by excavating around the base of the plant to a depth of approximately 60 cm and then collecting the root material plus soil in a plastic bag. The root material was then subsequently placed on a 1 mm sieve and rinsed with distilled water to remove soil. All collected maize plant materials were dried at 60 °C to determine moisture content and then ground in a stainless steel Wiley Mill (Thomas Scientific, Swedesboro, NJ, USA) to pass a 1 mm screen. Stem, leaf and root materials were analyzed for total organic C (Nelson and Sommers 1986), total N (Zellweger Analytics Inc. 1996a), and lignin, cellulose and ash (Goering and VanSoest 1970). Each plot was evaluated for European maize borer (EMB) infestation after harvest. Ten stalks per plot were cut longitudinally to determine tunnel counts and lengths per plant.

After grain harvest and surface application of remaining plant residues, plots were split into a block remaining in no-till and a block that was disk-harrowed in November 2002 and planted to soybean the following spring. Soil samples were taken in October 2002, May, June and October 2003 for soil inorganic N analysis. Ammonium-N and nitrate-N were analyzed in 2 M KCl extracts using a Lachat Quikchem Analyzer (Zellweger Analytics Inc. 1996b).

Aerobic incubation study

A 69-day aerobic leaching incubation study to evaluate N mineralization was conducted with four replications and three bulk soils representing silt loam, sandy loam and silty clay soil textural classes. The silt loam soil was collected from the Ap horizon of a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs), a claypan soil that is found in close association with the Putnam soil that was present in the field study. The silty clay soil was collected from the exposed argillic horizon of the Mexico soil from which the Ap horizon had been physically removed > 5 years prior to sampling for an erosion experiment; and the sandy loam soil was collected from the Ap horizon of a Haynie sandy loam (coarse-silty, mixed, calcareous, mesic Mollic Udifluvents). Ground root, leaf and stem material (≤ 1 mm diameter) from one Bt maize hybrid (Merschman-00112Bt) and its respective isoline (M-00110) were added to the soils at a rate of 2 mg g^{-1} soil. This pair of hybrids was selected from among the five hybrids tested in this research because initial tissue analysis showed that this hybrid pair was the only pair that had significantly higher lignin content in the tissue from the Bt hybrid compared to its non-transgenic isoline (Table 4). All soil – residue treatment combinations were replicated three times. Fifty grams of each soil were mixed with 50 g of acid-washed sand and placed in Falcon filter units (150 ml bottle-type, Becton Dickinson Labware, NJ, USA). The Falcon filters were fitted with pre-moistened cellulose acetate membrane filters (0.2 μm, 51 mm diam) and extra-thick glass fiber (47 mm diam) prefilters. Membrane filters are important for maintaining soil moisture potential (Motavalli et al. 1995). A Whatman glass micro fiber filter (70 mm diam) was placed on top of the soil to avoid dispersion during leaching. The filter units were initially leached with 100 ml of N-free nutrient solution (Nadelhoffer 1990) under 47 kPa suction for 1 h (Motavalli et al. 1995). Subsequent leachings were with 50 ml of N-free nutrient solution. The filter units were periodically leached after 2, 6, 13, 27, 41, 55 and 69 days of incubation at 25 °C. The leachates were collected and analyzed for NH_4^+–N and NO_3^-–N using a Lachat Quikchem Analyzer (Zellweger Analytics Inc. 1996b).

Statistical analysis

Analysis of variance (ANOVA) for evaluating the effects of years, maize variety, plant part and sampling time was determined using the general linear model (PROC GLM) (SAS Institute 2001) for a RCB design. For soil inorganic data, a split plot analysis of variance was used. Mean separation was by the Fisher's protected LSD method at $P < 0.05$ (SAS Institute 2001).

Results

Maize grain yields

Three Bt maize varieties, H9247Bt, G8484Bt and 33P67Bt, produced 880–1400 kg ha^{-1} more grain

Table 1. Maize grain yields and European maize borer tunnel counts and lengths for Bt and non-Bt isolines in 2002 and 2003.

Maize variety	Grain yield (kg ha^{-1})		EMB tunnel counts[a] (n $plant^{-1}$)		EMB tunnel lengths (cm $plant^{-1}$)	
	2002	2003	2002	2003	2002	2003
M00110[b]	6357	5655	5.58	0.25	2.15	0.19
M00112Bt	7009	5534	0.23	0.00	0.09	0.00
$LSD_{(0.05)}$	*NS*	*NS*	*0.79*	*0.20*	*0.32*	*0.15*
M6114	5845	5548	5.30	2.29	2.29	0.70
M9114Bt	8099	4835	0.18	0.15	0.15	0.03
$LSD_{(0.05)}$	*NS*	*NS*	*0.71*	*0.39*	*0.31*	*0.36*
H9229[c]	6538	6094	6.95	2.11	2.11	0.90
H9247Bt	7417	6749	1.30	0.55	0.55	0.18
$LSD_{(0.05)}$	*643*	*NS*	*0.83*	*0.41*	*0.29*	*0.45*
G8464[d]	6704	6686	4.25	2.25	2.25	0.21
G8484Bt	8102	5871	0.63	0.03	0.03	0.06
$LSD_{(0.05)}$	*1191*	*598*	*0.57*	*0.19*	*0.31*	*NS*
33P66[e]	6086	5239	5.83	2.03	2.03	0.54
33P67Bt	7464	5961	0.15	0.00	0.00	0.00
$LSD_{(0.05)}$	*881*	*NS*	*0.84*	*0.26*	*0.19*	*0.32*

[a]Number of European maize borer (EMB) tunnels per plant; [b]Merschman; [c]Golden Harvest; [d]Garst; and [e]Pioneer Seed Companies, respectively.

yields than their respective non-Bt isolines in 2002 (Table 1). In contrast Bt and non-Bt isolines produced similar grain yields in 2003, except the non-Bt hybrid G8464 that produced 815 kg ha^{-1} more grain than the Bt isoline (Table 1). Overall, Bt maize produced 652–2254 kg ha^{-1} more grain than non-Bt maize in 2002. However, no differences were observed in aboveground, stem or leaf biomass between Bt and non-Bt isolines in the 2 years.

Non-Bt isolines had higher EMB tunnel counts and lengths than Bt isolines in 2002 and 2003 with a greater infestation in 2002 (Table 1). On average each non-Bt plant had 4–6 borers (Table 1). Generally, Bt hybrids had higher grain yields than non-Bt isolines in 2002, when EMB infestation was higher (Table 1), while no consistent yield differences were observed between Bt and non-Bt maize hybrids in 2003 when EMB infestation was relatively lower.

Maize residue composition

Generally, no consistent differences were observed between Bt and non-Bt maize residues composition in two consecutive years. Table 2 shows a few differences observed for stem tissue, which were not sustained in the second year of analysis. M00112Bt stem tissue, for example, had higher lignin and lignin to N ratio than the non-Bt isoline. In contrast Pioneer Bt hybrid (33P67) had lower lignin content in the stem tissue than the non-Bt isoline (Table 2). Out of 140 comparisons (2 year × 5 Bt–non-Bt pairs × stem or leaf tissue × 7 characteristics), Bt and non-Bt were different in 13 of them (~10%), 11 of which were observed in 2002. As expected, stem tissue had higher cellulose and lignin content, and C to N, cellulose to N and lignin to N ratios than leaf tissue, while leaf tissue had higher total N content.

Aerobic incubation study

Soil and maize residues characteristics

Characteristics of bulk soils and residues used in the incubation study are shown in Tables 3 and 4, respectively. Generally, the silt loam soil had higher total organic C, total N, and Bray-1 P than the other two soils. The silt loam soil also had lower C:N ratio and pH (Table 3). For plant tissue, Bt leaf and stem tissues had higher lignin content, C:N and lignin:N ratios than non-Bt tissues (Table 4). Similarly, Bt root material had

Table 2. Stem tissue characteristics for Bt maize and its respective non-transgenic isolines in 2002.

Maize variety	TOC (%)	TKN (%)	Cellu (%)	Lignin (%)	C:N (%)	Cellu:N (%)	Lig:N (%)
M00110[a]	43.2	0.56	38.3	6.7	77	68	12.0
M00112Bt	42.4	0.49	37.1	7.7	87	76	15.8
$LSD_{(0.05)}$	*NS*	*NS*	*NS*	*0.2*	*NS*	*NS*	*3.4*
M6114	41.5	0.51	39.8	7.9	83	79	15.8
M9114Bt	41.9	0.44	41.6	7.7	103	104	19.6
$LSD_{(0.05)}$	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
H9229[b]	42.4	0.51	36.8	6.2	84	73	12.3
H9247Bt	41.0	0.53	33.7	6.0	79	66	11.9
$LSD_{(0.05)}$	*1.1*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
G8464[c]	41.9	0.84	33.5	6.6	52	42	8.2
G8484Bt	41.8	0.71	32.9	6.5	61	49	9.7
$LSD_{(0.05)}$	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
33P66[d]	42.5	0.60	40.6	7.5	73	70	13.0
33P67Bt	42.3	0.52	42.3	5.9	85	86	11.9
$LSD_{(0.05)}$	*NS*	*NS*	*NS*	*1.3*	*NS*	*NS*	*0.32*

TOC is total organic C, TKN is total Kjeldahl N, Cellu is cellulose and Lig is lignin.
[a]Merschman; [b]Golden Harvest; [c]Garst, and; [d]Pioneer Seed Companies, respectively.

Table 3. Characteristics of bulk soils used in the incubation study.

Soil property	Soils textural class		
	Silt loam[a]	Silty clay	Sandy loam
pH (1:1, $CaCl_2$)	6.7 (0.1)[b]	7.3 (0.1)	7.5 (0.1)
Total organic C (g kg^{-1})	20.3 (1.0)	16.4 (1.2)	4.4 (0.3)
Total N (g kg^{-1})	2.1 (0.1)	1.1 (0.1)	0.2 (0.01)
C:N ratio	9.7 (0.1)	14.9 (0.3)	22.0 (0.4)
Bray1-P (mg kg^{-1})	34.7 (2.0)	6.2 (1.7)	2.7 (0.8)
Exch. Ca (mg kg^{-1})	3805 (205)	3507 (788)	4955 (830)
Exch. Mg (mg kg^{-1})	372 (20)	365 (88)	541 (114)
Exch. K (mg kg^{-1})	236 (15)	97 (2)	169 (8)
Clay (g kg^{-1})	229 (2)	364 (3)	98 (6)
Silt (g kg^{-1})	728 (1)	587 (1)	221 (1)
Sand (g kg^{-1})	44 (2)	49 (4)	682 (6)

[a]Silt loam is from Ap horizon of a Mexico silt loam (Aeric Vertic Epiaqualfs), silty clay is from Bt horizon of a Mexico silt loam (Aeric Vertic Epiaqualfs), and sandy loam is from the Ap horizon of a Haynie sandy loam (Mollic Udifluvents).
[b]Values in parenthesis represent one standard deviation.

Table 4. Litter characteristics for Bt (M00110) and non-Bt maize residues used in the incubation study.

Characteristic	Leaf		Stem		Root	
	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
Org. C (%)	48.9 (0.08)[a]	48.3 (0.04)	50.6 (0.01)	49.8 (1.56)	43.5 (0.1)	41.7 (0.15)
Lignin (%)	3.29 (0.02)	2.10 (0.01)	7.75 (0.01)	4.30 (0.01)	11.7 (0.1)	9.94 (0.02)
Total N (%)	0.71 (0.01)	0.96 (0.01)	0.52 (0.01)	0.66 (0.01)	1.20 (0.01)	1.15 (0.01)
C:N	68.9 (0.11)	50.6 (0.33)	97.4 (0.03)	76.0 (1.57)	36.7 (0.14)	36.3 (0.13)
Lignin:N	4.63 (0.03)	2.20 (0.01)	11.8 (0.41)	8.27 (0.03)	9.89 (0.16)	8.64 (0.02)

[a]Values in paranthesis represent one standard deviation.

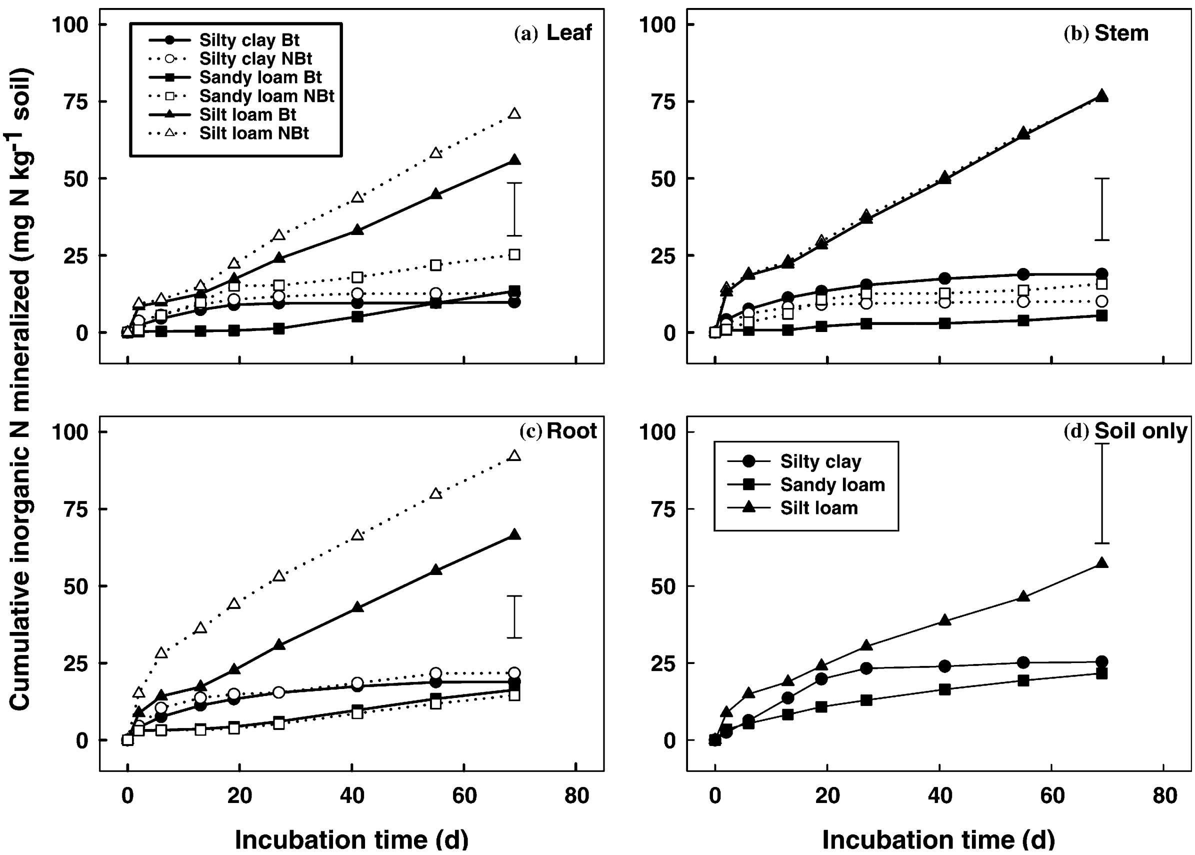

Figure 1. Cumulative total N mineralized in a 69-day aerobic incubation of Bt and non-Bt corn materials in soils of differing soil textures (a) leaf (b) stem and (c) root material and (d) unamended soil. Bars indicate LSD ($P < 0.05$) values at 69 days of incubation.

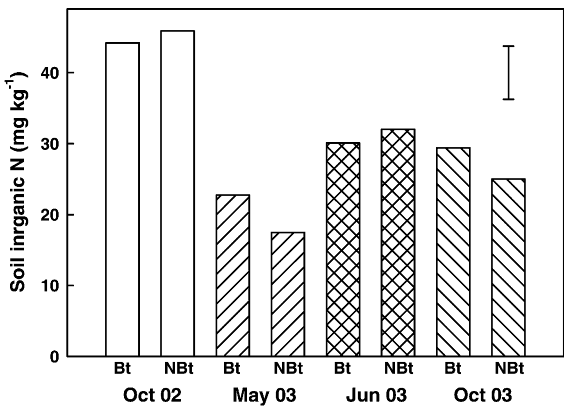

Figure 2. Seasonal changes in soil inorganic N following Bt maize (M00110) and its non-Bt isoline under no-till management.

higher lignin content and lignin:N ratio. In addition, Bt leaf and stem materials had lower total N content, while no differences in total N were observed for root tissues (Table 4). Lignin to N ratios for stem and root tissues were comparable and were both higher than in leaf tissues (Table 4).

Nitrogen mineralization

No differences were observed in the amounts of cumulative N mineralized from Bt and non-Bt maize leaves, stems and roots in three soils differing in texture, except for non-Bt maize roots which mineralized 2.7 times more N than Bt maize roots in silt loam soil (Figure 1 a–c). Overall N mineralization was higher in the silt loam soil compared to other soil textural classes whether amended or unamended (Figure 1 a–d).

Effects of maize residues on soil inorganic nitrogen in the field

Soil inorganic N content in the field at four sampling times during the growing season was similar following Bt or non-Bt maize residue application (Figure 2). Additionally, soil inorganic N did not differ among the different maize varieties whether under tilled or no-till conditions. Soil ammonium and nitrate N ranged from 3.0 to 12.4 and 9.8 to 43.1 mg N kg^{-1}, respectively. Ammonium N was lower than nitrate N at all sampling times for all maize varieties, and most of the treatments had nitrate N concentration greater than 15 mg N kg^{-1} (data not shown). Overall, soil sampled in October 2002 had higher soil inorganic N than at other sampling times (Figure 2). Nitrogen fertilizer was applied in the spring of 2002 and no additional N was added for the soybean crop in the following year.

Discussion

As observed for three of the five maize varieties in this study, Bt maize out yielded non-Bt maize, especially under high EMB infestation. Gianessi and Carpenter (1999) reported higher Bt maize yields by up to 750 kg ha^{-1} compared to non-Bt maize when EMB infestation was high, while the yield increase was about 250 kg ha^{-1} when EMB infestation was light. Similarly, Pioneer Bt hybrids consistently produced more grain at different plant populations (44,444–103,704 plants ha^{-1}) than non-Bt isolines at moderate and high EMB pressure, and differences between Bt and non-Bt hybrid response increased as both EMB infestation and plant population increased (O'Bryan 2003). The yield differences between 2002 and 2003 in our study may be due to greater EMB infestation in 2002 (Table 1) and differences in precipitation amounts and distribution. Total growing season precipitation was 644 and 575 mm in 2002 and 2003, respectively, with 68 and 44% of the precipitation available by May of each year.

Leaf and stem tissue characteristics did not differ consistently among Bt and non-Bt maize varieties. The results observed in this study match the diversity of results reported by other authors. Hopkins and Gregorich (2003) observed higher leaf N and C to N ratio in a Bt isoline (Pioneer 38W36) compared to the non-Bt (P3893) isoline, while Escher et al. (2000) reported a lower C to N ratio and lignin content in the leaves of one Bt isoline compared with the corresponding non-Bt isoline. Saxena and Stotzky (2001) reported that 10 Bt isolines had 33–97% more lignin content in their stem tissue than their respective non-Bt isolines whether grown in growth chambers or in the field. The variations reported in the literature may be explained by differences in methodologies used for plant composition analysis (Jung and Sheaffer 2004), the age of the maize material at the time of harvest, and the Bt transformation event in the transgenic maize variety tested. Since the maize residues were analyzed at approximately the same age, using the same methods in the two years of study, the few differences observed (< 10% of all comparisons) may indicate the natural variability of the residues under the current sensitivity of methods used for analysis, and that as a whole Bt maize residue composition does not differ from that of non-Bt residues.

The C to N ratio has been used extensively to predict N mineralization trends during crop residue decomposition, where net N mineralization occurs if the C to N ratio is less than 30, and net N immobilization occurs if the C to N ratio is greater than 30 (Wagner and Wolf 1999; Trinsoutrot et al. 2000). The N mineralization results observed with root materials in the silt loam soil may have been expected since for both Bt and non-Bt residues, the root material had a lower C to N ratio (Table 4). Although N mineralization is also influenced by other plant components, such as lignin, lignin content ranged from 3.3 to 9.9% (Table 5), which is below the 15% threshold above which N mineralization rate has been observed to decrease (Schroth 2003). Overall, Bt and non-Bt materials were within the same ranges in different characteristics possibly explaining the lack of differences in N mineralization. The observed higher N mineralization for non-Bt root material is hard to explain based on litter quality alone. Hopkins and Gregorich (2003) reported that the largest amount of the Bt endotoxin was found in live root fragments and a smaller, but significant amount in decomposing residues. These authors did not separate residues into different plant parts, and it is possible that Bt root residues also contained higher amount of endotoxin, which cannot be ruled out in this study.

Nitrogen mineralization from litter-amended soils was also influenced by soil properties. The higher N mineralization observed in silt loam soils may have been caused by an interaction of soil particle size and other properties. The silt loam soil initially contained more total N than the silty clay and sandy loam soils (Table 3). When dried and rewetted soils are used in incubation studies, soils high in total N mineralize higher N contents. Pare and Gregorich (1999), for example, reported higher N mineralization in clayey and loamy soils that had higher organic N content (0.14 and 0.21% total N, respectively) than in sandy soils with lower organic N (0.09% total N). Additionally, subsurface and coarse-textured soils usually have less diverse and active microbial populations than surface soils. Some of the differences observed between the soils used in this study may be attributed to differences in microbial community composition among the soils.

Factors that affect soil inorganic N include the N fertilizer source and the timing and amount of its application, soil N mineralization, the amount and composition of residues and tillage. Transgenic Bt and non-Bt hybrids did not differ in the amount of residue produced, and N mineralization dynamics (Figure 1), possibly explaining the lack of differences in soil inorganic N. In addition, disk harrowing, which is a form of reduced tillage, was used in this study and it did not have a significant effect on reducing residue cover on the soil surface (data not shown) or on soil inorganic N. Mahli et al. (1992) found no differences in soil nitrate N content among conventional, minimum, and no-till systems in western Canadian prairie. Tillage effects can be moderated by soil moisture conditions. Under dry conditions, availability of residue cover as in minimum tillage may favor more uniform N mineralization, while under wetter conditions availability of water may lead to increased mineralization (Kuo et al. 1997). In this study, precipitation during the 2003 growing season (the most active time for N mineralization) was evenly distributed, as was soil inorganic N. Likewise, field soil conditions were favorable for nitrification as shown by the high nitrate concentration (average 25 mg N kg^{-1}) relative to that of ammonium N (average 6 mg N kg^{-1}).

Conclusions

Results of this study confirm that Bt maize produces higher grain yields mainly under severe to moderate EMB infestation and that the yield benefit is minimal during low EMB infestation. Additionally, Bt and non-Bt maize residues analyzed in two consecutive years did not consistently differ in their tissue characteristics such as lignin, total N, and C:N ratio. Incorporation of Bt residues did not significantly affect N mineralization in a laboratory incubation or soil inorganic N in the field. Cropping systems that include Bt maize hybrids are not likely to experience changes in the composition of surface residues and soil N dynamics compared to use of conventional, non-Bt maize hybrids.

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